Handoff Procedures in Integrated GPRS (EGPRS) and WLAN network

PEIJUN BAI

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ABSTRACT

Handoff Procedures in integrated GPRS (EGPRS) and WLAN network

Peijun Bai

WLANs provide high speed services but the radio coverage is small and does not support good mobility performance as compared to cellular systems. In this thesis, an integrated network of GPRS and wireless LAN is presented and a handoff algorithm is proposed for the integrated network. Handoff is an important issue when considering mobility in an integrated wireless communication network. The objective of the algorithm is to achieve seamless network service coverage and maximum data transfer speed. Traditional cellular GPRS/EGPRS networks can provide good mobility performance but relatively low speed data service. In the proposed handoff algorithm, the mobile station can camp on the best serving access point based on its geographic position and moving speed. Accessing a WLAN network, if possible, has a higher priority than accessing GPRS/EGPRS cellular network. To achieve a comprehensive performance investigation, a simulation is implemented based on a large traffic load. Simulation results show the performance characteristics and functionalities of the algorithm that includes total throughput, call successful rate, call block rate, packet error rate, handoff rate and resource utilization. Simulation results demonstrate that the proposed handoff algorithm achieves higher throughput and call successful rate than the traditional cellular network. The optimization of the deployment of access points of the integrated network is also investigated.

Acknowledgement

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Lists of Abbreviations

8PSK	8-Phase Shift Key
AAA	Authentication, Authorization and Accounting
ACK	Acknowledge
AP	Access Point
APN	Access Point Name
BS	Base Station
BSC	Base Station Controller
BSS	Basic Service Set
CFP	Contention-Free Period
CN	Correspondent Node
COA	Care of Address
CP	Contention Period
CS	Circuit-Switched
DB	Database
DCF	Distributed Coordination Function
EGPRS	Enhanced GPRS
ESS	Extended Service Set
FA	Foreign Agent
GGSN	Gateway GPRS Support Node
GIF	GPRS Interworking Function
GMSK	Gaussian Minimum Shift Key

GPRS	General Packet Radio Service
GSM	Global System of Mobile Communications
GTP	GPRS Tunneling Protocol
HA	Home Agent
HLR	Home Location Register
IBSS	Independent Basic Service Set
IP	Internet Protocol
IR	Incremental Redundancy (IR)
ISP	Internet Service Provider
LA	Location Area
LAN	Local Area Network
MAC	Medium Access Control
MCS	Modulation Coding Scheme
MR	Mobile Router
MS	Mobile Station
MSC	Mobile Switch Center
NACC	Network Assisted Cell Change
NACK	Not Acknowledged
NAV	(802.11) Network Allocation Vector
PC	Point Coordinator
PCF	Point Coordination Function
PCU	Packet Unit
PIFS	Priority Inter-Frame Space

PS	Puncturing Scheme
RA	Routing Area
RADIUS	Remote Access Dial-In User Service
SGSN	Serving GPRS Support Node
SIFS	Short Interframe Space
SNR	Signal-to-Noise Ratio
SSID	Service Set Identifier
TFI	Temporary MS Identity
USF	Uplink State Flag
WLAN	Wireless Local Area Network

Chapter 1 Introduction to the IEEE 802.11 Wireless LAN

1.1 The IEEE 802.11 Network Structure

1.1.1 Network structure

Following the rapid growth of current mobile services, especially the increasing demand on high data rate of wireless communication services, the capacity of the widely used cellular network is facing a great challenge. Wireless Local Area Network (WLAN) is a network that can provide high data rate for users within a limited area. Typical WLAN provides up to 54Mbps (IEEE 802.11g standard) data rate. It also offers advantages in costs and flexibilities over the cellular mobile system. Therefore, WLAN is attracting much more attention as a potential public wideband wireless communication media.

Wireless LAN has two configurations, 'Infrastructure' and 'Ad-Hoc'. In the infrastructure wireless LAN, centralized access points (APs) present wireless access services for mobile subscribers in the network. In the ad-hoc network, on the other hand, peer-peer connections are set up independently. Indeed, there are no centralized service control nodes. The route between different nodes will be set up based upon a routing establishment algorithm.

In WLANs [1], an Independent Basic Service Set (IBSS) is a standalone BSS that has no backbone infrastructure and consists of at least two wireless stations. This type of network is often referred to as an ad-hoc network, which can meet most needs of users occupying a small area, such as a single room, an office environment or a hospital and the like.

If a designed coverage area is greater than a single AP configuration, Extended Service Set (ESS) can be used in a WLAN to provide a multi-cell architecture. In Figure 1.1, a number of APs are connected with a wire line backbone network. In this configuration, all mobile devices can roam within the coverage area while maintaining a live connection to the network.

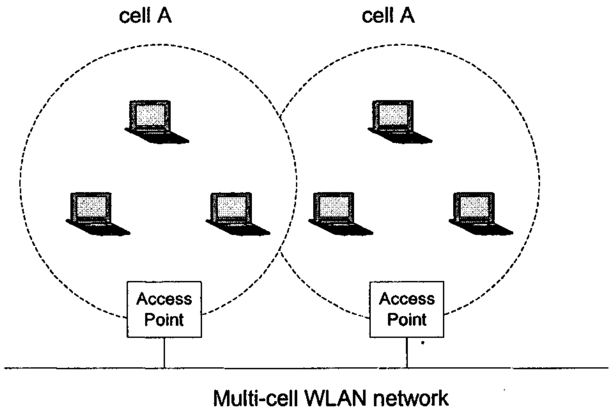


Figure 1.1 Multi-cell WLAN network

Like a cellular GPRS network, an infrastructure network has a multi-level and multi-cell topology, which enables a consistent architecture of a WLAN-GPRS to be an integrated network. Consequently, in this work, an infrastructure WLAN network is adopted for a proposed network, which integrates a GPRS and a WLAN.

1.1.2 DCF (Distributed Coordination Function) and PCF (Point Coordination Function)

Two kinds of MAS Service Data Unit (MSSDU) delivery service are defined [2] by IEEE 802.11 standard: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). DCF is used mainly for asynchronous data service that does not have strict time requirement. PCF, however, is used principally for real-time data service, such as video and voice data transmission.

DCF is the primary access protocol for the automatic sharing of the wireless medium found on the carrier sense mechanism. By way of using a random backoff time when a mobile device senses a busy medium, the collision problem can be solved. The period of time immediately following a busy medium is the time in which the highest probability of the collisions occurs, particularly under high utilization. Once the medium becomes idle, a random backoff time defers a mobile station from sending frames, minimizing the chance that stations will collide. Under low utilization, which is the most occurring case in an integrated cellular network, mobile stations are not forced to wait very long before sending frames.

PCF provides contention-free frame transfer for processing real-time communication services. In the PCF mode, a point coordinator resides in an AP to control the transmission of frames from stations. All stations abide by the point coordinator by setting their NAV value at the beginning of each contention-free period. Once a point coordinator sends a beacon frame to a station, the station will update its NAV value and capture the medium exclusively. When the contention-free time expires, the station will stop sending frames and give the beacon poll back to the point coordinator. When associating with an AP, a station can send a request to indicate its desire for transmitting frames. The point coordinator maintains a polling list of eligible stations that may receive a poll during the contention-free period (CFP).

Although PCF and DCF are distinct Medium Access Control (MAC) mechanisms, they can coexist by applying each other in a different time period. In the Contention Free Period (CFP), after an idle period indicated by Priority Interframe Space (PIFS), an AP sends a beacon frame in order to initiate polling. In order to improve the channel use, the data, polling and ACK can be combined together into one frame, Figure 1.2. Downlink and uplink data frames are sent and ACKs are returned. A time interval, Short Interframe Space (SIFS), is applied between uplink and downlink transmission. When a Point Coordinator (PC) sends out a CF-End frame, the CPF is terminated and a Contention Period (CP) will start.

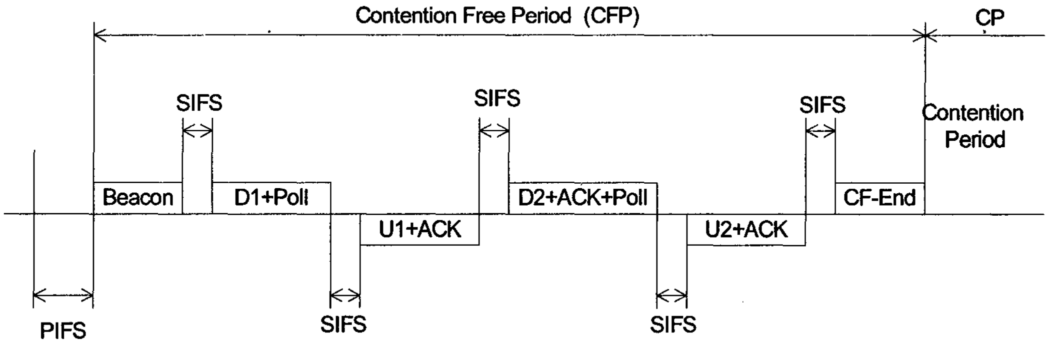


Figure 1.2 Transmissions under PCF

In the proposed integrated WLAN and cellular network, as the main traffic load originates within the cellular network, whose capacity is lower compared to a WLAN network, the probability of collision can also be low. Correspondingly, both DCF and PCF mechanisms can be used to address collision problems. Nevertheless, because of better support of infrastructure WLAN in integrated networks, PCF is preferred for our proposed integrated network.

1.2 Network mobility

The network mobility in WLAN enables a mobile user to maintain service connectivity while on the move.

In a mobile IP network [3] [4] [5] [6], Home Agent (HA) is a router on a MS's home network that maintains information about the MS's current location. Each MS has its own HA and all packets sent to the MS will be initially routed to the HA. Once the MS moves from the home network to a foreign network where a Foreign Agent (FA) is located, packets destined for the MS are forwarded via the HA in the home network of the MS and the FA in the visited wireless LAN. Figure 1.3 illustrates such a wide area wireless access network, where each wireless LAN is composed of multiple APs and those wireless LANs are connected via FAs.

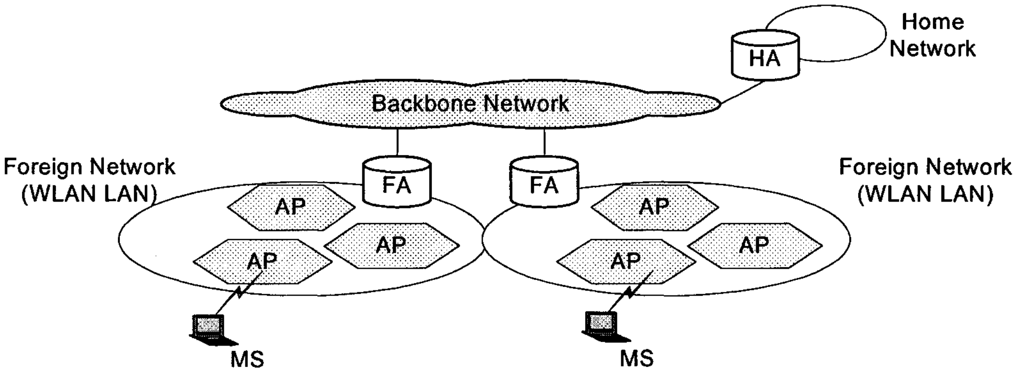


Figure1.3 Public WLAN service with Mobile IP

In [7], a mobile router (MR) is defined as "a router capable of changing its point of attachment to the Internet, moving from one link to another. The MR is capable of forwarding packets between two or more interfaces, and possibly running a dynamic routing protocol modifying the state by which it does packet forwarding." A mobile network can be composed of one or more mobile routers (MRs) and mobile stations (MSs) linked to the MR; in most simple cases, one MR is combined with one MS. Figure 1.4 demonstrates the basic mobile network architecture. While the MS moves from area of AP1 to AP2, the MR manages the mobility of the MS.

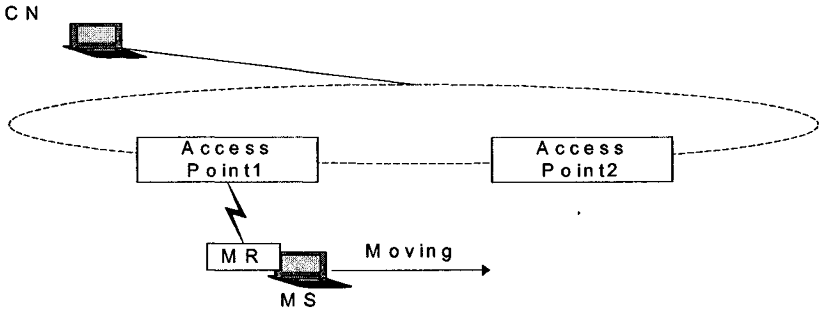


Figure 1.4 Basic network mobility concepts

In mobile IP networks [8], each MS is identified by its home address, managed by the home agent (HA), and located by its care of address (COA). A COA is a temporary IP address for a mobile node (mobile device) that enables message delivery when the device is connecting from somewhere other than its home network. The care of address identifies a mobile node's current point of attachment to the Internet and makes it possible to connect from a differing location without changing the device's home address (permanent IP address).

When an MS moves to another area, a new COA is needed from a foreign agent (FA) and binding update information will be sent to a HA. When a correspondent node (CN) wants to communicate with the MS, it will send a message to the home address of the MS. The HA will reroute the message to the destination according to the registration information sent from the MS. Figure 1.5 reveals a process how a certain CN reaches an MS when an MS moves to another service area. The CN sends a message to the MS using the home address of the MS, and the HA of the MS intercepts the message on behalf of the MS. Due to the fact that the HA knows the COA of the MS, it encapsulates the message and forwards it to the COA of the MS. The COA will point to the MR, which is the FA of the MS. And then the message is sent to the MR's HA. MR's HA sends the message to the MR, and the MR de-encapsulates the message and forwards it to the MS.

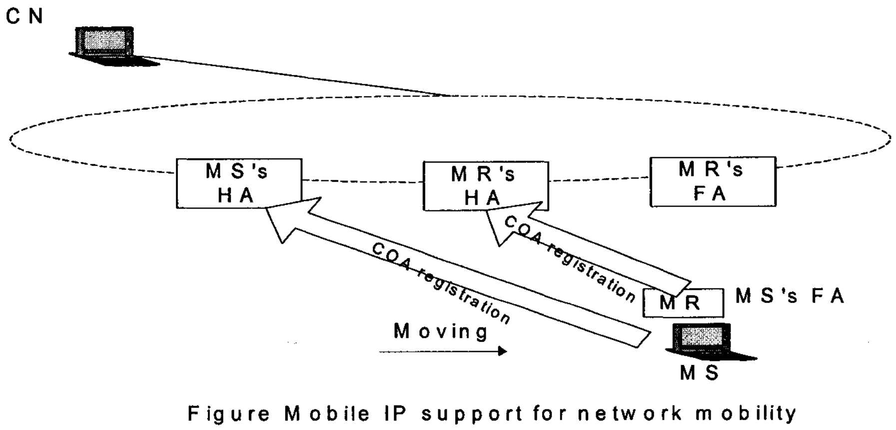


Figure1.5 Mobile IP support for network mobility

The current IEEE 802.11 standard WLAN is comprised of a fundamental building block called a basic service set (BSS), and a BSS can be linked to an extended service set (ESS) to provide coverage over large areas [9].

Within a certain WLAN [10], as long as the MR stays in the AP's coverage area, the MR will receive the message from the AP that is directed to it. If the MR does not have any message to receive from the AP, it confirms its reachability by means of a periodic neighbour advertisement message from the AP. If no message is received from the AP during a predetermined time, the MR will send a router solicitation message to the AP. If the AP does not response, the MR detects its unreachability to that particular AP.

After this unreachability detection, the MR sends a router solicitation message to a new AP for re-association. If a new AP replies with a neighbour advertisement message, the MR will receive prefix information from the AP and associates with the new AP by creating a COA. And then the MR sends a notice to its HA. All data sent to the MS will be rerouted to the new AP.

1.3 Handoff in a WLAN Network

1.3.1 Handoff Latency in a WLAN

Mobile IP handoff delay is divided into two elements: scanning process and registration process. Scanning process is to detect the movement of the MS and find available target APs. Registration process, or re-authentication process, is to verify the identity of the MS in the new AP coverage area.

In IEEE 802.11 [1], scanning is the process during which the MS searches for neighboring APs in order to find a new AP to associate with. If the MS moves out of a BSS, the SNR (Signal-to-Noise Ratio) between the MS and the current AP is degraded. If the SNR reaches a threshold, which may cause a high error rate or frame loss, the MS will initiate a scanning process to achieve an AP with better service. The MS will search all channels and, for all available APs, obtain the information including data transmission rate, synchronization, BSSID and SSID (Service Set Identifier), and so on. BSSID and SSID respectively indicate the MAC address of AP and the identity of ESS.

The scanning process [9] can be executed by two techniques: passive scanning and active scanning. In the passive scanning method, the MS passively listens to periodic beacon frames transmitted from APs. However, in the active scanning method, the MS transmits a probe request frame to all APs and solicits APs to send beacon frames. In both cases, the MS must stop the current data transfer and listen to the beacon for a specific time. When the MS gets the beacon, it records SNR for all available APs and selects the best one to correlate with. Because a typical beacon period is 100ms, the scanning process may contribute to a relatively significant delay for a handoff process.

According to recent studies [11], the handoff delay of IEEE 802.11 can exceed 300ms. The study [12] shows that most of handoff delays are due to the time spent on the scanning process.

A lot of efforts [13-20] have been made on how to implement an efficient handoff in a WLAN network. In [31], handoff agents are used to ensure that every packet is sent to the MS in order. [32] focuses on dynamic resource reservation to various users needed by handoff calls, thus reducing the probability of blocking caused by the hike of the load (new calls). To achieve a fast handoff in a WLAN network, in [10], a prediction-based handoff algorithm is presented for achieving the seamless and low-latency handoff. In [21], a tunnel-based handoff method is proposed for reducing the handoff delay caused by movement detection.

1.3.2 Prediction-Based handoff

In [10], a prediction-based handoff is presented for a mobile WLAN handoff. Figure 1.6 reveals the protocol architecture involving the MS, the MR and the CN. When an MS initially moves into a coverage area of APs, it is assigned an IP address and then the MR begins to perform mobility management on behalf of the MS, and then the mobility of mobile network becomes transparent to the MS.

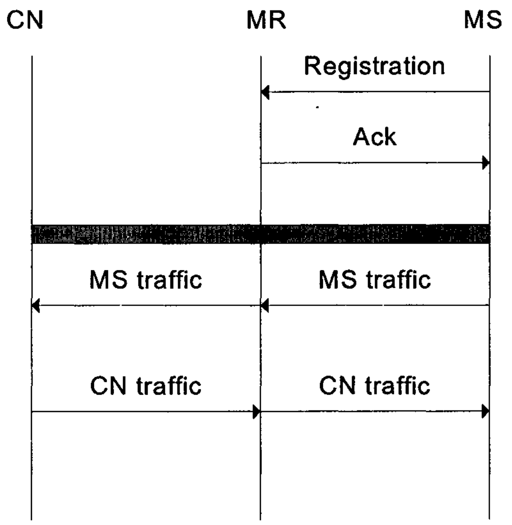


Figure1.6 MS initialization and connection to CN

If no message is received from the current AP, the MR will perform association with the next AP. From Figure 1.7, in the prediction-based handoff mechanism, the availability of the next AP is predicted based on the current position, the speed and the direction of the MS. If there is a target AP available, distance between the MS and the new AP and handoff time are evaluated. Once a handoff decision is made, because the MR is linked with the target AP in advance, the handoff can be performed rapidly and seamlessly. Once the MS moves into the coverage area of the new AP, the MR sends registration to the new AP and also the HA of the MS is informed by receiving binding update frames.

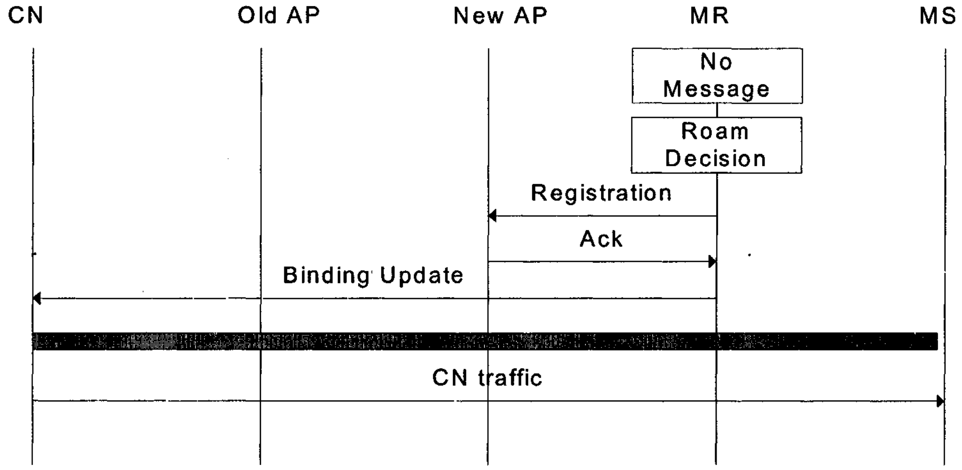


Figure1.7 Prediction-based handoff protocol for mobile networks

When the MS is associated with an AP, it routinely reports the distance to any reachable AP to the network. In order to properly predict the next associated AP, a cached database is maintained to store sequential information of each AP's location, relative distance and prefix. The handoff is decided when the moving distance between the associated MR and the current AP reaches the predicted distance for the handoff, i.e. the maximum coverage radius of an AP.

```
If (distance_handoff – distance_moving < threshold)
then
associate_with_next_AP();
```

Due to the radio interference and fading, the accuracy of the detection of movement may be degraded. To achieve a more precise evaluation of the result of the current movement of the MS, an advertise interval is introduced. Only when no frame is received correctly for an advertise interval time, the distance check criteria can be used for a handoff decision.

```
If (message_absense_time >= advertise_interval_time)
then if (distance_handoff – distance_moving < threshold)
then
associate_with_next_AP();
```

1.3.3 Tunnel Based fast handoff

In [21], a tunnel is used to improve the handoff latency. A fast handoff is achieved by the joint use of APs and a dedicated MAC bridge. Figure 1.8 expresses the procedure for the proposed handoff method.

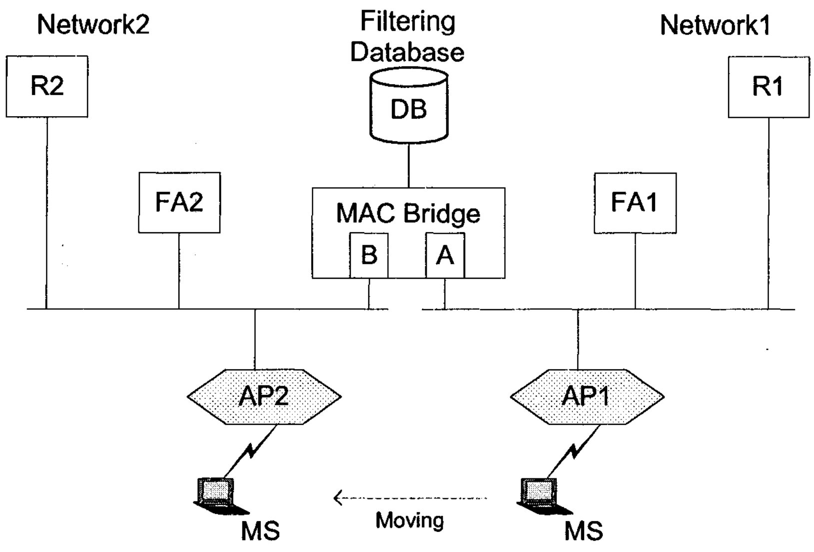


Figure 1.8 tunnel-based handoff procedures in a WLAN network

Initially, the MS establishes an association with the AP1 and register the COA with the HA according to the Mobile IP protocol.

When the signal strength of the source AP1 becomes lower than a certain threshold and the signal strength of the target AP2 is higher, the MS establishes a relationship with the new AP2. The AP2 will broadcast the MAC address registration request message.

Upon receiving the MAC address registration request message, the MAC Bridge stores an entry for the MAC address contained in the message and the port on which the message is receiving the filtering DB. Each entry has an aging time, and if no new MAC address registration request message arrives within this time period, the corresponding entry will be removed.

When the MAC Bridge receives a MAC frame on a port, it refers to the filtering DB to see if the destination MAC address is registered. If it is registered, the MAC Bridge will send it out to the corresponding port. Ongoing packet sent to the MS from FA1 will be redirected and bridged from port A to port B, and delivered to Network 2, to which the MS is now attached.

The MS detects movement by receiving new Agent Advertisement from FA2 and registers the new COA with the HA. When the registration is completed, packets destined for the MS are then tunneled to FA2 and delivered to the MS.

In the above procedures, because the MS can receive packets even before the Mobile IP registration is completed, the handoff latency is reduced and a fast handoff is achieved.

Chapter 2 Introduction to GPRS Network

2.1 GPRS Network Structure

As one of the most widely adopted mobile networks, the General Packet Radio Service (GPRS) network is experiencing a great development across the world. Today, the number of operational or planned GPRS networks exceeds one hundred. The GPRS is a wireless data service provided over the GSM network. The network management allows the GSM circuit-switched traffic and the GPRS packet-switched traffic dynamically sharing the same radio resources.

A GPRS network is an added network of the existing GSM network and does not affect the circuit-switched GSM services. In Figure 2.1, each MSC (Mobile Switch Center is connected to several BSCs (Base Station Controllers), and each BSC in turn controls several BSs (Base Stations). The BSC is connected to the MSC and the SGSN (Serving GPRS Support Node).

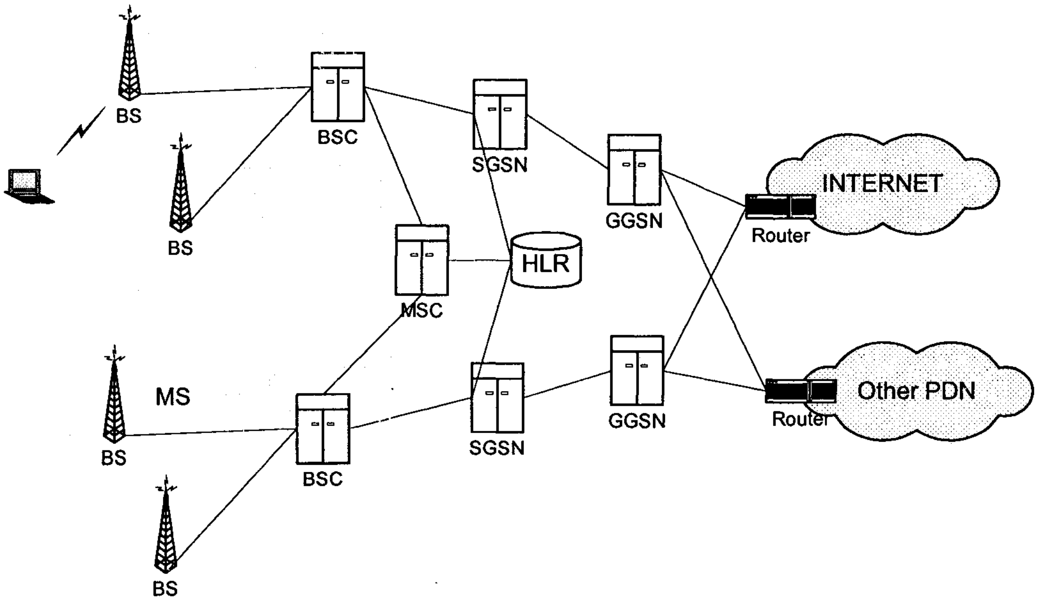


Figure 2.1 GSM System Architecture

2.1.1 GPRS Base Station System

The GPRS Base Station System consists of the Base Station Controller (BSC) and the Base Station (BS). The BS is the radio equipment that transmits and receives information over the air to let the BSC communicate with MSs in the BSC's service area. A group of BSs are controlled by a BSC. The BSC must contain the GPRS-specific software.

The BSC provides all radio-related functions [22]. The BSC can set up, supervise, and disconnect circuit-switched and packet-switched calls. Call handover and channel resource assignment are also performed by the BSC. GPRS services reuse the traditional GSM radio access network. Because a typical GPRS network shares the same BS and BSC with the GSM circuit-switched network, the BSC separates the circuit-switched calls from packet data communications. The BSC respectively forwards circuit-switched calls to the MSC, and packet calls to the SGSN.

2.1.2 GPRS Core Network System

The Mobile service Switching Center (MSC) performs the telephony switching function of the GSM circuit-switched system. The MSC coverage contains a number of Location Areas (LAs). An MSC Location Area contains a group of BSs. The system uses the LA to search for the MS in the active state. The SGSN Routing Area (RA) is a subset of the MSC LA.

The HLR stores the MS subscriber services information, which includes, let's say, supplementary services, authentication parameters, Access Point Name (APN) such as the Internet Service Provider (ISP) subscribers, and whether a static IP address is allocated to the MS. In addition, the HLR information comprises the location of the MS. Whenever an MS moves to another network region or a location update is initiated, the HLR will be notified. When an MS is paged for packet calls, the SGSN checks the location information from the HLR, and sends paging to the groups of BSs according to the location. For this reason, an MS can always be properly located and paged wherever it moves.

Like the MSC in a circuit-switched network, the SGSN performs the similar role as in a packet-switched network. The SGSN provides packet routing and transfer to and from the SGSN service area. The SGSN forwards incoming and outgoing IP packets address to/from an MS that is attached within the SGSN service area. When connected to a GPRS network, an MS has a logical connection to its SGSN and can perform handoff between different BSs without any change in that logical connection. The SGSN keeps track of which BSC to use when sending packets to an MS that arrives from outside networks. The SGSN also provides ciphering and authentication, session management, mobility management, logical link management towards the MS and some billing information management.

The GGSN handles the interface to the external IP packet networks. The GGSN, consequently, contains access functionality that interfaces with the external Internet Service Provider (ISP) functions, such as routers and RADIUS (remote Access Dial-In User Service) servers, which are used for security purposes and allocation of IP addresses. From the point of view of the external IP network, the GGSN acts as a router for the IP addresses of all subscribers served by the GPRS network. The GGSN, thus, exchanges routing information with the external network. Also, the GGSN provides the functionality for associating the MS with the right SGSN, session management, and some billing information management.

The GGSN and SGSN network constitute the core network of the GPRS. It may connect to another GGSN and SGSN network by using an IP based GPRS backbone network. A GPRS Tunneling Protocol (GTP) is used for handling the traffic over different GPRS core networks.

2.2 GPRS Radio Resource

2.2.1 Uplink / Downlink Resource Allocation

The GPRS network shares the same BS radio resource with the GSM circuit-switched network. A BS can handle several radio frequency carriers. Each carrier has a bandwidth of 200 KHz and can be divided into eight time slots. Indeed, each time slot can be taken as a radio channel and used by a GSM MS to provide circuit-switched service. A general GSM radio channel can offer a data rate of up to 13k bits/second.

In GPRS, downlink and uplink radio resources can be allocated separately to different MSs [22].

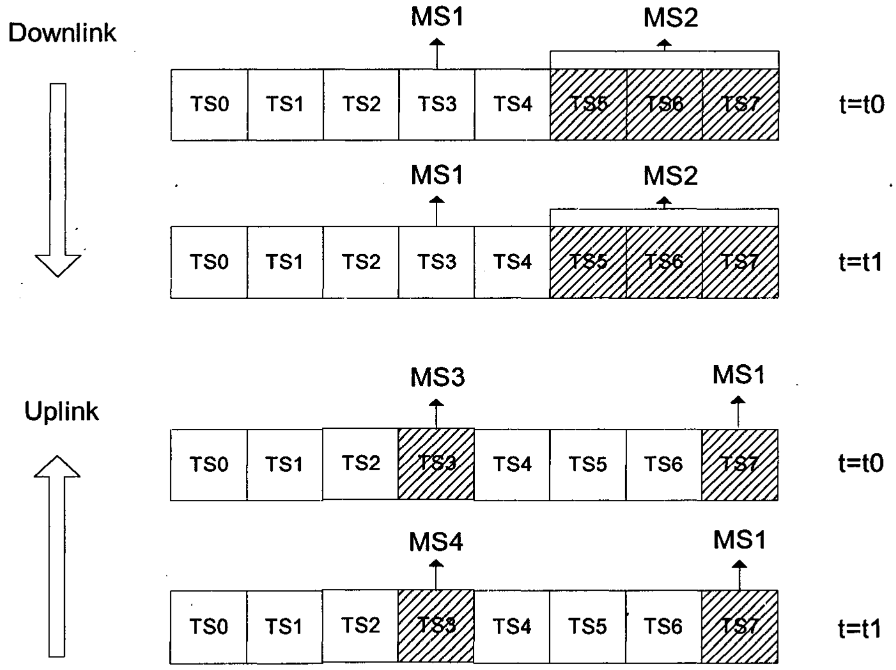


Figure 2.2 GPRS radio time slot resource allocation

To achieve higher data rates, an MS can be allocated with multiple time slots in GPRS network. In Figure 2.2, time slots 5, 6 and 7 in downlink are allocated to mobile MS 2.

The same time slot can be allocated to several MSs. In Figure 2.2, time slot 3 in uplink is used by MS 3 at moment t=t0. But one period later at t=t1, time slot 3 is used by MS 4. And again, a few periods later, time slot 3 will be used by MS 3.

When the BSC receives frames from the SGSN, the BSC checks whether the MS has already been allocated with downlink resources, if so, the new frames are put in queue with the other frames to that MS. If the MS has no downlink resources allocated, a Packet Downlink Assignment Message is sent to a mobile phone. This message contains the time slots that will be used for downlink transfer and a temporary MS identity (TFI).

If the SGSN does not know the location of the MS, i.e. which cell is the MS currently camping on, it will send out a Paging Request message. The paging message is broadcasted to all the cells belonging to the area indicated by the SGSN.

Once an MS has received the Packet Downlink Assignment message, the TFI (Temporary Flow Identity) in the header of radio blocks is read by the MS to identify whether the receiver of the packet frame is the MS or not. If the TFI present in the header is the same as the TFI allocated to the MS, the MS knows that this packet frame belongs to him. If not, the MS will ignore the rest of the received frames.

When there are no more frames to be transmitted to an MS, the downlink resources are released. If a new frame arrives, a new packet downlink assignment will be sent to the MS.

When an MS needs to send frames to the network, it sends the Packet Channel Request message to the BSC. The BSC replies to the MS with a Packet Uplink Assignment message. This message contains a list of time slots that will be used for uplink transfer, a temporary MS identity called a TFI and a USF (Uplink State Flag) number for each time slot included in the list. A USF indicates to an MS when it has to transmit.

Once an MS has received the Packet Uplink Assignment message with the list of time slots, the USF for each time slot and the TFI, it reads the header of downlink radio blocks sent in those time slots to know when it should transmit in uplink.

If the USF present in the header is the same as the USF allocated to the MS, the MS knows that it is authorized to send the next radio block. This mechanism avoids conflicts in uplink transmission when the same time slot is shared by several MSs. After all blocks have been sent, the uplink resources are released. If the MS has more new packets to send after the release, new uplink resources have to be established.

2.2.2 Coding Schemes in GPRS and EGPRS

In GPRS, the radio blocked size is always 456 bits. Therefore, to increase the number of coding bit, the number of information bits must decrease. In GPRS [23], seen from Tables 2.1, the four coding schemes (CS) have been defined according to distinct ratio of coding bits and information bits.

CS-1 is the most secured coding scheme, but provides the lowest rate of information bits. On the contrary, CS-4 is the least reliable coding scheme, but has the highest rate of information bits.

Coding	Max data rate per TS (kbps)	Target C/I (dB)	Modulation
CS-1	9.05	-6	GMSK
CS-2	13.4	-9	GMSK
CS-3	15.6	-12	GMSK
CS-4	21.4	-17	GMSK

Table 2.1 GPRS Radio Code Schemes

In GPRS, maximum four time slots can be used simultaneously for a downlink resource allocation. By using CS-4, the MS can achieve a downlink data rate up to 49.6 Kbps. The GMSK (Gaussian Minimum Shift Key) modulation is used for all the coding schemes.

EGPRS introduces a new modulation technique and new channel coding. Table 2.2 [23] shows that the GMSK modulation is still used by MCS-1 to MCS-4, but with MCS-5 to MCS-9, the 8PSK (8-Phase Shift Key) modulation is used.

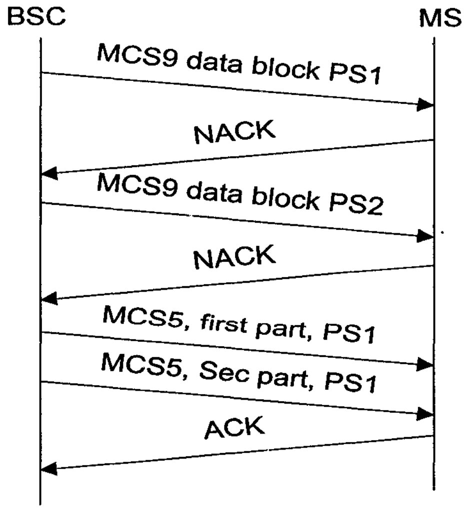
Coding	Max data rate per TS (kbps)	Modulation
MCS-1	8.8	GMSK
MCS-2	11.2	GMSK
MCS-3	14.8	GMSK
MCS-4	17.6	GMSK
MCS-5	2.4	8PSK
MCS-6	29.6	8PSK
MCS-7	44.8	8PSK

MCS-8	54.4	8PSK
MCS-9	59.2	8PSK

Table 2.2 EGPRS Radio Code Schemes

With the same modulation symbol rate, the 8PSK modulation has a higher bit rate than the GMSK, as a result, higher throughput can be achieved in MCS-5 to MCS-9 when there is a good radio link quality.

Link adaptation [24] is widely used in GPRS/EGPRS networks. With link adaptation, as demonstrated in Figure 2.3, a coding scheme, such as MCS-9, with very little error protection and without consideration for the actual radio link quality is initially used. When a high frame error rate is detected with the initial coding scheme, i.e. too many NACK (Not Acknowledged) messages are received, a lower coding scheme, for instance, MCS-5, is used. Segmentation will be used to divide the initial packet frame into two parts. Therefore, packet information can be encapsulated and sent with a lower coding scheme. This procedure will be repeated until the frame error rate decreases and information is successfully decoded.



MS sends Measurement Report with ack/nack

Figure 2.3 EGPRS Link Adaptation

For EGPRS networks, Incremental Redundancy (IR) is another essential technique to improve the packet data transfer rate. See Figure 2.4 [24], the encoded data are sent with initial coding scheme, i.e. MSC-9, and punctured with a Puncturing Scheme (PS) 1. When the MS cannot decode the MCS-9 data block PS1, it stores the unsuccessfully decoded data blocks PS1 and sends a NACK message to the BSC. The BSC then resends the data block, but with distinct puncturing schemes, say, the PS2. The coding scheme MCS-9 is still used in the resending. Once the MS receives the PS1 and the PS2, it uses the PS1 and the PS2 to jointly decode data block. If data block still can not be decoded, the BSC changes puncturing scheme and sends the PS3 to the MS. This procedure repeats until the MS decodes data block correctly.

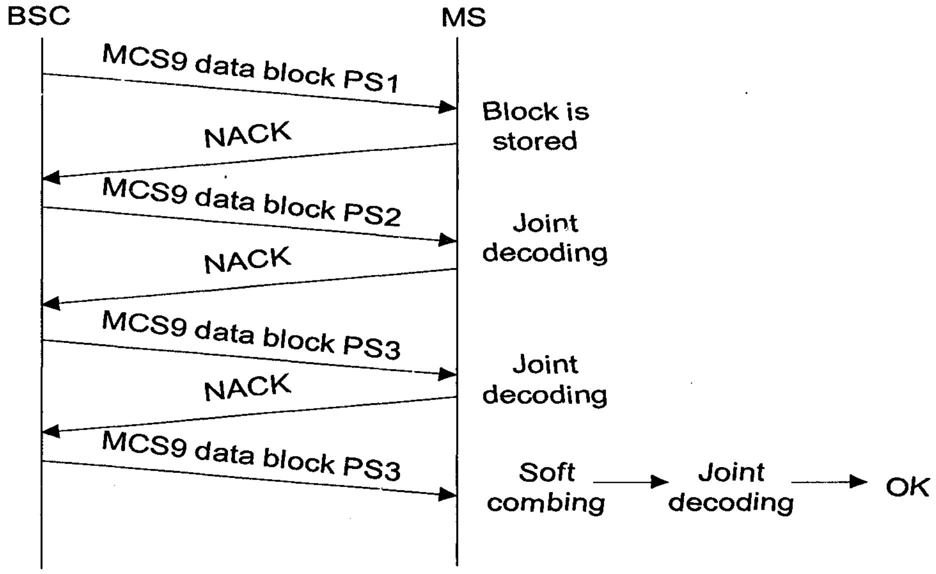


Figure 2.4 EGPRS Incremental Redundancy

If the buffer of the MS overflows or too many retransmissions occurs, the link adaptation process is triggered to use a lower coding scheme. By using the link adaptation and the IR, EGPR greatly improves the network packet data throughput.

2.3 GPRS Mobility

2.3.1 GPRS Radio Access Network Structure

An MS can be in packet idle mode, or packet traffic mode in a GPRS network. In idle mode, the network is based on the traditional GSM network. The geographical area covered by a GSM network is divided into different location areas. An MS notifies the network when each time it changes the location area and does the attachment procedure.

In GPRS, the same principle is applied and the area is called a Routing Area. A routing area can be smaller, yet is always included in a GSM location area.

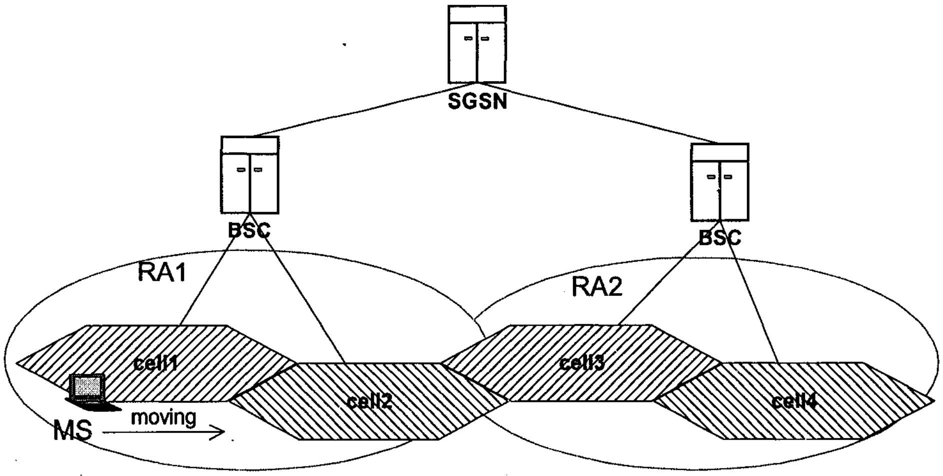


Figure 2.5 Routing Area in a GPRS network

In Figure 2.5, the Routing Area RA1 contains cell1 and cell2, and the Routing Areas RA2 contains cell3 and cell4.

The procedures used in GPRS for mobility management are similar to those used in GSM.

If the MS is powered off or becomes unreachable, a process called 'GPRS detach' is initiated to inform the network that the MS will be unreachable. If the MS is powered on and becomes reachable, the MS will send a 'GPRS attach' message to inform network to update the state of the MS.

When the MS moves from the coverage of one routing area to another, the MS should send a 'Routing Area Update' to inform network of the MS's location. If the MS moves from one cell to another which is under the same routing area, the MS may perform 'Cell Update' procedure to indicate the change of the serving cell of the MS.

In Figure 2.5, the MS is moving from cell1 to cell2. Once the MS moves into the area of cell2, it will send a Cell Update message to inform the network that it camps on cell2. If the MS keeps moving and reaches the area of cell3, which is under the coverage of different RA2, it will send a Routing Area Update message to update its location information.

2.3.2 GSM Handover

Handover is one of the most important mobility management functions in a GSM network. Figure 2.6 shows a brief handover procedure in a GSM network.

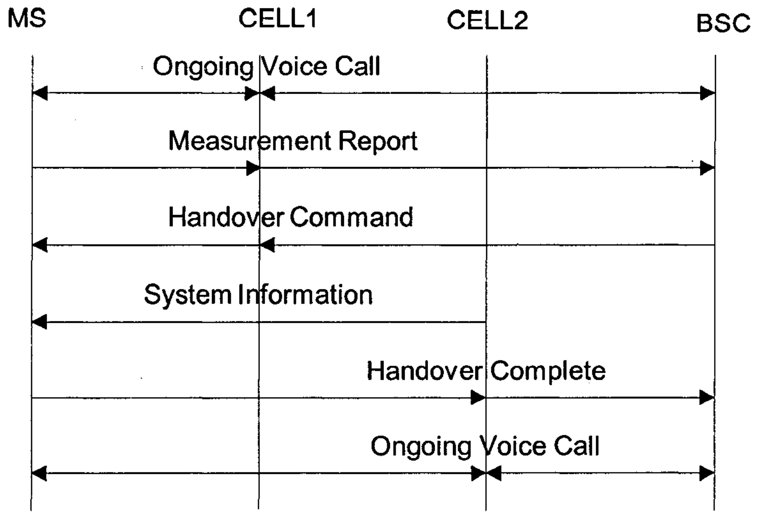


Figure 2.6 GSM Handover Procedure

Once a call is set up, the MS keeps sending Measurement Report to the BSS network. The received radio signal strength level (RXLEV), the received voice quality (RXQUAL) of serving cell and the neighbor cells are incorporated in the Measurement Reports. If the Measurement Results of one of the neighbor cells are better than the serving cell, i.e.

RXLEV (serving cell) < RXLEV (neighbor cell) + RXLEV (handover threshold),

RXQUAL (serving cell) > RXQUAL (neighbor cell),

the BSC may decide to make a handover.

If a handover procedure is triggered, the BSC will send a Handover Command message to the MS through cell1 (serving cell). After receiving the Handover Command message, the MS stops the voice traffic and starts to receive System Information from cell2 (the neighbor cell).

Once the MS receives the System Information of cell2 and makes preparation for a handover, it sends a Handover Complete message to the network to notify that the handover process has been completed. Then, the MS starts to transmit and receive voice traffic in cell2.

2.3.3 GRPS Cell Reselection / Handover

Because the GPRS and the GSM share the same radio access network, they have many common mobility management functionalities, such as PLMN (Public Land Mobile Network) roaming and attachment/detachment.

In the GPRS network, a handover process is also called a cell reselection process.

If the GPRS MS moves from the coverage of cell1 towards cell2, the radio signal strength of cell2 will get stronger than cell1. If the difference of received signal strength between cell1 and cell2 exceeds the handover threshold, the MS may trigger cell reselection/handover procedure.

In the GPRS networks [25], there are two kinds of cell change procedures, 'Normal Cell Change' and 'Network Assisted Cell Change' (NACC).

From Figure 2.7, we can figure out a typical procedure of cell change without NACC. Once the MS decides to perform cell reselection, it starts to read the System Information in the new cell2 while still hanging on the old cell1. The MS must receive all System Information before being allowed to access to the target cell. This procedure usually may take up 2~5 seconds.

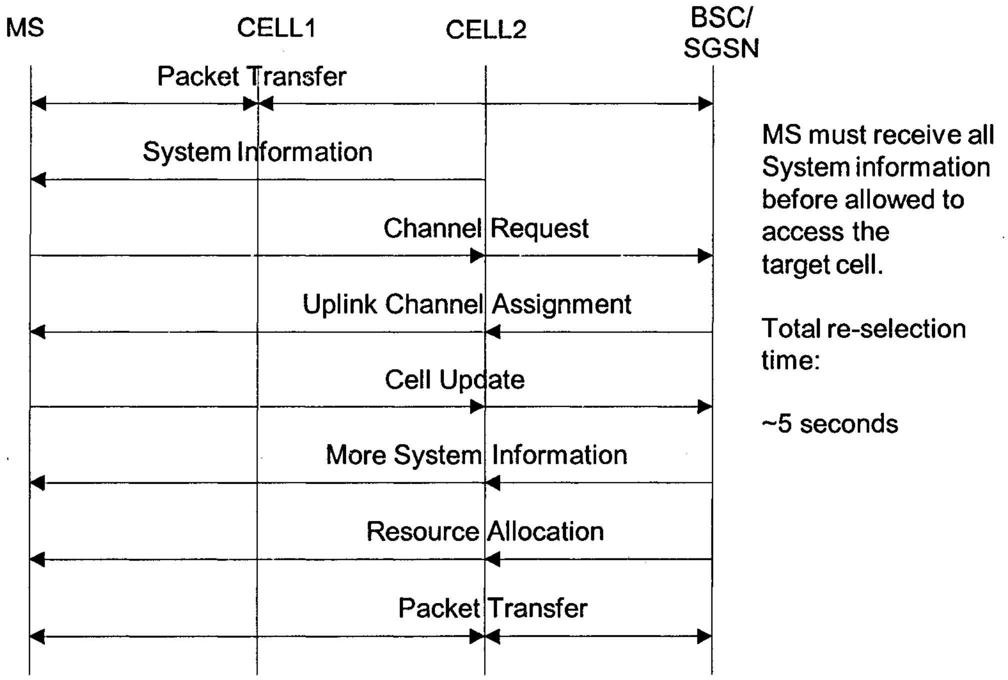


Figure 2.7 GPRS Cell Reselection Procedure without NACC

With NACC, Figure 2.8 indicates the information exchange among the MS, cell1 (old cell), cell2 (new cell) and the BSC/SGSN during a cell reselection procedure.

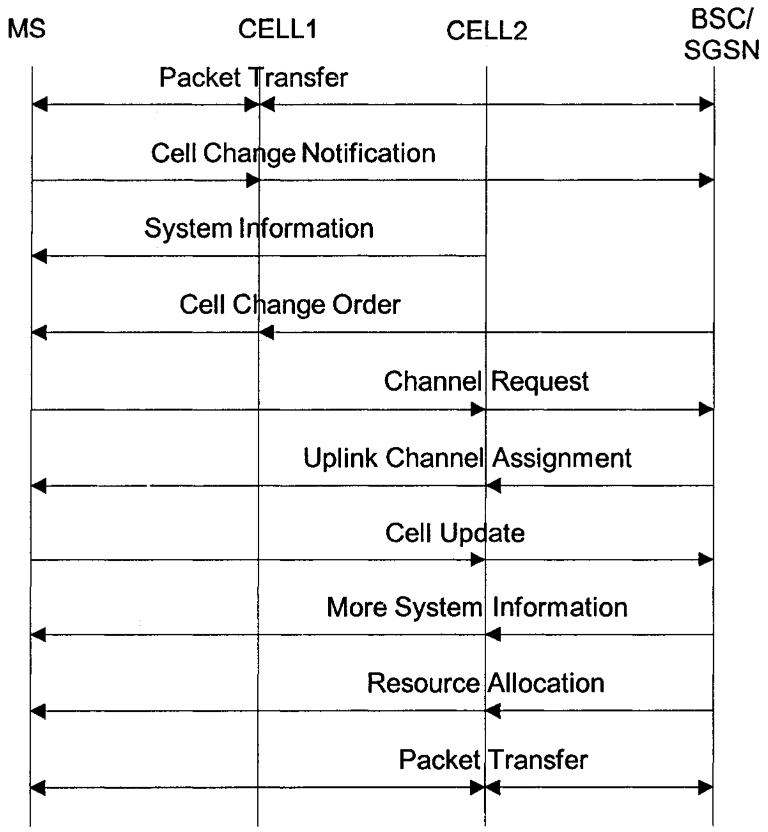


Figure 2.8 GPRS Cell Reselection Procedure with NACC

When the MS decides to perform a cell change, it sends a Cell Change Notification to the BSC/SGSN, and then starts to get the System Information from the new cell2.

The SGSN/BSC sends a Cell Change Order through the cell1 to the MS to notify the MS to start a cell change. The MS does not have to wait for receiving all the System Information to access the new cell2.

Upon the receipt of the Cell Change Order, the MS requests a new uplink channel from the cell2. Once the MS is assigned to an uplink channel, it sends a Cell Update to the SGSN/BSC to acknowledge the Cell Change Order from the SGSN/BSC.

If the MS needs more System Information, the SGSN/BSC sends such information to the MS through cell2 after receiving the Cell Update.

The MS is now camping on the new cell2 and resource allocation procedure will start to resume the packet transfer.

By using NACC, the MS handover time can be greatly reduced. Furthermore, the reliability is improved so that the MS can achieve a lower frame loss rate during the handover.

Chapter 3 Handoff Procedures Simulation in Integrated GPRS (EGPRS) and WLAN Network

3.1 Introduction

New technologies such as the video conferencing, the interactive multimedia service are more adopted by mobile users. With the surging needs of high-speed data service of mobile subscribers, more and more efforts are made on the integration of different types of mobile networks. The GPRS and the WLAN are mature systems and have been available in the market for years. The GPRS network's planning is focusing on good coverage and mobility support, on the other hand, the WLAN can provide more bandwidth. By seamlessly and efficiently integrating the GPRS and the WLAN network together, these two technologies can complement each other and give a better resource distribution solution. In places where high-speed data service is in high demand, such as business centers, enterprise locations, airports, the deployment of Access Points may relieve the congestion of the network. In places where there are not too many mobile users who need high-speed data services, a general coverage provided by a cellular network will be cost effective.

When it comes to the integration of cellular and WLAN networks, there are certain issues to be solved: the common billing and the customer care, the 3GPP system-based access control and charging, the access to 3GPP GPRS-based services, the access to 3GPP circuit-switched services, seamless service, and service continuity, and the like.

3.2 System Architecture

In [26], two typical architectures of integrated network are proposed: a tight architecture and a loosely coupled architecture.

A tight architecture uses the GPRS methods of authentication, authorization and accounting (AAA). The GPRS core network and the protocol is fully reused. By introducing a GPRS interworking function (GIF), a WLAN/LAN network can be perceived as a transparent Radio Access Network. Seamless and continuous network service can be provided when an MS moves between the GPRS and the WLAN network by using the GPRS mobility management mechanism.

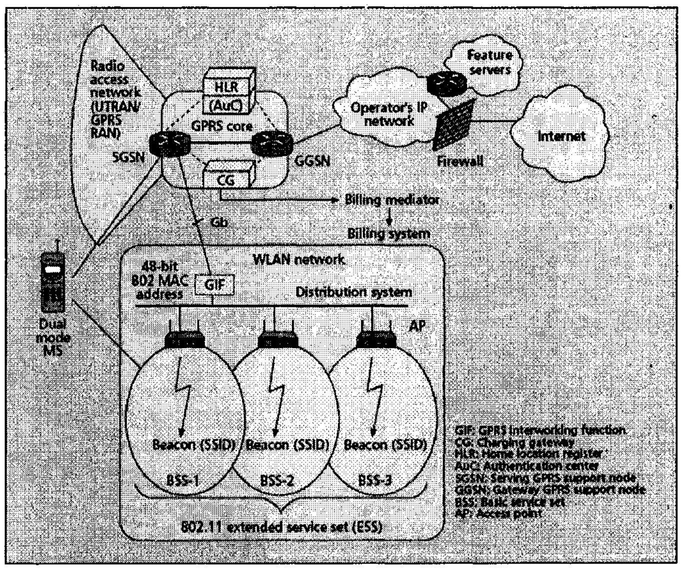


Figure 3.1 Tight Architecture for integrated network

In a loose architecture network, the traffic data in a WLAN will be sent directly to the operator's IP network instead of passing through the GPRS core network. AAA may be supported by both a GPRS and a WLAN network. An integrated billing system can handle the information collected from both networks. Mobile IP network will be used to present session mobility between GPRS and WLAN networks.

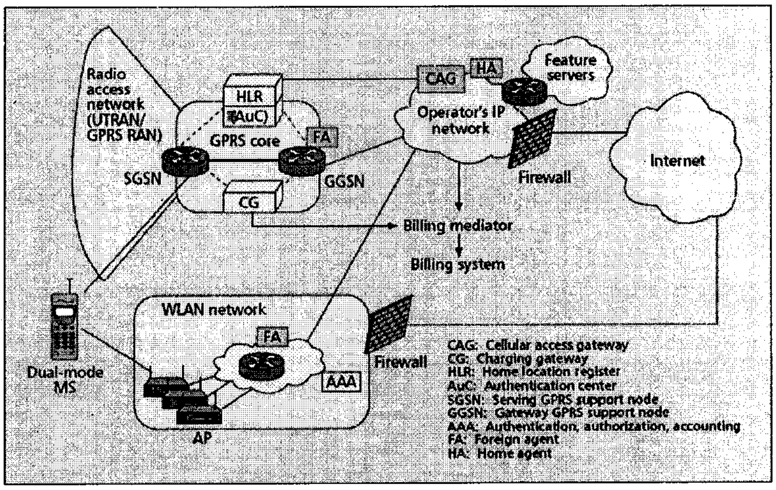


Figure3.2 Loose Architecture for integrated network

Both tight and loose architectures provide feasible solutions for the integration of a GPRS and WLAN network. A tight architecture is more apt to be adopted by a GPRS owned operator as it mostly reuses the current GPRS network resources and is a cost efficient system. The network can provide high reliable mobility for subscribers. A loose architecture network is more flexible and provides better support for all legacy WLAN and GPRS terminals, and is easily extended to non-GPRS technologies, such as CDMA2000 and WCDMA.

3.3 Handoff between GPRS and WLAN network

Handoff is a key issue for the mobility management of a wireless network. A number of works have been done on how to design system architecture for better support the MS's seamless wireless service. In this thesis, a typical tight architecture is assumed. A

WLAN is taken as a radio access network, in which the Access Points are equivalent to the Base Stations in the cellular network.

Some works have been done on the handover analysis of hybrid integrated networks [27-30].

In this work, based upon the characteristics of the GPRS and the WLAN network, a new efficient handover algorithm is proposed and implemented in the simulated network.

For a WLAN, the AP has a maximum service radius, i.e. APMaxRadius. An MS cannot access network through an AP if the distance between the MS and the AP is more than APMaxRadius for a certain time (Timer2). If an MS served by an AP moves away from the AP, handoff will be triggered if the distance between the MS and the AP reaches a distance threshold, i.e. APHODistance.

Likewise, for cellular networks, a BS has a maximum service radius BSMaxRadius. An MS cannot access network through a BS if the distance between the MS and the BS is more than BSMaxRadius for a certain time (Timer1). If an MS served by a BS moves away from the BS, handoff will be triggered if the distance between the MS and the BS reaches a distance threshold, i.e. BSHODistance.

For a slow-moving MS, i.e. Velocity<APMaxSpeed (AP maximum allowable velocity), WLAN has the higher priority for access and/or handoff. If no Access Point is available, GPRS network will be considered.

For a fast-moving MS, i.e. Velocity>= APMaxSpeed, a WLAN will not be considered to be a service provider for access and/or handoff. If no BS is available, a call will be blocked if a new call request is denied, or a call will be dropped if a handoff request is denied.

For a cellular network, a portion (HOSpareBS) of total capacity is reserved for handoff. If the percentage of remaining resource is less than HOSpareBS, any resource allocation for new call request will not be granted; only handoff request will be granted provided that there is enough resource available.

For a WLAN network, a portion (HOSpareAP) of total capacity is reserved for handoff.

Such conditions will be elaborated upon and explained in the flow diagram of Figures 3.4 to 3.8.

3.4 Simulation Procedure of Handoff between GPRS and WLAN network

In order to analyze the detailed performance of the integrated network, especially with the introduction of the proposed handover algorithm, a computer simulation was conducted for the operating of a WLAN and GPRS integrated network.

3.4.1 Simulation Environment

The simulation is implemented with C++ programming language. A seamlessly integrated network is assumed, based on which a handoff algorithm is designed.

In the simulation, an AP with capacity 1Mbits/second is assumed. A BS is assumed with 5 radio frequency carriers and 13Kbits/second per air channel. MS are divided into three groups based on their data rate requirements. Maximum MS data rate requirement is 200Kbits/seconds in the simulation. In real network, the AP and the BS can have more capacities, and the MS may have more data rate requirement as well.

Big traffic load is introduced to achieve more actual performance results. There are around 20,000 simulated packets (the average packet size is 16Kbits) being handled if the simulation program is executed one time. Performance result data is collected based on the average value of 20 times of the execution of the simulation program.

The following input parameters are used in this simulation to simulate an integrated network. Some input parameters are varied in a mentioned range. Input parameters combinations are also considered to achieve optimal performance results.

1) Testing area RANGE: $RANGE^2$=10000x10000 m^2
2) Number of GPRS Base Stations BSNumber: 4
3) Number of radio carriers per GPRS Base Station: 5
4) Maximum transmission range radius for GPRS Base Station:4000m
5) Maximum transmission range radius for WLAN Access Point: 300m
6) Channel/ time slot data rate for Base Station: 13Kbps
7) Channel rate for WLAN Access Point: 1Mbps
8) Number of WLAN Access Points APNumber: variable in the range(1, 200)
9) Number of Mobile Users: 1000
10) Average Packet size Pcket_Size: 16Kbits
11) Packet error rate for WLAN: 3%

12) Packet error rate for GPRS: 1%

13) Total Simulation time: 100000 loop unit

14) Loop unit time One_Loop_Time: 16μs

15) Average MS moving velocity user velocity: variable in the range(1, 100) Km/hour

16) Access Points' position coordinates x, y: randomly chosen in the range (0,10000) meters

17) Capacity reserved for handoff in Access Point (percentage) HOSpareAP: variable in the range (1%, 10%)

18) Capacity reserved for handoff in Base Station (percentage) HOSpareBS: variable in the range (1%, 30%)

19) Distance for handoff triggering in Base Stations BSHODiatance: variable in the range (100, 3000) meters

20) Distance for handoff triggering in Access Point APHODiatance: variable in the range (10, 200) meters

21) Average traffic per user Au: 0.03 Erlang

22) Average packets number per call cPacket: variable in the range (1, 50)

23) Low data rate use percentage (20~60Kbps) Group1: variable in the range (0, 100%)

24) Medium data rate percentage (60~100Kbps) Group2: variable in the range (0, 100%)

25) High data rate MS percentage (100~200Kbps) Group3: variable in the range (0, 100%)

A total of 4 GPRS Base Stations are confined to an area of 10000 meters wide and 10000 meters long. The four Base Stations in the simulation have position coordinates (x, y) of (2500, 2500), (2500, 7500), (7500, 2500), (7500, 7500) respectively. Figure 3.3 depicts the general simulation environment with four BSs evenly distributed in the simulated square area. Each Base Station has 5 radio carriers and 1 time slot is dedicated to the signaling channel. As a result, a BS has a total capacity of (5x8-1)*13=507 Kbps. A certain number of WLAN Access Points are integrated into the system. Access Points are randomly distributed in the simulated area. Each AP has a total capacity of 1Mbps. Every MS has its own movement direction, which is randomly determined and then kept the same throughout the whole simulation.

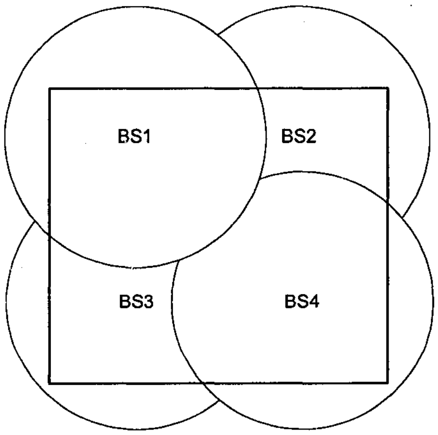


Figure 3.3 Simulation Environment

Based on the average traffic per user Au (in Erlangs), and the average user data rate

$\text{Rate}_{\text{average}}$. Average call holding time Hold_Time can be calculated as follows.

$\text{Rate}_{\text{average}}$=Group1*40+Group2*80+Group3*150,

where Group1 is the percentage of mobiles users which has a data rate between 20KB and 60KBytes/second. Group2 is the percentage of mobiles users which has a data rate between 60KB and 100KBytes/second. Group3 is the percentage of mobiles users which has a data rate between 100KB and 200KBytes/second.

Hold_Time=cPacket*Packet_Size/ $\text{Rate}_{\text{average}}$.

To simplify the above formula, packet error and resend are not taken into account for the calculation of the average call holding time.

Au denotes the average traffic per user (in Erlangs). The probability of call origination requests which are taking place during One_Loop_Time can be calculated as follows:

Prob_Call=(Au/Hold_Time)*One_Loop_Time.

According to the previous results, call origination request is simulated on an individual MS basis.

3.4.2 Performance Criteria

For further analysis of the performance of the integrated network, some performance criteria are introduced in the simulation. They are Total Throughput, Call Successful Rate, Total Handover Rate, Packet Sent by AP/BS Rate, AP/BS Resource Utilization and Average Packet Error Rate. The simulation is focusing on the throughput and handover performances. Some other performance criteria, such as packet delay, buffer usage, etc are not considered in this work.

1) Total Throughput

Total throughput is defined as successful throughput (Kbits/second) for the integrated network, including both throughputs provided by a WLAN and GPRS network.

2) Call Successful Rate

Average call successful rate is defined as the number of new successful calls out of the total number of new call attempts.

Call successful Rate = number of new successful calls / total number of new call attempts.

3) Total Handoff Rate

Total handoff rate is defined as the number of handoff calls out of the total number of successful calls. There are four kinds of handoffs: BS-to-BS handoff, BS-to-AP handoff, AP-to-BS handoff and AP-to-AP handoff.

Handoff rate = number of handoff occurrences / number of successful calls.

4) Packet Sent by AP/BS Rate

Packet sent by AP/BS rate is defined as the number of packets sent by AP/BS out of the total number of packets generated during the simulation period.

Packet Sent by AP Rate= number of packets sent by AP /total number of packets sent,

Packet Sent by BS Rate= number of packets sent by BS /total number of packets sent.

5) AP/BS Resource Utilization

The use of APs/BSs is the actual packet sent by APs/BSs out of the total capacity of the APs/BSs. In the simulated network, an AP has a relatively high capacity. Nonetheless, owing to the small coverage of an individual AP, the utilization of the APs may be rather low.

AP Resource Utilization= Actual AP resource used (Kbps) / total AP capacity (Kbps)

BS Resource Utilization= Actual BS resource used (Kbps) / total BS capacity (Kbps)

6) Average Call Blocked Rate

Average call blocking rate is defined as the number of blocked calls out of the total number of new calls. Calls can be blocked due to no resource available for a new call request.

Average Call Block Rate= number of blocked calls / total number of call attempts.

7) Average Packet Error Rate

Average packet error rate is defined as the number of packets in error divided by the total number of sent packets.

Average Packet Error Rate= number of packets in error / total number of packets sent

Due to the radio characteristic of WLAN, call served by APs has a relatively high packet error rate than the calls served by BSs. In this simulation, for simplicity, it is assumed that the Average Packet Error Rate of AP is 0.03 and the Average Packet Error Rate of BS is 0.01.

As a result, the Average Packet Error Rate can be derived by the following formula:

Average Packet Error Rate= (number of packets send by AP * 0.03 + number of packets send by BS * 0.03) / total number of packets sent

3.4.3 Handoff Simulation Algorithm and Implementation

Figure 3.4 depicts the general flow of the handoff simulation. Four cellular BSs are predefined for the simulation. An initialization process is called to randomly generate a number of WLAN APs with coordinates (x, y). A number of MSs are generated with their userID, initial position coordinates (x, y), data rate requirement, movement speed (v) and direction (θ).A location update process is called to refresh the environment information of each MS every 50 iterations. Call origination request is randomly generated found on the Prob_Call, which is derived form Au, call holding time and iteration time.

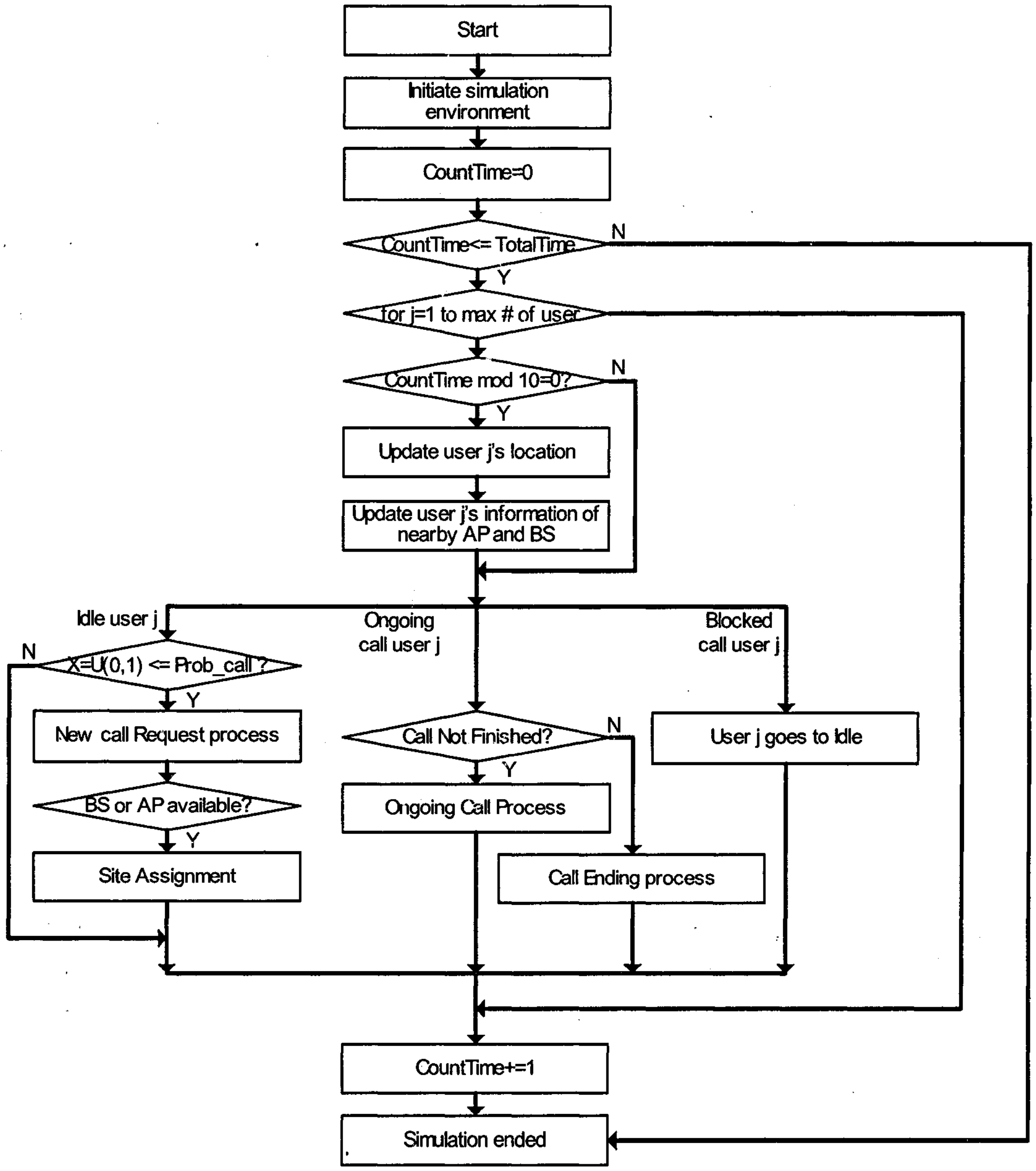


Figure 3.4 Simulation Main Flows

The new call request process, as in Figure 3.5, handles the origination request for an MS. When an MS originates a packet data call, it will search for the available service point first. For the slow moving MSs, once they find there is a WLAN available, nearest Access Point will be selected as the initial service point. The MS will send a call origination request in which a minimum and a maximum data rate are specified. If the Access Point has adequate bandwidth for the service request, the network will grant the service request and allocate resources for the MS. If there is no enough resource available in the Access Point, another Access Point will be chosen. If there is no Access Point available, cellular Base Station will be selected. If no Base Station is available, the call origination request will be blocked. For the fast moving MSs, the nearest BS will be selected as the initial service point. If there is no BS available, call origination request will be blocked. The term "available" means an MS is under the radio coverage of service point which has sufficient bandwidth for supporting the MS's request, either due to call origination or handoff.

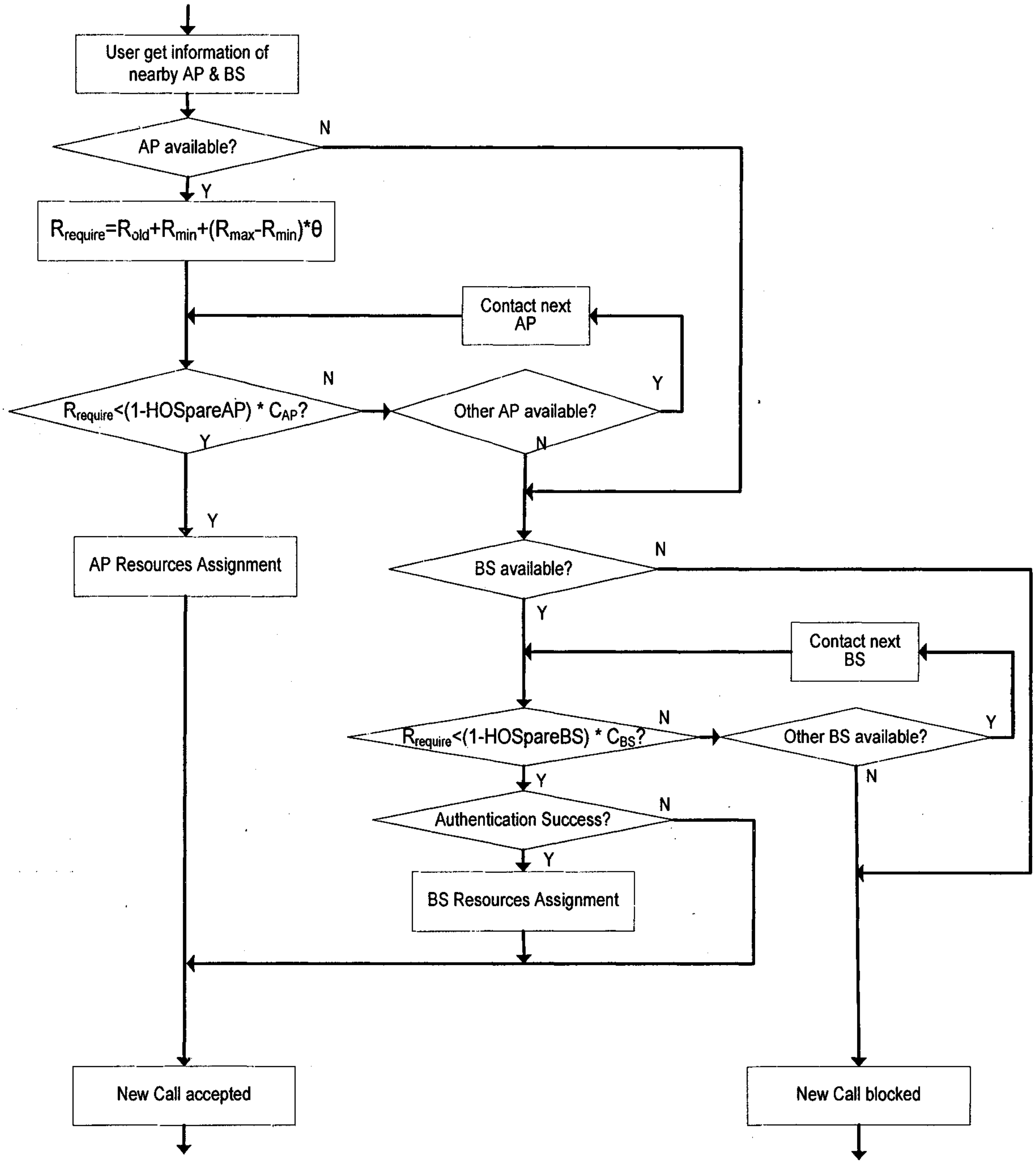


Figure 3.5 New Call Request Process

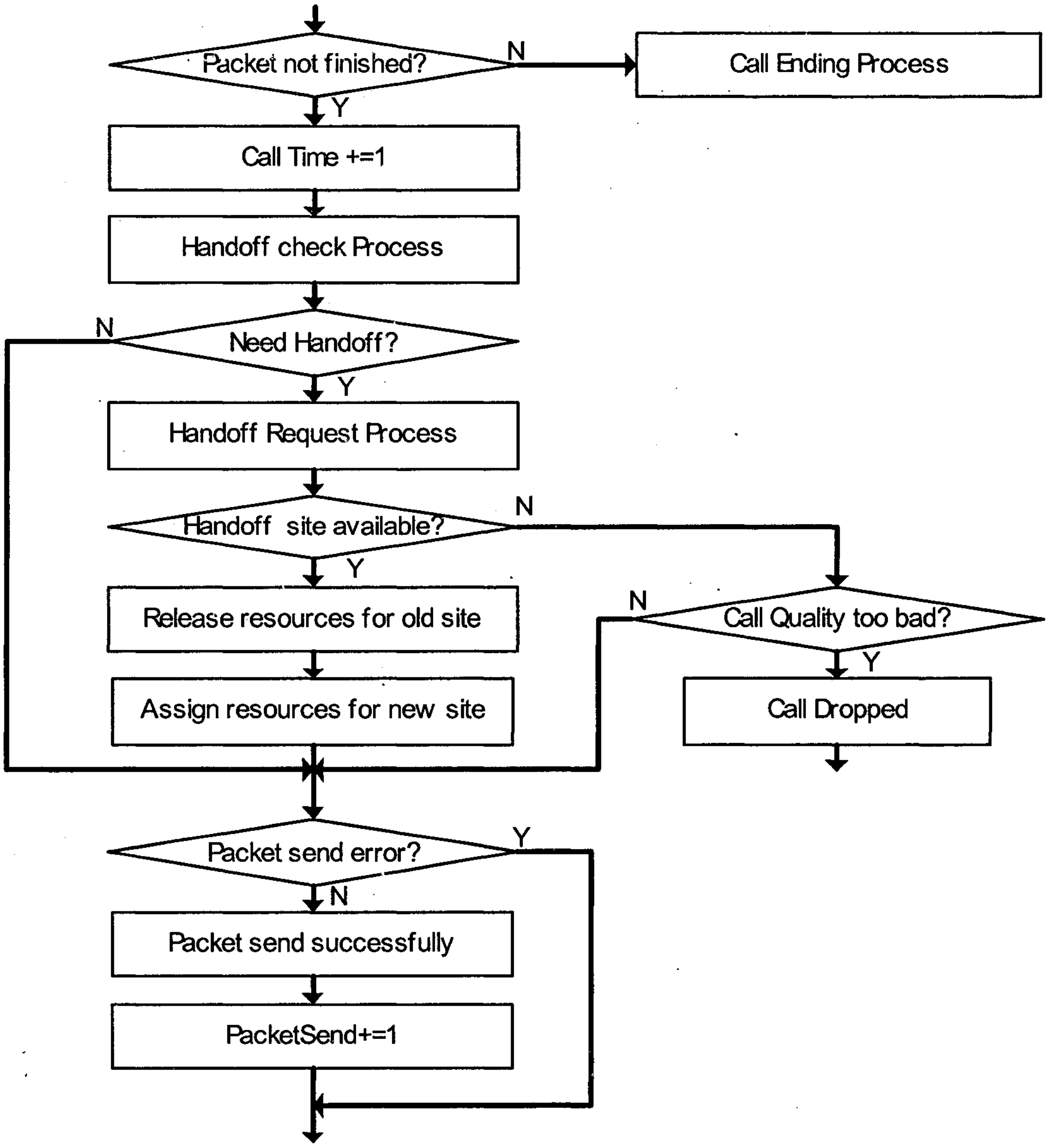


Figure 3.6 Ongoing call processes

Once the call origination request is granted, an MS starts to send its packets. An MS is now in call ongoing state. Figure 3.6 shows the flow chart of the implementation of ongoing call process. Handoff may take place when an MS is in ongoing call process. Based upon the service point type, various average packet error rate is applied. Typically, radio environment for a cellular network is more stable and has a lower packet error rate than a WLAN.

In this handoff algorithm, the homogeneous handoff, handoff between the differing BSs, is not encouraged when there is WLAN access available. If a slow-moving MS keeps moving out of current service point and the distance between the MS and the service point exceeds the threshold of handoff, the MS will start to search for a target service point to handoff. No matter what current service point type is, given a target AP is available, an AP Point is always considered to be a preferred target service point. If the current service point is a BS and a target BS has a higher priority as a target for handoff than an AP, because a GPRS network usually has a much better coverage than a WLAN, there would be very little possibility that an AP can be selected as a target service point for handoff. This will lead to uneven traffic distribution between a GPRS and a WLAN, i.e. a heavy traffic load in the cellular network and very low traffic load in a WLAN.

If handoff criteria is met and an AP is available, see figure 3.7, the call request will be granted and the call will be handed-off to the AP and the allocated resources in the previous service point will be released. If there is no AP available, a BS will be selected as a target service point based on its availability. If there is no BS available, i.e. there is no any target service point available, a handoff will not be granted and a call will still stay on the current service point. In any case, if the distance between an MS and a service point keeps increasing and exceeds the maximum transmission range radius, i.e. the channel conditions degrade and packet error rate exceeds a certain threshold, and a call will be dropped. To simplify, the distance between an MS and a service point, which is equivalent to the received signal strength and packet error rate, is regarded as the input to the Handoff Check process.

Two processes are involved in the implementation of the above algorithm, Handoff Check process (Figure 3.7) and Handoff Request process (Figure 3.8). Handoff Check is used to check whether the handoff criteria are met or not. If the criteria are met, a handoff will be triggered.

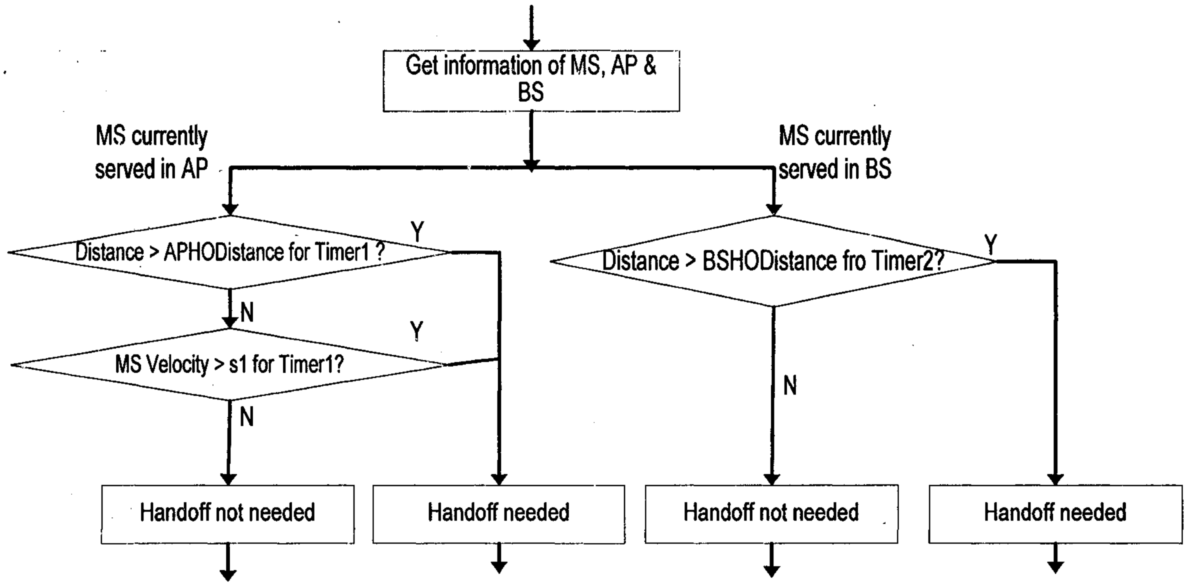


Figure 3.7 Handoff Check Process

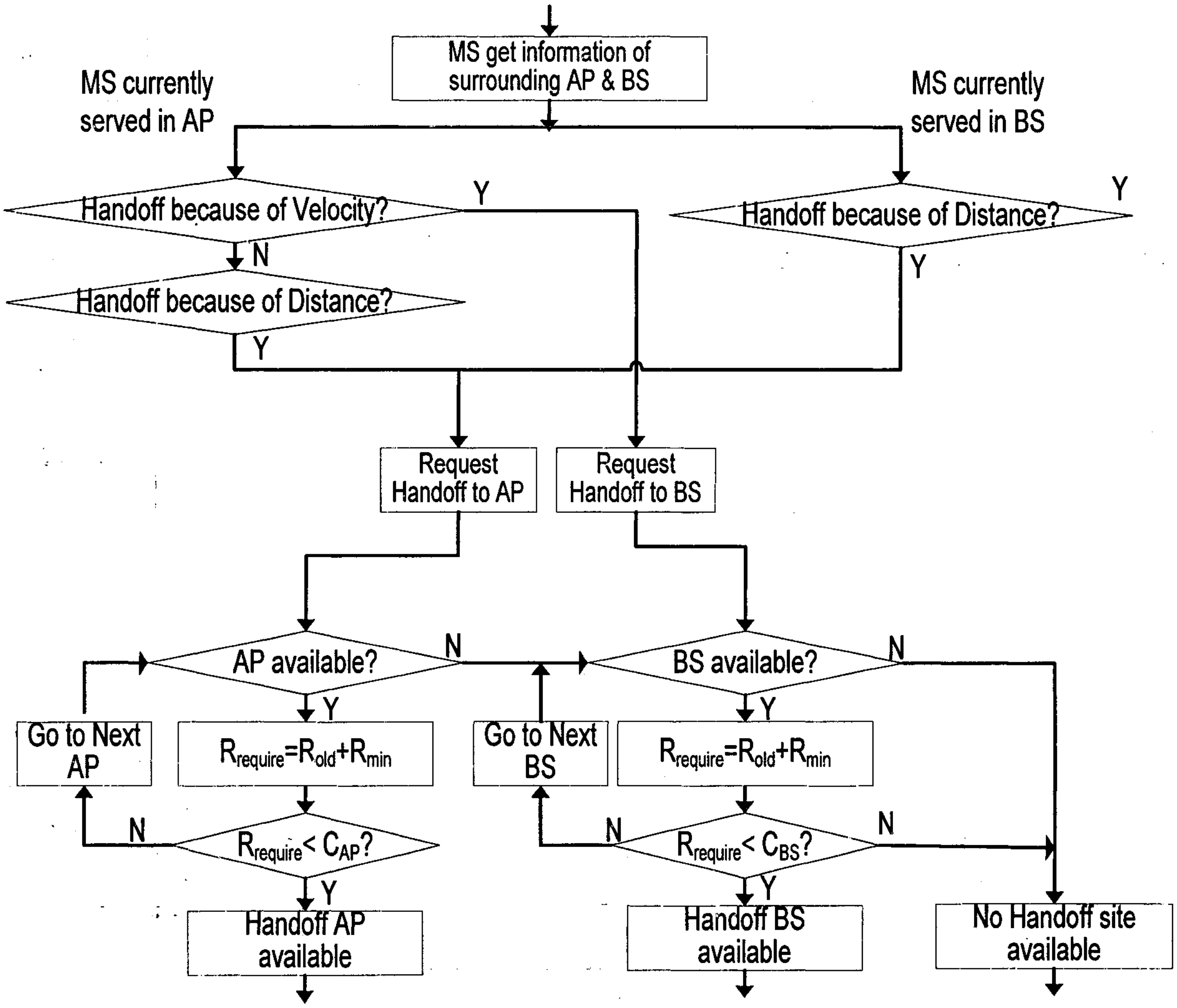


Figure 3.8 Handoff Request Process

If a handoff is triggered, Handoff Request process will be used to determine which BS or AP will be assigned as a target service point. In case, there is no target service point available, the handoff will fail and the call will still stay on the source service point.

If Handoff Request is denied and the packet error rate is higher than a predefined threshold for a certain time, the call will be declared as a loss.

3.5 Performance Result

3.5.1 Average Throughput

Figure 3.9 demonstrates that the total throughput decreases as the high-speed user rate decreases. High-speed user is defined as the MS that have a data-sending rate in the range from 100Kbits/s to 200Kbit/s. Higher data rate amounts to better utilization of the total resources, although it may contribute to more call blocking.

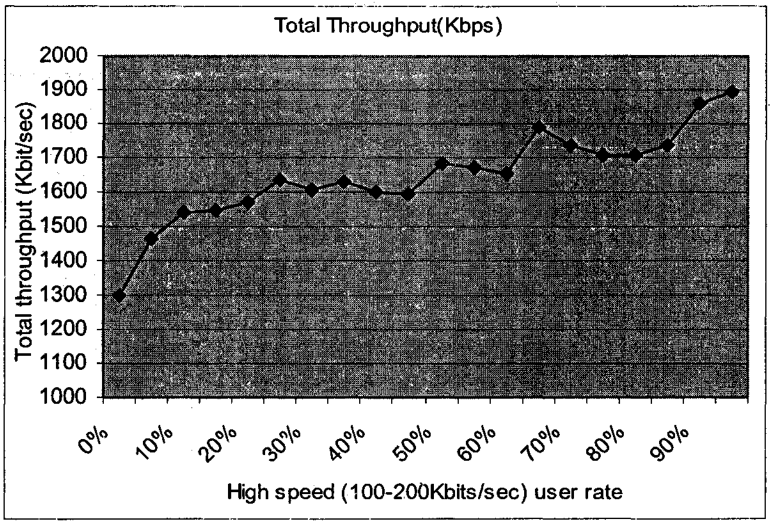


Figure 3.9 Total throughput versus High speed user (100-200Kbps) percentage

Figure 3.10 shows that if more capacity of a BS is reserved for handoff calls, the total throughputs will decrease accordingly. This is because if there is a large portion of capacity reserved for handoff, there will be relatively less capacity for new calls. Typically, the number of new call requests is much more than handoff requests. So there will be more call blocking and the utilization will decrease. On the other hand, because the capacity of WLAN is high, the increase of the spare capacity for handoff of APs will not affect the total throughput. From Figure 3.11, we can find out that the total throughput is truly steady and has no significant affect by the change APSpare.

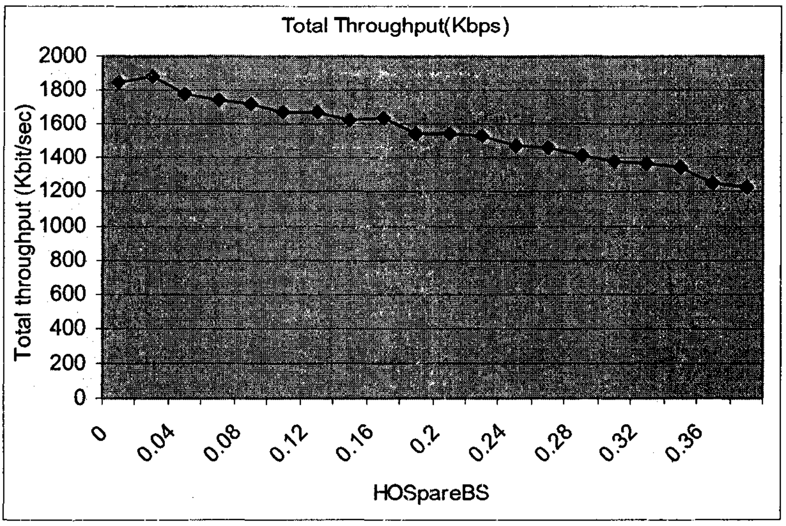


Figure 3.10 Total throughput versus Reserved capacity rate for handoff of BS (HOSpareBS)

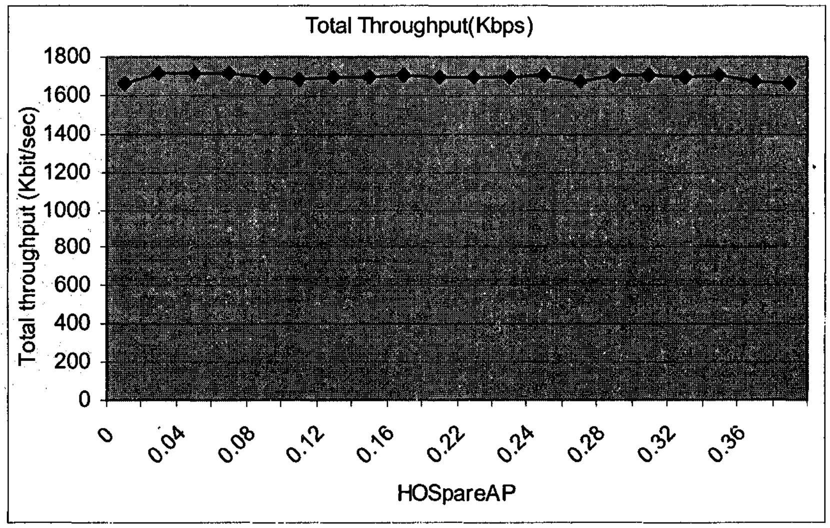


Figure 3.11 Total throughput versus Reserved capacity rate for handoff of AP (HOSpareAP)

Figure 3.12 reveals that too many APs in same area may not provide more throughputs when the average user speed is relatively high (average user moving speed is 50km/h in this figure). On the contrary, total capacity utilization may decrease dramatically with the increase in the number of APs (see Figure 3.13). When average user moving speed is relatively low, say 30Km/h, Figure3.14 shows that total throughputs will steadily surge with the increase of number of APs. In this simulation, the maximum allowable MS velocity in WLAN is 30Km/h.

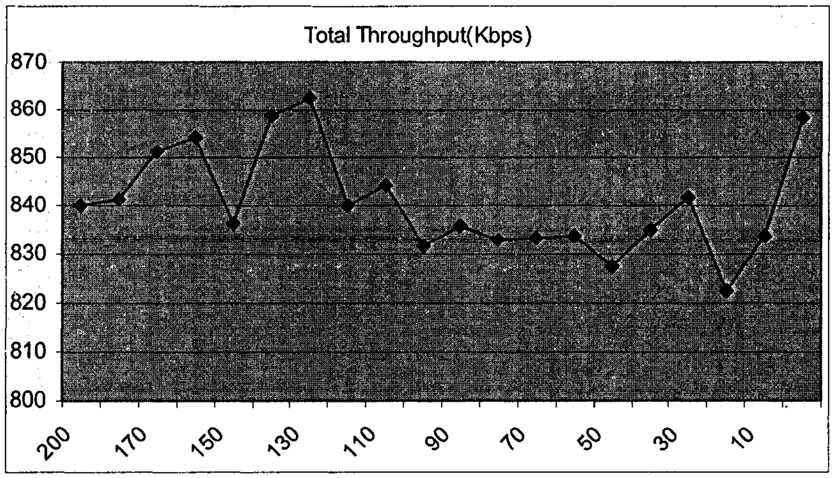


Figure 3.12 Total throughput versus number of APs (MS speed=50Km/h)

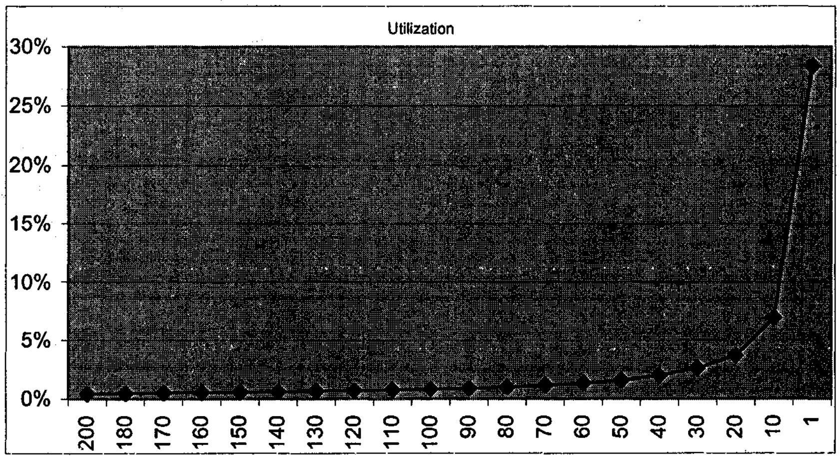


Figure 3.13 Total Capacity Utilization versus number of APs

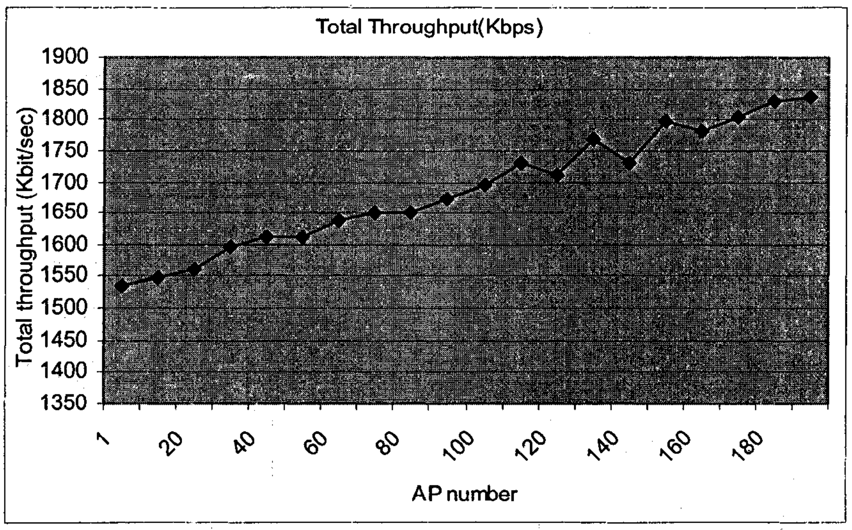


Figure 3.14 Total throughput versus number of APs (MS speed=30Km/h)

From Figure 3.15, we can be aware that the total throughput decreases when the average MS moving speed increases. This is because high moving speed may give rise to less usage of AP; an AP can only provide better service to a slow-moving MS.

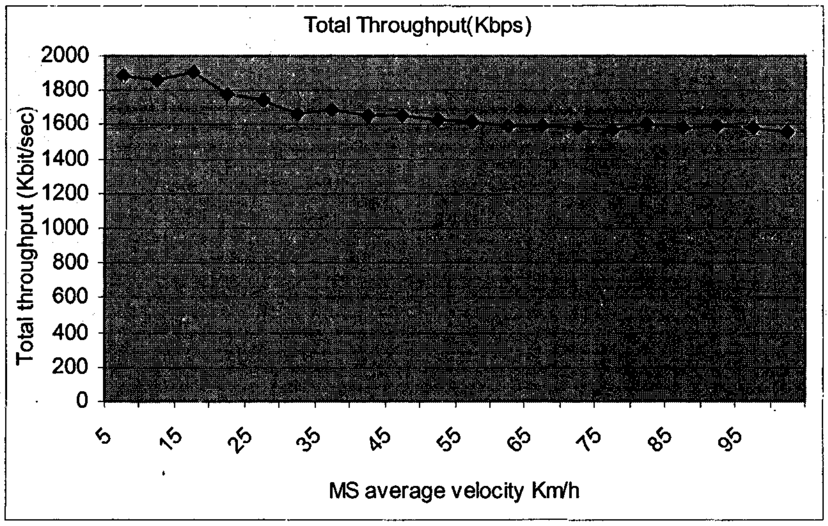


Figure 3.15 Total throughput versus average MS velocity (km/hour)

3.5.2 Average Call Successful Rate

Figure 3.16 indicates that call successful rate increases with the increase of the number of APs. This is because more APs bring more network capacity, and therefore more call requests can be granted. Apart from the increase of capacity, with the introduction of more APs, some radio coverage blind points of cellular network can be complemented. As a result, the radio service coverage of the whole area is improved.

Figure 3.17 expresses how the call successful rate is affected by the increase of the handoff reserved capacity of BS, HOSpareBS. The more the capacity reserved for handoff, the less the capacity the system has for new call requests. Because of a much larger radio coverage radius compared with a WLAN, cellular network provides the main coverage of the system. Seen from Figure 3.18, the packet sent by BS rate is very high, over 80%, even if we have a maximum AP number equal to 200. Thus, any change of the capacity of cellular network will significantly influcnce the total successful rate despite the number of APs in the system. If the HOSpareBS increases, the successful rate will decrease correspondingly.

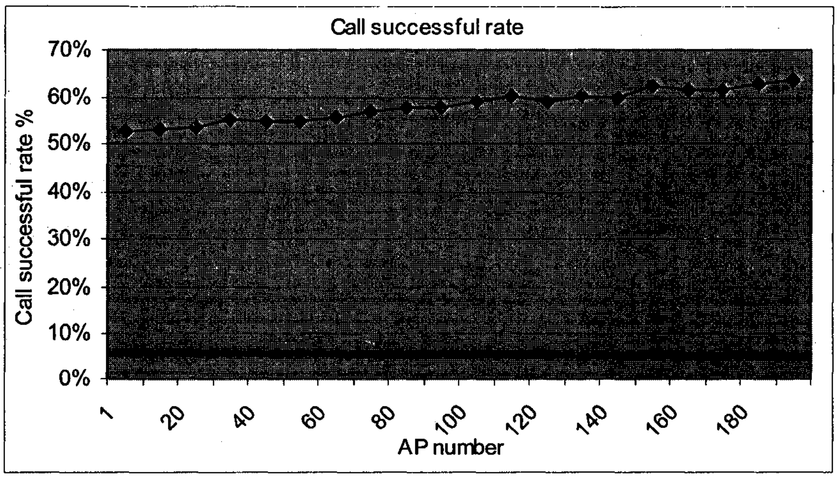


Figure 3.16 Call Successful Rate versus Number of APs

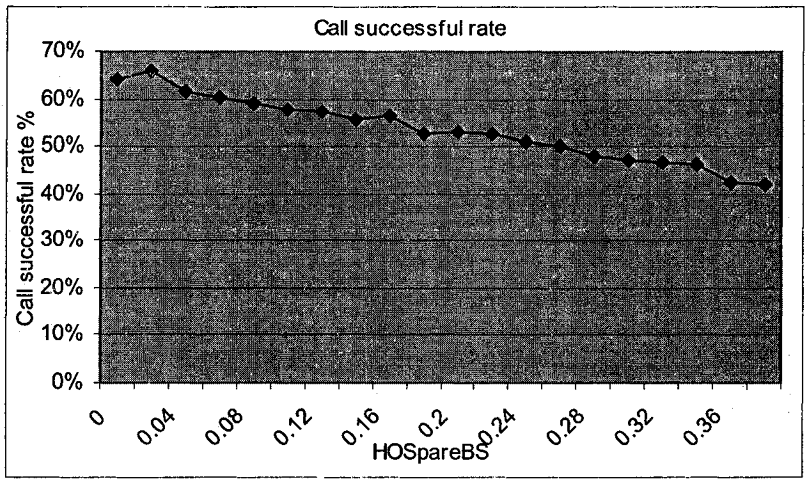


Figure 3.17 Call Successful Rate versus Reserved capacity rate for handoff of BS (HOSpareBS)

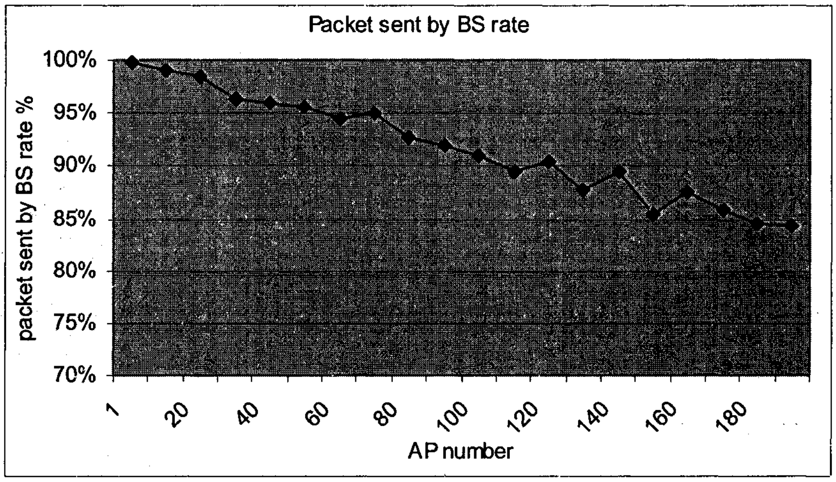


Figure 3.18 Packet rate sent by BS versus number of APs

In Figure 3.19, it can be seen that the call successful rate increases with the decrease of high-speed user, which has a data rate of 100-200Kbps. For a 0% high-speed user, call successful rate reaches almost 100%.

The average MS moving speed also affects call successful rate. We come to know that, from Figure 3.20, when the MS is moving at a higher speed, call successful rate will be lower. A fast-moving MS can be served only by cellular network and usually causes more handoff due to its movement. This will raise the potential call blocking rate and dropped rate. So call successful rate will decrease.

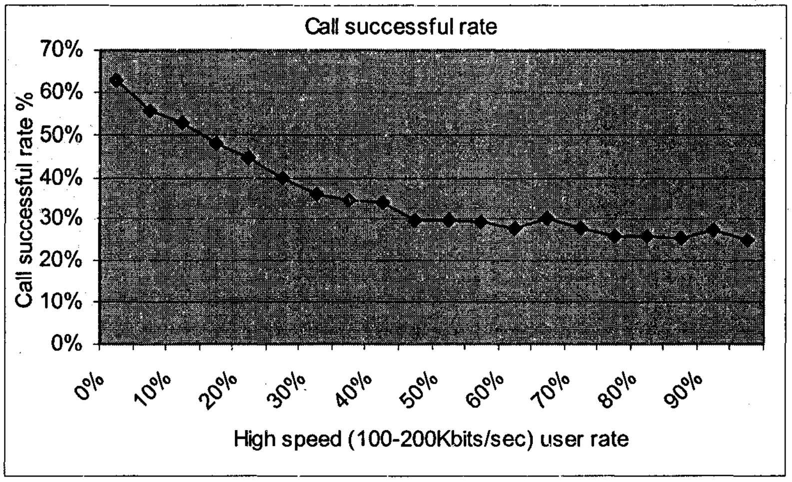


Figure 3.19 Call successful rate versus High speed user (100-200Kbps) percentage

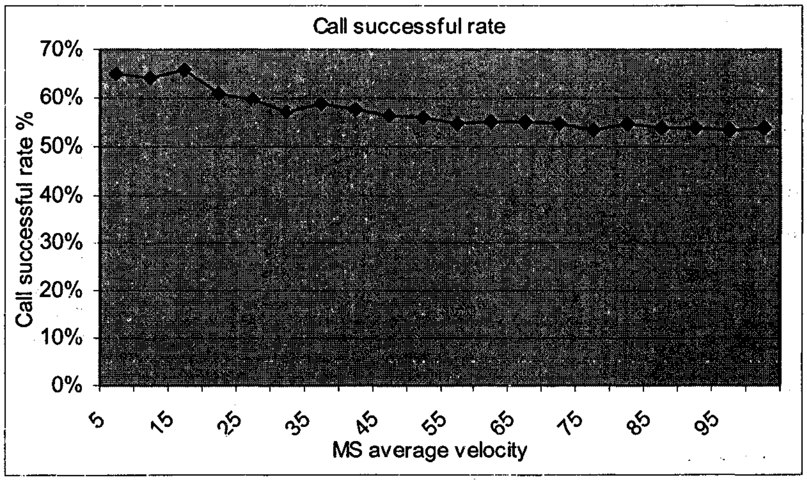


Figure 3.20 Call successful rate versus VS average MS velocity (km/hour)

3.5.3 Call Handoff Type Analysis

There are four kinds of handoffs: BS-to-BS handoff, AP-to-BS handoff, BS-to-AP handoff and AP-to-AP handoff. From Table 3.5.3.1 (the handoff rate here means the number of different types of handoffs divided by the total number of handoffs), we can discover that the average AP-to-BS and BS-to-BS handoffs are the most frequently occurring handoffs; the total of those two kinds of handoffs usually reach 99% of all handoffs. In most cases, the number of AP-to-BS handoffs is the most prevailing. The rates of the other two kinds of handoffs, BS-to-AP and AP-to-AP of handoffs, are very small and thus exert very little impact on the simulation performance.

As APs have a relatively small coverage and are randomly distributed in the simulation area, the chance of AP-to-AP handoff is very small.

An MS can have a high probability to be served by a BS as source, but it is not very easy to find an AP as a target to handoff because of the small coverage of a WLAN. This is why we have merely a small portion of BS-to-AP handoffs among all handoffs.

number of AP	1	50	100	200
HO AP->BS Rate	13.22%	92.05%	95.25%	96.48%
HO BS->BS Rate	86.34%	7.29%	4.21%	2.76%
HO BS->AP Rate	0.31%	0.44%	0.43%	0.52%
HO AP->AP Rate	0.00%	0.05%	0.10%	0.24%

Table 3.5.3.1 Average handoff rate of varied type handoffs

Figure 3.21 indicates that with the increase of the number of APs, the BS-to-BS handoff rate decreases, yet the AP-to-BS handoff increases. When there is a large number of APs, the probability that the source service point is an AP is high. Since the coverage of an AP is highly small, with the movement of the MS, call is very likely to handoff to cellular network. This is why the AP-to-BS handoff is the most frequently occurring handoff when the number of APs is high, As a BS has a good coverage, the handoff among BSs will also happen more often than not, even if less frequently than the AP-to-BS handoff.

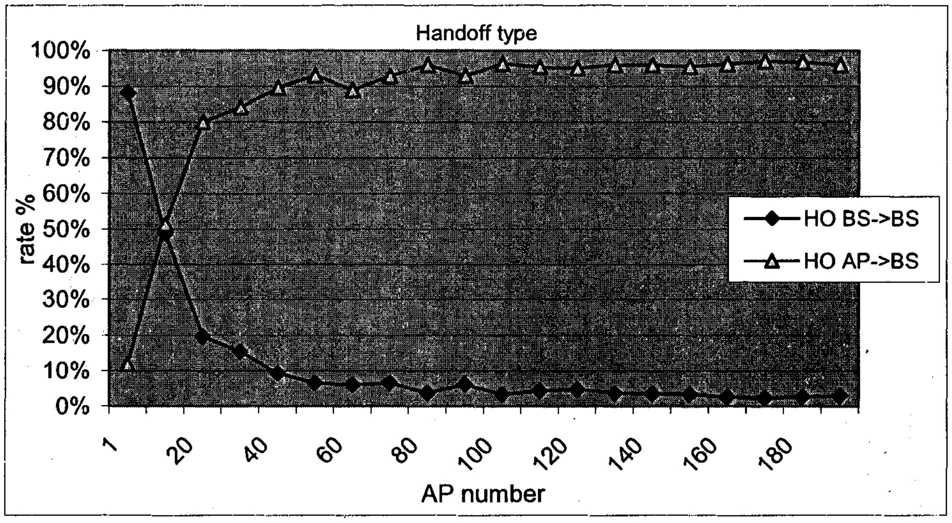


Figure 3.21 Varied Handoff rate versus number of APs

If the handoff triggering distance of a BS increases, Figure 3.22 shows that BS-to-BS handoff rate will decrease but AP-to-BS handoff rate will increase. If the BSHODistance is small, the probability of handoff will be high. As a BS always has a better radio coverage, so that the probability that handoff target service point is BS is higher than that of AP. That's the reason that we get a higher BS-to-BS handoff rate when BSHODistance is lower. On the other hand, when the BSHODistance increases, the handoff rate among BSs turns smaller, and as a result, we will get a higher rate of AP-to-BS handoff. As the previous result (Table 3.5.3.1), the rates of BS-to-AP and AP-to-AP of handoffs are very small.

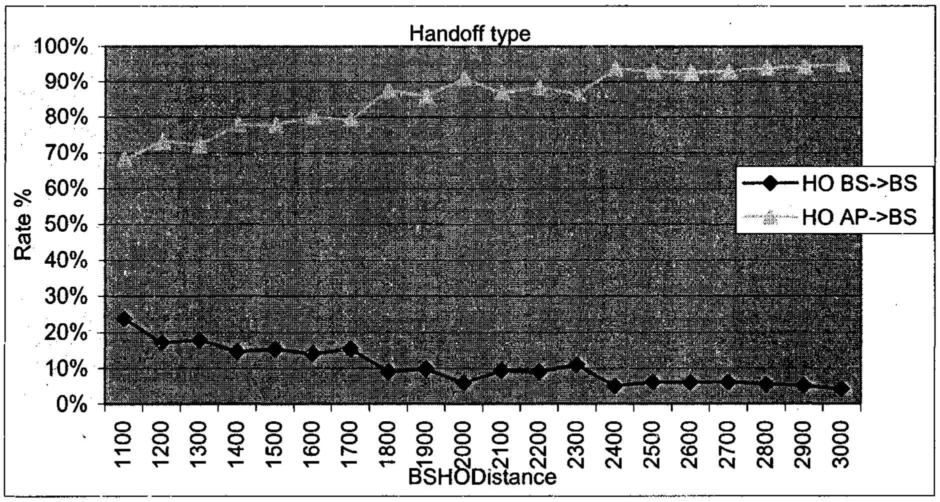


Figure 3.22 Varied Handoff rate versus handoff triggering distance of BS (BSHODistance)

Figure 3.23 displays how the different types of handoffs rate changes with the change of handoff triggering distance of APs. When APHODistance increases, total handoff rate will go down (see Figure 3.24). Because the APHODistance does not directly influence the number of BS-to-BS handoffs, the downside of total handoffs is mostly due to the decrease of the number of AP-to-BS handoffs. The percentage of BS-to-BS handoffs will increase accordingly.

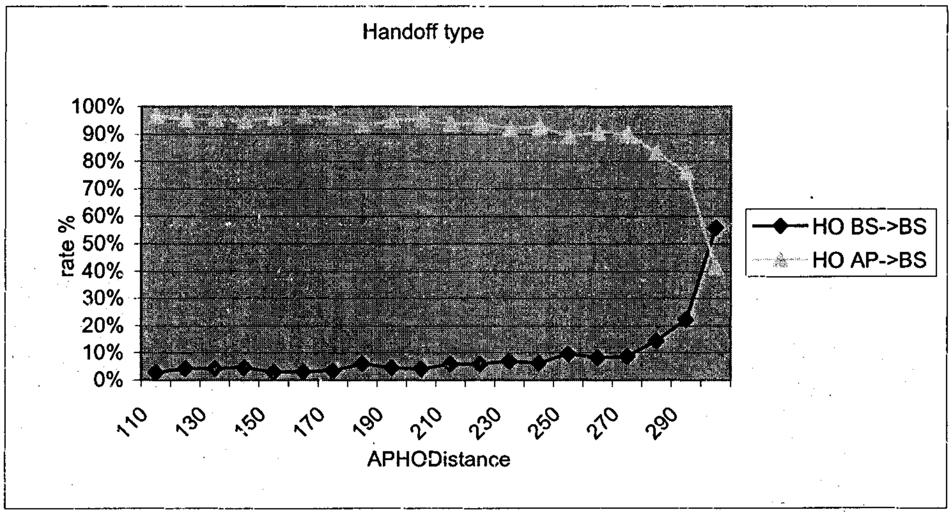


Figure 3.23 Varied Handoff rate versus handoff triggering distance of AP (APHODistance)

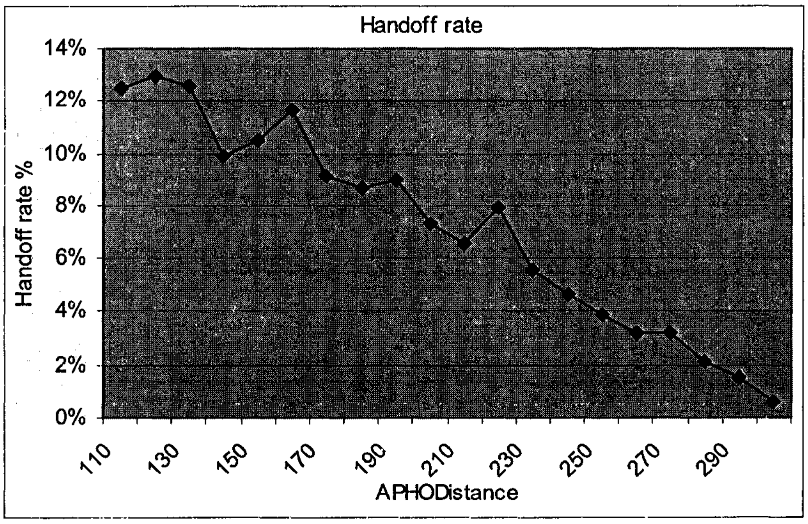


Figure 3.24 Total Handoff rate versus handoff triggering distance of AP (APHODistance)

Figure 3.25 manifests how the average MS moving velocity affects different handoff rates. With the change of velocity, the AP-to-BS and BS-to-AP handoff rates don't change significantly. A consistent result is that we still get a higher rate of AP-to-AP handoff, 88 to 98 %, and a less rate of AP-to-BS handoff.

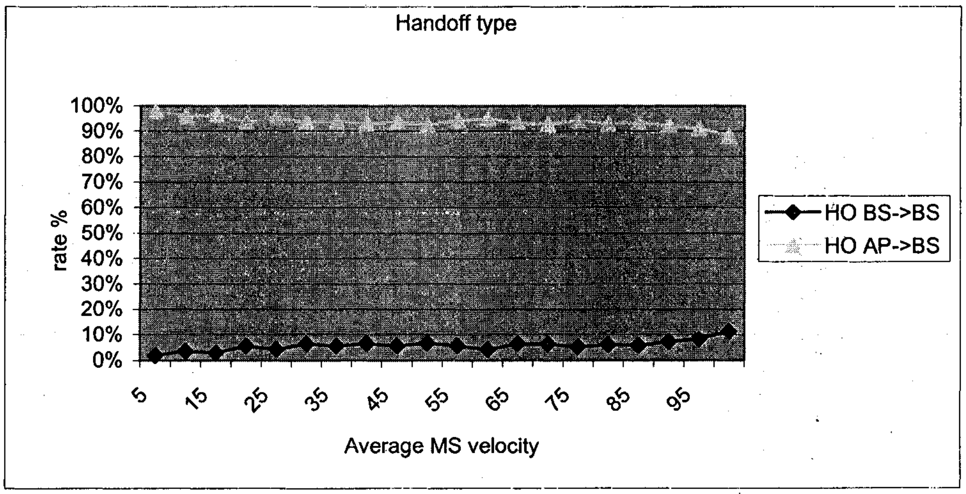


Figure 3.25 Variable Handoff rate versus average MS velocity (km/hour)

3.5.4 Call Handoff Rate

From the analysis in chapter 3.5.3, we have already seen that, under the most situations, the AP-to-BS handoff is the most frequently occuring handoff. In this section, we will look into the total handoff rate, i.e. the handoff probability. Figure 3.26 shows that, with the increase of the number of APs, the call handoff rate will increase accordingly. The more APs that are integrated into a cellular network, the more handoff will happen.

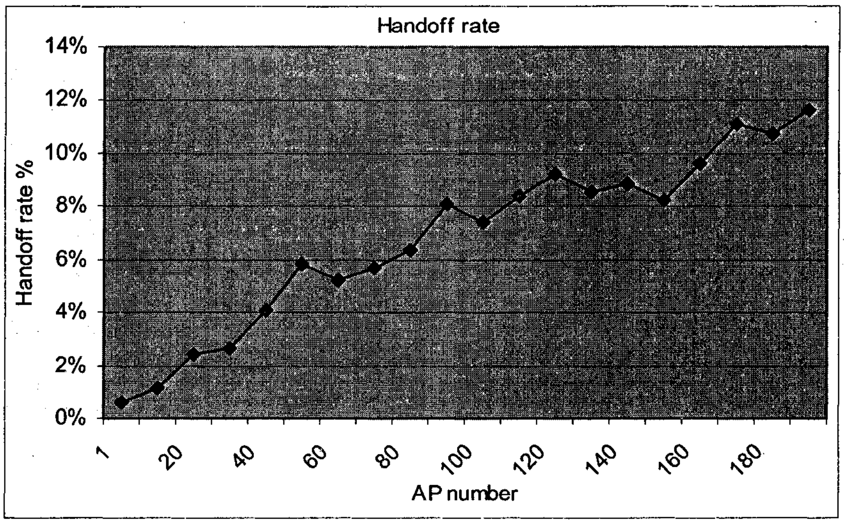


Figure 3.26 Handoff rate versus number of APs

Figure 3.27 reveals that the handoff rate increases with the increases of BSHODistance. A shorter handoff triggering distance of BS, BSHODistance, leads to a higher probability of handoff triggered from BS. And as a BS have much more coverage area than an AP, the change of BSHODistance has an immediate effect on the change of handoff rate. To avoid too many unnecessary handoffs, it is crucial to have a high value of BSHODistance, as long as the MS can be severed properly by the BS.

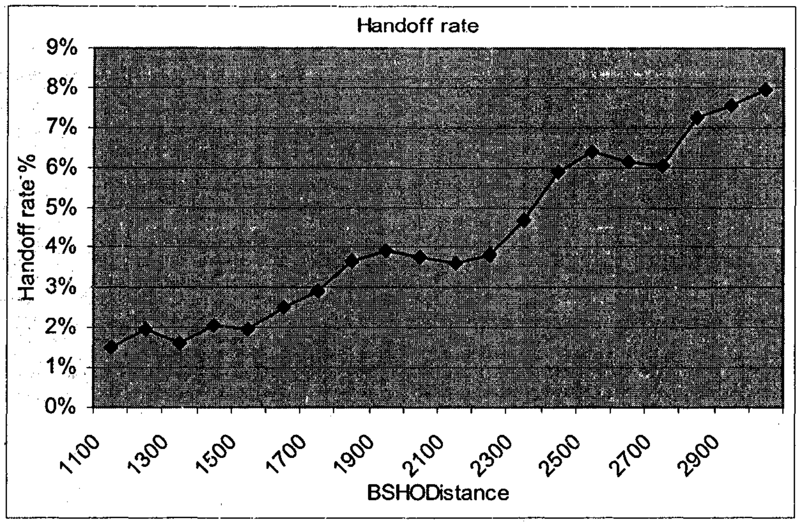


Figure 3.27 Handoff rate versus handoff triggering distance of BS (BSHODistance)

When the handoff-triggering distance of APs increases, Figure 3.28 expresses that the handoff rate will decrease proportionally. AP coverage area increases with the increase of the APHODistance; this will decrease the handoff probability of the calls that have APs as source service points. As the main handoff type is AP-to-BS handoff, the decrease of AP-to-BS handoff inevitably brings about the decrease of total handoff rate.

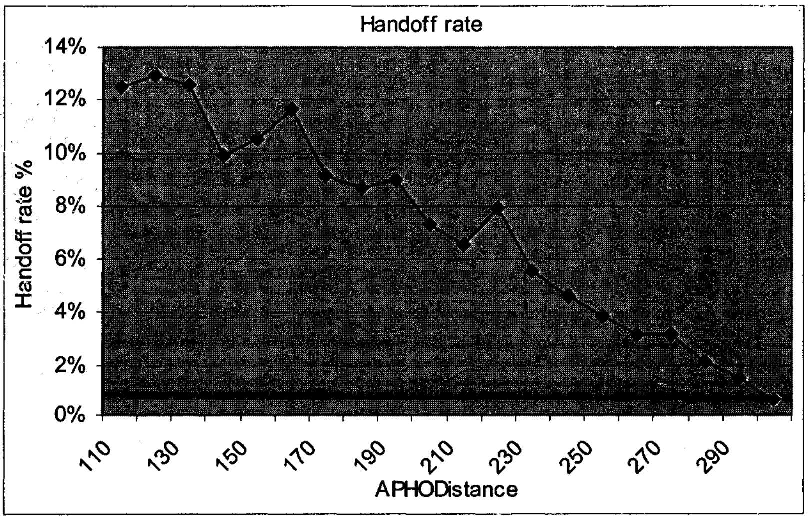


Figure 3.28 Handoff rate versus handoff triggering distance of AP (APHODistance)

Figure 3.29 reflects that handoff rate decreases with the increase of the average MS moving velocity. As the maximum allowable velocity of APs is 30Km/h, An AP cannot be taken as a source service point for a fast-moving MS. Thus the AP-to-BS and AP-to-AP handoff will decrease with the increase of the average velocity of MSs. Again, because most of the handoffs are AP-to-BS handoffs, the decrease of the number AP-to-BS handoffs amounts to the decrease of the number of total handoffs, i.e. handoff rate.

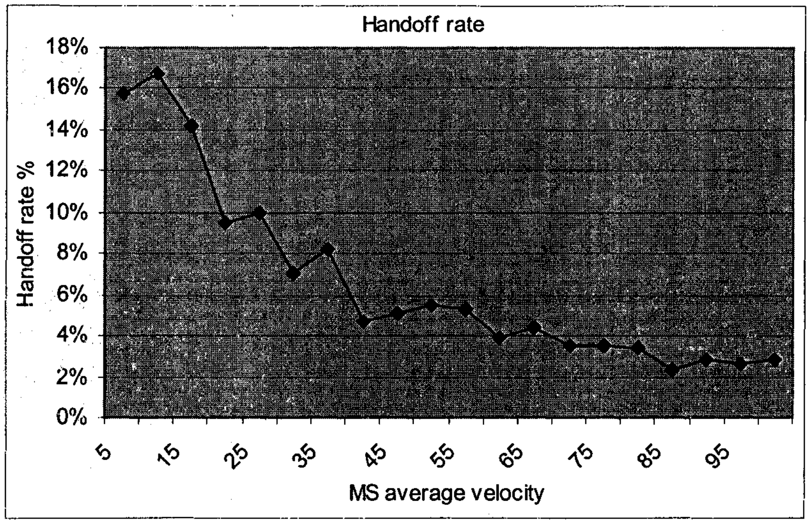


Figure 3.29 Handoff rate versus average MS velocity (km/hour)

If more capacity is reserved for handoff in BSs, there will be more AP-to-BS handoffs can be granted. As a result, from Figure 3.30, we may see that handoff rate will increase accordingly.

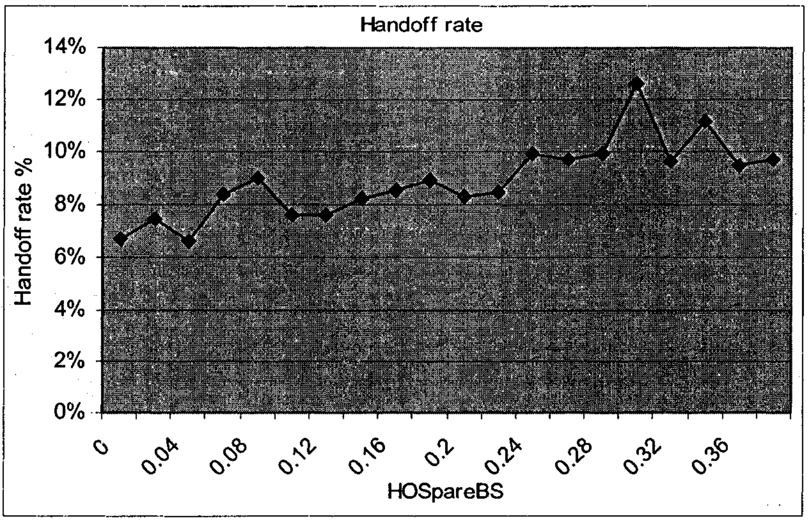


Figure 3.30 Handoff rate versus Reserved capacity rate for handoff of BS (HOSpareBS)

3.5.5 Packets Sent by BS/AP Rate

As a WLAN has a much more bandwidth capacity than a cellular network, MSs are encouraged to be served by APs. To evaluate the usage of APs, the packet sent by BS/AP rate time is a straightforward performance criterion. The more packets sent by APs, the higher system throughput could get.

From Figure 3.31, we find that the packet sent by BSs decreases (packet sent by APs increases) with the increase of the number of APs. More APs will lead to more packets sent by the WLAN. Figure 3.32 depicts how packets sent by BS rate changes with the change of handoff-triggering distance of APs. An MS in an AP will not trigger handoffs until the distance between the MS and the AP reaches the threshold, APHODistance. The larger the APHODistance is, the longer a call can stay in APs, and the better usage we can get for the WLAN.

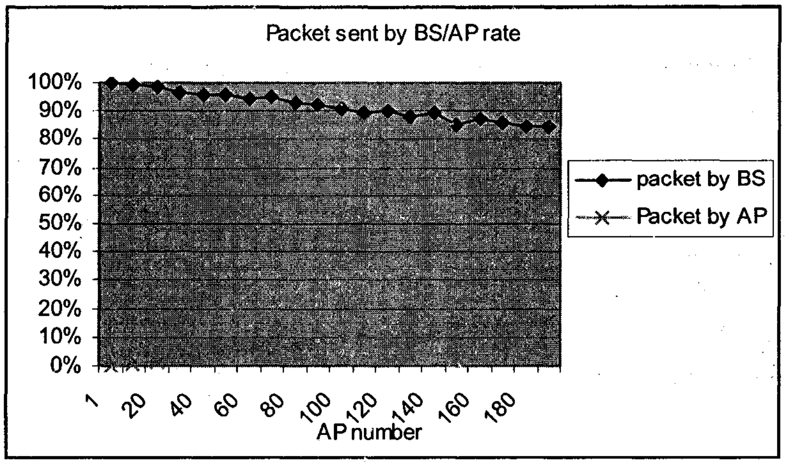


Figure3.31 Packets sent by BS/AP rate versus Number of APs

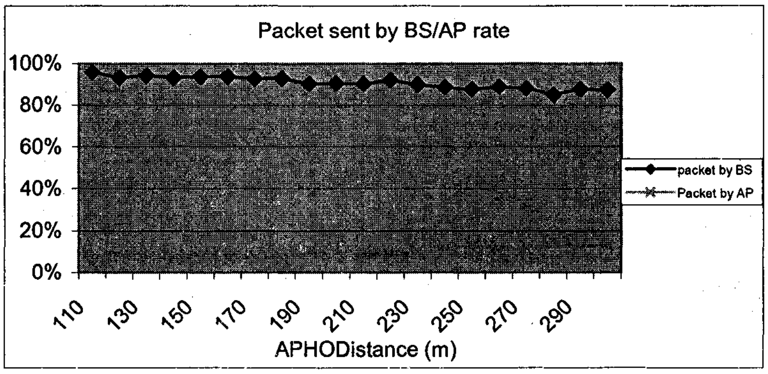


Figure 3.32 Packet sent by BS/AP versus handoff triggering distance of AP (APHODistance)

Figure 3.33 shows how packet sent by BS/AP rate changes with the change of average MS velocity. With the increase of average MS velocity, packet sent by AP rate decreases accordingly. This is because the WLAN cannot support a high moving speed of MSs; maximum velocity is set as 30Km/h in this simulation. With a very high average MS moving speed, for instance, 50-100Km/h, the packet sent by AP rate can be as low as 2-3%. Therefore, in a high-speed moving area, such as a highway, or a suburban area, it is not efficient to deploy a WLAN; this will lead to very low utilization of WLAN resources.

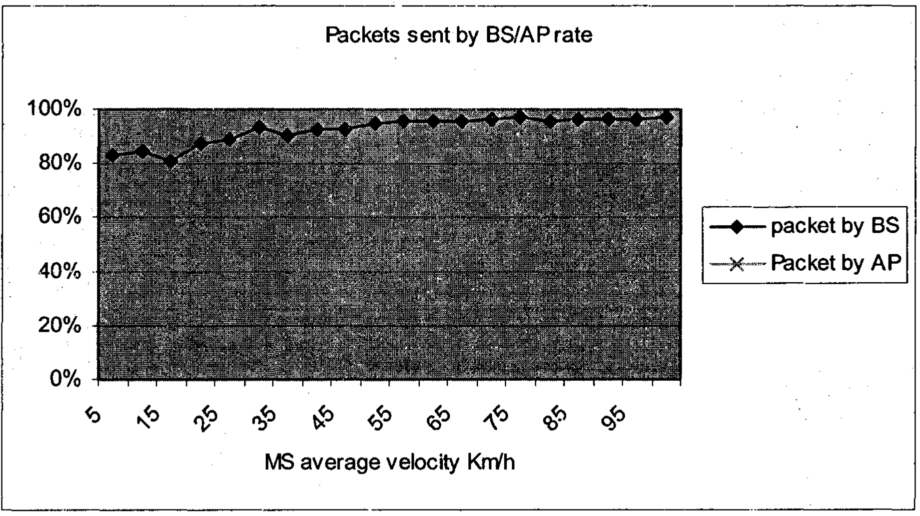


Figure 3.33 Packet sent by BS/AP versus average MS velocity (km/hour)

The percentage of high-speed users, 100-200Kbits/s in the simulation, also affects the usage of a WLAN. Figure 3.34 exhibits that the more high data rate demand we have in the network, the better usage we get for the APs.

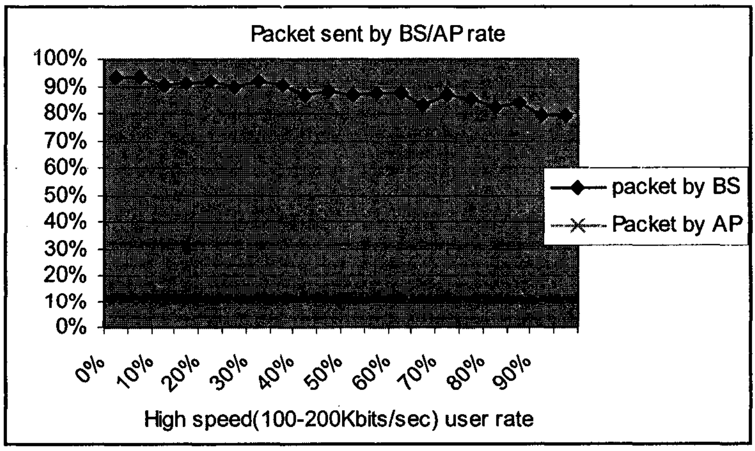


Figure 3.34 Packet sent by BS/AP versus Average high-speed (100-200Kbits/s) user rate

3.5.6 Average Packet Error Rate

In general, packet error rate in a WLAN will be higher than that in cellular network. This is the reason why a WLAN has low radio frequency signal strength, which is easier to be interfered. In this simulation, the average packer error rate is set as 1% in the cellular network is 3% in the WLAN.

Figure 3.35 shows that packet error rate increases with the increase of the number of APs. This is as with the increase of the number of APs, more calls will be served by APs and has a relatively high packer error rate.

If the handoff distance of APs increases, from Figure 3.36, we can see that packer error rate increases as well. If the network has a larger handoff distance of APs, MSs will stay on APs for longer time. As a result, the utilization of APs will increase, and the packet error rate will increase, too.

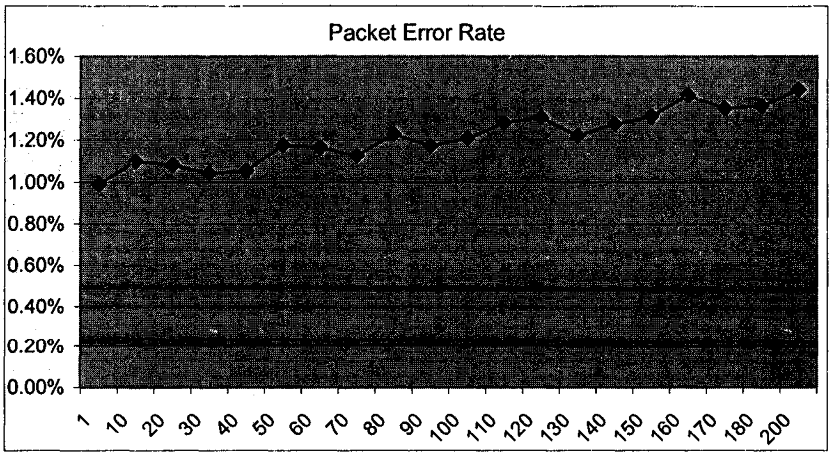


Figure 3.35 Packet error rate versus Number of APs

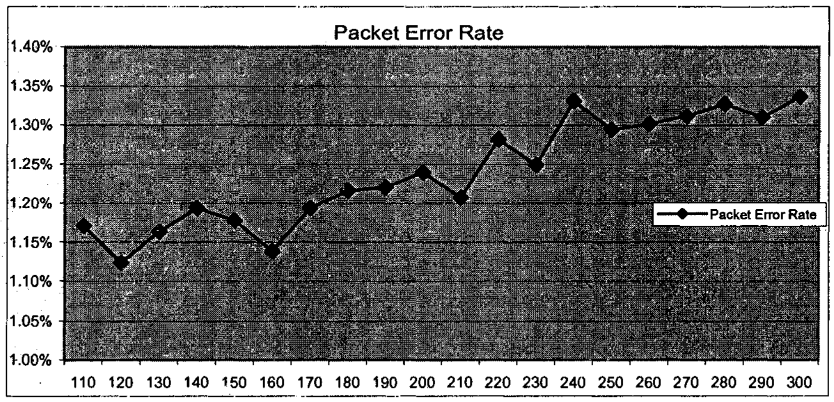


Figure 3.36 Packet error rate versus handoff triggering distance of AP (APHODistance)

Figure 3.37 reveals that, for low moving speed users, less than 30Km/hour in this simulation, the AP usage is high. And because there is a higher packet error rate in an AP than that in a BS, average packet error rate is also higher. And if the user's moving speed is high, a BS is more used by an MS, the packet error rate is getting lower and tends to be more stable.

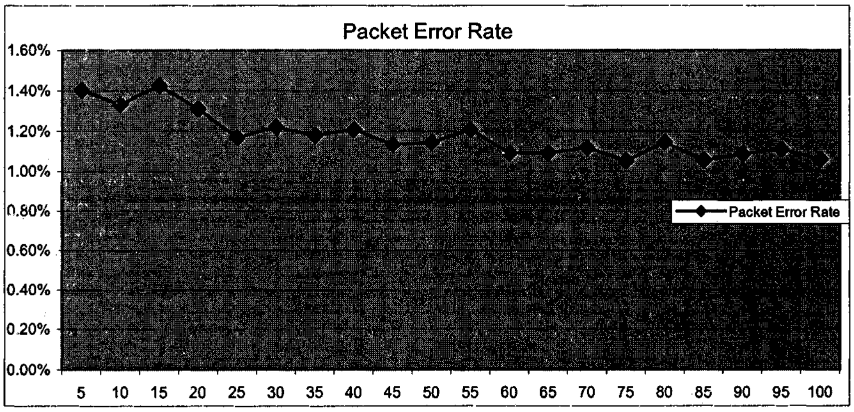


Figure 3.37 Packet error rate versus Average MS velocity (Km/hour)

3.5.7 Resource Utilization

Resource utilization is the percentage of the actual used throughput out of the total throughput capacity, including the throughput capacity provided by a cellular and WLAN network.

In a typical integrated network, the cellular network usually has a relatively low capacity and high resource utilization rate, whereas a WLAN network has a high capacity and low resource utilization rate. Figure 3.38 shows how the number of APs affects the resource utilization. Although the increase of the number of APs can improve the total throughput (chapter 3.5.1) and call successful rate (see chapter 3.5.2), it will inevitably lead to a significant decrease of the total resource utilization rate. We can see that, from Figure 3.39, the increase of the number of APs has little impact on the BS utilization. The reason is, the large number of APs cannot absorb proportionally much more traffic due to the small coverage area of a WLAN. To solve this problem, we need to deploy APs at the place where there is high user density and traffic load; this will improve the use of a WLAN and hence achieve higher total throughput.

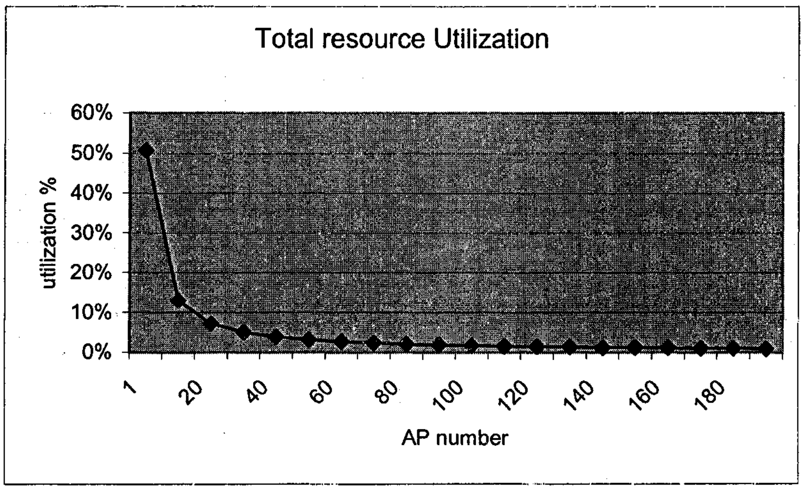


Figure 3.38 Total resource utilization versus the Number of APs

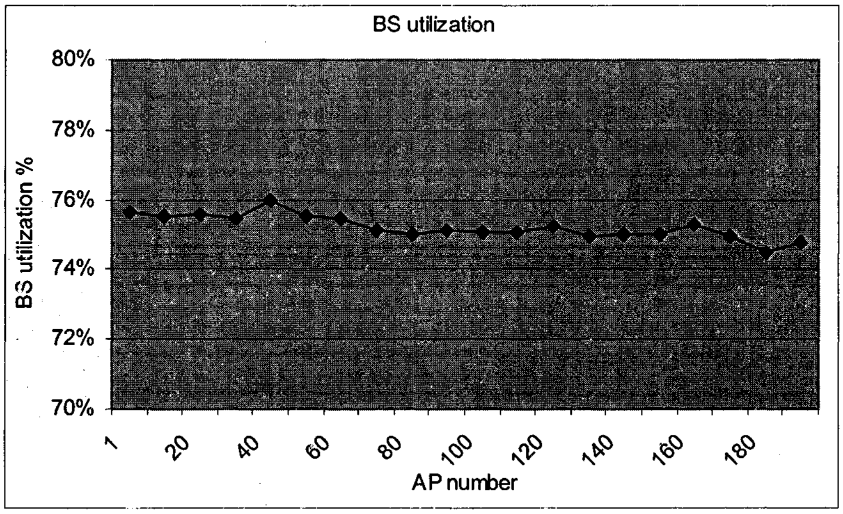


Figure 3.39 BS resource utilization versus the Number of APs

Figure 3.40 and 3.41 depict the tendency of the BS and AP resource utilization changes as the handoff-triggering distance of APs increases. A longer APHODistance enables a larger coverage area of a WLAN and hence increase the usage of APs; this obviously leads to a lower usage of BSs.

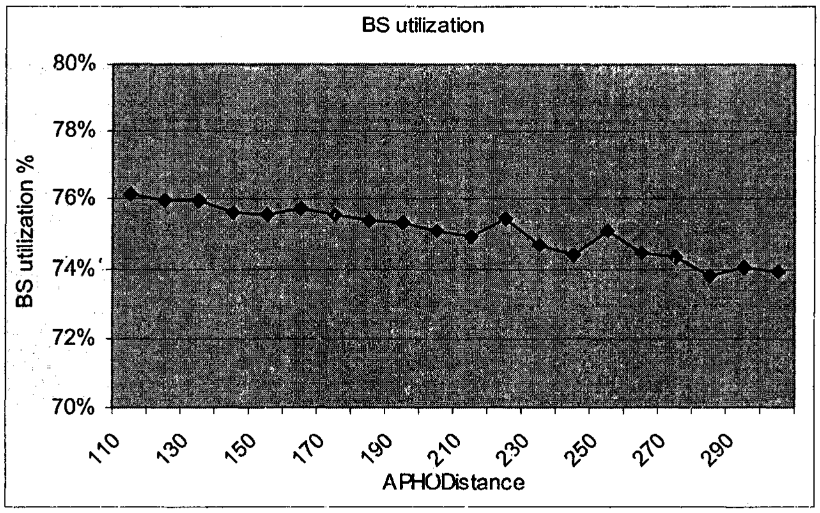


Figure 3.40 resource utilization of BSs versus handoff triggering distance of APs (APHODistance)

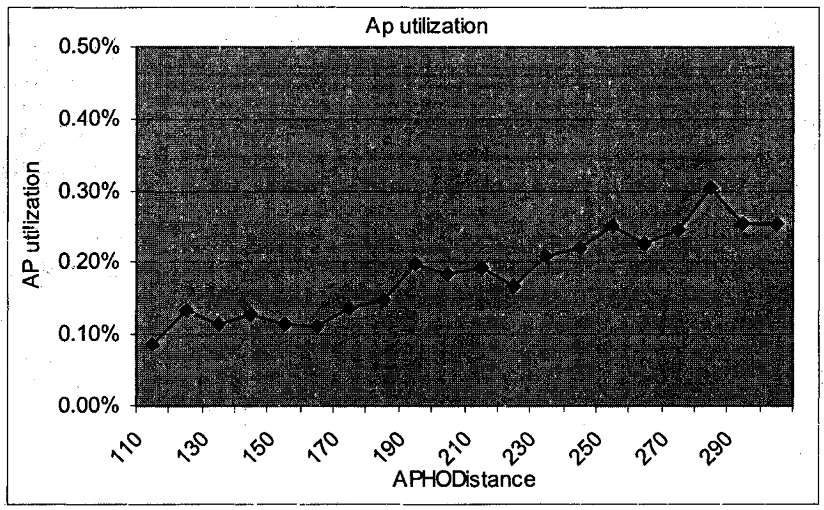


Figure 3.41 resource utilization of APs versus handoff triggering distance of APs (APHODistance)

In most cases, cellular network bears the main part of the total traffic load and has a relatively high usage. From Figure 3.42 and 3.43, it can be seen that BS utilization and also the total utilization decrease proportionally with the increase of the percentage of reserved capacity for handoff of BSs. This discloses that the main service request is still new call instead of handoff call. We should distribute resources accordingly when an integrated network is deployed.

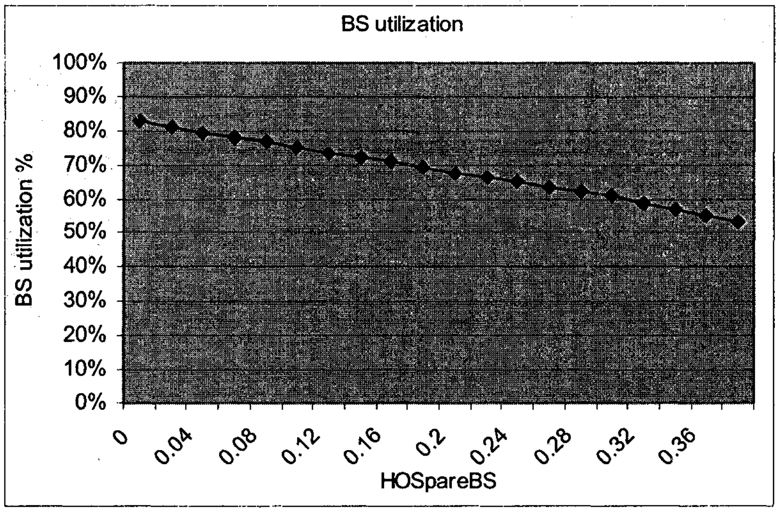


Figure 3.42 resource utilization of APs versus Reserved capacity rate for handoff of BSs (HOSpareBS)

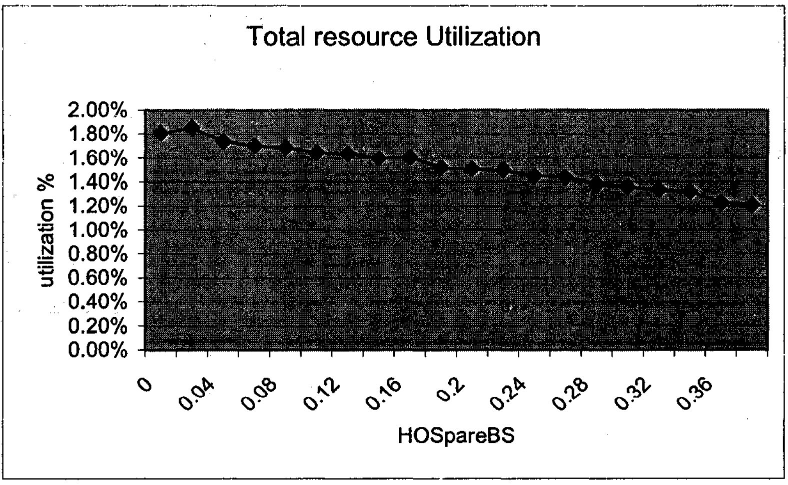


Figure 3.43 Total resource utilization versus Reserved capacity rate for handoff of BSs (HOSpareBS)

Figure 3.44 shows the tendency that total resource utilization changes with the increase of the average MS moving velocity. When the average moving velocity is less than around 30Km/h, which is the maximum allowable moving speed in a WLAN, the faster the MS moves, the lower total resource utilization the system gets. This is because with the increase of average moving speed, the probability that the MS has a more than 30Km/h moving speed increases; this will lead to a lower usage of a WLAN. When the average MS moving velocity is much larger than 30Km/h, it can be found that the trend of the decrease of the total resource utilization slows down and turns out to be stable. The cause is that, firstly, most MSs cannot be served by APs when the average moving speed is much larger than 30Km/h. Secondly; the utilization of BSs is stable with the change of the MS velocity.

On the other hand, Figure 3.45 shows that AP utilization decreases as the average MS moving velocity increases. This is because a MS has less probability to be served by APs when it has a higher velocity. Thus the usage of APs will decrease accordingly.

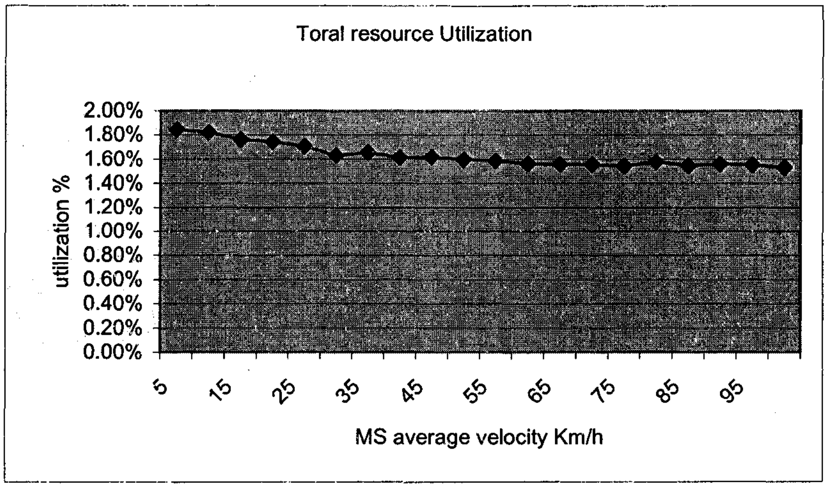


Figure 3.44 Total resource utilization versus average MS velocity (km/hour)

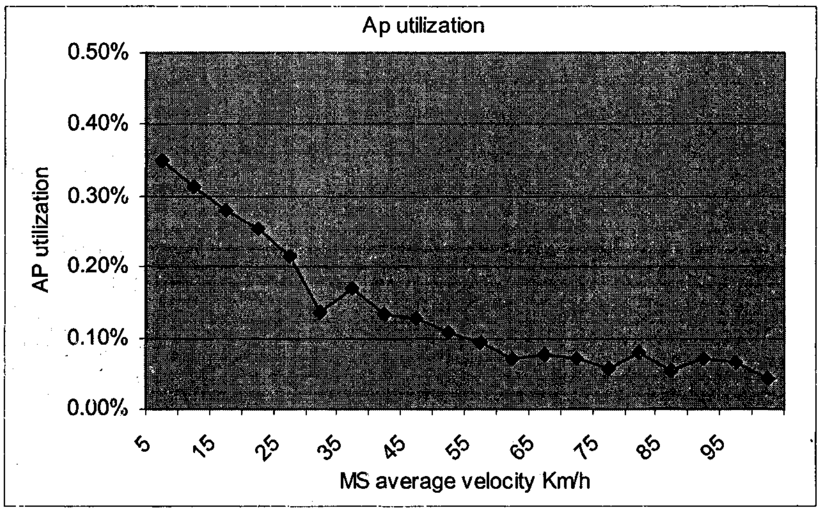


Figure 3.45 AP resource utilization versus average MS velocity (km/hour)

Chapter 4 Conclusion and Future Consideration

4.1 Conclusion

The objective of the research reported in this thesis is to investigate the performance of a GPRS cellular network and WLAN integrated network based on a proposed handoff algorithm. To achieve comprehensive performance results, the simulation makes use of a large traffic load and a large number of users. Based upon the analysis of network throughput, packet error rate, handoff rate, call successful rate and resource utilization, the performance overview of an integrated network is presented. For better understanding of the advantages of the integrated network, some performance analysis of both a pure cellular network and an integrated network are provided in this research work. In the proposed network, both a cellular network and a WLAN are presented and integrated to provide a seamless wireless data communication service. As an important design subject of an integrated network, handoff builds the relationship between two different networks. Based on a seamless integrated architecture, the aim of the handoff algorithm is to achieve maximum usage of the resources of a WLAN and an efficient network in terms of resource usage. In the proposed handoff algorithm, MSs are encouraged to use WLAN resources whenever there is a new call request or a handoff request is initiated. Due to the characteristic of a WLAN, fast-moving users are not allowed to access network through an AP. A certain percentage of the total capacity of a service point, both for a BS (BSHOSpare) and an AP (APHOSpare), is reserved for handoff. The handoff triggering algorithm is mostly found upon the distance of the mobile users and its service point in the simulation. The threshold distance of a BS (BSHODistance) and an AP

(APHODistance) are used in the handoff algorithm. From the performance analysis based on the simulation, some conclusions are summarized below.

1. The simulation results offer a certain improvement with the introduction of a WLAN into a cellular network, especially for call successful rate and total throughput. In a typical integrated network with the number of AP=100, from the simulation, we can get around 20 % (see figure 3.14) total throughput and around 10% (see figure 3.16) call successful rate gain.

2. The increase of the usage of APs is the key factor to attain a high network throughput. For getting a better usage of a WLAN, we can increase the number of APs, enlarge the handoff-triggering distance of APs, and deploy APs in the area with more slow-moving users. Performance results demonstrate that the gain of the usage of a WLAN is limited due to the small coverage area of a WLAN. In general, a cellular network has a high usage and bears 80-90% of total traffic load; the resource utilization of an AP can be as low as 2-3%.

3. With more APs deployed in the so-called hotspot where there is a high traffic density, the improvements of the performances are expected to be more significant.

4. Furthermore, the performance results express that AP-to-BS handoff is most occurring handoff in the integrated network. Therefore, in real networks, to achieve a better network performance, more efforts should be put on enhancing the handoff successful rate of AP-to-BS handoff. As a WLAN has a higher average packer error rate than a cellular network, more usage of APs may lead to the improvement of average packet error rate and packer resend probability. However, from the point of view of

throughput, the capacity to gain benefits from a WLAN compensates the rise of the packet error rate.

The integration of a WLAN with a cellular network can ease the traffic load on the cellular network and bring a relatively higher throughput, especially for slow-moving mobile users. A careful traffic and radio plan of the network deployment is needed to achieve a good performance.

In the simulation, we see fluctuation curve happened occasionally in the performance result (for example figure 3.12 total throughput versus number of AP). This is because of not having big enough simulation traffic load for some specific performance scenario analysis. The performance result is expected to be more consistent if a big enough simulation traffic load is used.

4.2 Future Work

The simulation performance results are based on an integrated network, which has randomly distributed APs. A cellular network has an almost full basic level coverage for the service area. We have found, from the simulation result of this research work, that a better way to implement an integrated network is to deploy more APs in hotspots and blind spots (the area that has no radio coverage) of a cellular network. Further research should be made to analyze on the performance of that kind of network.

The simulation has not attached adequate attention on the latency performance analysis. Future tasks can be completed on the mobile queue delay and buffer configuration to better acquire comprehensive performance results.

The GPRS network is the typical cellular network mode applied in this simulation. Nonetheless, the current GPRS network has already led to a much degree of improvement of the data rate. A wireless LAN is also a continuously improving technology. These developments will bring us a broader view of the future integrated network.

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