Evaluation of Roaming and Download Times in Universal Cellular /Wireless LAN Systems

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ABSTRACT

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The growing demand for wireless access has led to the emergence of all kinds of standards for wireless communication, each of which has its own special requirements. The future transceiver equipment of mobile station (MS) should support the operation of these systems from the viewpoint of system compatibility. In this case, multi-mode, multi-band operation is required for user's convenience. Moreover, realization of small size and low power consumption handy terminals is necessary. These are the trends that have led to continued discussion about software radios (also called software defined radio, SDR). SDR is emerging as a potential programmatic solution: a software implementation of the user terminal which able to reconfigure such terminal to suit the changing radio environment as for example in the case of global roaming. There are a great number of international organizations and forums for software defined radios around the world.

In this thesis, a generalized state diagram of a SDR reconfigurable, multi-mode mobile station that could roam/handoff between different wireless systems is developed. A detailed description of the power-up, roaming and download operation for this reconfigurable MS is presented. Furthermore, its roaming connection establishment acquisition time in different scenarios is evaluated. Specifically, the relationships between the roaming acquisition time and *system resource blocking probability, mobile station resource blocking probability, packet successful transmission probability over*

wireless channel and signaling bit rate over the universal base station channel in different cases and design scenarios are analyzed. Such evaluations are important for prior design of SDR mobile terminal and universal base station in global roaming situations.

Dedicated to My Parents, My Brother and My Husband

for Their Love and Encouragement

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Chapter 1 Introduction

1.1 Objective of The Thesis

The request for software radio is provocated by an expectant demand for multi-mode mobile terminals. Software radio technology will give the mobile station the ability of handling a wide range of wireless communication protocols by downloading software, switching from GSM to UMTS for example. A method of downloading software to a mobile terminal over the wireless link is adopted here. There are two main objectives for this thesis.

- To define for the re-configurable multi-mode mobile station, possible transitions from one kind of cellular standard to another, i.e. flexible roaming so as to accommodate several requirements of charging, quality of service (QoS), battery power level, network congestion etc. The mobile station should operate to handoff, not only from cell to cell, but also from one network standard to another, depending on the user satisfaction as above.
- To evaluate the average roaming, software download, handoff times in areas defined as having a mixture of universal cellular base stations, universal wireless LAN base stations, and classical base stations having only one cellular standard. The evaluation of the above roaming times also include times for sensing the universal pilot channel, classic base station pilot channel, association, and connection establishment signalling.

Universal base station means a base station that has the necessary software code for all standard systems such as GSM, CDMA IS-95, DECT, UMTS, etc. It will download such software code to a roaming mobile station upon request. The downloaded software will configure the modulation, access, and network functionalities of the reconfigurable and transparent mobile station. *Classical base station* means a standard base station that provides fixed single mode system access to roaming users.

1.2 Organization of The Thesis

The remainder of the thesis is organized as follows:

Chapter 2 provides an introduction to software radio and mobile communication system. For software radio, we mainly present its definition, architecture and benefits. For the understanding of wireless communication system, we firstly show several types of mobile radio systems and the architecture of a cellular mobile communication system. Next, we present a detailed description of the mobile station operation in a mobile communication system. GSM is taken as an example for discussing power-up registration, mobile station connection establishment, and handoff operation. CDMA system IS-95 is also taken as an example when discussing soft handoff, semi-soft handoff operation.

Chapter 3 and Chapter 4 are the main part of the thesis. In **Chapter 3**, we present a reconfigurable, multi-mode mobile station for wireless communication systems. At first, we propose the configuration for the universal base station and reconfigurable mobile station. Then, based on these proposals, we present a generalized state diagram of this mobile station and a brief description of its power-up registration and roaming connection establishment process. Furthermore, the transition probabilities and the total time spent in each state shown in the state diagram are calculated.

In **Chapter 4**, we focus on analyzing the transition function of the generalized state diagram in order to find the roaming connection establishment acquisition time. Because of the complexity of finding a general form of the transition function for the generalized state diagram, we choose five of the possible design scenarios for analysis. The transition function and roaming connection establishment acquisition time of these five scenarios are presented in Section 4.2.

In **Chapter 5**, we list six possible test cases and construct their input tables for the calculation of roaming connection establishment acquisition time in different design scenarios. But since the evaluation methods in these test cases are similar, we only choose case 1 for detailed test processing in five designed scenarios and choose scenario No.1 for detailed test processing in the six possible cases. The tests we performed are mainly in the analysis the relationship between the roaming acquisition time and *packet successful transmission probability over wireless channel* P_i *(Section 5.2), system resource blocking probability* P_s *(Section 5.3)*, and *mobile station resource blocking probability* P_m *(Section 5.4), signalling bit rate over the universal base station channel* R_b *(Section 5.5).*

Chapter 6 summarizes the result and contribution of this thesis.

Chapter 7 provides some suggestions for future research.

Appendix I presents the bibliographies that we have referred to.

Appendix II presents some frequently used acronyms in thesis.

Chapter 2 Overview of Cellular Systems

During the past two decades, traditional cordless system, cellular mobile systems, mobile data and mobile satellite systems have grown at a tremendous speed. Also, some new wireless communication concepts, such as wireless local area networks (WLAN) have appeared along the way. More and more people use mobile phones, wireless data services are available in many areas, and wireless local area networks (WLAN) are used in many places since 1997.

For a better understanding of the motivation of this thesis, a short history of cellular mobile communication is presented here. First generation wireless cellular systems began to appear in the 1980's. These systems, like Advanced Mobile Phone Service (AMPS) and Total Access Communication System (TACS), were all analog and were based on frequency division multiple access (FDMA). They were only meant for voice communications. However, the demand for capacity increased very quickly. Digital cellular systems (2G systems), such as GSM and PCS came into the picture, which used time division multiple access (TDMA). Soon also the code division multiple access (CDMA) based system IS-95 evolved since it was recognized as a potential to increase the capacity further. All these second generation systems were still mainly for voice communication but they already provided some data services but at rate far less than 64 Kb/s.

A great number of these kinds of wireless networks have come into existence over the years and these systems have utilized many kinds of software and hardware technologies. Today again capacity has become an issue. When the 3G systems such as universal mobile telecommunication system (UMTS) are taken into use, there are still a great many 2G systems working. These 2G and 3G systems differ from each other in terms of modulation, channel coding, multiple access, etc. which will eventually lead to need for different kind of multi-band, multi-mode terminals. This will in return result in many different product platforms that could be programmed to different standards.

In addition, the industrial competition between Asia, Europe, and America promises a very difficult path toward the definition of a unique standard for future mobile systems, although market analysis underline the trading benefits of a common worldwide standard. It is therefore in this field that the *software radio* concept is emerging as a potential programmatic solution: a software implementation of the mobile terminal which able to dynamically reconfigure such terminal to suit the changing radio environment as for example in the case of global roaming.

2.1 Introduction to Software Radio

As a starting point, mobile terminals were designed to support single mode operation. For the user side, it is inefficient to carry more than one communication terminals. Therefore, it is distinctly predictable that multi-mode mobile terminals will play an important role within the next generation of mobile communications. The new concept of software radio has been proposed to accommodate multi-modes on a single mobile terminal.

2.1.1 Definition of Software Radio

Software radio (also called software defined radio, SDR) is thought to build flexible radio systems, multi-service, multi-standard, multi-band, reconfigurable and re-programmable by software. Some definitions often found in the literatures are [12]:

- Flexible TX/RX (transceiver unit) architecture, controlled and programmable by software.
- Signal processing able to replace, as much as possible, radio functionalities.
- "Air interface download ability": radio equipment dynamically reconfigured by downloadable software at every level of the protocol stack.

- Software realization of terminals "multiple mode/standard".
- Transceiver where the following can be defined by software: a) Frequency band and radio channel bandwidth. b) Modulation and coding scheme. c) Radio resource and mobility management protocol. d) User applications.

2.1.2 Architecture and Benefits of Software Radio

With software radio (SDR), one would implement a common hardware platform and accommodate the different wireless communication system standards and technologies via software modules and firmware. If the hardware must be adapted to a new standard, then a slight reprogramming of the processor should be all that is needed. The reconfigurability of a SDR mobile station means digital signal processing (DSP) engine reprogrammability, which in real time, implement radio interface and upper layer protocols. It is important to note that by digital signal processing (DSP) is really intended the concept of digital signal processing, and therefore not only DSP chipsets in strict sense, but also Field Programmable Gate Arrays (FPGA) and general-purpose processors [12].

Ideally the software radio (SDR) would consist of a DSP unit, which is connected directly to antenna. The trend in SDR design is to place the Analogue-to-Digital (A/D) converter as close as possible to the antenna. This will permit a wider implementation of software, bringing the benefit of reconfiguration capability. However, today's technology has not yet reached the point at which this would be realizable, and therefore it does not utilize such architecture. Digitization at the IF is more likely to happen in the near future rather than the RF digitization. Software radio is now defined to be a piece of future radio equipment, which can be configured by software, to many different wireless systems. It provides real time operation and also, if needed, it can be used simultaneously in those systems. So a realizable software radio would consist of [15]:

- High quality analog wide band RF/IF stage.
- High performance wide band A/D and D/A converters.
- Digital signal processing unit consisting of general-purpose DSP processors, CPUs, configurable hardware and memory modules.

In the future an intelligent multi-band adaptive antenna system will also be included. The structure for the software radio is represented in Figure 2.1. [15]

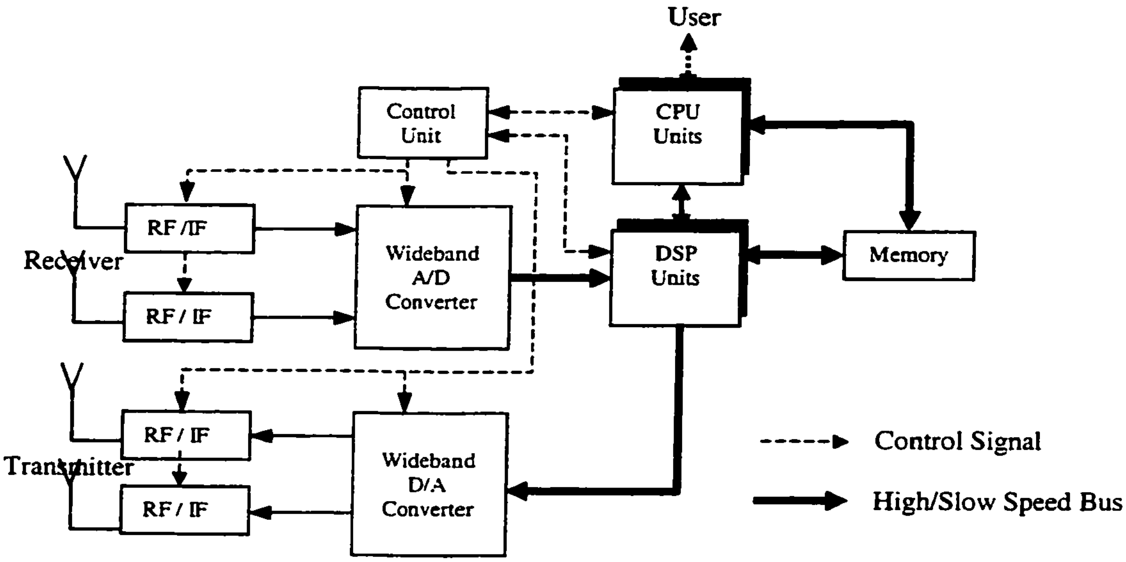


Figure 2.1 The Software Radio Architecture

We note that the interface between analog and digital part is shifted towards the antenna. This together with flexible software architectures makes it possible to achieve flexibility and plug-and-play type of use. All aspects relating to the air interface are implemented in programmable software or hardware and the mobile station can be reconfigured in real time over-the-air. The basic concept is based on the use of a simple hardware platform built using software radio to enable customers to modify the mobile terminal to work in different systems at different time and different area. The main difference compared to traditional mobile station is thus the total programmability.

Software radio can bring benefits not only to users but also to manufactures. For users, modifying the performance or functionality of the mobile terminal is achieved by downloading software. Downloading software modules, from user application layer to communication physical layer processing algorithms, will provide more flexibility to the terminal in terms of reconfiguration. For example, the software (SW) modules could be: speech codecs, modulation schemes, filters, interleaving method, or simply a set of parameters. Consequently, the mobile users will be able to adapt its personal communication device depending on his environment and preferences, so that the users take the advantage of worldwide mobility and coverage, reconfigurability and flexibility. Moreover, SDR technology increases hardware lifetime of both network and mobile station. To migrate to a new standard, reprogramming the hardware platform would be all that is needed.

For manufatures, the advantages would be the possibility to improve, correct the software during the operation, the possibility to concentrate R&D efforts on a reduced hardware platform set, applicable to many different standard, finally lead to lower costs.

This thesis mainly addresses the software download issues when the mobile station roams in different mobile communication systems, while SDR transceiver architecture, possible SW implementation, and network evolution issues are not considered in detail, these fundamental topics can be found in recent literature.

2.2 Introduction to Mobile Communication System

2.2.1 Different Types of Mobile Communication Systems

During the last few decades, mobile communication has constantly grown in importance. In order to let the reader quickly know the current existing mobile communication systems, a brief description of the different types of mobile communication systems is presented here.

- **Public cellular mobile communication systems**: extend the telephone service of wire-line networks area-wide to mobile users. Example standards are Advanced Mobile Phone Service (AMPS), Total Access Communication System (TACS), Global System for Mobile Communication (GSM), Digital Cellular System at 1800 MHz (DCS-1800), Interim Standard 54 (TDMA IS-54), CDMA IS-95, Universal Mobile Telecommunication System (UMTS).
- **Wireless local area networks**: take into account the growing demand to avoid cabling of workstation computers. Example standards are HIPERLAN, IEEE 802.11 wireless LAN.
- **Cordless communication system:** in which the cable between the telephone terminal and the handset is replaced by a radio path that allows a radio connection of up to 300m/50m (outdoors/indoors). Example standards are CT2, Digital European Cordless Telephone (DECT).
- **Mobile satellite radio systems:** provide global communication and accessibility.
- **Trunked mobile radio systems:** are optimized for commercial application and provide services like closed user group.
- **Paging systems:** allow the direct paging of subscribers with mobile, pocket-sized receivers through the transmission of a signal or short message.

The need for ubiquitous personal communications impels the development of new networking techniques that accommodate mobile voice and data users who move throughout cities, or countries. The cellular mobile telephone system is responsible for providing coverage throughout a particular territory and capable of providing voice and data service to mobile users. Therefore, we describe the cellular mobile communication system for detail in the following, similar principle can be applied to other types of mobile communication systems.

2.2.2 Cellular Mobile Communication System Architecture

Figure 2.2 illustrates a typical cellular mobile communication system of the early 1990s. Each mobile station uses a separate, temporary radio channel to talk to the base station. The base station talks to many mobile stations at once, using one channel per mobile station. Channels may use a pair of frequencies for communication (Frequency Division Duplex FDD mode)—one frequency for transmitting from the base station (the forward link) and one frequency for the base station to receive calls from the users (the reverse link), or channels may use single frequency band (Time Division Duplex TDD mode) to transmit signals alternately in forward and reverse directions.

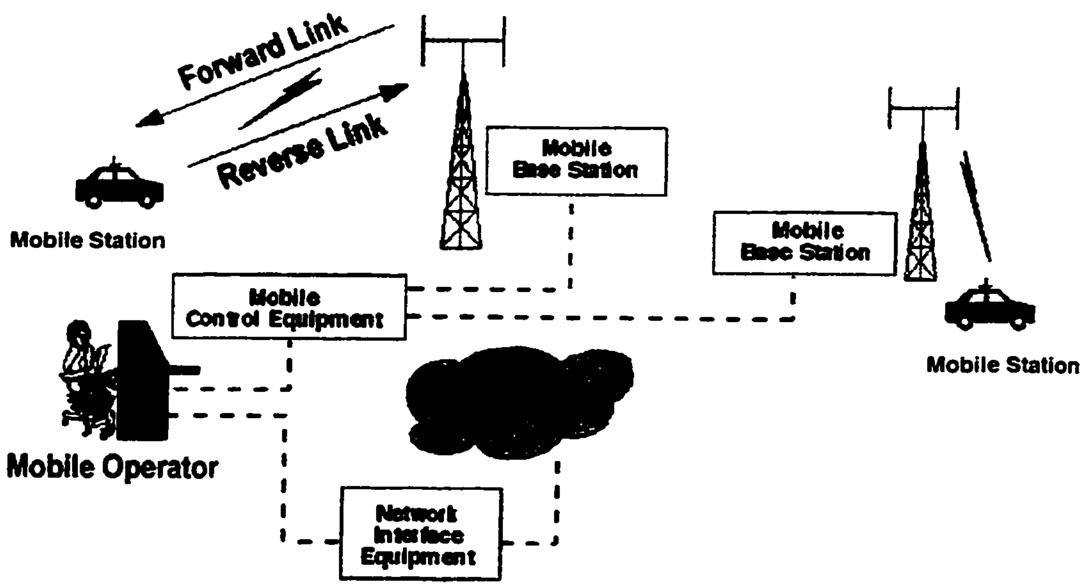


Figure 2.2 Cellular Mobile Communication System

The basic structure of mobile communication system includes radio services and telephone systems. Mobile radio service operates in a closed network and has no access to the public switched telephone system (PSTN), while mobile telephone service allows interconnection to the PSTN. The mobile communication system consists of the following four major components that work together to provide mobile service to subscribers.

- **Public switched telephone network (PSTN)**: is made up of local networks, the exchange area networks, and the long-haul network that interconnect telephones and other communication devices on a worldwide basis.
- **Mobile telephone switching office (MTSO)**: is the central office for mobile switching. It houses the mobile switching centre (MSC), field monitoring, and relay stations for switching calls from base stations to wire-line central offices (PSTN). In analog cellular networks, the MSC controls the system operation. The MSC controls calls, tracks billing information, and locates cellular subscribers.
- **Base station with antenna system (BS)**: is used to refer to the physical location of radio equipment that provides coverage within a cell. A list of hardware located at a cell site includes power sources, interface equipment, radio frequency transmitters and receivers, and antenna systems.
- **Mobile station (MS)**: consists of a control unit and a transceiver that transmits and receives radio transmissions to and from a base station.

2.2.3 Power-up Registration, Connection Establishment, and Handoff/Roaming Process

In order to understand the signalling operation of a mobile station in a mobile communication system, we will briefly describe the registration, connection establishment, and handoff/roaming process signalling. As there are many worldwide standards for mobile communication systems, it is unpredictable and unnecessary to present all of them here. In this section, we take GSM as the main example for description of the power-up registration, connection establishment and handoff process, not only because of market success, but also due to the system architecture that served many other systems as an early example. Specifically, some new handoff concepts such as soft handoff, semi-handoff are introduced by taking CDMA system IS-95 as an example when discussing handoff process.

2.2.3.1 Power-up Registration

The following power-up register process could be applied in the synchronization systems such as the first-generation and second-generation cellular mobile communication systems, e.g. AMPS, D-AMPS, GSM, CDMA IS-95, CDPD, etc.

Prior to establishing any communication links to other parties, the mobile station (MS) must first acquire synchronization with the mobile communication system. This begins after the MS is turned on in a Public Land Mobile Network (PLMN). The first step of the MS process is known as frequency synchronization. The frequency correction burst is unique and easily recognizable. For example, in GSM the frequency correction control channel (FCCH) burst is long sine wave that is offset by 67.7 KHz from the carrier frequency. The base station transmits all zeros for the frequency correction burst. The MS has to take out this offset before an estimate of the carrier frequency can be made.

After the frequency correction burst is detected, the MS will try to synchronize with the time synchronization burst (SCH). This time synchronization is generally carried out in two steps: coarse and fine. If synchronization does not occur, the process of frequency synchronization with the next highest power channel in the list may start.

Assuming that the mobile station is synchronized, it decodes the information on a broadcast/pilot channel. When these information are correctly decoded, the MS will follow one of the two paths:

1) If the broadcast control channel (BCCH) information includes the present BCCH channel number, then the MS will simply stay on the channel.

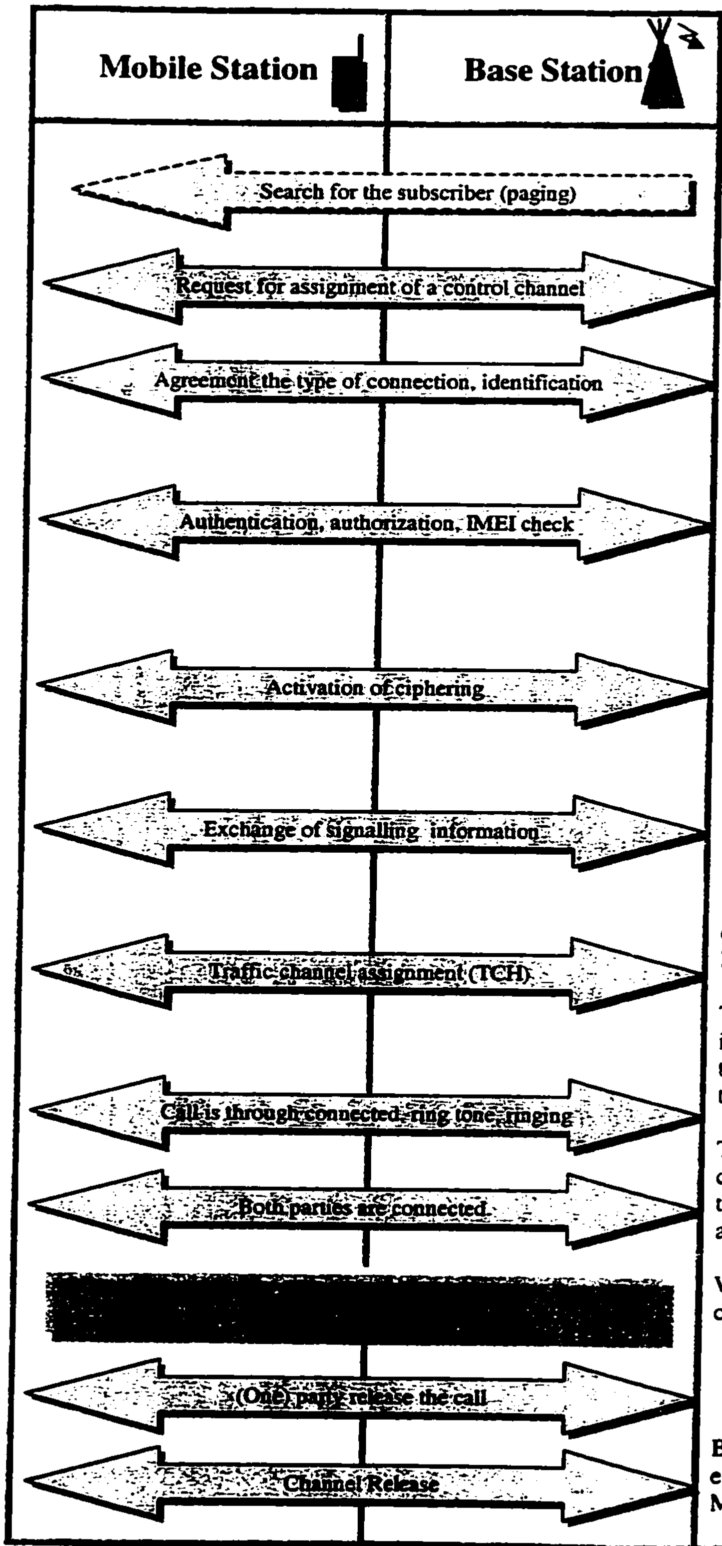
2) If the current channel is not included in the BCCH information list or the received signal strength level (BCCH level) is below the desired level, then the MS will continue searching for the next BCCH channel.

After the MS has successfully synchronized to the system timing, it must maintain the link and monitor the paging channel (PCH). The mobile station is also required to maintain information on the neighbouring BCCHs. The information, including sync information and the average measured RF levels of at least six adjacent cell channels, which is important for handoff process.

2.2.3.2 Connection Establishment

Basic steps in the formation of a connection include connection request, paging procedure, identification process, authentication, ciphering, and call clearing international mobile subscriber identity (IMSI) attach and detach. There are two possible situations: Mobile station origination call establishment (MOC) and Mobile station termination call establishment (MTC). A common block diagram for MOC and MTC is shown in Figure 2.3. [1]

Next, we present the detailed signalling for a mobile station connection establishment in a GSM system. In MTC, the MS is called by a calling station which can be outside the GSM network or another mobile station. Figure 2.4 shows the detailed steps and required signalling in MTC. In MOC, the MS transmits a request for a new connection. Figure 2.5 shows the detailed steps and required signalling in MOC. Note that we focus on the signalling between the mobile station and the mobile network, while the signalling between the networks is not discussed here. Some acronyms used below were presented in appendix II.



Explanation of the Diagram

Only in a mobile termination call (MTC) does the network search for a particular subscriber (paging).

When the mobile station (MS) is located or when the MS initiates a call, a control channel between MS and base station controller (BSC) has to be established.

The MS uses the control channel for identification and indicates to the BSC in detail which service is requested.

The BSC passes the service request of the MS to the network switching subsystem (NSS). For that purpose, the base station subsystem (BSS) has to request an SCCP connection from the mobile switching centre (MSC).
The NSS reacts on a connection request of any kind with a request for authentication (except for an emergency call). Additionally, the Mobile Station Equipment Identity (IMEI) may be checked.

Ciphering between base station transceiver (BTS) and MS is activated in successful authentication. Ciphering prevents tapping into air-interface.

Additional information between MS and NSS are exchanged after activation of ciphering. The additional information either terminates a successful location update (LU), or a connection request, defines the details of that connection. The process is synchronized between MS and NSS.

The assignment of the traffic channel (TCH) on the A-interface and Air-interface is done separately, except in the case of off-air call setup (OACSU). Up to this point, the communication has been done via a control channel.

The system waits, after assignment of the traffic channel, until an end-to-end connection is in place. At the end of this phase, the telephone on one side rings, and the other side hears the ring-back tone.

When the called subscriber takes the call, the actual conversation begins and charges apply from then on.

Both ends terminate the call after the conversation has ended. This is the trigger for the MSC, as well as for the MS, to release all the occupied channels and resources.

Figure 2.3 A Common Diagram of Call Flow

Mobile Station	Channel/Signalling Message	Base Station Side
	CCCH (PCH)/ PAG_REQ(TMSI)	In case of an incoming call, Mobile Switching Center/Visitor Location Register (MSC/VLR) requests PAG_REQ messages to be sent by all BTS's, which belong to the current location area of the called MS. When the BTS's are connected to different BSC's, one PAGING message is sent per BSC. From this PAGING message, the BSC generates the single PAG_CMD message, which is sent by the BTS's as PAG_REQ.
If the MS is reachable, then assignment of a control channel is requested from the BSC.	CCCH (RACH)/CHAN_REQ	BTS decodes the CHAN_REQ, calculates the distance (Timing advance), and forwards the whole information in a CHAN_RQD to the BSC. →After the BSC received and processed the CHAN_RQD, it informs the BTS of the channel type and number shall be assigned (CHAN_ACT).
Finds its IMM_ASS_CMD, based on the request reference, containing in the CHAN_REQ.	CCCH (AGCH)/IMM_ASS_CMD	The BSC sends IMM_ASS_CMD to activate the reserved channel. →BTS sends this information to MS.
The MS requests the BTS to establish a layer 2 connection (LAPDm) by sending a Set-asynchronous balance mode (SABM).	SDCCH (SABM)/PAG_RSP	
	SDCCH (UA) /PAG_RSP	The BTS confirms establishment of the layer2 by repeating PAG_RSP in a Unnumbered Acknowledgment (UA) message (LAPDm) and passes it to BSC.
		BSC partly processes the PAG_RSP and adds the Location Area Code (LAC) and Cell Identity (CI). This entire information is put as a CL3I in a SCCP, sent to MSC. →The Connection Request (CR) is answered with a Connection Confirm (CC), if the MSC can provide the requested Signalling Connection Control Part (SCCP) connection. A logical connection between MS & MSC/VLR exists from now on.
	SDCCH (I)/AUTH_REQ (RAND)	The MSC/VLR answers the PAG_RSP with an AUTH_REQ to the MS. Most important content is the random number RAND.
MS (SIM) calculates the result SRES, by applying RAND & Kj to A3. This result is transparently returned to the MSC/VLR in an AUTH_RSP message.	SDCCH (I)/AUTH_RSP (SRES)	*No CM_SERV_ACC is necessary in MTC. Without ciphering, a SETUP would follow immediately.*
	SDCCH (I)/CIPH_MOD_CMD	If ciphering is active, then encryption is switched on. →MSC/VLR sends information to BTS &MS. →BTS extracts Cipher Key Kc from the ENCR_CMD message and sends the rest in a CIPH_MOD_CMD message to MS. This message only contains the information, which algorithm A5/X the MS shall use.
Confirms the activation of ciphering by sending of a CIPH_MOD_COM message.	SDCCH (I)/CIPH_MOD_COM	
	SDCCH (I)/IDENT_REQ (IMEI, ..)	MSC/VLR requests the MS to provide its IMEI if Equipment Check (EC) is active. This is performed for the BSS transparent, IDENT_REQ message. The EC can be performed during almost any time during this scenario.

Figure 2.4 Mobile Station Termination Call Establishment (I)

Mobile Station	Channel/Signalling Message	Base Station Side
(Continued) Transmits its IMEI in an IDENT_RSP message to the MSC/VLR, where to check if the MS is reported stolen or not certified.	SDCCH (I)/IDENT_RSP (IMEI...)	
	SDCCH (I)/TMSI_REAL_CMD	MSC/VLR assigns a Temporary Mobile Subscriber Identity (TMSI) in place of IMSI in order to make tracking of subscribers more difficult. The TMSI_REAL_CMD is also a transparent message between MSC & MS. The most important content is the new TMSI.
Confirms with a TMSI_REAL _COM that the new TMSI was received and stored.	SDCCH(I)/ TMSI_REAL_COM	
	SDCCH(I) / SETUP	The SETUP message is also used for MTC. It informs the MS about the necessary technical preconditions (Bearer Capabilities) in order to accept the connection request, and, if active, conveys the identity of the caller transparently to the MS.
After receiving and checking the SETUP message, the MS confirms its capabilities to accept this connection request by sending CALL_CONF. This terminates the connection.	SDCCH (I)/ CALL_CONF(OK)	At this time, if off air call setup (OACSU) is not active, the MSC sends ASS_REQ to the BSC. Most important information is, which (speech) channel shall be used for this connection. → After receiving and processing of the ASS_REQ, BSC informs the BTS of the channel type & channel number shall be reserved (CHAN_ACT). → BTS confirms with CHAN_ACT_ACK that it received and processed the CHAN_ACT.
	SDCCH (I)/ ASS_CMD	With an ASS_CMD, the BSC assigns the traffic channel that the MS and BTS shall use on the Air-interface. ***The most important data are Transmission/Reception Unit (TRX) & Time Slot (TS).***
Sends a Set-asynchronous balance mode (SABM) to the BTS.	FACCH/SABM	The BTS expects that a SABM is sent from the MS, using the new channel, which enables the LAPDm layer2 connection.
	FACCH / UA	The BTS confirms with a UA message (LAPDm) that a SABM was received and layer2 was established. →At the same time, this confirmation is sent in a EST_IND message to BSC.
	FACCH(I)/ASS_COM	With sending of ASS_COM, the traffic channel on layer3 is operational. This also acknowledges the ASS_REQ to the MSC.
Starts ringing after traffic channel assignment. An alert message (never PROGRESS) is transparently sent to the MSC simultaneously. This triggers an ACM (ISUP) towards the calling subscriber & the generation of a ring back tone.	FACCH(I)/CON	BSC releases the occupied control channel by sending of RF_CHAN_REL. The BTS confirms release with RF_CH_REL_ACK.
	FACCH(I)/CON_ACK	Alerted by ringing, the mobile subscriber accepts the call. When the user presses the 'SEND' button, the MS transparently send a CON message to the MSC/VLR, that is conveyed to the peer as ANS message(ISUP). Furthermore, the MSC/VLR sends the CON_ACK message to the MS, which indicates start of the call and also initiates charging.

Figure 2.4 Mobile Station Termination Call Establishment (II)

Mobile Station	Channel/Signalling Message	Base Station Side
Request assignment of a control channel from the base station controller (BSC).	CCCH (RACH)/ CHAN_REQ →	The base station transceiver (BTS) decodes the CHAN_REQ. calculates the distance (Time Advance) & returns the complete information in a CHAN_RQD to the BSC. →BSC informs the BSC of the channel type & channel number shall be reserved (CHAN_ACT). →BTS acknowledges BSC with a CHAN_ACT_ACK.
	← CCCH (AGCH)/IMM_ASS_CAM	BSC, BTS sends the IMM_ASS_CMD to activate the previously reserved channel.
Request from the BTS, by sending a SABM (LAPDm) that a layer2 connection be established. It contains a CM_SERV_REQ for identifying the subscriber (IMSI/TMSI) & specifies the requested service.	SDCCH (SABM)/CM_SERV_REQ →	BTS confirms that a layer2 was established by repeating the CM_SERV_REQ in an UA message & forwards it to the BSC. →BSC partly processes the CM_SERV_REQ (MS class) and LAC, as well as CI are added. The complete Info. is packed in a CR (SCCP) as a CL3I (BSSM) and sent to the MSC. The CR also serves as a request for a SCCP connection. →MSC answers CR with a CC if it is able to provide the requested SCCP connection. →A logical connection exists from the MS to the MSC/VLR (Visitor Location Register). MSC/VLR answers to the CM_SERV_REQ with AUTH_REQ.
	← SDCCH (UA)/CM_SERV_REQ	
	← SDCCH (I)/AUTH_REQ (RAND)	BSC &BTS transparently forward the AUTH_REQ to the MS. Most important content is RAND, the random number.
MS (SIM) calculates the result SRES, by applying RAND & Kj to A3. This result is transparently returned to the MSC/VLR in an AUTH_RSP message.	SDCCH (I)/ AUTH_RSP(SRES) →	VLR compares SRES with the value provided by HLR. If the two match, authentication is successful. →MSC/VLR confirms the requested service in a CM_SERV_ACC message. (***only if ciphering isn't active.***) If ciphering is active, then no CM_SERV_ACC is sent. →MSC/VLR sends information to BTS & MS.
	← SDCCH (I) / CM_SERV_ACC	
	← SDCCH (I)/CIPH_MOD_CMD	BTS extracts Kc from the ENCR_CMD message and sends the rest in a CIPH_MOD_CMD message to MS. This message only contains the information, which algorithm A5/X the MS shall use.
Confirms by sending a CIPH_MOD_COM message that ciphering was activated.	SDCCH (I)/CIPH_MOD_COM →	
	← SDCCH (I)/IDENT_REQ (IMEI)	MSC/VLR requests the MS to provide its IMEI if Equipment Check (EC) is active. This is performed for the BSS transparent, IDENT_REQ message. The EC can be performed during almost any time during this scenario.
Transmits its IMEI in an IDENT_RSP message to the MSC/VLR, where to check if the MS is reported stolen or not certified.	SDCCH (I)/ IDENT_RSP(IMEI) →	
	← SDCCH (I)/TMSI_REAL_CMD	MSC/VLR assigns a TMSI in place of IMSI in order to make tracking of subscribers more difficult. The TMSI_REAL_CMD is also a transparent message for BSS.
(To be continued)		

Figure 2.5 Mobile Station Origination Call Establishment (I)

Mobile Station	Channel/Signalling Message	Base Station Side
(Continued) Confirms with TMSI_REAL-COM that the TMSI was received and stored.	SDCCH (I)/TMSI_REAL_COM	
The SETUP message contains the directory number of the called party, transparently from the MS to the MSC/VLR.	SDCCH/SETUP(called direct.No.)	
	SDCCH(I) / CALL_PROC	After the MSC/VLR receives this information, it sends an IAM (in case of ISDN), in order to set up the connection. The network confirms with CALL_PROC that the IAM was sent and that the MSC is processing the call establishment.
Request from the BTS, by sending a SABM (LAPDm) that a layer2 connection be established. It contains a CM_SERV_REQ for identifying the subscriber (IMSI/TMSI) & specifies the requested service.	SDCCH (I) / ASS_CMD	At this time, if off air call setup (OACSU) is not active, the MSC sends ASS_REQ to the BSC. Most important information is, which (speech) channel shall be used for this connection. →The physical situation on the air-interface can be queried by sending a PHY_CONTEXT_REQ message, before the BSC assigns the TCH on the Air-interface. In particular the actual distance to MS & the current power setting of MS data are conveyed to the BSC in a PHY_CONTEXT_CONF message. → After receiving and processing of the ASS_REQ, BSC informs the BTS of the channel type & channel number shall be reserved (CHAN_ACT). → BTS confirms with CHAN_ACT_ACK that it received and processed the CHAN_ACT. With an ASS_CMD, the BSC assigns the traffic channel that the MS and BTS shall use on the Air-interface. ***The most important data are Transmission/Reception Unit (TRX) & Time Slot (TS).***
Sends a SABM to the BTS.	FACCH/ SABM	The BTS expects that a SABM is sent from the MS, using the new channel, which enables the LAPDm layer2 connection.
	FACCH/UA	The BTS confirms with a UA message (LAPDm) that a SABM was received and layer2 was established. →At the same time, this confirmation is sent in a EST_IND message to BSC.
	FACCH (I)/ASS_COM	With sending of ASS_COM, the traffic channel on layer3 is operational. This also acknowledges the ASS_REQ to the MSC. BSC releases the occupied control channel by sending of RF_CHAN_REL. The BTS confirms release with RF_CH_REL_ACK.
	FACCH (I)/ ALERT/PROGRESS	When the MSC receives ACM (ISUP) for the connection set up, it either sends an ALERT or a PROGRESS message to MS. ALERT is used to indicate a change of state within the MS, e.g., generation of a ring tone. PROGRESS is used when no change of state is involved, e.g., when the ring tone is sent 'inband' from the NSS.

Figure 2.5 Mobile Station Origination Call Establishment (II)

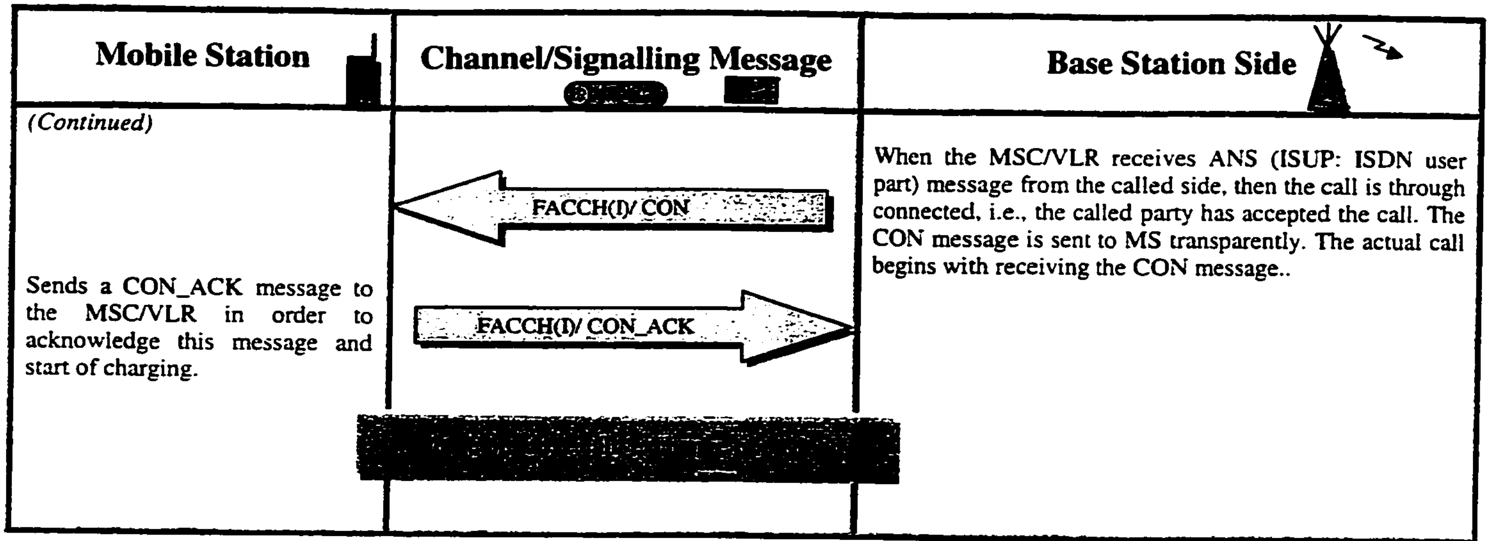


Figure 2.5 Mobile Station Origination Call Establishment (III)

2.2.3.3 Handoff /Handover Process

2.2.3.3.1 The Concept of Handoff /Handover

An obstacle in the development of the cellular mobile network involved the problem created when a mobile subscriber traveled from one cell to another during a call. As adjacent areas do not use the same radio channels (control channel or traffic channel), a call must either be dropped or transferred from one radio channel to another when a user crosses the line between adjacent cells in the same system or different systems. Because dropping the call is unacceptable, the process of handoff/handover was created.

A handoff is defined as the change of the currently used radio channel to another radio channel during an existing and active connection between mobile station (MS) and base station (BS). Note that the GSM-specific term handover corresponds to the same concept as handoff; in Europe, handover is used, while in North America handoff is used. The smaller the cell size and the faster the movement of a mobile station through the cells (up to 250 Km/h for GSM), the more handoffs/handovers of ongoing calls are required. In summary, there are two reasons for a handover.

- The mobile station moves out of the range of a base station transceiver (BTS) or a certain antenna of a BTS respectively. Thus, the received signal level becomes lower continuously until it falls underneath the minimal requirements for communication. Or the error rate may grow due to interference, the distance to the BTS may be too high etc. -- all these effects may diminish the quality of the radio link and make radio transmission impossible in the near future.
- The wire infrastructure such as mobile switching centre (MSC), base station centre (BSC) may decide that the traffic in one cell is too high and shift some MS to other cells with a lower load if possible. Thus, handover may be due to load balancing.

2.2.3.3.2 Handoff/Handover Processing

Figure 2.6 shows five possible handover scenarios in GSM:

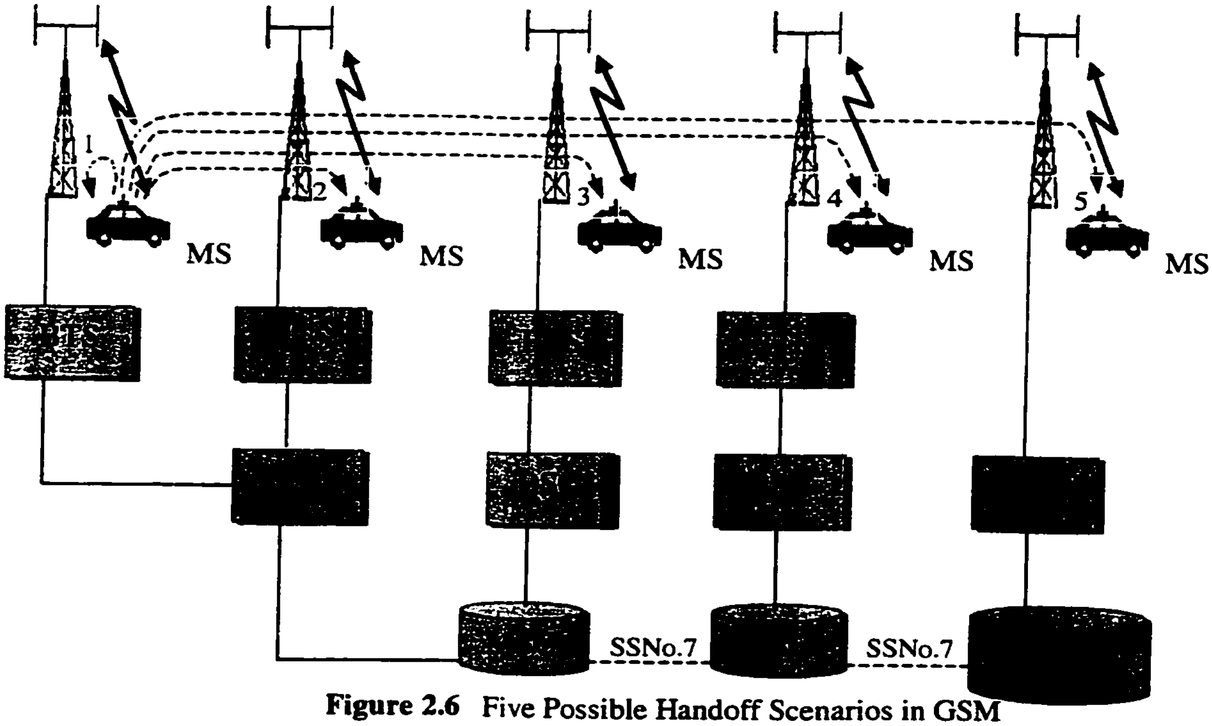


Figure 2.6 Five Possible Handoff Scenarios in GSM

1) Intra-BTS Handoff (Scenario 1): Within a cell, narrow-band interference could make transition at a certain frequency impossible. The BSC could then decide to change the carrier frequency. The procedure usually is executed autonomously by the BSC, but the MSC may also be in charge. In the intra-BTS handoff, a new channel in the same BTS is assigned to the MS. Note that an intra-BTS handoff is always synchronized, since all TRXs of a BTS have to use the same clock. Figure 2.7 shows a synchronized handoff process during a connection [1].

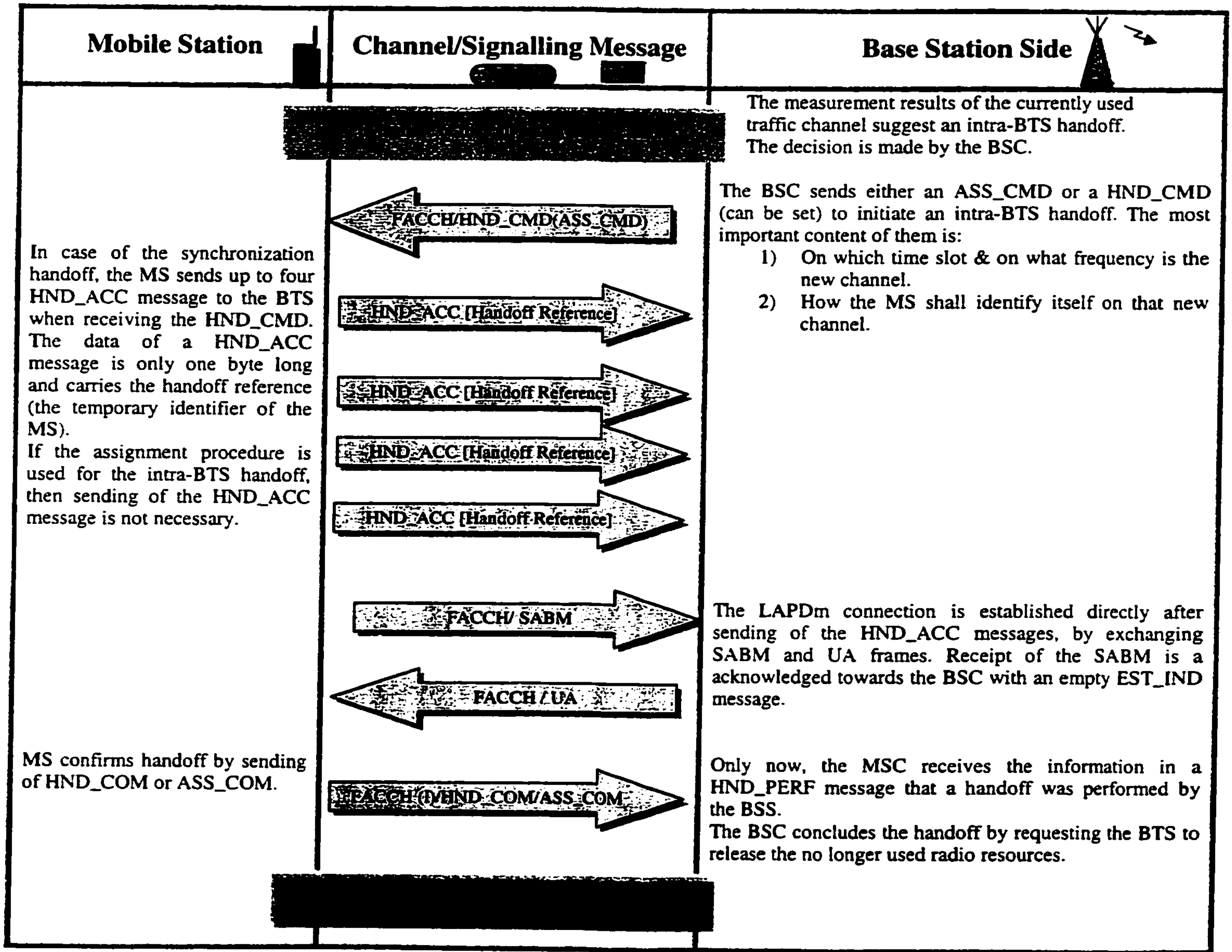


Figure 2.7 The Synchronized intra-BTS Handoff

2) Intra-BSC Handoff (Scenario 2): This is a typical handoff scenario. In the intra-BSC handoff, an MS changes the BTS but not the BSC. The intra-BSC handoff may be carried out autonomously by the BSC, without support from the MSC. It is an option by the network operator to decide that the MSC supervises the process. For intra-BSC handoff, depending on the circumstances, both synchronized and non-synchronized handoff are possible. A non-synchronized intra-BSC handoff process is shown in Figure 2.8. [1] The difference from the synchronized intra-BSC handoff is simply that the PHYS_INFO messages from the BTS would not have to be sent.

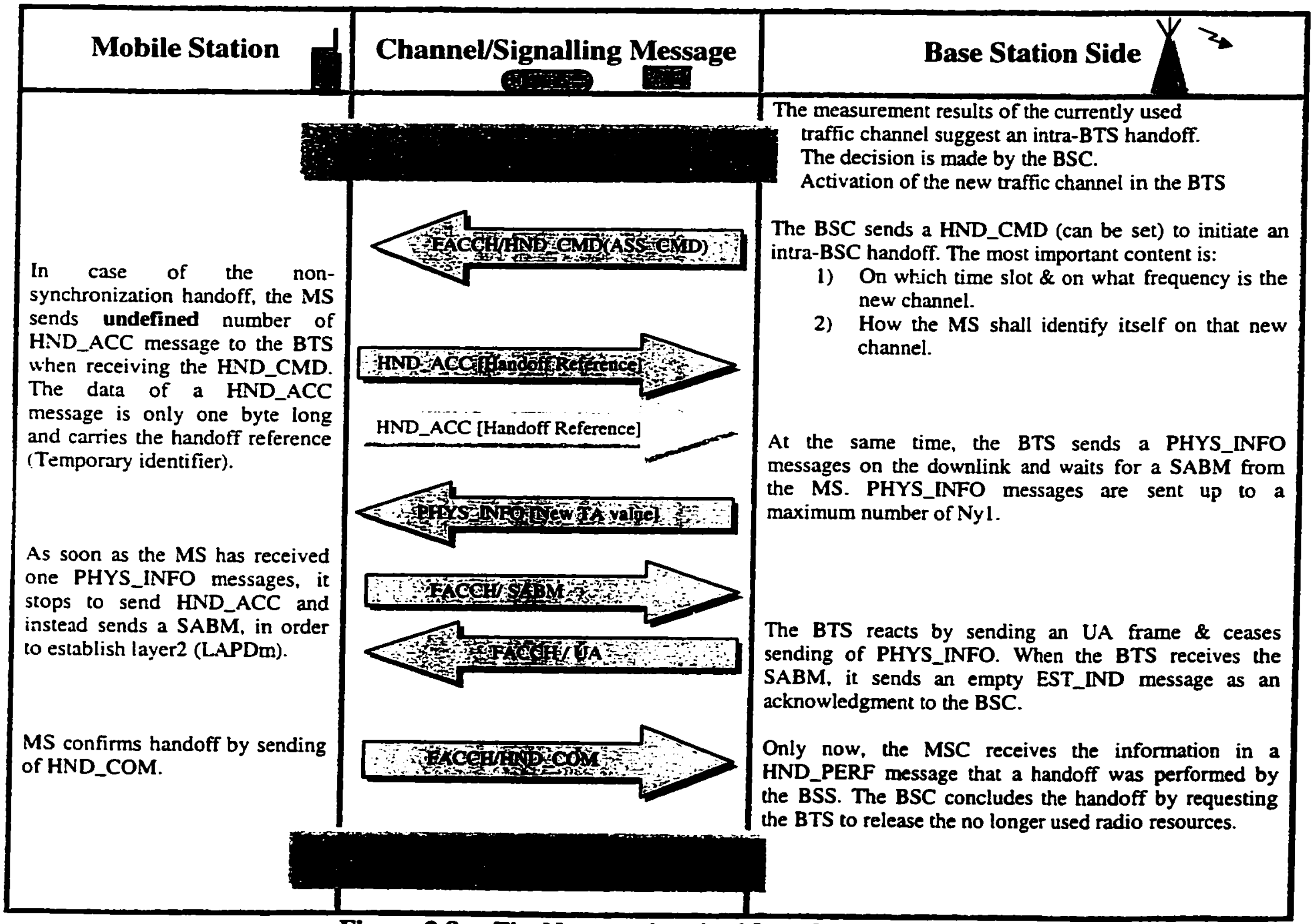


Figure 2.8 The Non-synchronized Intra-BSC Handoff

3) Intra-MSC Handoff (Scenario 3): In an intra-MSC handoff, the MS changes not only the BTS but also the BSC as well (external handoff). In contrast to the intra-BTS and intra-BSC handoff, the MSC mandatory is in charge for the execution of the intra-MSC handoff. However, the responsibility for the MSC does not include processing the measurements of the BTS or the MS or to conclude that a handoff is necessary. These functions always remain with the BSC. Figure 2.9 describes this scenario. [1]

Mobile Station	Channel/Signalling Message	Base Station Side
	[redacted] [To old BTS]. FACCH/HND_CMD	The measurement results of the currently used traffic channel suggest a handoff. The decision is made by the BSC. Possible target cells may lay outside of this BSS, hence the BSC has to inform the MSC. → The old BSC sends a HND_RQD to the MSC, which may be repeatedly sent in time intervals defined by BSS timer 7 if the MSC does not answer. The most important content is a list with all possible target cells for this handoff. The BSC has no knowledge whether a BTS belongs to the same MSC or not. That is, the BSC does not know whether an intra-MSC handoff or inter-MSC handoff will be necessary. → The MSC analyzes the HND_RQD to the target BSC, which assigns the channel to be used on the A-interface & specifies the target BTS. →The new BSC then activates a channel within the target BTS. (CHAN_ACT) → If the BTS confirms channel activation on the Air-interface, then the target BSC composes the HND_CMD message & sends a HND_REQ_ACK message back to the MSC. The MSC passes the HND_CMD message, received from the target BSC via the old BSC to the MS. The most important data are the HO-reference, i.e., the identifier of the MS when accessing the new BTS & the specification of type & target of the handoff (target frequency, time slot, synchronization).
When the MS receives the HND_CMD, then in case of the non-synchronized handoff, an undefined number of HND_ACC messages are sent to the BTS. The data of a HND_ACC is only 1-byte long & carries the handoff reference, that is the temporary identifier of MS.	HND_ACC [To new BTS] PHYS_INFO [From new BTS] HND_ACC [To new BTS] PHYS_INFO [From new BTS]	At the same time, the BTS sends a PHYS_INFO messages on the downlink (max Ny 1 times) and waits for a HND_ACC or a SABM from the MS. →when the first HND_ACC is received, the BTS sends HND_DET to the BSC. →The BSC forwards this message to the MSC, which switches the connection to the new BSC, although the HND_CMP is still pending. →The BTS does not stop sending PHYS_INFO, even when receiving HND_ACC.
After the MS receives a PHYS_INFO, it stops sending of HND_ACC & sends a SABM to the BTS in order to establish Layer2 (LAPDm).	[redacted] FACCH/SABM [To new BTS] FACCH/ UA [From new BTS] FACCH/HND_COM [To new BTS]	The BTS confirms to the MS that SABM was received by returning Unnumbered Acknowledgment (UA) and to the BSC by sending EST_IND. The new BSS terminates the handoff process by sending of HND_COM/HND_CMP. →MSC sends a CLR_CMD to the old BSC, as soon as the MSC receives the HND_CMP message to request release of the radio resources. →Finally, the SCCP connection to the old BSC is terminated and the related resources are released.

Figure 2.9 The intra-MSC Handoff

4) Inter-MSC Handoff and Subsequent Handoff (Scenario 4): *Inter-MSC handoff* is a handoff required between two cells belonging to different MSCs in the same type system. The control of the inter-MSC handoff stays with the old /original MSC. The original MSC always maintains the call control (CC) functionality, as the new MSC takes control over all radio resource (RR) task, which is internal to the MSC. These are in particular intra-MSC handoff–related tasks. Figure 2.10 shows this scenario. [1]

Old MSC Side (MSC A, BSC A)	**E-interface/Signalling**	**New MSC Side** (MSC B, BSC B)
For an active connection, BSC A determines that a handoff into another area is necessary. It then sends a HND_RQD to its MSC. The MSC detects that CI and LAC of the handoff candidate, provided in the HND_RQD, belong to another MSC area. After identifying the correct neighbour MSC, MSC A sends a PrepareHandoff (MAP) over the E-interface to MSC B.	PrepareHandoff HND_REQ → ← HND_REQ_ACK	VLR B subsequently assigns a temporary handoff number. →MSC B passes the included HND_REQ to the target BSC B and receives a complete HND_REQ_ACK back from BSC B, if those resources are available. MSC B answers to the original prepareHandoff by sending this BSSAP message back to MSC A.
MSC A reacts two folds: 1) By sending an IAM (ISUP), it requests that a traffic channel be established between MSC A and B. The address information in the IAM is the handoff number. 2) After receiving the corresponding ACM, MSC A sends the HND_CMD message via MSC A to the MS. On the air-interface, the MS performs handoff to the target BTS.	ISUP/IAM → ← ISUP/ACM ← ProcessAccSignaling[HND_DET]	BSS B indicates, by sending of HND_DET, that the HND_ACC message was received from the MS. MSC B forwards HND_DET in a processAccSignaling message (MAP) to MSC A.
	← ISUP/ANM	After that, by sending an ANM(ISUP), the traffic channel between MSC A and B is through connected. From then on, the transport of the payload is carried to MSC B. At the same time, the handoff number is released in VLR B.
Receiving of HND_CMP in BSS B or MSC B, respectively is signalled to MSC A in another MAP message, the SendEndSignal. This triggers MSC A to send a CLR_CMD message to BSC A, which then releases the no longer used radio connection. Release of the SCCP resources.	← SendEndSignal[HND_CMP]	

Figure 2.10 The inter-MSC Handoff

Subsequent handoff is applied such a second inter-MSC handoff: One case is a handoff from the new MSC back to the original MSC (See Figure 2.11); another is a handoff from the new

MSC into a third MSC area (See Figure 2.12). Although the new MSC initiates a subsequent handoff, the original MSC still maintains overall control of the call, during and even after a subsequent handoff. Overall control means that, in any case, independent of whether the target of the handoff is the original MSC or a third MSC, the CC functionality always remains with the old MSC.

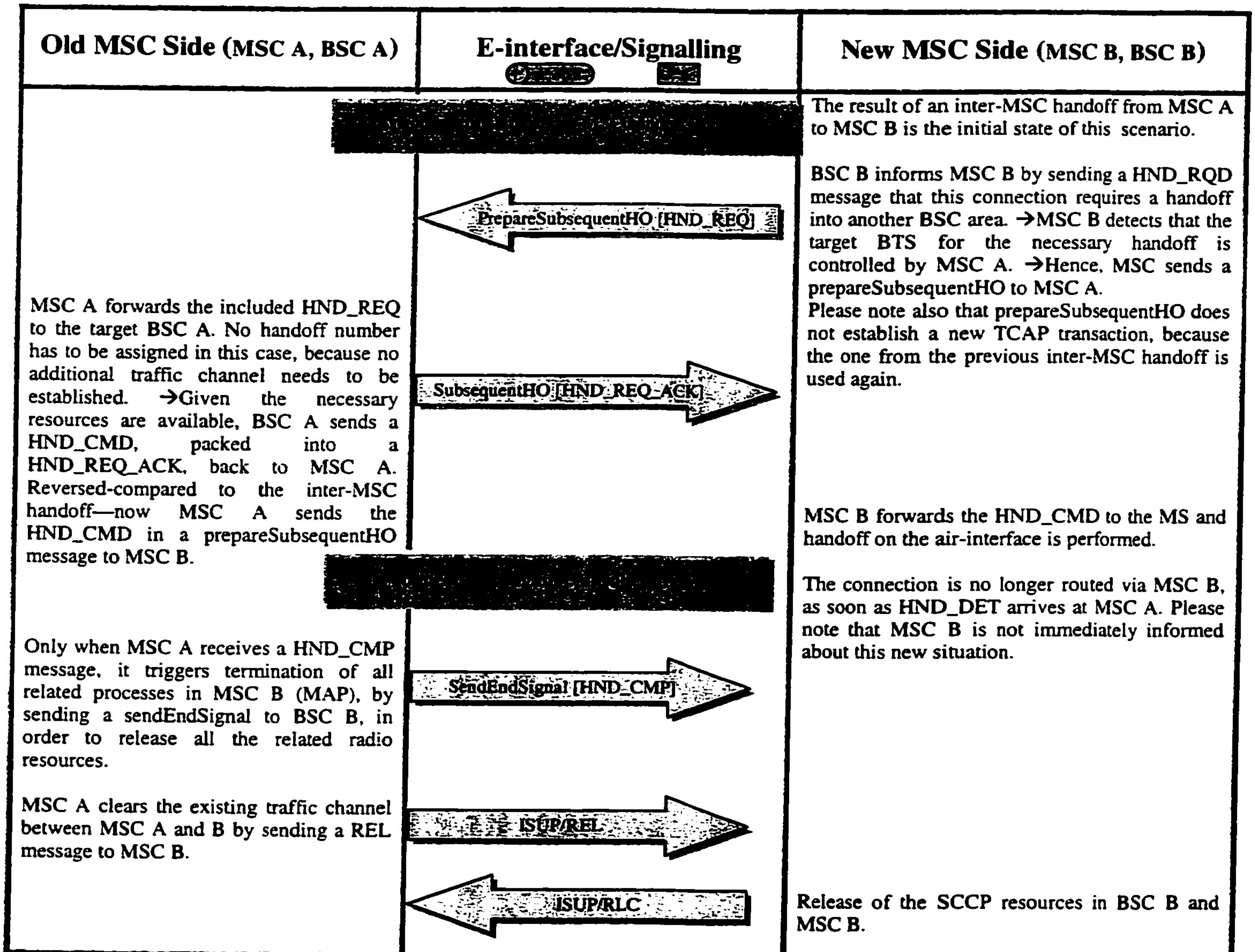


Figure 2.11 Scenario for Subsequent Handoff back to the Original MSC

Old MSC Side (MSC A, BSC A)	**New MSC Side** (MSC B, BSC B)	**Third MSC Side** (MSC C, BSC C)
	[redacted]	The initial state here is the same, as that of the previous scenario, which is the state after an inter-MSC handoff from MSC A to MSC B.
←	BSC B requests a handoff into a BSC area, which is controlled by a foreign MSC.→ MSC B sends a prepareSubsequentHO (MAP) to MSC A, which forwards this request in a prepareHandoff (MAP) to the target MSC (MSC C).	→ Now, MSC/VLR C have to provide the radio resources (HND_REQ) and have to assign a handoff number.
As an answer to the initial prepareHO (MAP), MSC A receives the final HND_CMD message, together with the handoff number from MSC C.		
MSC A sends the handoff number in an IAM (ISUP) message to establish a traffic channel between itself and MSC C.	→	MSC C confirms establishment of this channel (ACM).
MSC A forwards the HND_CMD to MSC B as its answer to prepareSubsequentHO.	MSC B sends the HND_CMD to the MS.	VLR(Visitor Location Register) C releases the handoff number. The MS executes handoff and reports this to BSS C.→BSS C then sends HND_DET, which is passed on from MSC C to MSC A.

Figure 2.12 Scenario for Subsequent Handoff to a Third MSC

5) Handoff (Roaming) between Two Different Systems (Scenario 5): is a handoff required between two cells belonging to different MSCs in the different systems, in order to provide seamless handoff. Currently, this requires a fix dual-/tri-mode mobile station and the inter-working of these two different systems to support this kind handoff operation (also called roaming). In Chapter 3, we will develop a new concept—which requires a re-configurable, multi-mode mobile station to support this kind of handoff operation (roaming). The main difference compared to traditional radios is thus the total programmability. Traditional mobile stations are typically composed of digital and analogue components. As most of the analogue components are not tuneable, SDR implementations in wireless handsets may be viewed in comparison with a generic PC model in the form of a multiple service model.

2.2.3.3.3 Five Major Types of Handoff in Mobile Communication System

For analog cellular, the MS is commanded to tune to a new frequency; the handoff process caused a short break in the voice path and a noticeable 'click' heard by both parties in the telephone call. For data modem, the click often causes data errors or loss of data synchronization. In CDMA, soft handoff greatly reduces the link outages in the transition region and in handoff using a technique that allows simultaneous transition to and from the user through two cells. During handoff, the signalling and voice information from multiple base stations must be combined in a common point with decisions made on the "quality" of the data. Similarly, voice and signalling information must be sent to multiple base stations, and the mobile station must combine the results. The common point could be anywhere in the network but is typically at the Mobile Switching Center (MSC). The call flows described here for handoff assume that the MSC contains the combining circuitry.

Subsequently, five types of handoff in current mobile systems, i.e. soft handoff, softer handoff, hard handoff, semi-soft handoff and idle handoff, are defined [6], [9]. Only detailed call flows of a soft handoff and idle handoff are presented, while other types of handoff process would be similar to the senarios described before.

1) Soft Handoff occurs when the new base station (BS) begins communications with the mobile station (MS) while the MS is still communicating with the old BS. The MSC combines the received signals from both base stations to process an uninterrupted signal to the distant party. The MS will receive the transmissions from the two base stations as additional multi-paths in the RAKE receiver and will process them as one signal. RAKE receiver consists of correlators, each receiving a multipath signal. After spreading by correlators, the signals are combined using.

The BS directs the MS to perform a soft handoff only when all forward traffic channel assigned to the MS have identical frequency assignments. Soft handoff provides diversity of forward traffic channels and reverse traffic channel paths on the boundaries between base stations.

At call initiation, the MS is supplied a tailored set of handoff thresholds and a list of cells that are most likely to be the candidates for handoff. While tracking the signal from the original cell, the MS searches for all the possible pilots and maintains a list of all pilots whose signals are above a threshold established in the initial setup. This list is transmitted to the MSC whenever

(1) It is requested;

(2) The list changes by having a new pilot appear on the list;

(3) When an existing pilot falls below a level that is useful to support the traffic.

A detail call flow of a soft handoff is illustrated in Figure 2.13.

Mobile Station	Channel/Signalling Message	Base Station Side
	[redacted]	
Determines that another BS has a sufficient pilot signal to be a target for handoff. & Sends a pilot strength measurement message to the old BS.	Pilot Strength Measurement Msg →	The old BS sends an inter-BS handoff request message to the MSC. →The MSC accepts request & sends an inter-BS handoff request message to the new BS. The new BS establishes the connection with MS by sending a Null traffic message & sends a join request message to the MSC.
	← Null Traffic message[From new BS]	
	← Handoff Direction message	The MSC conferences the connections from the two BSs so that the handoff can be processed without a break. Sends a join acknowledge to the new BS. → The new BS sends an inter-BS handoff acknowledgment message to the MSC. →MSC sends a inter-BS handoff acknowledgment message to the old BS. →The old BS sends a Handoff direction message to the MS.
The MS sends a handoff complete message to the old BS.	Handoff Complete Message →	
	← Pilot Measurement request order	The old BS sends a handoff information message to the MSC. →MSC confirms it. →The new BS sends a pilot measurement request order to the MS.
Sends a pilot strength measurement message to the new BS.	Pilot strength measurement message →	
	[redacted]	
If the MS determines that the old BS has insufficient pilot signal to continue to be a BS in soft handoff. →Sends a pilot strength message to the old BS to drop off.	Pilot strength measurement message →	
	← Handoff direction message	The old BS sends a handoff direction message to the MS.
The MS sends a handoff complete message to it.	Handoff Complete message →	The old BS sends an interface primary transfer message to the new BS.→The new BS confirms with acknowledge message & sends a handoff information message to the MSC. →The MSC sends back an acknowledge message to the new BS.
	← Pilot Measurement request order	The new BS sends a pilot measurement request order to the MS.
The MS sends a pilot strength measurement message to the new BS.	Pilot strength measurement message →	The old BS sends to the MSC a remove request message, which requests that the BS be dropped from the connection. The MSC confirms the message by sending a remove acknowledge message to the old BS.
Note: The procedures to drop a new BS from a soft handoff are similar.		

Figure 2.13 The Call Flow of a Soft Handoff

2) Softer Handoff occurs when the MS is in handoff between two different sectors at the same cell/BTS. Typically, a BS is designed so that an antenna transmits and receives over a 120° sector rather than a full 360°. For the discussion of softer handoffs, it is useful to designate a sector as a primary sector (the older sector serving the call). The operaion of softer handoff is similar to that of intra-BTS handoff discussed before.

3) Hard Handoff occurs when the two base stations are not synchronized or not on the same frequency and an interruption in voice or data communication occurs. Hard handoffs can occur when more than one frequency band is used, or the two BSs are not synchronized, e.g., in two different systems. For CDMA IS-95 system, another type of hard handoff occurs when there is no serving CDMA base station available and the MS must be directed to an analog cellular channel. For example, CDMA to CDMA hard handoff, in which the BS directs the MS to transition between disjoint sets of base stations, different frequency assignments, or different frame offsets. In addition CDMA to analog handoff, in which the BS directs the MS from a forward traffic channel to an analog voice channel.

4) Semi-soft handoff occurs when the handoff appears as a soft handoff within the network but the MS processes it as a hard handoff. This handoff occurs in CDMA system only.

5) Idle handoff procedures: An idle handoff occurs when a MS has moved from the coverage area of one base station into the coverage area of another base station during the MS idle state. The MS determines that an idle handoff should occur when it denotes a sufficiently strong pilot/broadcast channel signal other than that of the current base station's pilot/broadcast channel signal.

For CDMA IS-95 in the MS idle state, the mobile station continuously searches for the strongest pilot channel signal on the current CDMA frequency assignment whenever it monitors the paging channel. If the MS determines that one of the neighbour set or remaining set pilot channel signals is sufficiently stronger than the active set pilot channel, the MS should performed an idle handoff as specified in the following.

While performing an idle handoff, the MS operates in the non-slotted mode until the MS has received at least one valid message on the new paging channel. Following the reception of this message the mobile station resumes slotted mode operation. After performing an idle handoff, the MS discards all unprocessed messages received on the old paging channel.

In CDMA, both the BS and the MS monitor the performance of the radio link and can request handoffs. Handoffs requested by a mobile station are called *mobile-assisted handoffs*; and those requested by the BS are called *base station assisted handoffs*. Either side can initiate the handoff process whenever the following triggers occur: base station traffic load, distance limits exceeded, pilot signal strength below threshold, power level exceeded. The mobile station determines the parameters for the handoff request from the system parameters message in the CDMA system and the broadcast message in the wideband code division multiple access (W-CDMA). Both messages are transmitted on their system's paging channels.

In the next Chapter 3, we propose a reconfiguable multi-mode MS that could perform seamless handoff/roaming between different wireless systems.

Chapter 3 Reconfigurable Multi-mode Mobile Station for Mobile Communication Systems

3.1 Profile of the Reconfigurable Multi-mode Mobile Station

For a reconfigurable mobile station (MS), instead of changing the ROM for application software, new version of the software is downloaded from the universal base station. The new system software code could be saved as a new file or could replace the old one in the flash memory at a MS. Restrictions on the memory size and power consumption at mobile station should be considered for further design. Software radio can provide the terminal agent function, which is realized according to the user's favor such as cost effectiveness, quality of service (QoS), etc.

While the MS moves to a new area, in addition if the quality of service (QoS) of the mobile is bad and the same system is not available, the mobile will automatically switch to a new system by downloading new system software over-the-air. The downloaded new system software codes are then saved as a file in the memory. Possibility of the change of system is rather high when the systems are overlapped in the same area. This chapter mainly addresses the software download issues in a reconfigurable mobile station, all the transition probabilities and all transition times involved to all download. The downloaded software will consist of two parts: The first controls the hardware configuration of the MS unit and the second constitute the medium access control (MAC), signaling and higher networking layer at the MS.

3.1.1 Over-the-Air Reconfiguration

3.1.1.1 Configuration of the Universal Base Station

Universal base station means a base station that has the neccessary software for all standard systems such as GSM, CDMA IS-95, DECT, UMTS etc. This BS will download such software code to a power-up or roaming mobile station upon request. Each universal base station has two types of channels—universal pilot channel and universal data channel.

Universal pilot channel is a synchronization reference, message broadcasting, and signaling channel. The mobile will use this channel to exchange signaling with the universal base station for system software to be downloaded. We assume that new universal pilot channels would be generating in each of the 900, 1800, 1900, 2400, 5000 MHz band.

Universal data channel is dedicated to the mobile station for downloading the system software code, which will configure the modulation, access, and network functionalities of the reconfigurable and transparent mobile station. This mobile station has general firmware that can be programmed to any standards.

In a general sense, *software download (SW_DL)* can be defined as being the "process of introducing new program code to a terminal to modify its operation or performance". Normally, there are two methods for downloading system software code to a mobile—a smart card loading (e.g. SIM) and air interface loading. Herein, we propose downloading the software data over the wireless link. When the mobile station is in areas defined as having a mixture of universal cellular base stations, universal wireless LAN base stations, and classical base stations having only one cellular standard, the scenario is shown in Figure 3.1.

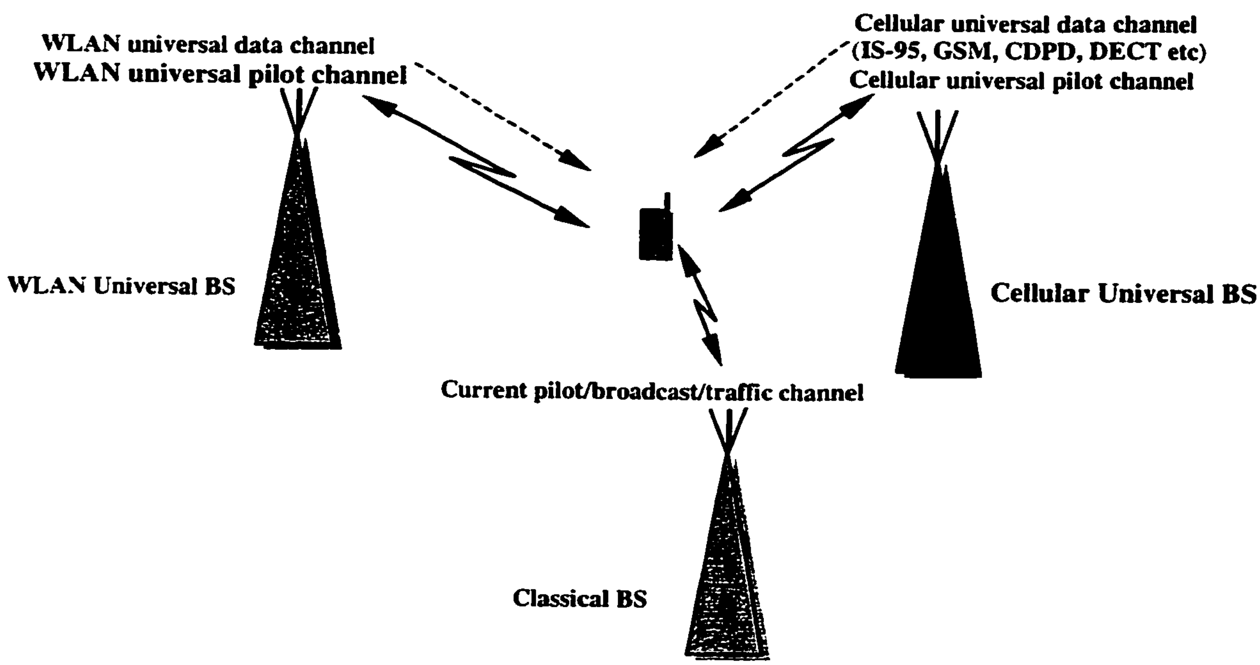


Figure 3.1 Over-the-Air Reconfiguration

3.1.1.2 Configuration of the Mobile Station

To make the mobile terminal reconfigurable, two configurations on the mobile station will be defined here. First of all, each mobile station would have *a certain ROM* for storing the default software code as defined by home location, such as GSM, CDMA IS-95, DECT etc, together with *a certain memory* for storing two system software code files. In addition, each mobile station would have a *universal save button*, which could be used by the user to control the system software download mode.

3.1.1.2-1 Code Tree

We define 7 function indication bits for a reconfigurable multi-mode mobile station as shown in Table 3.1. While the mobile station is power-up or roaming, it will check these functional indicator bits to make a initial state transition decision. Before discussing how the mobile station operates accordingly, we present a code tree that shows all the possible combinations of these indication bits in Figure 3.2. Note that the branch going up represents the value 1.

Table 3.1 7 Function Indication Bits for the Mobile Station

Indicator & Symbol		Probability	Meaning of symbol value I_i =1
Universal save button	I_1	θ_1	MS battery level is low then it will be forced to switch on the universal button or the button is pressed so that the user can select different systems.
Cellular universal pilot channel	I_2	θ_2	Cellular universal pilot channel is available in this area.
WLAN universal pilot channel	I_3	θ_3	WLAN universal pilot channel is available in this area.
Same kind BS/system	I_4	θ_4	Same kind of BS or system is available in this area.
QoS over the current system	I_5	θ_5	Current quality of service is good.
Cellular universal data channel	I_6	θ_6	Data channel for downloading new cellular software is available.
WLAN universal data channel	I_7	θ_7	Data channel for downloading new WLAN software is available.

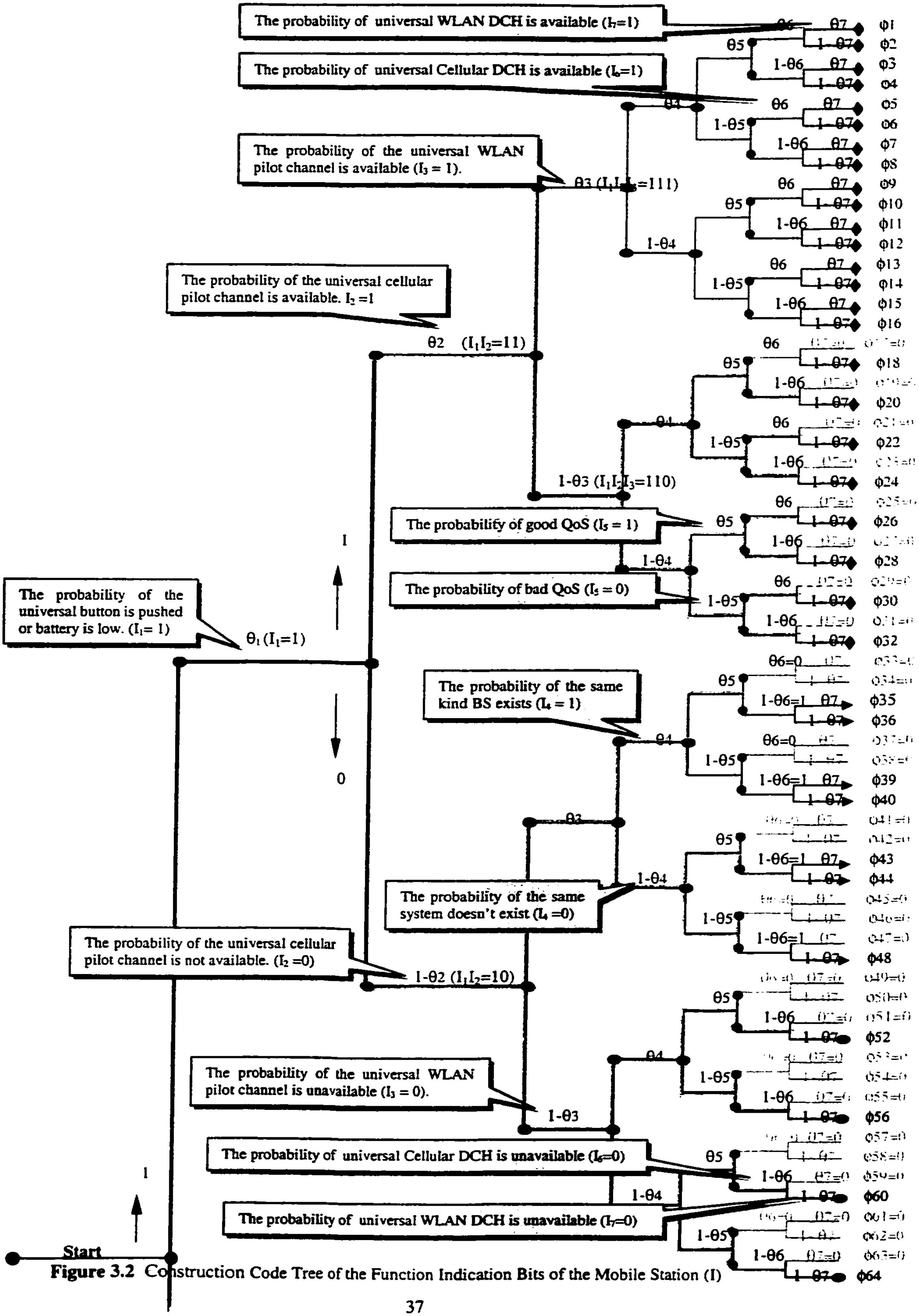


Figure 3.2 Construction Code Tree of the Function Indication Bits of the Mobile Station (I)

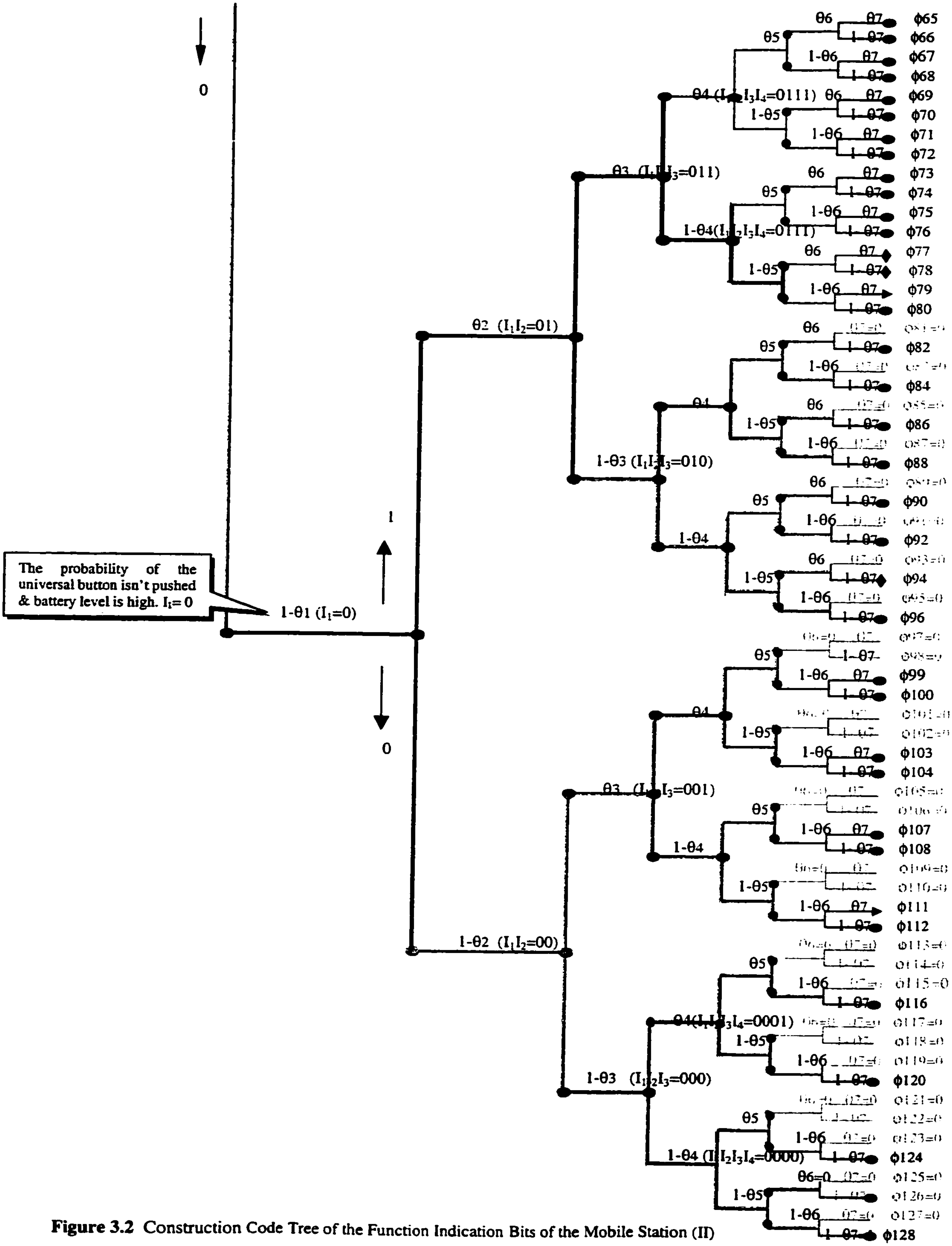


Figure 3.2 Construction Code Tree of the Function Indication Bits of the Mobile Station (II)

In this code tree, we labeled the probabilities of the functional bits beyond the branches or the leaves and placed the joint probabilities ϕ_i on the right side of the leaves. The joint probability ϕ_i is the probability of that the corresponding branch code value occurs. Based on this concept, it is clear that the probability of $I_1I_2I_3I_4I_5I_6I_7$ =1111111 occuring is ϕ_1, the probability of $I_1I_2I_3I_4I_5I_6I_7$ =1111110 occuring is ϕ_2, the probability of $I_1I_2I_3I_4I_5I_6I_7$ =1111101 occuring is ϕ_3, the probability of $I_1I_2I_3I_4I_5I_6I_7$ =0000000 occuring is ϕ_{128}, etc.

Since the construction of the code tree from the function indication bits is independent, the joint probability ϕ_i corresponding to a branch equals to the products of all the probabilities labeled on this branch. For example, $\phi_1 = \theta_1\theta_2\theta_3\theta_4\theta_5\theta_6\theta_7$, $\phi_2 = \theta_1\theta_2\theta_3\theta_4\theta_5\theta_6(1-\theta_7)$, $\phi_{128} = (1-\theta_1)(1-\theta_2)(1-\theta_3)(1-\theta_4)(1-\theta_5)(1-\theta_6)(1-\theta_7)$, and so on. Further, the probability of $I_1I_2I_3I_4I_5I_6I_7$ =1111111 is $\phi_1 = \theta_1\theta_2\theta_3\theta_4\theta_5\theta_6\theta_7$, the probability of $I_1I_2I_3I_4I_5I_6I_7$ =0000000 is $\phi_{128} = (1-\theta_1)(1-\theta_2)(1-\theta_3)(1-\theta_4)(1-\theta_5)(1-\theta_6)(1-\theta_7)$, and so on.

In fact, some of the combinations in the code tree in Figure 3.2 will never occur, since I_6 will be automatically set to zero if I_2 =0; similarly, I_7 =0 if I_3 =0. This means that the cellular software code download is not available if there is no cellular universal pilot channel, and the wireless LAN software code download is not available if there is no wireless LAN universal pilot channel. This also implies that when the cellular universal pilot does not exist, i.e. I_2 =0, the probability of the cellular software download data channel available θ_6 =0; same principle applies to wireless LAN, i.e. when I_3 =0, the probability of the wireless LAN software download available θ_7 =0. For those leaves, we marked ϕ_i =0 in the code tree, which means it won't happen. For example, ϕ_{17} =0 means the probability of $I_1I_2I_3I_4I_5I_6I_7$ =1101111 equals to zero; ϕ_{105} =0 means the probability of $I_1I_2I_3I_4I_5I_6I_7$ =0010110 equals to zero,etc.

In order to show how the mobile station makes a path decision in automatic mode, we distribute all the branches in this code tree into four groups and mark them in different symbols --"♦", "→","•","–". This means that if the function indication bit $I_1I_2I_3I_4I_5I_6I_7$ equal to:

a) One of the values corresponding to the "♦" branches, the mobile station will make the transition to cellular system software code download path.

b) One of the values corresponding to the "→" branches, the mobile station will make the transition to wireless LAN system software code download path.

c) One of the values corresponding to the "•" branches, the mobile station will make the transition to the same system path.

d) One of the values corresponding to the "–" branches, some errors may have occurred. The mobile station ignores these values, since these branches represent the cases that will not happen.

3.1.1.2-2 State Diagram

To represent the set of events that can take place while the MS is roaming and trying to make a connection with the network, we build up a generalized roaming connection state diagram of the reconfigurable mobile station as illustrated in Figure 3.3. It consists of 12 states S_0, S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}; their corresponding meanings are described in the following **Table 3.2.**

Table 3.2 The Possible States of the Mobile Station

State	Meaning
S_0	Starting state.
S_1	Listening to the cellular universal pilot channel.
S_2	Listening to the WLAN universal pilot channel.
S_3	Listening to the same kind base station pilot /broadcast channel.
S_4	Authentication, signaling exchange with cellular universal base station.
S_5	Authentication, information exchange with WLAN universal base station.
S_6	Authentication, information exchange with the same kind system.
S_7	Authenticated MS is downloading new cellular system software from data channel.
S_8	Authenticated MS is downloading new wireless LAN software from data channel.
S_9	Call establishment in the same system (Handoff/roaming may happen at this time).
S_{10}	New system update, call establishment signaling with the new cellular system.
S_{11}	New system update, connection establishment signaling with WLAN.
S_{12}	Connected to the network.

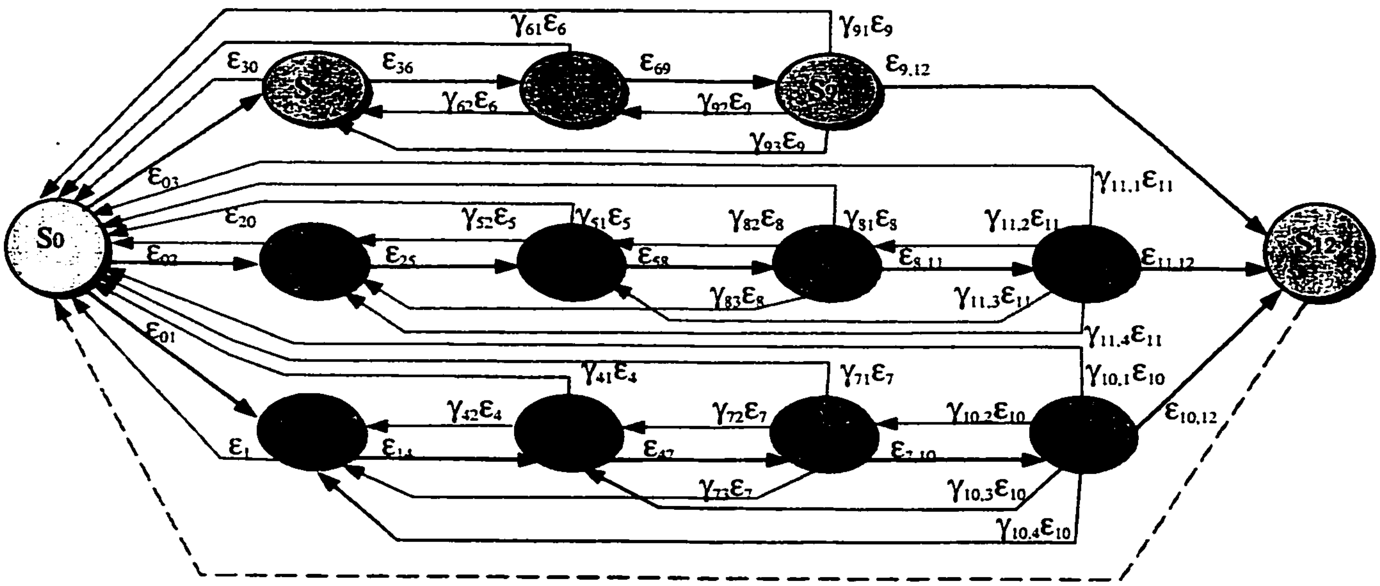


Figure 3.3 The Generalized State Diagram of the Mobile Station

The cellular system download path is path 1, i.e., $S_0 \rightarrow S_1 \rightarrow S_4 \rightarrow S_7 \rightarrow S_{10} \rightarrow S_{12}$,

The wireless LAN system download path is path 2, i.e., $S_0 \rightarrow S_2 \rightarrow S_5 \rightarrow S_8 \rightarrow S_{11} \rightarrow S_{12}$,

The same system path is path 3, i.e., $S_0 \rightarrow S_3 \rightarrow S_6 \rightarrow S_9 \rightarrow S_{12}$.

When the mobile station moves to a new area, if the quality of service (QoS) of the mobile is bad and the same system is not available, the mobile will automatically switch to a new system by downloading a new system software over-the-air. The downloaded new system software codes are then saved as a file in the memory of the MS. In next section, we mainly discuss the software download modes in a reconfigurable mobile station.

3.1.1.2-3 Software Download Modes

Here, we maintain that the user can choose automatic mode or preferred mode for the mobile station (MS). In *automatic mode*, the MS may take different paths in the state diagram, with initial transition probabilities of three paths are ε_{01}, ε_{02}, ε_{03} respectively. These 3 pathes correspond to downloading various cellular system software code, wireless LAN software code or staying in the same system.

In the *cellular system preferred mode,* the MS may take path 1 or path 3 in the state diagram, with transition probabilities ε_{01} and ε_{03} respectively. Thus, it may request universal cellular BS to download various cellular system software code or stay in the same system. The MS will never take path 2 in this mode, i.e., $\varepsilon_{02} = 0$. In *wireless LAN system preferred mode,* the MS may take path 2 or path 3 in the state diagram, with transition probabilities ε_{02} and ε_{03} respectively. Therefore, it may download various wireless LAN code or stay in the same system. The MS will never take path 3 in this mode, i.e., $\varepsilon_{03} = 0$. We can conclude that:

1) In the **automatic mode,** $I_1 = 1$ (probability is θ_1):

- If $I_2 = 1$, transition is made to state S_1 (See Figure 3.3).
- If $I_2 = 0$ and $I_3 = 1$, transition is made to state S_2 (See Figure 3.3).
- Else, $I_2 = 0$ and $I_3 = 0$, transition is made to state S_3 (See Figure 3.3).

That is to say, in the automatic mode, the MS will select the cellular download path once the universal cellular pilot is available, whatever the other conditions are satisfied or not. The MS will select the WLAN download path only when the universal cellular pilot is not available but the WLAN pilot is available. Otherwise, the MS will still operate on the current system.

2) In the **cellular system preferred mode,** $I_1 = 1$ (probability is θ_1):

- If $I_2 = 1$, transition is made to state S_1. (See Figure 3.3)
- Else, $I_2 = 0$, transition is made to state S_3. (See Figure 3.3)

3) In the **wireless LAN (WLAN) preferred mode,** $I_1 = 1$ (probability is θ_1):

- If $I_3 = 1$, transition is made to state S_2. (See Figure 3.3)
- Else, $I_3 = 0$, transition is made to state S_3. (See Figure 3.3)

That is to say, in the cellular preferred mode, the mobile station will select the cellular download path once the universal cellular pilot is available, whatever the other conditions are satisfied or not; otherwise, the mobile station will still operate on the current system. In the WLAN preferred mode, the mobile station will select the WLAN download path once the universal WLAN pilot is available, whether other conditions are satisfied or not; otherwise, the mobile station will still operate on the current system.

4) When the universal button is **OFF**, $I_1 = 0$ (probability is $1-\theta_1$):

a) In the case of I_4 **OR** $I_5 = 0$,

- If I_2 **AND** $I_6 = 1$, transition is made to state S_1.
- If I_2 **AND** $I_6 = 0$ & I_3 **AND** $I_7 = 1$, transition is made to state S_2.
- Else, transition is made to state S_3.

b) In the case of I_4 **OR** $I_5 = 1$, transition is made to state S_3.

That is to say, in the OFF mode, the mobile station will select the cellular download path, only when the QoS is bad and the same system is not available, but the cellular universal pilot channel and software download data channel are available. The MS will select the WLAN download path, if the QoS is bad and the same type system is not available, in addition the cellular universal pilot and software download are not available, but the Wireless LAN universal pilot channel and software download data channel are available. Otherwise, the mobile station will still operate on the current system.

Next, we further present how these will be taken into account in the initial transition probabilities of different pathes of the state diagram. The calculation of initial transition probabilities $\varepsilon_{01}, \varepsilon_{02}, \varepsilon_{03}$ are given below:

1) In automatic mode:

$$\varepsilon_{01} = \sum_{i=1}^{32} \phi i + \phi_{77} + \phi_{78} + \phi_{94} = \theta_1 * \theta_2 + (1-\theta_1) * \theta_2 * (1-\theta_4) * (1-\theta_5) * \theta_6$$

$$\varepsilon_{02} = \sum_{i=33}^{48} \phi i + \phi_{79} + \phi_{111} = \theta_1 * (1-\theta_2) * \theta_3 + (1-\theta_1) * \theta_3 * (1-\theta_4) * (1-\theta_5) * (1-\theta_6) * \theta_7$$

$$\varepsilon_{03} = 1 - \varepsilon_{01} - \varepsilon_{02}$$

2) In the cellular preferred mode:

$$\varepsilon_{01} = \sum_{i=1}^{32} \phi i + \phi_{77} + \phi_{78} + \phi_{94} = \theta_1 * \theta_2 + (1-\theta_1) * \theta_2 * (1-\theta_4) * (1-\theta_5) * \theta_6$$

$$\varepsilon_{02} = 0$$

$$\varepsilon_{03} = 1 - \varepsilon_{01}$$

3) In the WLAN preferred mode:

$\varepsilon_{01} = 0$

$$\varepsilon_{02} = \sum_{i=1}^{16} \phi i + \sum_{i=33}^{48} \phi i + \phi_{79} + \phi_{111} = \theta_1 * \theta_3 + (1 - \theta_1) * \theta_3 * (1 - \theta_4) * (1 - \theta_5) * (1 - \theta_6) * \theta_7$$

$\varepsilon_{03} = 1 - \varepsilon_{02}$

3.1.2 Description of the Power-up Registration, Roaming Process

In general, there are two scenarios that possibly require software download process. One is when the mobile station just powers up; another is when the mobile station roams to a new area. Since the roaming process is somewhat similar to the power-up process for a mobile, we describe the power-up process as an example.

When a reconfigurable mobile station just powers up, its first task is to acquire a universal pilot and data channel if the user wants new system software, or to acquire a classical pilot channel if the user wants to use the default mode or last registered (history) system. After the mobile station has successfully downloaded the system software, it updates its hardware according to the new system and operates as the classical single-mode mobile station. Hence, we can describe the power-up registration of the mobile station roughly in two distinct phases.

Phase1: New system software acquisition (Operating on the universal base station).

Phase2: Classical system updating, registration, connection establishment (Operating on the classical base station).

A power-up registration is performed according to the flowchart of Figure 3.4. A mobile station first checks the universal button indicator I_1.

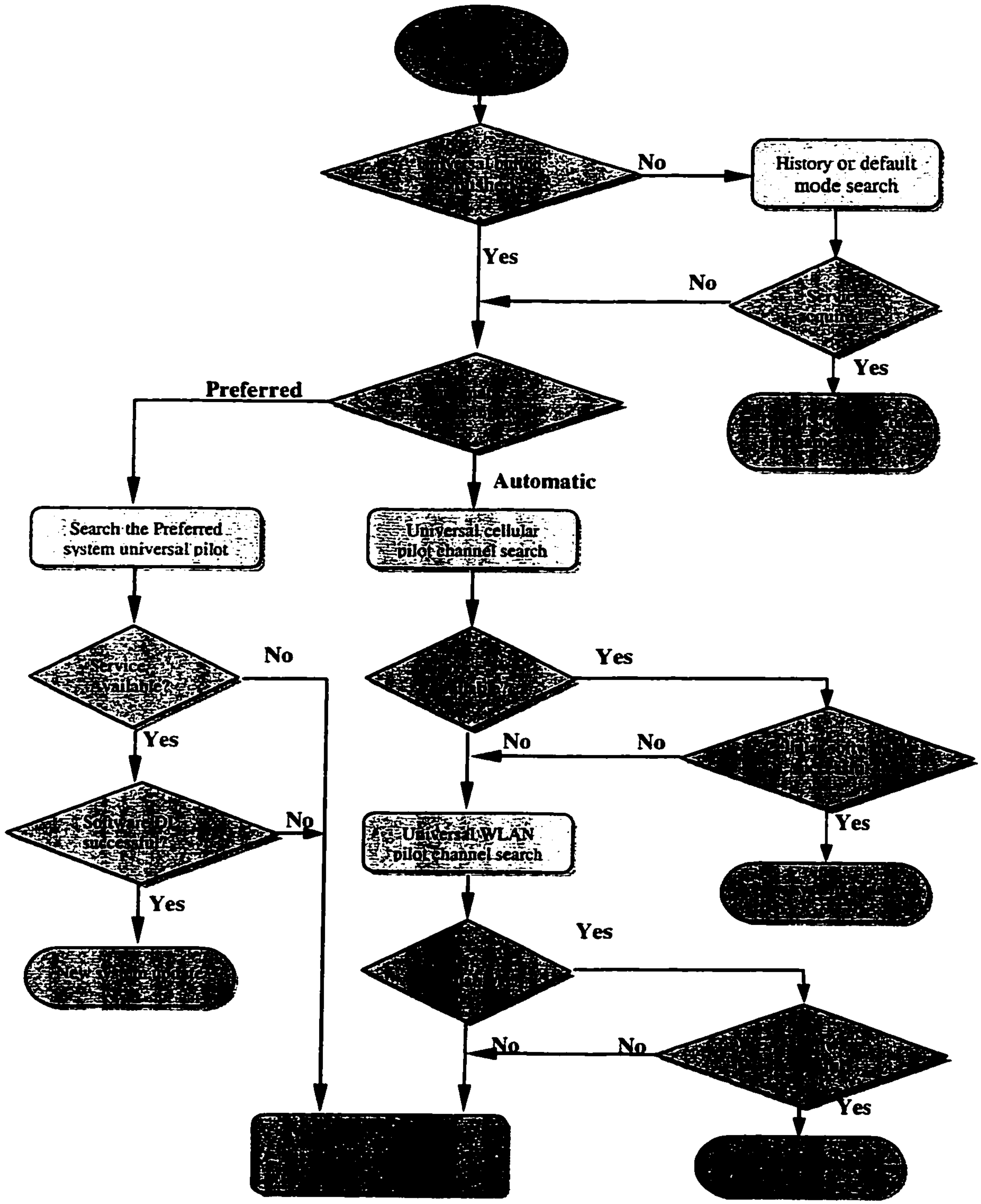


Figure 3.4 Flowchart of the MS Power-up or Roaming Procedure

1) If the user has not pushed the universal save button (i.e., $I_1 = 0$), the MS calls the system software stored in file 1 and conducts what is called a history search of a list of channels, where the MS either has obtained service in the past or has obtained information in the past indicating there is a high probability of obtaining service on these channels. The entries in the pilot/paging channel history table (PCHHT) are checked. The received signal strength on the PCHHT entries must be above a certain prespecified history threshold in order to be considered during the historic search. If the mobile station obtains service from the last registered system, it will start the initialization, registration process, or connection establishment in this system.

If the mobile station completes the historic search portion of the power-up scan without obtaining service, it enters a default mode/home system scan. During a default/home system scan, the mobile scans the default/home system frequency bands trying to obtain service from the base station that is available. If the mobile station fails to find service on an acceptable service provider while checking the last registered mode and default/home system, **"system X is no service here"** message is shown in the mobile station. At the same time, the mobile station will automatically switch the universal button on and sets $I_1 = 1$, then it operates as if the universal button has been pushed.

This guarantees that if the mobile is powered up in the same general area where it was powered down, or in the area that was served by the home service provider, the mobile will quickly find service on the same/home service provider.

2) If the universal button is pushed (i.e., $I_1 = 1$), the user may choose the automatic software download mode or the preferred system download mode. **In the automatic mode,** the mobile station begins searching the universal cellular and wireless LAN pilot channels, which enables the signaling exchange between the mobile station requiring new system software and the universal base station.

In the universal base station, the available software codes of new systems are listed in a certain order so called software database (SWDB) order here. Correspondingly, a system database (SYSDB) list will broadcast to the mobile stations covered by the universal base station through the universal pilot channel. The SYSDB within a mobile may be updated as the roaming situation change using the over-the-air programming tele-service. Reprogramming of the SYSDB is a valuable feature for the mobile and service provider, because the new system configurations may change in some areas. The basic principle to build the SWDB is that the system providing voice and data services and requiring less memory space for downloading is placed in the first order, the system that can only provide voice service is placed in the middle order, the system that can only provide data service and needs much memory for downloading is placed in the last order, etc. For instance, if the universal cellular pilot channel is detected, the mobile station will take the cellular software download path. The mobile station will select the wireless LAN download path only when the universal cellular pilot channel is not available but the wireless LAN pilot channel is available, since the wireless LAN provides only computer/data communication. The traffic situation in different serving areas is also considered while the universal base station builds the SWDB.

In each software code download path, the mobile station firstly tunes to the pilot channel and begins authentication and signaling exchange with the universal base station through this channel. If the mobile station is authenticated, the universal base station will dedicate a data channel to the mobile station for downloading the new system software. When the system software is downloaded successfully, the mobile station may obtain service and may initiate a mobile originated/terminated call as the single-mode mobile immediately.

Note that:

- *To avoid the unnecessary software download, the MS will reset the universal button to OFF after the software download procedure finished, until the software download mode is activated again.*
- *It is suggested that the mobile station move slowly while downloading.*

If all the universal software download data channel are busy, a **"Traffic is blocking"** message is sent to the mobile station, then the mobile station will check the function indication bits to make a new decision again. The network providers should reduce the occurrence of network resource blocking.

If the mobile station searches all the bands in the band order without finding a universal pilot channel in this area, it has to search the system using the default mode and the last stored file. In the event that no service is available, the MS will periodically restart the power-up registration as described above.

When the mobile station is in automatic mode, it is worth mentioning:

a) In normal cases, the mobile station will select the cellular universal BS for new system software downloading if there exist such services in this area, even though the traffic is crowded. According to the software database (SWDB) order, the universal base station will dedicate a data channel for downloading the software code of a new system that can provides both voice and data service.

b) In some specific cases, the universal BS can only download voice or data service system software codes to the mobile statoin, such as the mobile power or memory limitation, the system or network configuration limitation in some area. For example, when the cellular universal pilot channel is not available but the wireless LAN universal pilot channel is available (i.e., I2=0 & I3=1), the mobile station will select the wireless LAN software download path. Or for instance, the memory size in a mobile station is only enough for storing the AMPS system software code, in such case the mobile station can obtain voice service only.

In the user **preferred mode**, the mobile station begins searching the cellular universal pilot channel and wireless LAN universal pilot channel, which is responsible for the signaling exchange between the universal base station and the mobile station requiring new system software. A system database (SYSDB) list will broadcast to the mobile stations covered by the universal base station through the universal pilot channel. Immediately following the download of a new SYSDB, the user knows about the new systems around him. If the user selects the cellular preferred mode, the mobile station will take the cellular software download path once the cellular universal pilot channel is available, whether the other conditions are satisfied or not. If the user selects the wireless LAN preferred mode, the mobile station will select the wireless LAN software download path once the WLAN universal pilot channel is available, whether the other conditions are satisfied or not. Upon entering each path, the mobile station repeats the same procedure as the automatic mode.

Nonetheless, if the mobile station searches all the bands in the band order without finding an universal pilot channel in this area, it has to search the system using the default mode and the last stored file. In the event that no service is available, the MS will periodically restart the power-up registration as described above and the whole process repeats.

3.2 Connection Establishment of the Roaming Mobile Station

3.2.1 Description

3.2.1.1 The Transition Operation of the MS State Diagram

When the mobile station (MS) is roaming, the connection processing can proceed in two possible ways – roaming in the current system or roaming to a new system. In the former situation, the mobile station operates in the way no different from a classical mobile station, such that no new software code downloading is required. In the later situation, the mobile station will register in a new system, using the existing software stored in the memory or downloading a system software code through a universal base station. After the mobile station has registered in the new base station, it can make a connection to the network as a classical mobile station. The details about connection/call establishment, handoff signalings for a classical mobile station have been presented in Chapter 2. In the following, we focus on discussing the new concepts about the reconfigurable multi-mode mobile station, referring to the state diagram in Figure 3.3.

For the state diagram in Figure 3.3, S_0, S_1, S_2, S_4, S_5, S_7, S_8 belong to phase 1, and S_3, S_6, S_9, S_{10}, S_{11}, S_{12} belong to phase 2. This implies that:

a) The mobile station operates on the universal base station and their channels when it is in the state S_0, S_1, S_2, S_4, S_5, S_7, S_8 in path 1 and path 2;

b) The mobile station operates on the classical base station and their channels when it is in the state S_3, S_6, S_9, S_{12} in path 3 and S_{10}, S_{11}, S_{12} in path 1 and path 2.

c) The mobile station will skip the Phase 1 and takes the path 3 if it doesn't download the new system software code.

When the mobile just powers up or the mobile is currently listening to a system pilot/broadcast channel but initiates a transition request, it enters the start state S_0. In this state, the mobile station begins searching for the universal pilot channel signals from the universal cellular (or wireless LAN) base station and the pilot channel signal from the classical base station. The mobile station will check the functional indicator bits to make a state transition decision, possible cases are listed in Table 3.3. The initial transition probabilities of three paths are $\varepsilon_{01}, \varepsilon_{02}, \varepsilon_{03}$ respectively.

Table 3.3 Mobile Station Transition Operation Table (X – Don't care 1 or 0)

Mode	I_1	I_2	I_3	I_4	I_5	I_6	I_7	MS Operations
AUTOMATIC	1	1	X	X	X	1	X	Transition is made to S_1, Chooses the cellular SW_DL path1 & data channel is available to the mobile station.
	0	1	X	0	0	1	X	
	1	1	X	X	X	0	X	Transition is made to S_1, Chooses the cellular SW_DL path1, but data channel is NOT available to the mobile station.
	1	0	1	X	X	X	1	Transition is made to S_2, Chooses the WLAN SW_DL path2 & data channel is available to the mobile station.
	0	1	1	0	0	0	1	
	0	0	1	0	0	0	1	
	1	0	1	X	X	X	0	Transition is made to S_2, Chooses the WLAN SW_DL path2, but data channel is NOT available to the mobile.
	E L S E							Transition is made to S_3, Chooses the same system path3.
CELLULAR	1	1	X	X	X	1	X	Transition is made to S_1, Chooses the cellular SW_DL path1 & data channel is available to the mobile station.
	0	1	X	0	0	1	X	
	1	1	X	X	X	0	X	Transition is made to S_1, Chooses the cellular SW_DL path1, but data channel is NOT available to the mobile station.
	E L S E							Transition is made to S_3, Chooses the same system path3.
WLAN	1	X	1	X	X	X	1	Transition is made to S_2, Chooses the WLAN SW_DL path2 & data channel is available to the mobile station.
	0	1	1	0	0	0	1	
	0	0	1	0	0	0	1	
	1	X	1	X	X	X	0	Transition is made to S_2, Chooses the WLAN SW_DL path2, but data channel is NOT available to the mobile station.
	E L S E							Transition is made to S_3, Chooses the same system path3.

In general, in each state S_i for $i = 1, 2, \cdots, 11$, if the mobile station have transmitted and received the required signaling data packets successfully within the timer period, it will move to the next state in the path; otherwise if it fails to deliver the data packets or timeout, the mobile station may go back to one of the previous states. Figure 3.3 shows this idea and all the possible backward transitions in each state S_i. We have labeled all transition probabilities for each states and the calculation of these values will be given in Section 3.2.2.1. In fact, when the packets in each state fails to deliver within a certain limit, the mobile station will choose only one of the previous states to move according to different design scenarios. Different scenario can be obtained by setting γ_{ij} to 1 or 0 in the general state diagram in Figure 3.3, each scenario corresponds to a different roaming times and delays that we will show in Chapter 5 Test Results.

Next, we will describe the operation of the mobile station in each path. Because the operation of the mobile station in path 2 is quite similar to that in path 1, we mainly discuss the operation of the mobile station in path1 (See Figure 3.4) and path3 (See Figure 3.5).

3.2.1.2 The Transition Operation of the MS in Path 1 and Path 2

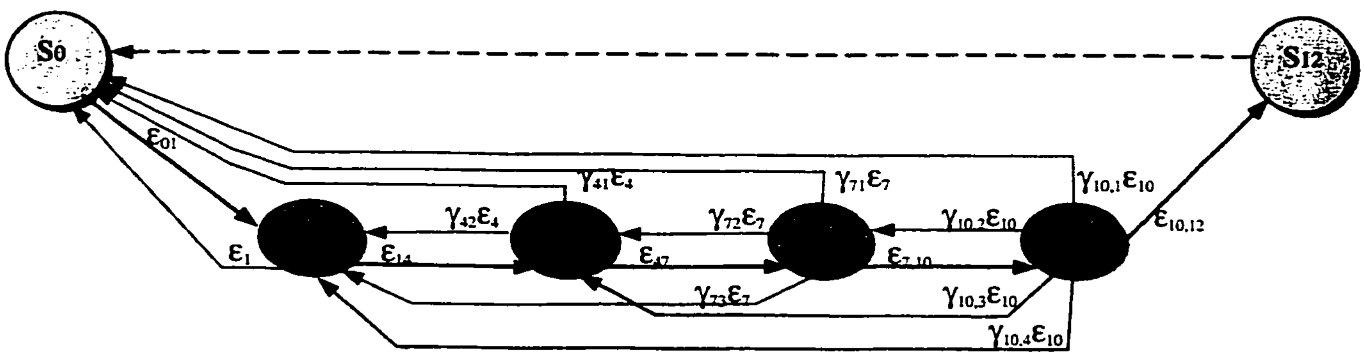


Figure 3.5 Cellular System Software Download Path of the Mobile Station Connection Establishment

Upon entering state S_1 (path1), with probability ε_{01}, the mobile station synchronizes to the universal base station in time and frequency. Then, it can listen to the cellular universal pilot channel and receive broadcast messages. In state S_1, the mobile station sends the software download request (Cellular_DL_Request) to the universal base station and listens to the universal cellular pilot channel, waiting for the authentication request (Authen_Request) from this pilot channel. However, if the mobile station cannot tune to the cellular universal pilot channel, it will return to the start state; this may happen with the probability ε_1 and corresponds to one of the feedback scenarios mentioned.

Subscriber authentication is performed at each new system software download process, at each call set-up attempt (mobile originating or terminated), and before performing some supplementary services such as activation or deactivation of the mobile. A universal base station should apply the authentication procedure to the mobile station in order to forbit the illegal mobile station access. The authentication procedure is performed after the subscriber identity (IMSI/TMSI) is known by the network and before the mobile station is dedicated a data channel for new system software download.

Upon receipt of the authentication request (Authen_Request) message, the mobile station sends authentication confirmation (Cellular_DL_Authen_Confirm) message. This implies it is entering the authentication and association state S_4. The mobile station begins authentication, association and signaling exchange with the universal base station through a universal pilot channel. ***(The details about how the universal base station reaches the database and details of the universal authentication method are beyond the scope of this thesis.)*** During this period, the MS may encounter one of the three possible situations.

- If the mobile station is authenticated, it will firstly send out a "short file"—memory and battery message to the universal base station. By considering these messages, the universal base station will send a CellularSW_DL_Ready message and dedicate a data channel (DCH) to the MS if the system resouce is available. The mobile station will moves to the next state S_7 with transition probability ε_{47}.
- If the authentication and signaling process fails due to error or system resource blocking, the MS will return to one of the previous state that depends on the design scenario. Or

else, the mobile station is illegal, it will never be permitted to access the data channel for download the system software codes. The mobile station may move to state S_0, S_1, with backward transition probability $\gamma_{41}\varepsilon_4$, $\gamma_{42}\varepsilon_4$ respectively.

Upon receipt of CellularSW_DL_Ready message and the download data channel (DCH) message, the mobile station enters state S_7 and begins to download the new system software code through the universal data channel. What kind of system software code will be downloaded? This is depending on both the traffic situation of the system and the mobile station resource situation. For instance, when the mobile station is in automatic mode, there are two general cases that have been discussed in Section 3.1.2 (See page 49).

On the other hand, when the MS is in the user prefered mode, by checking the new downloaded SYSDB, the user knows about the systems around him. If the user selects the system he wants, the mobile station will send this information to the universal base station during the authentication and signaling exchange period.

In state S_7, if the mobile resource is enough for the downloading process, the mobile station receives the codes on the data channel and stores them as a file so that the mobile station may call it anytime later. However, if the remained memory size of the MS is not enough for the codes, an blocking indication message is sent to the user **"Memory is full, would you like to delete the old file for more space?"** In this case, if the user answers with "Yes", the mobile station will lose the system file stored in the other memory address; furthermore, if the mobile station is communicating with that system, the communication will be terminated immediately. Otherwise, if the user answers with "No", the download process will be terminated immediately. ***(We propose that each re-configurable mobile station could have a default mode whose data is***

stored in a ROM by the manufacture and have two download modes whose data are saved as file1 and file2 stored in the memory such details are left for further research.)

During this period, the MS may encounter one of four possible situations:

- If the system software has been downloaded completely, the mobile station sends out a download completed (CellularSW_DL_Completed) message to the universal cellular base station. The mobile station will moves to the next state S_{10} with transition probability $\varepsilon_{7,10}$.
- If the system software code downloading process fails due to error or resource blocking, the mobile station will return to one of the previous state that depends on the design scenario. But if the user terminates the process, the mobile station will return to the start state and begins a new searching. The mobile station may move to state S_0, S_1, S_4 with backward transition probability $\gamma_{71}\varepsilon_7$, $\gamma_{72}\varepsilon_7$, $\gamma_{73}\varepsilon_7$ respectively.

Having finished downloading the system software, the mobile station enters state S_{10}. In this state, it may process new system update, connection establishment signaling with the new cellular system. During this period, the mobile may result in five possible scenarios.

- If the downloaded system software code can be called correctly, the mobile station updates its hardware according to the new system, processes connection establishment signaling with the new network. Up to now, the user may initiate a mobile originated/terminated call using the single-mode mobile. The details about the registration and call procedure of different systems have been discussed before in Chapter 2. By receiving a connected (Cellular_Connected) message, such as alert signaling, from the new classical base station. The mobile station will move to the next state S_{12} with transition probability $\varepsilon_{10,12}$.

- If the connection establishment fails due to error or system resource blocking, the mobile station may return to one of the previous states that depends on the design scenario. If the new system updating fails due to some part of the software code error, it is a more effective design to return to S_7. But if the mobile station terminates the process, it will return to the start state S_0 and begins a new searching. The mobile station may move to state S_0, S_1, S_4, S_7 with backward transition probability $\gamma_{10,1}\varepsilon_{10}$, $\gamma_{10,2}\varepsilon_{10}$, $\gamma_{10,3}\varepsilon_{10}$ $\gamma_{10,3}\varepsilon_{10}$ respectively.

Similar principle and process may be applied to the mobile station while it takes **path2**.

3.2.1.3 The Transition Operation of the MS in Path 3

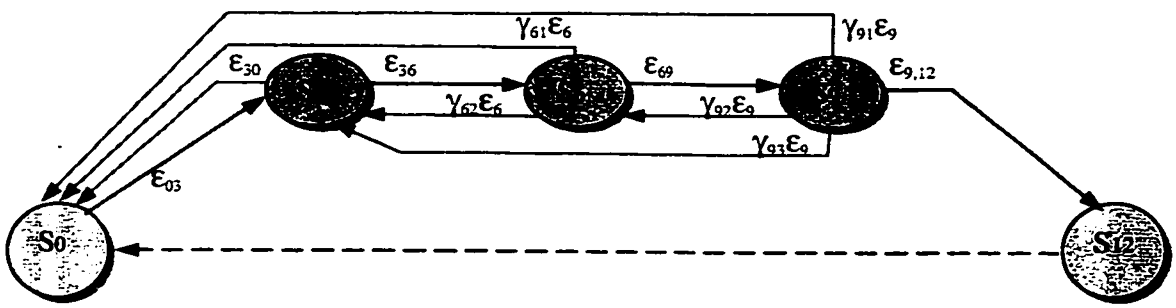


Figure 3.6 Same System Path of the Mobile Station Connection Establishment

As we have discussed before, start state S_0 may imply that the mobile station (MS) just powers up or the mobile is currently listening to a system pilot/broadcast channel but initiates a transition request. If the MS just powers up, firstly, it starts a historic search by calling the system software in file 1 or 2. If the mobile station completes the historic search portion of the power-up scan without obtaining service, it enters a default mode/home system scan. The mobile station may obtain service, with probability ε_{03}, moving from the start state S_0 to the state S_3 and synchronizing to the base station. If the mobile station is currently operating on a given system, entering the state S_3 means that the mobile should continue to listen to the pilot/broadcast channel of the same system.

Upon entering state S_3 (path3), with probability ε_{03}, the mobile station listens to the pilot channel and may receive broadcast messages from the classical base station. In state S_3, the mobile station sends the connection (SameSystem_Setup) message or handoff request message while necessary to the classical base station and listens to the pilot/paging channel, waiting for the authentication request (Authen_Request) from the network. However, if the mobile station cannot register in the classical base stations, it will return to the start state; this may happen with the probability ε_{30}.

Upon receipt of the authentication request (Authen_Request) message, the mobile station sends authentication confirmation (SameSys_Authen_Confirm) message. This implies it is entering the authentication and association state S_6. The mobile station begins authentication, association and signaling exchange with the classical base station. Subscriber authentication is performed at each registration, at each call set-up attempt (mobile originating or terminated), at each handoff and intelligent roaming process, and before performing some supplementary services such as activation or deactivation of the mobile. This procedure is different among different wireless systems, for details, the reader can refer to the references [1], [2], [3], [4], [6]. During this period, the mobile may encounter one of three possible situations.

- If the mobile station is authenticated, it will move to the next state S_9 with transition probability ε_{69}.
- If the authentication and signaling process fails due to error or system resource blocking, the mobile station will return to one of the previous states that as per design scenario selected. Or else, the mobile station is illegal, it will never be permitted to access the

traffic channel for communication. The mobile station may move to state S_0, S_3, with backward transition probability $\gamma_{61}\varepsilon_6$, $\gamma_{62}\varepsilon_6$ respectively.

In state S_{10}, it may process system handoff, connection establishment signaling with the new cellular system. By successfully handoff, the base station will send a SameSys_HO_Completed message and dedicate a new control channel (CCH) or traffic channel (TCH) to the mobile if the system resouce is available. During this period, the mobile may encounter one of four possible situations.

- The user may initiate a mobile origination and termination connection establishment immediately as using the single-mode mobile. Or handoff may occur in the same system while necessary. The details about the registration, connection, and handoff procedure of different systems have been discussed before in Section. By receiving a connected (SameSys_Connected) message, such as alert signaling, from the new classical base station. The mobile station will moves to the next state S_{12} with transition probability $\varepsilon_{9,12}$.
- If the connection establishment fails due to error or system resource blocking, the mobile station may return to one of the previous state as per design scenario selected. But if the user terminates the process, the mobile station will return to the start state S_0 and begins a new searching. The mobile station may move to state S_0, S_3, S_6 with backward transition probability $\gamma_{91}\varepsilon_9$, $\gamma_{92}\varepsilon_9$, $\gamma_{93}\varepsilon_9$ respectively.

Note that: the connection procedure while the mobile station is in state S_6 and S_9 are the same as a classical single- or dual-mode mobile station. The main difference between them is only that the re-configurable mobile station can provide more intelligent roaming process. When the mobile station moves to a new area, if the same type of system is available in this area, the handoff and roaming process of the mobile station in the current system is the same as a single-mode MS described in Chapter 2. However, for the case where there is no "same band" or "same mode" system provided to the mobile station, we have to introduce one new concept—intelligent roaming, which are originally derived from Digital PCS [4].

Intelligent roaming is a method for ensuring that a mobile station (MS) obtains service from the best provider in an area without requiring user intervention. While the MS moves to a new area, if the quality of service (QoS) of the MS is bad and the same system is not available, the MS will automatically switch to a new system by calling the file saved in the memory or downloading a new system software over-the-air. Intelligent roaming is only possible from a service provider using the same air interface technology, such as Digital PCS, by using a classical dual-mode mobile. But with the introduction of software radio concept to the RF circuit design, it would also be possible for multi standards.

The primary event that triggered the need for intelligent roaming was the opening of the various frequency bands and standards for cellular service, cordless service and the wireless local area network (wireless LAN), which are possible at 800MHz, 900MHz, 1800MHz, 1900MHz, 2.4GHz or 5GHz bands. Also, the development of multi-band, re-configurable multi-mode mobile stations urges this feature.

There are two basic ways of providing intelligent roaming to mobile users: network-directed and mobile-directed. In *network-directed intelligent roaming*, the MS finds a universal pilot channel on one of the available bands and signaling is used to direct the mobile to the most appropriate band and system for it to obtain service in the area. In *mobile-directed intelligent roaming*, the mobile has all the information necessary to decide which band to operate on in any given area. Both air interface and intersystem signaling are required for network-directed intelligent roaming. Which method should be adopted? Both. ***(Now, many research works have proved that a SDR radio system is realizable, but the most difficult part to put these ideas into commercial is the implementation of a multi-function DSP, that is the hardware implementation issue).***

3.2.2 Calculation of the Transition Probability for the State Diagram

3.2.2.1 Transition Probabilities

In the state diagram shown in Figure 3.3, each transition of the diagram has been labeled with the probability of occurrence of the transition. The transition probabilities ε_{ij} are the forward transition probabilities of successully passing from state S_i to the next state S_j; ε_i are the backfard transition probabilities of state S_i; γ_{ik} are the transition probabilities from state Si returned to state S_k when the MS fails to reach the next state.

The transition probabilities $\gamma_{ik} = 1$ or 0 are decided by the prior choice of one out of different scenarios, while the transition probabilities ε_i, ε_{ij} are calculated from the universal base station resource blocking probability Ps_u, the classical base station resource blocking probability Ps_c, and the mobile station resource blocking probability Pm_i. Where: Ps_u is the probability of universal base station resource blocking such that the mobile station (MS) cannot be assigned a pilot or data channel for signaling or downloading; Ps_c is the probability of classical base station resource blocking such that the MS cannot be assigned a control or traffic channel for signaling and communication; Pm_i is the probability of the MS resource is blocking in state S_i, e.g, the memory size is not enough for downloading the new system software, or the battery level is low.

The initial transition probabilities ε_{01}, ε_{02}, ε_{03} have been discussed in the previous section (See Page 44 - 45). The remaining transition probabilities are defined according to the following formulas. In these formulas, we assume that the resource blocking probabilities of the universal cellular base station and the universal wireless LAN base station in each state are the same, denoted as Ps_u, the resource blocking probabilities of the mobile station in each state are the same, denoted as P_m.

$\varepsilon_{01} + \varepsilon_{02} + \varepsilon_{03} = 1$

$\varepsilon_{14} = (1-Ps_u)*(1-P_m)$	$\varepsilon_{1} = 1 - \varepsilon_{14}$	
$\varepsilon_{25} = (1-Ps_u)*(1-P_m)$	$\varepsilon_{20} = 1 - \varepsilon_{25}$	
$\varepsilon_{36} = (1-Ps_c)*(1-P_m)$	$\varepsilon_{30} = 1 - \varepsilon_{36}$	
$\varepsilon_{47} = (1-Ps_u)*(1-P_m)$	$\varepsilon_{4} = 1 - \varepsilon_{47}$	$\gamma_{41}+\gamma_{42}=1$
$\varepsilon_{58} = (1-Ps_u)*(1-P_m)$	$\varepsilon_{5} = 1 - \varepsilon_{58}$	$\gamma_{51}+\gamma_{52}=1$
$\varepsilon_{69} = (1-Ps_c)*(1-P_m)$	$\varepsilon_{6} = 1 - \varepsilon_{69}$	$\gamma_{61}+\gamma_{62}=1$
$\varepsilon_{7,10} = (1-Ps_u)*(1-P_m)$	$\varepsilon_{7} = 1 - \varepsilon_{7,10}$	$\gamma_{71}+\gamma_{72}+\gamma_{73}=1$
$\varepsilon_{8,11} = (1-Ps_u)*(1-P_m)$	$\varepsilon_{8} = 1 - \varepsilon_{8,11}$	$\gamma_{81}+\gamma_{82}+\gamma_{83}=1$
$\varepsilon_{9,12} = (1-Ps_c)*(1-P_m)$	$\varepsilon_{9} = 1 - \varepsilon_{9,12}$	$\gamma_{91}+\gamma_{92}+\gamma_{93}=1$
$\varepsilon_{10,12} = (1-Ps_c)*(1-P_m)$	$\varepsilon_{10} = 1 - \varepsilon_{10,12}$	$\gamma_{10,1}+\gamma_{10,2}+\gamma_{10,3}+\gamma_{10,4}=1$
$\varepsilon_{11,12} = (1-Ps_c)*(1-P_m)$	$\varepsilon_{11} = 1 - \varepsilon_{11,12}$	$\gamma_{11,1}+\gamma_{11,2}+\gamma_{11,3}+\gamma_{11,4}=1$

3.2.2.2 Total Time in Each State

It is certain that the total time required in each state is related to the transmission bit error rate and the minimum time spent in that state. Assuming that the signaling data and the system software code are transmitted in forms of packets, then we can use packet successful transmission probability to reflect the transmission bit error rate. In the following discuss, we show the relationship among the total time, the minimum time and the packet successful transmission probability.

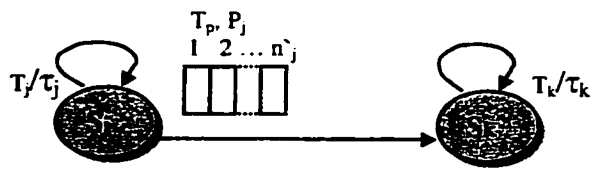


Figure 3.7 Calculation of the Total Time in Each State

In Figure 3.7, we denote $\mathbf{T_j}$ as the minimum time required to transmit and receive the packets in state S_j, $\Delta\mathbf{T_j}$ as the increased time in T_j due to channel packet error. Then, the total time required for the packets transmission in each state due to error will be the sum of the minimum time T_j and the retransmission time for the failure channel packets ΔT_j, denoted by $\boldsymbol{\tau_j}$.

Thus, if the transmission time for one packet is T_p, then the minimum number of the required transmission packets in state S_j, let's denote it as $\mathbf{n`_j}$, will equal to the quotient of the minimum required time $T_j$ devided by one packet time Tp when the remainder is zero and will equal to the quotient +1 when the remainder is not zero, i.e. $\mathbf{n`_j} = \lfloor \mathbf{T_j/T_p} \rfloor$

Also, we denote P_j as the successful packet transmission probability in state S_j, k (maximum $n`_j$) as the number of failure deliver packets due to errors. Then, the number of failure deliver packets k has the "Binomial probability density function" [20]

$$P(k) = \binom{n'_j}{k} (1-P_j)^k P_j^{(n'_j-k)}, \qquad \text{for } k = 0, 1, 2, 3, \ldots, n'_j$$

With mean: $E[k] = n'_j*(1-P_j)$,

Furthermore, let i represents the extra retransmission times for one failed transmitted packets, then i has the "Geometric probability density function" [20]

$$P(i) = (1-P_j)^i P_j \qquad \text{for } i = 0, 1, 2, 3\ldots$$

Such that $\sum_{i=0}^{\infty} (1-P_j)^i P_j = 1$, (3.1)

Differentiating both sides of the equation (3.1) with respect to P_j and simplifying gives

$$\sum_{i=1}^{\infty} i\,(1-P_j)^{i-1} P_j = 1/P_j, \text{ or } \sum_{i=0}^{\infty} i\,(1-P_j)^i P_j = (1-P_j)/P_j$$

The mean of i: $E[i] = \sum_i i\,P(i) = (1-P_j)/P_j$

Finally, since the number of failed packets due to errors k and the retransmission times for one failure transmitted packets i are independent, we obtain the mean number of increased packets needed to transmit due to error:

$$\overline{\Delta n_j(i,k)} = \sum_i \sum_k kP(k)(1+i\,P(i))$$
$$= E[k]*(1+E[i]) = n'_j * (1-P_j)/P_j$$

Hence, the total number of transmitted packets in state S_j is:

$$\mathbf{n}_j = n'_j + \overline{\Delta n_j(i,k)} = n'_j * [1+(1-P_j)/P_j] = n'_j/P_j$$

The total time spent in state S_j is:

$$\tau_j = n_j T_p = [n'_j + \overline{\Delta n_j(i,k)}]\, T_p$$

$$= (T_p*n'_j)/P_j$$

$$= T_j/P_j \qquad \text{for } j = 1, 2, \ldots 11 \qquad (3.2)$$

Chapter 4 Estimation of the Roaming Acquisition Time

4.1 Transition Function and Roaming Connection Establishment Acquisition Time

4.1.1 RoamingConnection Establishment Acquisition Time

R*oaming acquisition time* is the neccessary time for the mobile station (MS) to roam from one wireless standard to another. During this period, the MS maybe handoff to the same system or the need may arise to download new system software for the roaming. With the state diagram shown in Figure 3.3, the mobile station roaming connection acquisition time is the average acquisition time to move from state S_0 to S_{12}.

In order to find out the mobile station acquisition time (should not be confused with spread spectrum codes acquisition time) from state S_0 to S_{12}, we apply flow graph technique similar to the one that was first presented by DiCarlo, DiCarlo and Weber[10], where they calculated the mean and standard deviation of the synchronization time for a spread spectrum code serial-search system. The concept of reprenting all possible paths through a state-transition diagram by a function H(z) leads to the generalized solution for average acquisition time, this function H(z) is defined as the *transition function of the state diagram*. The roaming connection acquisition time for a mobile station to proceed from state S_0 to S_{12} is defined as:

$$Tsum = \left.\frac{dH(z)}{dz}\right|_{z=1} \tag{4.1}$$

4.1.2 Transition Function

The state diagram in Figure 3.3 can be represented by a signal-flow graph as shown in Figure 4.1(a),(b). In this figure, each transition branch of the diagram has been labeled with the probability of occurrence of the transition and Z raised to a power equal to the total time associated with the 'from' state. The transition probabilities ε_{ij} are the probabilities of moving from state S_i to state S_j, and the parameter Z is used to mark time as one proceeds through the graph and its power represents the total time spent in traversing that branch.

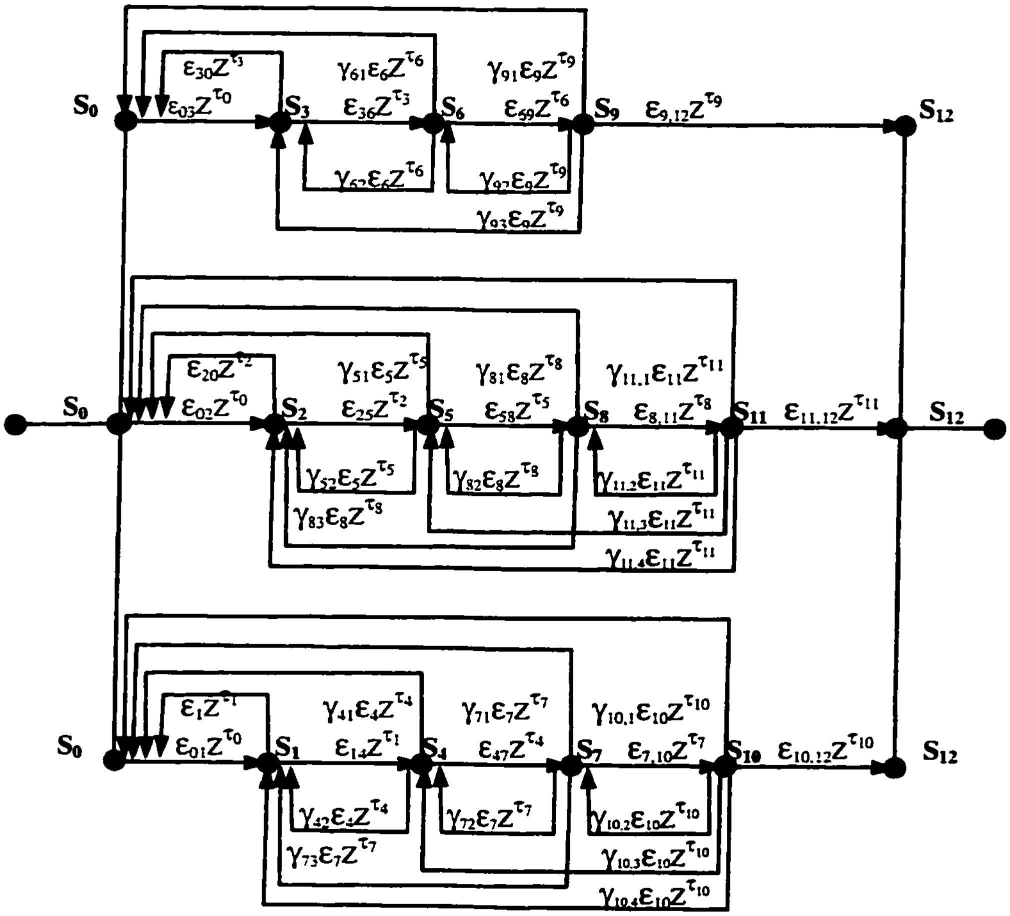


Figure 4.1(a) A Signal Flow Graph I

To calculate the transition function of the state diagram, there are two basic techniques, block diagram reduction technique and signal flow graph gain formula. Block diagrams are adequate for the representation of the interrelationships of controlled and input variables. However, for a system with reasonably complex interrelationships, such as a mobile station having the state diagram shown in Figure 3.3, the block diagram reduction technique is often quite difficult. The signal-flow graph gain formula provides a reasonably straightforward approach for the evaluation of complicated systems. Therefore, a flow graph gain formula developed by Mason is adopted here. The transition function can be determined by considering the state diagram as a signal flow graph and applying Mason's formula [21].

A signal-flow graph is a diagram consisting of nodes that are connected by several directed branches and is a graphical representation of a set of linear relations. The basic element of a signal-flow graph is a unidirectional path segment called *a branch.* The gain of each branch is marked in the simplified flow graph Figure 4.1(a). In a signal flow graph, a path connecting the initial state (node) to the final state (node) which does not go through any state twice is called a *forward path.* Let F_i be the gain of the ith forward path. A closed path starting at any state and returning to that state without going through any other state twice is called a *loop.* Let C_i be the gain of the ith loop. A set of loops is *nontouching* if no state belongs to more than one loop in in the set. Two touching loops share one or more common states (nodes). Then define:

Determinant of the graph Δ = 1-(sum of all different loop gains) +(sum of the gain products of all combinations of 2 nontouching loops) -(sum of the gain products of all combinations of 3 nontouching loops) + $\cdots$

$$= 1-\sum_i C_i+\sum_{jk}C_jC_k-\sum_{lmn} C_lC_mC_n+\cdots$$

Forward path gain $\mathbf{F_i}$ is defined as the continous succession of branches that are traversed in the direction of the arrows and with no node encoutered more than once.

Cofactor of the path F_i, Δ_i is defined exactly like Δ, but only for that portion of the graph not touching the ith forward path; that is, all states along the ith forward path, together with all branches connected to these states, are removed from the graph when computing Δ_i.

Mason's formula for computing the transition function H(z) of a graph can now be stated as:

$$\mathbf{H(z)} = \frac{\sum_i F_i \Delta_i}{\Delta} \qquad (4.2)$$

By applying this theory to the signal flow diagram shown in Figure 4.1(a), we can obtain a simplified flow graph shown in Figure 4.1(b)

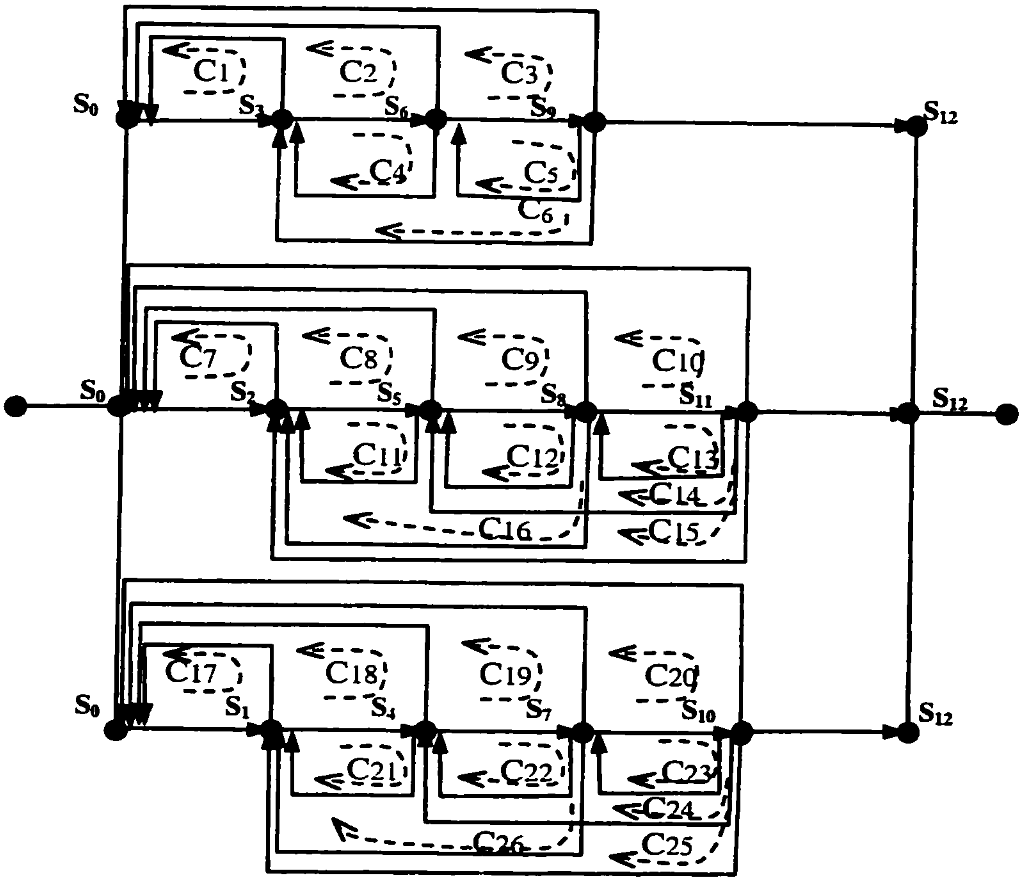


Figure 4.1(b) A Simplified Flow Graph II

There are 26 self-loops in the state diagram:

$C_1 = \varepsilon_{30}\varepsilon_{03}Z^{\tau0+\tau3}$

$C_2 = \gamma_{61}\varepsilon_6\varepsilon_{03}\varepsilon_{36}Z^{\tau0+\tau3+\tau6}$

$C_3 = \gamma_{91}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau0+\tau3+\tau6+\tau9}$

$C_4 = \gamma_{62}\varepsilon_6\varepsilon_{36}Z^{\tau3+\tau6}$

$C_5 = \gamma_{92}\varepsilon_9\varepsilon_{69}Z^{\tau6+\tau9}$

$C_6 = \gamma_{93}\varepsilon_9\varepsilon_{36}\varepsilon_{69}Z^{\tau3+\tau6+\tau9}$

$C_7 = \varepsilon_{20}\varepsilon_{02}Z^{\tau0+\tau2}$

$C_8 = \gamma_{51}\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau0+\tau2+\tau5}$

$C_9 = \gamma_{81}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau0+\tau2+\tau5+\tau8}$

$C_{10} = \gamma_{11,1}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau0+\tau2+\tau5+\tau8+\tau11}$

$C_{11} = \gamma_{52}\varepsilon_5\varepsilon_{25}Z^{\tau2+\tau5}$

$C_{12} = \gamma_{82}\varepsilon_8\varepsilon_{58}Z^{\tau5+\tau8}$

$C_{13} = \gamma_{11,2}\varepsilon_{11}\varepsilon_{8,11}Z^{\tau8+\tau11}$

$C_{14} = \gamma_{11,3}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{58}Z^{\tau5+\tau8+\tau11}$

$C_{15} = \gamma_{11,4}\varepsilon_{11}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau2+\tau5+\tau8+\tau11}$

$C_{16} = \gamma_{8,3}\varepsilon_{8}\varepsilon_{25}\varepsilon_{58}Z^{\tau2+\tau5+\tau8}$

$C_{17} = \varepsilon_{1}\varepsilon_{01}Z^{\tau0+\tau1}$

$C_{18} = \gamma_{41}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}Z^{\tau0+\tau1+\tau4}$

$C_{19} = \gamma_{71}\varepsilon_{7}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau7}$

$C_{20} = \gamma_{10,1}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}$

$C_{21} = \gamma_{42}\varepsilon_{4}\varepsilon_{14}Z^{\tau1+\tau4}$

$C_{22} = \gamma_{72}\varepsilon_{7}\varepsilon_{47}Z^{\tau4+\tau7}$

$C_{23} = \gamma_{10,2}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau7+\tau10}$

$C_{24} = \gamma_{10,3}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{47}Z^{\tau4+\tau7+\tau10}$

$C_{25} = \gamma_{10,4}\varepsilon_{10}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau1+\tau4+\tau7+\tau10}$

$C_{26} = \gamma_{7,3}\varepsilon_{7}\varepsilon_{14}\varepsilon_{47}Z^{\tau1+\tau4+\tau7}$

At the end of this section, we present the generalized form of acquisition time calculation result of three specific events, in which the mobile station is 100% certain to take one of the path1, path2, or path3 while ignoring the other paths. This may happen when the mobile station is set in preferred mode, together with the universal base station or classical base station resource is available, which has been discussed in Section 3.1.1.2-3. In these events, the acquisition time in different scenarios can be obtained by substituting their corresponding γ_{ij} values to the generalized form of the acquisition time.

Event 1: If the initial transition probability distributions of path1, 2, 3 are $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03} = 0/0/1$, i.e, the transition is made to S_3 in path3, then H(z) equals to the path3 transition function.

There are 6 self-loops:

$C_1 = \varepsilon_{30}\varepsilon_{03}Z^{\tau0+\tau3}$

$C_2 = \gamma_{61}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}Z^{\tau0+\tau3+\tau6}$

$C_3 = \gamma_{91}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau0+\tau3+\tau6+\tau9}$

$C_4 = \gamma_{62}\varepsilon_{6}\varepsilon_{36}Z^{\tau3+\tau6}$

$C_5 = \gamma_{92}\varepsilon_{9}\varepsilon_{69}Z^{\tau6+\tau9}$

$C_6 = \gamma_{93}\varepsilon_{9}\varepsilon_{36}\varepsilon_{69}Z^{\tau3+\tau6+\tau9}$

There is 1 pair of nontouching loop:

$C_1C_5 = \gamma_{92}\varepsilon_{9}\varepsilon_{69}\varepsilon_{30}\varepsilon_{03}Z^{\tau0+\tau3+\tau6+\tau9}$

Thus,

$$\Delta = 1 - \sum_{i=1}^{6} C_i + C_1C_5 = 1-\varepsilon_{30}\varepsilon_{03}Z^{\tau0+\tau3} -\gamma_{61}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}Z^{\tau0+\tau3+\tau6} -\gamma_{62}\varepsilon_{6}\varepsilon_{36}Z^{\tau3+\tau6} -\gamma_{91}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau0+\tau3+\tau6+\tau9} -\gamma_{92}\varepsilon_{9}\varepsilon_{69}Z^{\tau6+\tau9} -\gamma_{93}\varepsilon_{9}\varepsilon_{36}\varepsilon_{69}Z^{\tau3+\tau6+\tau9} + \gamma_{92}\varepsilon_{9}\varepsilon_{69}\varepsilon_{30}\varepsilon_{03}Z^{\tau0+\tau3+\tau6+\tau9}$$

There is only one forward path: $F_1 = \varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}Z^{\tau_0+\tau_3+\tau_6+\tau_9}$, $\Delta_1 = 1$, $F(z)= F_1*\Delta_1$

$$H(z) = \frac{F(z)}{\Delta} = \frac{\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}Z^{\tau_0+\tau_3+\tau_6+\tau_9}}{\Delta}$$

$$\frac{dH(z)}{dz} = \frac{F'(z)}{\Delta(z)} - \frac{F(z)*\Delta'(z)}{\Delta^2(z)}$$

Where:

$F'(z) = \varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}*(\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau_0+\tau_3+\tau_6+\tau_9-1}$

$\Delta'(z) = -\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3)Z^{\tau 0+\tau 3-1}-\gamma_{61}\varepsilon_6\varepsilon_{03}\varepsilon_{36}*(\tau_0+\tau_3+\tau_6)Z^{\tau 0+\tau 3+\tau 6-1}-\gamma_{62}\varepsilon_6\varepsilon_{36}*(\tau_3+\tau_6)Z^{\tau 3+\tau 6-1}-\gamma_{91}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_0+\tau_3+\tau_6+\tau_9)$
$Z^{\tau 0+\tau 3+\tau 6+\tau 9-1}-\gamma_{92}\varepsilon_9\varepsilon_{69}*(\tau_6+\tau_9)Z^{\tau 6+\tau 9-1}-\gamma_{93}\varepsilon_9\varepsilon_{36}\varepsilon_{69}*(\tau_3+\tau_6+\tau_9)Z^{\tau 3+\tau 6+\tau 9-1}+\gamma_{92}\varepsilon_9\varepsilon_{69}\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau 0+\tau 3+\tau 6+\tau 9-1}$

The acquisition time from S_0 to S_{12} can be found by setting z =1 in dH(z)/dz, then we get

$$Tsum = \left.\frac{dH(z)}{dz}\right|_{z=1} = N_1/M_1 + N_2/M_1^2 \qquad (4.3)$$

where :

$N_1 = F'(z)\big|_{z=1} = \varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}*(\tau_0+\tau_3+\tau_6+\tau_9)$

$N_2 = -F(z)*\Delta'(z)\big|_{z=1} = -\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}*[-\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3)-\gamma_{61}\varepsilon_6\varepsilon_{03}\varepsilon_{36}*(\tau_0+\tau_3+\tau_6)-\gamma_{62}\varepsilon_6\varepsilon_{36}*(\tau_0+\tau_3)$
$-\gamma_{91}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_0+\tau_3+\tau_6+\tau_9)-\gamma_{92}\varepsilon_9\varepsilon_{69}*(\tau_6+\tau_9)-\gamma_{93}\varepsilon_9\varepsilon_{36}\varepsilon_{69}*(\tau_3+\tau_6+\tau_9)+\gamma_{92}\varepsilon_9\varepsilon_{69}\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3+\tau_6+\tau_9)]$

$M_1 = \Delta(z)\big|_{z=1} = 1-\varepsilon_{30}\varepsilon_{03}-\gamma_{61}\varepsilon_6\varepsilon_{03}\varepsilon_{36}-\gamma_{62}\varepsilon_6\varepsilon_{36}-\gamma_{91}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}-\gamma_{92}\varepsilon_9\varepsilon_{69}-\gamma_{93}\varepsilon_9\varepsilon_{36}\varepsilon_{69}+\gamma_{92}\varepsilon_9\varepsilon_{69}\varepsilon_{30}\varepsilon_{03}$

Event 2: If the initial transition probability distributions of path1, 2, 3 are $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03} = 0/1/0$, i.e, the transition is made to S_2 in path2, then H(z) equals to the path2 transition function.

There are 10 self-loops:

$C_7 = \varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2}$

$C_8 = \gamma_{51}\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau 0+\tau 2+\tau 5}$

$C_9 = \gamma_{81}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau 0+\tau 2+\tau 5+\tau 8}$

$C_{10} = \gamma_{11,1}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}$

$C_{11} = \gamma_{52}\varepsilon_5\varepsilon_{25}Z^{\tau 2+\tau 5}$

$C_{12} = \gamma_{82}\varepsilon_8\varepsilon_{58}Z^{\tau 5+\tau 8}$

$C_{13} = \gamma_{11,2}\varepsilon_{11}\varepsilon_{8,11}Z^{\tau 8+\tau 11}$

$C_{14} = \gamma_{11,3}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{58}Z^{\tau 5+\tau 8+\tau 11}$

$C_{15} = \gamma_{11,4}\varepsilon_{11}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau 2+\tau 5+\tau 8+\tau 11}$

$C_{16} = \gamma_{8,3}\varepsilon_8\varepsilon_{25}\varepsilon_{58}Z^{\tau 2+\tau 5+\tau 8}$

There are 5 groups of nontouching loop:

$C_7C_{12} = \gamma_{82}\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2+\tau 5+\tau 8}$

$C_7C_{13} = \gamma_{11,2}\varepsilon_{20}\varepsilon_{02}\varepsilon_{11}\varepsilon_{8,11}Z^{\tau 0+\tau 2+\tau 8+\tau 11}$

$C_7C_{14} = \gamma_{11,3}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}$

$C_8C_{13} = \gamma_{51}\gamma_{11,2}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}$

$C_{11}C_{13} = \gamma_{52}\gamma_{11,2}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_5\varepsilon_{25}Z^{\tau 2+\tau 5+\tau 8+\tau 11}$

Thus,

$\Delta = 1 - \sum_{i=7}^{16} C_i + \sum_{i=12}^{14} C_7C_i + C_8C_{13} = 1-\varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2}-\gamma_{51}\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau 0+\tau 2+\tau 5}-\gamma_{52}\varepsilon_5\varepsilon_{25}Z^{\tau 2+\tau 5}-\gamma_{81}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau 0+\tau 2+\tau 5+\tau 8}$
$-\gamma_{82}\varepsilon_8\varepsilon_{58}Z^{\tau 5+\tau 8}-\gamma_{8,3}\varepsilon_8\varepsilon_{25}\varepsilon_{58}Z^{\tau 2+\tau 5+\tau 8}-\gamma_{11,1}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}-\gamma_{11,2}\varepsilon_{11}\varepsilon_{8,11}Z^{\tau 8+\tau 11}-\gamma_{11,3}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{58}Z^{\tau 5+\tau 8+\tau 11}$
$-\gamma_{11,4}\varepsilon_{11}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau 2+\tau 5+\tau 8+\tau 11}+\gamma_{82}\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2+\tau 5+\tau 8}+\gamma_{11,2}\varepsilon_{20}\varepsilon_{02}\varepsilon_{11}\varepsilon_{8,11}Z^{\tau 0+\tau 2+\tau 8+\tau 11}+\gamma_{11,3}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}$
$+\gamma_{51}\gamma_{11,2}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}+\gamma_{52}\gamma_{11,2}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_5\varepsilon_{25}Z^{\tau 2+\tau 5+\tau 8+\tau 11}$

Forward path : $F_2 = \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}$, $\Delta_2 = 1$, $F(z) = F_2\Delta_2$

$$H(z) = \frac{F(z)}{\Delta} = \frac{\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}}{\Delta}$$

$$\frac{dH(z)}{dz} = \frac{F'(z)}{\Delta(z)} - \frac{F(z)*\Delta'(z)}{\Delta^2(z)}$$

Where:

$F'(z) = \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau0+\tau2+\tau5+\tau8+\tau11-1}$

$\Delta'(z) = -\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2)Z^{\tau0+\tau2-1}-\gamma_{51}\varepsilon_5\varepsilon_{02}\varepsilon_{25}*(\tau_0+\tau_2+\tau_5)Z^{\tau0+\tau2+\tau5-1}-\gamma_{52}\varepsilon_5\varepsilon_{25}*(\tau_2+\tau_5)Z^{\tau2+\tau5-1}-\gamma_{81}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_0+\tau_2+\tau_5+\tau_8)$
$*Z^{\tau0+\tau2+\tau5+\tau8-1}-\gamma_{82}\varepsilon_8\varepsilon_{58}*(\tau_5+\tau_8)Z^{\tau5+\tau8-1}-\gamma_{8.3}\varepsilon_8\varepsilon_{25}\varepsilon_{58}*(\tau_2+\tau_5+\tau_8)Z^{\tau2+\tau5+\tau8-1}-\gamma_{11.1}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})$
$*Z^{\tau0+\tau2+\tau5+\tau8+\tau11-1}-\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}*(\tau_8+\tau_{11})Z^{\tau8+\tau11-1}-\gamma_{11.3}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{58}*(\tau_5+\tau_8+\tau_{11})Z^{\tau5+\tau8+\tau11-1}$
$-\gamma_{11.4}\varepsilon_{11}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}*(\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau2+\tau5+\tau8+\tau11-1}+\gamma_{82}\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau0+\tau2+\tau5+\tau8-1}$
$+\gamma_{11.2}\varepsilon_{20}\varepsilon_{02}\varepsilon_{11}\varepsilon_{8.11}*(\tau_0+\tau_2+\tau_8+\tau_{11})Z^{\tau0+\tau2+\tau8+\tau11-1}+\gamma_{11.3}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau0+\tau2+\tau5+\tau8+\tau11-1}$
$+\gamma_{51}\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_5\varepsilon_{02}\varepsilon_{25}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau0+\tau2+\tau5+\tau8+\tau11-1}+\gamma_{52}\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_5\varepsilon_{25}*(\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau2+\tau5+\tau8+\tau_{11}-1}$

The acquisition time from S_0 to S_{12} can be found by setting z =1 in dH(z)/dz, then we get

$$Tsum = \left.\frac{dH(z)}{dz}\right|_{z=1} = N_1/M_1 + N_2/M_1^2 \tag{4.4}$$

where :

$N_1 = F'(z)\Big|_{z=1} = \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})$

$N_2 = -F(z)*\Delta'(z)\Big|_{z=1} = -\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}*[-\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2)-\gamma_{51}\varepsilon_5\varepsilon_{02}\varepsilon_{25}*(\tau_0+\tau_2+\tau_5)-\gamma_{52}\varepsilon_5\varepsilon_{25}*(\tau_2+\tau_5)$
$-\gamma_{81}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_0+\tau_2+\tau_5+\tau_8)-\gamma_{82}\varepsilon_8\varepsilon_{58}*(\tau_5+\tau_8)-\gamma_{8.3}\varepsilon_8\varepsilon_{25}\varepsilon_{58}*(\tau_2+\tau_5+\tau_8)-\gamma_{11.1}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})$
$-\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}*(\tau_8+\tau_{11})-\gamma_{11.3}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{58}*(\tau_5+\tau_8+\tau_{11})-\gamma_{11.4}\varepsilon_{11}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}*(\tau_2+\tau_5+\tau_8+\tau_{11})+\gamma_{82}\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2+\tau_5+\tau_8)$
$+\gamma_{11.2}\varepsilon_{20}\varepsilon_{02}\varepsilon_{11}\varepsilon_{8.11}*(\tau_0+\tau_2+\tau_8+\tau_{11}) +\gamma_{11.3}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})+\gamma_{51}\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_5\varepsilon_{02}\varepsilon_{25}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})$
$+\gamma_{52}\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_5\varepsilon_{25}*(\tau_2+\tau_5+\tau_8+\tau_{11})]$

$M_1 = \Delta(z)\Big|_{z=1} = 1-\varepsilon_{20}\varepsilon_{02}-\gamma_{51}\varepsilon_5\varepsilon_{02}\varepsilon_{25}-\gamma_{52}\varepsilon_5\varepsilon_{25}-\gamma_{81}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}-\gamma_{82}\varepsilon_8\varepsilon_{58}-\gamma_{8.3}\varepsilon_8\varepsilon_{25}\varepsilon_{58}-\gamma_{11.1}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}-\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}$
$-\gamma_{11.3}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{58}-\gamma_{11.4}\varepsilon_{11}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}+\gamma_{82}\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}+\gamma_{11.2}\varepsilon_{20}\varepsilon_{02}\varepsilon_{11}\varepsilon_{8.11}+\gamma_{11.3}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}+\gamma_{51}\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_5\varepsilon_{02}\varepsilon_{25}$
$+\gamma_{52}\gamma_{11.2}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_5\varepsilon_{25}$

Event 3: If the transition probability distributions of path1, 2, 3 are $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03} = 1/0/0$, i.e, the transition is made to S_1 in path1, then H (z) equals to the path1 transition function.

There are 10 self-loops:

$C_{17} = \varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1}$

$C_{18} = \gamma_{41}\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau0+\tau_1+\tau_4}$

$C_{19} = \gamma_{71}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau_7}$

$C_{20} = \gamma_{10.1}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}Z^{\tau0+\tau1+\tau4+\tau_7+\tau_{10}}$

$C_{21} = \gamma_{42}\varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4}$

$C_{22} = \gamma_{72}\varepsilon_7\varepsilon_{47}Z^{\tau4+\tau7}$

$C_{23} = \gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau7+\tau10}$

$C_{24} = \gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}Z^{\tau4+\tau_7+\tau_{10}}$

$C_{25} = \gamma_{10.4}\varepsilon_{10}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}Z^{\tau1+\tau4+\tau7+\tau10}$

$C_{26} = \gamma_{7.3}\varepsilon_7\varepsilon_{14}\varepsilon_{47}Z^{\tau1+\tau4+\tau7}$

There are 5 groups of nontouching loop:

$C_{17}C_{22} = \gamma_{72}\varepsilon_7\varepsilon_{47}\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1+\tau4+\tau7}$

$C_{17}C_{23} = \gamma_{10.2}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau0+\tau1+\tau7+\tau10}$

$C_{17}C_{24} = \gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}$

$$C_{18}C_{23} = \gamma_{41}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}$$
$$C_{21}C_{23} = \gamma_{42}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4+\tau7+\tau10}$$

Thus,

$$\Delta = 1 - \sum_{i=17}^{26} C_i + \sum_{i=22}^{24} C_{17}C_i + C_{18}C_{23} = 1-\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1}-\gamma_{41}\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau0+\tau1+\tau4}-\gamma_{42}\varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4}$$
$$-\gamma_{71}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau7}-\gamma_{72}\varepsilon_7\varepsilon_{47}Z^{\tau4+\tau7}-\gamma_{7.3}\varepsilon_7\varepsilon_{14}\varepsilon_{47}Z^{\tau1+\tau4+\tau7}-\gamma_{10.1}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}-\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau7+\tau10}$$
$$-\gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}Z^{\tau4+\tau7+\tau10}-\gamma_{10.4}\varepsilon_{10}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}Z^{\tau1+\tau4+\tau7+\tau10}+\gamma_{72}\varepsilon_7\varepsilon_{47}\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1+\tau4+\tau7}+\gamma_{10.2}\varepsilon_{10}\varepsilon_{01}\varepsilon_1\varepsilon_{7.10}Z^{\tau0+\tau1+\tau7+\tau10}$$
$$+\gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}+\gamma_{41}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}+\gamma_{42}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau1+\tau4+\tau7+\tau10}$$

Forward path : $F_3 = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10,12}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}$, $\Delta 3 = 1$, $F(z) = F3*\Delta 3$

$$H(z) = \frac{F(z)}{\Delta} = \frac{\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}}{\Delta}$$

$$\frac{dH(z)}{dz} = \frac{F`(z)}{\Delta(z)} - \frac{F(z)* \Delta`(z)}{\Delta^2(z)}$$

Where:

$$F`(z) = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau0+\tau1+\tau4+\tau7+\tau10-1}$$

$$\Delta`(z)=-\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1)Z^{\tau0+\tau1-1}-\gamma_{41}\varepsilon_4\varepsilon_{01}\varepsilon_{14}*(\tau_0+\tau_1+\tau_4)Z^{\tau0+\tau1+\tau4-1}-\gamma_{42}\varepsilon_4\varepsilon_{14}*(\tau_1+\tau_4)Z^{\tau1+\tau4-1}-\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}*(\tau_7+\tau_{10})Z^{\tau7+\tau10-1}$$
$$-\gamma_{71}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau0+\tau1+\tau4+\tau7-1}-\gamma_{72}\varepsilon_7\varepsilon_{47}*(\tau_4+\tau_7)Z^{\tau4+\tau7-1}-\gamma_{7.3}\varepsilon_7\varepsilon_{14}\varepsilon_{47}*(\tau_1+\tau_4+\tau_7)Z^{\tau1+\tau4+\tau7-1}$$
$$-\gamma_{10.1}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})\ Z^{\tau0+\tau1+\tau4+\tau7+\tau10-1}-\gamma_{103}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}*(\tau_4+\tau_7+\tau_{10})Z^{\tau4+\tau7+\tau10-1}$$
$$-\gamma_{10.4}\varepsilon_{10}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}*(\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau1+\tau4+\tau7+\tau10-1}+\gamma_{72}\varepsilon_7\varepsilon_{47}\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau0+\tau1+\tau4+\tau7-1}$$
$$+\gamma_{10.2}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7.10}*(\tau_0+\tau_1+\tau_7+\tau_{10})Z^{\tau0+\tau1+\tau7+\tau10-1}+\gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau0+\tau1+\tau4+\tau7+\tau10-1}$$
$$+\gamma_{41}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{01}\varepsilon_{14}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau0+\tau1+\tau4+\tau7+\tau10-1}+\gamma_{42}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{14}*(\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau1+\tau4+\tau7+\tau10-1}$$

The acquisition time from S_0 to S_{12} can be found by setting z =1 in dH(z)/dz, then we get

$$Tsum = \left.\frac{dH(z)}{dz}\right|_{z=1} = N_1/M_1 + N_2/M_1^2 \qquad (4.5)$$

where :

$$N_1= F`(z)\Big|_{z=1} = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})$$

$$N_2= -F(z)* \Delta`(z)\Big|_{z=1} = -\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}*[-\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1)-\gamma_{41}\varepsilon_4\varepsilon_{01}\varepsilon_{14}*(\tau_0+\tau_1+\tau_4)-\gamma_{42}\varepsilon_4\varepsilon_{14}*(\tau_1+\tau_4)$$
$$-\gamma_{71}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_0+\tau_1+\tau_4+\tau_7)-\gamma_{72}\varepsilon_7\varepsilon_{47}*(\tau_4+\tau_7)-\gamma_{73}\varepsilon_7\varepsilon_{14}\varepsilon_{47}*(\tau_1+\tau_4+\tau_7)-\gamma_{10.1}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})$$
$$-\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}*(\tau_7+\tau_{10})-\gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}*(\tau_4+\tau_7+\tau_{10})-\gamma_{10.4}\varepsilon_{10}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}*(\tau_1+\tau_4+\tau_7+\tau_{10})+\gamma_{72}\varepsilon_7\varepsilon_{47}\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1+\tau_4+\tau_7)$$
$$+\gamma_{10.2}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7.10}*(\tau_0+\tau_1+\tau_7+\tau_{10})+\gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})+\gamma_{41}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{01}\varepsilon_{14}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})$$
$$+\gamma_{42}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{14}*(\tau_1+\tau_4+\tau_7+\tau_{10})$$

$$M_1=\Delta(z)\Big|_{z=1} = 1-\varepsilon_1\varepsilon_{01}-\gamma_{41}\varepsilon_4\varepsilon_{01}\varepsilon_{14}-\gamma_{42}\varepsilon_4\varepsilon_{14}-\gamma_{71}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}-\gamma_{72}\varepsilon_7\varepsilon_{47}-\gamma_{7.3}\varepsilon_7\varepsilon_{14}\varepsilon_{47}-\gamma_{10.1}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}-\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}$$
$$-\gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}-\gamma_{10.4}\varepsilon_{10}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}+\gamma_{72}\varepsilon_7\varepsilon_{47}\varepsilon_1\varepsilon_{01}+\gamma_{10.2}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7.10}+\gamma_{10.3}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{47}\varepsilon_1\varepsilon_{01}+\gamma_{41}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{01}\varepsilon_{14}$$
$$+\gamma_{42}\gamma_{10.2}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{14}$$

4.2 The Five Scenarios Considered

As we mentioned before in Section 3.2.1, different scenarios can be obtained by setting γ_{ij} to 1 or 0 in the generalized state diagram in Figure 3.3. We assume that the mobile station will have only one forward transition branch and one backward transition branch for each state in the state diagram corresponding to one scenario. There are 36 combinations of γ_{ij} listed in Table 4.1, corresponding to 36 possible state diagrams designed scenarios. In fact, there are more than 36 possible combinations and scenarios generated from different values of γ_{ij}, but similar principle can be applied. Therefore, we choose five of them to evaluate and analyze the roaming acquisition time. These scenarios are highlighted in the Table 4.1, scenario number1, 6, 19, 20, 26.

Table 4.1

Scenario Number	$\gamma_{6,1}$ $\gamma_{5,1}$ $\gamma_{4,1}$	$\gamma_{6,2}$ $\gamma_{5,2}$ $\gamma_{4,2}$	$\gamma_{8,1}$ $\gamma_{7,1}$	$\gamma_{8,2}$ $\gamma_{7,2}$	$\gamma_{8,3}$ $\gamma_{7,3}$	$\gamma_{11,1}$ $\gamma_{10,1}$	$\gamma_{11,2}$ $\gamma_{10,2}$	$\gamma_{11,3}$ $\gamma_{10,3}$	$\gamma_{11,4}$ $\gamma_{10,4}$	$\gamma_{9,1}$	$\gamma_{9,2}$	$\gamma_{9,3}$
1	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**
2	1	0	0	1	0	1	0	0	0	1	0	0
3	1	0	0	1	0	1	0	0	0	0	1	0
4	1	0	0	0	1	1	0	0	0	1	0	0
5	1	0	0	0	1	1	0	0	0	0	0	1
6	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**
7	1	0	1	0	0	0	1	0	0	0	1	0
8	1	0	0	1	0	0	1	0	0	0	1	0
9	1	0	0	0	1	0	1	0	0	0	0	1
10	1	0	0	0	1	0	1	0	0	0	1	0
11	1	0	1	0	0	0	0	1	0	1	0	0
12	1	0	1	0	0	0	0	1	0	0	0	1
13	1	0	0	1	0	0	0	1	0	0	1	0
14	1	0	0	1	0	0	0	1	0	0	0	1
15	1	0	0	0	1	0	0	1	0	0	0	1
16	1	0	1	0	0	0	0	0	1	1	0	0
17	1	0	0	1	0	0	0	0	1	0	1	0
18	1	0	0	0	1	0	0	0	1	0	0	1

19	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**
20	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**
21	0	1	0	1	0	1	0	0	0	0	1	0
22	0	1	0	0	1	1	0	0	0	0	0	1
23	0	1	0	0	1	1	0	0	0	1	0	0
24	0	1	1	0	0	0	1	0	0	1	0	0
25	0	1	1	0	0	0	1	0	0	0	1	0
26	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**
27	0	1	0	0	1	0	1	0	0	0	0	1
28	0	1	0	0	1	0	1	0	0	0	1	0
29	0	1	1	0	0	0	0	1	0	1	0	0
30	0	1	1	0	0	0	0	1	0	0	0	1
31	0	1	0	1	0	0	0	1	0	0	1	0
32	0	1	0	1	0	0	0	1	0	0	0	1
33	0	1	0	0	1	0	0	1	0	0	0	1
34	0	1	1	0	0	0	0	0	1	1	0	0
35	0	1	0	1	0	0	0	0	1	0	1	0
36	0	1	0	0	1	0	0	0	1	0	0	1

4.2.1 Scenario 1

4.2.1.1 State Diagram for Connection Establishment

By substituting $\gamma_{42} = \gamma_{52} = \gamma_{62} = \gamma_{72} = \gamma_{73} = \gamma_{82} = \gamma_{83} = \gamma_{92} = \gamma_{93} = \gamma_{10,2} = \gamma_{10,3} = \gamma_{10,4} = \gamma_{11,2} = \gamma_{11,3} = \gamma_{11,4} = 0$ and $\gamma_{41} = \gamma_{51} = \gamma_{61} = \gamma_{71} = \gamma_{81} = \gamma_{91} = \gamma_{10,1} = \gamma_{11,1} = 1$ to the general state diagram in Figure 3.3, we obtain the following state diagram of the MS Figure 4.2 Figure 4.2, which corresponds to scenario number 1 in the Table 4.1. In this design scheme, in each state on a path i, the MS will move to the next state if the transmission is successful; otherwise, the MS will return to the start state S_0 and make a decision again. Table 4.2 presents a summary of the most important messages and their effect on the state diagram Figure 4.2.

The advantage of this design is that the software process is simple, and it is suitable for all scenarios irrespective of the MS's speed. The main disadvantage is long processing time in the case of high transmission error rate. This is attributed to the fact that the MS always goes back to the starting point to make a decision again if the transmission fails.

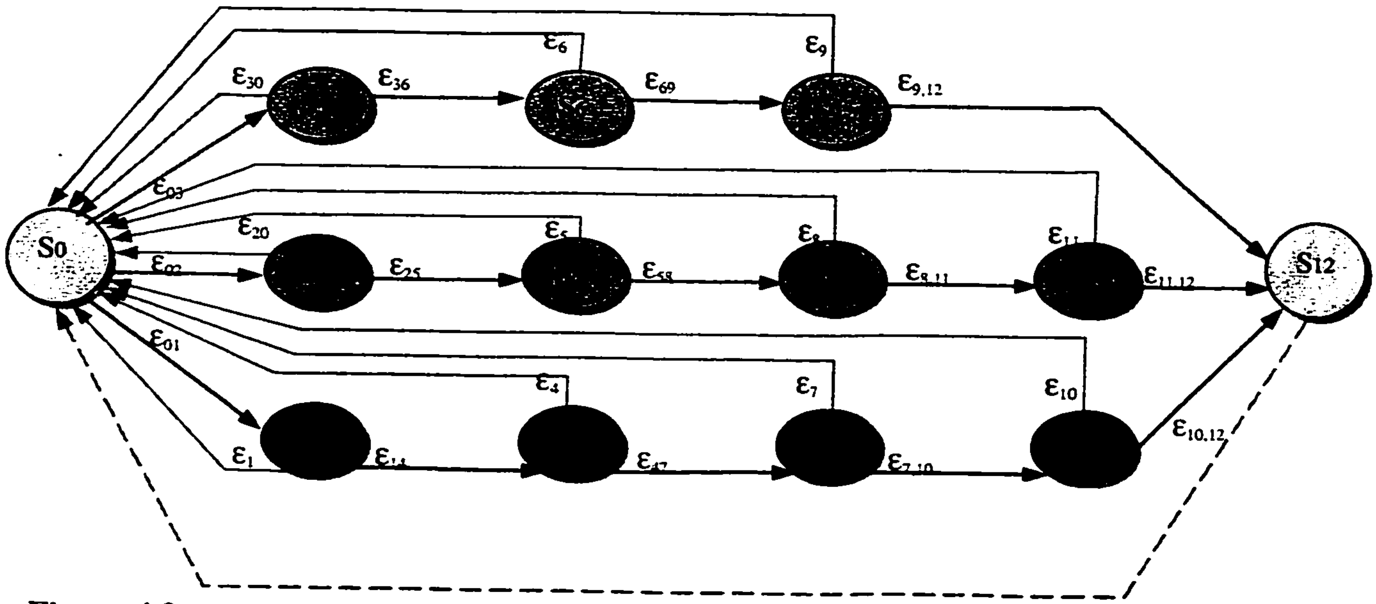


Figure 4.2 State Diagram for Connection Control of a reconfigurable Mobile Station (Scenario 1)

Table 4.2 The transitions in the state diagram (Scenario 1)

From State	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	To
Cellular_DL_Request	X													S_1
WLAN_DL_Request	X													S_2
SameSystem_Setup	X													S_3
Cellular_DL_Authen_Confirm		X												S_4
WLAN_DL_Authen_Confirm			X											S_5
SameSys_HO_Authen_Confirm				X										S_6
Cellluar SW_DL_Ready					X									S_7
WLAN SW_DL_Ready						X								S_8
SameSys_HO_Completed							X							S_9
CellSW_DL_Completed								X						S_{10}
WLANSW_DL_Completed									X					S_{11}
SameSys_Connected										X				S_{12}
Cellular_Connected											X			S_{12}
WLAN_Connected												X		S_{12}
Process_Fails &Timeout (Auto) Or Release_Req (Manual)		X	X	X	X	X	X	X	X	X	X	X	X	S_0

Where: X denotes the two states are connected and transition is possible for example.

4.2.1.2 Roaming Acquisition Time Calculation for Scenario 1

1) Transition Function

There are 11 loops in the diagram, which corresponds to the general flow graph C_1, C_2, C_3, C_7, C_8, C_9, C_{10}, C_{17}, C_{18}, C_{19}, C_{20}.

$C_1 = \varepsilon_{30}\varepsilon_{03}Z^{\tau 0+\tau 3}$

$C_2 = \varepsilon_6\varepsilon_{03}\varepsilon_{36}Z^{\tau 0+\tau 3+\tau 6}$

$C_3 = \varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau 0+\tau 3+\tau 6+\tau 9}$

$C_7 = \varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2}$

$C_8 = \varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau 0+\tau 2+\tau 5}$

$C_9 = \varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau 0+\tau 2+\tau 5+\tau 8}$

$C_{10} = \varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}$

$C_{17} = \varepsilon_1\varepsilon_{01}Z^{\tau 0+\tau 1}$

$C_{18} = \varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau 0+\tau 1+\tau 4}$

$C_{19} = \varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau 0+\tau 1+\tau 4+\tau 7}$

$C_{20} = \varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}Z^{\tau 0+\tau 1+\tau 4+\tau 7+\tau 10}$

There are no non-touching loops in the state diagram, thus

$$\Delta(z) = 1 - \Sigma_{i=1}^{3}C_i - \Sigma_{i=7}^{10}C_i - \Sigma_{i=17}^{20}C_i = 1 - \varepsilon_{30}\varepsilon_{03}Z^{\tau 0+\tau 3} - \varepsilon_6\varepsilon_{03}\varepsilon_{36}Z^{\tau 0+\tau 3+\tau 6} - \varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau 0+\tau 3+\tau 6+\tau 9} - \varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2}$$
$$- \varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau 0+\tau 2+\tau 5} - \varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau 0+\tau 2+\tau 5+\tau 8} - \varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11} - \varepsilon_1\varepsilon_{01}Z^{\tau 0+\tau 1} - \varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau 0+\tau 1+\tau 4} - \varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau 0+\tau 1+\tau 4+\tau 7}$$
$$- \varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}Z^{\tau 0+\tau 1+\tau 4+\tau 7+\tau 10}$$

There are 3 forward paths :

Forward path1: $F_1 = \varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}Z^{\tau 0+\tau 3+\tau 6+\tau 9}$, $\Delta_1 = 1$

Forward path2: $F_2 = \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11}$, $\Delta_2 = 1$

Forward path3: $F_3 = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}Z^{\tau 0+\tau 1+\tau 4+\tau 7+\tau 10}$, $\Delta_3 = 1$

$$F(z) = F_1*\Delta_1+F_2*\Delta_2+F_3*\Delta_3$$
$$= \varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}Z^{\tau 0+\tau 3+\tau 6+\tau 9} + \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11} + \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}Z^{\tau 0+\tau 1+\tau 4+\tau 7+\tau 10}$$

Then, according to the defination given in equation (4.2), we get the transition function of this state diagram as below :

$$H(z) = \frac{F_1*\Delta_1+F_2*\Delta_2+F_3*\Delta_3}{\Delta(z)} = \frac{F(z)}{\Delta(z)}$$

$$\frac{dH(z)}{dz} = \frac{F`(z)}{\Delta(z)} - \frac{F(z)*\Delta`(z)}{\Delta^2(z)}$$

Where:

$$F`(z) = \varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}*(\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau 0+\tau 3+\tau 6+\tau 9-1}+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11-1}$$
$$+\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau 0+\tau 1+\tau 4+\tau 7+\tau 10-1}$$

$$\Delta`(z)= -\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3)Z^{\tau 0+\tau 3-1} - \varepsilon_6\varepsilon_{03}\varepsilon_{36}*(\tau_0+\tau_3+\tau_6)Z^{\tau 0+\tau 3+\tau 6-1} - \varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau 0+\tau 3+\tau 6+\tau 9-1} - \varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2)Z^{\tau 0+\tau 2-1}$$
$$- \varepsilon_5\varepsilon_{02}\varepsilon_{25}*(\tau_0+\tau_2+\tau_5)Z^{\tau 0+\tau 2+\tau 5-1} - \varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau 0+\tau 2+\tau 5+\tau 8-1} - \varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau 0+\tau 2+\tau 5+\tau 8+\tau 11-1}$$
$$- \varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1)Z^{\tau 0+\tau 1-1} - \varepsilon_4\varepsilon_{01}\varepsilon_{14}*(\tau_0+\tau_1+\tau_4)Z^{\tau 0+\tau 1+\tau 4-1} - \varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau 0+\tau 1+\tau 4+\tau 7-1}$$
$$- \varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau 0+\tau 1+\tau 4+\tau 7+\tau 10-1}$$

2) Roaming Acquisition time of Scenario 1

According to the definition given in equation (4.1) that the acquisition time from S_0 to S_{12} can be found by setting z =1 in dH(z)/dz, then we obtain the roaming acquisition time of Scenario 1 :

$$Tsum = \left.\frac{dH(z)}{dz}\right|_{z=1} = N_1/M_1 + N_2/M_1^2 \qquad (4.6)$$

where :

$$N_1 = F'(z)\Big|_{z=1}$$
$$= \varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}*(\tau_0+\tau_3+\tau_6+\tau_9) + \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}) + \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})$$

$$N_2 = -F(z)*\Delta'(z)\Big|_{z=1} = (\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}+\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12})*[\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3)+\varepsilon_6\varepsilon_{03}\varepsilon_{36}*(\tau_0+\tau_3+\tau_6)$$
$$+\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2)+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_0+\tau_3+\tau_6+\tau_9)+\varepsilon_5\varepsilon_{02}\varepsilon_{25}*(\tau_0+\tau_2+\tau_5)+\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_0+\tau_2+\tau_5+\tau_8)+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})$$
$$+\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1)+\varepsilon_4\varepsilon_{01}\varepsilon_{14}*(\tau_0+\tau_1+\tau_4)+\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_0+\tau_1+\tau_4+\tau_7)+\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})]$$

$$M_1 = \Delta(z)\Big|_{z=1}$$
$$= 1-\varepsilon_{30}\varepsilon_{03}-\varepsilon_6\varepsilon_{03}\varepsilon_{36}-\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}-\varepsilon_{20}\varepsilon_{02}-\varepsilon_5\varepsilon_{02}\varepsilon_{25}-\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}-\varepsilon_1\varepsilon_{01}-\varepsilon_4\varepsilon_{01}\varepsilon_{14}-\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}-\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}$$

4.2.2 Scenario 6

4.2.2.1 State Diagram for Connection Establishment

By substituting $\gamma_{42} = \gamma_{52} = \gamma_{62} = \gamma_{72} = \gamma_{73} = \gamma_{82} = \gamma_{83} = \gamma_{92} = \gamma_{93} = \gamma_{10,1} = \gamma_{10,3} = \gamma_{10,4} = \gamma_{11,1} = \gamma_{11,3} = \gamma_{11,4} = 0$ and $\gamma_{41} = \gamma_{51} = \gamma_{61} = \gamma_{71} = \gamma_{81} = \gamma_{91} = \gamma_{10,2} = \gamma_{11,2} = 1$ to the generalized state diagram, we obtain the following state diagram of the mobile station (MS) Figure 4.3, which corresponds to scenario number 6 in the Table 4.1. Table 4.3 presents a summary of the most important messages and their effects on the state diagram Figure 4.3.

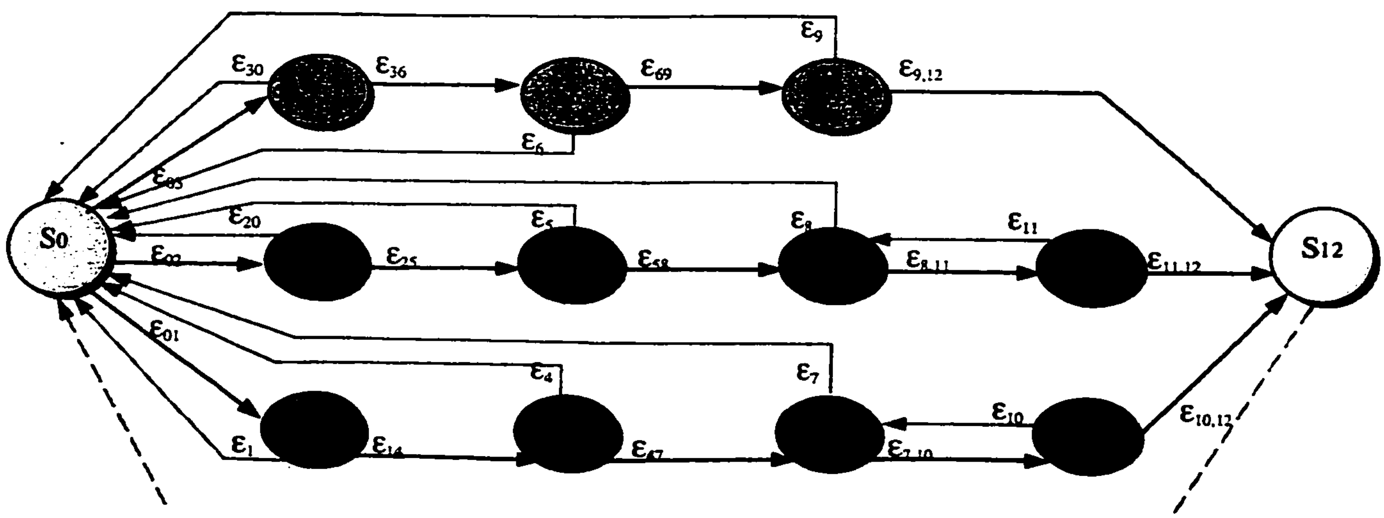


Figure 4.3 State Diagram for Connection Control of a reconfigurable Mobile Station

Table 4.3 The transitions in the state diagram (Scenario 6)

From State	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	To
Cellular_DL_Request	X													S_1
WLAN_DL_Request	X													S_2
SameSystem_Setup	X													S_3
Cellular_DL_Authen_Confirm		X												S_4
WLAN_DL_Authen_Confirm			X											S_5
SameSys_HO_Authen_Confirm				X										S_6
Cellluar SW_DL_Ready					X									S_7
WLAN SW_DL_Ready						X								S_8
SameSys_HO_Completed							X							S_9
CellSW_DL_Completed								X						S_{10}
WLANSW_DL_Completed									X					S_{11}
SameSys_Connected										X				S_{12}
Cellular_Connected											X			S_{12}
WLAN_Connected												X		S_{12}
Process_Fails &Timeout (Auto) Or Release_Req (**Manual**)		X	X	X	X	X	X	X	X	X			X	S_0
NewSysUpdate_Fails &Timeout											X			S_7
NewSysUpdate_Fails &Timeout												X		S_8

Where: X denotes the two states are connected and transition is possible for example.

4.2.2.2 Roaming Acquisition Time Calculation of Scenario 6

1) Transition Function

There are 11 loops in the diagram, which are corresponding to the general flow graph C_1, C_2, C_3, C_7, C_8, C_9, C_{13}, C_{17}, C_{18}, C_{19}, C_{23}.

$C_1 = \varepsilon_{30}\varepsilon_{03}Z^{\tau0+\tau3}$

$C_2 = \varepsilon_6\varepsilon_{03}\varepsilon_{36}Z^{\tau0+\tau3+\tau6}$

$C_3 = \varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau0+\tau3+\tau6+\tau9}$

$C_7 = \varepsilon_{20}\varepsilon_{02}Z^{\tau0+\tau2}$

$C_8 = \varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau0+\tau2+\tau5}$

$C_9 = \varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau0+\tau2+\tau5+\tau8}$

$C_{13} = \varepsilon_{11}\varepsilon_{8,11}Z^{\tau8+\tau11}$

$C_{17} = \varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1}$

$C_{18} = \varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau0+\tau1+\tau4}$

$C_{19} = \varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau7}$

$C_{23} = \varepsilon_{10}\varepsilon_{7,10}Z^{\tau7+\tau10}$

There are 17 groups of two non-touching loops :

C_1C_{13}, C_1C_{23}, C_2C_{13}, C_2C_{23}, C_3C_{13}, C_3C_{23}, C_7C_{13}, C_7C_{23}, C_8C_{13}, C_8C_{23}, C_9C_{23}, $C_{13}C_{17}$, $C_{13}C_{18}$, $C_{13}C_{19}$, $C_{13}C_{23}$, $C_{17}C_{23}$, $C_{18}C_{23}$

There are 7 groups of three non-touching loops :

$C_1C_{13}C_{23}$, $C_2C_{13}C_{23}$, $C_3C_{13}C_{23}$, $C_7C_{13}C_{23}$, $C_8C_{13}C_{23}$, $C_{13}C_{17}C_{23}$, $C_{13}C_{18}C_{23}$

Thus,

$$\Delta(z)=1-C_1-C_2-C_3-C_7-C_8-C_9-C_{13}-C_{17}-C_{18}-C_{19}-C_{23}+(C_1+C_2+C_3+C_7+C_8)*(C_{13}+C_{23})+C_9C_{23}+C_{13}*(C_{17}+C_{18}+C_{19}+C_{23})$$
$$+C_{23}*(C_{17}+C_{18})-C_{13}C_{23}*(C_1+C_2+C_3+C_7+C_8+C_{17}+C_{18})$$

$$=1-\varepsilon_{30}\varepsilon_{03}Z^{\tau_0+\tau_3}-\varepsilon_6\varepsilon_{03}\varepsilon_{36}Z^{\tau_0+\tau_3+\tau_6}-\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau_0+\tau_3+\tau_6+\tau_9}-\varepsilon_{20}\varepsilon_{02}Z^{\tau_0+\tau_2}-\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau_0+\tau_2+\tau_5}-\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau_0+\tau_2+\tau_5+\tau_8}-\varepsilon_{11}\varepsilon_{8.11}Z^{\tau_8+\tau_{11}}$$
$$-\varepsilon_1\varepsilon_{01}Z^{\tau_0+\tau_1}-\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau_0+\tau_1+\tau_4}-\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau_0+\tau_1+\tau_4+\tau_7}-\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_7+\tau_{10}}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{30}\varepsilon_{03}Z^{\tau_8+\tau_{11}+\tau_0+\tau_3}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_6\varepsilon_{03}\varepsilon_{36}Z^{\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6}$$
$$+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6+\tau_9}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{20}\varepsilon_{02}Z^{\tau_8+\tau_{11}+\tau_0+\tau_2}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau_8+\tau_{11}+\tau_0+\tau_2+\tau_5}+\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{30}\varepsilon_{03}Z^{\tau_7+\tau_{10}+\tau_0+\tau_3}$$
$$+\varepsilon_{10}\varepsilon_{7.10}\varepsilon_6\varepsilon_{03}\varepsilon_{36}Z^{\tau_7+\tau_{10}-\tau_0+\tau_3+\tau_6}+\varepsilon_{10}\varepsilon_{7.10}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau_7+\tau_{10}+\tau_0+\tau_3+\tau_6+\tau_9}+\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{20}\varepsilon_{02}Z^{\tau_7+\tau_{10}+\tau_0+\tau_2}+\varepsilon_{10}\varepsilon_{7.10}\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5}$$
$$+\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_7+\tau_{10}}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_1\varepsilon_{01}Z^{\tau_8+\tau_{11}+\tau_0+\tau_1}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}$$
$$*Z^{\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_8+\tau_{11}+\tau_7+\tau_{10}}+\varepsilon_{10}\varepsilon_{7.10}\varepsilon_1\varepsilon_{01}Z^{\tau_7+\tau_{10}+\tau_0+\tau_1}+\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau_7+\tau_{10}+\tau_0+\tau_1+\tau_4}$$
$$-\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{30}\varepsilon_{03}Z^{\tau_7+\tau_{10}+\tau_8+\tau_{11}+\tau_0+\tau_3}-\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_6\varepsilon_{03}\varepsilon_{36}Z^{\tau_7+\tau_{10}+\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6}$$
$$-\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau_7+\tau_{10}+\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6+\tau_9}-\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_{20}\varepsilon_{02}Z^{\tau_7+\tau_{10}+\tau_8+\tau_{11}+\tau_0+\tau_2}$$
$$-\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_5\varepsilon_{02}\varepsilon_{25}Z^{\tau_7+\tau_{10}+\tau_8+\tau_{11}+\tau_0+\tau_2+\tau_5}-\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_1\varepsilon_{01}Z^{\tau_7+\tau_{10}+\tau_8+\tau_{11}+\tau_0+\tau_1}-\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}\varepsilon_4\varepsilon_{01}\varepsilon_{14}Z^{\tau_7+\tau_{10}+\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4}$$

There are three forward paths :

Forward path1: $F_1=\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}$, $\Delta_1=1-C_{13}=1-\varepsilon_{11}\varepsilon_{8.11}Z^{\tau_8+\tau_{11}}$

Forward path2: $F_2=\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}$, $\Delta_2=1-C_{23}=1-\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_7+\tau_{10}}$

Forward path3: $F_3=\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}Z^{\tau_0+\tau_3+\tau_6+\tau_9}$,

$$\Delta_3=1-C_{13}-C_{23}+C_{13}C_{23}=1-\varepsilon_{11}\varepsilon_{8.11}Z^{\tau_8+\tau_{11}}-\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_7+\tau_{10}}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_7+\tau_{10}+\tau_8+\tau_{11}}$$

$$F(z)=F_1*\Delta_1+F_2*\Delta_2+F_3*\Delta_3=\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_{11}\varepsilon_{8.11}Z^{\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}Z^{\tau_0+\tau_3+\tau_6+\tau_9}$$
$$-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}\varepsilon_{11}\varepsilon_{8.11}Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_8+\tau_{11}}-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10}}+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10}+\tau_8+\tau_{11}}$$

Then, according to the defination given in equation (4.2), we get the transition function of this state diagram as below :

$$H(z)=\frac{F_1*\Delta_1+F_2*\Delta_2+F_3*\Delta_3}{\Delta(z)}=\frac{F(z)}{\Delta(z)}$$

$$\frac{dH(z)}{dz}=\frac{F`(z)}{\Delta(z)}-\frac{F(z)*\Delta`(z)}{\Delta^2(z)}$$

Where:

$$F`(z)=\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1}+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1}$$
$$-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_{11}\varepsilon_{8.11}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_8+\tau_{11})Z^{\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1}$$
$$-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_{10}\varepsilon_{7.10}*(\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1}$$
$$+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}*(\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau_0+\tau_3+\tau_6+\tau_9-1}-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}\varepsilon_{11}\varepsilon_{8.11}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_8+\tau_{11})Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_8+\tau_{11}-1}$$
$$-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}\varepsilon_{10}\varepsilon_{7.10}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10})Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10}-1}$$
$$+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9.12}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10}+\tau_8+\tau_{11})Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10}+\tau_8+\tau_{11}-1}$$

$$\Delta`(z)=-\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3)Z^{\tau_0+\tau_3-1}-\varepsilon_6\varepsilon_{03}\varepsilon_{36}*(\tau_0+\tau_3+\tau_6)Z^{\tau_0+\tau_3+\tau_6-1}-\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau_0+\tau_3+\tau_6+\tau_9-1}$$
$$-\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2)Z^{\tau_0+\tau_2}-\varepsilon_5\varepsilon_{02}\varepsilon_{25}*(\tau_0+\tau_2+\tau_5)Z^{\tau_0+\tau_2+\tau_5-1}-\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau_0+\tau_2+\tau_5+\tau_8-1}-\varepsilon_{11}\varepsilon_{8.11}*(\tau_8+\tau_{11})Z^{\tau_8+\tau_{11}-1}$$
$$-\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1)Z^{\tau_0+\tau_1-1}-\varepsilon_4\varepsilon_{01}\varepsilon_{14}*(\tau_0+\tau_1+\tau_4)Z^{\tau_0+\tau_1+\tau_4-1}-\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau_0+\tau_1+\tau_4+\tau_7-1}-\varepsilon_{10}\varepsilon_{7.10}*(\tau_7+\tau_{10})Z^{\tau_7+\tau_{10}-1}$$
$$+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{30}\varepsilon_{03}*(\tau_8+\tau_{11}+\tau_0+\tau_3)Z^{\tau_8+\tau_{11}+\tau_0+\tau_3-1}+\varepsilon_{11}\varepsilon_{8.11}\varepsilon_6\varepsilon_{03}\varepsilon_{36}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6)Z^{\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6-1}$$

$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau8+\tau11+\tau0+\tau3+\tau6+\tau9-1}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{20}\varepsilon_{02}*(\tau_8+\tau_{11}+\tau_0+\tau_2)Z^{\tau8+\tau11+\tau0+\tau2-1}$$
$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}*(\tau_8+\tau_{11}++\tau_0+\tau_2+\tau_5)Z^{\tau8+\tau11+\tau0+\tau2+\tau5-1}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{30}\varepsilon_{03}*(\tau_7+\tau_{10}+\tau_0+\tau_3)Z^{\tau7+\tau10+\tau0+\tau3-1}$$
$$+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}*(\tau_7+\tau_{10}+\tau_0+\tau_3+\tau_6)Z^{\tau7+\tau10+\tau0+\tau3+\tau6-1}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_7+\tau_{10}+\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau7+\tau10+\tau0+\tau3+\tau6+\tau9-1}$$
$$+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{20}\varepsilon_{02}*(\tau_7+\tau_{10}+\tau_0+\tau_2)Z^{\tau7+\tau10+\tau0+\tau2-1}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}*(\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5)Z^{\tau7+\tau10+\tau0+\tau2+\tau5-1}$$
$$+\varepsilon_{8}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{10}\varepsilon_{7,10}*(\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau0+\tau2+\tau5+\tau8+\tau7+\tau10-1}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{1}\varepsilon_{01}*(\tau_8+\tau_{11}+\tau_0+\tau_1)Z^{\tau8+\tau11+\tau0+\tau1-1}$$
$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}*(\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4)Z^{\tau8+\tau11+\tau0+\tau1+\tau4-1}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{7}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau8+\tau11+\tau0+\tau1+\tau4+\tau7-1}$$
$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}*(\tau_7+\tau_{10}+\tau_8+\tau_{11})Z^{\tau8+\tau11+\tau7+\tau10-1}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{1}\varepsilon_{01}*(\tau_7+\tau_{10}+\tau_0+\tau_1)Z^{\tau7+\tau10+\tau0+\tau1-1}$$
$$+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}*(\tau_7+\tau_{10}+\tau_0+\tau_1+\tau_4)Z^{\tau7+\tau10+\tau0+\tau1+\tau4-1}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{30}\varepsilon_{03}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_7+\tau_{10})Z^{\tau7+\tau10+\tau8+\tau11+\tau0+\tau3-1}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6+\tau_7+\tau_{10})Z^{\tau7+\tau10+\tau8+\tau11+\tau0+\tau3+\tau6-1}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10})Z^{\tau7+\tau10+\tau8+\tau11+\tau0+\tau3+\tau6+\tau9-1}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{20}\varepsilon_{02}*(\tau_8+\tau_{11}+\tau_0+\tau_2+\tau_7+\tau_{10})Z^{\tau7+\tau10+\tau8+\tau11+\tau0+\tau2-1}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}*(\tau_8+\tau_{11}+\tau_0+\tau_2+\tau_5+\tau_7+\tau_{10})Z^{\tau7+\tau10+\tau8+\tau11+\tau0+\tau2+\tau5-1}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{1}\varepsilon_{01}*(\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_7+\tau_{10})Z^{\tau7+\tau10+\tau8+\tau11+\tau0+\tau1-1}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}*(\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau7+\tau10+\tau8+\tau11+\tau0+\tau1+\tau4-1}$$

2) Roaming Acquisition Time of Scenario 6

According to the definition given in equation (4.1) that the acquisition time from S_0 to S_{12} can be found by setting z =1 in dH(z)/dz, then we get the roaming acquisition time of Scenario 6 :

$$Tsum = \frac{dH(z)}{dz}\bigg|_{z=1} = N_1/M_1 + N_2/M_1^2 \qquad (4.7)$$

where :

$$N_1 = F`(z)\Big|_{z=1} = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_{11}\varepsilon_{8,11}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_8+\tau_{11})$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_{10}\varepsilon_{7,10}*(\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}*(\tau_0+\tau_3+\tau_6+\tau_9)$$
$$-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_{11}\varepsilon_{8,11}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_8+\tau_{11})-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_{10}\varepsilon_{7,10}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10})$$
$$+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10}+\tau_8+\tau_{11})$$

$$N_2 = -F(z)*\Delta`(z)\Big|_{z=1} = -(\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_{11}\varepsilon_{8,11}+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_{10}\varepsilon_{7,10}$$
$$+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_{11}\varepsilon_{8,11}-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_{10}\varepsilon_{7,10}+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10})$$
$$*[-\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3)-\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}*(\tau_0+\tau_3+\tau_6)-\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_0+\tau_3+\tau_6+\tau_9)-\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2)-\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}*(\tau_0+\tau_2+\tau_5)$$
$$-\varepsilon_{8}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_0+\tau_2+\tau_5+\tau_8)-\varepsilon_{11}\varepsilon_{8,11}*(\tau_8+\tau_{11})-\varepsilon_{1}\varepsilon_{01}*(\tau_0+\tau_1)-\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}*(\tau_0+\tau_1+\tau_4)-\varepsilon_{7}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_0+\tau_1+\tau_4+\tau_7)-\varepsilon_{10}\varepsilon_{7,10}*(\tau_7+\tau_{10})$$
$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{30}\varepsilon_{03}*(\tau_8+\tau_{11}+\tau_0+\tau_3)+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6)+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6+\tau_9)$$
$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{20}\varepsilon_{02}*(\tau_8+\tau_{11}+\tau_0+\tau_2)+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}*(\tau_8+\tau_{11}+\tau_0+\tau_2+\tau_5)+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{30}\varepsilon_{03}*(\tau_7+\tau_{10}+\tau_0+\tau_3)$$
$$+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}*(\tau_7+\tau_{10}+\tau_0+\tau_3+\tau_6)+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_7+\tau_{10}+\tau_0+\tau_3+\tau_6+\tau_9)+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{20}\varepsilon_{02}*(\tau_7+\tau_{10}+\tau_0+\tau_2)$$
$$+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}*(\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5)+\varepsilon_{8}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{10}\varepsilon_{7,10}*(\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8)+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{1}\varepsilon_{01}*(\tau_8+\tau_{11}+\tau_0+\tau_1)$$
$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}*(\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4)+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{7}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7)+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}*(\tau_7+\tau_{10}+\tau_8+\tau_{11})$$
$$+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{1}\varepsilon_{01}*(\tau_7+\tau_{10}+\tau_0+\tau_1)+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}*(\tau_7+\tau_{10}+\tau_0+\tau_1+\tau_4)-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{30}\varepsilon_{03}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_7+\tau_{10})$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6+\tau_7+\tau_{10})-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_8+\tau_{11}+\tau_0+\tau_3+\tau_6+\tau_9+\tau_7+\tau_{10})$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{20}\varepsilon_{02}*(\tau_8+\tau_{11}+\tau_0+\tau_2+\tau_7+\tau_{10})-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}*(\tau_8+\tau_{11}+\tau_0+\tau_2+\tau_5+\tau_7+\tau_{10})$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{1}\varepsilon_{01}*(\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_7+\tau_{10})-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}*(\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})]$$

$$M_1 = \Delta(z)\Big|_{z=1} = 1-\varepsilon_{30}\varepsilon_{03}-\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}-\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}-\varepsilon_{20}\varepsilon_{02}-\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}-\varepsilon_{8}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}-\varepsilon_{11}\varepsilon_{8,11}-\varepsilon_{1}\varepsilon_{01}-\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}-\varepsilon_{7}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}$$
$$-\varepsilon_{10}\varepsilon_{7,10}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{30}\varepsilon_{03}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{20}\varepsilon_{02}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{30}\varepsilon_{03}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}$$
$$+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{20}\varepsilon_{02}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}+\varepsilon_{8}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{10}\varepsilon_{7,10}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{1}\varepsilon_{01}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{7}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}$$
$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{1}\varepsilon_{01}+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{30}\varepsilon_{03}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{6}\varepsilon_{03}\varepsilon_{36}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{20}\varepsilon_{02}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{5}\varepsilon_{02}\varepsilon_{25}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{1}\varepsilon_{01}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}\varepsilon_{4}\varepsilon_{01}\varepsilon_{14}$$

4.2.3 Scenario 19

4.2.3.1 State Diagram for Connection Establishment

By substituting $\gamma_{41} = \gamma_{51} = \gamma_{61} = \gamma_{72} = \gamma_{73} = \gamma_{82} = \gamma_{83} = \gamma_{92} = \gamma_{93} = \gamma_{10,2} = \gamma_{10,3} = \gamma_{10,4} = \gamma_{11,2} = \gamma_{11,3} = \gamma_{11,4} = 0$ and $\gamma_{42} = \gamma_{52} = \gamma_{62} = \gamma_{71} = \gamma_{81} = \gamma_{91} = \gamma_{10,1} = \gamma_{11,1} = 1$ to the generalized state diagram Figure 3.3, we obtain the following state diagram of the mobile station (MS) Figure 4.4, which is corresponding to scenario number 19 in the Table 4.1. Table 4.4 presents a summary of the most important messages and their effects on the state diagram Figure 4.4.

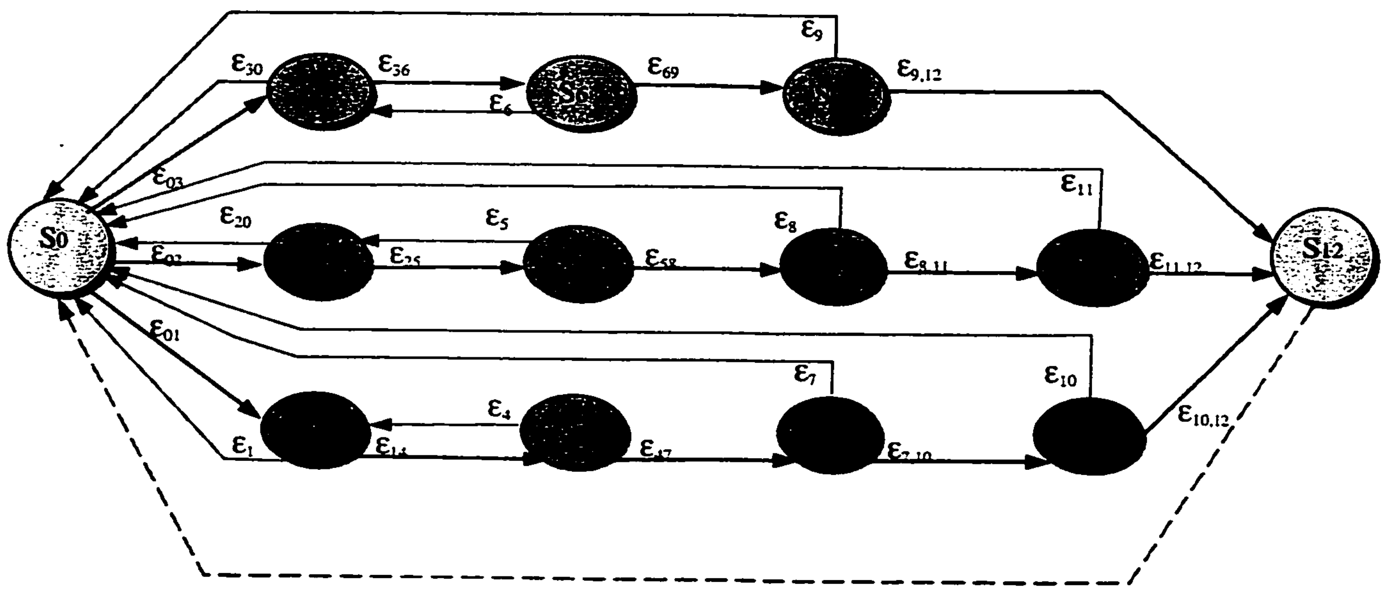


Figure 4.4 State Diagram for Connection Control of a reconfigurable Mobile Station (Scenario 19)

Table 4.4 The transitions in the state diagram (Scenario 19)

From State	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	To
Cellular_DL_Request	X													S_1
WLAN_DL_Request	X													S_2
SameSystem_Setup	X													S_3
Cellular_DL_Authen_Confirm		X												S_4
WLAN_DL_Authen_Confirm			X											S_5
SameSys_HO_Authen_Confirm				X										S_6
Cellluar SW_DL_Ready					X									S_7
WLAN SW_DL_Ready						X								S_8
SameSys_HO_Completed							X							S_9
CellSW_DL_Completed								X						S_{10}
WLANSW_DL_Completed									X					S_{11}
SameSys_Connected										X				S_{12}
Cellular_Connected											X			S_{12}
WLAN_Connected												X		S_{12}
Process_Fails &Timeout (Auto) Or Release_Req (Manual)		X	X	X				X	X	X	X	X	X	S_0
Process_Fails &Timeout (Auto)					X									S_1
Process_Fails &Timeout (Auto)						X								S_2
Process_Fails &Timeout (Auto)							X							S_3

Where: X denotes the two states are connected and transition is possible.

4.2.3.2 Roaming Acquisition Time Calculation

1) Transition Function

There are 11 loops in the diagram, which are corresponding to the general flow graph C_1, C_3, C_4, C_7, C_9, C_{10}, C_{11}, C_{17}, C_{19}, C_{20}, C_{21}

$C_1 = \varepsilon_{30}\varepsilon_{03}Z^{\tau0+\tau3}$

$C_3 = \varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau0+\tau3+\tau6+\tau9}$

$C_4 = \varepsilon_6\varepsilon_{36}Z^{\tau3+\tau6}$

$C_7 = \varepsilon_{20}\varepsilon_{02}Z^{\tau0+\tau2}$

$C_9 = \varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau0+\tau2+\tau5+\tau8}$

$C_{10} = \varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau0+\tau2+\tau5+\tau8+\tau11}$

$C_{11} = \varepsilon_5\varepsilon_{25}Z^{\tau2+\tau5}$

$C_{17} = \varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1}$

$C_{19} = \varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau7}$

$C_{20} = \varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}$

$C_{21} = \varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4}$

There are 19 groups of two non-touching loops :

C_1C_{11}, C_1C_{21}, C_3C_{11}, C_3C_{21}, C_4C_7, C_4C_9, C_4C_{10}, C_4C_{11}, C_4C_{17}, C_4C_{19}, C_4C_{20}, C_4C_{21}, C_7C_{21}, C_9C_{21}, $C_{10}C_{21}$, $C_{11}C_{17}$, $C_{11}C_{19}$, $C_{11}C_{20}$, $C_{11}C_{21}$

There are 9 groups of three non-touching loops :

$C_1C_{11}C_{21}$, $C_3C_{11}C_{21}$, $C_7C_4C_{21}$, $C_9C_4C_{21}$, $C_{10}C_4C_{21}$, $C_{17}C_4C_{11}$, $C_{19}C_4C_{11}$, $C_{20}C_4C_{11}$, $C_{21}C_4C_{11}$

Thus,

$$\Delta(z) = 1-C_1-C_3-C_4-C_7-C_9-C_{10}-C_{11}-C_{17}-C_{19}-C_{20}-C_{21}+(C_1+C_3)*(C_{11}+C_{21}) +C_4*(C_7+C_9+C_{10}+C_{11}+C_{17}+C_{19}+C_{20}+C_{21})$$
$$+C_{21}*(C_7+C_9+C_{10})+C_{11}*(C_{17}+C_{19}+C_{20}+C_{21}) -C_1C_{11}C_{21}-C_3C_{11}C_{21}-C_4C_{21}*(C_7+C_9+C_{10})-C_4C_{11}*(C_{17}+C_{19}+C_{20}+C_{21})$$

$$=1-\varepsilon_{30}\varepsilon_{03}Z^{\tau_0+\tau_3}-\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau_0+\tau_3+\tau_6+\tau_9}-\varepsilon_6\varepsilon_{36}Z^{\tau_3+\tau_6}-\varepsilon_{20}\varepsilon_{02}Z^{\tau_0+\tau_2}-\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau_0+\tau_2+\tau_5+\tau_8}-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}$$
$$-\varepsilon_5\varepsilon_{25}Z^{\tau_2+\tau_5}-\varepsilon_1\varepsilon_{01}Z^{\tau_0+\tau_1}-\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau_0+\tau_1+\tau_4+\tau_7}-\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}-\varepsilon_4\varepsilon_{14}Z^{\tau_1+\tau_4}+\varepsilon_{30}\varepsilon_{03}\varepsilon_5\varepsilon_{25}Z^{\tau_2+\tau_5+\tau_0+\tau_3}$$
$$+\varepsilon_{30}\varepsilon_{03}\varepsilon_4\varepsilon_{14}Z^{\tau_1+\tau_4+\tau_0+\tau_3}+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_5\varepsilon_{25}Z^{\tau_2+\tau_5+\tau_0+\tau_3+\tau_6+\tau_9}+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_4\varepsilon_{14}Z^{\tau_1+\tau_4+\tau_0+\tau_3+\tau_6+\tau_9}+\varepsilon_6\varepsilon_{36}\varepsilon_{20}\varepsilon_{02}Z^{\tau_3+\tau_6+\tau_0+\tau_2}$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8}+\varepsilon_6\varepsilon_{36}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}+\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}Z^{\tau_3+\tau_6+\tau_2+\tau_5}+\varepsilon_6\varepsilon_{36}\varepsilon_1\varepsilon_{01}Z^{\tau_3+\tau_6+\tau_0+\tau_1}$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7}+\varepsilon_6\varepsilon_{36}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}+\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}Z^{\tau_3+\tau_6+\tau_1+\tau_4}+\varepsilon_4\varepsilon_{14}\varepsilon_{20}\varepsilon_{02}Z^{\tau_1+\tau_4+\tau_0+\tau_2}$$
$$+\varepsilon_4\varepsilon_{14}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8}+\varepsilon_4\varepsilon_{14}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}+\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7}$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}Z^{\tau_0+\tau_1+\tau_2+\tau_5}+\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}+\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}Z^{\tau_2+\tau_5+\tau_1+\tau_4}-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_{30}\varepsilon_{03}Z^{\tau_1+\tau_4+\tau_2+\tau_5+\tau_0+\tau_3}$$
$$-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau_1+\tau_4+\tau_2+\tau_5+\tau_0+\tau_3+\tau_6+\tau_9}-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_{20}\varepsilon_{02}Z^{\tau_1+\tau_4+\tau_3+\tau_6+\tau_0+\tau_2}-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}Z^{\tau_1+\tau_4+\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8}$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau_1+\tau_4+\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}Z^{\tau_2+\tau_5+\tau_3+\tau_6+\tau_0+\tau_1}-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}Z^{\tau_2+\tau_5+\tau_3+\tau_6+\tau_1+\tau_4}$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}Z^{\tau_2+\tau_5+\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7}-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau_2+\tau_5+\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}$$

There are three forward paths :

Forward path1: $F_1 = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}$,

$$\Delta_1 = 1 -C_4 -C_{11} +C_4C_{11} = 1- \varepsilon_6\varepsilon_{36}Z^{\tau_3+\tau_6}-\varepsilon_5\varepsilon_{25}Z^{\tau_2+\tau_5}+\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}Z^{\tau_3+\tau_6+\tau_2+\tau_5}$$

Forward path2: $F_2 = \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}$,

$$\Delta_2 = 1 -C_4 -C_{21} +C_4C_{21} = 1-\varepsilon_6\varepsilon_{36}Z^{\tau_3+\tau_6}-\varepsilon_4\varepsilon_{14}Z^{\tau_1+\tau_4}+\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}Z^{\tau_3+\tau_6+\tau_1+\tau_4}$$

Forward path3: $F_3 = \varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}Z^{\tau_0+\tau_3+\tau_6+\tau_9}$,

$$\Delta_3 = 1 -C_{11} -C_{21} +C_{11}C_{21} = 1 -\varepsilon_5\varepsilon_{25}Z^{\tau_2+\tau_5}-\varepsilon_4\varepsilon_{14}Z^{\tau_1+\tau_4}+\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}Z^{\tau_2+\tau_5+\tau_1+\tau_4}$$

$$F(z)=F_1*\Delta_1+F_2*\Delta_2+F_3*\Delta_3 = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_6\varepsilon_{36}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6}$$
$$-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_5\varepsilon_{25}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_2+\tau_5}+\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6+\tau_2+\tau_5}$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_6\varepsilon_{36}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_4\varepsilon_{14}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_1+\tau_4}$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6+\tau_1+\tau_4}+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}Z^{\tau_0+\tau_3+\tau_6+\tau_9}-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_5\varepsilon_{25}Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5}$$
$$-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_4\varepsilon_{14}Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_1+\tau_4}+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\,\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5+\tau_1+\tau_4}$$

Then, according to the defination given in equation (4.2), we get the transition function of this state diagram as below :

$$H(z) = \frac{F_1*\Delta_1+F_2*\Delta_2 +F_3*\Delta_3}{\Delta(z)} = \frac{F(z)}{\Delta(z)}$$

$$\frac{dH(z)}{dz} = \frac{F`(z)}{\Delta(z)} - \frac{F(z)*\Delta`(z)}{\Delta^2(z)}$$

Where:

$$F`(z)=\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_6\varepsilon_{36}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6)$$
$$*Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6-1}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_5\varepsilon_{25}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_2+\tau_5)Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_2+\tau_5-1}$$
$$+\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6+\tau_2+\tau_5)Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6+\tau_2+\tau_5-1}$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_6\varepsilon_{36}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6)$$
$$*Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6-1}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_1+\tau_4)Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_1+\tau_4-1}$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6+\tau_1+\tau_4)Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6+\tau_1+\tau_4-1}$$
$$+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}*(\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau_0+\tau_3+\tau_6+\tau_9-1}-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_5\varepsilon_{25}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5)Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5-1}$$
$$-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_1+\tau_4)Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_1+\tau_4-1}$$
$$+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5+\tau_1+\tau_4)Z^{\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5+\tau_1+\tau_4-1}$$

$$\Delta`(z)= -\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3)Z^{\tau_0+\tau_3-1}-\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau_0+\tau_3+\tau_6+\tau_9-1}-\varepsilon_6\varepsilon_{36}*(\tau_3+\tau_6)Z^{\tau_3+\tau_6-1}-\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2)Z^{\tau_0+\tau_2-1}$$
$$-\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau_0+\tau_2+\tau_5+\tau_8-1}-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1}-\varepsilon_5\varepsilon_{25}*(\tau_2+\tau_5)Z^{\tau_2+\tau_5-1}$$
$$-\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1)Z^{\tau_0+\tau_1-1}-\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau_0+\tau_1+\tau_4+\tau_7-1}-\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1}$$
$$-\varepsilon_4\varepsilon_{14}*(\tau_1+\tau_4)Z^{\tau_1+\tau_4-1}+\varepsilon_{30}\varepsilon_{03}\varepsilon_5\varepsilon_{25}*(\tau_2+\tau_5+\tau_0+\tau_3)Z^{\tau_2+\tau_5+\tau_0+\tau_3-1}+\varepsilon_{30}\varepsilon_{03}\varepsilon_4\varepsilon_{14}*(\tau_1+\tau_4+\tau_0+\tau_3)Z^{\tau_1+\tau_4+\tau_0+\tau_3-1}$$
$$+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_5\varepsilon_{25}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5)Z^{\tau_2+\tau_5+\tau_0+\tau_3+\tau_6+\tau_9-1}+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_1+\tau_4)Z^{\tau_1+\tau_4+\tau_0+\tau_3+\tau_6+\tau_9-1}$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_{20}\varepsilon_{02}*(\tau_3+\tau_6+\tau_0+\tau_2)Z^{\tau_3+\tau_6+\tau_0+\tau_2-1}+\varepsilon_6\varepsilon_{36}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8-1}$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}*(\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1}+\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}*(\tau_3+\tau_6+\tau_2+\tau_5)Z^{\tau_3+\tau_6+\tau_2+\tau_5-1}$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_1\varepsilon_{01}*(\tau_3+\tau_6+\tau_0+\tau_1)Z^{\tau_3+\tau_6+\tau_0+\tau_1-1}+\varepsilon_6\varepsilon_{36}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7-1}$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}*(\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1}+\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}*(\tau_3+\tau_6+\tau_1+\tau_4)Z^{\tau_3+\tau_6+\tau_1+\tau_4-1}$$
$$+\varepsilon_4\varepsilon_{14}\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2+\tau_1+\tau_4)Z^{\tau_1+\tau_4+\tau_0+\tau_2-1}+\varepsilon_4\varepsilon_{14}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8-1}$$
$$+\varepsilon_4\varepsilon_{14}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}*(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1}+\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1+\tau_2+\tau_5)Z^{\tau_0+\tau_1+\tau_2+\tau_5-1}$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7-1}+\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}*(\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1}$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}*(\tau_2+\tau_5+\tau_1+\tau_4)Z^{\tau_2+\tau_5+\tau_1+\tau_4-1}-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_{30}\varepsilon_{03}*(\tau_2+\tau_5+\tau_0+\tau_3+\tau_1+\tau_4)Z^{\tau_1+\tau_4+\tau_2+\tau_5+\tau_0+\tau_3-1}$$
$$-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_1+\tau_4+\tau_2+\tau_5+\tau_0+\tau_3+\tau_6+\tau_9)Z^{\tau_1+\tau_4+\tau_2+\tau_5+\tau_0+\tau_3+\tau_6+\tau_9-1}$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_{20}\varepsilon_{02}*(\tau_3+\tau_6+\tau_1+\tau_4+\tau_0+\tau_2)Z^{\tau_1+\tau_4+\tau_3+\tau_6+\tau_0+\tau_2-1}-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_3+\tau_6)$$
$$*Z^{\tau_1+\tau_4+\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8-1}-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}*(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6)Z^{\tau_1+\tau_4+\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1}$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_3+\tau_6+\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau_2+\tau_5+\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7-1}$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}*(\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6)Z^{\tau_2+\tau_5+\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1}$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}*(\tau_3+\tau_6+\tau_2+\tau_5+\tau_0+\tau_1)Z^{\tau_2+\tau_5+\tau_3+\tau_6+\tau_0+\tau_1-1}-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}*(\tau_3+\tau_6+\tau_2+\tau_5+\tau_1+\tau_4)Z^{\tau_2+\tau_5+\tau_3+\tau_6+\tau_1+\tau_4-1}$$

2) Roaming Acquisition time of Scenario 19

According to the definition given in equation (4.1) that the acquisition time from S_0 to S_{12} can be found by setting z =1 in dH(z)/dz, then we get the roaming acquisition time of Scenario 19 :

$$Tsum = \frac{dH(z)}{dz}\bigg|_{z=1} = N_1/M_1 + N_2/M_1^2 \qquad (4.8)$$

where :

$$N_1= F`(z)\Big|_{z=1}= \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_6\varepsilon_{36}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6)$$
$$-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_5\varepsilon_{25}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_2+\tau_5)+\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6+\tau_2+\tau_5)$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}) -\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_6\varepsilon_{36}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6)$$
$$-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_1+\tau_4) +\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6+\tau_1+\tau_4)$$
$$+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}*(\tau_0+\tau_3+\tau_6+\tau_9)-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_5\varepsilon_{25}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5)-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_1+\tau_4)$$
$$+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5+\tau_1+\tau_4)$$

$$N_2= -F(z)*\Delta`(z)\Big|_{z=1} = -(\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_6\varepsilon_{36}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_5\varepsilon_{25}$$
$$+\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_6\varepsilon_{36}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_4\varepsilon_{14}$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14} +\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_5\varepsilon_{25}-\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_4\varepsilon_{14}+\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_{9,12}\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14})$$
$$*[-\varepsilon_{30}\varepsilon_{03}*(\tau_0+\tau_3)-\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_0+\tau_3+\tau_6+\tau_9)-\varepsilon_6\varepsilon_{36}*(\tau_3+\tau_6)-\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2)-\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_0+\tau_2+\tau_5+\tau_8)$$
$$-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}*(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})-\varepsilon_5\varepsilon_{25}*(\tau_2+\tau_5) -\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1) -\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_0+\tau_1+\tau_4+\tau_7)$$
$$-\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}*(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})-\varepsilon_4\varepsilon_{14}*(\tau_1+\tau_4)+\varepsilon_{30}\varepsilon_{03}\varepsilon_5\varepsilon_{25}*(\tau_2+\tau_5+\tau_0+\tau_3)+\varepsilon_{30}\varepsilon_{03}\varepsilon_4\varepsilon_{14}*(\tau_1+\tau_4+\tau_0+\tau_3)$$
$$+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_5\varepsilon_{25}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_2+\tau_5)+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_4\varepsilon_{14}*(\tau_0+\tau_3+\tau_6+\tau_9+\tau_1+\tau_4)+\varepsilon_6\varepsilon_{36}\varepsilon_{20}\varepsilon_{02}*(\tau_3+\tau_6+\tau_0+\tau_2)$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8)+\varepsilon_6\varepsilon_{36}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}*(\tau_3+\tau_6+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})+\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}*(\tau_3+\tau_6+\tau_2+\tau_5)$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_1\varepsilon_{01}*(\tau_3+\tau_6+\tau_0+\tau_1)+\varepsilon_6\varepsilon_{36}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7)+\varepsilon_6\varepsilon_{36}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}*(\tau_3+\tau_6+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}*(\tau_3+\tau_6+\tau_1+\tau_4)+\varepsilon_4\varepsilon_{14}\varepsilon_{20}\varepsilon_{02}*(\tau_0+\tau_2+\tau_1+\tau_4)+\varepsilon_4\varepsilon_{14}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8)$$
$$+\varepsilon_4\varepsilon_{14}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}*(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})+\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}*(\tau_0+\tau_1+\tau_2+\tau_5)+\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7)$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}*(\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})+\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}*(\tau_2+\tau_5+\tau_1+\tau_4)-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_{30}\varepsilon_{03}*(\tau_2+\tau_5+\tau_0+\tau_3+\tau_1+\tau_4)$$
$$-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}*(\tau_1+\tau_4+\tau_2+\tau_5+\tau_0+\tau_3+\tau_6+\tau_9)-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_{20}\varepsilon_{02}*(\tau_3+\tau_6+\tau_1+\tau_4+\tau_0+\tau_2)$$

$$-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}*(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_3+\tau_6)-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}*(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_3+\tau_6)$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}*(\tau_3+\tau_6+\tau_2+\tau_5+\tau_0+\tau_1)-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}*(\tau_3+\tau_6+\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7)$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}*(\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_3+\tau_6)-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}*(\tau_3+\tau_6+\tau_2+\tau_5+\tau_1+\tau_4)]$$

$$M_1=\Delta(z)\Big|_{z=1}$$
$$=1-\varepsilon_{30}\varepsilon_{03}-\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}-\varepsilon_6\varepsilon_{36}-\varepsilon_{20}\varepsilon_{02}-\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}-\varepsilon_5\varepsilon_{25}-\varepsilon_1\varepsilon_{01}-\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}-\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}-\varepsilon_4\varepsilon_{14}+\varepsilon_{30}\varepsilon_{03}\varepsilon_5\varepsilon_{25}$$
$$+\varepsilon_{30}\varepsilon_{03}\varepsilon_4\varepsilon_{14}+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_5\varepsilon_{25}+\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}\varepsilon_4\varepsilon_{14}+\varepsilon_6\varepsilon_{36}\varepsilon_{20}\varepsilon_{02}+\varepsilon_6\varepsilon_{36}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}+\varepsilon_6\varepsilon_{36}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}+\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}+\varepsilon_6\varepsilon_{36}\varepsilon_1\varepsilon_{01}$$
$$+\varepsilon_6\varepsilon_{36}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}+\varepsilon_6\varepsilon_{36}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}+\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}+\varepsilon_4\varepsilon_{14}\varepsilon_{20}\varepsilon_{02}+\varepsilon_4\varepsilon_{14}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}+\varepsilon_4\varepsilon_{14}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}+\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}+\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}+\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_{30}\varepsilon_{03}-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_9\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_{20}\varepsilon_{02}-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_8\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}$$
$$-\varepsilon_6\varepsilon_{36}\varepsilon_4\varepsilon_{14}\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}-\varepsilon_6\varepsilon_{36}\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}$$

4.2.4 Scenario 20

4.2.4.1 State Diagram for Connection Establishment

By substituting $\gamma_{41}=\gamma_{51}=\gamma_{61}=\gamma_{71}=\gamma_{73}=\gamma_{81}=\gamma_{83}=\gamma_{92}=\gamma_{93}=\gamma_{10,2}=\gamma_{10,3}=\gamma_{10,4}=\gamma_{11,2}=\gamma_{11,3}=\gamma_{11,4}=0$ and $\gamma_{42}=\gamma_{52}=\gamma_{62}=\gamma_{72}=\gamma_{82}=\gamma_{91}=\gamma_{10,1}=\gamma_{11,1}=1$ to the generalized state diagram in Figure 3.3, we obtain the following state diagram of the mobile station Figure 4.5, which corresponds to scenario number 20 in the Table 4.1.

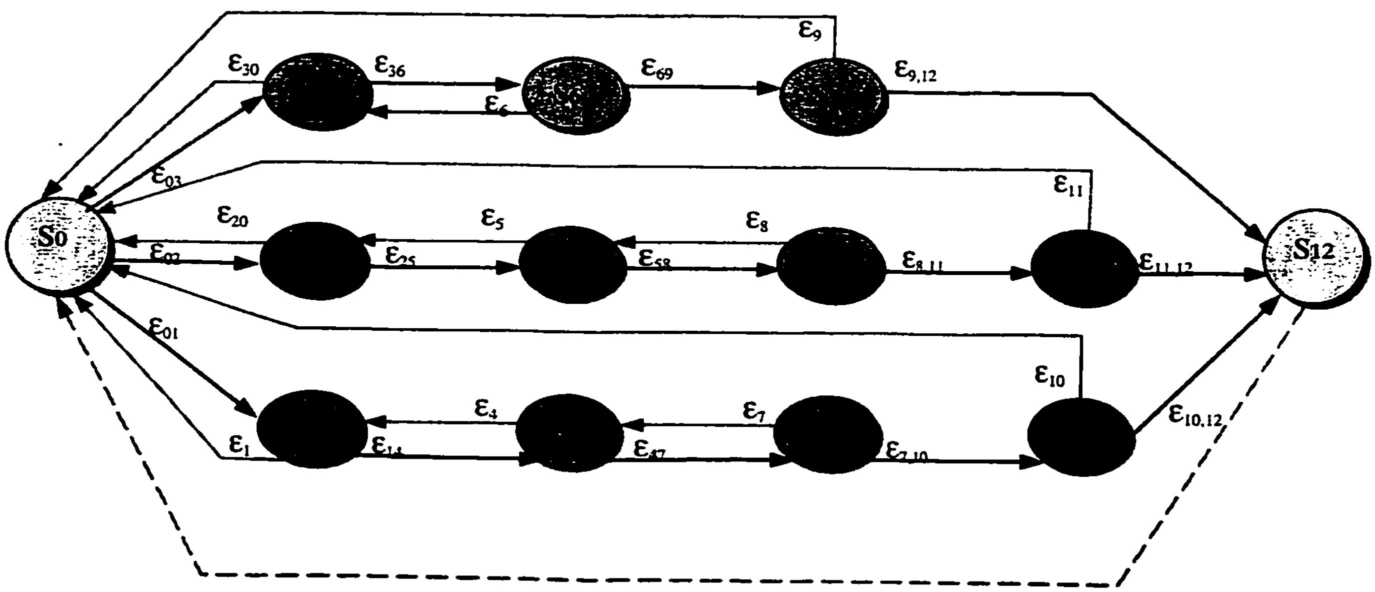


Figure 4.5 State Diagram for Connection Establishment of a reconfigurable Mobile Station (Scenario 20)

Table 4.5 The transitions in the state diagram (Scenario 20)

From State	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	To
Cellular_DL_Request	X													S_1
WLAN_DL_Request	X													S_2
SameSystem_Setup	X													S_3
Cellular_DL_Authen_Confirm		X												S_4
WLAN_DL_Authen_Confirm			X											S_5
SameSys_HO_Authen_Confirm				X										S_6
Cellluar SW_DL_Ready					X									S_7
WLAN SW_DL_Ready						X								S_8
SameSys_HO_Completed							X							S_9
CellSW_DL_Completed								X						S_{10}
WLANSW_DL_Completed									X					S_{11}
SameSys_Connected										X				S_{12}
Cellular_Connected											X			S_{12}
WLAN_Connected												X		S_{12}
Process_Fails &Timeout (Auto)		X	X	X						X	X	X	X	S_0
Cellular_DL_Authen_Failed					X									S_1
WLAN_DL_Authen_Failed						X								S_2
SameSys_HO_Authen_Failed							X							S_3
Cellluar SW_DL_Unavailable								X						S_4
WLAN SW_DL_Unavailable									X					S_5

Where: X denotes the two states are connected and transition is possible for example.

4.2.4.2 Roaming Acquisition Time Calculation of Scenario 20

1) Transition Function

There are 11 loops in the diagram, which are corresponding to the general flow graph C_1, C_3, C_4, C_7, C_{10}, C_{11}, C_{12}, C_{17}, C_{20}, C_{21}, C_{22}

$C_1 = \varepsilon_{30}\varepsilon_{03}Z^{\tau0+\tau3}$

$C_3 = \varepsilon_{9}\varepsilon_{03}\varepsilon_{36}\varepsilon_{69}Z^{\tau0+\tau3+\tau6+\tau9}$

$C_4 = \varepsilon_{6}\varepsilon_{36}Z^{\tau3+\tau6}$

$C_7 = \varepsilon_{20}\varepsilon 0_{2}Z^{\tau0+\tau2}$

$C_{10} = \varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}Z^{\tau0+\tau2+\tau5+\tau8+\tau11}$

$C_{11} = \varepsilon_{5}\varepsilon_{25}Z^{\tau2+\tau5}$

$C_{12} = \varepsilon_{8}\varepsilon_{58}Z^{\tau5+\tau8}$

$C_{17} = \varepsilon_{1}\varepsilon_{01}Z^{\tau0+\tau1}$

$C_{20} = \varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}$

$C_{21} = \varepsilon_{4}\varepsilon_{14}Z^{\tau1+\tau4}$

$C_{22} = \varepsilon_{7}\varepsilon_{47}Z^{\tau4+\tau7}$

There are 30 groups of two non-touching loops :

C_1C_{11}. C_1C_{12}. C_1C_{21}. C_1C_{22}. C_3C_{11}. C_3C_{12}. C_3C_{21}. C_3C_{22}. C_4C_7. C_4C_{10}. C_4C_{11}. C_4C_{12}. C_4C_{17}. C_4C_{20}. C_4C_{21}. C_4C_{22}. C_7C_{12}. C_7C_{21}. C_7C_{22}. $C_{11}C_{17}$. $C_{11}C_{20}$. $C_{11}C_{21}$. $C_{11}C_{22}$. $C_{10}C_{21}$. $C_{10}C_{22}$. $C_{12}C_{17}$. $C_{12}C_{20}$. $C_{12}C_{21}$. $C_{12}C_{22}$. $C_{17}C_{22}$

There are 26 groups of three non-touching loops :

$C_1C_{11}C_{21}$. $C_1C_{11}C_{22}$. $C_1C_{12}C_{21}$. $C_1C_{12}C_{22}$. $C_3C_{11}C_{21}$. $C_3C_{11}C_{22}$. $C_3C_{12}C_{21}$. $C_3C_{12}C_{22}$.

$C_4C_7C_{12}$. $C_4C_7C_{21}$. $C_4C_7C_{22}$. $C_4C_{10}C_{21}$. $C_4C_{10}C_{22}$. $C_4C_{11}C_{17}$. $C_4C_{11}C_{20}$. $C_4C_{11}C_{21}$. $C_4C_{11}C_{22}$.

$C_4C_{12}C_{17}$. $C_4C_{12}C_{20}$. $C_4C_{12}C_{21}$. $C_4C_{12}C_{22}$. $C_4C_{17}C_{22}$. $C_7C_{12}C_{21}$. $C_7C_{12}C_{22}$. $C_{11}C_{17}C_{22}$. $C_{12}C_{17}C_{22}$

There are 3 groups of four non-touching loops :

$C_4C_7C_{12}C_{21}$. $C_4C_{11}C_{17}C_{22}$. $C_4C_{12}C_{17}C_{22}$

Thus,

$\Delta(z) = 1$ – (sum of all different loop gains) + (sum of the gain products of two nontouching loops)
– (sum of the gain products of three nontouching loops)
+ (sum of the gain products of four nontouching loops)

This will bring us a very complex, cumbersome transition function for this state diagram. We consider a special case only, in which case the transition probability distributions of path1, 2, 3 are $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03} = \varepsilon_{01}/\varepsilon_{02}/0$, i.e, the transition is made to S_1 in path1 or S_2 in path2 with probability ε_{01} or ε_{02} respectively; the transition will not be made to path3. Then we will get the acquisition time of the worst case.

There are 8 loops in the state diagram : C_7, C_{10}, C_{11}, C_{12}, C_{17}, C_{20}, C_{21}, C_{22}

$C_7 = \varepsilon_{20}\varepsilon_{02}Z^{\tau0+\tau2}$
$C_{11} = \varepsilon_5\varepsilon_{25}Z^{\tau2+\tau5}$
$C_{17} = \varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1}$
$C_{21} = \varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4}$

$C_{10} = \varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau0+\tau2+\tau5+\tau8+\tau11}$
$C_{12} = \varepsilon_8\varepsilon_{58}Z^{\tau5+\tau8}$
$C_{20} = \varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}$
$C_{22} = \varepsilon_7\varepsilon_{47}Z^{\tau4+\tau7}$

There are 14 groups of two non-touching loops :

C_7C_{12}. C_7C_{21}. C_7C_{22}. $C_{11}C_{17}$. $C_{11}C_{20}$. $C_{11}C_{21}$. $C_{11}C_{22}$. $C_{10}C_{21}$. $C_{10}C_{22}$. $C_{12}C_{17}$. $C_{12}C_{20}$. $C_{12}C_{21}$. $C_{12}C_{22}$. $C_{17}C_{22}$

There are 4 groups of three non-touching loops :

$C_7C_{12}C_{21}$. $C_7C_{12}C_{22}$. $C_{11}C_{17}C_{22}$. $C_{12}C_{17}C_{22}$

Thus,

$$\Delta(z)=1-C_7-C_{10}-C_{11}-C_{12}-C_{17}-C_{20}-C_{21}C_{22}+C_7C_{12}+C_7C_{21}+C_7C_{22}+C_{10}C_{21}+C_{10}C_{22}+C_{11}C_{17}+C_{11}C_{20}+C_{11}C_{21}+C_{11}C_{22}$$
$$+C_{12}C_{17}+C_{12}C_{20}+C_{12}C_{21}+C_{12}C_{22}+C_{17}C_{22}-C_7C_{12}C_{21}-C_7C_{12}C_{22}-C_{11}C_{17}C_{22}-C_{12}C_{17}C_{22}$$

$$= 1-\varepsilon_{20}\varepsilon_{02}Z^{\tau0+\tau2}-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}Z^{\tau0+\tau2+\tau5+\tau8+\tau11}-\varepsilon_{5}\varepsilon_{25}Z^{\tau2+\tau5}-\varepsilon_{8}\varepsilon_{58}Z^{\tau5+\tau8}-\varepsilon_{1}\varepsilon_{01}Z^{\tau0+\tau1}-\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}$$
$$-\varepsilon_{4}\varepsilon_{14}Z^{\tau1+\tau4}-\varepsilon_{7}\varepsilon_{47}Z^{\tau4+\tau7}+\varepsilon_{20}\varepsilon_{02}\varepsilon_{8}\varepsilon_{58}Z^{\tau5+\tau8+\tau0+\tau2}+\varepsilon_{20}\varepsilon_{02}\varepsilon_{4}\varepsilon_{14}Z^{\tau1+\tau4+\tau0+\tau2}+\varepsilon_{20}\varepsilon_{02}\varepsilon_{7}\varepsilon_{47}Z^{\tau4+\tau7+\tau0+\tau2}+\varepsilon_{1}\varepsilon_{01}\varepsilon_{7}\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau7}$$
$$+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{4}\varepsilon_{14}Z^{\tau0+\tau2+\tau5+\tau8+\tau_{11}+\tau1+\tau4}+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{7}\varepsilon_{47}Z^{\tau0+\tau2+\tau5+\tau8+\tau_{11}+\tau4+\tau7}+\varepsilon_{5}\varepsilon_{25}\varepsilon_{1}\varepsilon_{01}Z^{\tau2+\tau5+\tau0+\tau1}$$
$$+\varepsilon_{5}\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau2+\tau5+\tau0+\tau1+\tau4+\tau7+\tau10}+\varepsilon_{5}\varepsilon_{25}\varepsilon_{4}\varepsilon_{14}Z^{\tau2+\tau5+\tau1+\tau4}+\varepsilon_{5}\varepsilon_{25}\varepsilon_{7}\varepsilon_{47}Z^{\tau2+\tau5+\tau4+\tau7}+\varepsilon_{8}\varepsilon_{58}\varepsilon_{1}\varepsilon_{01}Z^{\tau5+\tau8+\tau0+\tau1}$$
$$+\varepsilon_{8}\varepsilon_{58}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}Z^{\tau5+\tau8+\tau0+\tau1+\tau4+\tau7+\tau10}+\varepsilon_{8}\varepsilon_{58}\varepsilon_{4}\varepsilon_{14}Z^{\tau5+\tau8+\tau1+\tau4}+\varepsilon_{8}\varepsilon_{58}\varepsilon_{7}\varepsilon_{47}Z^{\tau5+\tau8+\tau4+\tau7}-\varepsilon_{8}\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_{4}\varepsilon_{14}Z^{\tau1+\tau4+\tau0+\tau2+\tau5+\tau8}$$
$$-\varepsilon_{8}\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_{7}\varepsilon_{47}Z^{\tau_4+\tau7+\tau0+\tau2+\tau5+\tau8}-\varepsilon_{5}\varepsilon_{25}\varepsilon_{1}\varepsilon_{01}\varepsilon_{7}\varepsilon_{47}Z^{\tau_0+\tau1+\tau_4+\tau_7+\tau2+\tau5}-\varepsilon_{8}\varepsilon_{58}\varepsilon_{1}\varepsilon_{01}\varepsilon_{7}\varepsilon_{47}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_5+\tau_8}$$

There are 2 forward paths :

Forward path1: $F_1 = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}$, $\Delta_1 = 1-C_{11}-C_{12} = 1-\varepsilon_5\varepsilon_{25}Z^{\tau2+\tau5}-\varepsilon_8\varepsilon_{58}Z^{\tau5+\tau8}$

Forward path2: $F_2 = \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}Z^{\tau0+\tau2+\tau5+\tau8+\tau11}$, $\Delta_2 = 1-C_{21}-C_{22} = 1-\varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4}-\varepsilon_7\varepsilon_{47}Z^{\tau4+\tau7}$

$$F(z)=F_1*\Delta_1+F_2*\Delta_2=\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}Z^{\tau0+\tau1+\tau4+\tau7+\tau10}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_5\varepsilon_{25}Z^{\tau2+\tau5+\tau0+\tau1+\tau4+\tau7+\tau10}$$
$$-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_8\varepsilon_{58}Z^{\tau5+\tau8+\tau0+\tau1+\tau4+\tau7+\tau10}+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}Z^{\tau0+\tau2+\tau5+\tau8+\tau11}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4+\tau0+\tau2+\tau5+\tau8+\tau11}$$
$$-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_7\varepsilon_{47}Z^{\tau4+\tau7+\tau0+\tau2+\tau5+\tau8+\tau11}$$

Then, according to the defination given in equation (4.2), we get the transition function of this state diagram in special case $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}=\varepsilon_{01}/\varepsilon_{02}/0$, i.e

$$H(z) = \frac{F_1*\Delta_1+F_2*\Delta_2}{\Delta(z)} = \frac{F(z)}{\Delta(z)}$$

$$\frac{dH(z)}{dz} = \frac{F`(z)}{\Delta(z)} - \frac{F(z)*\Delta`(z)}{\Delta^2(z)}$$

Where:

$$F`(z)=\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau_0+\tau1+\tau4+\tau7+\tau_{10}-1}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_5\varepsilon_{25}(\tau_0+\tau_1+\tau_{2+}\tau_4+\tau_5+\tau_7+\tau_{10})$$
$$*Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}\varepsilon_{10,12}\varepsilon_8\varepsilon_{58}(\tau_0+\tau_1+\tau_{4+}\tau_5+\tau_7+\tau_8+\tau_{10})Z^{\tau5+\tau8+\tau0+\tau1+\tau4+\tau7+\tau10-1}$$
$$+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau0+\tau2+\tau5+\tau8+\tau11-1}-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_{2+}\tau_4+\tau_5+\tau_8+\tau_{11})Z^{\tau1+\tau4+\tau0+\tau2+\tau5+\tau8+\tau11-1}$$
$$-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_{11,12}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_{4+}\tau_5+\tau_7+\tau_8+\tau_{11})Z^{\tau4+\tau7+\tau0+\tau2+\tau5+\tau8+\tau11-1}$$

$$\Delta`(z) =-\varepsilon_{20}\varepsilon_{02}(\tau_0+\tau_2)Z^{\tau0+\tau2-1}-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau0+\tau2+\tau5+\tau8+\tau11-1}-\varepsilon_5\varepsilon_{25}(\tau_2+\tau_5)Z^{\tau2+\tau5-1}-\varepsilon_8\varepsilon_{58}(\tau_5+\tau_8)Z^{\tau5+\tau8-1}$$
$$-\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1)Z^{\tau0+\tau1-1}-\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau0+\tau1+\tau4+\tau7+\tau10}-\varepsilon_4\varepsilon_{14}(\tau_1+\tau_4)Z^{\tau1+\tau4-1}-\varepsilon_7\varepsilon_{47}(\tau_4+\tau_7)Z^{\tau4+\tau7-1}$$
$$+\varepsilon_{20}\varepsilon_{02}\varepsilon_8\varepsilon_{58}(\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau0+\tau2+\tau5+\tau8-1}+\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4)Z^{\tau0+\tau2+\tau1+\tau4-1}+\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_7)Z^{\tau0+\tau2+\tau4+\tau7-1}$$
$$+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau0+\tau2+\tau5+\tau8+\tau11+\tau1+\tau4-1}+\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau0+\tau1+\tau4+\tau7-1}$$
$$+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8,11}\varepsilon_7\varepsilon_{47}(\tau_4+\tau_7+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau0+\tau2+\tau5+\tau8+\tau11+\tau4+\tau7-1}+\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_5)Z^{\tau0+\tau1+\tau2+\tau5-1}$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}(\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau2+\tau5+\tau0+\tau1+\tau4+\tau7+\tau10-1}+\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_2+\tau_4+\tau_5)Z^{\tau1+\tau4+\tau2+\tau5-1}$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{47}(\tau_2+\tau_4+\tau_5+\tau_7)Z^{\tau2+\tau5+\tau4+\tau7-1}+\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1+\tau_5+\tau_8)Z^{\tau0+\tau1+\tau5+\tau8-1}+\varepsilon_8\varepsilon_{58}\varepsilon_7\varepsilon_{47}(\tau_4+\tau_5+\tau_7+\tau_8)Z^{\tau4+\tau5+\tau7+\tau8-1}$$
$$+\varepsilon_8\varepsilon_{58}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7,10}(\tau_5+\tau_8+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau5+\tau8+\tau0+\tau1+\tau4+\tau7+\tau10-1}+\varepsilon_8\varepsilon_{58}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_4+\tau_5+\tau_8)Z^{\tau1+\tau4+\tau5+\tau8-1}$$
$$-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_8)Z^{\tau0+\tau2+\tau1+\tau4+\tau5+\tau8-1}-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8)Z^{\tau0+\tau2+\tau4+\tau7+\tau5+\tau8-1}$$
$$-\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7)Z^{\tau0+\tau1+\tau4+\tau7+\tau2+\tau5-1}-\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_8+\tau_4+\tau_5+\tau_7)Z^{\tau0+\tau1+\tau4+\tau5+\tau7+\tau8-1}$$

2) Roaming Acquisition time of scenario 20 in case $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}=\varepsilon_{01}/\varepsilon_{02}/0$

According to the definition given in equation (4.1) that the acquisition time from S_0 to S_{12} can be found by setting z =1 in dH(z)/dz, then we get the roaming acquisition time in special case $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}=\varepsilon_{01}/\varepsilon_{02}/0$

$$Tsum = \frac{dH(z)}{dz}\Bigg|_{z=1} = N_1/M_1 + N_2/M_1^2 \tag{4.9}$$

where :

$$N_1 = F`(z)\Big|_{z=1} = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_5\varepsilon_{25}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_{10})$$
$$-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_8\varepsilon_{58}(\tau_0+\tau_1+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10})+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})$$
$$-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_8+\tau_{11}) -\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{11})$$

$$N_2 = -F(z)*\Delta`(z)\Big|_{z=1} = -(\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_5\varepsilon_{25}-\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_8\varepsilon_{58}+\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}$$
$$-\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_4\varepsilon_{14} -\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_7\varepsilon_{47})*[-\varepsilon_{20}\varepsilon_{02}(\tau_0+\tau_2)-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})-\varepsilon_5\varepsilon_{25}(\tau_2+\tau_5)$$
$$-\varepsilon_8\varepsilon_{58}(\tau_5+\tau_8)-\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1) -\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})-\varepsilon_4\varepsilon_{14}(\tau_1+\tau_4)-\varepsilon_7\varepsilon_{47}(\tau_4+\tau_7)+\varepsilon_{20}\varepsilon_{02}\varepsilon_8\varepsilon_{58}(\tau_0+\tau_2+\tau_5+\tau_8)$$
$$+\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4)+\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_7)+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})+\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_4+\tau_7)$$
$$+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_7\varepsilon_{47}(\tau_4+\tau_7+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})+\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_5)+\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}(\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_2+\tau_4+\tau_5)+\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{47}(\tau_2+\tau_4+\tau_5+\tau_7)+\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1+\tau_5+\tau_8)+\varepsilon_8\varepsilon_{58}\varepsilon_7\varepsilon_{47}(\tau_4+\tau_5+\tau_7+\tau_8)$$
$$+\varepsilon_8\varepsilon_{58}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}(\tau_5+\tau_8+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})+\varepsilon_8\varepsilon_{58}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_4+\tau_5+\tau_8)-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_8)$$
$$-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8)-\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7)-\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_8+\tau_4+\tau_5+\tau_7)]$$

$$M_1 = \Delta(z)\Big|_{z=1}$$
$$=1-\varepsilon_{20}\varepsilon_{02}-\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}-\varepsilon_5\varepsilon_{25}-\varepsilon_8\varepsilon_{58}-\varepsilon_1\varepsilon_{01}-\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_4\varepsilon_{14}\varepsilon_7\varepsilon_{47}+\varepsilon_{20}\varepsilon_{02}\varepsilon_8\varepsilon_{58}+\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14} +\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}$$
$$+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_4\varepsilon_{14}+\varepsilon_{11}\varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_7\varepsilon_{47}+\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}+\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}+\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10} +\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}+\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{47}+\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}$$
$$+\varepsilon_8\varepsilon_{58}\varepsilon_{10}\varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}+\varepsilon_8\varepsilon_{58}\varepsilon_4\varepsilon_{14}+\varepsilon_8\varepsilon_{58}\varepsilon_7\varepsilon_{47}-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}-\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}-\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}$$

4.2.5 Scenario 26

4.2.5.1 State Diagram for Connection Establishment

By substituting $\gamma_{41} = \gamma_{51} = \gamma_{61} = \gamma_{71} = \gamma_{73} = \gamma_{81} = \gamma_{83} = \gamma_{91} = \gamma_{93} = \gamma_{10,1} = \gamma_{10,3} = \gamma_{10,4} = \gamma_{11,1}= \gamma_{11,3}= \gamma_{11,4} = 0$ and $\gamma_{42}= \gamma_{52}= \gamma_{62}= \gamma_{72}= \gamma_{82}= \gamma_{92}= \gamma_{10,2}= \gamma_{11,2} = 1$ to the generalized state diagram Figure 3.3, we obtain the following state diagram of the mobile station Figure 4.6, which corresponds to scenario number 26 in the Table 4.1. Table 4.6 presents a summary of the most important messages and their effects on the state diagram in Figure 4.6.

In this design scheme, from each state Sj on a path i, the MS will move to the next state if the transmission is successful; otherwise, the MS will return to its previous state. This design has shorter processing time than scheme 1 when transmission fails in one state and needs to continue, e.g, in the case of same kind Base Station (BS) system exists. However, it has longer processing time when the MS needs to return to the start point, because the MS has to return to the previous state one by one.

Therefore, this scheme is suitable for a MS moving slowly and it is not in the edge between two different systems, which implies that the BS types do not change frequently to as MS roams. The main disadvantage is long processing time when the process on the path i has to be terminated during a procedure.

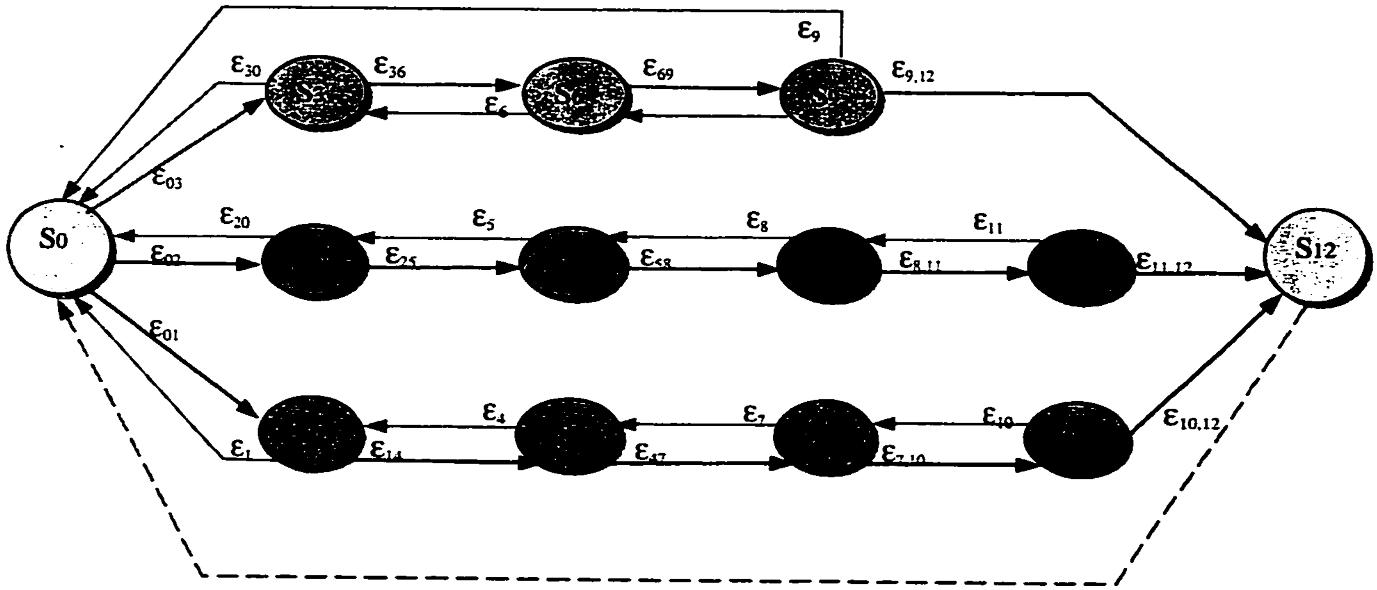


Figure 4.6 State Diagram for Connection Control of a reconfigurable Mobile Station (Scenario 26)

Table 4.6 The transitions in the state diagram (Scenario 26)

From State	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	To
Cellular_DL_Request	X													S_1
WLAN_DL_Request	X													S_2
SameSystem_Setup	X													S_3
Cellular_DL_Authen_Confirm		X												S_4
WLAN_DL_Authen_Confirm			X											S_5
SameSys_HO_Authen_Confirm				X										S_6
Cellluar SW_DL_Ready					X									S_7
WLAN SW_DL_Ready						X								S_8
SameSys_HO_Completed							X							S_9
CellSW_DL_Completed								X						S_{10}
WLANSW_DL_Completed									X					S_{11}
SameSys_Connected										X				S_{12}
Cellular_Connected											X			S_{12}
WLAN_Connected												X		S_{12}
Process_Fails &Timeout (Auto)		X	X	X									X	S_0
Cellular_DL_Authen_Failed					X									S_1
WLAN_DL_Authen_Failed						X								S_2
SameSys_HO_Authen_Failed							X							S_3

Cellluar SW_DL_Unavailable								X						S_4
WLAN SW_DL_Unavailable									X					S_5
SameSys_HO_Unavailable										X				S_6
New Systen Update_Failed											X			S_7
New Systen Update_Failed												X		S_8

Where: X denotes the two states are connected and transition is possible for example.

4.2.5.2 Roaming Acquisition Time Calculation

1) Transition Function

There are 11 loops in the diagram, which are corresponding to the general flow graph C_1, C_4, C_5, C_7, C_{11}, C_{12}, C_{13}, C_{17}, C_{21}, C_{22}, C_{23}

$C_1 = \varepsilon_{30}\varepsilon_{03}Z^{\tau 0+\tau 3}$

$C_4 = \varepsilon_6\varepsilon_{36}Z^{\tau 3+\tau 6}$

$C_5 = \varepsilon_9\varepsilon_{69}Z^{\tau 6+\tau 9}$

$C_7 = \varepsilon_{20}\varepsilon_{02}Z^{\tau 0+\tau 2}$

$C_{11} = \varepsilon_5\varepsilon_{25}Z^{\tau 2+\tau 5}$

$C_{12} = \varepsilon_8\varepsilon_{58}Z^{\tau 5+\tau 8}$

$C_{13} = \varepsilon_{11}\varepsilon_{8,11}Z^{\tau 8+\tau 11}$

$C_{17} = \varepsilon_1\varepsilon_{01}Z^{\tau 0+\tau 1}$

$C_{21} = \varepsilon_4\varepsilon_{14}Z^{\tau 1+\tau 4}$

$C_{22} = \varepsilon_7\varepsilon_{47}Z^{\tau 4+\tau 7}$

$C_{23} = \varepsilon_{10}\varepsilon_{7,10}Z^{\tau 7+\tau 10}$

There are 44 groups of two non-touching loops :

C_1C_5, C_1C_{11}, C_1C_{12}, C_1C_{13}, C_1C_{21}, C_1C_{22}, C_1C_{23}, C_4C_7, C_4C_{11}, C_4C_{12}, C_4C_{13}, C_4C_{17}, C_4C_{21}, C_4C_{22}, C_4C_{23}, C_5C_7, C_5C_{11}, C_5C_{12}, C_5C_{13}, C_5C_{17}, C_5C_{21}, C_5C_{22}, C_5C_{23}, C_7C_{12}, C_7C_{13}, C_7C_{21}, C_7C_{22}, C_7C_{23}, $C_{11}C_{13}$, $C_{11}C_{17}$, $C_{11}C_{21}$, $C_{11}C_{22}$, $C_{11}C_{23}$, $C_{12}C_{17}$, $C_{12}C_{21}$, $C_{12}C_{22}$, $C_{12}C_{23}$, $C_{13}C_{17}$, $C_{13}C_{21}$, $C_{13}C_{22}$, $C_{13}C_{23}$, $C_{17}C_{22}$, $C_{17}C_{23}$, $C_{21}C_{23}$

Moreover, there are 79 groups of three non-touching loops, 62 groups of four non-touching loops, 16 groups of five non-touching loops and 1 group of five non-touching loops.

Thus,

$\Delta(z)$ = 1 –(sum of all different loop gains) +(sum of the gain products of two nontouching loops)
– (sum of the gain products of three nontouching loops)
+ (sum of the gain products of four nontouching loops)
- (sum of the gain products of five nontouching loops)
+ (sum of the gain products of six nontouching loops)

This will bring us a very complex, cumbersome transition function for this state diagram scenario. We consider a special case only, in which case the transition probability distributions of path1, 2, 3 are $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03} = \varepsilon_{01}/\varepsilon_{02}/0$, i.e, the transition is made to S_1 in path1 or S_2 in path2 with probability ε_{01} or ε_{02} respectively; the transition will not be made to path3. Then we will get the roaming acquisition time of the worst case.

There are 8 loops in the state diagram : $C_7, C_{11}, C_{12}, C_{13}, C_{17}, C_{21}, C_{22}, C_{23}$

$C_7 = \varepsilon_{20}\varepsilon_{02}Z^{\tau0+\tau2}$
$C_{12} = \varepsilon_8\varepsilon_{58}Z^{\tau5+\tau8}$
$C_{17} = \varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1}$
$C_{22} = \varepsilon_7\varepsilon_{47}Z^{\tau4+\tau7}$

$C_{11} = \varepsilon_5\varepsilon_{25}Z^{\tau2+\tau5}$
$C_{13} = \varepsilon_{11}\varepsilon_{8,11}Z^{\tau8+\tau11}$
$C_{21} = \varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4}$
$C_{23} = \varepsilon_{10}\varepsilon_{7,10}Z^{\tau7+\tau10}$

There are 21 groups of two non-touching loops :

C_7C_{12}, C_7C_{13}, C_7C_{21}, C_7C_{22}, C_7C_{23}, $C_{11}C_{13}$, $C_{11}C_{17}$, $C_{11}C_{21}$, $C_{11}C_{22}$, $C_{11}C_{23}$, $C_{12}C_{17}$, $C_{12}C_{21}$, $C_{12}C_{22}$, $C_{12}C_{23}$, $C_{13}C_{17}$, $C_{13}C_{21}$, $C_{13}C_{22}$, $C_{13}C_{23}$, $C_{17}C_{22}$, $C_{17}C_{23}$, $C_{21}C_{23}$

There are 20 groups of three non-touching loops :

$C_7C_{12}C_{21}$, $C_7C_{12}C_{22}$, $C_7C_{12}C_{23}$, $C_7C_{13}C_{21}$, $C_7C_{13}C_{22}$, $C_7C_{13}C_{23}$, $C_7C_{21}C_{23}$, $C_{11}C_{13}C_{17}$, $C_{11}C_{13}C_{21}$, $C_{11}C_{13}C_{22}$, $C_{11}C_{13}C_{23}$, $C_{11}C_{17}C_{22}$, $C_{11}C_{17}C_{23}$, $C_{11}C_{21}C_{23}$, $C_{12}C_{17}C_{22}$, $C_{12}C_{17}C_{23}$, $C_{12}C_{21}C_{23}$, $C_{13}C_{17}C_{22}$, $C_{13}C_{17}C_{23}$, $C_{13}C_{21}C_{23}$

There are 5 groups of three non-touching loops

$C_7C_{12}C_{21}C_{23}$, $C_7C_{13}C_{21}C_{23}$, $C_{11}C_{13}C_{17}C_{22}$, $C_{11}C_{13}C_{17}C_{23}$, $C_{11}C_{13}C_{21}C_{23}$

Thus,

$$\Delta(z)=1-C_7-C_{11}-C_{12}-C_{13}-C_{17}-C_{21}-C_{22}-C_{23}+C_7\cdot(C_{12}+C_{13}+C_{21}+C_{22}+C_{23})+C_{11}\cdot(C_{13}+C_{17}+C_{21}+C_{22}+C_{23})$$
$$+(C_{12}+C_{13})\cdot(C_{17}+C_{21}+C_{22}+C_{23})+C_{17}\cdot(C_{22}+C_{23})+C_{21}C_{23}-C_7C_{12}\cdot(C_{21}+C_{22}+C_{23})-C_7C_{13}\cdot(C_{21}+C_{22}+C_{23})-C_7C_{21}C_{23}$$
$$-C_{11}C_{13}\cdot(C_{17}+C_{21}+C_{22}+C_{23})-C_{11}C_{17}(C_{22}+C_{23})-C_{11}C_{21}C_{23}-C_{12}C_{17}(C_{22}+C_{23})-C_{12}C_{21}C_{23}-C_{13}C_{17}(C_{22}+C_{23})-C_{13}C_{21}C_{23}$$
$$+C_7C_{12}C_{21}C_{23}+C_7C_{13}C_{21}C_{23}+C_{11}C_{13}C_{17}C_{22}+C_{11}C_{13}C_{17}C_{23}+C_{11}C_{13}C_{21}C_{23}$$

$$=1-\varepsilon_{20}\varepsilon_{02}Z^{\tau_0+\tau_2}-\varepsilon_5\varepsilon_{25}Z^{\tau_2+\tau_5}-\varepsilon_8\varepsilon_{58}Z^{\tau_5+\tau_8}-\varepsilon_{11}\varepsilon_{8,11}Z^{\tau_8+\tau_{11}}-\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1}-\varepsilon_4\varepsilon_{14}Z^{\tau_1+\tau_4}-\varepsilon_7\varepsilon_{47}Z^{\tau_4+\tau_7}-\varepsilon_{10}\varepsilon_{7,10}Z^{\tau_7+\tau_{10}}+\varepsilon_{20}\varepsilon_{02}\varepsilon_8\varepsilon_{58}Z^{\tau_0+\tau_2+\tau_5+\tau_8}$$
$$+\varepsilon_{20}\varepsilon_{02}\varepsilon_{11}\varepsilon_{8,11}Z^{\tau0+\tau_2+\tau_8+\tau_{11}}+\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}Z^{\tau0+\tau2+\tau1+\tau4}+\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}Z^{\tau0+\tau2+\tau4+\tau7}+\varepsilon_{20}\varepsilon_{02}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau2+\tau7+\tau10}+\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8,11}Z^{\tau2+\tau5+\tau8+\tau11}$$
$$+\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1+\tau2+\tau5}+\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4+\tau2+\tau5}+\varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{47}Z^{\tau2+\tau5+\tau4+\tau7}+\varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau2+\tau5+\tau7+\tau10}+\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1+\tau5+\tau8}$$
$$+\varepsilon_8\varepsilon_{58}\varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4+\tau5+\tau8}+\varepsilon_8\varepsilon_{58}\varepsilon_7\varepsilon_{47}Z^{\tau4+\tau5+\tau7+\tau8}+\varepsilon_8\varepsilon_{58}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau5+\tau7+\tau8+\tau10}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_1\varepsilon_{01}Z^{\tau0+\tau1+\tau11+\tau8}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_4\varepsilon_{14}Z^{\tau1+\tau4+\tau11+\tau8}$$
$$+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_7\varepsilon_{47}Z^{\tau_4+\tau_{11}+\tau7+\tau8}+\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau_{11}+\tau_7+\tau_8+\tau_{10}}+\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}Z^{\tau_0+\tau1+\tau_4+\tau_7}+\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau_0+\tau1+\tau_7+\tau_{10}}+\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau1+\tau_4+\tau_7+\tau_{10}}$$
$$-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}Z^{\tau0+\tau2+\tau1+\tau4+\tau5+\tau8}-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}Z^{\tau0+\tau2+\tau4+\tau7+\tau5+\tau8}-\varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau2+\tau5+\tau8+\tau7+\tau10}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}Z^{\tau0+\tau2+\tau1+\tau4+\tau8+\tau11}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}Z^{\tau0+\tau2+\tau4+\tau7+\tau8+\tau11}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{20}\varepsilon_{02}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau2+\tau7+\tau10+\tau8+\tau11}$$
$$-\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau2+\tau1+\tau4+\tau7+\tau10}-\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_1\varepsilon_{01}Z^{\tau2+\tau5+\tau0+\tau1+\tau11+\tau8}-\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_4\varepsilon_{14}Z^{\tau2+\tau5+\tau1+\tau4+\tau11+\tau8}$$
$$-\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_7\varepsilon_{47}Z^{\tau2+\tau5+\tau4+\tau11+\tau7+\tau8}-\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau2+\tau5+\tau11+\tau7+\tau8+\tau10}-\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau7+\tau2+\tau5}$$
$$-\varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau1+\tau7+\tau10+\tau2+\tau5}-\varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau1+\tau4+\tau7+\tau10+\tau2+\tau5}-\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau7+\tau5+\tau8}$$
$$-\varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau1+\tau7+\tau10+\tau5+\tau8}-\varepsilon_8\varepsilon_{58}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau1+\tau4+\tau7+\tau10+\tau5+\tau8}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}Z^{\tau0+\tau1+\tau4+\tau7+\tau8+\tau11}$$
$$-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau1+\tau7+\tau10+\tau8+\tau11}-\varepsilon_{11}\varepsilon_{8,11}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau1+\tau4+\tau7+\tau10+\tau8+\tau11}+\varepsilon_{20}\varepsilon_{02}\varepsilon_8\varepsilon_{58}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau2+\tau1+\tau4+\tau7+\tau10+\tau5+\tau8}$$
$$+\varepsilon_{20}\varepsilon_{02}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau0+\tau2+\tau1+\tau4+\tau7+\tau10+\tau8+\tau11}+\varepsilon_7\varepsilon_{47}\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_1\varepsilon_{01}Z^{\tau2+\tau5+\tau0+\tau1+\tau11+\tau8+\tau4+\tau7}$$
$$+\varepsilon_{10}\varepsilon_{7,10}\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_1\varepsilon_{01}Z^{\tau2+\tau5+\tau0+\tau1+\tau11+\tau8+\tau7+\tau10}+\varepsilon_4\varepsilon_{14}\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8,11}\varepsilon_{10}\varepsilon_{7,10}Z^{\tau1+\tau4+\tau2+\tau5+\tau11+\tau7+\tau8+\tau10}$$

There are 2 forward paths :

Forward path1: $F_1 = \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}}$,

$$\Delta_1 = 1 - C_{11} - C_{12} - C_{13} + C_{11}C_{13} = 1 - \varepsilon_5\varepsilon_{25}Z^{\tau_2+\tau_5} - \varepsilon_8\varepsilon_{58}Z^{\tau_5+\tau_8} - \varepsilon_{11}\varepsilon_{8.11}Z^{\tau_8+\tau_{11}} + \varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8.11}Z^{\tau_2+\tau_5+\tau_8+\tau_{11}}$$

Forward path2: $F_2 = \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}$,

$$\Delta_2 = 1 - C_{21} - C_{22} - C_{23} + C_{21}C_{23} = 1 - \varepsilon_4\varepsilon_{14}Z^{\tau_1+\tau_4} - \varepsilon_7\varepsilon_{47}Z^{\tau_4+\tau_7} - \varepsilon_{10}\varepsilon_{7.10}Z^{\tau_7+\tau_{10}} + \varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_1+\tau_4+\tau_7+\tau_{10}}$$

$$\begin{aligned}
F(z) = F_1{*}\Delta_1 + F_2{*}\Delta_2 =\ & \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}} - \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_5\varepsilon_{25}Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}} \\
& - \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_8\varepsilon_{58}Z^{\tau_5+\tau_8+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}} - \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_{11}\varepsilon_{8.11}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_8+\tau_{11}} \\
& + \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8.11}Z^{\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}} + \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}} \\
& - \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_4\varepsilon_{14}Z^{\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}} - \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_7\varepsilon_{47}Z^{\tau_4+\tau_7+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}} \\
& - \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}} + \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7.10}Z^{\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}}
\end{aligned}$$

Then, according to the definition given in equation (4.2), we get the transition function of this state diagram in special case $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03} = \varepsilon_{01}/\varepsilon_{02}/0$:

$$H(z) = \frac{F_1{*}\Delta_1 + F_2{*}\Delta_2 + F_3{*}\Delta_3}{\Delta(z)} = \frac{F(z)}{\Delta(z)}$$

$$\frac{dH(z)}{dz} = \frac{F'(z)}{\Delta(z)} - \frac{F(z){*}\,\Delta'(z)}{\Delta^2(z)}$$

Where:

$$\begin{aligned}
F'(z) =\ & \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1} - \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_5\varepsilon_{25}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_{10})Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1} \\
& - \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_8\varepsilon_{58}(\tau_0+\tau_1+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10})Z^{\tau_5+\tau_8+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1} - \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_{11}\varepsilon_{8.11}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_8+\tau_{10}+\tau_{11}) \\
& {*}Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_8+\tau_{11}-1} + \varepsilon_{01}\varepsilon_{14}\varepsilon_{47}\varepsilon_{7.10}\varepsilon_{10.12}\varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8.11}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_2+\tau_5+\tau_8+\tau_{11}+\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10}-1} \\
& + \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1} - \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_8+\tau_{11})Z^{\tau_1+\tau_4+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1} \\
& - \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{11})Z^{\tau_4+\tau_7+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1} - \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_2+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11}) \\
& {*}Z^{\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1} + \varepsilon_{02}\varepsilon_{25}\varepsilon_{58}\varepsilon_{8.11}\varepsilon_{11.12}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11}-1}
\end{aligned}$$

$$\begin{aligned}
\Delta'(z) =\ & -\varepsilon_{20}\varepsilon_{02}(\tau_0+\tau_2)Z^{\tau_0+\tau_2-1} - \varepsilon_5\varepsilon_{25}(\tau_2+\tau_5)Z^{\tau_2+\tau_5-1} - \varepsilon_8\varepsilon_{58}(\tau_5+\tau_8)Z^{\tau_5+\tau_8-1} - \varepsilon_{11}\varepsilon_{8.11}(\tau_8+\tau_{11})Z^{\tau_8+\tau_{11}-1} - \varepsilon_1\varepsilon_{01}(\tau_0+\tau_1)Z^{\tau_0+\tau_1-1} \\
& - \varepsilon_4\varepsilon_{14}(\tau_1+\tau_4)Z^{\tau_1+\tau_4-1} - \varepsilon_7\varepsilon_{47}(\tau_4+\tau_7)Z^{\tau_4+\tau_7-1} - \varepsilon_{10}\varepsilon_{7.10}(\tau_7+\tau_{10})Z^{\tau_7+\tau_{10}-1} + \varepsilon_{20}\varepsilon_{02}\varepsilon_8\varepsilon_{58}(\tau_0+\tau_2+\tau_5+\tau_8)Z^{\tau_0+\tau_2+\tau_5+\tau_8-1} \\
& + \varepsilon_{20}\varepsilon_{02}\varepsilon_{11}\varepsilon_{8.11}(\tau_0+\tau_2+\tau_8+\tau_{11})Z^{\tau_0+\tau_2+\tau_8+\tau_{11}-1} + \varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4)Z^{\tau_0+\tau_2+\tau_1+\tau_4-1} + \varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_7)Z^{\tau_0+\tau_2+\tau_4+\tau_7-1} \\
& + \varepsilon_{20}\varepsilon_{02}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_2+\tau_7+\tau_{10})Z^{\tau_0+\tau_2+\tau_7+\tau_{10}-1} + \varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8.11}(\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_2+\tau_5+\tau_8+\tau_{11}-1} + \varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_5)Z^{\tau_0+\tau_1+\tau_2+\tau_5-1} \\
& + \varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_2+\tau_4+\tau_5)Z^{\tau_1+\tau_4+\tau_2+\tau_5-1} + \varepsilon_5\varepsilon_{25}\varepsilon_7\varepsilon_{47}(\tau_2+\tau_4+\tau_5+\tau_7)Z^{\tau_2+\tau_5+\tau_4+\tau_7-1} + \varepsilon_5\varepsilon_{25}\varepsilon_{10}\varepsilon_{7.10}(\tau_2+\tau_5+\tau_7+\tau_{10})Z^{\tau_2+\tau_5+\tau_7+\tau_{10}-1} \\
& + \varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1+\tau_5+\tau_8)Z^{\tau_0+\tau_1+\tau_5+\tau_8-1} + \varepsilon_8\varepsilon_{58}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_4+\tau_5+\tau_8)Z^{\tau_1+\tau_4+\tau_5+\tau_8-1} + \varepsilon_8\varepsilon_{58}\varepsilon_7\varepsilon_{47}(\tau_4+\tau_5+\tau_7+\tau_8)Z^{\tau_4+\tau_5+\tau_7+\tau_8-1} \\
& + \varepsilon_8\varepsilon_{58}\varepsilon_{10}\varepsilon_{7.10}(\tau_5+\tau_7+\tau_8+\tau_{10})Z^{\tau_5+\tau_7+\tau_8+\tau_{10}-1} + \varepsilon_{11}\varepsilon_{8.11}\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1+\tau_8+\tau_{11})Z^{\tau_0+\tau_1+\tau_{11}+\tau_8-1} + \varepsilon_{11}\varepsilon_{811}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_4+\tau_8+\tau_{11})Z^{\tau_1+\tau_4+\tau_{11}+\tau_8-1} \\
& + \varepsilon_{11}\varepsilon_{8.11}\varepsilon_7\varepsilon_{47}(\tau_4+\tau_7+\tau_8+\tau_{11})Z^{\tau_4+\tau_{11}+\tau_7+\tau_8} + \varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}(\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_{11}+\tau_7+\tau_8+\tau_{10}-1} + \varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_4+\tau_7)Z^{\tau_0+\tau_1+\tau_4+\tau_7-1} \\
& + \varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_1+\tau_7+\tau_{10})Z^{\tau_0+\tau_1+\tau_7+\tau_{10}-1} + \varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7.10}(\tau_1+\tau_4+\tau_7+\tau_{10})Z^{\tau_1+\tau_4+\tau_7+\tau_{10}-1} \\
& - \varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_8)Z^{\tau_0+\tau_2+\tau_1+\tau_4+\tau_5+\tau_8-1} - \varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8)Z^{\tau_0+\tau_2+\tau_4+\tau_7+\tau_5+\tau_8-1} \\
& - \varepsilon_8\varepsilon_{58}\varepsilon_{20}\varepsilon_{02}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_2+\tau_5+\tau_7+\tau_8+\tau_{10})Z^{\tau_0+\tau_2+\tau_5+\tau_8+\tau_7+\tau_{10}-1} - \varepsilon_{11}\varepsilon_{8.11}\varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_8+\tau_{11})Z^{\tau_0+\tau_2+\tau_1+\tau_4+\tau_8+\tau_{11}-1} \\
& - \varepsilon_{11}\varepsilon_{8.11}\varepsilon_{20}\varepsilon_{02}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_7+\tau_8+\tau_{11})Z^{\tau_0+\tau_2+\tau_4+\tau_7+\tau_8+\tau_{11}-1} - \varepsilon_{11}\varepsilon_{8.11}\varepsilon_{20}\varepsilon_{02}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_2+\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_0+\tau_2+\tau_7+\tau_{10}+\tau_8+\tau_{11}-1} \\
& - \varepsilon_{20}\varepsilon_{02}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_7+\tau_{10})Z^{\tau_0+\tau_2+\tau_1+\tau_4+\tau_7+\tau_{10}-1} - \varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_1\varepsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_5+\tau_8+\tau_{11})Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_{11}+\tau_8-1} \\
& - \varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_4\varepsilon_{14}(\tau_1+\tau_2+\tau_4+\tau_5+\tau_8+\tau_{11})Z^{\tau_2+\tau_5+\tau_1+\tau_4+\tau_{11}+\tau_8-1} - \varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_7\varepsilon_{47}(\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{11})Z^{\tau_2+\tau_5+\tau_4+\tau_{11}+\tau_7+\tau_8-1} \\
& - \varepsilon_5\varepsilon_{25}\varepsilon_{11}\varepsilon_{8.11}\varepsilon_{10}\varepsilon_{7.10}(\tau_2+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_2+\tau_5+\tau_{11}+\tau_7+\tau_8+\tau_{10}-1} - \varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7)Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_2+\tau_5-1} \\
& - \varepsilon_5\varepsilon_{25}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_5+\tau_7+\tau_{10})Z^{\tau_0+\tau_1+\tau_7+\tau_{10}+\tau_2+\tau_5-1} - \varepsilon_5\varepsilon_{25}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7.10}(\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_{10})Z^{\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_2+\tau_5-1} \\
& - \varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_4+\tau_5+\tau_7+\tau_8)Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_5+\tau_8-1} - \varepsilon_8\varepsilon_{58}\varepsilon_1\varepsilon_{01}\varepsilon_{10}\varepsilon_{7.10}(\tau_0+\tau_1+\tau_5+\tau_7+\tau_8+\tau_{10})Z^{\tau_0+\tau_1+\tau_7+\tau_{10}+\tau_5+\tau_8-1} \\
& - \varepsilon_8\varepsilon_{58}\varepsilon_4\varepsilon_{14}\varepsilon_{10}\varepsilon_{7.10}(\tau_1+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10})Z^{\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_5+\tau_8-1} - \varepsilon_{11}\varepsilon_{8.11}\varepsilon_1\varepsilon_{01}\varepsilon_7\varepsilon_{47}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_8+\tau_{11})Z^{\tau_0+\tau_1+\tau_4+\tau_7+\tau_8+\tau_{11}-1}
\end{aligned}$$

$$-\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_0+\tau_1+\tau_7+\tau_{10}+\tau_8+\tau_{11}-1}-\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_1+\tau_4+\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_8+\tau_{11}-1}$$
$$+\epsilon_{20}\epsilon_{02}\epsilon_8\epsilon_{58}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10})Z^{\tau_0+\tau_2+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_5+\tau_8-1}+\epsilon_{20}\epsilon_{02}\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_7+\tau_8+\tau_{10}+\tau_{11})$$
$$*Z^{\tau_0+\tau_2+\tau_1+\tau_4+\tau_7+\tau_{10}+\tau_8+\tau_{11}-1}+\epsilon_7\epsilon_{47}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{11})Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_{11}+\tau_8+\tau_4+\tau_7-1}$$
$$+\epsilon_{10}\epsilon_{7.10}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_2+\tau_5+\tau_0+\tau_1+\tau_{11}+\tau_8+\tau_7+\tau_{10}-1}$$
$$+\epsilon_4\epsilon_{14}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_{10}\epsilon_{7.10}(\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})Z^{\tau_1+\tau_4+\tau_2+\tau_5+\tau_{11}+\tau_7+\tau_8+\tau_{10}-1}$$

2) Roaming Acquisition time for the special case $\epsilon_{01}/\epsilon_{02}/\epsilon_{03}=\epsilon_{01}/\epsilon_{02}/0$

According to the definition given in equation (4.1) that the acquisition time from S_0 to S_{12} can be found by setting z =1 in dH(z)/dz, then we get the roaming acquisition time :

$$Tsum=\left.\frac{dH(z)}{dz}\right|_{z=1} = N_1/M_1+N_2/M_1^2 \qquad (4.10)$$

where :

$$N_1= F'(z)\Big|_{z=1}=\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_{10})-\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}\epsilon_5\epsilon_{25}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_{10})$$
$$-\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}\epsilon_8\epsilon_{58}(\tau_0+\tau_1+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10})-\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}\epsilon_{11}\epsilon_{8.11}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_8+\tau_{10}+\tau_{11})$$
$$+\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})+\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}(\tau_0+\tau_2+\tau_5+\tau_8+\tau_{11})$$
$$-\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}\epsilon_4\epsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_8+\tau_{11})-\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}\epsilon_7\epsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{11})$$
$$-\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_2+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})+\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})$$

$$N_2= -F(z)*\Delta'(z)\Big|_{z=1}= -(\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}-\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}\epsilon_5\epsilon_{25}-\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}\epsilon_8\epsilon_{58}-\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}\epsilon_{11}\epsilon_{8.11}$$
$$+\epsilon_{01}\epsilon_{14}\epsilon_{47}\epsilon_{7.10}\epsilon_{10.12}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}+\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}-\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}\epsilon_4\epsilon_{14}-\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}\epsilon_7\epsilon_{47}-\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}\epsilon_{10}\epsilon_{7.10}$$
$$+\epsilon_{02}\epsilon_{25}\epsilon_{58}\epsilon_{8.11}\epsilon_{11.12}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10})*[-\epsilon_{20}\epsilon_{02}(\tau_0+\tau_2)-\epsilon_5\epsilon_{25}(\tau_2+\tau_5)-\epsilon_8\epsilon_{58}(\tau_5+\tau_8)-\epsilon_{11}\epsilon_{8.11}(\tau_8+\tau_{11})-\epsilon_1\epsilon_{01}(\tau_0+\tau_1)-\epsilon_4\epsilon_{14}(\tau_1+\tau_4)$$
$$-\epsilon_7\epsilon_{47}(\tau_4+\tau_7)-\epsilon_{10}\epsilon_{7.10}(\tau_7+\tau_{10})+\epsilon_{20}\epsilon_{02}\epsilon_8\epsilon_{58}(\tau_0+\tau_2+\tau_5+\tau_8)+\epsilon_{20}\epsilon_{02}\epsilon_{11}\epsilon_{8.11}(\tau_0+\tau_2+\tau_8+\tau_{11})+\epsilon_{20}\epsilon_{02}\epsilon_4\epsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4)$$
$$+\epsilon_{20}\epsilon_{02}\epsilon_7\epsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_7)+\epsilon_{20}\epsilon_{02}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_2+\tau_7+\tau_{10})+\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}(\tau_2+\tau_5+\tau_8+\tau_{11})+\epsilon_5\epsilon_{25}\epsilon_1\epsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_5)$$
$$+\epsilon_5\epsilon_{25}\epsilon_4\epsilon_{14}(\tau_1+\tau_2+\tau_4+\tau_5)+\epsilon_5\epsilon_{25}\epsilon y\epsilon_{47}(\tau_2+\tau_4+\tau_5+\tau_7)+\epsilon_5\epsilon_{25}\epsilon_{10}\epsilon_{7.10}(\tau_2+\tau_5+\tau_7+\tau_{10})+\epsilon_8\epsilon_{58}\epsilon_1\epsilon_{01}(\tau_0+\tau_1+\tau_5+\tau_8)$$
$$+\epsilon_8\epsilon_{58}\epsilon_4\epsilon_{14}(\tau_1+\tau_4+\tau_5+\tau_8)+\epsilon_8\epsilon_{58}\epsilon_7\epsilon_{47}(\tau_4+\tau_5+\tau_7+\tau_8)+\epsilon_8\epsilon_{58}\epsilon_{10}\epsilon_{7.10}(\tau_5+\tau_7+\tau_8+\tau_{10})+\epsilon_{11}\epsilon_{811}\epsilon_1\epsilon_{01}(\tau_0+\tau_1+\tau_8+\tau_{11})$$
$$+\epsilon_{11}\epsilon_{811}\epsilon_4\epsilon_{14}(\tau_1+\tau_4+\tau_8+\tau_{11})+\epsilon_{11}\epsilon_{8.11}\epsilon_7\epsilon_{47}(\tau_4+\tau_7+\tau_8+\tau_{11})+\epsilon_{11}\epsilon_{8.11}\epsilon_{10}\epsilon_{7.10}(\tau_7+\tau_8+\tau_{10}+\tau_{11})+\epsilon_1\epsilon_{01}\epsilon_7\epsilon_{47}(\tau_0+\tau_1+\tau_4+\tau_7)$$
$$+\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_7+\tau_{10})+\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_1+\tau_4+\tau_7+\tau_{10})-\epsilon_8\epsilon_{58}\epsilon_{20}\epsilon_{02}\epsilon_4\epsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_8)-\epsilon_8\epsilon_{58}\epsilon_{20}\epsilon_{02}\epsilon_7\epsilon_{47}$$
$$*(\tau_0+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8)-\epsilon_8\epsilon_{58}\epsilon_{20}\epsilon_{02}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_2+\tau_5+\tau_7+\tau_8+\tau_{10})-\epsilon_{11}\epsilon_{8.11}\epsilon_{20}\epsilon_{02}\epsilon_4\epsilon_{14}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_8+\tau_{11})$$
$$-\epsilon_{11}\epsilon_{8.11}\epsilon_{20}\epsilon_{02}\epsilon_7\epsilon_{47}(\tau_0+\tau_2+\tau_4+\tau_7+\tau_8+\tau_{11})-\epsilon_{11}\epsilon_{8.11}\epsilon_{20}\epsilon_{02}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_2+\tau_7+\tau_8+\tau_{10}+\tau_{11})-\epsilon_{20}\epsilon_{02}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_7+\tau_{10})$$
$$-\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_5+\tau_8+\tau_{11})-\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}(\tau_1+\tau_2+\tau_4+\tau_5+\tau_8+\tau_{11})-\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_7\epsilon_{47}(\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{11})$$
$$-\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_{10}\epsilon_{7.10}(\tau_2+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})-\epsilon_5\epsilon_{25}\epsilon_1\epsilon_{01}\epsilon_7\epsilon_{47}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7)-\epsilon_5\epsilon_{25}\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_5+\tau_7+\tau_{10})$$
$$-\epsilon_5\epsilon_{25}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_{10})-\epsilon_8\epsilon_{58}\epsilon_1\epsilon_{01}\epsilon_7\epsilon_{47}(\tau_0+\tau_1+\tau_4+\tau_5+\tau_7+\tau_8)-\epsilon_8\epsilon_{58}\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_5+\tau_7+\tau_8+\tau_{10})$$
$$-\epsilon_8\epsilon_{58}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_1+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10})-\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}\epsilon_7\epsilon_{47}(\tau_0+\tau_1+\tau_4+\tau_7+\tau_8+\tau_{11})-\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_7+\tau_8+\tau_{10}+\tau_{11})$$
$$-\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_1+\tau_4+\tau_7+\tau_8+\tau_{10}+\tau_{11})+\epsilon_{20}\epsilon_{02}\epsilon_8\epsilon_{58}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10})$$
$$+\epsilon_{20}\epsilon_{02}\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_7+\tau_8+\tau_{10}+\tau_{11})+\epsilon_7\epsilon_{47}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{11})$$
$$+\epsilon_{10}\epsilon_{7.10}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}(\tau_0+\tau_1+\tau_2+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})+\epsilon_4\epsilon_{14}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_{10}\epsilon_{7.10}(\tau_1+\tau_2+\tau_4+\tau_5+\tau_7+\tau_8+\tau_{10}+\tau_{11})]$$

$$M_1=\Delta(z)\Big|_{z=1}$$
$$=1-\epsilon_{20}\epsilon_{02}-\epsilon_5\epsilon_{25}-\epsilon_8\epsilon_{58}-\epsilon_{11}\epsilon_{8.11}-\epsilon_1\epsilon_{01}-\epsilon_4\epsilon_{14}-\epsilon_7\epsilon_{47}\epsilon_{10}\epsilon_{7.10}+\epsilon_{20}\epsilon_{02}\epsilon_8\epsilon_{58}+\epsilon_{20}\epsilon_{02}\epsilon_{11}\epsilon_{8.11}+\epsilon_{20}\epsilon_{02}\epsilon_4\epsilon_{14}+\epsilon_{20}\epsilon_{02}\epsilon_7\epsilon_{47}+\epsilon_{20}\epsilon_{02}\epsilon_{10}\epsilon_{7.10}$$
$$+\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}+\epsilon_5\epsilon_{25}\epsilon_1\epsilon_{01}+\epsilon_5\epsilon_{25}\epsilon_4\epsilon_{14}+\epsilon_5\epsilon_{25}\epsilon_7\epsilon_{47}+\epsilon_5\epsilon_{25}\epsilon_{10}\epsilon_{7.10}+\epsilon_8\epsilon_{58}\epsilon_1\epsilon_{01}+\epsilon_8\epsilon_{58}\epsilon_4\epsilon_{14}+\epsilon_8\epsilon_{58}\epsilon_7\epsilon_{47}+\epsilon_8\epsilon_{58}\epsilon_{10}\epsilon_{7.10}+\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}$$
$$+\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}+\epsilon_{11}\epsilon_{8.11}\epsilon_7\epsilon_{47}+\epsilon_{11}\epsilon_{8.11}\epsilon_{10}\epsilon_{7.10}+\epsilon_1\epsilon_{01}\epsilon_7\epsilon_{47}+\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}+\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}-\epsilon_8\epsilon_{58}\epsilon_{20}\epsilon_{02}\epsilon_4\epsilon_{14}-\epsilon_8\epsilon_{58}\epsilon_{20}\epsilon_{02}\epsilon_7\epsilon_{47}$$
$$-\epsilon_8\epsilon_{58}\epsilon_{20}\epsilon_{02}\epsilon_{10}\epsilon_{7.10}-\epsilon_{11}\epsilon_{8.11}\epsilon_{20}\epsilon_{02}\epsilon_4\epsilon_{14}-\epsilon_{11}\epsilon_{8.11}\epsilon_{20}\epsilon_{02}\epsilon_7\epsilon_{47}-\epsilon_{11}\epsilon_{8.11}\epsilon_{20}\epsilon_{02}\epsilon_{10}\epsilon_{7.10}-\epsilon_{20}\epsilon_{02}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}-\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}$$
$$-\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}-\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_7\epsilon_{47}-\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_{10}\epsilon_{7.10}-\epsilon_5\epsilon_{25}\epsilon_1\epsilon_{01}\epsilon_7\epsilon_{47}-\epsilon_5\epsilon_{25}\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}-\epsilon_5\epsilon_{25}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}-\epsilon_8\epsilon_{58}\epsilon_1\epsilon_{01}\epsilon_7\epsilon_{47}$$
$$-\epsilon_8\epsilon_{58}\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}-\epsilon_8\epsilon_{58}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}-\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}\epsilon_7\epsilon_{47}-\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}\epsilon_{10}\epsilon_{7.10}-\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}+\epsilon_{20}\epsilon_{02}\epsilon_8\epsilon_{58}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}$$
$$+\epsilon_{20}\epsilon_{02}\epsilon_{11}\epsilon_{8.11}\epsilon_4\epsilon_{14}\epsilon_{10}\epsilon_{7.10}+\epsilon_7\epsilon_{47}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}+\epsilon_{10}\epsilon_{7.10}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_1\epsilon_{01}+\epsilon_4\epsilon_{14}\epsilon_5\epsilon_{25}\epsilon_{11}\epsilon_{8.11}\epsilon_{10}\epsilon_{7.10}$$

Chapter 5 Test Results

5.1 Possible Cases

As we have discussed in the previous section, the mobile station operates on the universal base station and its channels when it is in the state S_0, S_1, S_2, S_4, S_5, S_7, S_8, and operates on the classical base station and its channels when it is in the state S_3, S_6, S_9, S_{12} in path 3, state S_{10}, S_{11}, S_{12} in path 1 & path 2. Also, in normal case, the data rate or bit rate of the universal pilot channel and data channel may be different from that of the classical channel, and the data rate or bit rate in different mobile systems are also different. Therefore, one should consider those factors for precise time estimation.

During the mobile station connection establishment signaling period, we assume that the signaling bit rates in the classical base station channels of different mobile systems are the same, take 50Kb/s for example, our results are general though could apply to any signaling rate. The propagation delay time in the link is not taken into account in this project, and the estimation method will be no different from the current mobile communication system.

We condition the various acquisition time on the starting point and the final point, i.e., the acquisition time for updating a new system is related to the starting and target system. For instance, if the user wants to use the CDMA IS-95 network now, then the acquisition time to authenticate, associate and download this system software code are different from other cases where mobile station is currently in GSM or wireless LAN (because of the different number of bits required).

Next, we will present the six possible cases and build up the tables listing the size of code for listening, authentication, association, downloaded software, connection establishment signaling and the minimum time in each state (they are approximations). The values of code size, bit rate and time satisfy the following equation:

The minimum time Ti = Size of Code in Number bits/ Channel Bit Rate

Then, the total time τ_i spent in each state Si can be easily found by τ_i = Ti/Pi –equation (3.2), which will be used for evaluation input values in the following.

We assume that:

- The signaling bit rates of different cellular systems are the same as R_{bcell} =50Kb/s and the signaling bit rates of wireless LAN is R_{bWLAN} =50Kb/s during the mobile station connection establishing signaling period, without losing any generality of our results, this is one example.
- The total time spent in start state τ_0 = 50ms, and 1 packet = 1Kbits.

Case 1: When the mobile station starts from GSM and moves to other mobile systems, the required size of code, the number of packets, and the minimum time spent in each state will be different. Their relative values are shown in Table 5.1(a) and Table 5.1(b), since one packet contains 1Kbits, then one packet transmission time T_p = 10ms if the transmission bit rate R_b =100 Kb/s.

Table 5.1(a) **The required number of kilo-bits and packets in each state for the transition from GSM to the other wireless systems.**

To / Size of code in each state S_i (Kb)/(Packets)	Cellular System					Cordless	Wireless LAN	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz	2.4GHz, 5GHz	
$S_1/S_2/S_3$	40	100	100	100	100	100	100	*20*
$S_4/S_5/S_6$	50	200	200	150	150	120	200	*50*
S_7/S_8	200	1,500	2,000	500	500	1,000	1,000	---
$S_9/S_{10}/S_{11}$	*150*	*200*	*200*	*150*	*150*	*100*	*300*	*150*
Total Bit/ Packets	**440K /440**	**2,000K /2,000**	**2,500K /2,500**	**900K /900**	**900K /900**	**1,320K /1,320**	**1,600K /1,600**	**220K /220**

We assume that the signaling bit rates of different cellular mobile systems are same as R_{bcell} =50Kb/s and the signaling bit rates of wireless LAN is R_{bWLAN} =50Kb/s during the mobile station connection establishment signaling period, again without losing generality and applicability of our techniques. If the bit rate in universal channels is R_b=100Kb/s, we can derive the following Table 5.1(b) from Table 5.1(a).

Table 5.1(b) The minimum time spent in each state for the transition from GSM to one of the other wireless systems. (R_b=100Kb/s)

To / Minimum time in each state S_i (ms)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$T_1/T_2/T_3$	400	1,000	1,000	1,000	1,000	1,000	1,000	*400*
$T_4/T_5/T_6$	500	2,000	2,000	1,500	1,500	1,200	2,000	*1,000*
T_7/T_8	2,000	15,000	20,000	5,000	5,000	10,000	10,000	---
$T_9/T_{10}/T_{11}$	*3,000*	*4,000*	*4,000*	*3,000*	*3,000*	*2,000*	*6,000*	*3,000*

If the universal channel bit rate R_b=50Kb/s or R_b=200Kb/s, we can derive the following Table 5.1(c) and Table 5.1(d) from Table 5.1(a).

Table 5.1(c) The minimum time spent in each state for the transition from GSM to one of the following system. (R_b=50Kb/s)

To / Minimum time in each state S_i (ms)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$T_1/T_2/T_3$	800	2,000	2,000	2,000	2,000	2,000	2,000	*400*
$T_4/T_5/T_6$	1000	4,000	4,000	3,000	3,000	2,400	4,000	*1,000*
T_7/T_8	4,000	30,000	40,000	10,000	10,000	20,000	20,000	---
$T_9/T_{10}/T_{11}$	*3,000*	*4,000*	*4,000*	*3,000*	*3,000*	*2,000*	*6,000*	*3,000*

Table 5.1(d) The minimum time spent in each state for the transition from GSM to one of the following system. (R_b=200Kb/s)

To / Minimum time in each state S_i (ms)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$T_1/T_2/T_3$	200	500	500	500	500	500	500	*400*
$T_4/T_5/T_6$	250	1,000	1,000	750	750	600	1000	*1,000*
T_7/T_8	1,000	7,500	10,000	2,500	2,500	5,000	5,000	---
$T_9/T_{10}/T_{11}$	*3,000*	*4,000*	*4,000*	*3,000*	*3,000*	*2,000*	*6,000*	*3,000*

Case 2: When the mobile station starts from TDMA system IS-54 or IS-136 and moves to the other wireless systems, then the required size of code, the number of packets, and the minimum time spent in each state will be different. Their relative values are shown in Table 5.2 (a) and Table 5.2(b), since one packet contains 1Kbits, one packet transmission time T_p = 10ms if the transmission bit rate R_b =100 Kb/s.

Table 5.2(a) The required number of kilo-bits and packets in each state for the transition from TDMA IS-54 to the other wireless systems.

To / Size of code in each state S_i (Kb)/(Packets)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$S_1/S_2/S_3$	100	40	100	100	100	100	100	*20*
$S_4/S_5/S_6$	200	50	200	150	150	120	200	*50*
S_7/S_8	1,500	200	2,000	500	500	1,000	1,000	---
$S_9/S_{10}/S_{11}$	*150*	*200*	*200*	*150*	*150*	*100*	*300*	*150*
Total Bit/ Packets	**1,950K /1,950**	**490K /490**	**2,500K /2,500**	**900K /900**	**900K /900**	**1,320K /1,320**	**1,600K /1,600**	**220K /220**

We assume that the signaling bit rates of different cellular systems are same as R_{bcell} =50Kb/s and the signaling bit rates of wireless LAN is R_{bWLAN} =50Kb/s during the mobile station connection establishment signaling period. If the bit rate in universal channels is R_b=100Kb/s, we can derive the following Table 5.2(b) from Table 5.2(a).

Table 5.2(b) The minimum time spent in each state for the transition from TDMA IS-54 to the other wireless systems. (R_b=100Kb/s)

To / Minimum time in each state S_i (ms)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$T_1/T_2/T_3$	1,000	400	1,000	1,000	1,000	1,000	1,000	*400*
$T_4/T_5/T_6$	2,000	500	2,000	1,500	1,500	1,200	2,000	*1,000*
T_7/T_8	15,000	2,000	20,000	5,000	5,000	10,000	10,000	---
$T_9/T_{10}/T_{11}$	*3,000*	*4,000*	*4,000*	*3,000*	*3,000*	*2,000*	*6,000*	*3,000*

Case 3: When the mobile station starts from CDMA system IS-95 or 3G and moves to the other wireless systems, then the required size of code, the number of packets, and the minimum time spent in each state will be different. Their relative values are shown in Table 5.3(a) and Table 5.3 (b), since one packet contains 1Kbits, one packet transmission time T_p = 10ms if the transmission bit rate R_b =100 Kb/s.

Table 5.3 (a) The required number of kilo-bits and packets in each state for the transition from CDMA system to the other wireless systems.

To / Size of code in each state S_i (Kb)/(Packets)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$S_1/S_2/S_3$	150	150	50	80	80	120	100	*50*
$S_4/S_5/S_6$	200	200	50	100	100	120	200	*50*
S_7/S_8	2,000	2,000	200	800	800	1,000	800	---
$S_9/S_{10}/S_{11}$	*150*	*200*	*200*	*150*	*150*	*100*	*300*	*200*
Total Bit/ Packets	2,500K /2,500	2,550K /2,550	500K /500	1,130K /1,130	1,130K /1,130	1,320K /1,320	1,400K /1,400	300K /300

We assume that the signaling bit rates of different cellular systems are same as R_{bcell} =50Kb/s and the signaling bit rates of wireless LAN is R_{bWLAN} =50Kb/s during the mobile station connection establishment signaling period. If the bit rate in universal channels is R_b=100Kb/s, we can derive Table 5.3(b) from Table 5.3(a).

Table 5.3(b) The minimum time spent in each state for the transition from CDMA system to the other wireless systems. (R_b=100Kb/s)

To / Minimum time in each state S_i (ms)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$T_1/T_2/T_3$	1,500	1,500	500	800	800	1,200	1,000	*1,000*
$T_4/T_5/T_6$	2,000	2,000	500	1,000	1,000	1,200	2,000	*1,000*
T_7/T_8	20,000	20,000	2,000	8,000	8,000	10,000	8,000	---
$T_9/T_{10}/T_{11}$	*3,000*	*4,000*	*4,000*	*3,000*	*3,000*	*2,000*	*6,000*	*4,000*

Case 4: When the mobile station starts from DECT cordless system and moves to other wireless systems, the required size of code, the number of packets, and the minimum time spent in each state will be different. Their relative values are shown in Table 5.4(a) and Table 5.4(b), since one packet contains 1Kbits, one packet transmission time T_p = 10ms if the transmission bit rate R_b =100 Kb/s.

Table 5.4(a) The required number of kilo-bits and packets in each state for the transition from DECT to the other wireless systems.

To / Size of code in each state S_i (Kb)/(Packets)	Cellular System					Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz		
$S_1/S_2/S_3$	100	100	100	100	100	150	*20*
$S_4/S_5/S_6$	200	200	200	150	150	200	*30*
S_7/S_8	1,500	1,500	2,000	500	500	1,000	---
$S_9/S_{10}/S_{11}$	*150*	*200*	*200*	*150*	*150*	*300*	*150*
Total Bit/ Packets	**1,950K /1,950**	**2,000K /2,000**	**2,500K 2,500**	**900K /900**	**900K /900**	**1,650K /1,650**	**200K /200**

We assume that the signaling bit rates of different cellular systems are same as R_{bcell} =50Kb/s and the signaling bit rates of wireless LAN is R_{bWLAN} =50Kb/s during the mobile station connection establishment signaling period. If the bit rate in universal channels is R_b=100Kb/s, we can derive the following Table 5.4(a) from Table 5.4(b).

Table 5.4(b) The minimum time spent in each state for the transition from DECT to the other wireless systems. (R_b=100Kb/s)

To / Minimum time in each state S_i (ms)	Cellular System					Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz		
$T_1/T_2/T_3$	1,000	1,000	1,000	1,000	1,000	1,500	*400*
$T_4/T_5/T_6$	2,000	2,000	2,000	1,500	1,500	2,000	*600*
T_7/T_8	15,000	15,000	20,000	5,000	5,000	10,000	---
$T_9/T_{10}/T_{11}$	*3,000*	*4,000*	*4,000*	*3,000*	*3,000*	*6,000*	*3,000*

Case 5: When the mobile station starts from AMPS or CDPD and moves to other wireless systems, the required size of code, the number of packets, and the minimum time spent in each state will be different. Their relative values are shown in Table 5.5(a) and Table 5.5(b), since one packet contains 1Kbits, one packet transmission time T_p = 10ms if the transmission bit rate R_b =100 Kb/s.

Table 5.5(a) The required kilo-bits and packets in each state for the transition from AMPS/CDPD to the other wireless systems.

To / Size of code in each state S_i (Kb)/(Packets)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$S_1/S_2/S_3$	100	100	100	20	20	100	100	*50*
$S_4/S_5/S_6$	200	150	200	500	500	120	200	*50*
S_7/S_8	1,500	1,500	2,000	300	300	1,000	1,000	---
$S_9/S_{10}/S_{11}$	*150*	*200*	*200*	*150*	*150*	*100*	*300*	*200*
Total Bit/ Packets	1,950K /1,950	1,950K /1,950	2,500K /2,500	970K /970	970K /970	1,320K /1,320	1,600K /1,600	300K /300

We assume that the signaling bit rates of different cellular systems are same as R_{bcell} =50Kb/s and the signaling bit rates of wireless LAN is R_{bWLAN} =50Kb/s during the mobile station connection establishment signaling period. If the bit rate in universal channels is R_b=100Kb/s, we can derive the following Table 5.5(b) from Table 5.5(a).

Table 5.5(b) The minimum time spent in each state for the transition from AMPS/CDPD to the other wireless systems. (R_b=100Kb/s)

To / Minimum time in each state S_i (ms)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$T_1/T_2/T_3$	1,000	1,000	1,000	200	200	1,000	1,000	*1,000*
$T_4/T_5/T_6$	2,000	1,500	2,000	5,000	5,000	1,200	2,000	*1,000*
T_7/T_8	15,000	15,000	20,000	3,000	3,000	10,000	10,000	---
$T_9/T_{10}/T_{11}$	*3,000*	*4,000*	*4,000*	*3,000*	*3,000*	*2,000*	*6,000*	*4,000*

Case 6: When the mobile station starts from wireless local area network (WLAN) and moves to other wireless systems, the required size of code, the number of packets, and the minimum time spent in each state will be different. Their relative values are shown in Table 5.6(a) and Table 5.6(b), since one packet contains 1Kbits, one packet transmission time T_p = 10ms if the transmission bit rate R_b =100 Kb/s.

Table 5.6(a) The required number of kilo-bits and packets in each state for the transition from WLAN to the other wireless systems.

To / Size of code in each state S_i (Kb)/(Packets)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$S_1/S_2/S_3$	100	100	100	100	100	100	100	*50*
$S_4/S_5/S_6$	200	200	200	50	50	120	200	*50*
S_7/S_8	2,500	2,500	2,000	800	800	1,000	500	---
$S_9/S_{10}/S_{11}$	*150*	*200*	*200*	*150*	*150*	*100*	*300*	*200*
Total Bit/ Packets	2,950K /2,950	3,000K /3,000	2,500K /2,500	1,100K /1,100	1,100K /1,100	1,320K /1,320	1,100K /1,100	300K /300

We assume that the signaling bit rates of different cellular systems are same as R_{bcell} =50Kb/s and the signaling bit rates of wireless LAN is R_{bWLAN} =50Kb/s during the mobile station connection establishment signaling period. If the bit rate in universal channels is R_b=100Kb/s, we can derive the following Table 5.6(b) from Table 5.6(a).

Table 5.6(b) The minimum time spent in each state for the transition from WLAN to the other wireless systems. (R_b=100Kb/s)

To / Minimum time in each state S_i (ms)	Cellular System					Cordless	Wireless LAN 2.4GHz, 5GHz	Same System
	GSM 900,1800MHz	TDMA IS-54,IS-136	CDMA IS-95, 3G	AMPS 800 MHz	CDPD 800MHz	DECT 1800 MHz		
$T_1/T_2/T_3$	1,000	1,000	1,000	1,000	1,000	1,000	1,000	*1,000*
$T_4/T_5/T_6$	2,000	2,000	2,000	500	500	1,200	2,000	*1,000*
T_7/T_8	25,000	25,000	20,000	8,000	8,000	10,000	5,000	---
$T_9/T_{10}/T_{11}$	*3,000*	*4,000*	*4,000*	*3,000*	*3,000*	*2,000*	*6,000*	*4,000*

Besides the above assumptions, we further assume that:

1) The resource blocking probabilities of the universal base station and the classical base station in each state are the same, let $Ps_u = Ps_c = Ps$ so called system resource blocking probability.

2) The mobile station (MS) resource blocking probability in each state is the same, denoted as P_m.

3) The packet successful transmission probability in each state is the same, denoted as P_i.

Then, we can find the relationship between the roaming connection establishment acquisition time **Tsum** (called roaming acquisition time for convenience) and *packet successful transmission probability over radio channel **Pi** (Section 5.2), system resource blocking probability **Ps** (Section 5.3), mobile station resource blocking probability **Pm** (Section 5.4), and signaling bit rate over the universal base station channel* $\boldsymbol{R_b}$ *(Section 5.5)* for different cases and design scenarios. The roaming acquisition time Tsum in design scenario number 1, 6, 19, 20, 26 can be found by equation given by (4.6), (4.7), (4.8), (4.9), and (4.10) respectively.

In the following sections, we will compute the roaming time performance for the designed scenario number 1 in case 1, 2, 3, 4, 5, 6 listed above (Section 5.6). For other designed scenarios, we take case 1 for evaluation only, because the mobile station operates similarly in case 1, 2, 3, 4, 5, 6.

It is also noted that the relationship between the average roaming acquisition time and the initial path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ is evaluated under the worst case assumption that:

- The cellular system download path 1 has the largest software (SW) code size system for downloading. For example, CDMA system SW code in case 1, 2, 4, 5, TDMA IS-54 system SW code size in case 3, 6.
- The wireless LAN system download path 2 has the largest software (SW) code size system for downloading.

5.2 Roaming Acquisition Time Versus Packet Successful Transmission Probability

Taking the minimum time value Ti in Table 5.1 (b) for evaluation, the total time τ_i spent in each state can be found by $\tau_i = T_i/P_i$ –equation (3.2).

5.2.1 Scenario Number 1:

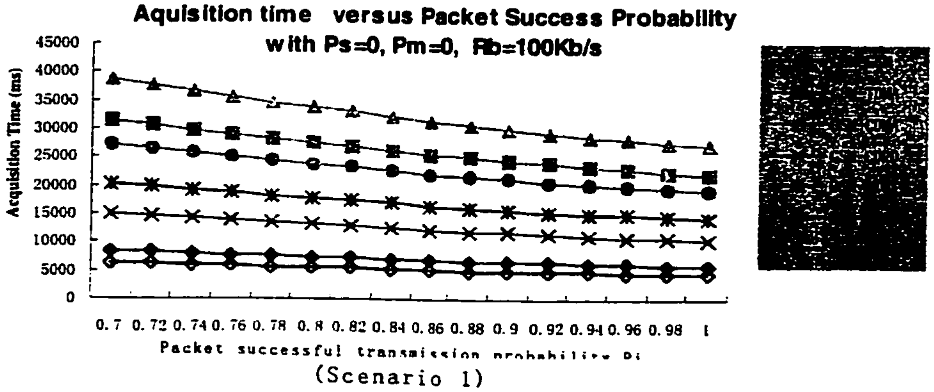


Figure 5.1(a) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 1, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0, and MS resource blocking probability Pm=0.

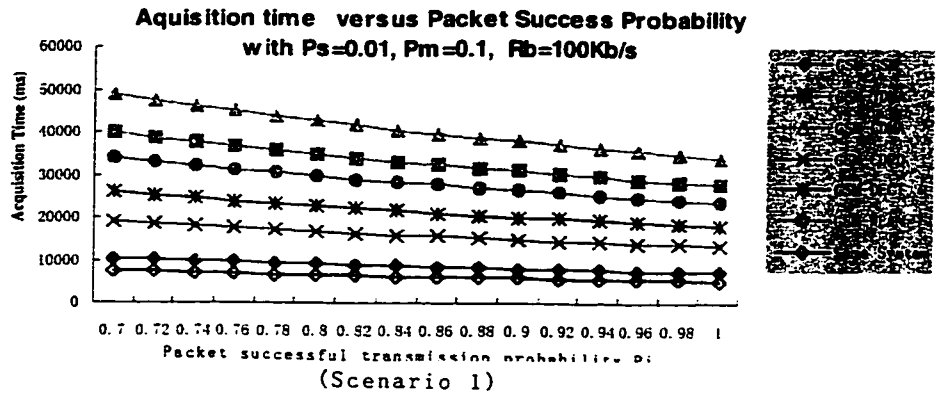


Figure 5.1(b) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 1, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

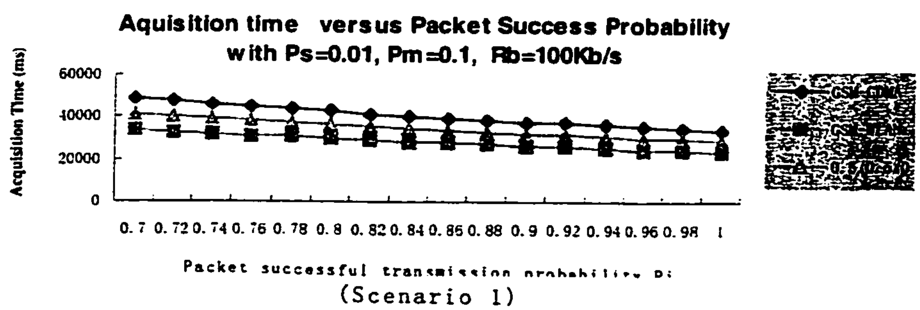


Figure 5.1(c) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 1, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.2.2 Scenario Number 6:

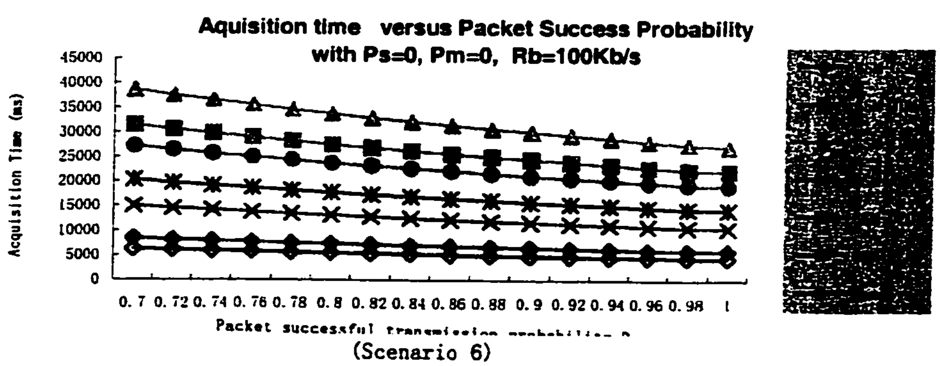


Figure 5.2(a) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 6, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0, and MS resource blocking probability Pm=0.

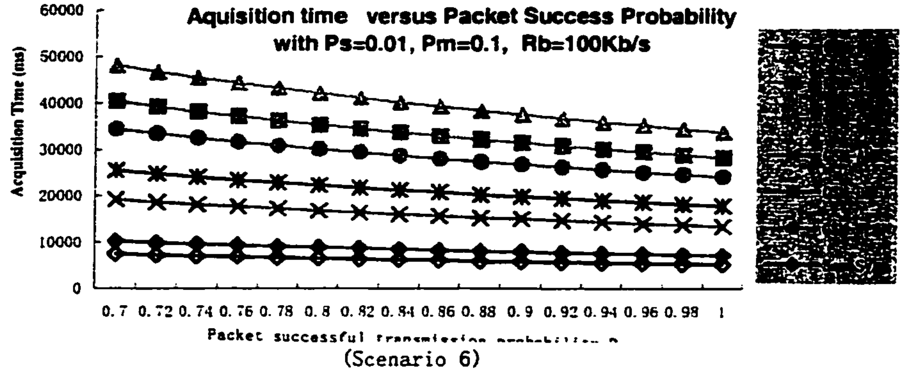


Figure 5.2(b) Acquisition Time versus Packet successful transmission probability P_i for designed scenario number 6, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate R_b=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

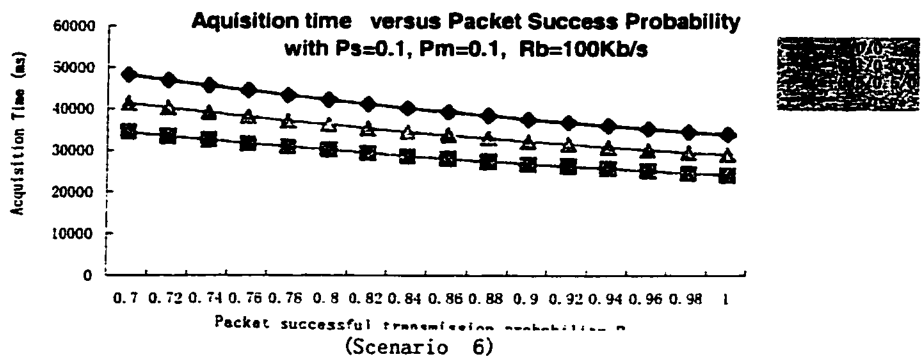


Figure 5.2(c) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 6, with initial path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.2.3 Scenario Number 19:

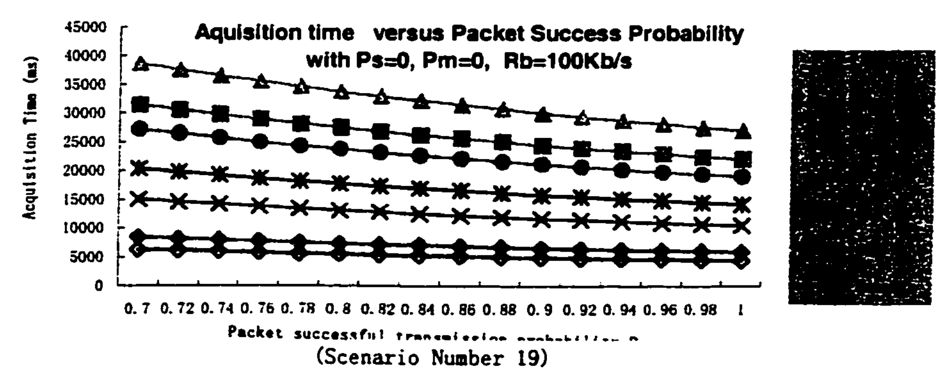
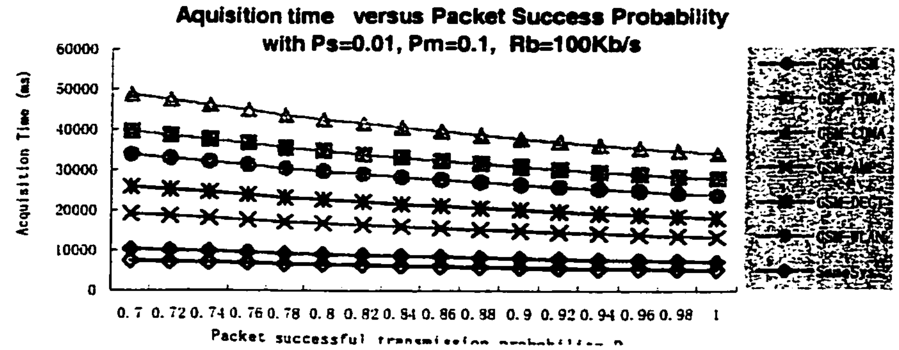
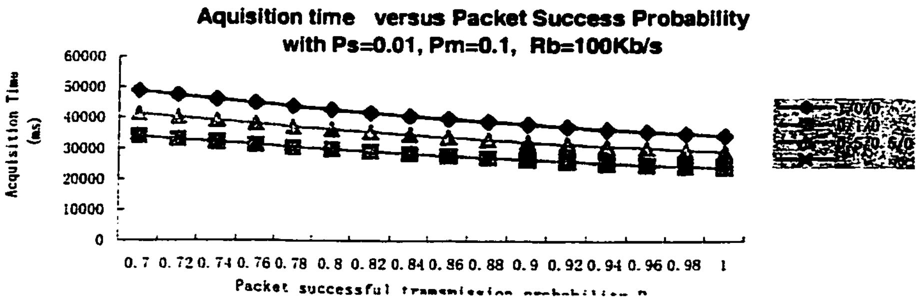


Figure 5.3(a) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 19, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0, and MS resource blocking probability Pm=0.



(Scenario Number 19)

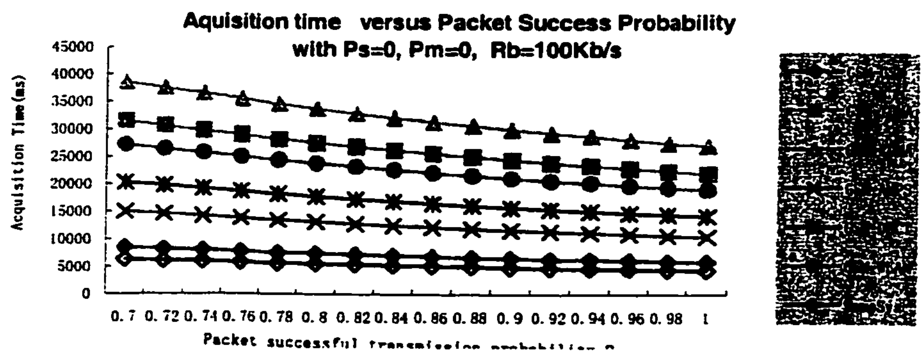
Figure 5.3(b) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 19, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.



(Scenario 19)

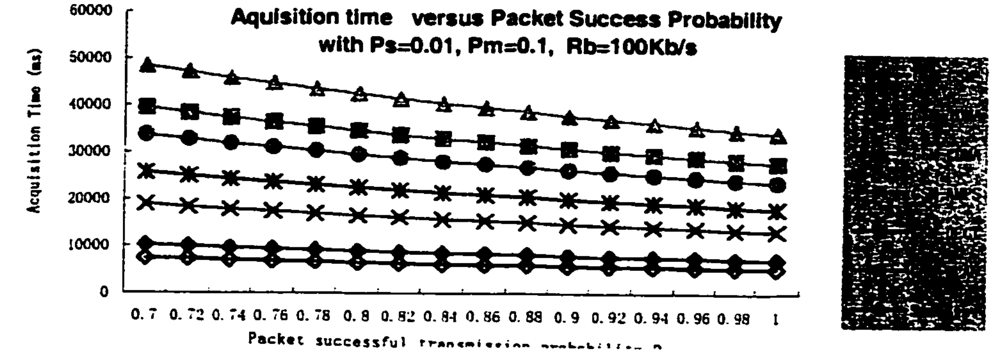
Figure 5.3(c) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 19, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.2.4 Scenario Number 20:



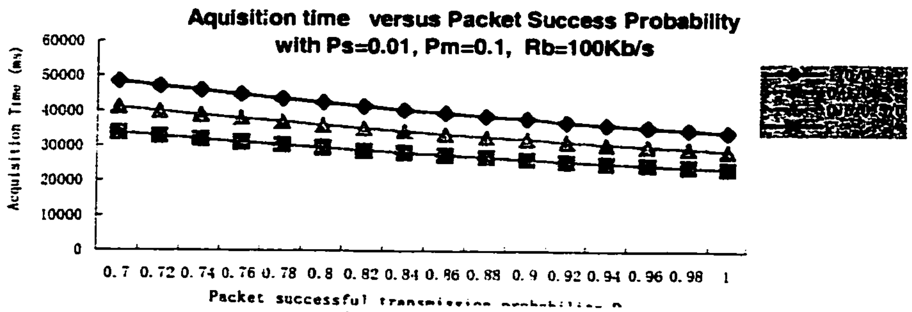
(Scenario Number 20)

Figure 5.4(a) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 20, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0, and MS resource blocking probability Pm=0.



(Scenario 20)

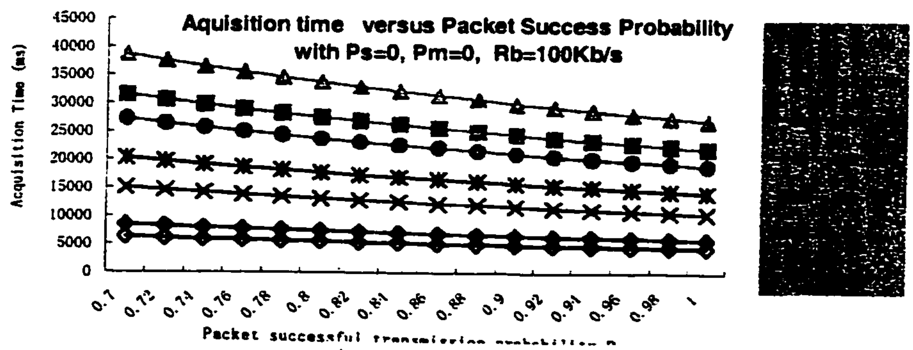
Figure 5.4(b) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 20, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.



(Scenario 20)

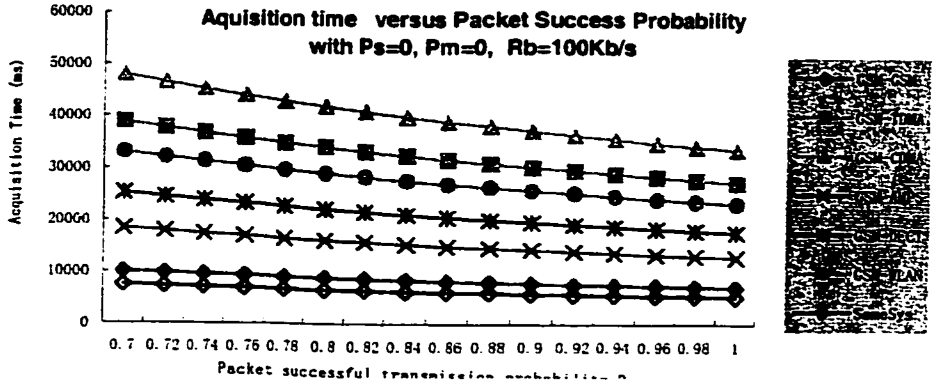
Figure 5.4(c) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 20, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.2.5 Scenario Number 26:



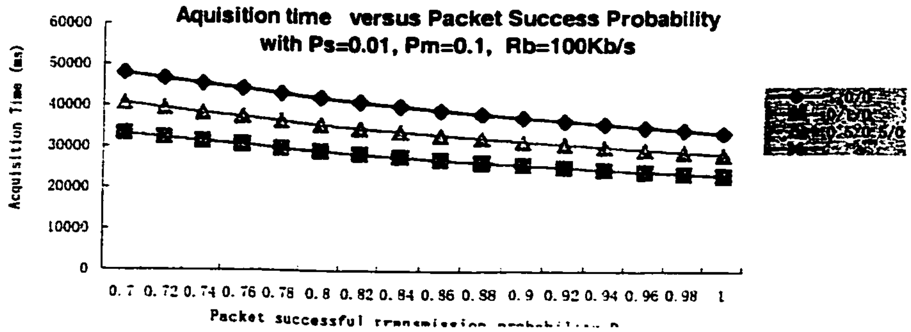
(Scenario 26)

Figure 5.5(a) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 26, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0, and MS resource blocking probability Pm=0.



(Scenario 26)

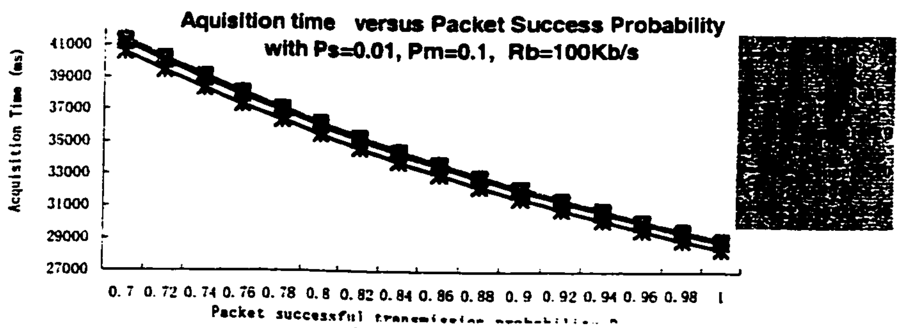
Figure 5.5(b) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 26, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.



(Scenario 26)

Figure 5.5(c) Acquisition Time versus Packet successful transmission probability Pi for designed scenario number 26, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.2.6 Comparison:



(0.5/0.5/0)

Figure 5.6 Comparison of Acquisition Time versus Packet successful transmission probability Pi in different designed scenario number 1, 6, 19, 20, 26, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =0.5/0.5/0, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.2.7 Performance Analysis:

By observing Figure 5.1 (a), (b), (c), Figure 5.2 (a), (b), (c), Figure 5.3 (a), (b), (c), Figure 5.4 (a), (b), (c), Figure 5.5 (a), (b), (c), we can see that:

- The roaming acquisition time decreases as the packet transmission successful probability increases.
- The roaming acquisition time for connection establishment in a new system is different from the target system when the MS starts from GSM system. For the MS reaches to a target system, the larger software code size required, the longer processing time under the same conditions. It is shown that the MS needs the longest roaming acquisition time while it roams from a GSM system to a CDMA system, and the MS needs the shortest roaming acquisition time while it handoffs in the same GSM system.
- The average roaming acquisition time for connection establishment in a new system is also different from the initial path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ when the MS starts from GSM system. The higher probability spent in a large code size system download path, the longer acquisition time is required.
- The packet transmission successful probability contributes slight effect on the roaming acquisition time comparing to the target system effect.

As seen from Figure 5.6, the average roaming acquisition time has slight difference in different designed scenarios, and scenario 26 has the shortest acquisition time among them.

It is predictable that these results can be applied to the general scenario, since the tested scenarios are chosen randomly.

5.3 Roaming Acquisition Time Versus System Resource Blocking Probability

5.3.1 Scenario Number 1:

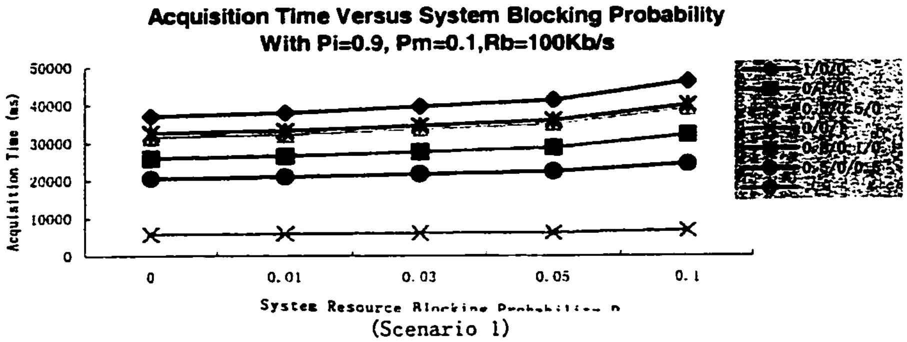


Figure 5.7(a) Acquisition Time versus System Resource Blocking Probability Ps for designed scenario number 1, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0, 0/0/1, 0.8/0.1/0.1, and 0.5/0/0.5 respectively, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

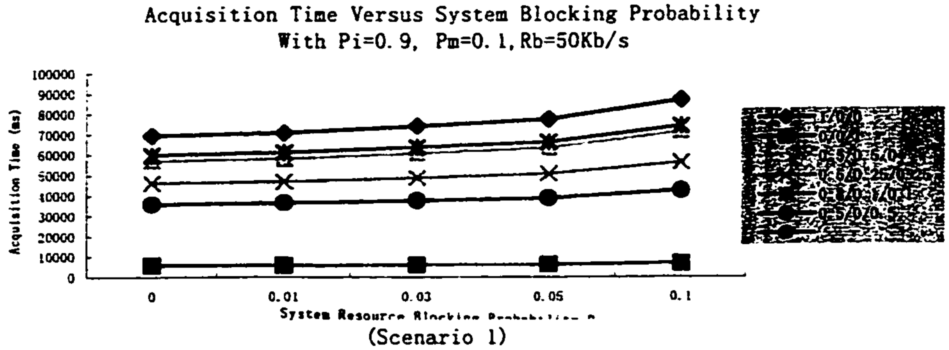


Figure 5.7(b) Acquisition Time versus System Resource Blocking Probability Ps for designed scenario number 1, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0, 0/0/1, 0.8/0.1/0.1, and 0.5/0/0.5 respectively, universal channel bit rate Rb=50Kb/s, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

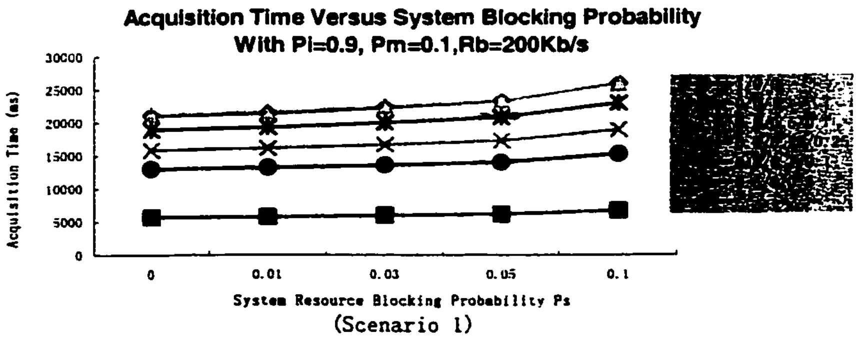


Figure 5.7(c) Acquisition Time versus System Resource Blocking Probability Ps for designed scenario number 1, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0, 0/0/1, 0.8/0.1/0.1, and 0.5/0/0.5 respectively, universal channel bit rate Rb=200Kb/s, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.3.2 Scenario Number 6:

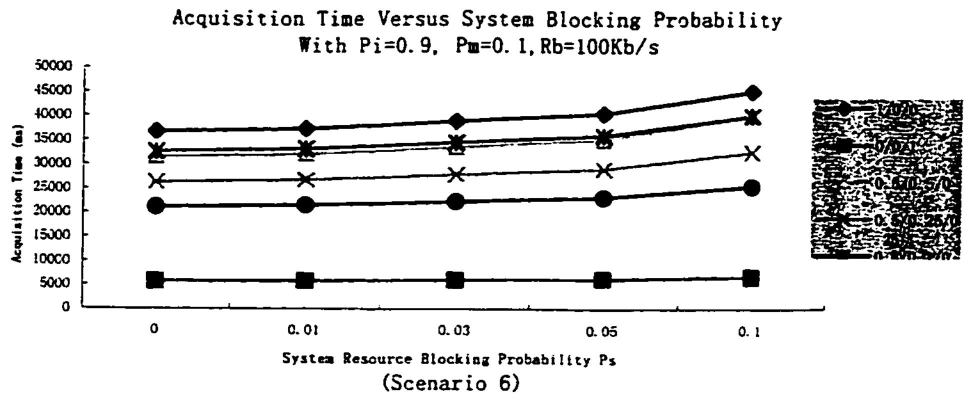


Figure 5.8 Acquisition Time versus System Resource Blocking Probability Ps for designed scenario number 6, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0, 0/0/1, 0.8/0.1/0.1, and 0.5/0/0.5 respectively, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.3.3 Scenario Number 19:

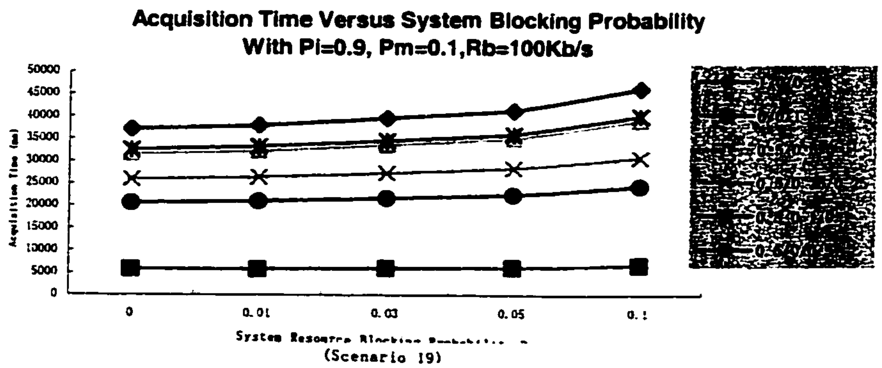


Figure 5.9 Acquisition Time versus System Resource Blocking Probability Ps for designed scenario number 19, with path transition probability dstribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0, 0/0/1, 0.8/0.1/0.1, and 0.5/0/0.5 respectively, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.3.4 Scenario Number 20:

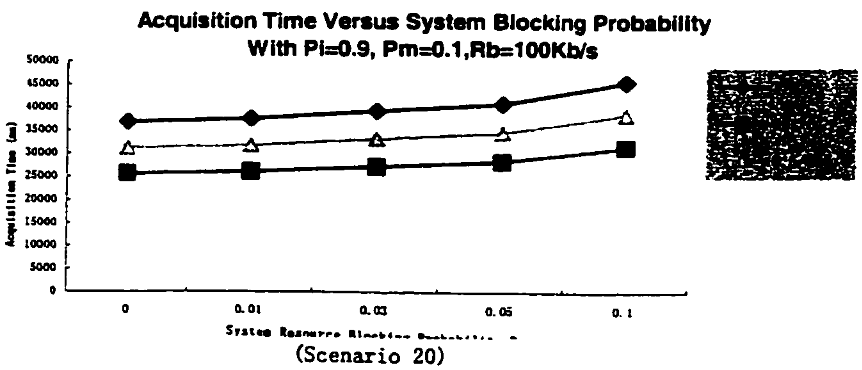
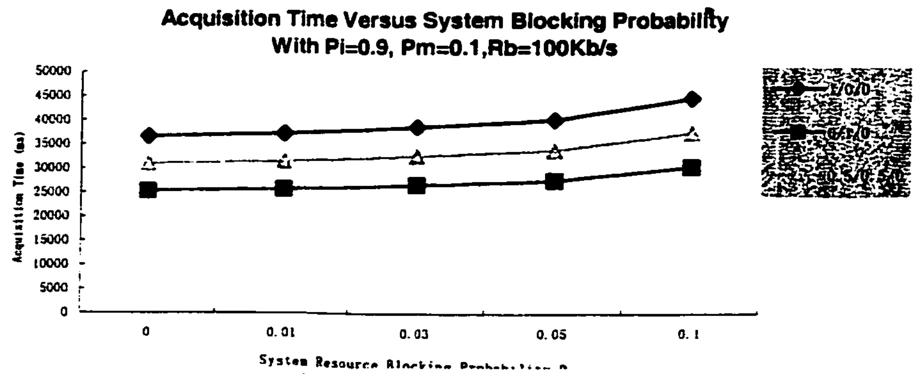


Figure 5.10 Acquisition Time versus System Resource Blocking Probability Ps for designed scenario number 20, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate R_b=100Kb/s, packet successful transmission probability P_i=0.9, and MS resource blocking probability P_m=0.1.

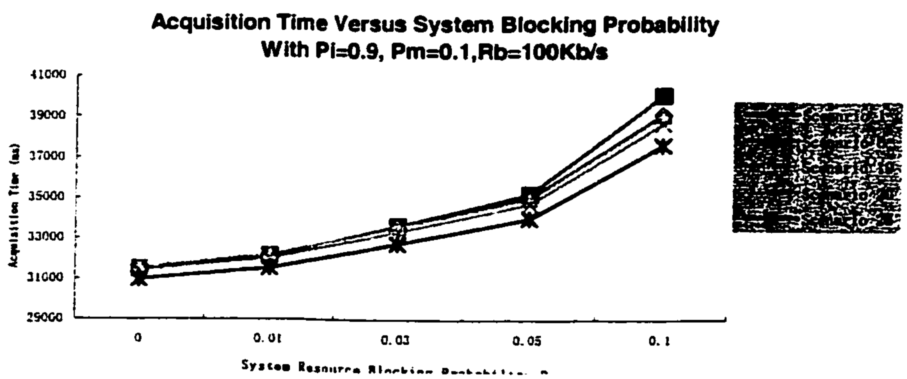
5.3.5 Scenario Number 26:



(Scenario Number 26)

Figure 5.11 Acquisition Time versus System Resource Blocking Probability Ps for designed scenario number 26, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate R_b=100Kb/s, packet successful transmission probability P_i=0.9, and MS resource blocking probability Pm=0.1.

5.3.6 Comparison



(0. 5/0. 5/0)

Figure 5.12 Comparison of the Acquisition Time versus System Resource Blocking Probability Ps in different designed scenarios number 1, 6, 19, 20, 26, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =0.5/0.5/0, universal channel bit rate R_b=100Kb/s, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.3.7 Performance Analysis:

By observing Figure 5.7 (a), (b), (c), Figure 5.8, Figure 5.9, Figure 5.10, Figure 5.11, we can see that:

- The roaming acquisition time increases as the system resource blocking probability increases.
- The average roaming acquisition time for connection establishment in a new system is also different from the path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ when the MS starts from GSM system. The higher probability spent in a large code size system download path, the longer acquisition time is required.

As seen from Figure 5.12, the average roaming acquisition time has slight difference in different designed scenarios, and scenario 26 has the shortest acquisition time among them. It is predictable that these results can be applied to the general scenario.

5.4 Roaming Acquisition Time Versus Mobile Station Resource Blocking Probability

5.4.1 Scenario Number 1:

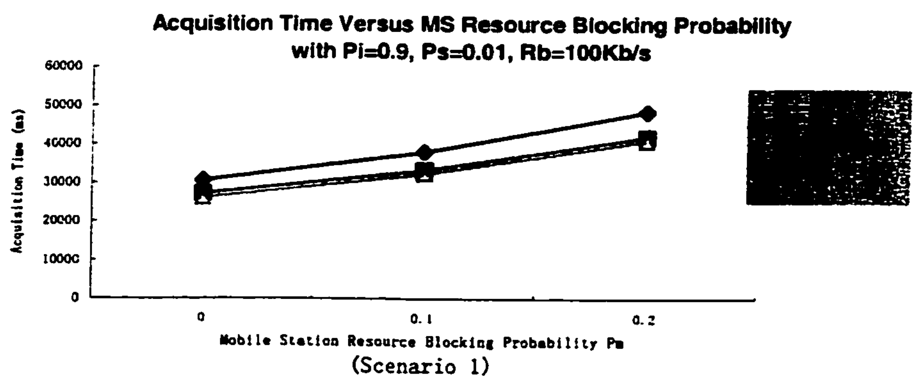


Figure 5.13 Acquisition Time versus MS Resource Blocking Probability Pm for designed scenario number 1, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0.8/0.1/0.1, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and system resource blocking probability Ps=0.01.

5.4.2 Scenario Number 6:

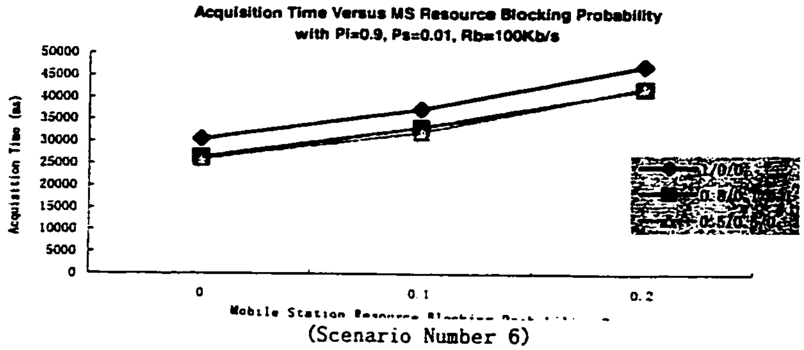


Figure 5.14 Acquisition Time versus MS Resource Blocking Probability Pm for designed scenario number 6, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0.8/0.1/0.1, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and system resource blocking probability Ps=0.01.

5.4.3 Scenario Number 19:

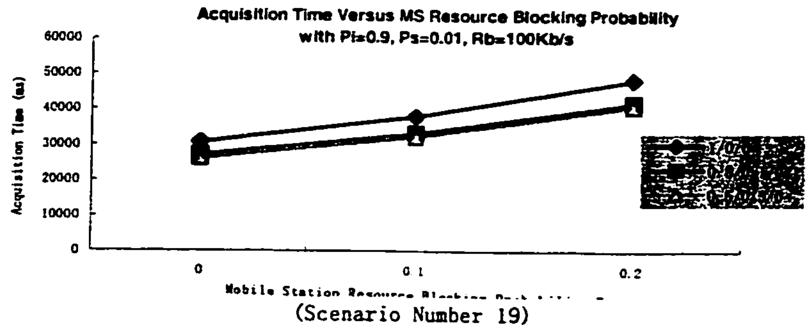


Figure 5.15 Acquisition Time versus MS Resource Blocking Probability Pm for designed scenario number 19, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0.8/0.1/0.1, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and system resource blocking probability Ps=0.01.

5.4.4 Scenario Number 20:

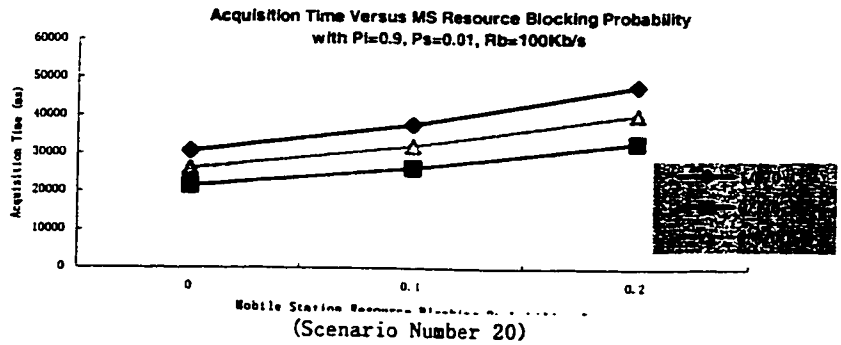


Figure 5.16 Acquisition Time versus MS Resource Blocking Probability Pm for designed scenario number 20, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and system resource blocking probability Ps=0.01.

5.4.5 Scenario Number 26:

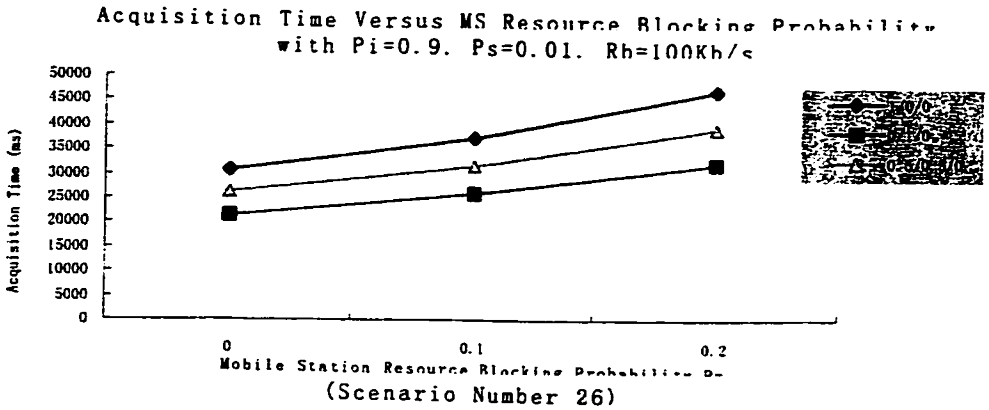


Figure 5.17 Acquisition Time versus MS Resource Blocking Probability Pm for designed scenario number 26, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, 0.5/0.5/0 respectively, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and system resource blocking probability Ps=0.01.

5.4.6 Comparison

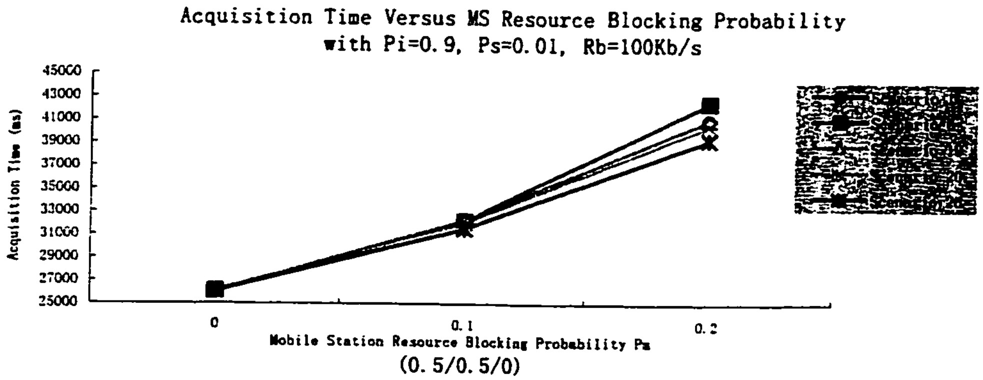


Figure 5.18 Comparison of the Acquisition Time versus MS Resource Blocking Probability Pm in different designed scenarios number 1, 6, 19, 20, 26, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =0.5/0.5/0, universal channel bit rate Rb=100Kb/s, packet successful transmission probability Pi=0.9, and system resource blocking probability Ps=0.01.

5.4.7 Performance Analysis:

By observing Figure 5.13, Figure 5.14, Figure 5.15, Figure 5.16, Figure 5.17, we can see that:

- The roaming acquisition time increases as the mobile station resource blocking probability increases.
- The average roaming acquisition time for connection establishment in a new system is also different from the path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ when the MS starts from GSM system. The higher probability spent in a large code size system download path, the longer acquisition time is required.

As seen from Figure 5.18, the average roaming acquisition time has slight difference in different designed scenarios, and scenario 26 also has the shortest acquisition time among them.

It is predictable that these results can be applied to the general scenario.

5.5 Roaming Acquisition Time Versus Universal Channel Bit Rate

5.5.1 Scenario Number 1:

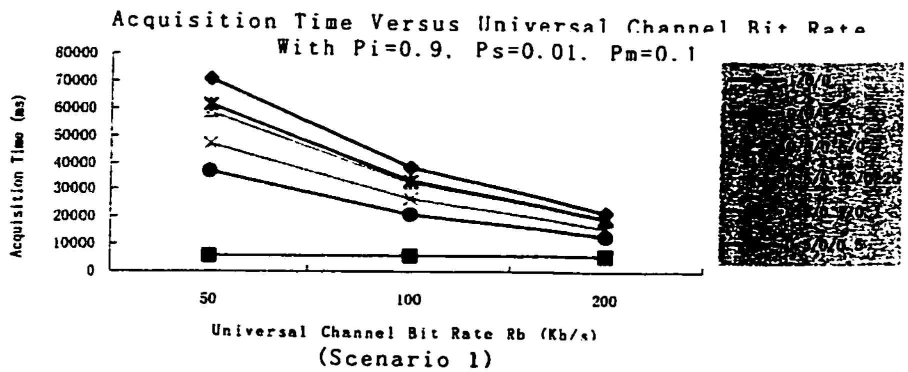


Figure 5.19 Acquisition Time versus Universal Channel Bit Rate Rb for designed scenario number 1, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/0/1, 0.5/0.5/0, 0.5/0.25/0.25, 0.8/0.1/0.1, and 0.5/0/0.5 respectively, system resource blocking probability Ps=0.01, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.5.2 Scenario Number 6

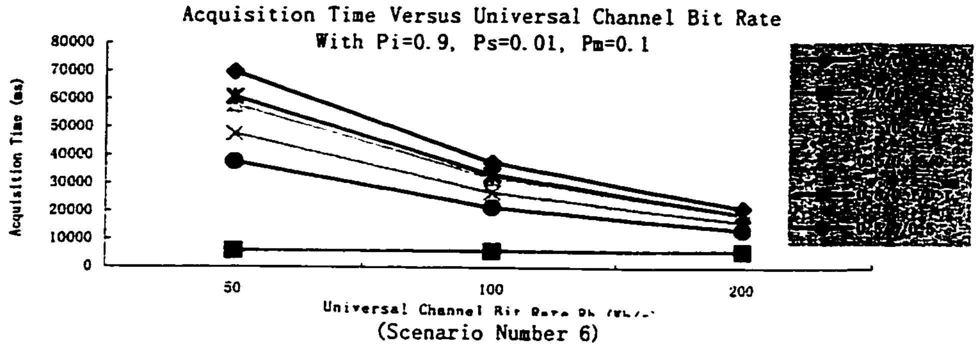


Figure 5.20 Acquisition Time versus Universal Channel Bit Rate Rb for designed scenario number 6, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/0/1, 0.5/0.5/0, 0.5/0.25/0.25, 0.8/0.1/0.1, and 0.5/0/0.5 respectively, system resource blocking probability Ps=0.01, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.5.3 Scenario Number 19

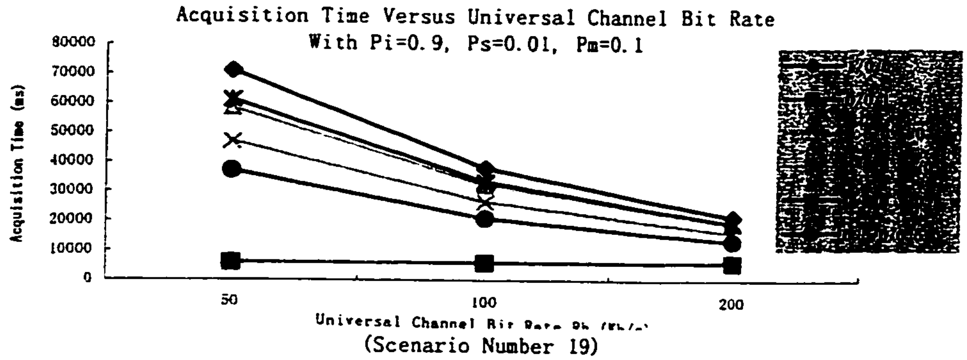


Figure 5.21 Acquisition Time versus Universal Channel Bit Rate Rb for designed scenario number 19, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/0/1, 0.5/0.5/0, 0.5/0.25/0.25, 0.8/0.1/0.1, and 0.5/0/0.5 respectively, system resource blocking probability Ps=0.01, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.5.4 Scenario Number 20

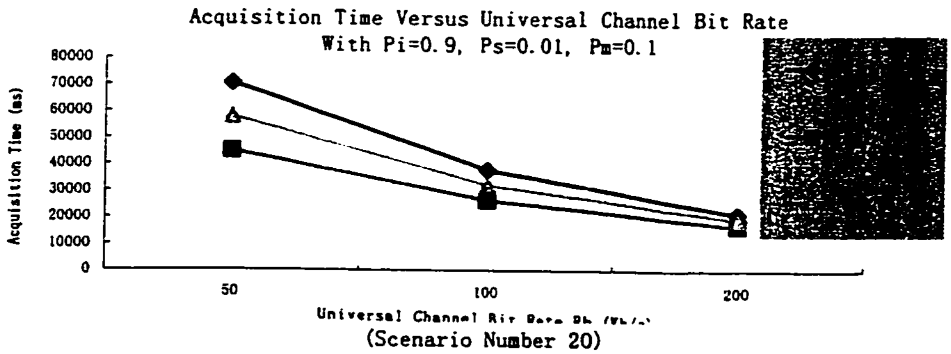


Figure 5.22 Acquisition Time versus Universal Channel Bit Rate Rb for designed scenario number 20, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, and 0.5/0.5/0 respectively, system resource blocking probability Ps=0.01, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.5.5 Scenario Number 26

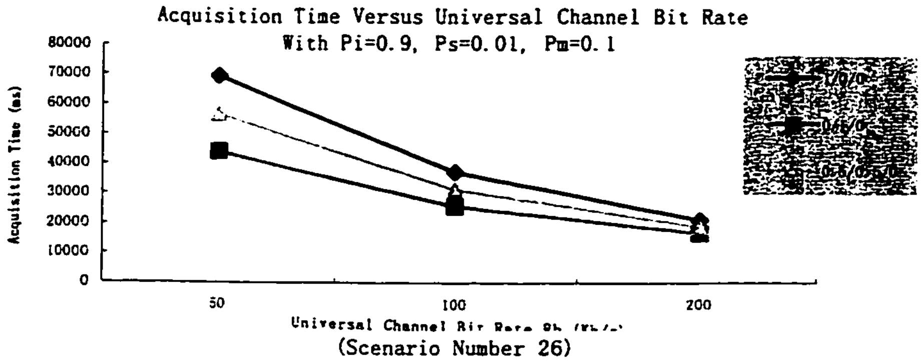


Figure 5.23 Acquisition Time versus Universal Channel Bit Rate Rb for designed scenario number 26, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ =1/0/0, 0/1/0, and 0.5/0.5/0 respectively, system resource blocking probability Ps=0.01, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.5.6 Comparison

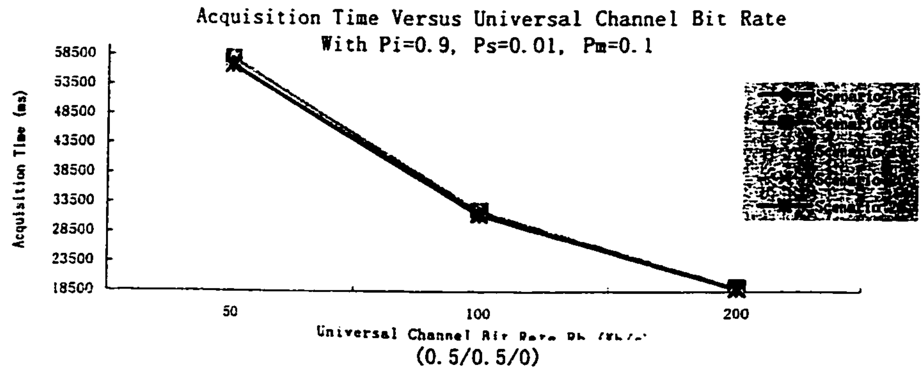


Figure 5.24 Comparison of the Acquisition Time versus Universal Channel Bit Rate Rb in different designed scenarios number 1, 6, 19, 20, 26, with path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ = 0.5/0.5/0, system resource blocking probability Ps=0.01, packet successful transmission probability Pi=0.9, and MS resource blocking probability Pm=0.1.

5.5.7 Performance Analysis:

By observing Figure 5.19, Figure 5.20, Figure 5.21, Figure 5.22, Figure 5.23, we can see that:

- The roaming acquisition time decreases as the universal channel bit rate increases if the mobile station needs to download new system software (i.e. if $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ is not equal to 0/0/1). The roaming acquisition time is not affected by the universal channel bit rate if the mobile station keeps in the same system path 3 (i.e. if $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ is equal to 0/0/1).

- When the universal channel bit rate is higher, e.g. R_b=200 Kb/s, the roaming acquisition time is affected by the path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ slighter. When the universal channel bit rate is lower, e.g. R_b=50 Kb/s, the roaming acquisition time is affected by the path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ more seriously.
- The average roaming acquisition time for connection establishment in a new system is also different from the path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ when the MS starts from GSM system. The higher probability spent in a large code size system download path, the longer acquisition time is required.

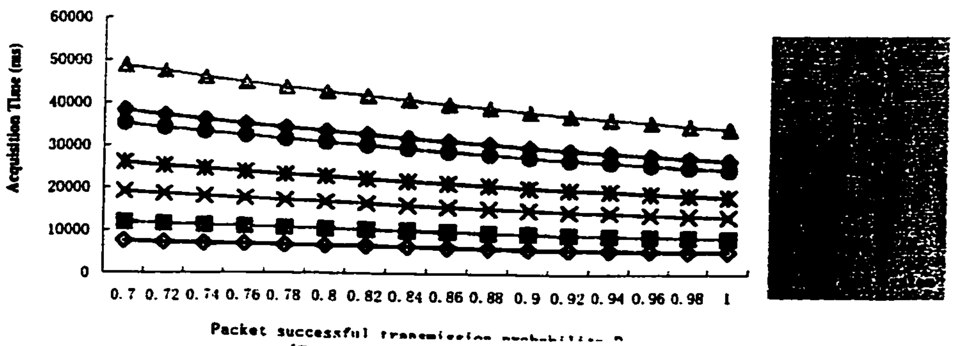
As seen from Figure 5.24, the average roaming acquisition time has slight difference in different designed scenarios, and scenario 26 also has the shortest acquisition time among them. It is predictable that these results can be applied to the general scenario.

5.6 Other Tests on Roaming Acquisition Time in Scenario Number 1

Roaming Acquisition Time Versus Packet Successful Transition Probability test for Scenario Number 1 by taking Case 2, 3, 4, 5, 6 for evaluation.

5.6.1 Case 2:

When the mobile station starts from TDMA system IS-54 or IS-136 and moves to the other wireless systems, we take Table 5.2 (b) for evaluation.

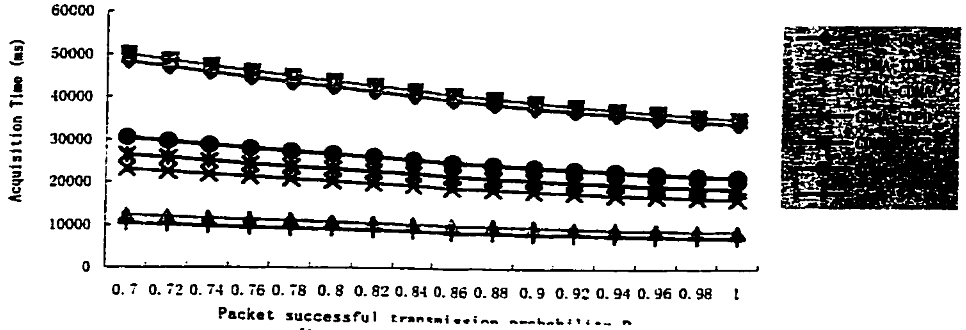


(Scenario 1 in case 2)

Figure 5.25 Acquisition Time versus Packet successful transmission probability Pi for evaluating case 2, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.6.2 Case 3:

When the mobile station starts from CDMA IS-95 and moves to the other wireless systems, we take Table 5.3 (b) for evaluation.

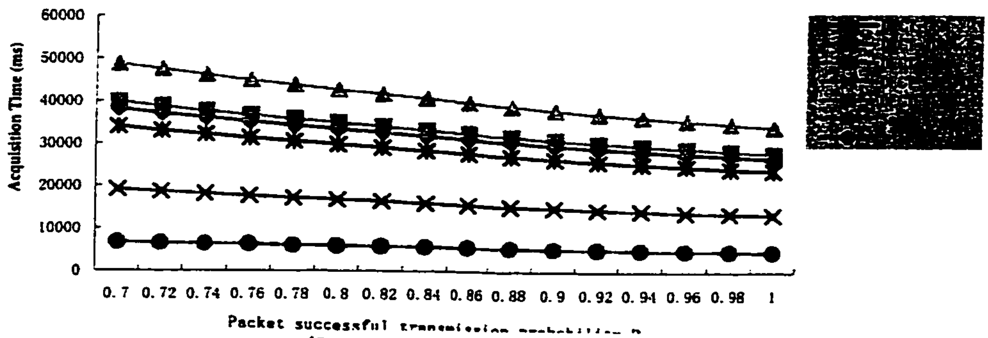


(Scenario 1 in case 3)

Figure 5.26 Acquisition Time versus Packet successful transmission probability Pi for evaluating case 3, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.6.3 Case 4:

When the mobile station starts from DECT and moves to the other wireless systems, we take Table 5.4 (b) for evaluation.

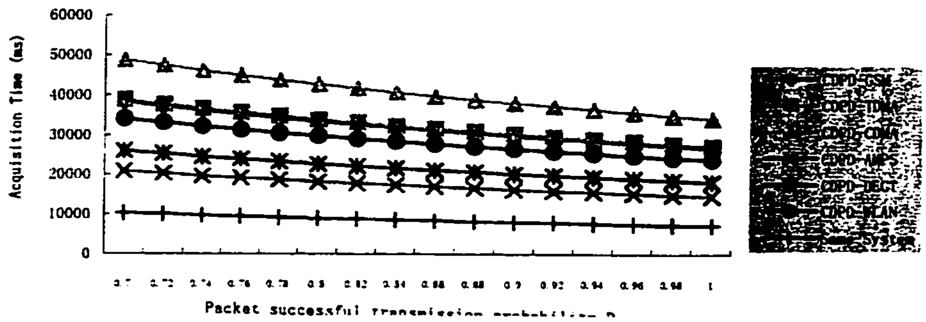


(Scenario 1 in case 4)

Figure 5.27 Acquisition Time versus Packet successful transmission probability Pi for evaluating case 4, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.6.4 Case 5:

When the mobile station starts from CDPD or AMPS and moves to the other wireless systems, we take Table 5.5 (b) for evaluation.

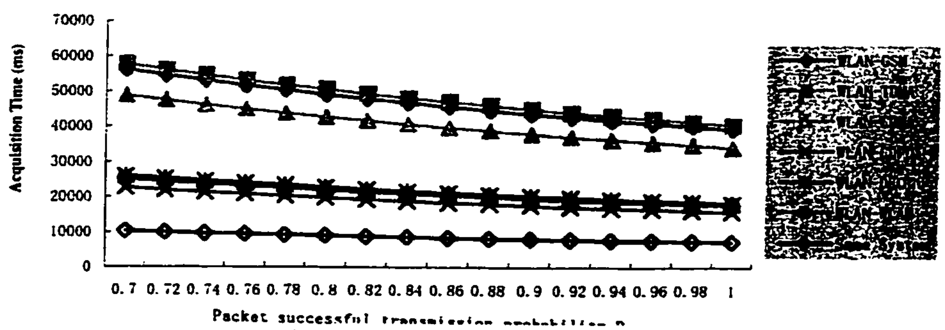


(Scenario 1 in case 5)

Figure 5.28 Acquisition Time versus Packet successful transmission probability Pi for evaluating case 5, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate R_b=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.6.5 Case 6:

When the mobile station starts from wireless LAN and moves to the other wireless systems, we take Table 5.6 (b) for evaluation.



(Scenario 1 in case 6)

Figure 5.29 Acquisition Time versus Packet successful transmission probability Pi for evaluating case 6, with path transition probability ε_{01} or ε_{02} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1.

5.6.6 Comparison:

When the mobile station starts from different wireless systems and moves to the same wireless system, the acquisition time may be different. We take CDMA, GSM, wireless LAN as the target system for evaluation, testing in designed Scenario Number 1.

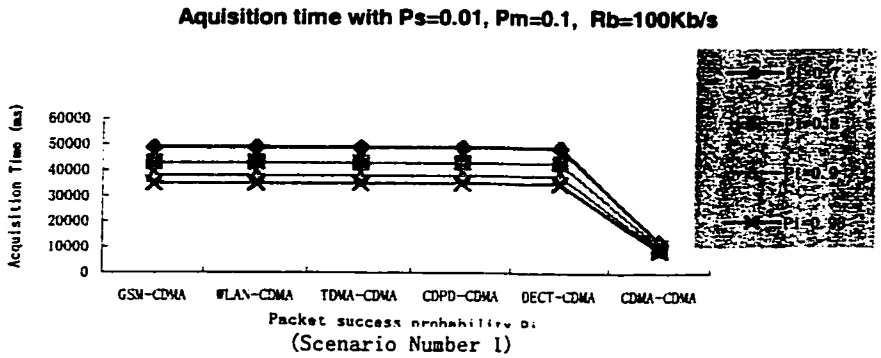


Figure 5.30(a) Roaming Acquisition Time from other systems to CDMA in scenario 1, with path transition probability ε_{01} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1, packet successful transmission probability Pi = 0.7, 0.8, 0.9, 0.98 respectively.

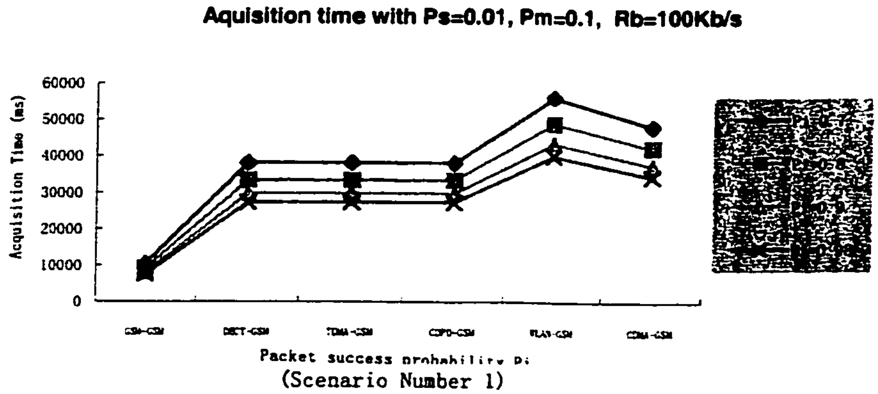


Figure 5.30(b) Roaming Acquisition Time from other systems to GSM in scenario 1, with path transition probability ε_{01} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1, packet successful transmission probability Pi = 0.7, 0.8, 0.9, 0.98 respectively.

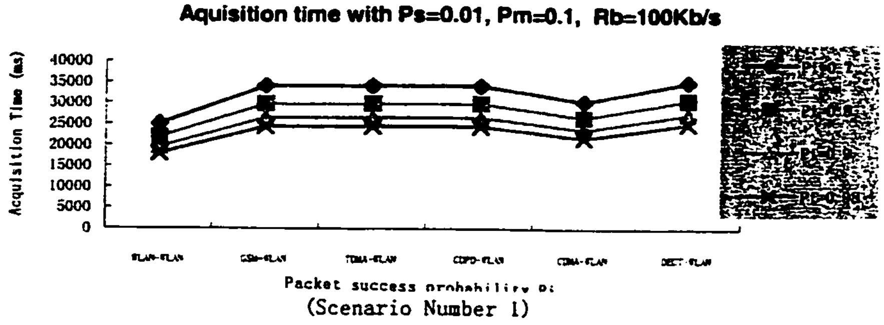


Figure 5.30(c) Roaming Acquisition Time from other systems to wireless LAN in scenario 1, with path transition probability ε_{01} or ε_{03} =1, universal channel bit rate Rb=100Kb/s, system resource blocking probability Ps=0.01, and MS resource blocking probability Pm=0.1, packet successful transmission probability Pi = 0.7, 0.8, 0.9, 0.98 respectively.

5.6.7 Performance Analysis:

By observing Figure 5.25, Figure 5.26, Figure 5.27, Figure 5.28, Figure 5.29, we can see that:

- The roaming acquisition time decreases as the packet transmission successful probability increases. This is true for 6 possible cases.
- The roaming acquisition time for connection establishment in a new system may be different when the mobile station starts roaming from the same system to the different target system. For the MS reaches to a target system, the larger software code size required, the longer processing time under the same conditions.

As seen from Figure 5.30 (a), (b), (c), the roaming acquisition time for connection establishment in a new system may be different when the mobile station starts roaming from the different system to the same target system. For the MS reaches to a target system, the larger software code size required, the longer processing time under the same conditions. It is predictable that these results can be applied to the general scenarios, since the tested scenarios are chosen randomly.

Chapter 6 Conclusion and Contribution

In this thesis, derived from the software defined radio technique, we proposed a reconfigurable multi-mode mobile station (MS) possible transition from one kind of wireless system standard to another. The reconfigurability of the MS is obtained by downloading the system software code over-the-air. Thus, a generalized state diagram of the multi-mode MS was presented for this purpose. Moreover, a detail description of the roaming operation and transition probabilities in this state diagram was presented. Furthermore, we focused on the evaluation of the roaming connection establishment acquisition time performance. The evaluation of the above roaming times include time for sensing the universal pilot channel, classic base station pilot channel, association time, and connection establishment signaling.

In acquisition time performance test, we investigated the effects of packet successful transmission probability over wireless channel $\mathbf{P_i}$, system resource blocking probability $\mathbf{P_s}$, mobile station resource blocking probability $\mathbf{P_m}$, and signaling bit rate over the universal base station channel $\mathbf{R_b}$ on the roaming connection establishment acquisition time performance for different cases and designed scenarios. By summarizing the performance analysis presented in Section **5.2.7**, Section **5.3.7**, Section **5.4.7**, Section **5.5.7**, and Section **5.6.7**, and since the tested scenarios are chosen randomly, we can conclude that:

1) The roaming acquisition time decreases as the packet transmission successful probability increases.
2) The roaming acquisition time increases as the system resource blocking probability increases.
3) The roaming acquisition time increases as the MS resource blocking probability increases.

4) The roaming acquisition time decreases as the universal channel bit rate increases if the mobile station needs to download new system software (i.e. if $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ is not equal to 0/0/1). The roaming acquisition time is not affected by the universal channel bit rate if the mobile station keeps in the same system path 3 (i.e. if $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ is equal to 0/0/1).
5) The packet transmission successful probability contributes slight effect on the roaming acquisition time comparing to the target system effect.
6) When the universal channel bit rate is higher, e.g. R_b=200 Kb/s, the roaming acquisition time is affected by the initial path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ slighter. When the universal channel bit rate is lower, e.g. R_b=50 Kb/s, the roaming acquisition time is affected by the initial path transition probability distribution $\varepsilon_{01}/\varepsilon_{02}/\varepsilon_{03}$ more seriously.
7) The roaming acquisition time for connection establishment in a new system may be different when the mobile station starts roaming from the different system to the same target system. Vice versa, the roaming acquisition time may be different when the mobile station starts roaming from the same system to the different target system. For the MS reaches to a target system, the larger software code size required, the longer processing time under the same conditions.
8) The average roaming acquisition time has only slight difference among different designed scenarios.

In this thesis, we have developed a generalized state diagram of a SDR reconfigurable, multi-mode MS and presented a detailed description of its roaming and download operation. These contribtions would provide a good reference to the future design of SDR mobile terminal. The time evaluations in this thesis are important for prior design of SDR in global roaming situations and would be asset for the design of universal BS, such as for the choice of channel bandwidth.

Also, we derived a generalized test case table and acquisition time formula in order to compute the roaming connection establishment acquisition time for the MS in areas defined as having a mixture of universal cellular base station, universal wireless LAN base station, and classical base stations. It should be noted that our test case table and acquisition time formula could also be applied to some other situations' acquisition time estimation, such as roaming registration acquisition time. This can be done by changing the code size in the possible case table and by modifying the values of transition probabilities in the state diagram. For example, to compute the registration acquisition time, one could set the values of $\varepsilon_{9,12}$, $\varepsilon_{10,12}$, $\varepsilon_{11,12}$ to 1 and reduce the code size, i.e., minimum time for signaling spent in the state S_9, S_{10}, S_{11} in the input test table.

However, some complex situations roaming connection acquisition time evaluation, such as in the case of roaming to a different system happens during call processing period, the MS roams to a different system during SW downloading, have not been discussed in this thesis. Since these issues requires more complicated mathematic and network planning analysis, or these maybe cause call dropping, we just suggested the MS should move slowly while it is downloading new system software code and considered that the connection establishment occurs in the center but not at the edge of a wireless system.

Chapter 7 Suggestion for Further Research

Software defined radio represents an idea target for R & D. In this thesis, we addressed some software download issues and time performance analysis. Several suggestions are presented here for further research:

- At present, the development of an software radio system remains very utopian because of several problems, overall technological ones, such as the amount of signal processing is too much for most processors.
- We propose that each re-configurable mobile station could have a default mode whose data is stored in a ROM by the manufacture and have two download modes whose data are saved as file1 and file2 stored in the memory such details are left for further research. Another problem arisen is how to increase the size of memory but not increase the power consumption—low power consumption component implementation issue.
- The details about how the universal base station reaches the database and details of its authentication method need to be considered for further research.
- The downloaded software code should be platform independent and could re-configure the MS to different wireless system standard, what kind of language should be adopted need to be investigated for further research, even though some literatures suggested that JAVA would be the suitable candidate.

Software radio is an emerging technology, an increasing literature addresses the SDR terminal architecture and the other related issues (wideband ADC, RF filtering, DSP, multi-band antenna). I believe that a breakthrough point to this research area would be the hardware implementation.

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Appendix II: Acronyms

1G: First Generation Communication

2G: Second Generation Communication

3G: Third Generation Communication

Abis-interface: Interface between BTS and BSC.

A-interface: Interface between MSC and BSC.

Air-interface: Interface between MS and BTS.

Active set: consists of the BSs involved in the soft handoff with given MS.

A/D: Analogue to Digital Converter

AMPS: Advanced Mobile Phone System

ARQ: Automatic Repeat Request

AuC: Authentication Centre

B-interface: Interface between MSC and VLR.

BCCH: Broadcast Control Channel

BSC: Base Station Controller

BSS: Base Station Subsystem

BTS: Base Transceiver Station

Candidate Set: consists of BSs that fulfil the criteria to be included in the active set but have not yet been included in active set.

CC: Call Control

CC: Connection Confirm

CCCH: Common Control Channel

CCH: Control Channel

CDMA: Code Division Multiple Access

CDPD: Cellular Digital Packet Data

CellularSW_DL: Cellular system Software Download

CI: Cell Identity

CKSN: Ciphering Key Sequence Number

CM: Call Management

Cnf: Confirmation

CR: Connection Request

CSMA: Carrier Sense Multiple Access

D-AMPS: Digital-AMPS

DCCH: Dedicated Control Channel

DCH: Data Channel

DCS: Digital Cellular System

DECT: Digital Enhanced Cordless Telecommunication

Discard Set: is the set of BSs that belongs to the current active set but are going to be dropped from the active set since they no longer fulfil the criteria for the active set.

DL: Download

DLC: Data Link Control

DPCCH: Dedicated Physical Control Channel

DSP: Digital Signal Processing

ETSI: European Telecommunication Standard Institute

FACCH: Fast Associated Dedicated Control Channel

FCCH: Frequency Correction Channel

FDD: Frequency Division Duplex

FDMA: Frequency Division Multiple Access

FPGA: Field Programmable Gate Array

GPRS: General Packet Radio Service

GSM: Global System for Mobile Communications

HLR: Home Location Register

HO: Handover/Handoff

HW: Hardware

ID: Identifier

IEEE: Institute of Electrical and Electronics Engineers

IMEI: International Mobile Equipment Identity

IMSI: International Mobile Subscriber Identity

IN: Intelligent Network

ISDN: Integrated Service Digital Network

ISO: International Organization for Standardization

ISUP: ISDN User Part

ITU: International Telecommunication Union

LA: Location Area

LAC: Location Area Code

LAI: Location Area Identification

LAN: Local Area Network

LAPC: Link Access Procedure for the C-plane

LAPD: Link Access Procedure for the D-channel

LAPDm: LAPD for Mobile

LC: Link Controller

LLC: Logic Link Control

LOS: Light-Of-Sight

MAC: Medium Access Control

MM: Mobility Management

MNC: Mobile Network Code

MOC: Mobile Originated Call

M-QoS: Mobile QoS

MS: Mobile Station

MSC: Mobile Switching Centre

MSIN: Mobile Subscriber Identification Number

MTC: Mobile Terminated Call

MTSO: Mobile Telephone Switching Office

NA-TDMA: North American-TDMA

Neighbor Set: contains the BSs that are likely candidates for soft handoff.

NMT: Nordic Mobile Telephone

NSS: Network and Switching Subsystem

OSI: Open System Interconnection

PC: Personal Computer

PCH: Paging Channel

PCHHT: Pilot/Paging Channel History Table

PCS: Personal Communication Service

PCS: Personal Cellular System

PHY: Physical Layer

PIN: Personal Identity Number

PLMN: Public Mobile Land Network

PS: Power Saving

PSTN: Public Switched Telephone Network

PTM: Point-to-Multipoint

PTP: Point-to-Point

QoS: Quality of Service

RACH: Random Access Channel

RAND: Random Number

Remaining Set: contains all BSs excluded from the other sets.

Req: Request

Res: Response

RLC: Radio Link Control

RLP: Radio Link Protocol

RM: Resource Management

RNS: Radio Network Subsystem

ROM: Read Only Memory

RR: Radio Resource

RRC: Radio Resource Control

RRM: Radio Resource Management

RSS: Radio Subsystem

RTS: Request To Send

SABM: Set Asynchronous Balance Mode

SACCH: Slow Associated Dedicated Control Channel

SC: Synchronization Channel

SCCP: Signalling Connection Control Part

SCF: Service Control Function

SCH: Synchronization Channel

SDCCH: Stand-alone Dedicated Control Channel

SDMA: Space Division Multiple Access

SDR: Software Defined Radio/ Software Radio

SIM: Subscriber Identity Module

SMS: Short Message Service

SN: Subscriber Number

SNDCP: Sub-Network Dependent Convergence Protocol

SS7: Signaling System No. 7

SW: Software

SWDB: Software Database

SYSDB: System Database

TCH: Traffic Channel

TCH/F: TCH Full Rate

TCH/FS: TCH/F Speech

TCH/H: TCH Half Rate

TCH/HS: TCH/H Speech

TD-CDMA: Time Division-CDMA

TDD: Time Division Duplex

TDMA: Time Division Multiple Access

TMN: Traffic Management Network

TMSI: Temporary Mobile Subscriber Identity

TOS: Type Of Service

TRX: Transmission/Reception Unit

TS: Time Slot

UA: Unnumbered Acknowledgment

VLR: Visitor Location Register

W-CDMA: Wideband-CDMA

W-CTRL: Wireless Control

WLAN: Wireless LAN

WLL: Wireless Local Loop

WMT: Wireless Mobile Terminal