

Resource assignment for adaptively modulated interconnected
WLANs

Amiotosh Ghosh

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ABSTRACT

Resource assignment for adaptively modulated interconnected WLANs

Amiotosh Ghosh

Deployment of large wireless local area network (WLAN) in outdoor environment to provide broadband wireless access (BWA) is gaining more attention. Although several standards have been developed for this purpose numerous research and development is going on to improve the performance of the standards. Management of the wireless resource is one of the key ingredients for providing BWA to the users and total number of serviceable users in a certain area.

In this thesis we investigate WLANs performance in a metropolitan area using HiperLAN type 2 standard. Inside the LANs user can move from one place to another and user rates are dynamically adjusted based on their distance from the Access Points. To manage the wireless resources of the network we propose resource allocation schemes and evaluate their performance. We develop a generic simulation software for the network and use it for three resource allocation policies namely Minimum Overhead Round Robin (MORR), which does not depend on user's buffer condition, Weighted Minimum Overhead Round Robin (WMORR) which is a function of user buffer as well as the waiting time for transmission opportunity and Weighted Round Robin (WRR) which is a function of user buffer only. We evaluate average buffer occupancy, packet delivery time, buffer packet drop probability, overhead in downlink and uplink phases for performance comparison of the new allocation schemes. Our results show that the second adaptive resource allocation technique i.e. WMORR outperforms the other two.

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List of Abbreviations

AP	Access Point
ACH	Access feedback CHannel
ACF	Association Control Function
ARQ	Automatic Repeat Request
BC	Broadcast Phase
BCH	Broadcast Channel
BPSK	Binary Phase Shift Keying
BWA	Broadband Wireless Access
CC	Central Controller
CEPT	European Conference of Postal and Telecommunications Administrations
CL	Convergence Layer
CRC	Cyclic Redundancy Check
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
DFS	Dynamic Frequency Selection
DiL	Direct Link
DL	Downlink
DLC	Data Link Control
DLCC	DLC Connection
DLCC ID	DLC Connection Identifier
DM	Direct Mode
EC	Error Control
EIRP	Equivalent Isotropic Radiated Power
ETSI	European Telecommunication Standardization Institute
FCC	Federal Communications Commission (USA)
FCH	Frame CHannel
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FCH	Frame CHannel
FIFO	First In First Out
IE	Information Element
IEEE	Institute of Electrical and Electronic Engineers
IFFT	Inverse Fast Fourier Transform
IP	Internet Protocol
LCH	Long transport CHannel
LLC	Logical Link Control
LOS	Line of Sight
LUT	Look Up Table
MAC	Medium Access Control
MAC ID	MAC Identifier
MORR	Minimum Overhead Round Robin
MT	Mobile terminal
NLOS	Non Line Of Sight
OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open System Interconnection
PER	PDU Error Ratio
PDU	Protocol Data Unit
PHY	Physical
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service

QPSK	QuaternaryPhase Shift Keying
RA	Random Access
RCH	Random access Channel
RF	Radio Frequency
RLC	Radio Link Control Protocol
RR	Resource Request
RRC	Radio Resource Control
SAP	Service Access Point
SCH	Short transport CHannel
UL	Uplink
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
WMORR	Weighted Minimum Overhead Round Robin
WPAN	Wireless Personal Area Network
WRR	Weighted Round Robin

List of symbols

f_c	Carrier Frequency
K_{MOD}	Modulation dependent normalisation factor
CW_a	Contention window
n	Total number of RCH phase
a	Total number of retransmission
r_a	RCH slot number
f_s	Sampling frequency
T_u	Useful symbol part duration
T_{cp}	Cyclic prefix duration
T_{Total}	Total symbol duration
Δf	Sub-carrier spacing
$n_{carrier}$	Carrier number
B_{MTi}	Number of PDUs in the buffer of MT
W_{MTi}	Waiting time for transmission opportunity of MT
T_{Frame}	Duration of Uplink or Downlink phase of TDMA frame
N	Noise floor
NF	Noise factor
S_R	Received Signal Strength
P_L	Path loss
S_T	Transmitted Signal Strength
d	Distance
C/N	Carrier to noise ratio
$U(0,1)$	Uniform random number generator between 0 and 1

Chapter 1: Introduction

Huge demand on 'anywhere any moment connection requirement' has led to numerous research and development efforts for wireless technologies. As an outcome of these efforts, wireless local area network (WLAN) standards have offered the capability of delivering all the services possible in wired infrastructure. Wireless technologies are replacing and complementing their wired counterpart due to their flexibility, equivalent performance and user friendly devices. This led to advancement and improvement of a number of standards developed by different standardization body such as IEEE, ETSI, etc.

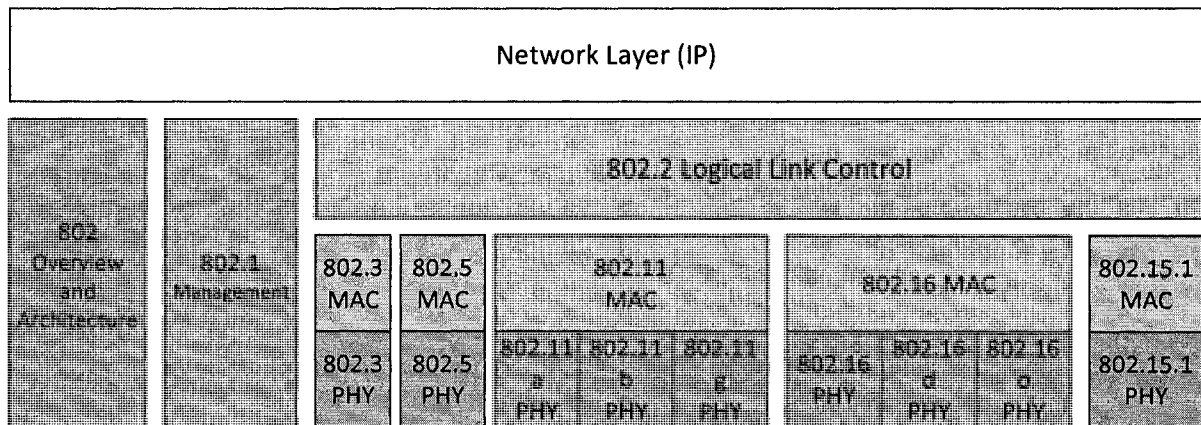


Figure 1.1. IEEE 802 standards

1.1. IEEE 802 Standards

The IEEE 802 standards family defines the physical (PHY) and media access (MAC) layer of the 7-layer OSI model. These standards family include the IEEE 802.3 (Wired Ethernet) standard, IEEE 802.1 (management) standard, IEEE 802.5 (token ring) standard,

very famous IEEE 802.11 (WLAN) and IEEE 802.16 or WiMAX standard. Fig. 1.1 [1] shows the structure of these standards.

○ IEEE 802.11

It is the most widely deployed wireless LAN standard all over the world. The standard uses variety of modulation techniques and can supports data rates from 1Mbps up to 54 Mbps. The physical layer of the standard is defined as follows:

- IEEE 802.11b operates in the 2.4 GHz industrial, scientific and medical (ISM) band. This standard can support data rate up to 11 Mbps and use direct sequence spread spectrum (DSSS) for wireless access [4].
- IEEE 802.11g also operates in the 2.4 GHz industrial, scientific and medical (ISM) band. This standard can support data rate up to 54 Mbps and use orthogonal frequency division multiplexing (OFDM) for wireless access [5].
- IEEE 802.11a operates in the 5 GHz Unlicensed National Information Infrastructure (UNII) band. For wireless access this standard also uses orthogonal frequency division multiplexing (OFDM) and operates at lower transmit power around a maximum of 20 mW while the 802.11g version operates at power maximum of 100 mW. The IEEE 802.11a standard can support data rates up to 54 Mbps [3].

Fig.1.2 shows the logical architecture [2] of the IEEE 802.11 standard where MAC layer is same for all versions of IEEE 802.11(a, b or g). The wireless channel is shared by the users using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The logical link control layer (LLC) serves as an adapter to the higher layers. The service area of this standard is multiple of 3m to 30m.

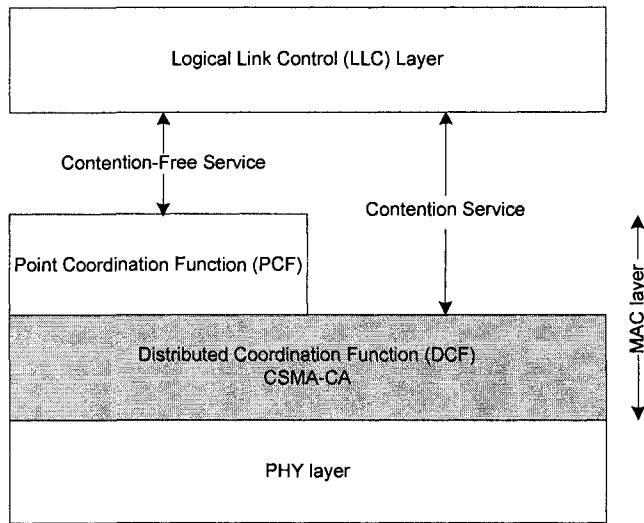


Figure 1.2. IEEE 802.11 logical architecture.

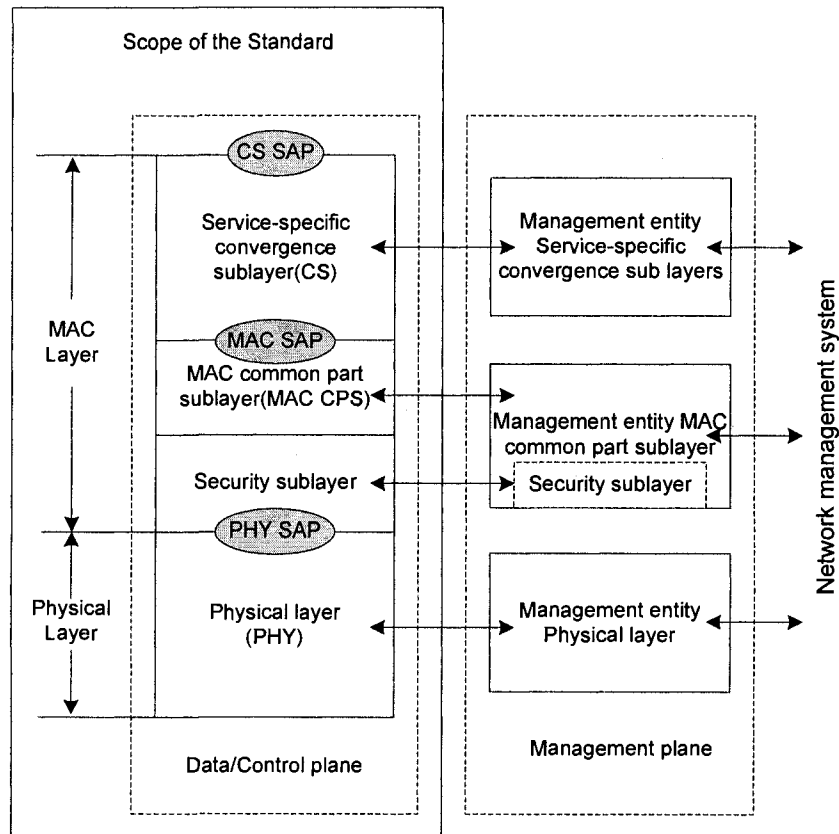


Figure 1.3. IEEE 802.16 protocol stack.

○ **WiMAX or IEEE 802.16**

WiMAX standard is well known name of the air interface standard of IEEE 802.16. It is one of the most popular broadband wireless access (BWA) technologies available today which can provides BWA service to fixed, nomadic, portable and mobile stations and enables interoperability and coexistence of BWA systems from different manufactures in a cost-effective way. The IEEE 802.16 standard family defines physical layer and MAC layer of 7 layer OSI reference model as show in fig. 1.3. Two variation of WiMAX is currently available: one is based on IEEE 802.16-2004, for fixed wireless application and another is for mobile users based on IEEE 802.16e. Table 1.1 [6] shows a comparison between some of the versions of IEEE 802.16 standards.

Table 1.1. Comparison among IEEE 802.16, 802.16a, 802.16-2004 and 802.16e.

	802.16	802.16a	802.16-2004	802.16e
Frequency of operation	10-66 GHz	2-11 GHz	2-11 GHz, 10-66 GHz	2-6 GHz
Ch. condition	LOS	NLOS	NLOS	NLOS
Bandwidth	20, 25 and 28 MHz	1.25-28 MHz	1.25-28 MHz	1.25-20 MHz
Modulation Scheme	QPSK, 16QAM and 64QAM	OFDM, QPSK, 16QAM and 64QAM	OFDM, QPSK, 16QAM and 64QAM	OFDM, QPSK, 16QAM and 64QAM
Network architecture	PTP, PMP	PTP, PMP, mesh	PTP, PMP, mesh	PTP, PMP, mesh
Bit rate	32-134 Mbps	Up to 75 Mbps	Up to 75 Mbps	Up to 15 Mbps
Mobility	Fixed	Fixed	Fixed	Pedestrian Mobility--regional roaming, maximum mobility support 125 km/h
Typical cell radius	1-3 miles	Maximum range is 30 miles on the basis of antenna height, antenna gain and transmit power	Maximum range is 30 miles on the basis of antenna height, antenna gain and transmit power	1-3 miles
Applications	Replacement of E1/T1 services for enterprises,backhaul for hot spots, residential roadband access, SOHO (Small office/home office)	Alternative to E1/T1, DSL, cable backhaul for cellular and WiFi, VoIP, Internet connections	801.16 plus 802.16a applications	802.16-2004 applications plus fixed VoIP QoS-based applications, and enterprise networking

- **IEEE 802.15**

The IEEE 802.15 standard focus on WPANs with ranges only in the order of 10 feet. Despite of this short service range network using this standard is increasingly prevalent as wireless networking evolves to support a variety of platforms, including those in the home such as household applications. As for example mobile phones enabled with IEEE 802.15 technologies benefit from ability to connect to other phones, computers or devices [1].

1.2. HiperLAN/2 Standard

For providing wireless connectivity in domestic premises as well as business premises as for example apartments, small house, large hall room, office, hospital, university, shopping mall, airport, etc (Fig. 1.4). Broadband Radio Access Networks (BRAN) division of European Telecommunications Standards Institute (ETSI) developed high performance wireless LAN standard known as High Performance Radio Local Area Network (HiperLAN/2) [7]. It is analogous to the IEEE 802.11 standard and considered as superior in terms of throughput and design perspective.

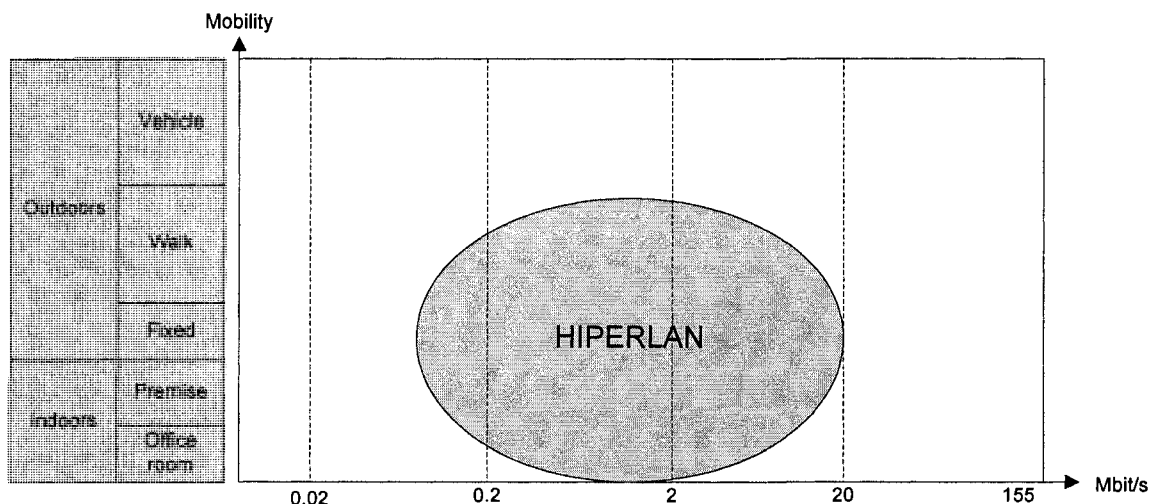


Figure 1.4. HiperLAN operation conditions.

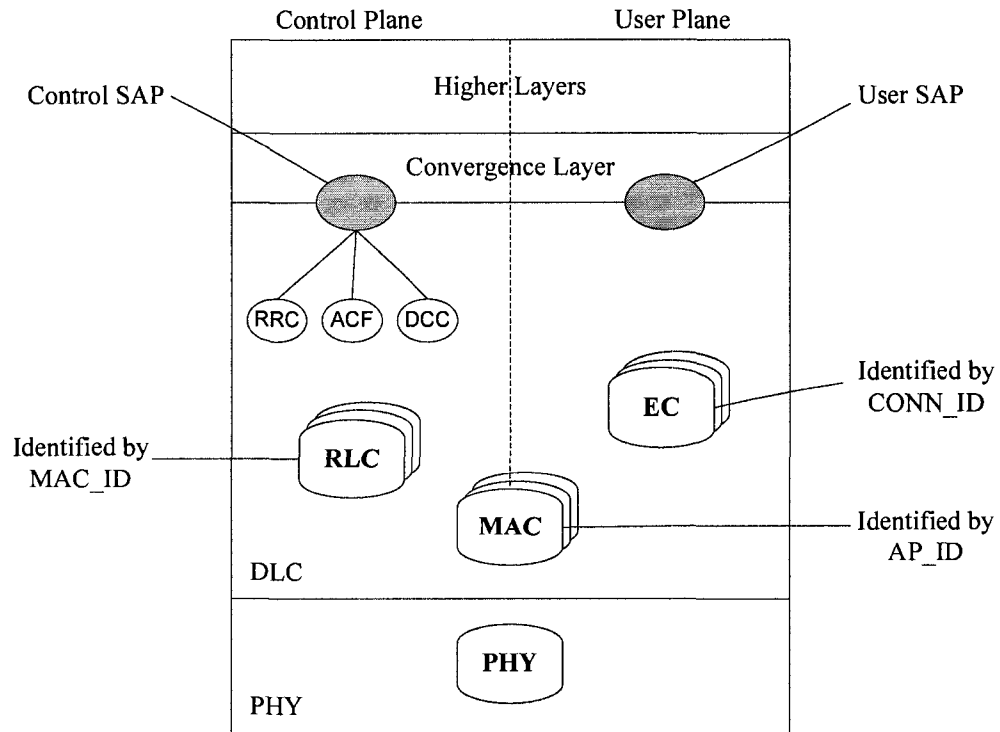


Figure 1.5. HiperLAN/2 protocol stack and functions.

The HiperLAN type 2 standard defines the Physical layer and the Data link layer of 7 layer OSI reference model. In the standard Convergence Layer (CL), Data Link Control layer (DLC) and Physical Layer are defined in details (Fig. 1.5) [7]. Here the Convergence Layer performs as an adapter for DLC and Physical layer to the higher layer and makes the system able to provide wide range of service such as IP, ATM and UMTS. An H/2 system can provide flexible service to hand held devices, computers, laptops or other wireless equipments. The standard operates at 5 Ghz band and can offers data rates from 6 Mbps up to 54 Mbps. It uses orthogonal frequency division multiplexing (OFDM) in its physical layer and dynamic TDMA/TDD based protocol in MAC layer.

Physical layer of HiperLAN/2 system uses OFDM to cope with fading effect. Each OFDM symbol contains 52 subcarriers around one of the possible carriers (Table 2.7) where 48 subcarriers are data carrier and 4 are pilot carriers. Data received from data link layer is

used to modulate the subcarriers using 7 different types of modulation techniques depending of channel condition. A particular modulation technique is chosen to achieve highest data rate for the erroneous channel.

To deploy HiperLAN/2 system total coverage area is divided into cells. Each cell is served by an Access Point. Each cell operates in a frequency that is different from neighbouring Access Points. Mobile nodes choose Access Point for association, depending on signal strength and it is known as dynamic frequency selection (DFS). Mobile terminals can move from one cell to another. Network uses roaming procedure to provide services to the mobile terminal. A central controller supervises this roaming procedure.

According to the HiperLAN/2 standard [7] network can be setup in two ways: one in infrastructure mode and another in ad-hoc mode. In infrastructure mode mobile terminals exchange their data through the Access Point. On the other hand in ad-hoc mode mobile terminals communicate directly under supervision of Access Point. Inside a cell, mobile node gets access of resource using dynamic TDMA. To serve different types of data and ensure their QoS, the standard defines two types of resource allocation services for time bounded traffic and delay insensitive traffic. For delay sensitive traffic while setting up connection, mobile nodes negotiate with the Access Point for fixed capacity assignment (FCA). In FCA mobile nodes get certain amount of time assignment in each time slot. But for delay insensitive traffic such as 'data traffic' Access Point distributes available bandwidth among the mobile nodes using some preset procedure. Here mobile terminals (MT) put their service request in the specific predefined time slot known as contention period of the time frame, if the mobile terminal is not associated with the Access Point. The mobile terminals can also put its service request at the end of its transmission to the Access Point (AP) in uplink phase. The

AP grants the service request of the mobile terminals using parameters received through the service request and other rules set for the allocation purpose. APs use certain portion of the time frame to inform the status of the service requests to the MT. In this feedback message AP also inform the mobile terminals the specific time and the length of time, i.e. when and how long it will receive or able to transmit data. Remaining part of the time frame is used by the mobile terminals to exchange data between them or with Access Point in uplink or downlink slots.

1.3. Motivation

It is the function of MAC layer of an Access Point to divide available transmission time among the mobile nodes and build a TDMA/TDD frame. To do this job Access Points have to use a set of rules. But the HiperLAN/2 standard does not define any protocol for this purpose. In this thesis we proposed two protocols for resource allocation purpose and evaluated their performance for a dynamically modulated interconnected WLAN.

We also found that very few studies had been done to evaluate the capability of HiperLAN/2 deliver different kinds of traffic. Among the studies, optimum number of random access slots for different kinds of traffic to meet certain QoS requirement is studied in [11]-[14]. In the HiperLAN/2 standard optimum number of resource allocation phases in a TDMA\TDD frame is not specified and in [11]-[14] authors treats this deficiency. In [15]-[19] capability of HiperLAN/2 is evaluated to serve different kinds of traffic using well known resource allocation schemes such as round robin, minimum overhead Round Robin (MORR) and First In First Out (FIFO) schemes. But in these studies the condition of buffers in the mobile terminals was not examined and also these studies were performed only for error free channel and with stationary mobile terminals for either in uplink or in downlink phase. But in

our study we have considered erroneous channel and dynamic modulation for both uplink and downlink channel.

1.4. Thesis objective

Packet loss can occur in the network during transmission and also in the buffer due to overflow as buffer size is fixed. Packet loss in the buffer can be minimized using resource allocation i.e., providing transmission opportunity to the user. In this thesis our objective is to investigate performance of three resource allocation schemes namely Minimum Overhead Round Robin (MORR), which does not depend on user's buffer condition, Weighted Minimum Overhead Round Robin (WMORR) which is a function of user buffer as well as the waiting time for transmission opportunity and Weighted Round Robin (WRR) which is a function of user buffer only. These schemes are used for resource allocation to the users of the WLANs deployed in the metropolitan area using the HiperLAN type 2 standard. For this purpose we design WLAN system where user can move from one place to another inside the WLANs and user rates are dynamically adjusted based on their distance from the Access Points. We develop generic simulation software for the network and use it for the three resource allocation policies. To evaluate performance of the allocation schemes we used average buffer occupancy, packet delivery time, packet drop probability, overhead in downlink and uplink phases.

1.5. Thesis organization

The thesis is organized as follows: chapter 2 describes physical layer and MAC layer of H/2 system. The proposed three resource allocation schemes and simulation setup are described in chapter 3 and 4 respectively. Simulation results are presented in chapter 5. Finally conclusion and suggestion for future work are presented in chapter 6.

Chapter 2: H/2 MAC & Physical Layer

2.1. MAC Layer

HiperLAN/2 standard use TDMA/TDD based MAC protocol [8]. Duration of a MAC frame is 2 ms. This 2 ms time frame is further divided into a number of short time phases to accommodate broadcast phase, uplink (data direction MT to AP) phase, downlink (data direction AP to MT) phase, direct link (data exchange between two MT directly) phase and random access phase. Data exchanges between MTs can occur in two ways: through AP in infrastructure mode or directly between MTs supervised by AP in Ad-hoc mode. In the infrastructure five variable length phases make up the MAC frame (Fig. 2.1). These short time phases are described below.

○ Broadcast phase

In this part of the MAC frame, time to receive data, assigned transmission opportunity, amount of receivable data, time at which a particular MT should transmit and other control information is announced by the AP using three BCH, FCH and ACH broadcast transport channels (Fig. 2.1).

- BCH (Broadcast CHannel): Different control channel information of the whole cell is broadcasted by AP using BCH.

- FCH (Frame CHannel): In this short phase AP inform MTs about time to receive or transmit, total allocated time for receive or transmit data and selected physical mode for uplink or downlink.
- ACH (Access Feedback CHannel): Results of service request by MTs in RCH phase of previous MAC frame is announced by AP using ACH.

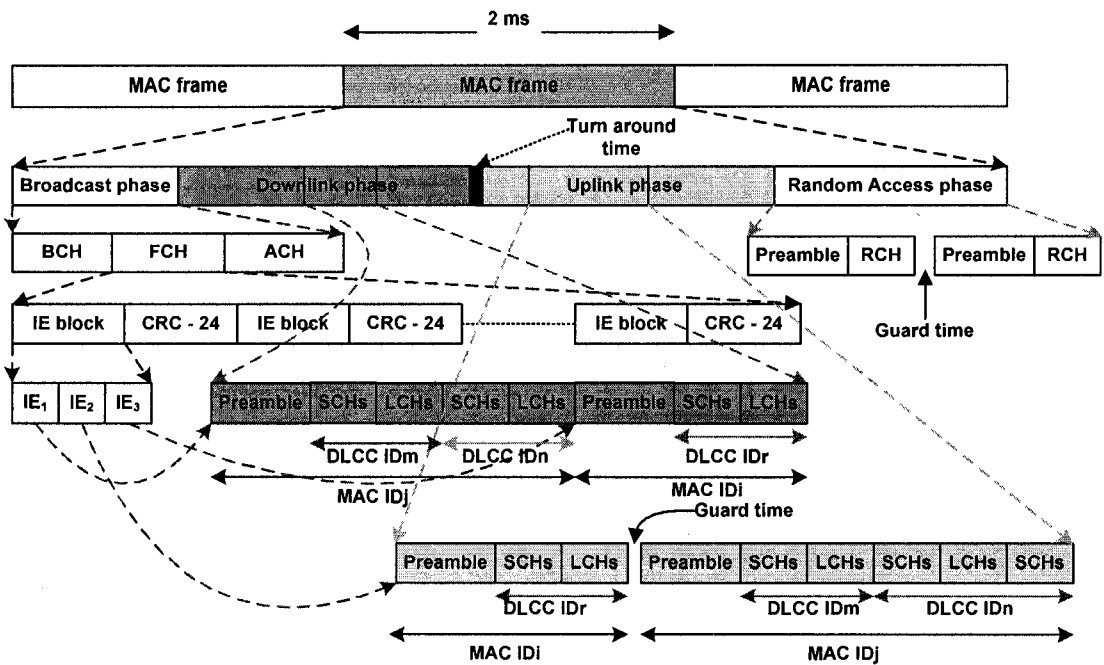


Figure 2.1. MAC frame structure.

o Downlink Phase (DL)

Protocol Data Units (PDU) of AP destined to MTs form this phase. A stream of PDUs transmitted by AP for a MT consists of a preamble followed by number of Long transport Channels (LCH) and Short transport Channels (SCH) (Fig. 2.1). LCHs contain data for MT while SCH contains ARQ and other control information. AP combine all the LCHs and SCHs scheduled for transmission and use one uplink burst for transmission to a MT.

- **Uplink Phase (UL)**

MTs when polled as per the FCH channel transmit their uplink data in this phase. Uplink burst contains (Fig. 2.1) number of LCH PDUs for data transmission and/or SCH PDUs for acknowledgement, resource request and various control messages. MT combine all the LCHs and SCHs scheduled for transmission and use one uplink burst for transmission to the AP.

- **Random Access phase**

A Slotted-ALHOA based contention is used in this short period. Collision may occur in this slot. To control access to the RCH phase a contention window CW_a is maintained in each MT. The size of contention window derived using the number a , where a is the number of retransmission attempts made by the MT. For the first access the value of a is set to 0. The size of CW_a is defined as below:

Initial Attempt: $a = 0, CW_a = n$

$$\text{Retransmission : } a \geq 1, CW_a = \begin{cases} 256 & 2^a \geq 256 \\ 2^a & n < 2^a \leq 256 \\ n & n \geq 2^a \end{cases}$$

Here, n is the number of RCHs in the MAC frame. The RCH used for a^{th} transmission is chosen by a uniformly distributed random value r_a within the interval $[1, CW_a]$. To determine the RCH, when $a=0$ the MT start counting from the first RCH of the current MAC frame. But in the case of retransmission MT starts counting from the MAC frame in which it gets information about failure in the previous transmission event. When the RCH number equals r_a , MT transmits resource request.

2.2. Physical Layer

In the H/2 standard, the physical layer [20] is based on Orthogonal Frequency Division Multiplexing (OFDM) as shown in fig. 2.2. OFDM causes physical bursts to perform better with interference such as frequency selective fading and burst errors caused by wideband fading channel.

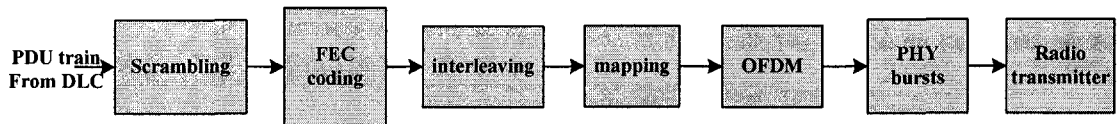


Figure 2.2. Block diagram of HiperLAN/2 physical layer.

Data supplied to the physical layer is scrambled with a length-127 scrambler (Fig. 2.3). In the scrambler, a generator polynomial (equation 2.1) is used [20]. Receiver side uses the same scrambler to descramble the data.

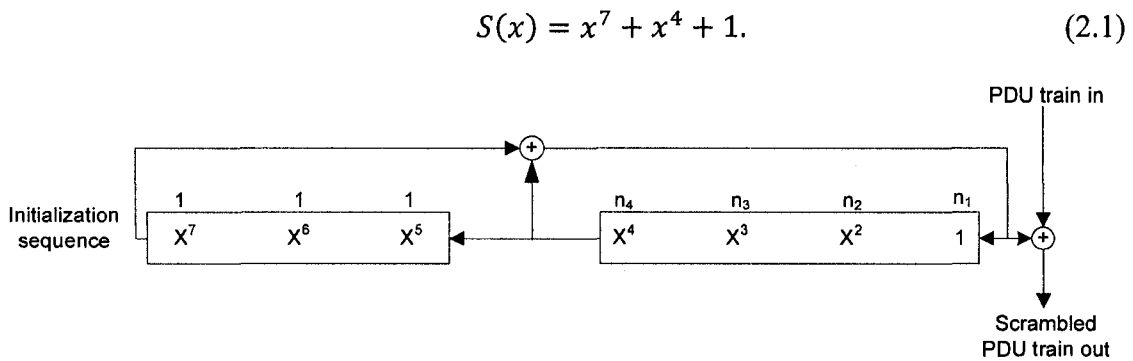


Figure 2.3. HiperLAN/2 scrambler.

The scrambled data is encoded with a 1/2 rate convolutional encoder followed by puncturing. Using Puncturing, 1/2, 3/4 or 9/16 data rates are achieved. This coded data is passed through an interleave stage to combat burst channel error.

Improvement of radio link capability in different kinds of channel interferences are achieved by using one of the 7 modulation schemes dynamically as in table 2.1 [20].

Appropriate data rate is assigned by AP depending on the channel condition. Data from Interleave stage is divided into groups of 1, 2, 4 or 6 bits. Each group is converted into complex numbers representing BPSK, QPSK, 16QAM or 64QAM constellation points (Fig. 2.4). Gray coding is used to map the data bits into the constellation points. A normalization factor K_{MOD} is multiplied with the complex valued output of the mapper to get the final output from this stage as shown in table 2.2 and table 2.3. A PDU train can have PDUs modulated by different types of modulation but inside a particular PDU only one modulation type is used.

Table 2.1. H/2 PHYSICAL LAYER MODES.

Mode	Modulation	Code rate	Nominal bit rate (Mb/s)	Coded bits per sub-carrier	Coded bits per OFDM symbol	Data bits per OFDM symbol
1	BPSK	1/2	6	1	48	24
2	BPSK	3/4	9	1	48	36
3	QPSK	1/2	12	2	96	48
4	QPSK	3/4	18	2	96	72
5	16 QAM	9/16	27	4	192	108
6	16 QAM	3/4	36	4	192	144
7	64 QAM	3/4	54	6	288	216

Table 2.2. MODULATION DEPENDENT NORMALIZATION FACTOR K_{MOD} .

Modulation	K_{MOD}
BPSK	1
QPSK	$1/\sqrt{2}$
16QAM	$1/\sqrt{10}$
64QAM	$1/\sqrt{42}$

Table 2.3. ENCODING TABLES FOR BPSK, QPSK, 16QAM AND 64QAM.

BPSK		
Input bit b_1	I-out	Q-out
0	-1	0
1	1	0

QPSK			
Input bit b_1	I-out	Input bit b_2	Q-out
0	-1	0	-1
1	1	1	1

16QAM			
Input bit b_1b_2	I-out	Input bit b_3b_4	Q-out
00	-3	00	-3
01	-1	01	-1
11	1	11	1
10	3	10	3

64QAM			
Input bit $b_1b_2b_3$	I-out	Input bit $b_4b_5b_6$	Q-out
000	-7	000	-7
001	-5	001	-5
011	-3	011	-3
010	-1	010	-1
110	1	110	1
111	3	111	3
101	5	101	5
100	7	100	7

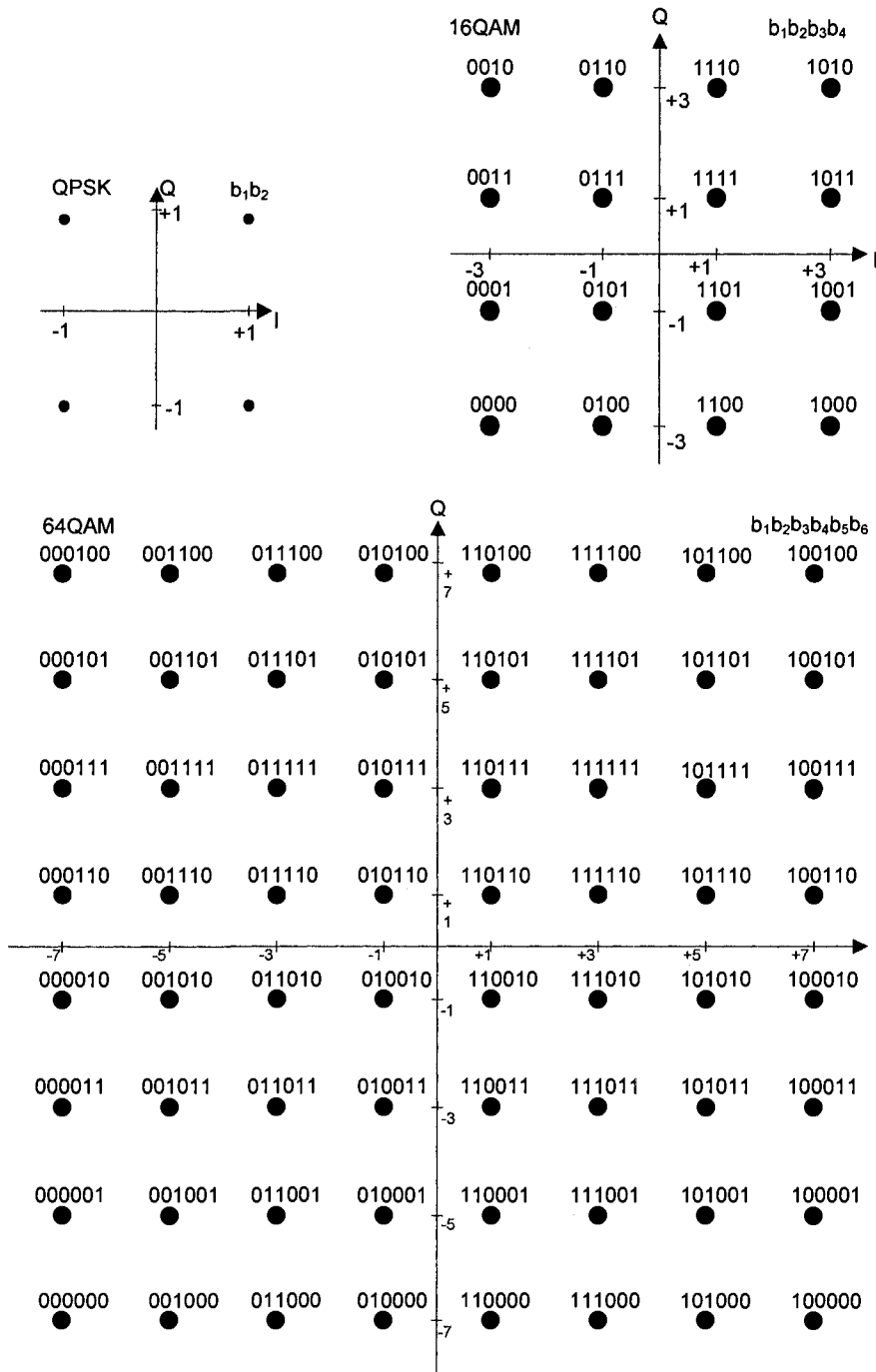


Figure 2.4. H/2 physical layer BPSK, QPSK, 16QAM or 64QAM constellation points.

Complex valued output of the selected mapper is divided into groups to be transmitted by 48 subcarriers of an OFDM symbol. 4 pilot carriers are added with the 48 subcarriers to complete the OFDM symbol of 52 subcarriers. A certain amount of the useful part of the

OFDM symbol, known as cyclic prefix is repeated at the beginning to form the final symbol to prevent inter symbol interference (ISI) and inter-carrier interference (ICI). Numerical values of OFDM parameters [20] used in the H/2 are presented in table 2.4.

Table 2.4. OPDM PARAMETERS.

Parameter	Value
Sapling rate (f_s)	20 MHz
Useful symbol duration (T_u)	3.2 μ s
Cyclic prefix duration (T_{cp})	0.8
Total symbol duration (T_{Total})	4.0
Number of data subcarrier	48
Number of pilot subcarrier	4
FFT size	64
Subcarrier spacing (Δf)	0.3125 MHz
Total bandwidth	16.875 MHz

o **Frequency Band**

Regulatory bodies such as FCC in US and CEPT in Europe specified frequency band to setup wireless systems using H/2 standard. According to the decision made by CEPT, to build Public or Private system using H/2 standard, deployment should be in 5 GHz frequency band as summarized in Table 2.5 [1].

Table 2.5. H/2 OPERATING CONDITIONS.

Frequency band	RF Power limit	Comments
5150 MHz to 5350 MHz	200mW mean EIRP	Indoor use only and implementation of Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC)
5470 MHz to 5725 MHz	1W mean EIRP	Indoor and outdoor use implementation of DFS and TPC.

o **Channel model**

According to the standard HiperLAN/2, 5 channel models [23] are defined (table 2.6) during the standardization process to setup WLAN in domestic premises as well as business premises to cover areas such as apartments, small house, large hall room, office, hospital, university, shopping mall, airport, etc. The defined channels represent a range of different

noise and interference condition in different deployment scenario. We used Channel model E in our simulation, as it is designed for outdoor environment and NLOS.

Table 2.6. H/2 CHANNEL MODELS.

Name	RMS delay spread	Characteristic	Environment
A	50 ns	Narrowband Rayleigh	Residential NLOS
B	100 ns	Wideband Rayleigh	Small Office NLOS
C	150 ns	Wideband Rayleigh	Large Office NLOS
D	140 ns	Wideband Rician	Large Office LOS
E	250 ns	Wideband Rayleigh	Outdoor NLOS

○ **Radio transmission: RF carrier**

Two frequency bands are defined in HiperLAN/2 standard [20]. One is named as lower frequency band occupying 5150 MHz to 5350 MHz and the other one is upper frequency band between 5470 MHz to 5725 MHz. The carrier number $n_{carrier}$ is defined as in equation 2.2.

$$n_{carrier} = \frac{f_c - 5000 \text{ MHz}}{5 \text{ MHz}} \quad (2.2)$$

Carrier frequency are spaced 20 MHz apart. All transmission is centered on one of the nominal frequencies. According to the standard the centre frequencies in Europe are as in table 2.7.

Table 2.7. NOMINAL CARRIER FREQUENCY ALLOCATION TABLE FOR H/2 IN EUROPE.

n_{carrier}	Band	f_c [MHz]	Mean EIRP[dBm]
36	Lower	5180	23
40	Lower	5200	23
44	Lower	5220	23
48	lower	5240	23
52	lower	5260	23
56	lower	5280	23
60	lower	5300	23
64	lower	5320	23
100	upper	5500	30
104	upper	5520	30
108	upper	5540	30
112	upper	5560	30
116	upper	5580	30
120	upper	5600	30
124	upper	5620	30
128	upper	5640	30
132	upper	5660	30
136	upper	5680	30
140	upper	5700	23

Chapter 3: Resource allocation policies

One of the main functions of an AP is to organize the TDMA frame. Efficiency of the system depends on the allocation mechanism adopted by the AP. QoS provided by MT also depends on the allocation mechanism of AP. We simulate the system for three allocation schemes.

3.1. Minimum Overhead Round Robin (MORR)

In this scheme AP allocates equal capacity share to all active MTs. Whenever one MT is given transmission opportunity, it gets the opportunity to transmit up to the system capacity. If the MT does not have enough packets in the buffer, frame is filled by packets of another MT. A certain MT is visited again when AP has completed its visit to all other MTs. This process helps to reduce overhead of the system. Fig. 3.1 shows a flowchart for this scheme.

3.2. Weighted Minimum Overhead Round Robin (WMORR)

Resource request of MT contains its buffer condition and AP has the information in regard to the elapsed time since last transmission opportunity the MT has got. Using product of this two information an allocation mechanism is designed to give transmission opportunity to a MT waiting for long and that has highest number of packets in buffer. It is termed as MORR because whenever a MT is visited capacity is assigned up to the capacity of the network. Mathematically the buffer status and waiting time gives a matrix M (equation 3.1). The AP compares and combines all such matrix of all MT and hence decides upon the

capacity allocation to each MT. Basically the time or capacity assigned to i^{th} MT is given by equation 3.2. Flowchart of this scheme is presented in Fig. 3.2.

$$M_i = B_{MT_i} \times W_{MT_i} \quad (3.1)$$

$$T_{MT_i} = T_{Frame} \frac{M_i}{\sum_{j=1}^N M_j} \quad (3.2)$$

Where,

B_{MT_i} = No. of PDUs in the buffer of MT_i .

W_{MT_i} = Waiting time for transmission opportunity of MT_i .

M_i = Weight of MT_i .

N = Total no. of MTs associated with AP.

T_{Frame} = Total Uplink or Downlink time in a TDMA frame.

T_{MT_i} = Total downlink or uplink time allocated to MT_i .

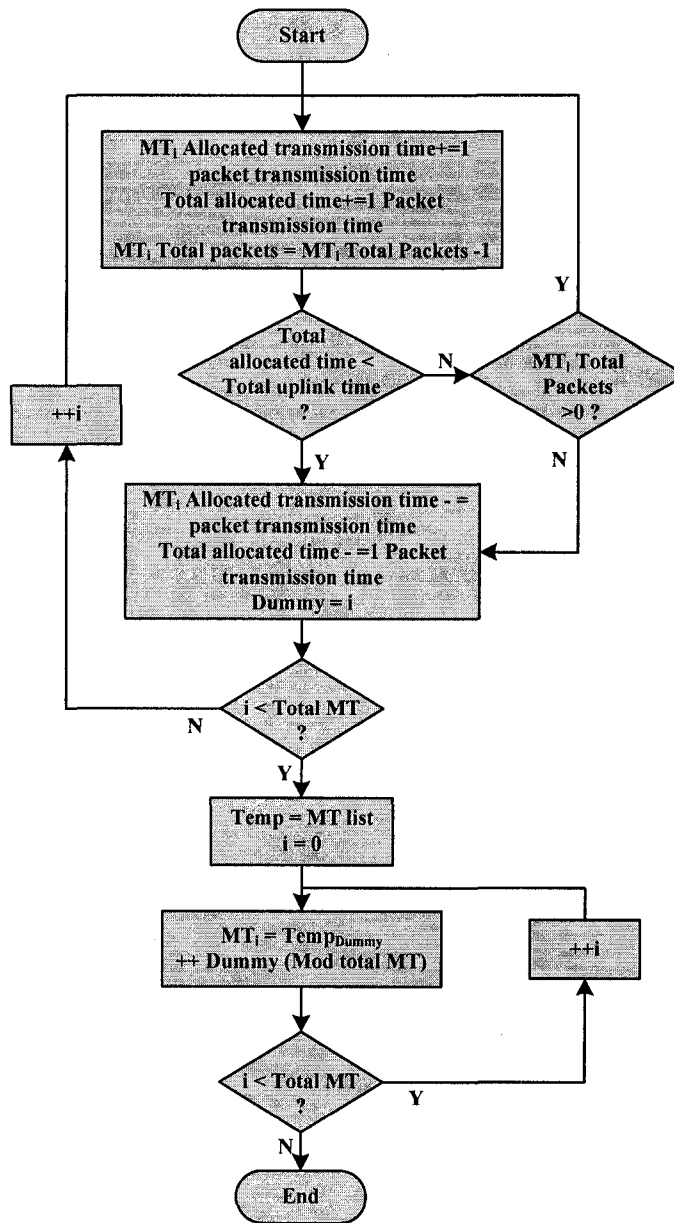


Figure 3.1. Flow chart MORR scheme.

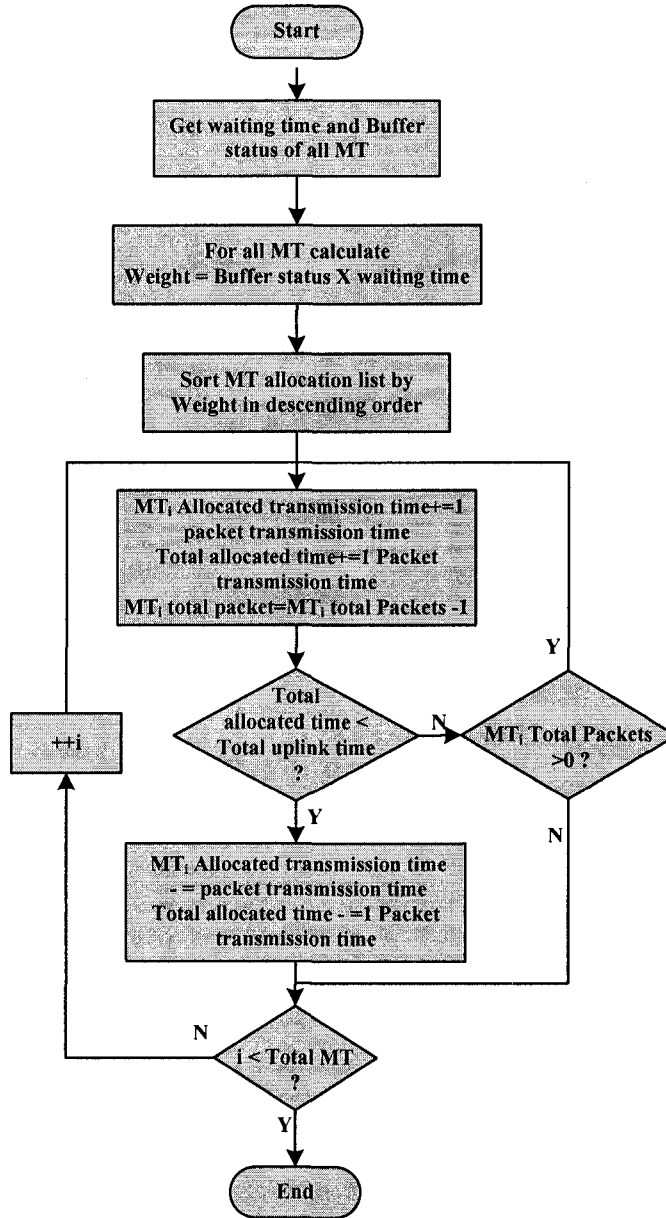


Figure 3.2. Flowchart for WMORR scheme.

3.3. Weighted Round Robin (WRR)

With this scheme, resource is allocated to MTs by using a look up table. Whenever a particular MT is visited, transmission time equal to one PDU is allocated to it. A certain MT is visited again if time is left in frame provided that AP has completed its visit to all other MTs. The look up table for resource allocation is prepared using the addresses of the associated

MTs and their weight. Weight of the MT is defined as the number of PDUs in the buffer of that MT. The look up table is rearranged and updated in every frame using buffer status of the MTs and MT with more weight is placed higher in the look up table. Basically this scheme works as Round Robin algorithm but only difference is that MTs are polled as per their demand. A flowchart for this scheme is shown in Fig. 3.3.

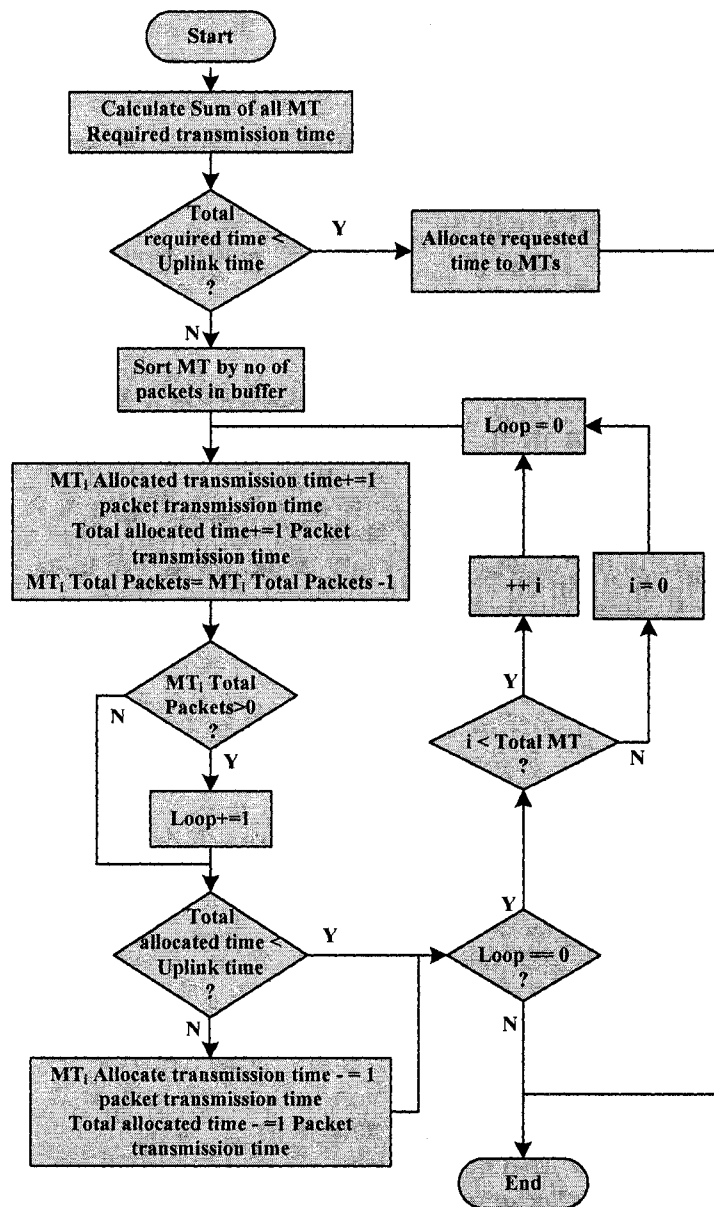


Figure 3.3. Flowchart for WRR scheme.

Chapter 4: System Setup

The simulation is done in a module based manner using VC++. Each module is independent and data is transferred from one module to another by predefined global variable in the program. We simulate the H/2 system for both uplink (Data direction MT to AP) and downlink (Data direction AP to MT) considering best effort packet delivery.

4.1. Simulation Setup

In our simulation we choose parameters to operate our system in an open space outdoor environment. We simulate four independent LANs as shown in fig. 4.1. Service area of an AP is the largest distance from the AP where data rate becomes zero. It is determined from the knowledge of physical layer parameters. A central controller (CC) connects all the APs.

All the packets transmitted by MTs have to pass through its associated AP in our network. If a received data packet of by AP has a destination MT which is located in the service area of another AP, packet is routed through the CC to that AP. For routing, a look up table (LUT) is used where each MT, AP and CC is listed using unique address. We assume that no packet loss occurs in packet exchange process between AP and CC. But we consider the effects of packet losses in the link between MTs and APs. In the simulation, we set a variable in each PDU. When the PDU is transmitted by MT or AP we call $U(0,1)$ and store the outcome in the variable of the PDU. At the destination of the PDU we compare the value

of this variable with the acceptable error value which is 0.01 (Error rate 1 out of 100 PDUs). If the value of the variable is equal to or greater than 0.01 we took the PDU as successful one.

In our system APs communicate with the CC using HIPERLINK standard [7] at data rate 155 Mbits/s. Queuing delay is added with a PDU when it pass through CC. Queuing delay depends on the number of PDUs sent to CC by APs. Using the model for M/M/1queuing [21] this average delay is calculated using equation 4.1, where μ is the PDU service rate of CC and λ is the PDU arrival rate to CC.

$$E[T] = \frac{1}{\mu - \lambda} \tag{4.1}$$

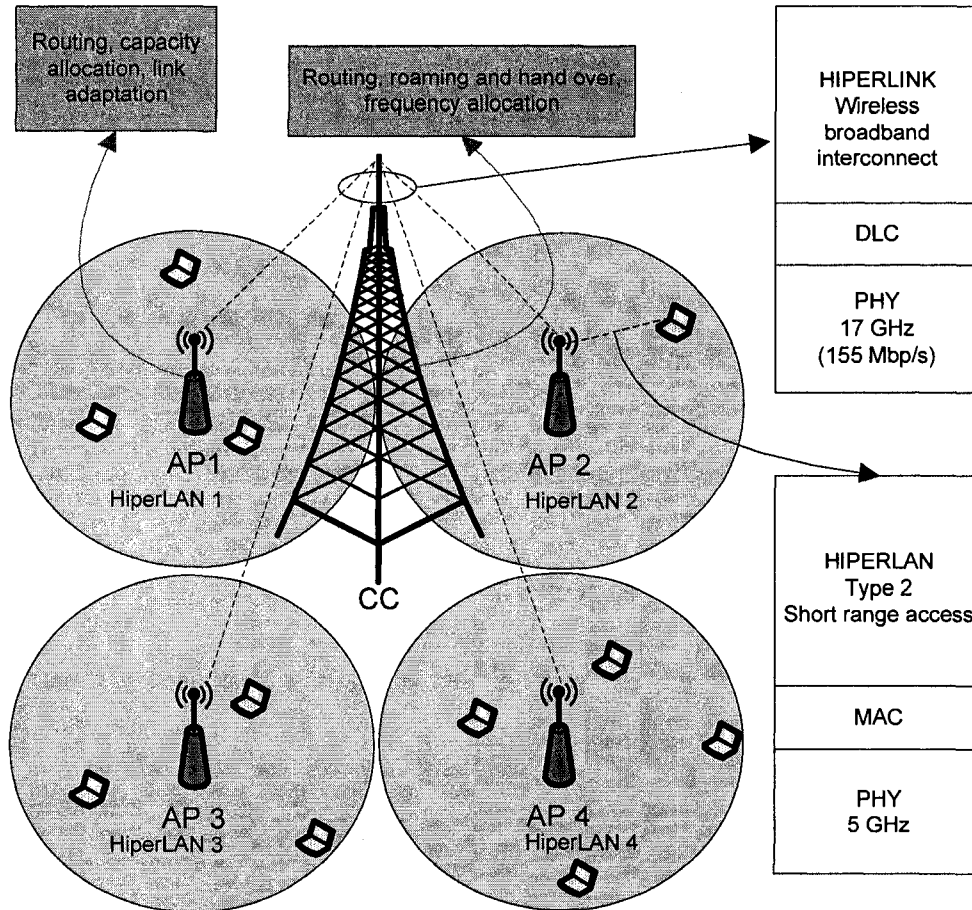


Figure 4.1. Simulation system setup.

4.2. Simulation Flowchart

The length of each MAC frame is 2 ms. The frame is divided into number of short time phases. Data from MAC layer mapped to physical burst using the physical layer transmission rate as shown in table 4.1. We simulate the system in modular manner where each module corresponds to a short time phase of a TDMA/TDD frame. Using the operation parameters of table 4.1 we developed flow charts of each short phase of the TDMA/TDD frame and realized them by the VC++ code. The flowchart for the whole system is shown in fig. 4.2. It contains four sub-routines and each one represents one short time phase. Subroutines for the broadcast phase, uplink phase, downlink phase and random access phase is shown in fig. 4.3, 4.4, 4.5 and 4.6 respectively.

Table 4.1. OPERATION PARAMETER SETTING

Transport Channel	Modulation & Code rate	Tx time (μ s)
Broadcast PDU Train		
Preamble		16
BCH	BPSK, code rate $\frac{1}{2}$	20
FCH	BPSK, code rate $\frac{1}{2}$	Multiple of 36
ACH	BPSK, code rate $\frac{1}{2}$	12
Downlink PDU train		
Preamble		8
SCH	BPSK, code rate $\frac{1}{2}$	12
LCH	BPSK, code rate $\frac{1}{2}, \frac{3}{4}$	72, 48
	QPSK, code rate $\frac{1}{2}, \frac{3}{4}$	36, 24
	16QAM, code rate $\frac{9}{16}, \frac{3}{4}$	16, 12
	64 QAM, code rate $\frac{3}{4}$	8
Uplink PDU train		
Preamble (Short)		12
SCH	Same as downlink	
LCH	Same as downlink	
Guard time		2
Random access		
Preamble (Short)		12
RCH	BPSK, code rate $\frac{1}{2}$	12
Guard time		2
Radio turn-around (max)		6

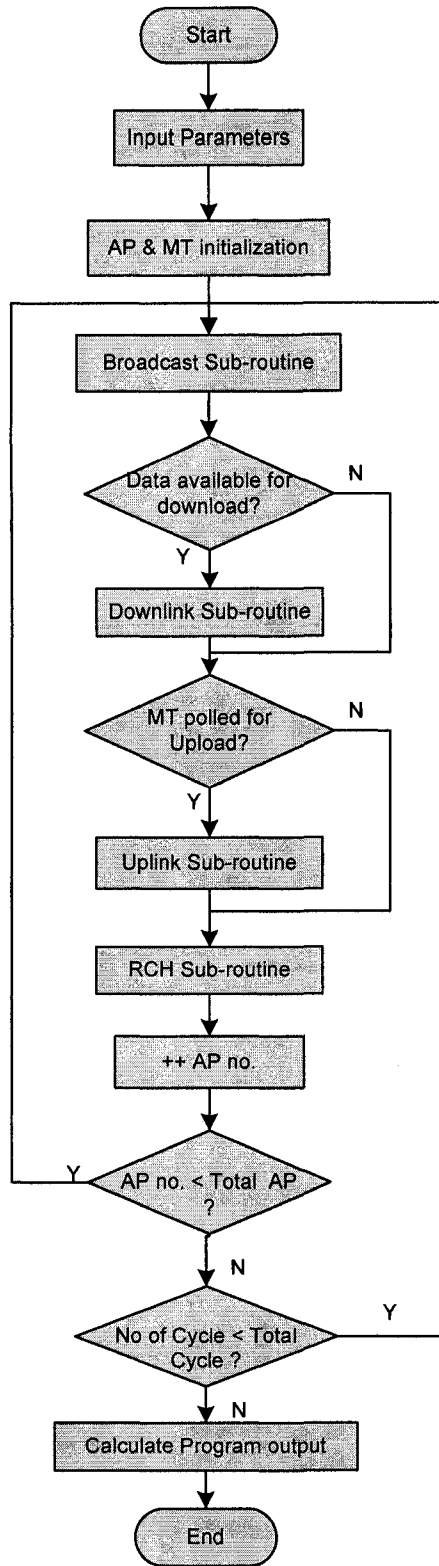


Figure 4.2. Flowchart for the system.

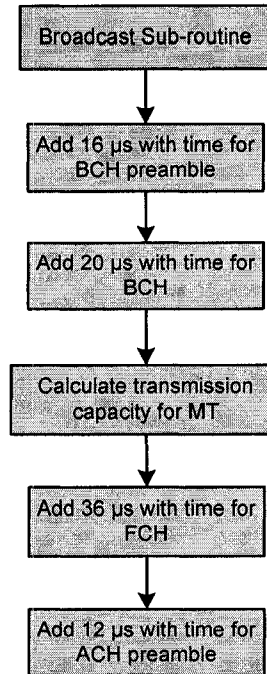


Figure 4.3. Flowchart for Broadcast phase.

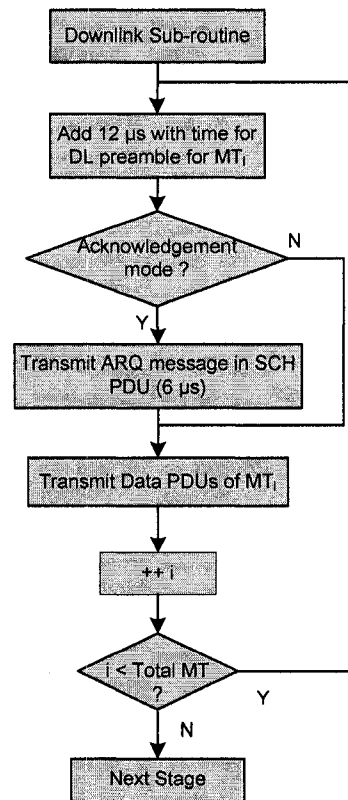


Figure 4.4. Flowchart for Downlink phase.

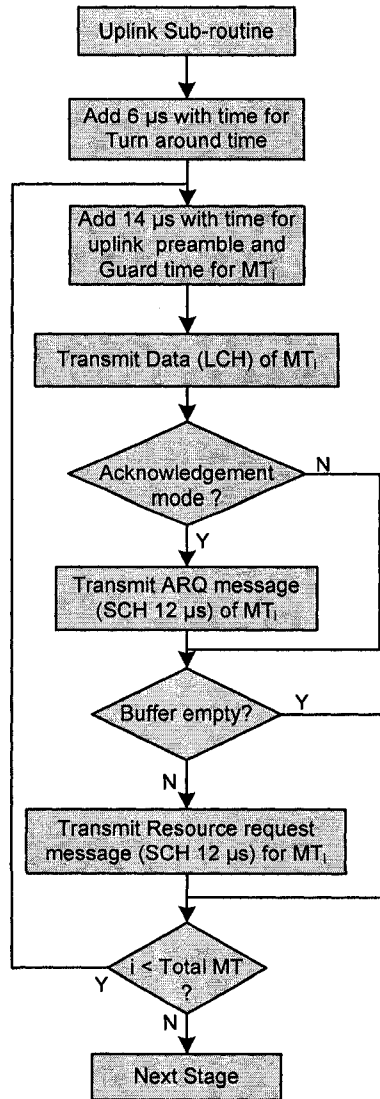


Figure 4.5. Flowchart for Uplink phase.

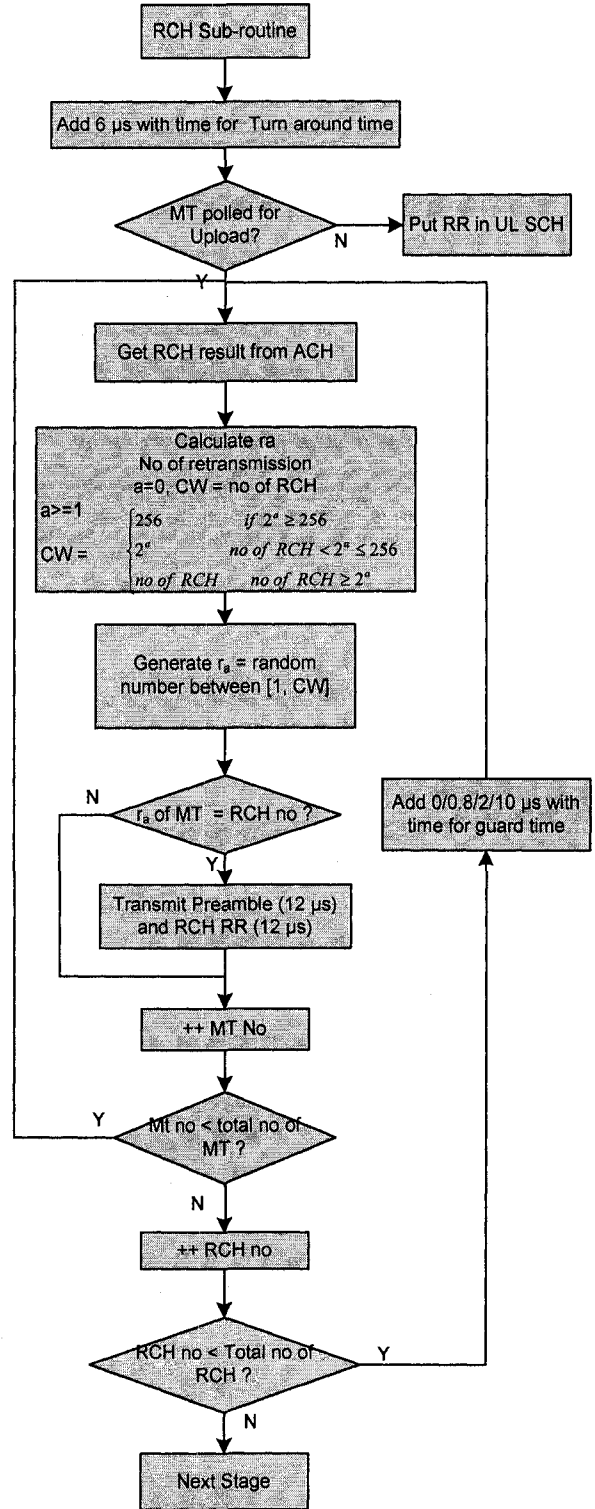


Figure 4.6. Flowchart for RCH phase.

4.3. Data rate Calculation

We simulate the system in outdoor environment i.e. Channel E and consider Omni-directional antenna having height 12 m and EIRP 1W. Each AP uses link adaptation procedure to select the appropriate data rate for the associated MTs. For link adaptation at a particular C/N value, choice is made in favour of the highest value of achievable data rate considering Modulation and PER (PDU Error Rate) for that value of C/N . Using the following steps and the simulated PER vs C/N graph (Fig. 4.7) [23] we generate link adaptation curve (fig. 4.8) and table 4.2, considering 1% PER specification.

1. At the receiver (MT or AP) side noise floor N is calculated by equation 4.2. Where the $H/2$ bandwidth, $B = 20$ MHz and Noise factor, $NF = 6$ dB.

$$(4.2)$$

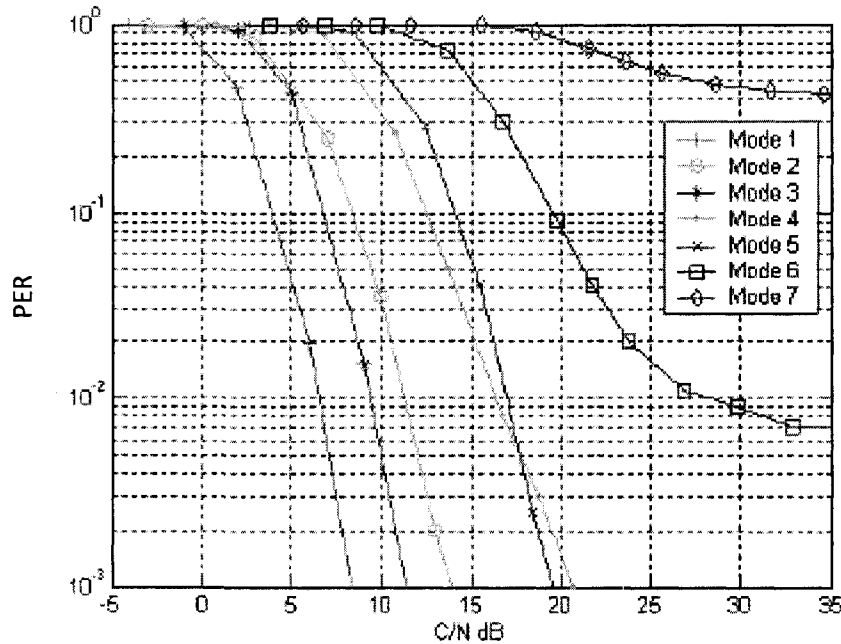


Figure 4.7. PER vs C/N curve for channel E.

2. For a particular mode from the PER vs. C/N curve (Fig. 4.7) [23], we determine the highest value of carrier to noise ratio (C/N) for which the specification of 0.01 PER is maintained.
3. We use this value of the C/N , the value of N from step 1 and consider 2 dB as implementation factor (L_{impl}) in equation 4.3 to calculate the minimum received carrier power (C_R).

$$C_R = N + \frac{C}{N} + L_{impl}. \quad (4.3)$$

4. The path loss (P_L) for this C_R is calculated by equation 4.4, where transmitted carrier power (C_T) is 30 dBm.

$$P_L = C_T - C_R. \quad (4.4)$$

5. Using the value of path loss we determine the distance for this path loss using path loss model (equation 4.5) [22], where $b=20$ and $n=4.5$ (For antenna height =12 m in urban area and NLOS).

$$P_L = b + 10n \log_{10} d. \quad (4.5)$$

6. This is the highest distance or range of a particular mode, up to where the mode maintains 0.01 PER specification.
7. We followed the steps 2 to 6 for all the modes and determine the range of each mode.
8. Finally, for a particular distance we choose a mode that gives the highest data rate.

In our simulation we used table 4.2 as LUT to determine uplink or downlink data rate for any distance between MT and AP. It is to be noted that for this particular channel Mode 2 and Mode 7 is never used because of the very high PER in this channel.

Table 4.2. LOOK UP TABLE FOR MODE SELECTION.

Distance (m)	C/N (dB)	Mode
137.26 – 119.55	6.8 – 9.5	1
119.55 – 83.56	9.5 – 16.5	3
83.56 – 80.41	16.5 – 17.25	4
80.41 – 47.59	17.25 – 27.5	5
< 47.59	27.5+	6

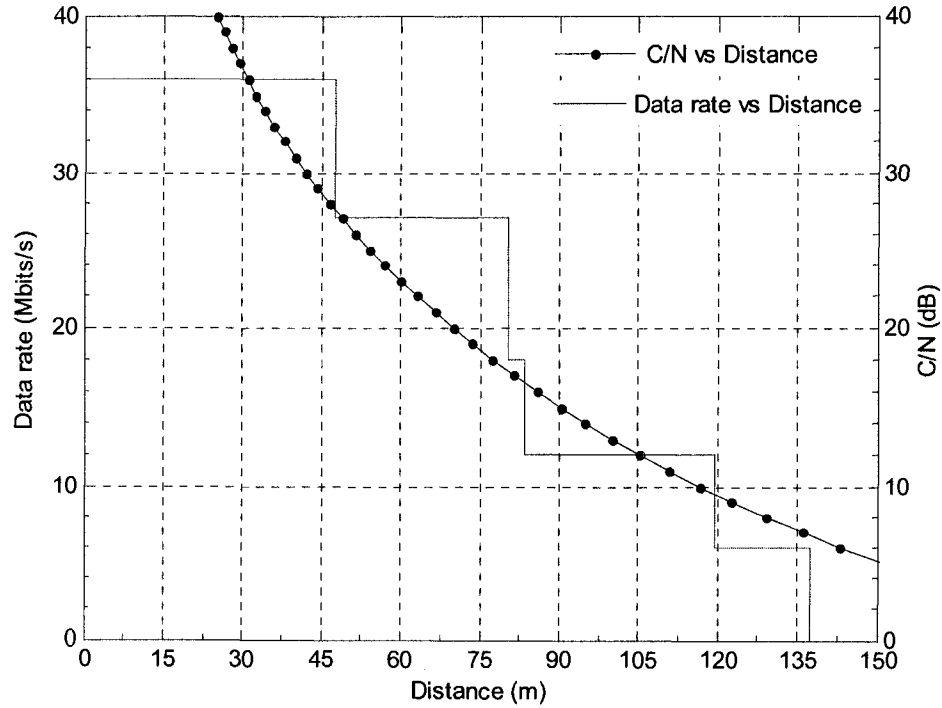


Figure 4.8. C/N Vs Distance curve for outdoor channel.

4.4. MT Position and Mobility

In our simulation MTs are scattered randomly inside the service area of an AP. Position of a mobile terminal is randomized using uniform distribution. In our simulation we simulate the condition where MTs are free to move within the service area of AP but cannot leave their respective AP. In our simulation we let the MTs to move at a maximum rate of 10 m/s. When a MT overtake the boundary of the service area of its associated AP we turned it back inside the service area of AP and assign a position at the edge of the boundary of the service area. A

snapshot of transmission rate of a typical MT during simulation runtime is presented in fig. 4.8.

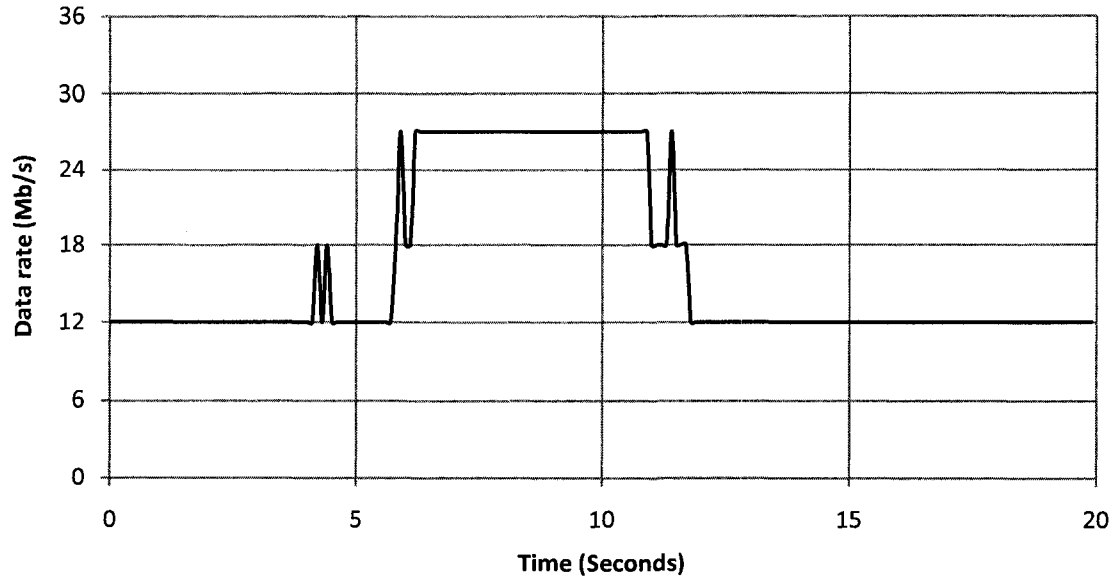


Figure 4.9. A snapshot of transmission rate of a typical MT during simulation.

To make an equal condition for performance measurement of the allocation policies we stored the location of each MT in the WLAN area after each TDMA/TDD frame in a separate data file at the beginning of our simulation. This position indicator data file is used as input for MT position in the rest of the simulation program.

4.5. Simulation Criteria

○ Average Number of PDUs in Buffer and its Variance

PDUs received from the DLC layer are stored in the buffer of each MT for transmission in the TDMA frame. As length of each TDMA frame is fixed, buffers in the MTs grow up if discharge rate is lower than the arrival rate. Average number of PDUs in the buffer of MTs indicates the buffer occupancy of the MTs. To calculate average number of PDUs in the Buffer, the number of PDUs in the buffer of MTs for the simulation period is averaged by

equation 4.6 first. This result is averaged again by adding up and dividing by the total number of MTs (equation 4.7), to get Average Number of PDUs in Buffer finally.

$$B_i = \frac{\sum_{j=1}^{\text{Total no. of iteration}} B_{ij}}{\text{Total no. of iteration}} \quad (4.6)$$

$$\bar{B} = \frac{\sum_{i=1}^{\text{Total no. of MT}} B_i}{\text{Total no. of MT}} \quad (4.7)$$

Where,

B_{ij} = Number of PDUs in the buffer of i^{th} MT at j^{th} iteration.

B_i = Average number of PDUs in the buffer of the i^{th} MT for the simulation runtime.

\bar{B} = Average number of PDUs in the Buffer.

The variance of the average number of PDUs in the buffer of MTs is calculated by the equation 4.8 as below:

$$\sigma_{\bar{B}}^2 = \frac{\sum_{i=1}^{\text{Total no. of MT}} (B_i - \bar{B})^2}{\text{Total no. of MT} - 1} \quad (4.8)$$

o Probability of Buffer Overflow and its Variance

PDUs from the DLC connections are stored in the buffer of MT using First In First Out algorithm (FIFO). If the PDU arrival rate is higher than the discharge rate PDUs accumulates in the buffer of MTs. As the buffer size is finite overflow occurs when buffer gets full and any new PDU from the DLC connection is discarded. To calculate the probability of buffer overflow we set a counter in the buffer of the MT. This counter is incremented by 1, if one PDU is discarded. Average number of buffer overflow for a MT for the simulation runtime is calculated by equation 4.9. This value is averaged over the number of MT to get the Average Probability of Buffer Overflow (equation 4.10).

$$O_i = \frac{100 \times \sum_{j=1}^{Total\ no.\ of\ itaration} O_{ij}}{Total\ no.\ of\ itaration} \quad (4.9)$$

$$\bar{O} = \frac{\sum_{i=1}^{Total\ no.\ of\ MT} O_i}{Total\ no.\ of\ MT} \quad (4.10)$$

Where,

O_{ij} = Number of overflow in the buffer of i^{th} MT at j^{th} iteration.

O_i = Average number of buffer overflow of the i^{th} MT for the simulation runtime.

\bar{O} = Probability of Buffer Overflow.

The variance of the buffer overflow of MTs is calculated by the equation 4.11 as below:

$$\sigma_{\bar{O}}^2 = \frac{\sum_{i=1}^{Total\ no.\ of\ MT} (O_i - \bar{O})^2}{Total\ no.\ of\ MT - 1} \quad (4.11)$$

o **Average PDU delivery time and its variance**

PDU delivery time is the total amount of time required by a PDU to reach its destination after generation. In the system it can happen in two ways:

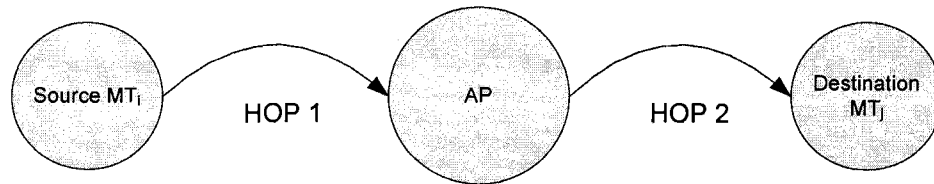


Figure 4.10. PDU delivery event under in same AP.

- If the source and the destination MT of a PDU is located inside the service area of an AP (Fig. 4.1), total time is the summation of time elapsed by the PDU in the buffer of source MT, transmission time by source MT, time elapsed by the PDU in the buffer of AP and transmission time of the PDU by AP (Fig. 4.10).

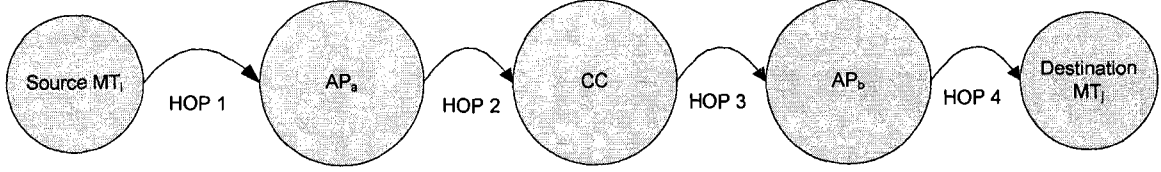


Figure 4.11. PDU delivery event under in different AP.

- If destination MT of the PDU is located in the service area of AP other than the AP of the source MT, total time is the summation of time elapsed by the PDU in the buffer of source MT, transmission time by source MT, time elapsed by the PDU in the buffer of AP and CC, queuing delay in the buffer of CC and transmission time of the PDU by AP and CC (Fig. 4.10).

To calculate the average PDU delivery time, average delivery time for PDUs of all the MTs is calculated first by equation 4.12. These results are added and divided by the total number of MTs to get the final result (equation 4.13).

$$DT_i = \frac{\sum_{j=1}^{Total\ no.\ of\ Successful\ PDU} DT_{ij}}{Total\ no.\ of\ Successful\ PDUs\ of\ MT_i} \quad (4.12)$$

$$\overline{DT} = \frac{\sum_{i=1}^{Total\ no.\ of\ MT} DT_i}{Total\ no.\ of\ MT} \quad (4.13)$$

Where,

DT_{ij} = Delivery time for j^{th} PDU of i^{th} MT.

DT_i = Average PDU delivery time for the i^{th} MT.

\overline{DT} = Average PDU delivery time.

The variance of the PDU delivery time is calculated by the equation 4.14 as below:

$$\sigma_{DT}^2 = \frac{\sum_{i=1}^{Total\ no.\ of\ MT} (DT_i - \overline{DT})^2}{Total\ no.\ of\ MT - 1} \quad (4.14)$$

○ **Average Overhead in uplink phase and its variance**

We added overhead in the uplink phase of TDMA/TDD frame of all user and expressed it as percentage of total uplink time of an AP. This result is averaged over the total number of frames to determine the overhead in the uplink phase of the AP as in equation 4.15. We calculate the average overhead in uplink phase by adding up the overhead in uplink phase of each AP and dividing the summation by total number of APs as in equation 4.16.

$$\eta_{UL_i} = \frac{\sum_{j=1}^{Total\ no.\ of\ Frames} \frac{UTO_{ij} \times 100}{UT_{ij}}}{Total\ no.\ of\ Frames} \quad (4.15)$$

$$\overline{\eta_{UL}} = \frac{\sum_{i=1}^{Total\ no.\ of\ AP} \eta_{UL_i}}{Total\ no.\ of\ AP} \quad (4.16)$$

Where,

UT_{ij} = Total uplink time of j^{th} TDMA frame of i^{th} AP.

UTO_{ij} = Summation of all user overhead in j^{th} frame of i^{th} AP.

η_{UL_i} = Average uplink overhead for the i^{th} AP.

$\overline{\eta_{UL}}$ = Average uplink overhead.

The variance of the uplink overhead percentage is calculated by equation 4.17:

$$\sigma_{\eta_{UL}}^2 = \frac{\sum_{i=1}^{Total\ no.\ of\ AP} (\eta_{UL_i} - \overline{\eta_{UL}})^2}{Total\ no.\ of\ AP - 1} \quad (4.17)$$

○ **Average Overhead in Downlink phase and its variance**

We added overhead in the downlink phase of TDMA/TDD frame of all user and expressed it as percentage of total downlink time of an AP. This result is averaged over the

total number of frames to determine the overhead in the downlink phase of the AP as in equation 4.18. We calculate the average overhead in downlink phase by adding up the overhead in downlink phase of each AP and dividing the summation by total number of APs as in equation 4.19.

$$\eta_{DLi} = \frac{\sum_{j=1}^{Total\ no.\ of\ Frames} \frac{DTO_{ij} \times 100}{DT_{ij}}}{Total\ no.\ of\ Frames} \quad (4.18)$$

$$\overline{\eta_{DL}} = \frac{\sum_{i=1}^{Total\ no.\ of\ AP} \eta_{DLi}}{Total\ no.\ of\ AP} \quad (4.19)$$

Where,

DT_{ij} = Total downlink time of j^{th} TDMA frame of i^{th} AP.

DTO_{ij} = Summation of all user overhead in j^{th} frame of i^{th} AP.

η_{DLi} = Average downlink overhead percentage for the i^{th} AP.

$\overline{\eta_{DL}}$ = Average downlink overhead.

The variance of the downlink overhead percentage is calculated by the equation 4.20 as below:

$$\sigma_{\eta_{DL}}^2 = \frac{\sum_{i=1}^{Total\ no.\ of\ AP} (\eta_i - \overline{\eta_{DL}})^2}{Total\ no.\ of\ AP - 1} \quad (4.20)$$

Chapter 5: Simulation results

We run a large number of iterations, equivalent to 20 seconds in real time for the simulation setup of chapter 4, where each iteration represents one TDMA/TDD frame. To measure the performance of the resource allocation schemes, we have simulated our system for two cases:

- Fixed amount of data generation per TDMA/TDD frame to represent idle state of web browsing.
- Random amount of data generation per TDMA/TDD frame to represent busy state of web browsing.

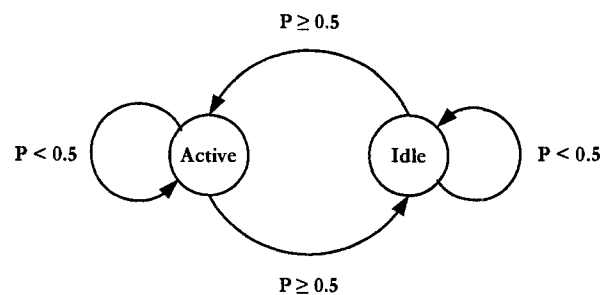


Figure 5.1. ON-OFF model.

5.1. Fixed Burst

In the simulation we generate a fixed amount of data (1 PDU or 54 bytes) per time period of 2 ms using the ON-OFF model as shown in fig. 5.1. We consider one TDMA frame or 2 ms as length of ON or OFF period for PDU arrival event. In our ON-OFF model, the data

generator changes its state from ON to OFF or from OFF to ON with a probability greater than or equal to 0.5. We call a U(0,1), if the outcome is greater than or equal to 0.5 the user is ON state. This data generation technique gives out an average data arrival rate to the buffer of each MT equal to 108 kb/s.

We have calculated the system load by dividing the total requested time in the uplink phase of all MT associated with an AP by the capacity of that AP as in equation 5.1. Here the capacity of the AP is the Uplink time in a TDMA frame. Fig. 5.2 shows the load distribution over the number of mobile terminals that we get as outcome of the simulation. The other parameter used to setup the system is summarized in table 5.1.

$$\begin{aligned}
 \text{Load} &= \frac{\text{Total requested time per TDMA frame}}{\text{Total available time in a TDMA frame}} \\
 &= \frac{\text{Total MT per AP} \times \frac{0.5 \times 432}{940 \times 10^{-6}}}{940 \times 10^{-6}} \quad (5.1)
 \end{aligned}$$

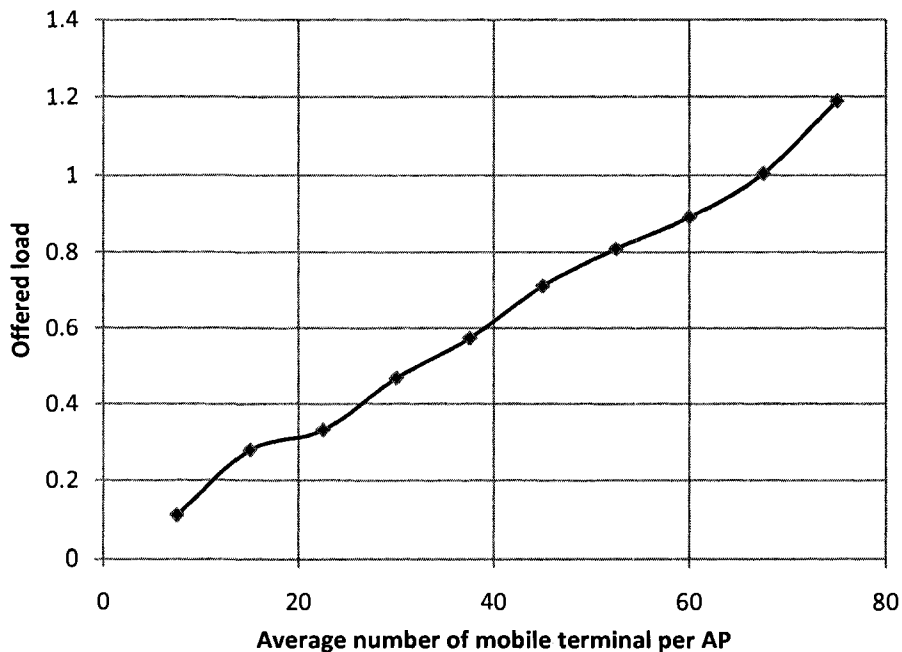


Figure 5.2. Load distribution over number of mobile terminals.

Table 5.1. SIMULATION PARAMETERS FOR FIXED BURST.

Network Parameters	
No of CC	1
No of AP	4
Network area	538 m x 538 m
AP coverage radius	137.26 m
AP Tx power	1 Watt
Antenna height	12 m
Antennal type	Omnidirectional
AP location	Urban area
AP buffer size	100 PDU
CC buffer size	400 PDU
No. of RCH phase	1
Simulation runtime	10000 frames
DL/UL time	940x10 ⁻⁶ s
Source model	
LCH PDU length	54 byte
SCH PDU length	9 byte
Max. MT movement rate	10 m/s
MT Buffer size	5/10/15 PDU
MT Buffer Management	FIFO

○ **Average Number of PDUs in Buffer and its Variance**

Fig. 5.3-5.5 shows the average number of PDUs in buffer of MTs as a function of offered load for the three resource allocation policies, where buffer size is 5, 10 and 15 PDUs respectively. In the figures, the WMORR and MORR policies show almost equal performance in terms of buffer occupancy. It is important to note that WMORR and MORR allocation schemes outperform the WRR scheme in terms of buffer occupancy. We also notice that when offered load is around 0.3 there is a sharp change in average number of PDUs in the user buffer. It indicates that before this load total PDU arrived to the MTs is equal to the PDU service rate of MTs. After this load PDU arrival rate becomes higher than the PDU service rate but the system remains in stable as the undelivered PDUs are stored in the buffer for future transmission.

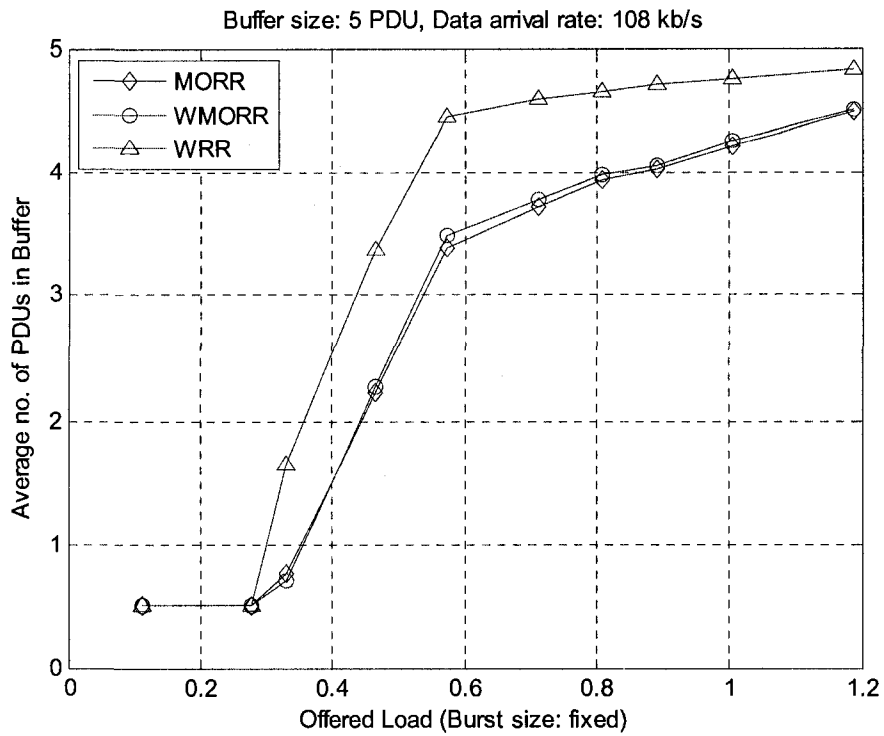


Figure 5.3. Average number of PDUs in Buffer vs Offered load for buffer size 5 PDU at fixed burst.

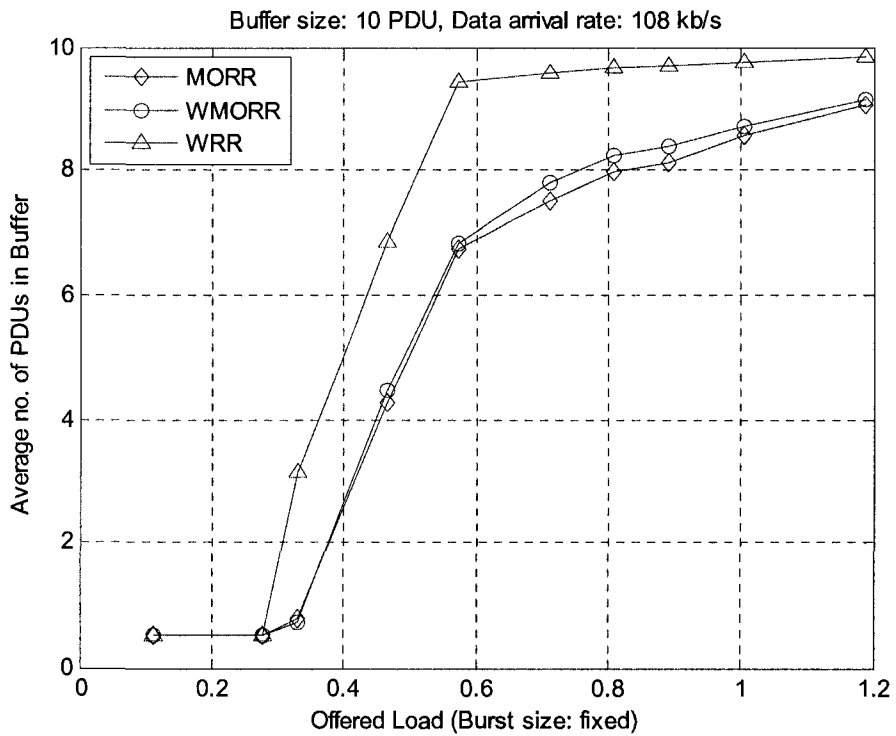


Figure 5.4. Average number of PDUs in Buffer vs Offered load for buffer size 10 PDU at fixed burst.

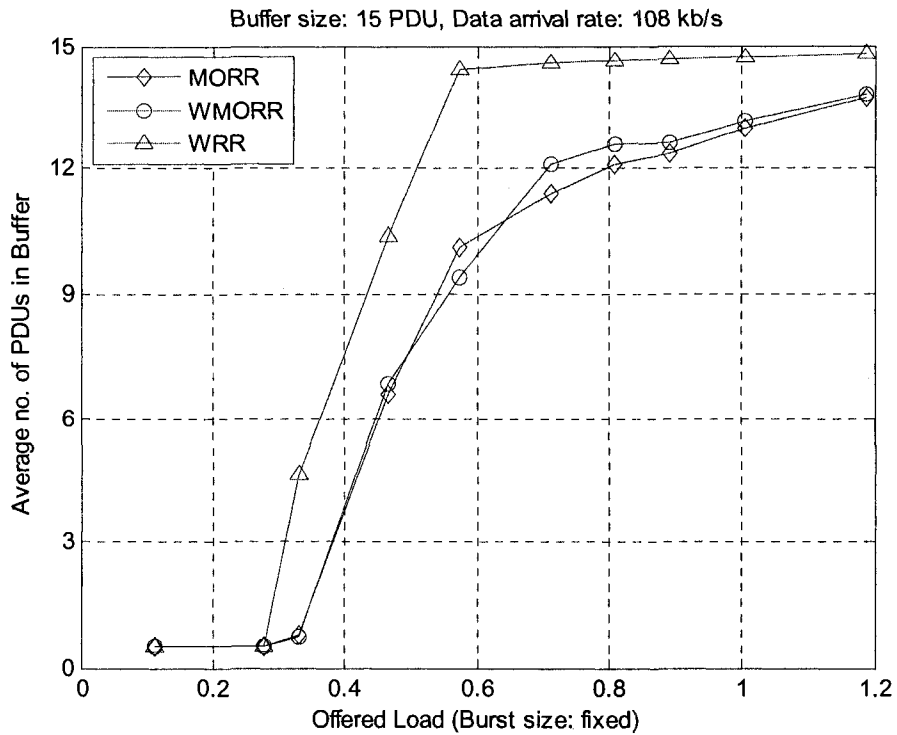


Figure 5.5. Average number of PDUs in Buffer vs Offered load for buffer size 15 PDU at fixed burst.

Fig. 5.6, 5.7 and 5.8 shows the average number of PDUs in buffer of MTs as a function of offered load for the buffer size 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. The figure shows that at very low offered load buffer occupancy is the same for all buffer sizes and as offered load increases, the number of PDUs in the buffer also increases. Average number of PDUs in the buffer of MTs becomes almost constant at load higher than 0.5 and it gradually becomes equal to the size of the buffer. We also notice that the smaller sized buffer becomes full at lower offered load but for larger sized buffer it happens at very high offered load.

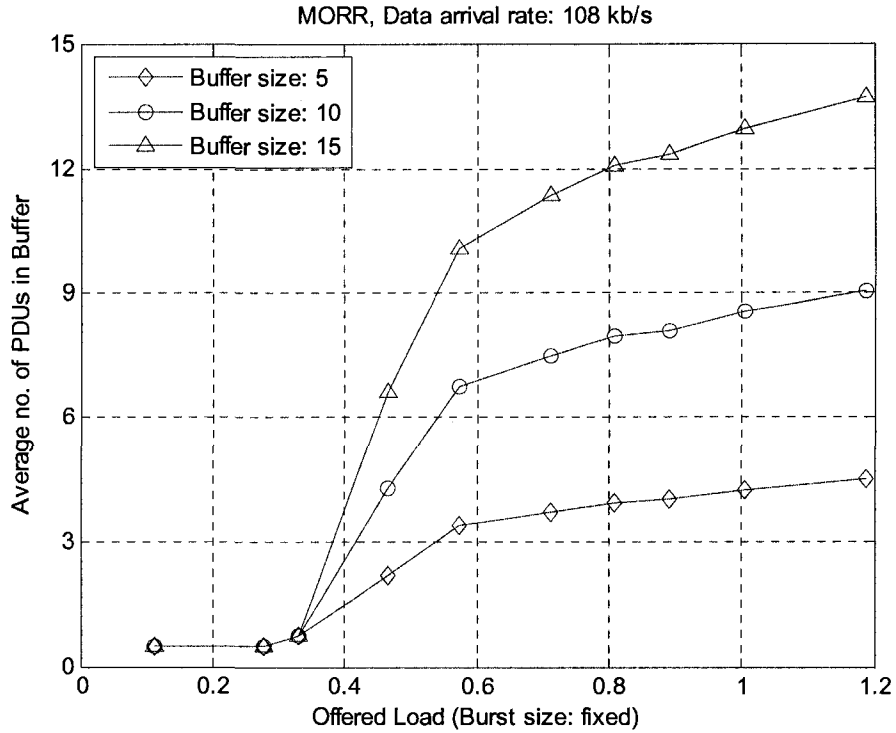


Figure 5.6. Average number of PDUs in Buffer vs Offered load for MORR allocation scheme at fixed burst.

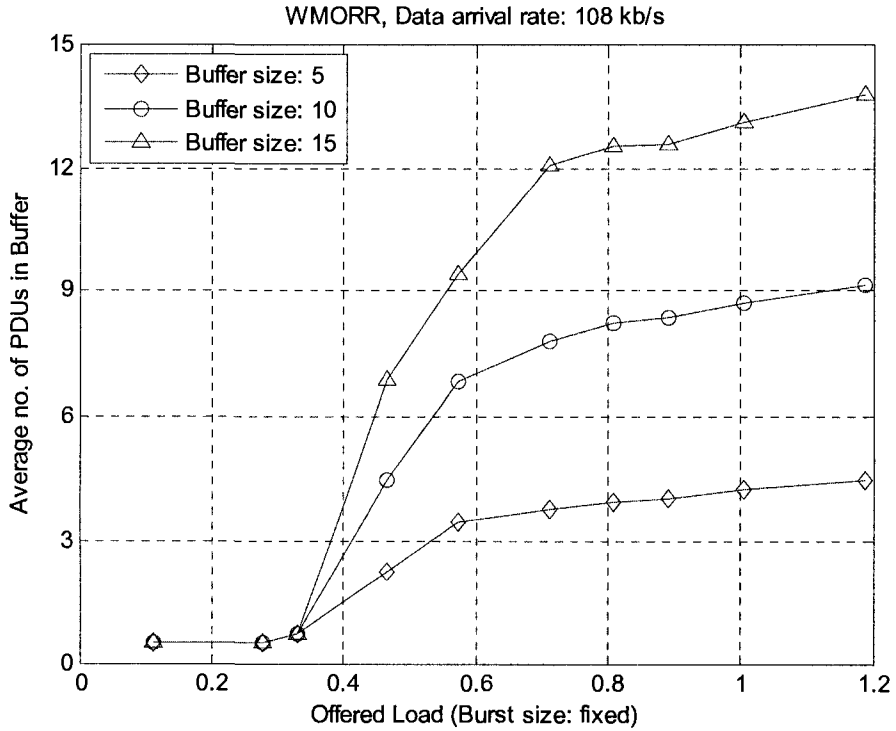


Figure 5.7. Average number of PDUs in Buffer vs Offered load for MORR allocation scheme at fixed burst.

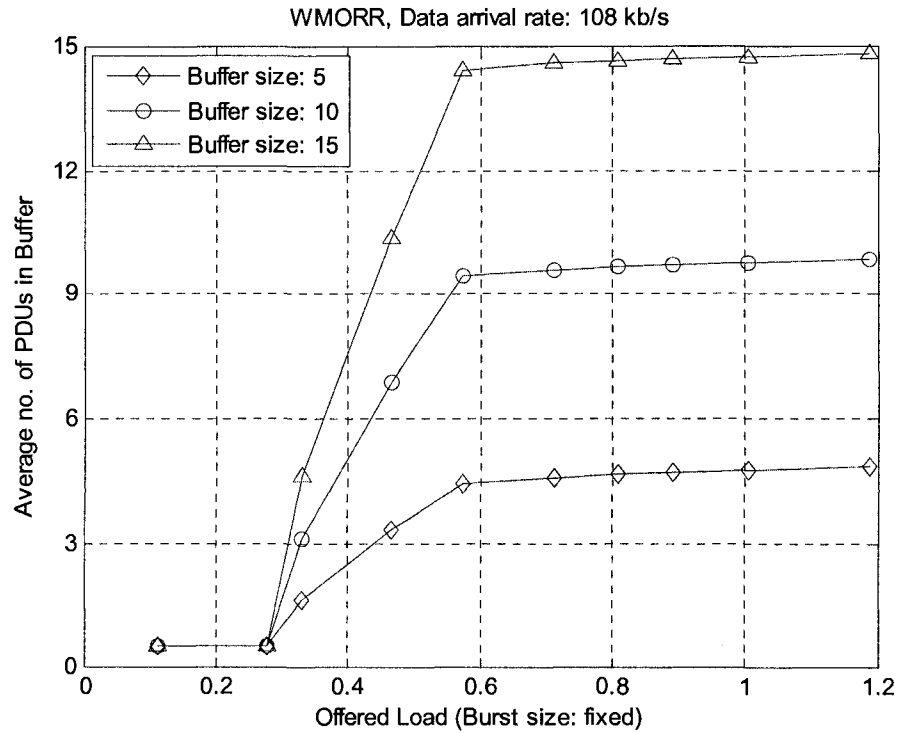


Figure 5.8. Average number of PDUs in Buffer vs Offered load for MORR allocation scheme at fixed burst.

Variance in the number of PDUs in the buffer of MTs is shown in the fig. 5.9, 5.10 and 5.11 as a function of the offered load for the three resource allocation schemes and the figures represent the results for the buffer size 5, 10 and 15 PDUs respectively. For all curves the variance of the number of PDUs in the buffer shows large changes for load values 0.3 – 0.8. For very high and low value of offered load the variance is very low and constant. This change of variance corresponds to the change in number of PDUs in the buffer (Fig. 5.2 to 5.7), where the number of PDUs in the buffer is almost constant at high and low load and it changes a lot when the offered load is between 0.3 and 0.8. It is important to notice that the curves are symmetrical around the load value 0.5 because actual carried load for the load higher than 0.5 and lower than 0.5 is the same. This indicates that our network can carry load up to 0.5.

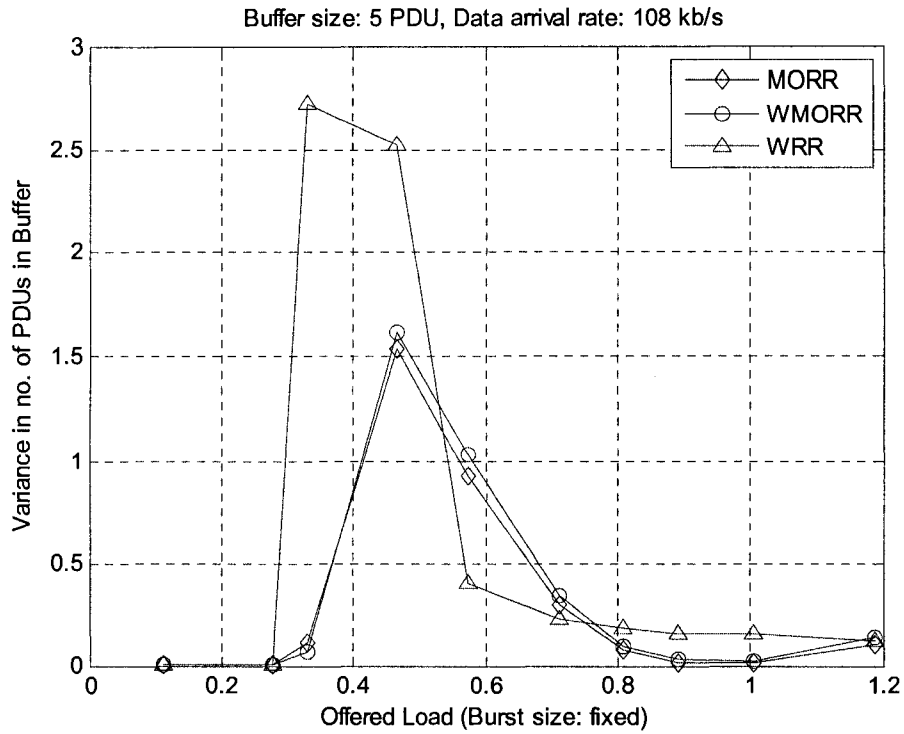


Figure 5.9. Variance in number of PDUs in Buffer vs Offered load for buffer size 5 at fixed burst.

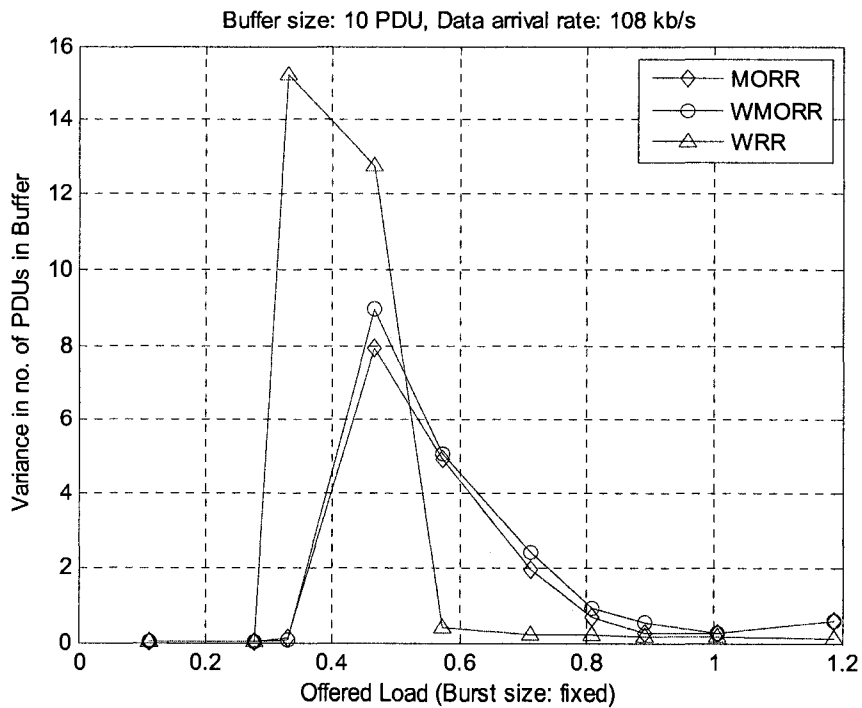


Figure 5.10. Variance in number of PDUs in Buffer vs Offered load for buffer size 10 at fixed burst.

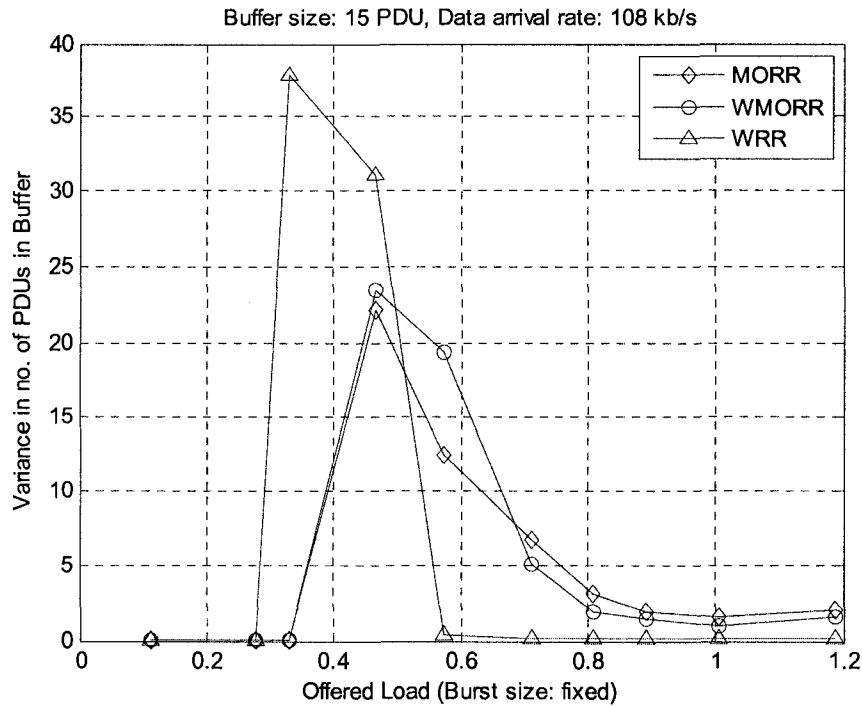


Figure 5.11. Variance in number of PDUs in Buffer vs Offered load for buffer size 5 at fixed burst.

o Probability of Buffer Overflow and its variance

Fig. 5.12, 5.13 and 5.14 depicts the probability of buffer overflow as a function of offered load for the three resource allocation policies, where buffer size is 5, 10 and 15 PDUs respectively. In figures the WMORR allocation scheme shows the lowest probability of overflow among the three schemes. It is interesting to note that the probability of overflow is zero when the load is very low and it starts increasing when the offered load is increased above 0.3. We also notice that the probability of overflow continues to increase after this load. This value of load i.e. 0.3 is significant because at load higher than this the PDU arrival rate at our system becomes higher than the PDU service rate and the numbers of PDUs in buffer starts to increase (Fig. 5.2 to 5.7) .

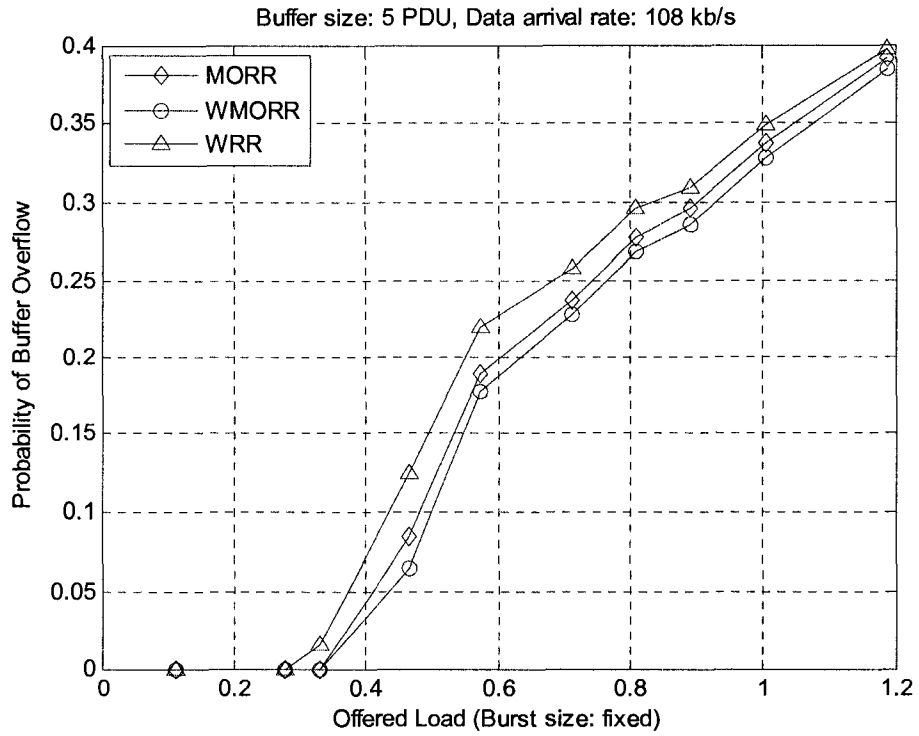


Figure 5.12. Probability of buffer overflow vs offered load for buffer size 5 at fixed burst.

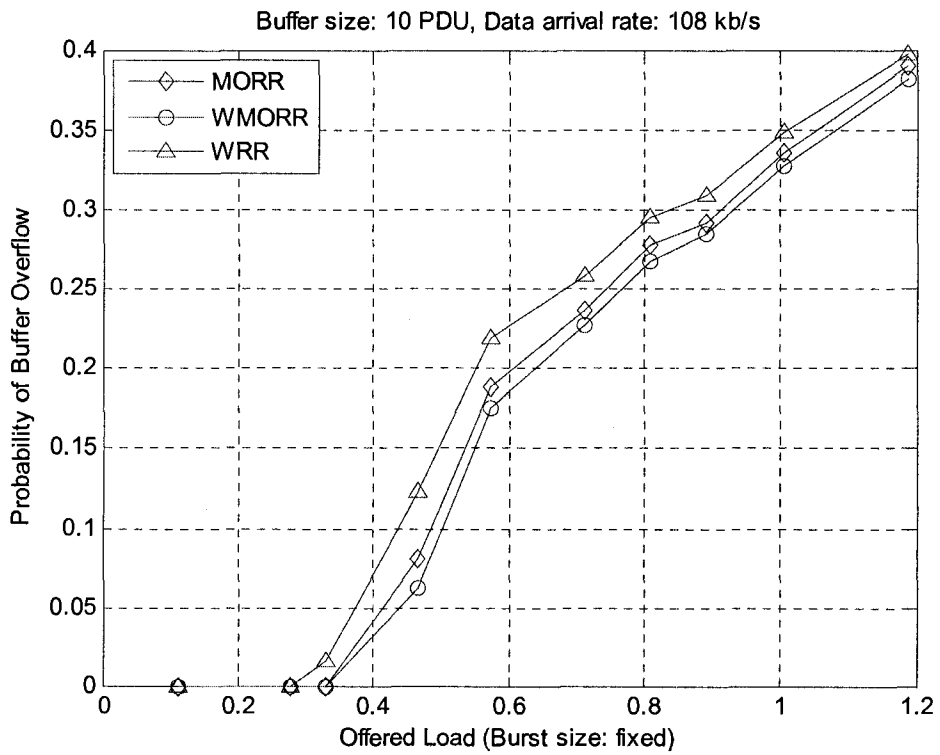


Figure 5.13. Probability of buffer overflow vs offered load for buffer size 10 at fixed burst.

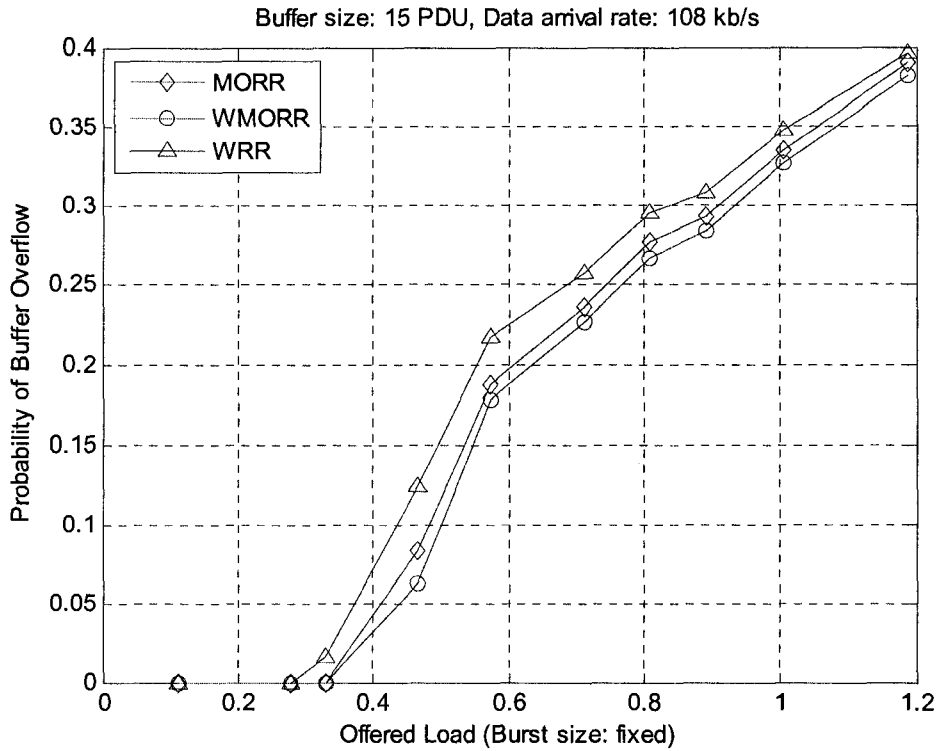


Figure 5.14. Probability of buffer overflow vs offered load for buffer size 5 at fixed burst.

Fig. 5.15, 5.16 and 5.17 shows the Probability of buffer overflow as a function of offered load for the buffer size 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. The figures do not show any significant change in the overflow with the increase of buffer size. It is due to large PDU arrival rate used in our simulation.

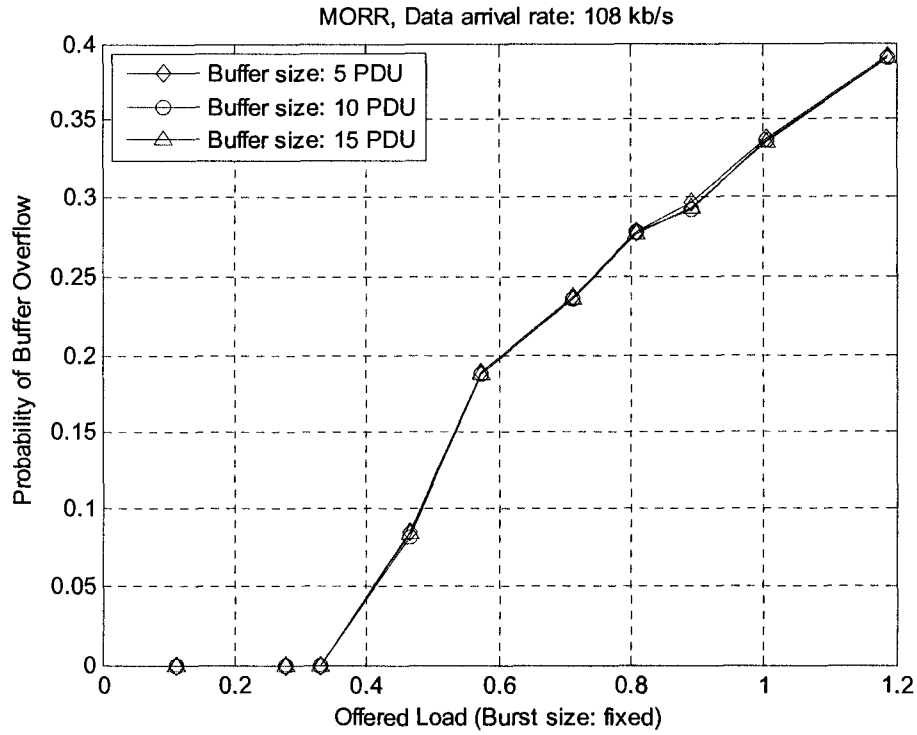


Figure 5.15. Probability of buffer overflow vs offered load for MORR allocation scheme at fixed burst.

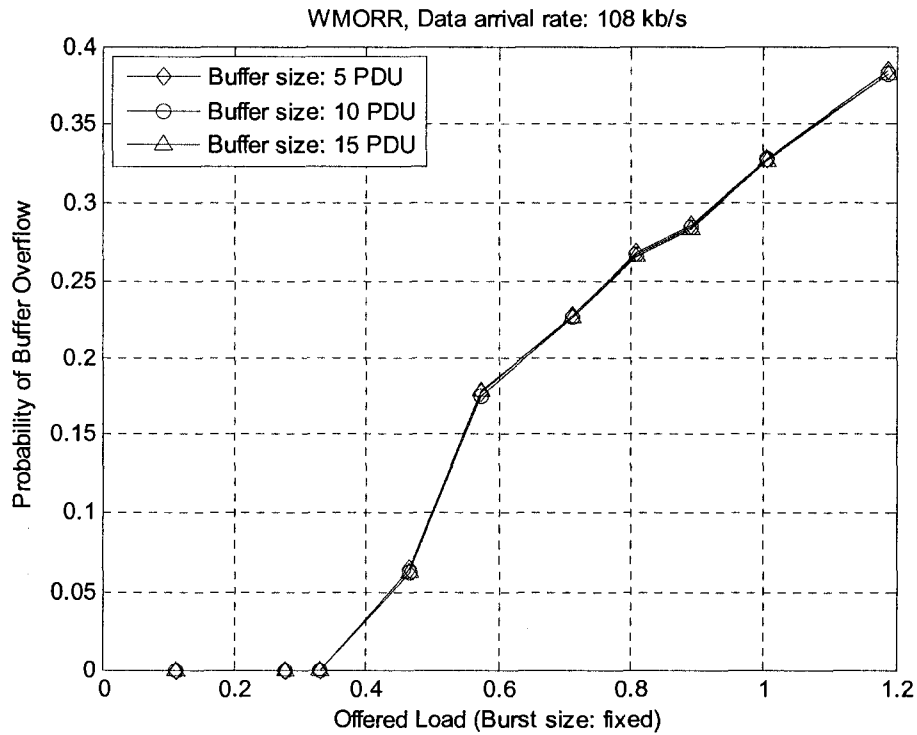


Figure 5.16. Probability of buffer overflow vs offered load for WMORR allocation scheme at fixed burst.

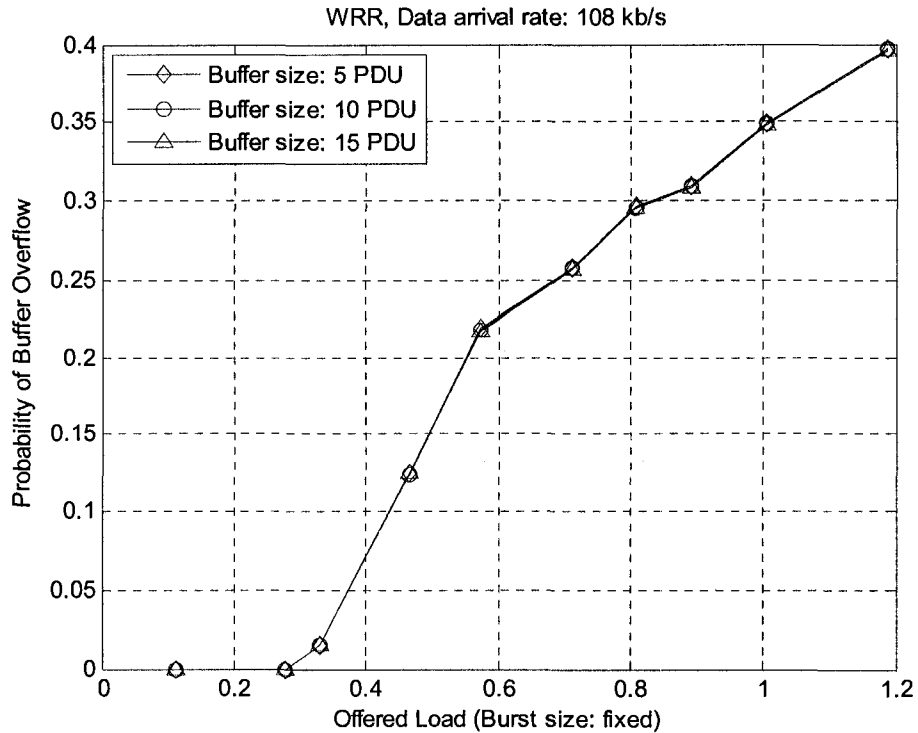


Figure 5.17. Probability of buffer overflow vs offered load for WRR allocation scheme at fixed burst.

Variance in the buffer overflow is shown in the fig. 5.18, 5.19 and 5.20 as a function of the offered load for the three resource allocation schemes and the figures represent the results for the buffer size 5, 10 and 15 PDUs respectively. For all the curves, the variance of buffer overflow is zero for low value of offered load as buffer overflow is also zero (Fig. 5.12 to 5.17). But for higher value of offered load the variance becomes large as the change in probability of buffer overflow is large when load is high. We notice that the curves are almost symmetrical around the load value 0.5. This is due to the fact that actual carried load is same for loads below and above of 0.5 and the network is efficient up to load value 0.5.

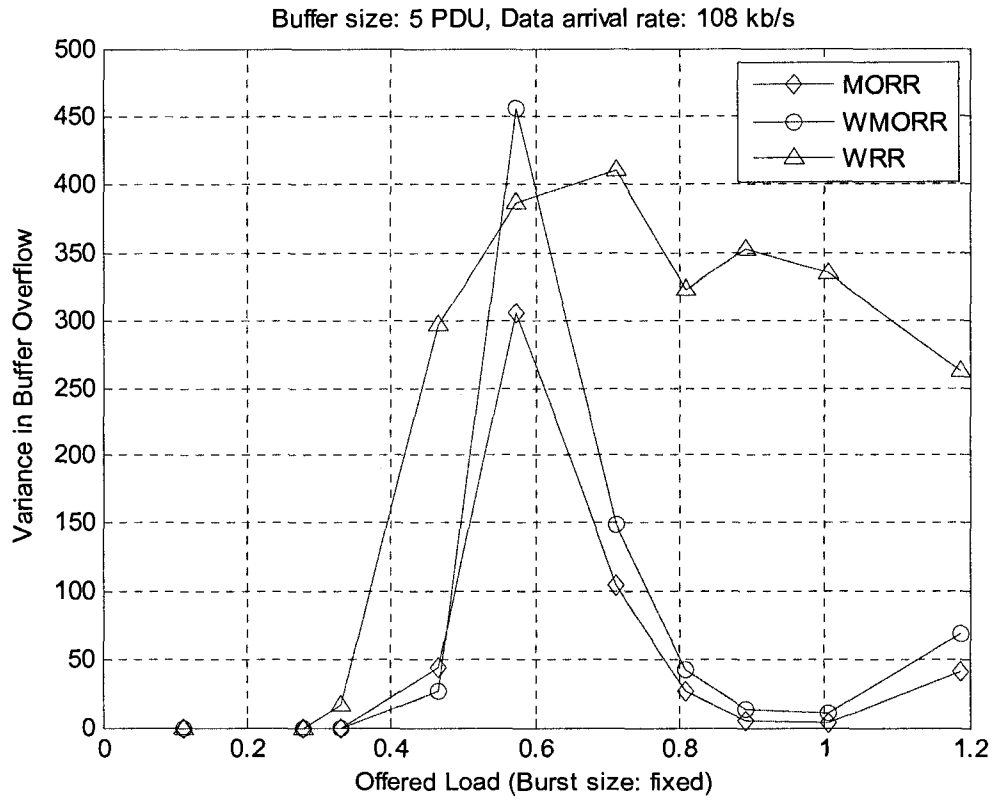


Figure 5.18. Variance in buffer overflow vs offered load for buffer size 5 at fixed burst.

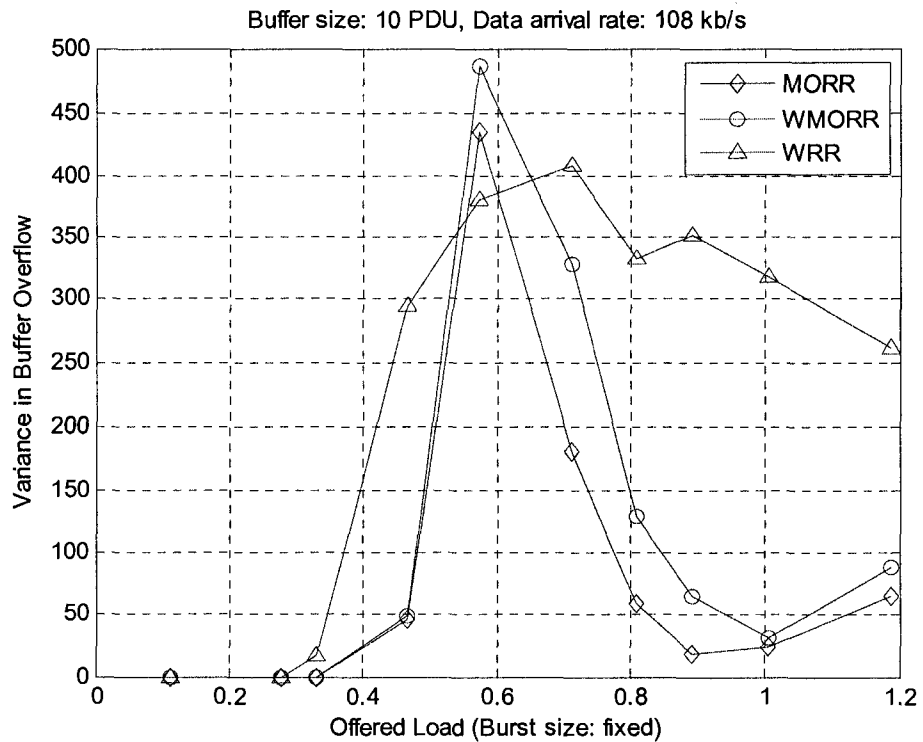


Figure 5.19. Variance in buffer overflow vs offered load for buffer size 10 at fixed burst.

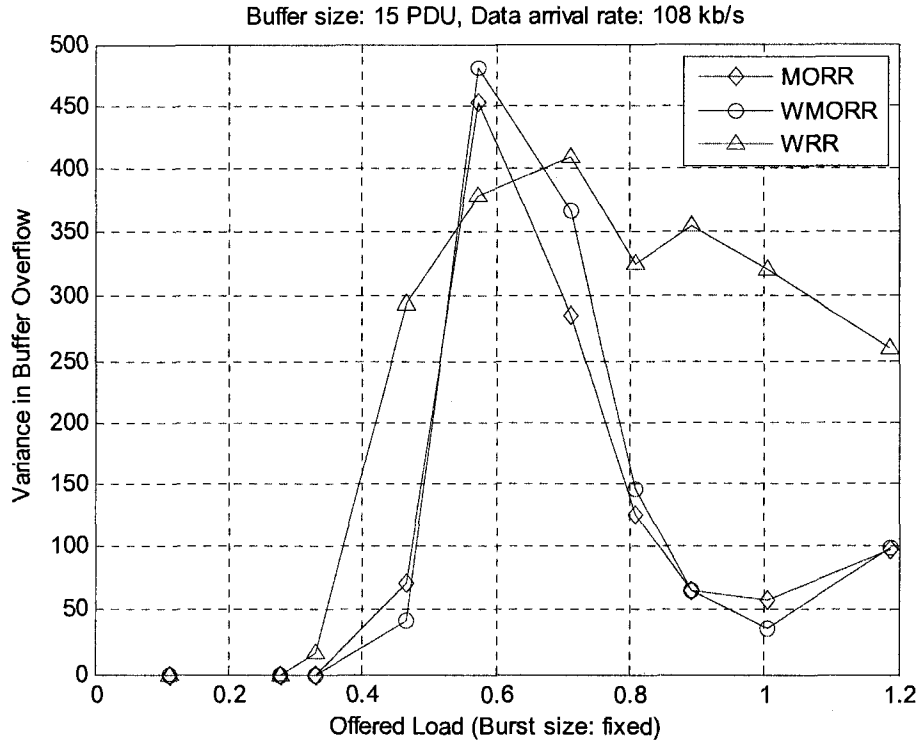


Figure 5.20. Variance in buffer overflow vs offered load for buffer size 15 at fixed burst.

o **Average PDU delivery time and its variance**

Fig. 5.21, 5.22 and 5.23 depicts average PDU delivery time (Seconds) as a function of offered load for the three resource allocation policies, where the buffer size is 5, 10 and 15 PDUs respectively. In the figures all the allocation policies show almost equal performance except for very high load where the WRR scheme shows less PDU delivery time compared to other allocation schemes. For low value of offered load the delivery time is low because PDUs spend very small amount of time in the buffer. It is important to note here that for load lower than 0.3 delivery time is constant as PDUs do not have to wait in buffer for transmission opportunity. When the offered load increases above 0.3, PDU service rate becomes lower than the arrival rate and PDUs have to wait longer in the buffer to get the transmission opportunity.

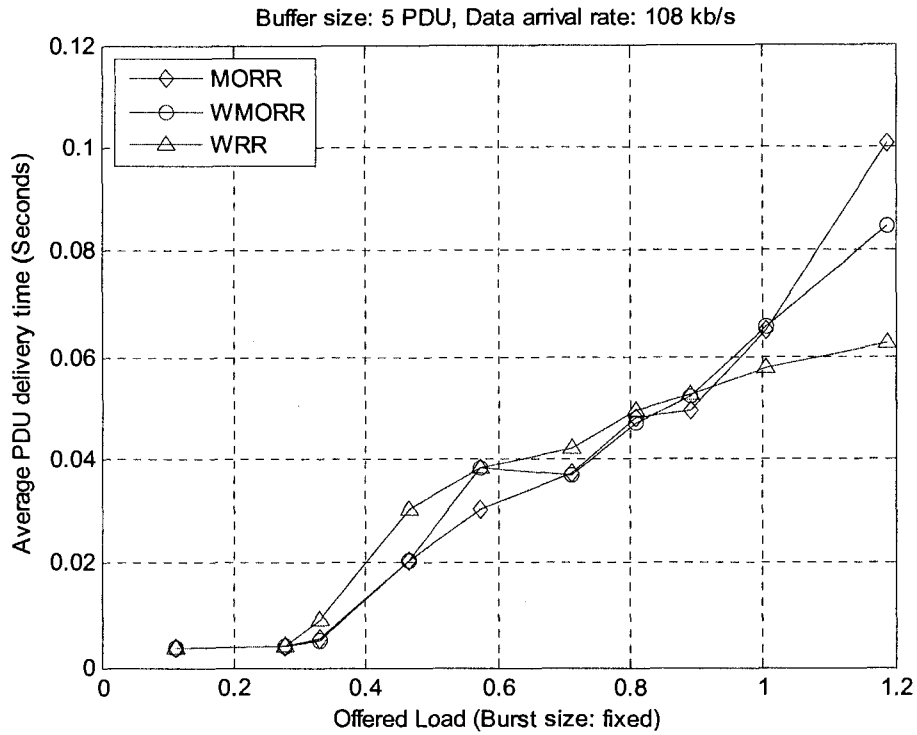


Figure 5.21. Average PDU delivery time vs offered load for buffer size 5 at fixed burst.

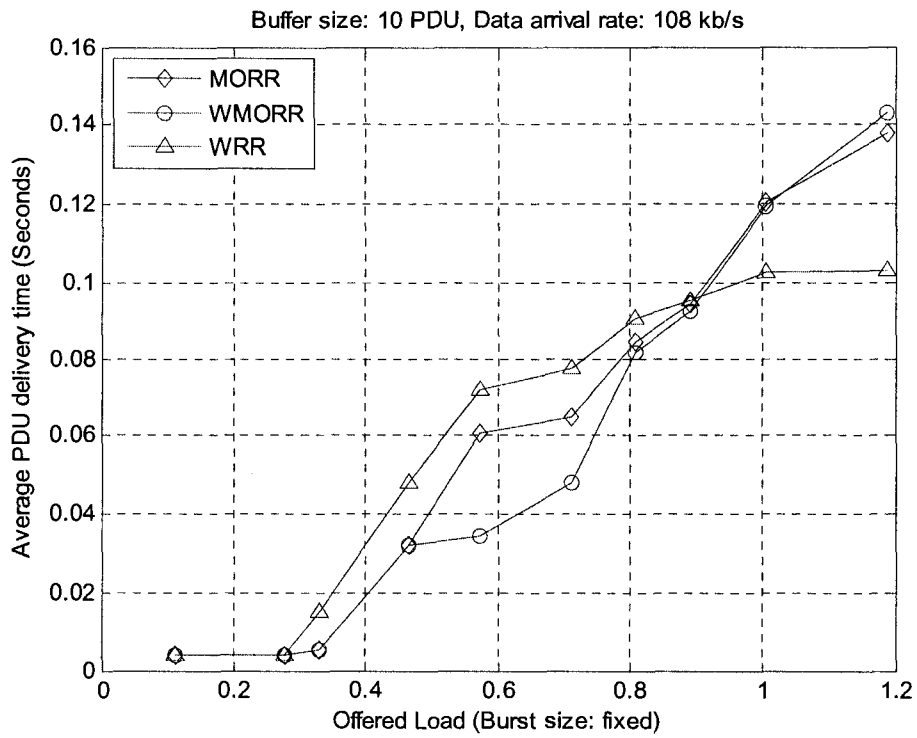


Figure 5.22. Average PDU delivery time vs offered load for buffer size 10 at fixed burst.

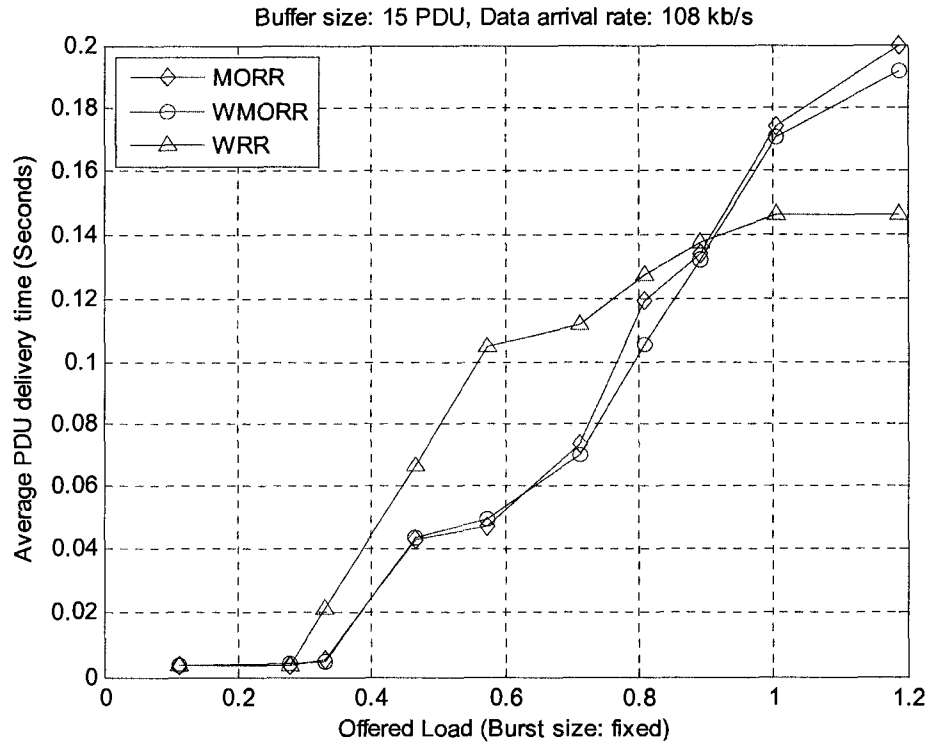


Figure 5.23. Average PDU delivery time vs offered load for buffer size 15 at fixed burst.

Fig. 5.24, 5.25 and 5.26 shows the average of PDU delivery time in seconds as a function of offered load for buffer sizes 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. All the figures show that with the increase of buffer size average delivery time also increases as PDUs have to wait longer in the buffer to get the transmission opportunity. Also in these figures we notice that for offered load lower than 0.3 PDU delivery time does not depend on buffer size.

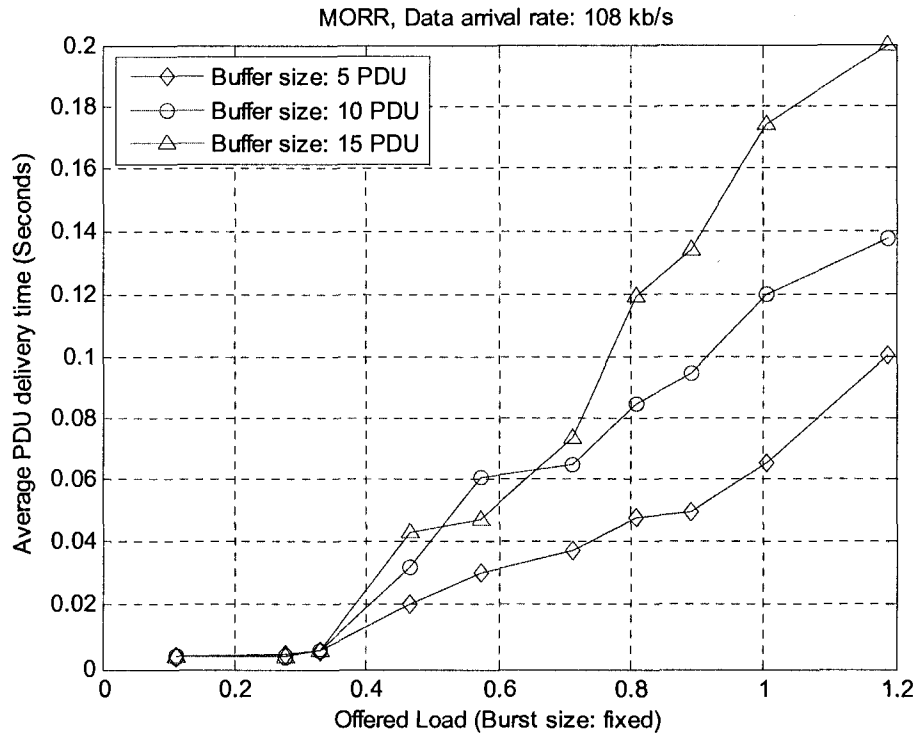


Figure 5.24. Average PDU delivery time vs offered load for MORR allocation scheme at fixed burst.

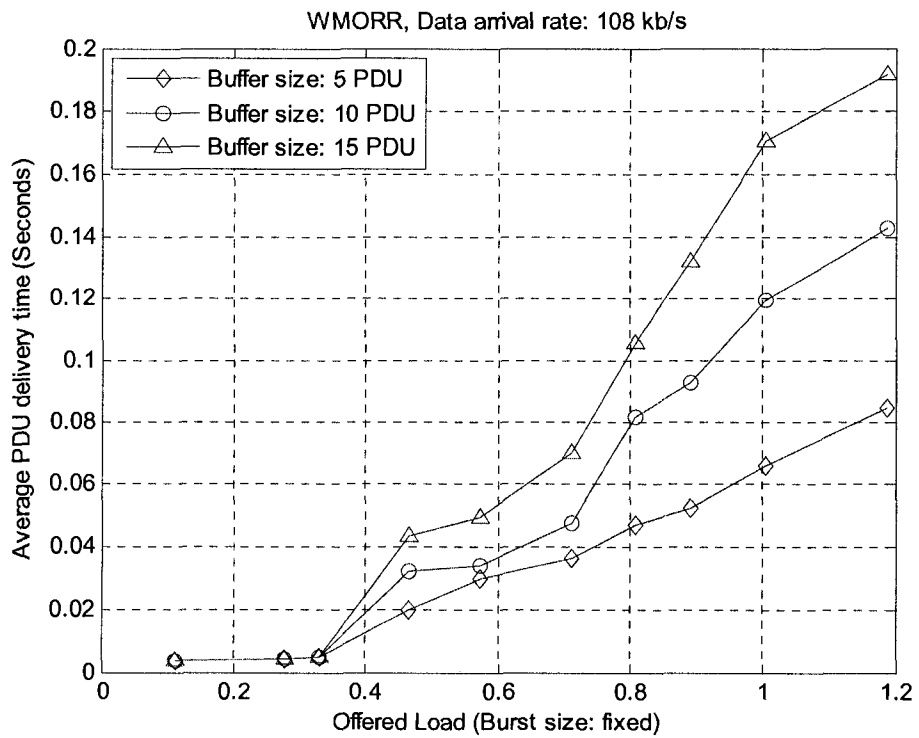


Figure 5.25. Average PDU delivery time vs offered load for WMORR allocation scheme at fixed burst.

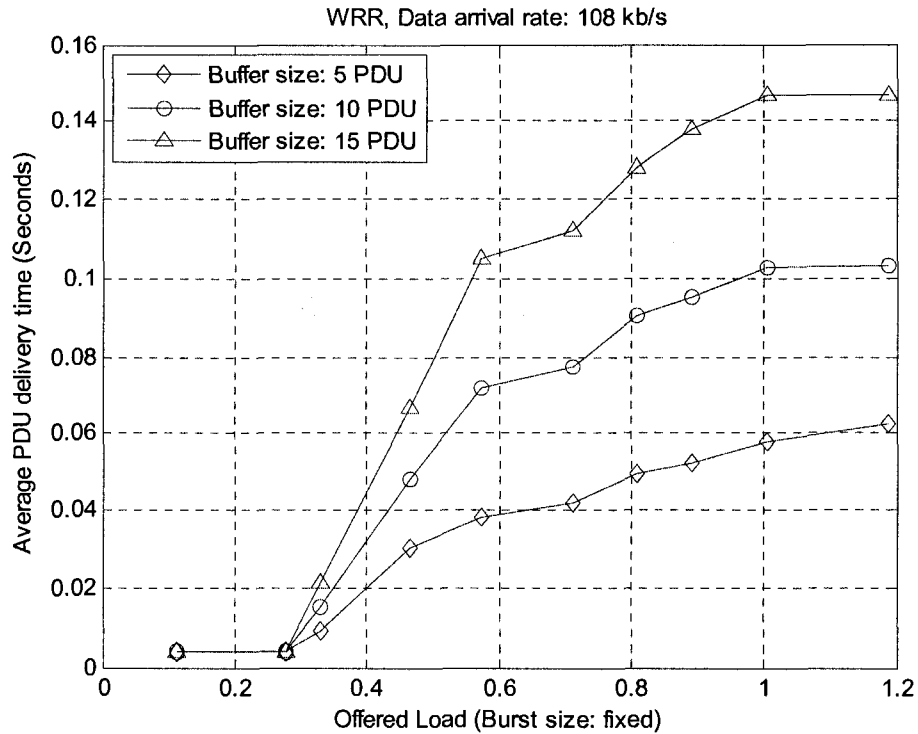


Figure 5.26. Average PDU delivery time vs offered load for WRR allocation scheme at fixed burst.

Variance in the PDU delivery time is shown in the fig. 5.27, 5.28 and 5.29 as a function of offered load for the three resource allocation schemes and the figures gives the results for the buffer size 5, 10 and 15 PDUs respectively. For all the curves the variance of PDU delivery time is zero for offered load lower than 0.3 as PDU delivery time is almost constant (Fig. 5.21 to 5.26) around these loads. But for higher value of offered load variance in delivery time becomes high. We also notice that the WRR scheme has higher variance than the other two allocation schemes.

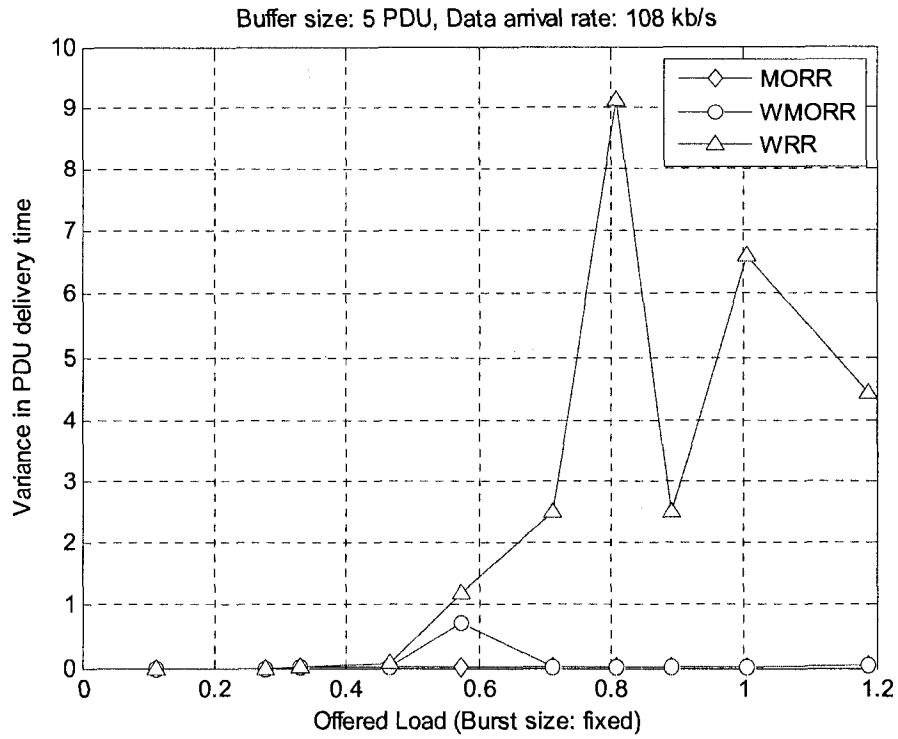


Figure 5.27. Variance in PDU delivery time vs offered load for buffer size 5 at fixed burst.

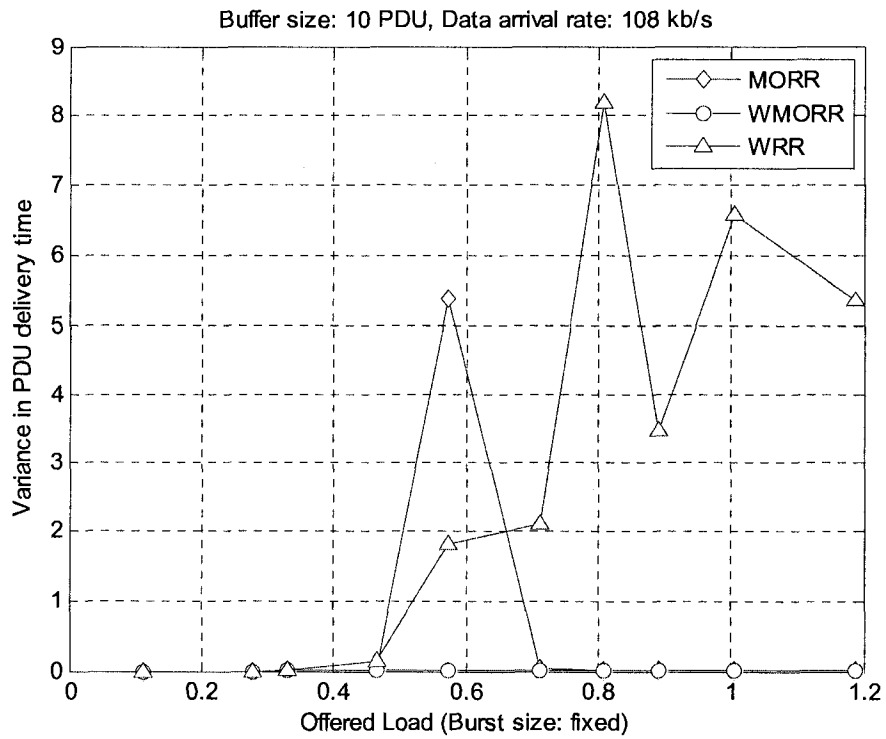


Figure 5.28. Variance in PDU delivery time vs offered load for buffer size 10 at fixed burst.

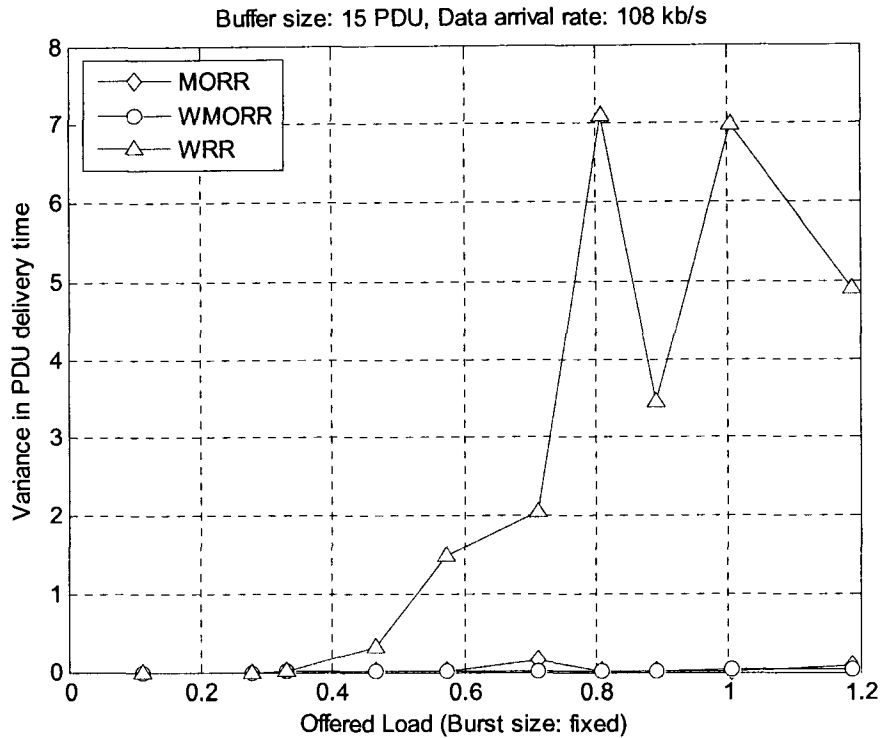


Figure 5.29. Variance in PDU delivery time vs offered load for buffer size 15 at fixed burst.

○ **Average overhead in Uplink phase and its variance**

Fig. 5.30, 5.31 and 5.32 depict the average overhead (Percentage of total uplink time) in uplink phase as a function of offered load for the three resource allocation policies, where the buffer size is 5, 10 and 15 PDUs respectively. These figures show that the MORR and WMORR policies have low overhead compared to the WRR allocation scheme. For low value of offered load the uplink overhead is large as all the arrived PDU gets the transmission opportunity and overhead of all the user add up to give a large overhead. But as the load increases arrival rate beomes higher than the service rate and very few of the user get the transmission opportunity. This results very low overhead for MORR and WMORR scheme as whenever an user is visited, maximum capacity is assigned to it in these schemes. But for the WRR scheme as all the user buffer is visited during a TDMA frame, overhead of all the user adds up and the summaion continue to increase with the increase of load.

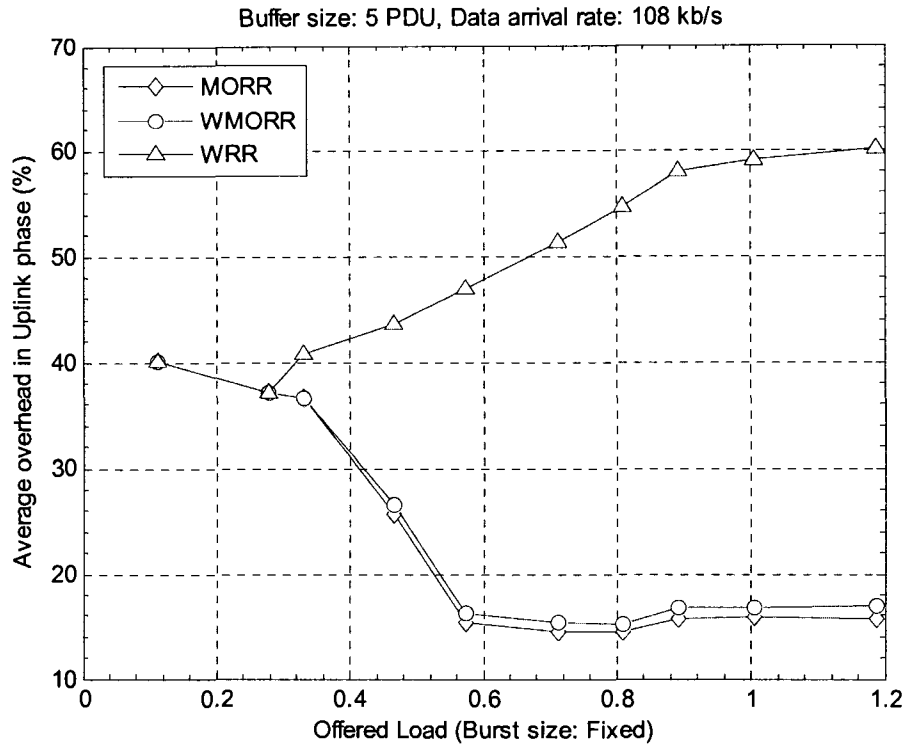


Figure 5.30. Average overhead in Uplink phase vs offered load for buffer size 5 at fixed burst.

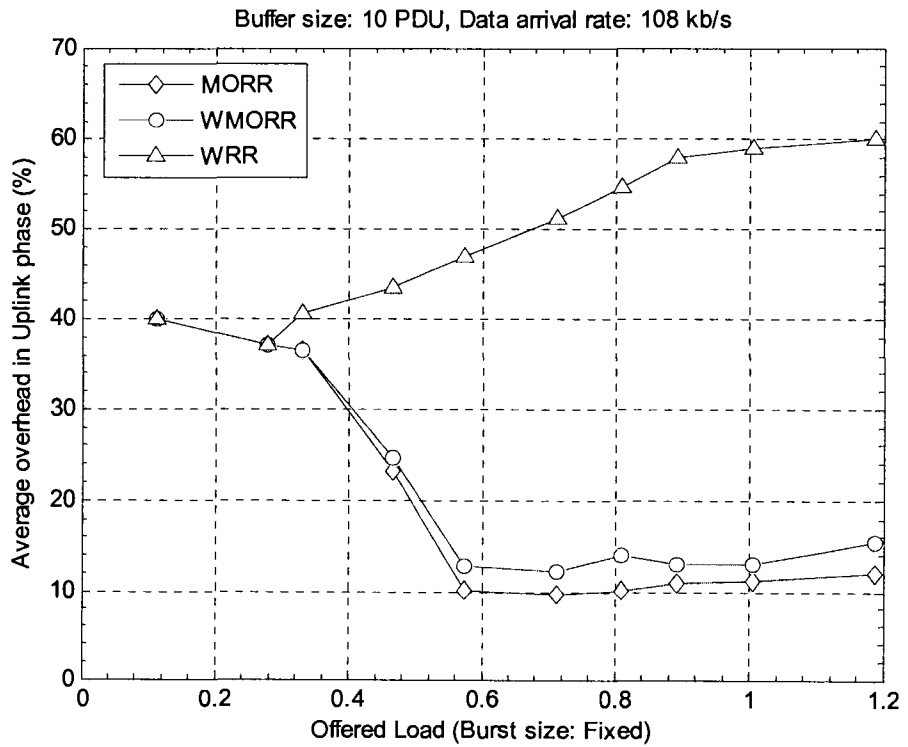


Figure 5.31. Average overhead in Uplink phase vs offered load for buffer size 10 at fixed burst.

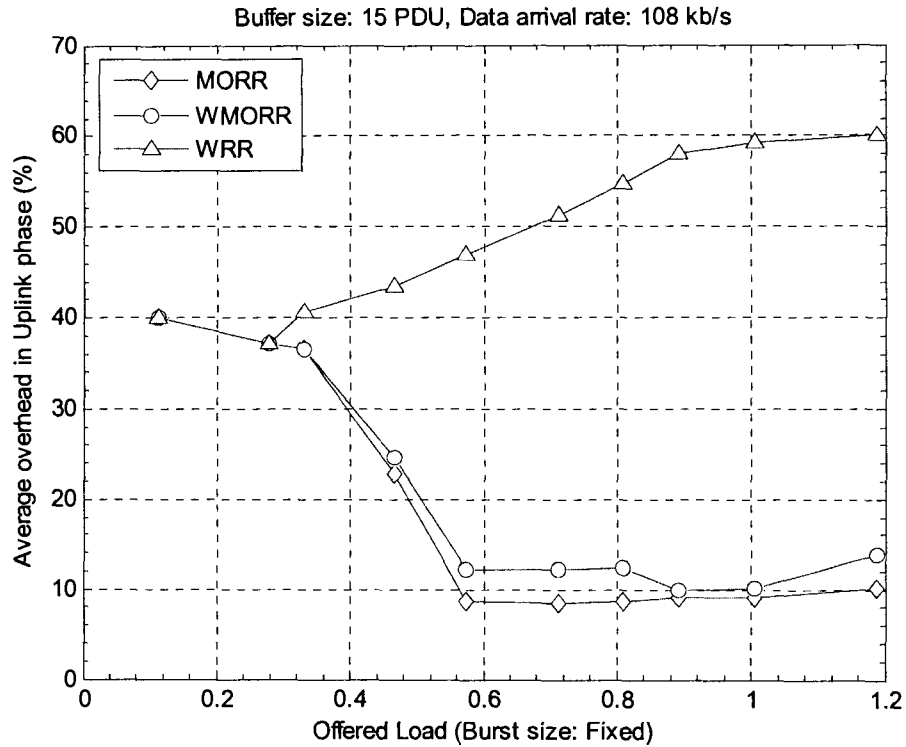


Figure 5.32. Average overhead in Uplink phase vs offered load for buffer size 15 at fixed burst.

Fig. 5.33, 5.34 and 5.35 shows the average overhead (Percentage of total uplink time) in uplink phase as a function of offered load for buffer sizes 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. We notice that for WMORR and MORR schemes overhead decreases with the increase of buffer size and for the WRR scheme overhead remains same for all buffer sizes. This change in overhead corresponds to the allocation policy, as for low load all MTs are scheduled for transmission in the TDMA frame but at high load a few number of MTs are scheduled for transmission in the MORR and WMORR schemes. For the WRR scheme overhead does not depend on the buffer size as all the MTs are scheduled for transmission in the TDMA frame.

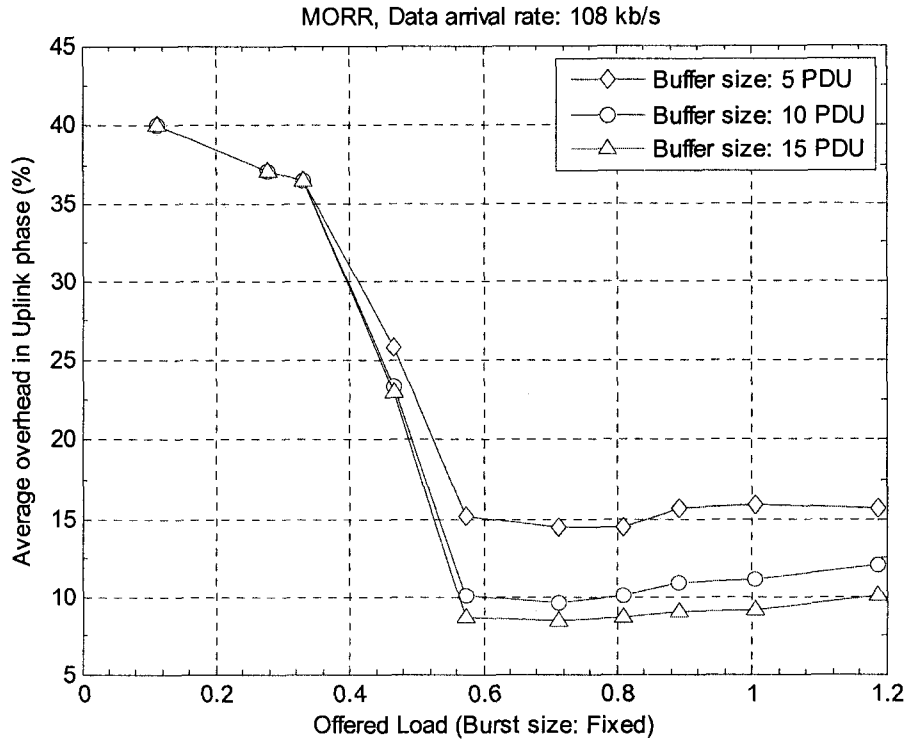


Figure 5.33. Average overhead in Uplink phase vs offered load for MORR scheme at fixed burst.

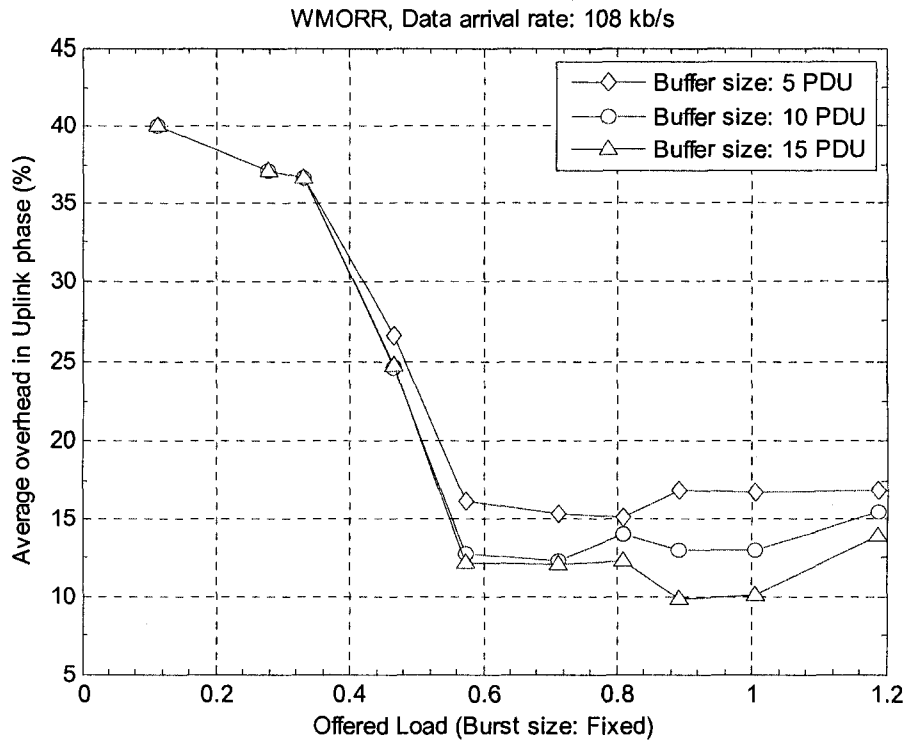


Figure 5.34. Average overhead in Uplink phase vs offered load for WMORR scheme at fixed burst.

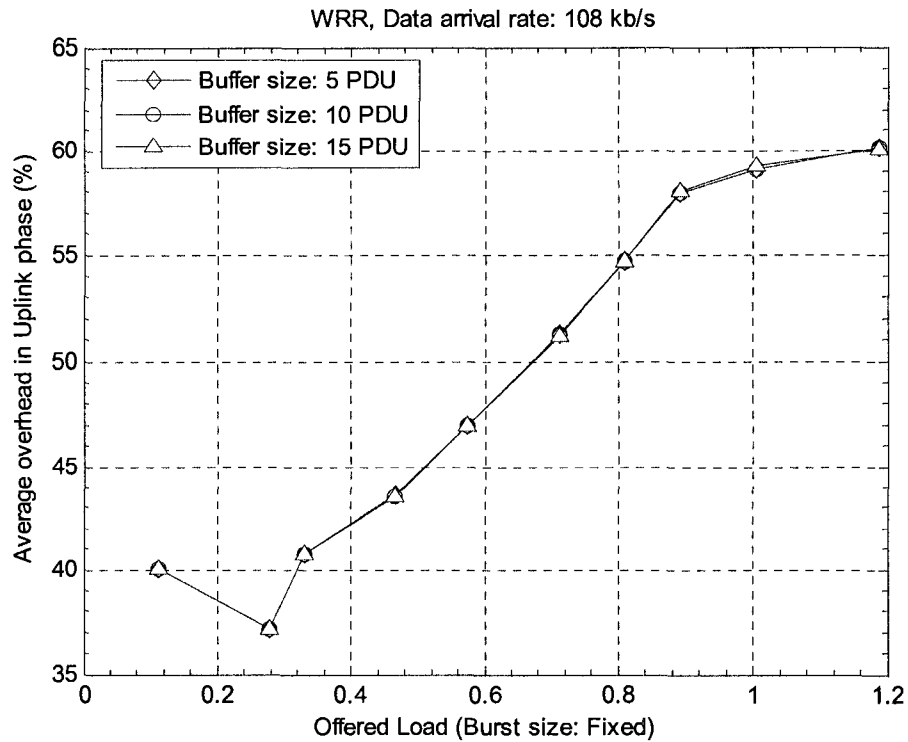


Figure 5.35. Average overhead in Uplink phase vs offered load for WRR scheme at fixed burst.

Variance in overhead of uplink phase is shown in fig. 5.36, 5.37 and 5.38 as a function of offered load for the three resource allocation schemes and the figures represent the results when the buffer size is 5, 10 and 15 PDUs respectively. In the figures we noticed that the variance is symmetrical around the load value 0.5. This is due to the reason that actual carried load below and above of this load is the same. We also notice that change in variance corresponds to the curves in fig. 5.30 – 5.35.

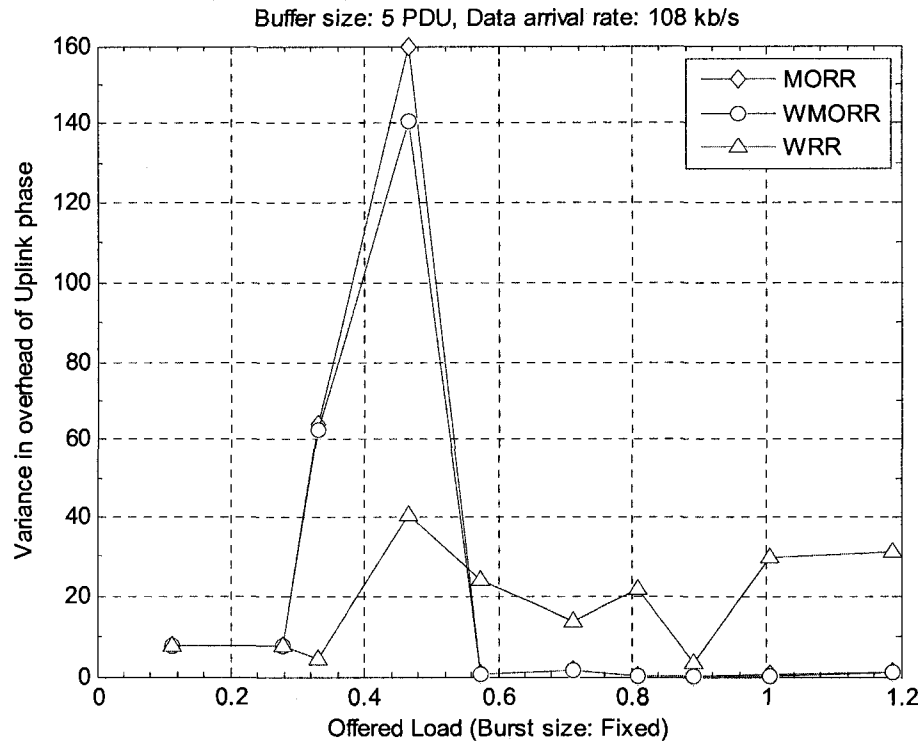


Figure 5.36. Variance in overhead of uplink phase vs offered load for buffer size 5 at fixed burst.

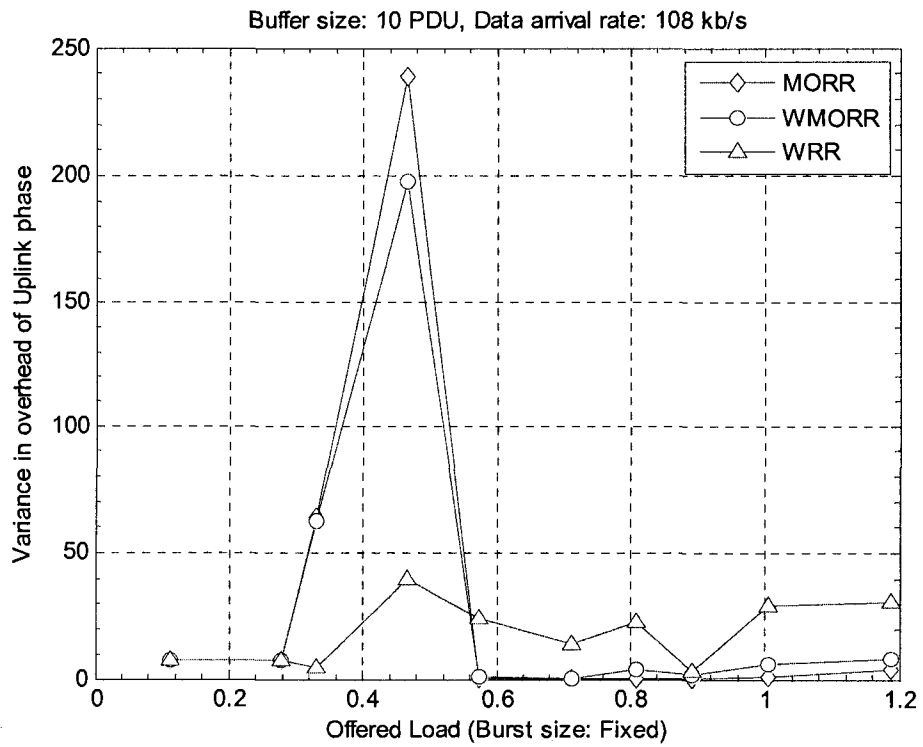


Figure 5.37. Variance in overhead of uplink phase vs offered load for buffer size 10 at fixed burst.

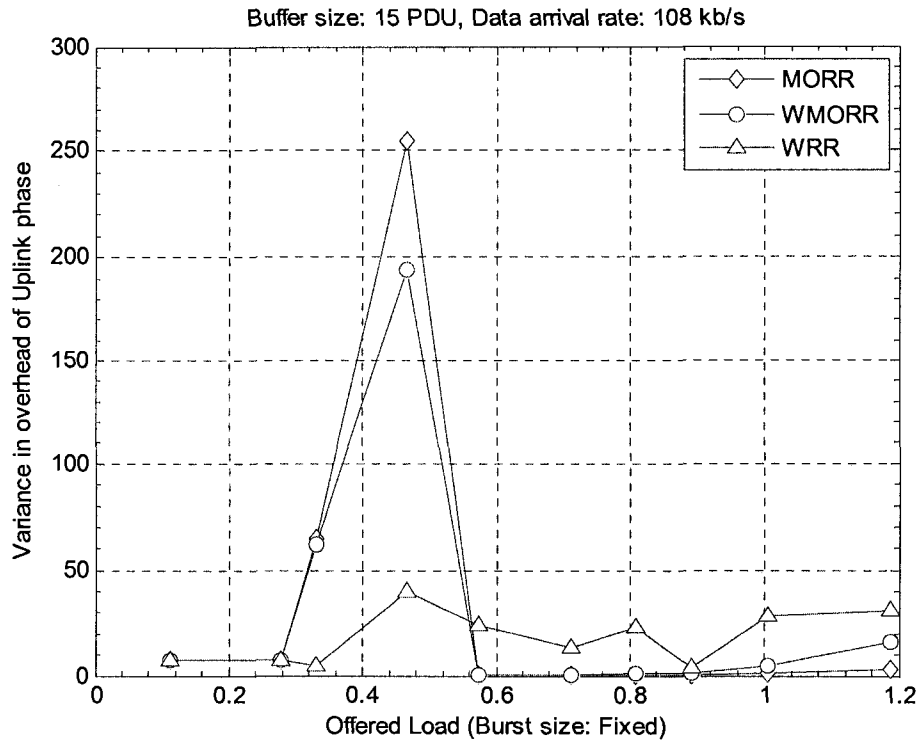


Figure 5.38. Variance in overhead of uplink phase vs offered load for buffer size 15 at fixed burst.

o **Average Overhead in Downlink Phase and its variance**

Fig. 5.39, 5.40 and 5.41 depict the average overhead (Percentage of downlink time) in downlink phase as a function of offered load for the three resource allocation policies, where buffer size is 5, 10 and 15 PDUs respectively. The figures show that the MORR and WMORR policies have low overhead compared to the WRR allocation scheme. For low value of offered load the downlink overhead is large as all the arrived PDU gets the transmission opportunity and overhead of all the user add up to give a large overhead. But as the load increases arrival rate beomes higher than the service rate and very few of the users get the transmission opportunity. This results very low overhead for MORR and WMORR scheme as when ever an user is visited, maximum capacity is assigned to it in these schemes. But for the WRR scheme as all the user buffer is visited during a TDMA frame, overhead of all the user adds up and the summaion continue to increase with the increase of load.

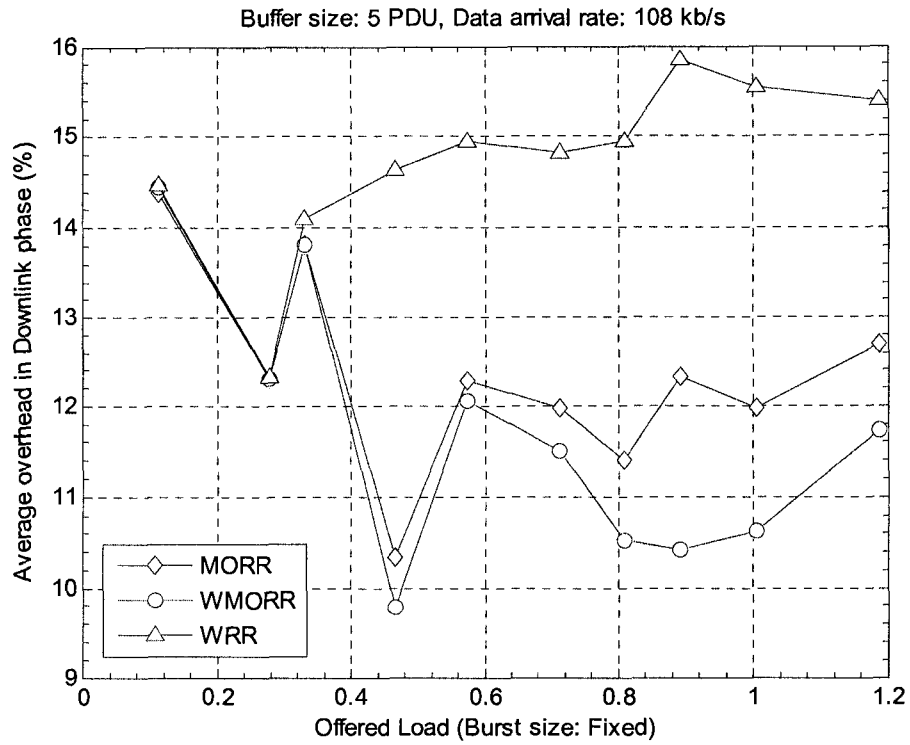


Figure 5.39. Average overhead in downlink phase vs offered load for buffer size 5 at fixed burst.

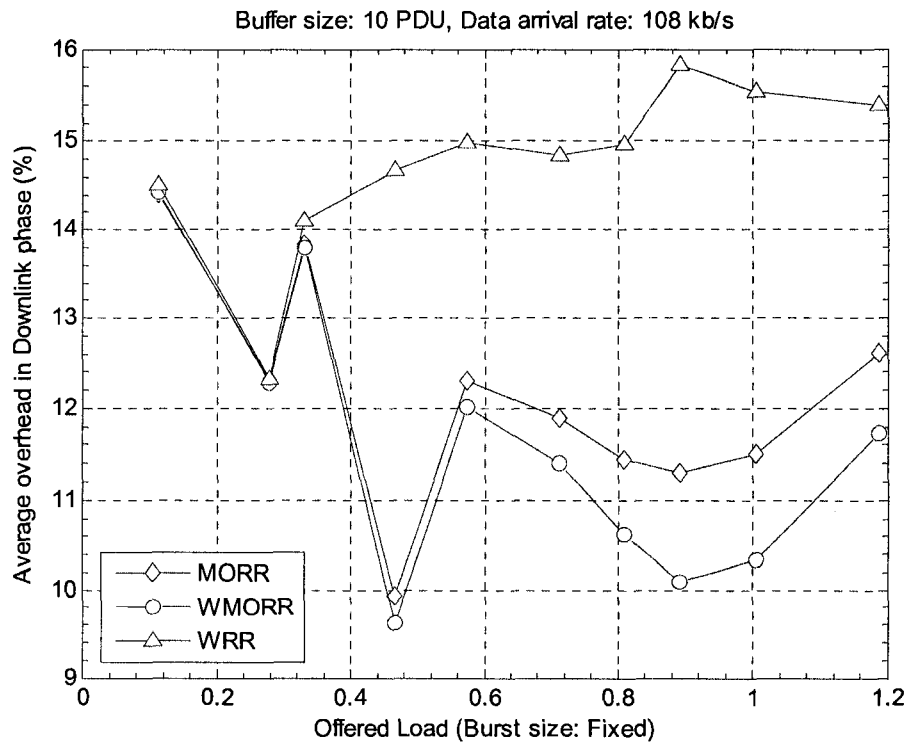


Figure 5.40. Average overhead in downlink phase vs offered load for buffer size 10 at fixed burst.

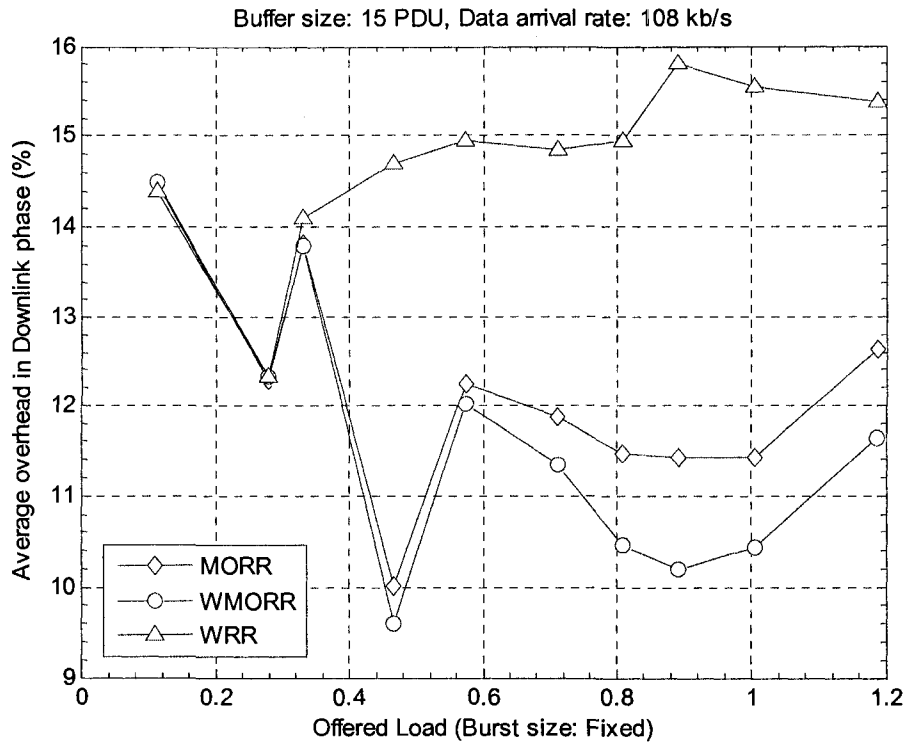


Figure 5.41. Average overhead in downlink phase vs offered load for buffer size 15 at fixed burst.

Fig. 5.42, 5.43 and 5.44 shows the average overhead in downlink phase as a function of offered load for buffer sizes 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. We notice that for all the schemes change in overhead does not depend on buffer size of the MT. It is due to the fact that here resource is distributed using the number of PDUs for the MTs, in the buffer of AP not using the the MT buffer size.

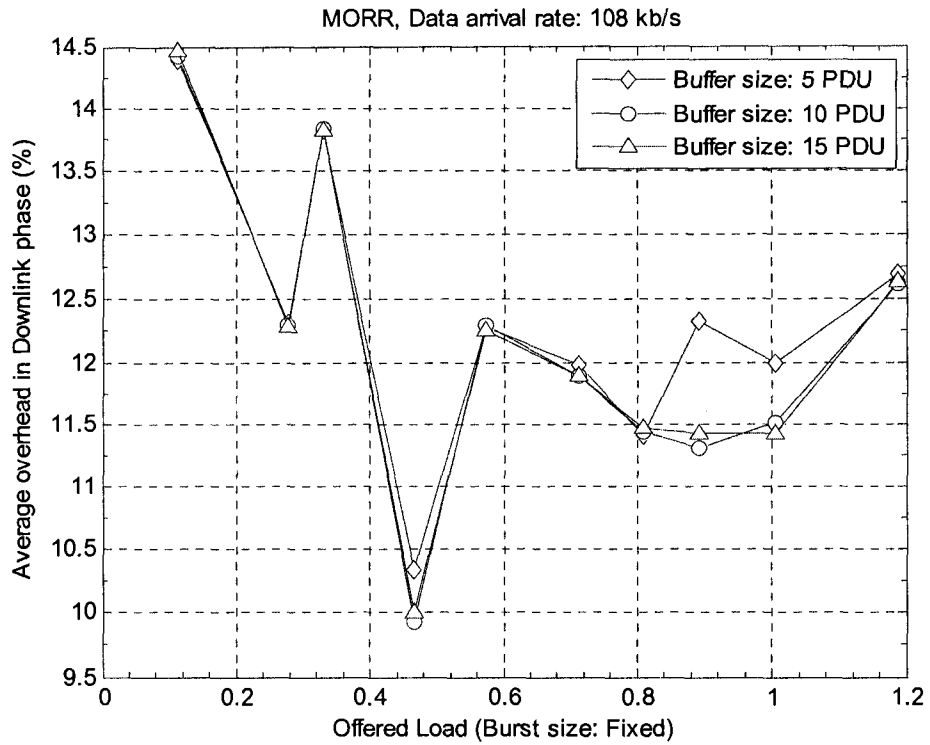


Figure 5.42. Average overhead in downlink phase vs offered load for MORR scheme at fixed burst.

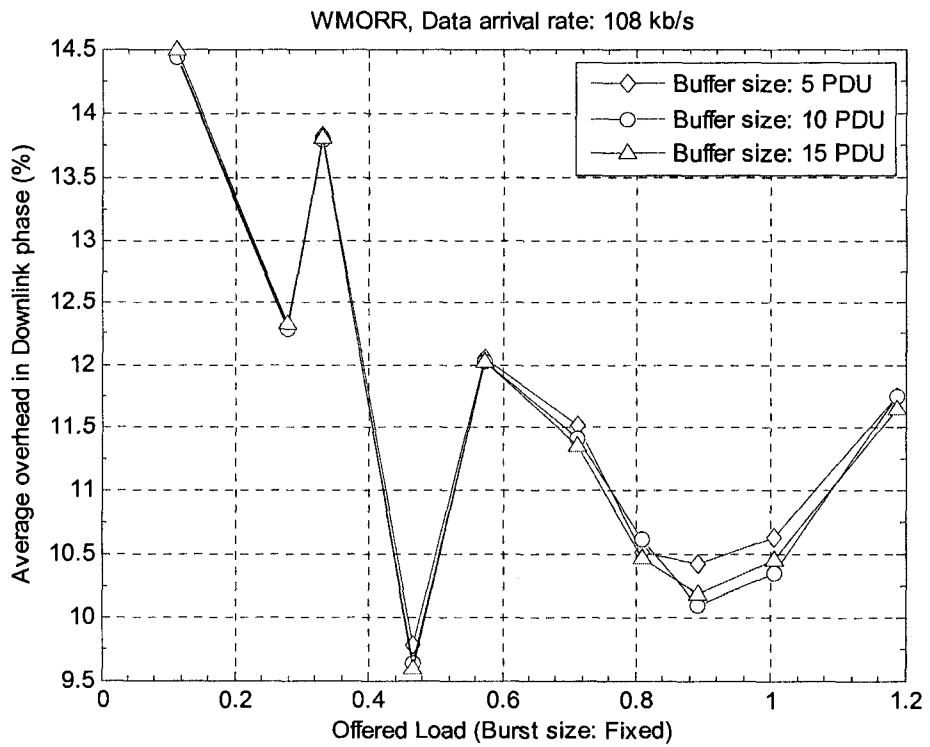


Figure 5.43. Average overhead in downlink phase vs offered load for WMORR scheme at fixed burst.

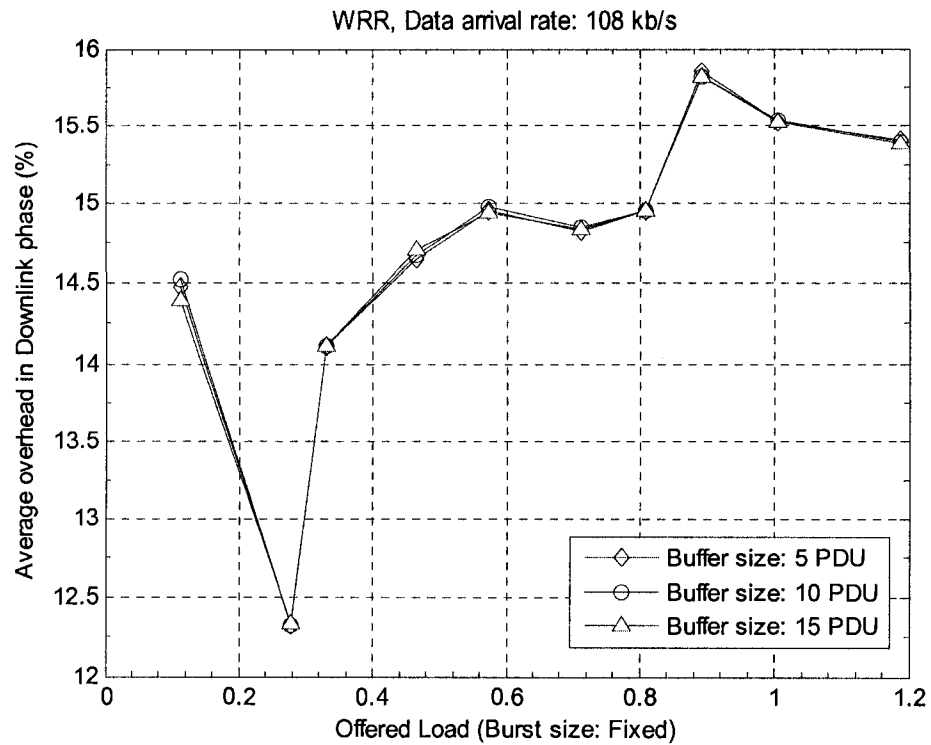


Figure 5.44. Average overhead in downlink phase vs offered load for WRR scheme at fixed burst.

Variance in overhead of downlink phase is shown in fig. 5.45, 5.46 and 5.47 as a function of offered load for the three resource allocation schemes and the figures represent the results when the buffer size is 5, 10 and 15 PDUs respectively. In the figures we noticed that change in variance corresponds to the change in curves of fig. 5.39 – 5.44.

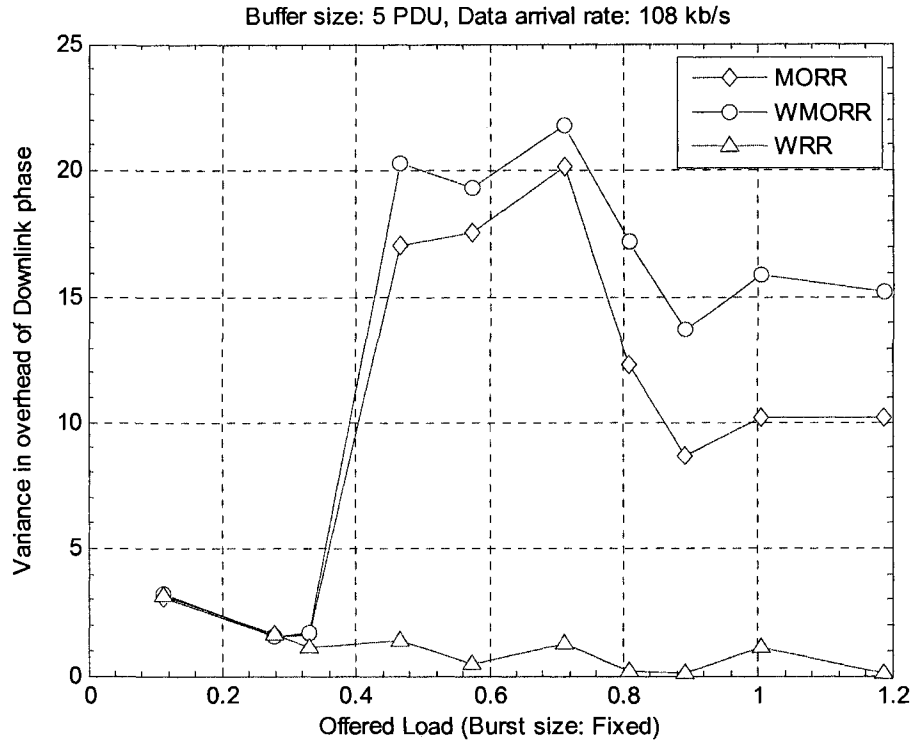


Figure 5.45. Variance in overhead of downlink phase vs offered load for buffer size 5 at fixed burst.

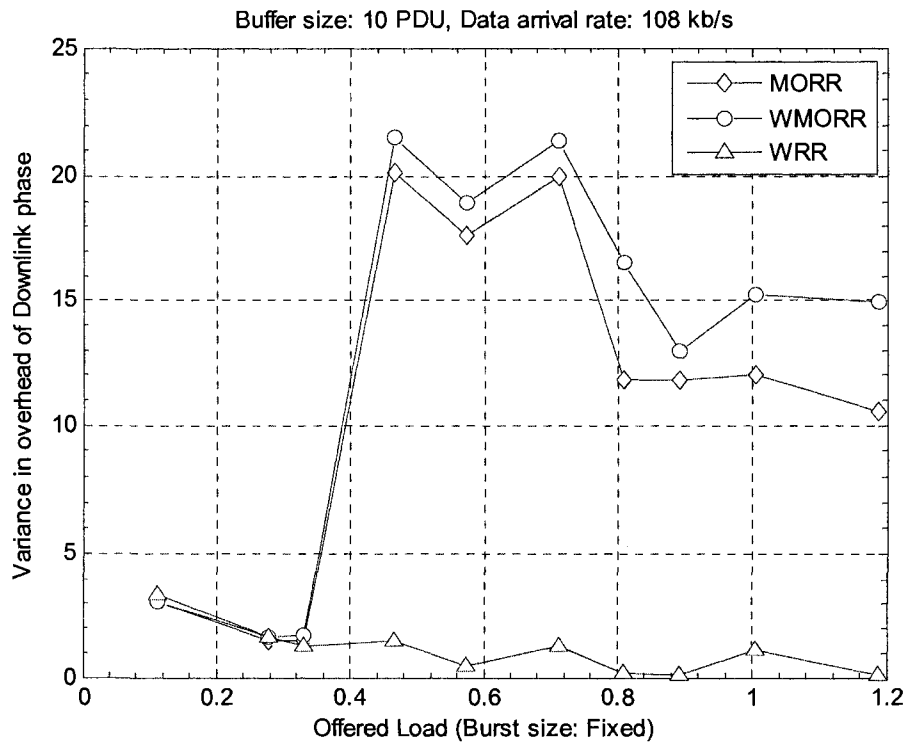


Figure 5.46. Variance in overhead of downlink phase vs offered load for buffer size 10 at fixed burst.

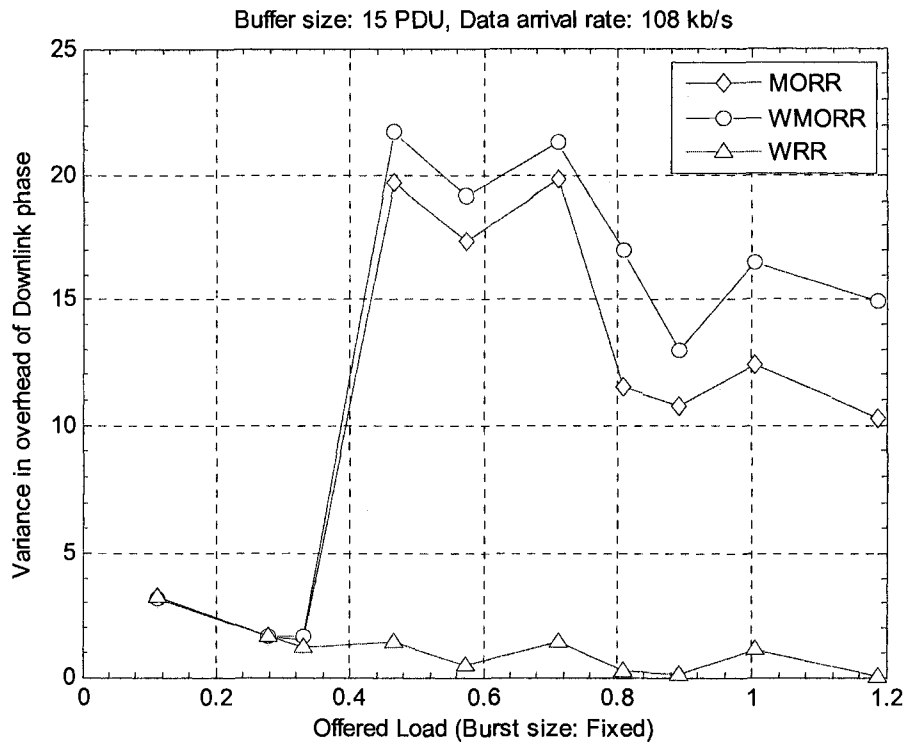


Figure 5.47. Variance in overhead of downlink phase vs offered load for buffer size 5 at fixed burst.

5.2. Random Burst

In the event of random burst, the simulation programme generates a random amount of data ranging from 1 PDU to 5 PDU per time period of 2 ms using the ON-OFF model (Fig. 5.1). This PDU generation rate corresponds to data arrival rate 108 kb/s to 1024 kb/s at the buffer of each MT. To get the number of PDUs to be generated, we call a $U(0,1)$ and multiply the outcome by 5 and rounded the result. In the on-off model we consider the probability of changing a state is equal to greater than 0.5 and length of ON or OFF time equals to one TDMA/TDD frame time or 2 ms. We call a $U(0,1)$, if the outcome is greater than or equal to 0.5 the user change its state from ON to OFF or vice versa. Other parameter used to setup the system is summarized in table 5.2.

Table 5.2. SIMULATION PARAMETERS FOR RANDOM BURST.

Network Parameters	
No of CC	1
No of AP	4
Network area	538 m x 538 m
AP coverage radius	137.26 m
AP Tx power	1 Watt
Antenna height	12 m
Antennal type	Omnidirectional
AP location	Urban area
AP buffer size	100 PDU
CC buffer size	400 PDU
No. of RCH phase	1
Simulation runtime	10000 frames
DL/UL time	940X10 ⁻⁶ s
Source model	
LCH PDU length	54 byte
SCH PDU length	9 byte
Max. MT movement rate	10 m/s
MT Buffer size	5/10/15 PDU
MT Buffer Management	FIFO

Using the same methodology that we used for the fixed burst, we calculated the offered load for this case using the equation 5.2. In the equation the total requested time in the uplink phase of all MT associated with an AP is divided by the uplink capacity of that AP to calculate the offered load. Here the capacity of the AP is the Uplink time in a TDMA frame. Fig. 5.48 shows distribution of load over the number of mobile terminals that we get as outcome of the simulation.

$$\begin{aligned}
 \text{Load} &= \frac{\text{Total requested time per TDMA frame}}{\text{Total available time in a TDMA frame}} \\
 &= \frac{\text{Total MT per AP} \times \frac{0.5 \times 2.5 \times 432}{\text{Average transmission rate per MT}}}{940 \times 10^{-6}} \quad (5.2)
 \end{aligned}$$

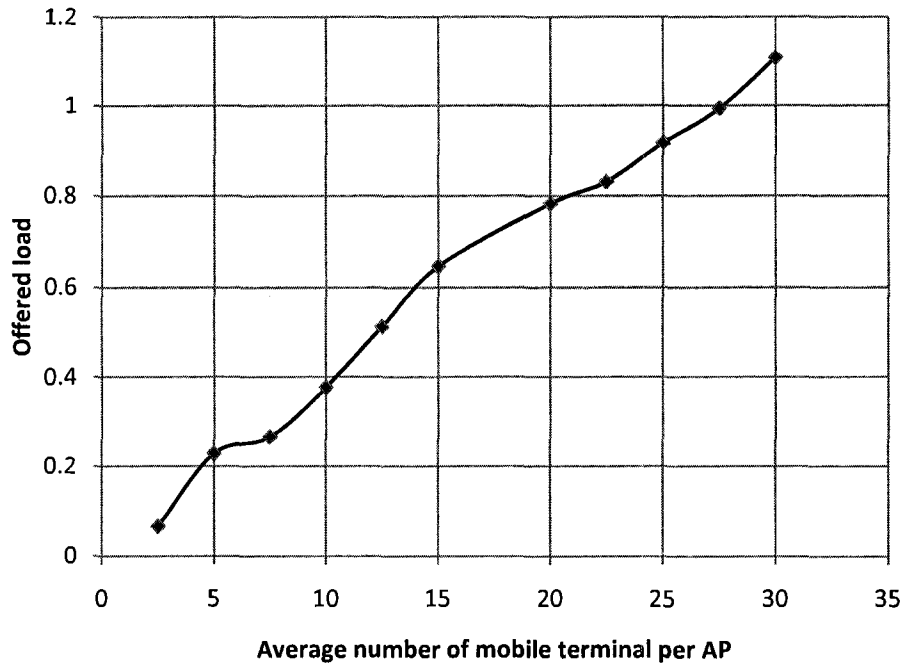


Figure 5.48. Load distribution over number of mobile terminals.

○ **Average Number of PDUs in Buffer and its Variance**

Fig. 5.49, 5.50 and 5.51 shows the average number of PDUs in buffer of MTs as a function of offered load for the three resource allocation policies, where buffer size is 5, 10 and 15 PDUs respectively. In the figures WMORR and MORR policies show almost equal performance in terms of buffer occupancy and WMORR and MORR allocation schemes also outperform the WRR scheme in terms of buffer occupancy. It is important to notice that around offered load 0.4 there is a sharp change in average number of PDUs in the user buffer for WRR scheme but the same thing happens after load value 0.65 for MORR and WMORR schemes. For the load, where the number of PDUs in the buffer is constant indicates that the amount of PDU arrival rate to the MTs is equal to the PDU service rate of MTs. Rise in number of PDUs in buffer occurs when the arrival rate becomes larger than the service rate for higher load. Our simulation system remains stable at higher load because the undelivered PDUs are stored in the buffer of MTs for future transmission.

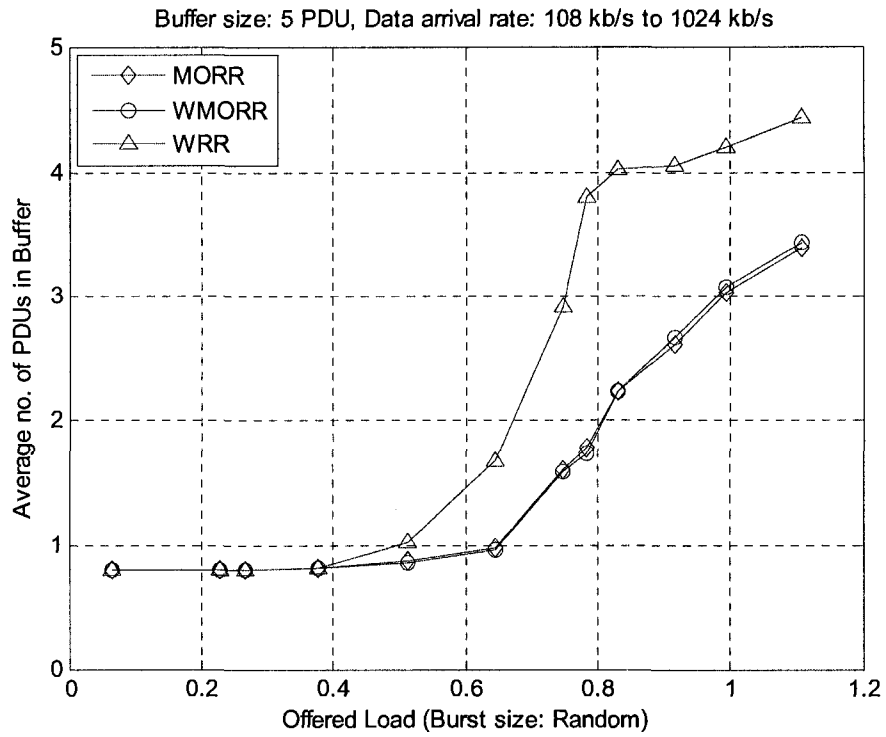


Figure 5.49. Average number of PDUs in buffer vs offered load for buffer size 5 at random burst.

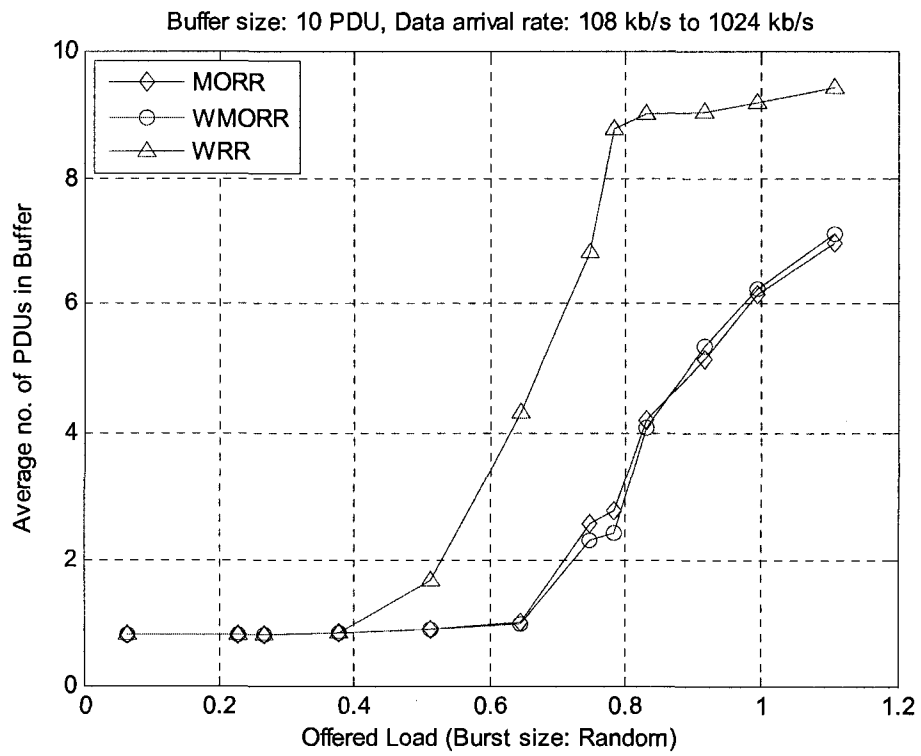


Figure 5.50. Average number of PDUs in buffer vs offered load for buffer size 10 at random burst.

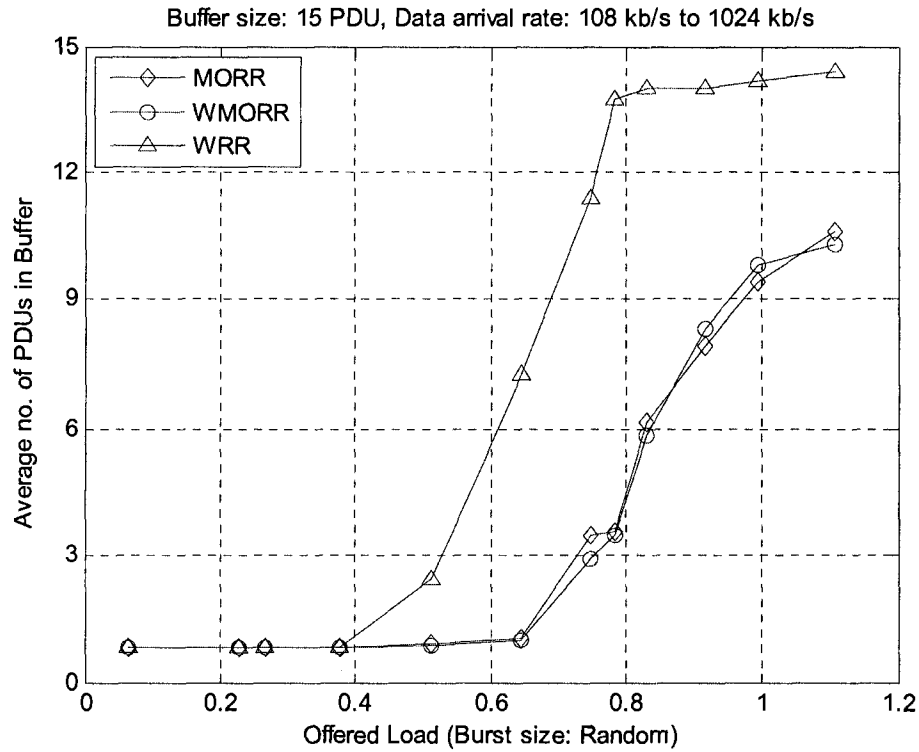


Figure 5.51. Average number of PDUs in buffer vs offered load for buffer size 15 at random burst.

Fig. 5.52, 5.53 and 5.54 show the average number of PDUs in buffer of MTs as a function of offered load for the buffer size 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. The figures show that at very low offered load buffer occupancy does not depend on the size of buffer and as the load increases number of PDUs in the buffer also increases. For the WRR scheme average number of PDUs in the buffer of MTs becomes almost constant and equal to the buffer size at loads higher than 0.8. On the other hand for MORR and WMORR schemes buffers do not reach at saturation around this high load.

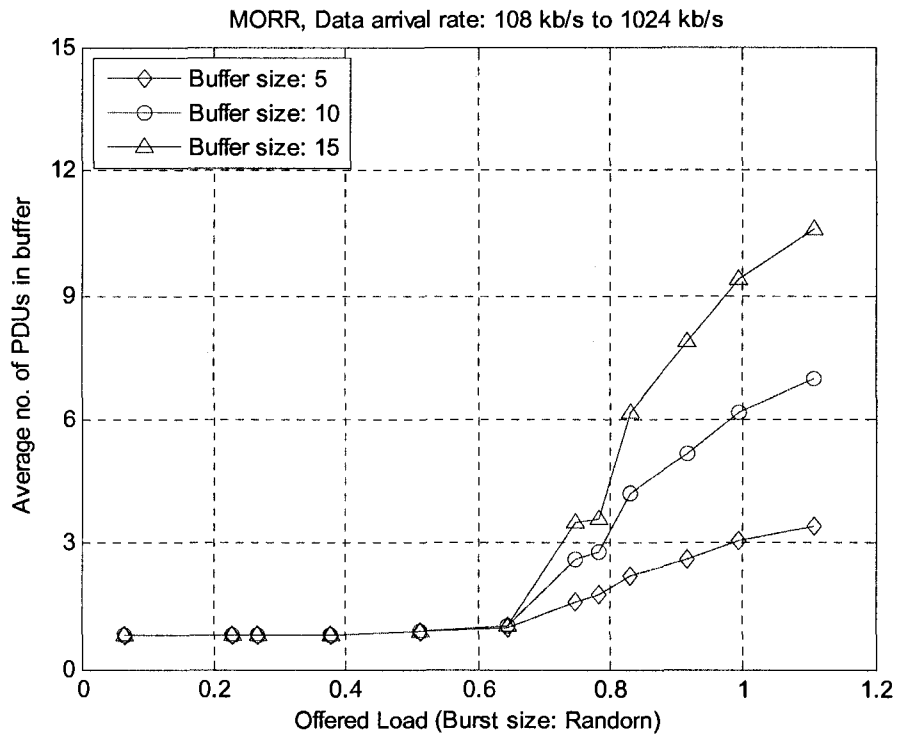


Figure 5.52. Average number of PDUs in buffer vs offered load for MORR scheme at random burst.

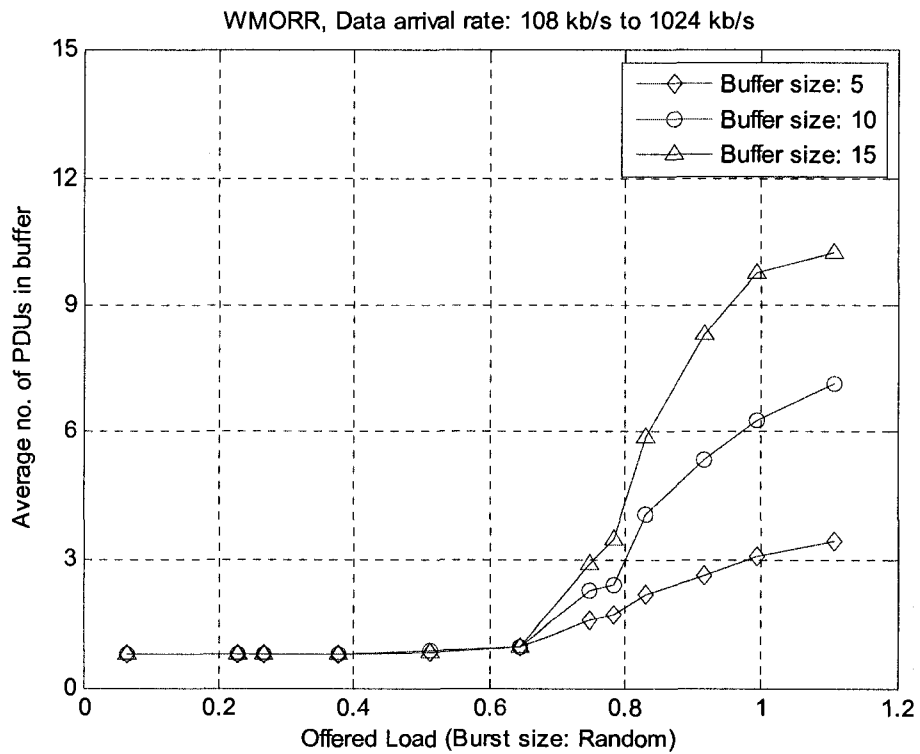


Figure 5.53. Average number of PDUs in buffer vs offered load for WMORR at random burst.

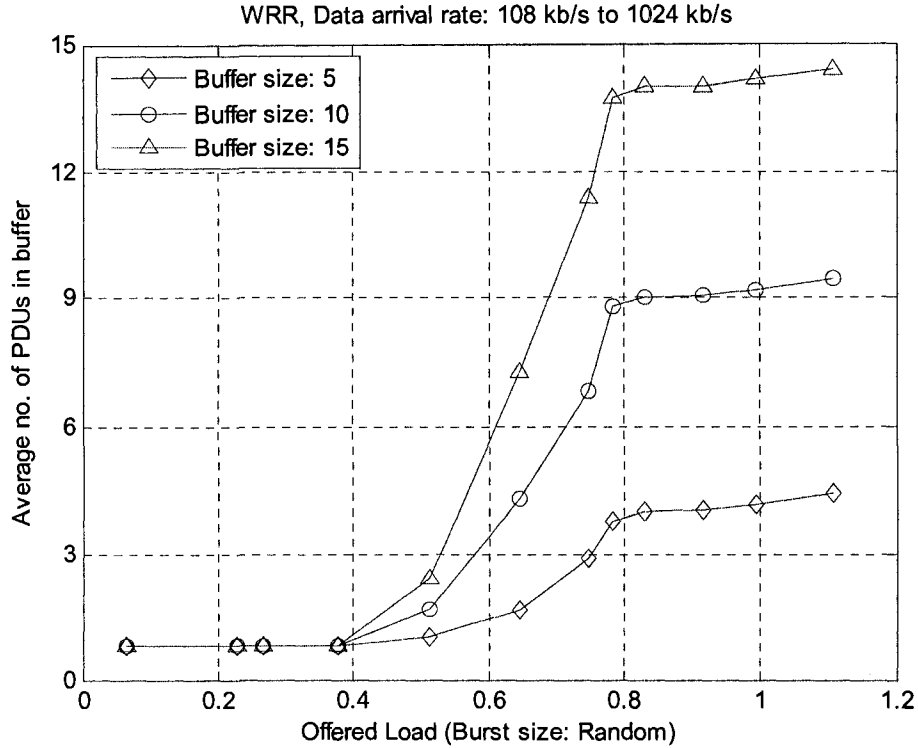


Figure 5.54. Average number of PDUs in buffer vs offered load for WRR at random burst.

Variance in the number of PDUs in the buffer of MTs is shown in the fig. 5.55, 5.56 and 5.57 as a function of offered load for the three resource allocation schemes and the figures represent the curves when the buffer size is 5, 10 and 15 PDUs respectively. It is important to notice that the change in variance in the following curves corresponds to the fig. 5.49-5.54. For the WRR scheme variance is large when load is in the range 0.4 to 0.8 and for the MORR and WMORR variance is large when the load is beyond 0.8. We also notice that for the WRR scheme variance curve is symmetrical around the load value 0.6 and for MORR and WMORR this happens around load value 0.8. This is due to the actual carried load below and above of these load value is same. This system behaviour indicates that for the WRR scheme system is operatable below load value 0.6 on the other hand for MORR and WMORR it is 0.8.

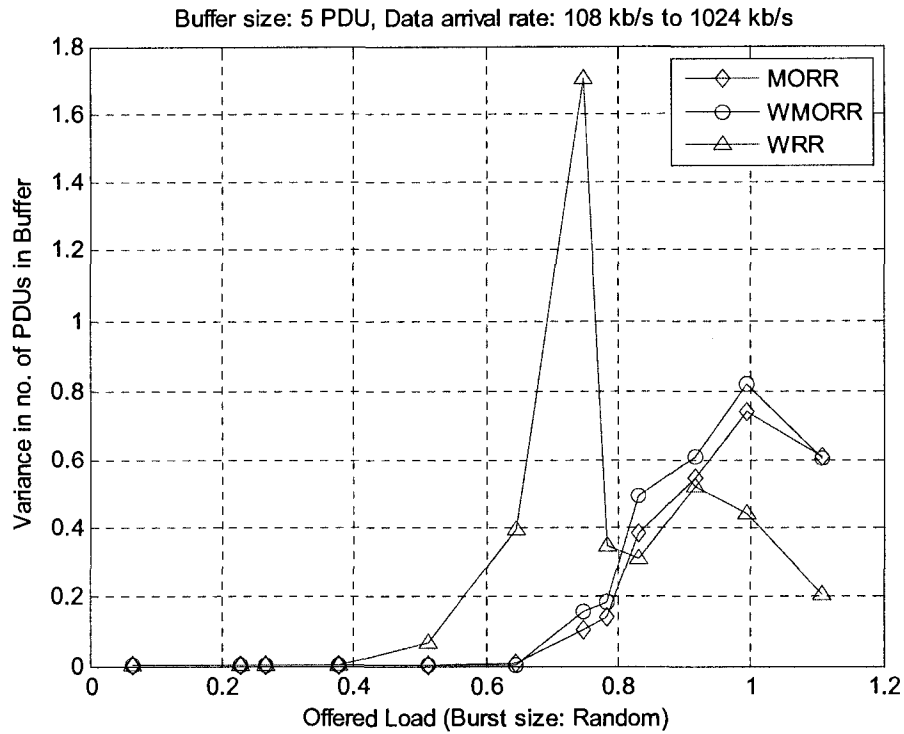


Figure 5.55. Variance in number of PDUs in buffer vs offered load for buffer size 5 at random burst.

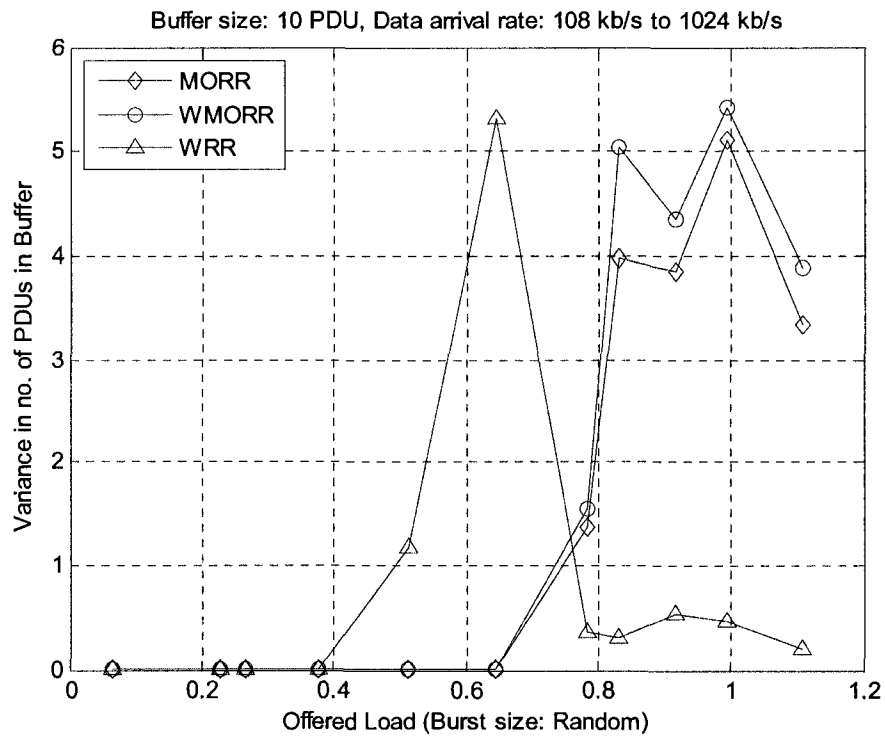


Figure 5.56. Variance in number of PDUs in buffer vs offered load for buffer size 10 at random burst.

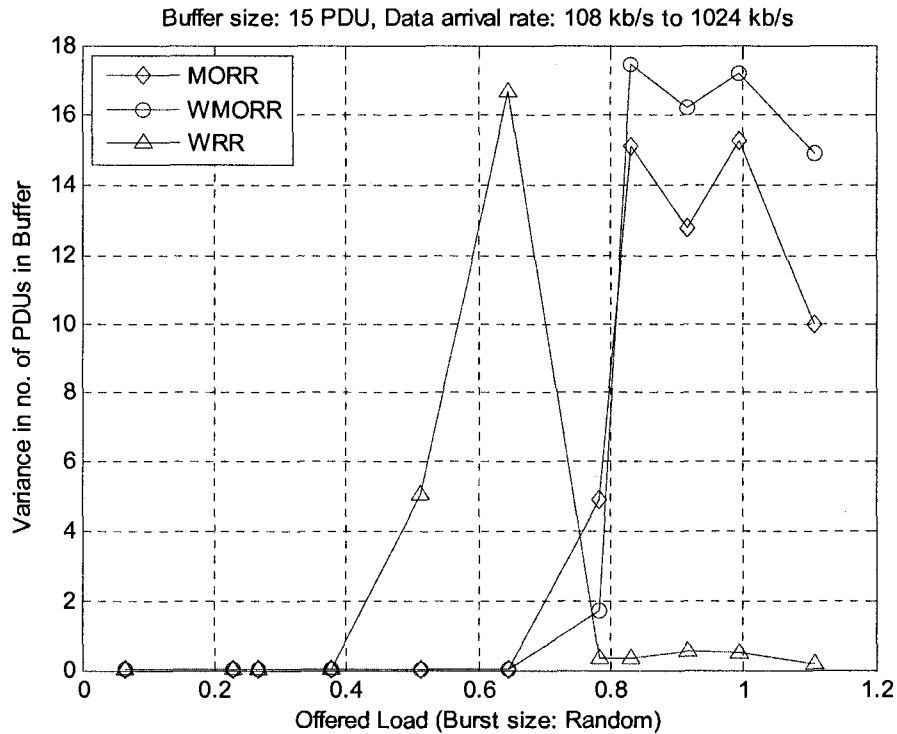


Figure 5.57. Variance in number of PDUs in buffer vs offered load for buffer size 15 at random burst.

o **Probability of Buffer Overflow and its variance**

Figs. 5.58, 5.59 and 5.60 depict the probability of buffer overflow as a function of offered load for the three resource allocation policies, where buffer size is 5, 10 and 15 PDUs respectively. The figures show that the WMORR allocation scheme has the lowest probability of overflow among the three schemes. It is important to note that probability of overflow is zero when the load is very low and it starts to increase when the offered load is increased above 0.5 for WRR and 0.6 for MORR and WMORR schemes. These value of load is significant because at load higher than this the total PDU arrival rate at our system becomes higher than the PDU service rate and the numbers of PDUs in the buffer starts to increase (Fig. 5.49 to 5.54) .

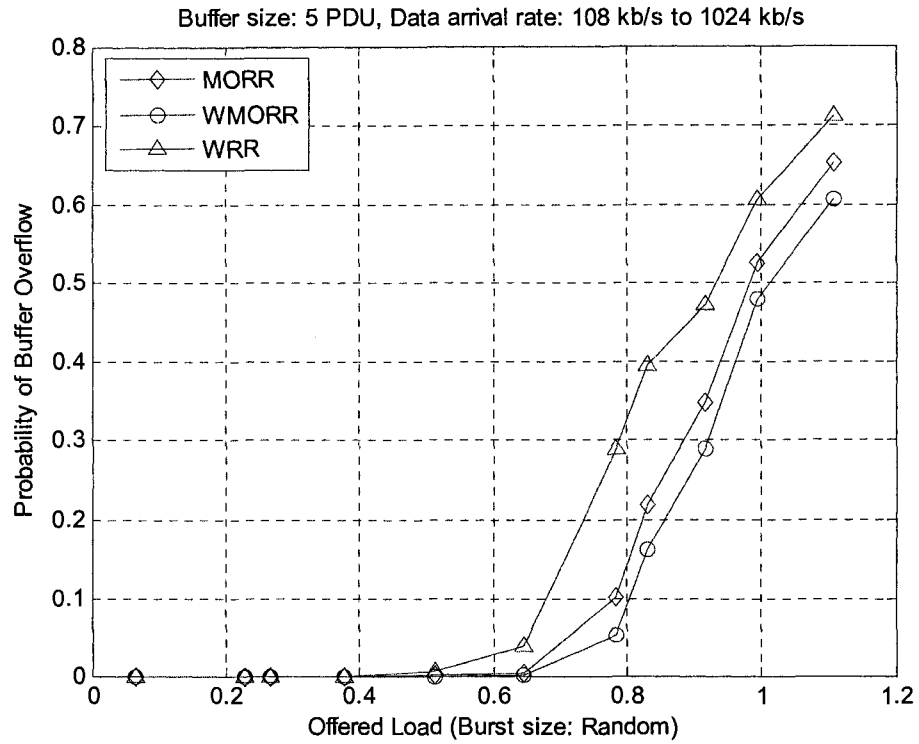


Figure 5.58. Probability of buffer overflow vs offered load for buffer size 5 at random burst.

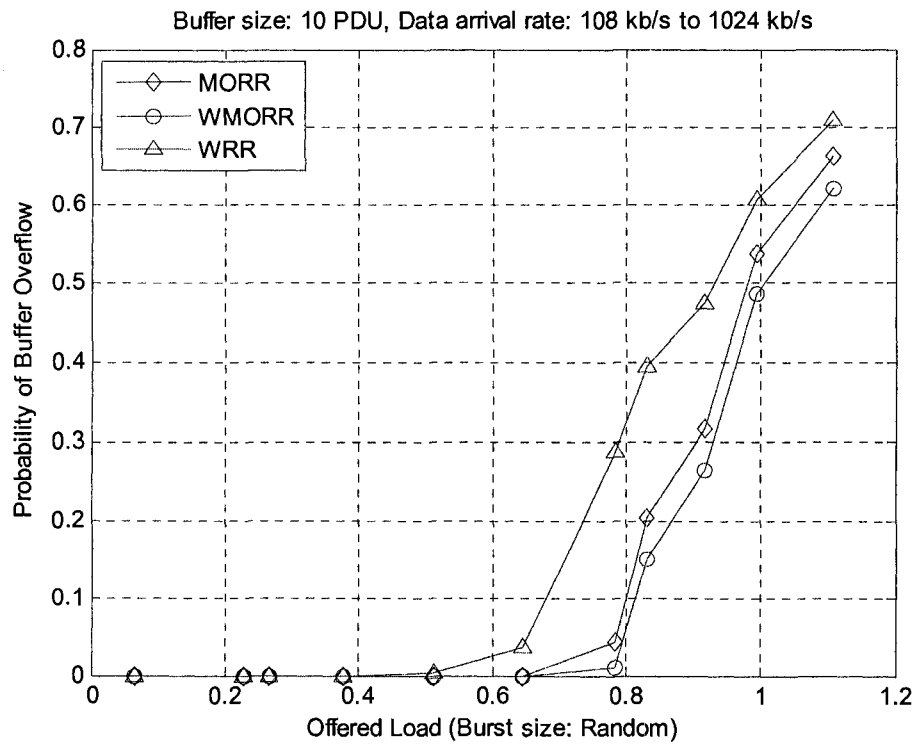


Figure 5.59. Probability of buffer overflow vs offered load for buffer size 10 at random burst.

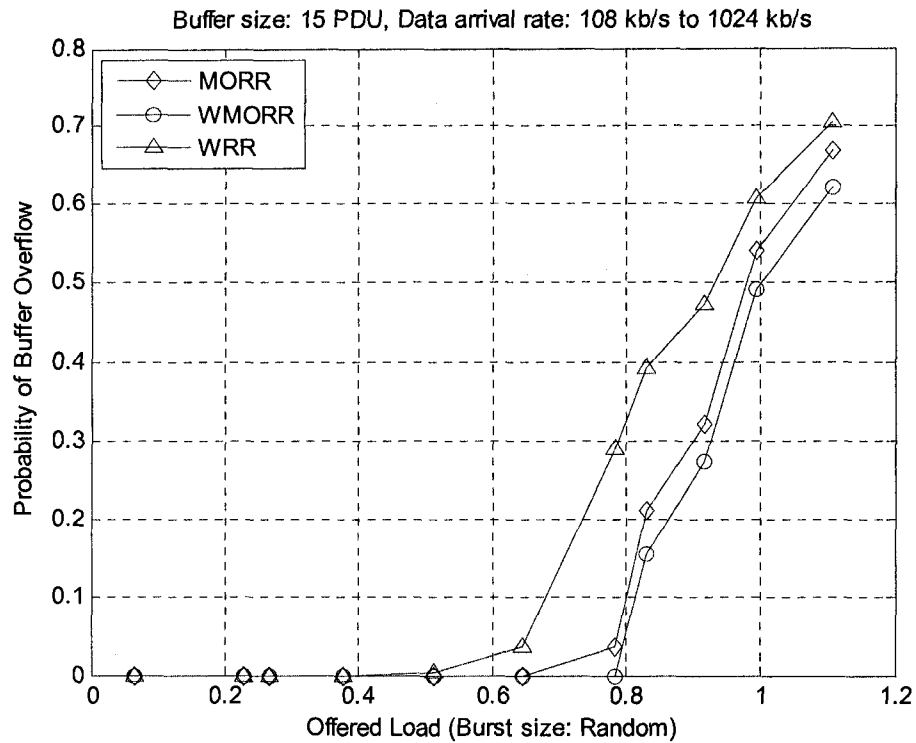


Figure 5.60. Probability of buffer overflow vs offered load for buffer size 15 at random burst.

Fig. 5.61, 5.62 and 5.63 shows the Probability of buffer overflow as a function of offered load for the buffer sizes 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. In the fig. 5.61 and 5.62 when the load is between 0.6 and 0.8 buffer size 15 shows the lowest probability of overflow and the buffer size 5 shows the highest probability of overflow. But in Fig. 5.63 we do not notice any significant change in probability of overflow due to change in buffer size.

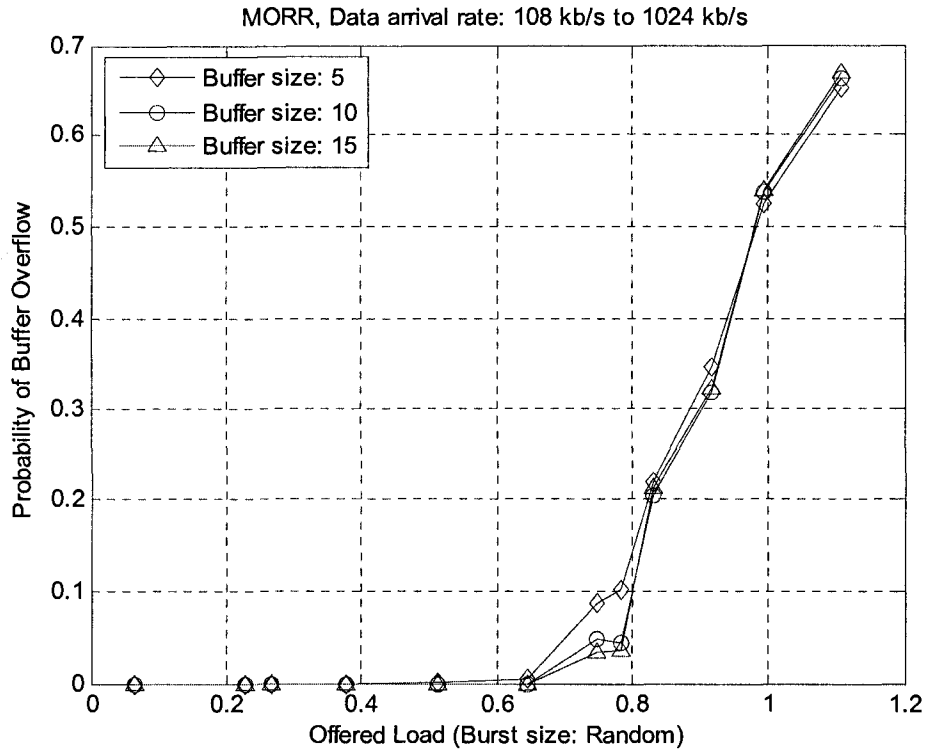


Figure 5.61. Probability of buffer overflow vs offered load for MORR scheme at random burst.

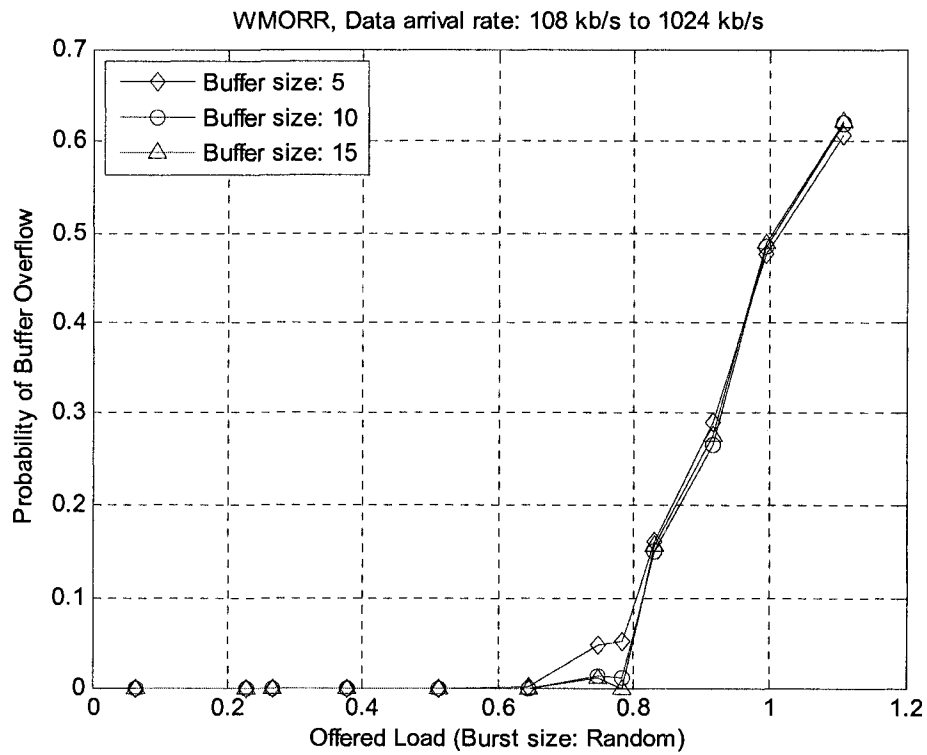


Figure 5.62. Probability of buffer overflow vs offered load for WMORR scheme at random burst.

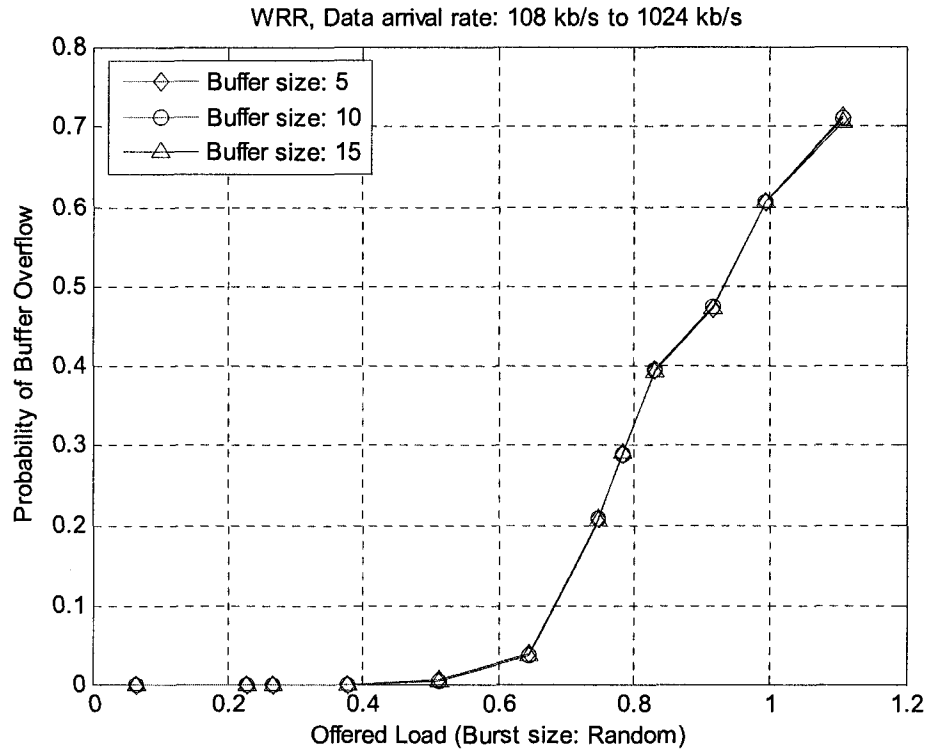


Figure 5.63. Probability of buffer overflow vs offered load for WRR scheme at random burst.

Variance in the buffer overflow is shown in the fig. 5.64, 5.65 and 5.66 as a function of offered load for the three resource allocation schemes and the figures represent the results when the buffer size is 5, 10 and 15 PDUs respectively. For all the curves the variance of buffer overflow is zero for low value of offered load as buffer overflow is also zero (Fig. 5.58 to 5.63). But for higher value of offered load the variance becomes large as the change in probability of buffer overflow is large at high load.

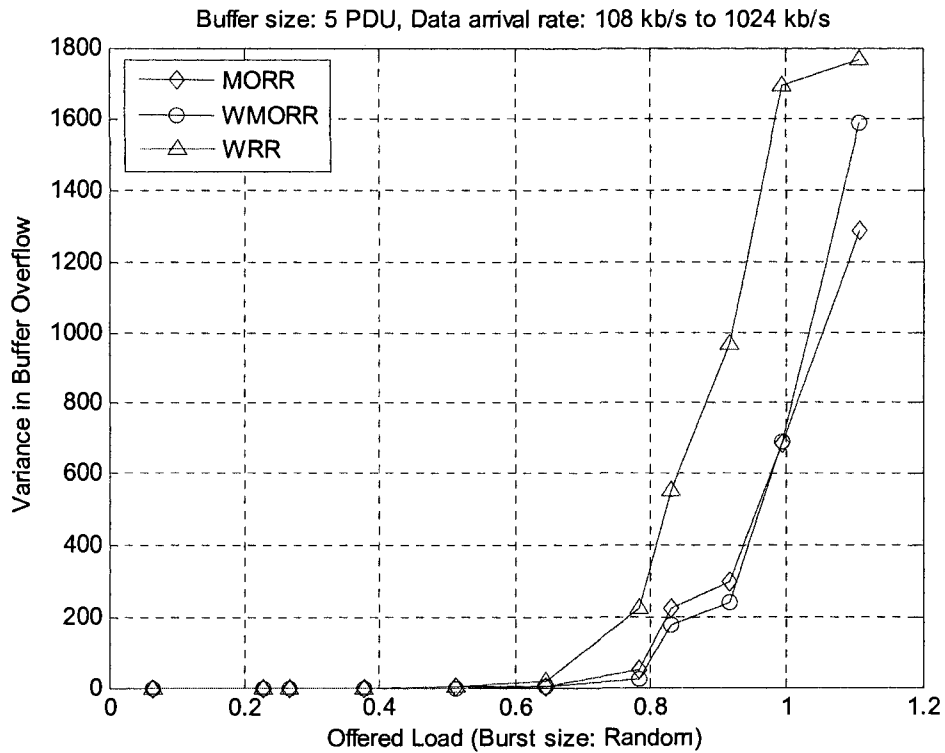


Figure 5.64. Variance in buffer overflow vs offered load for buffer size 5 at random burst.

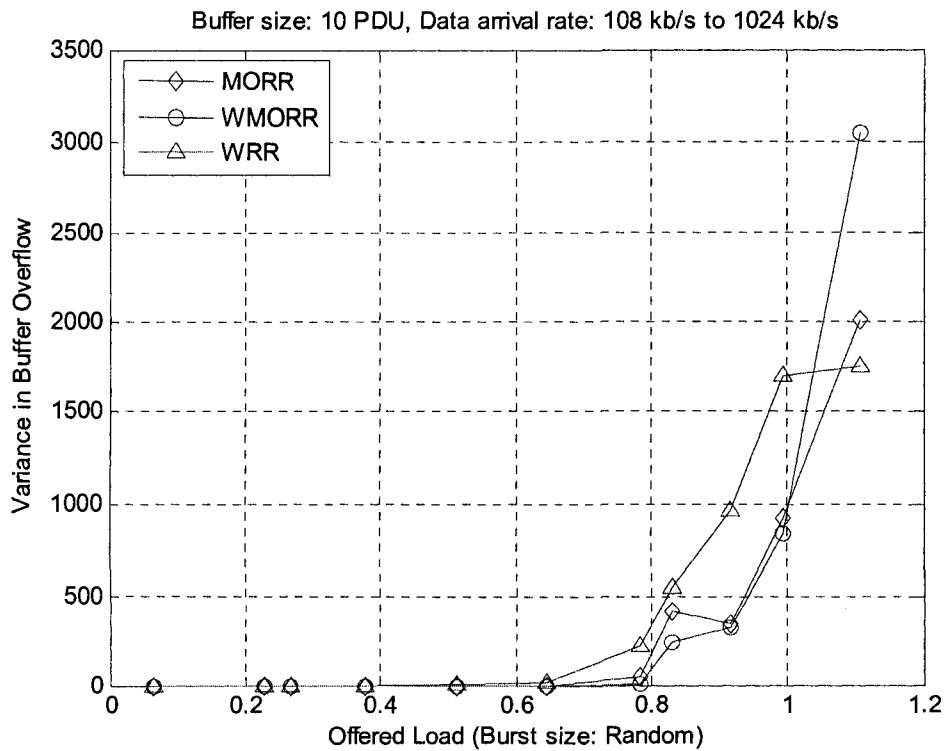


Figure 5.65. Variance in buffer overflow vs offered load for buffer size 10 at random burst.

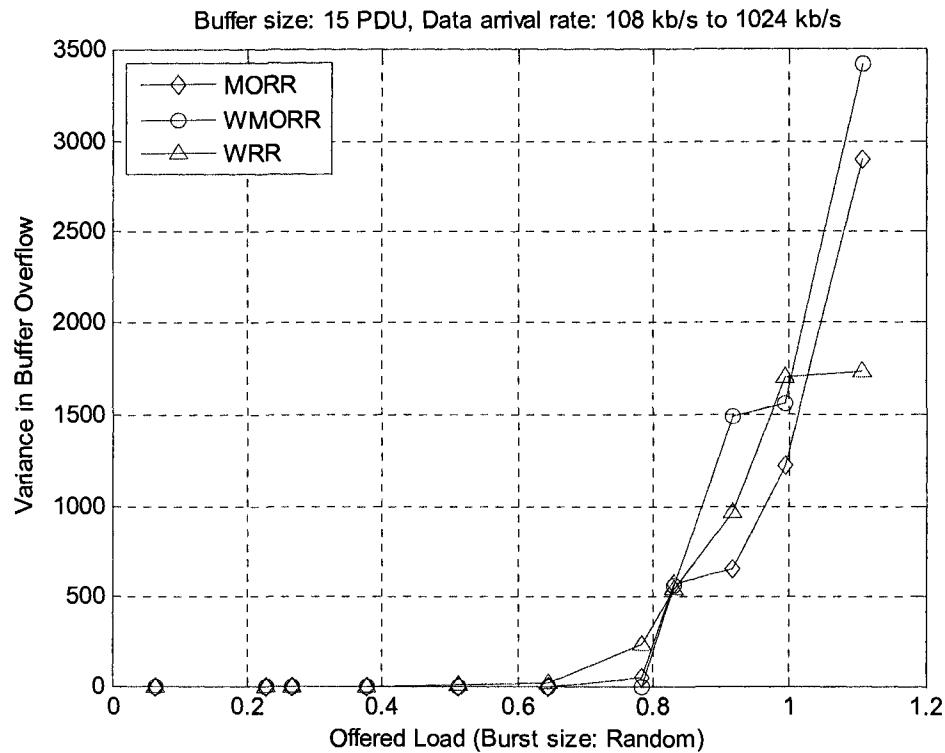


Figure 5.66. Variance in buffer overflow vs offered load for buffer size 15 at random burst.

o **Average PDU delivery time and its variance**

Fig. 5.67, 5.68 and 5.69 depicts average PDU delivery time in seconds as a function of offered load for the three resource allocation policies, where the buffer size is 5, 10 and 15 PDUs respectively. In the figures MORR and WMORR schemes show lower PDU delivery time compared to WRR scheme. For low value of offered load the delivery time is low and remains constant for all the allocation policy because PDU content in buffer is also constant (Fig. 5.49 to 5.54) and PDUs spend very small amount of time in the buffer. But when the system load increases PDU service rate becomes lower than the arrival rate and PDUs have to wait long in the buffer to get the transmission opportunity.

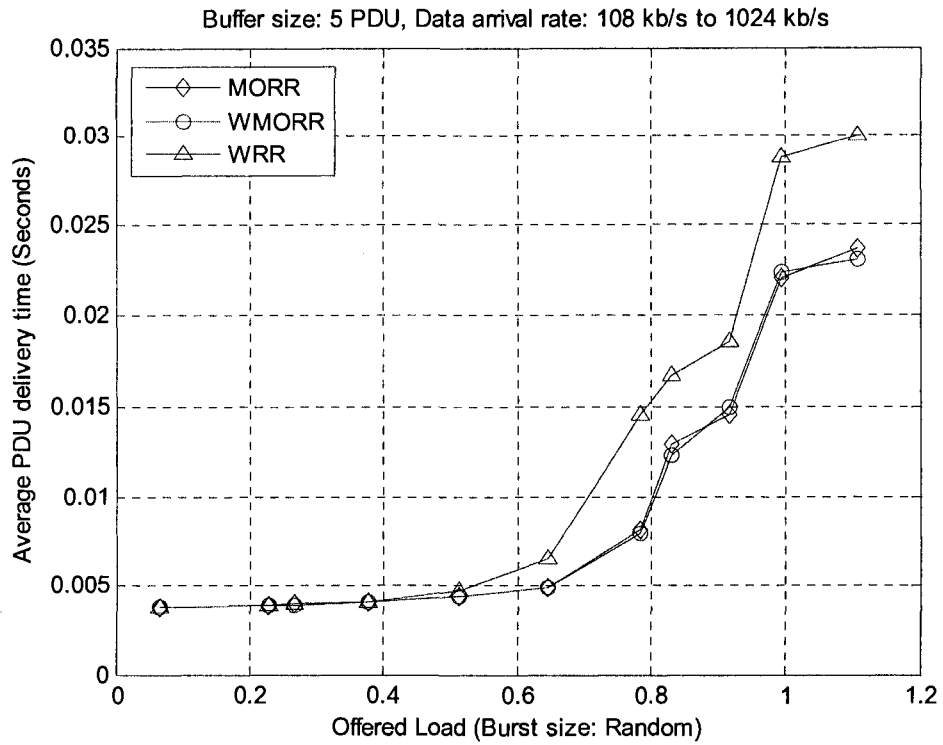


Figure 5.67. Average PDU delivery time vs offered load for buffer size 5 at random burst.

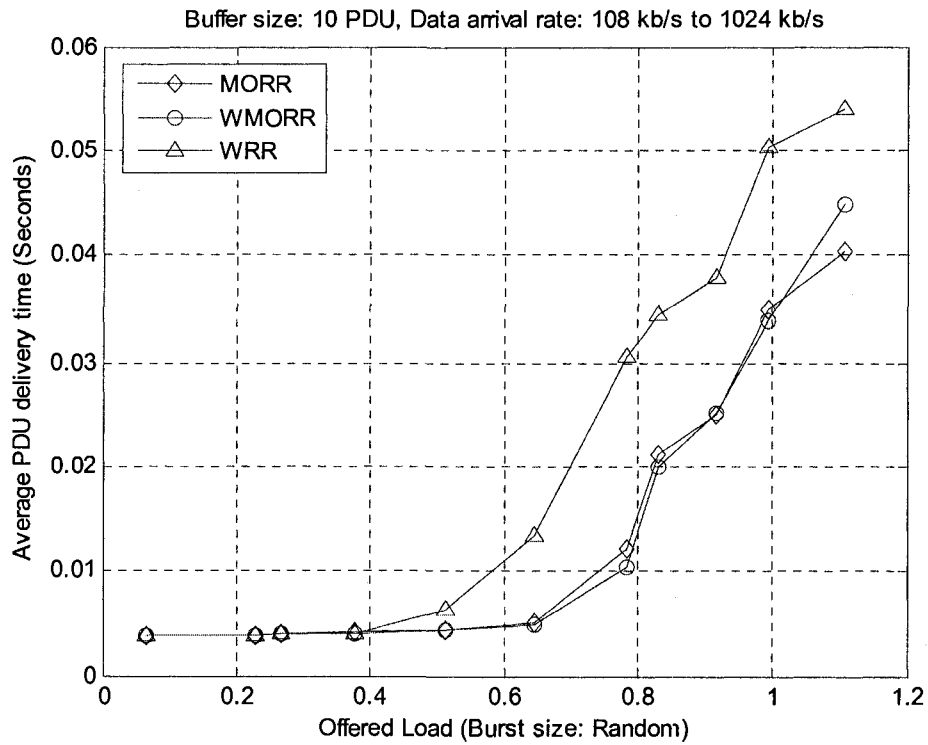


Figure 5.68. Average PDU delivery time vs offered load for buffer size 10 at random burst.

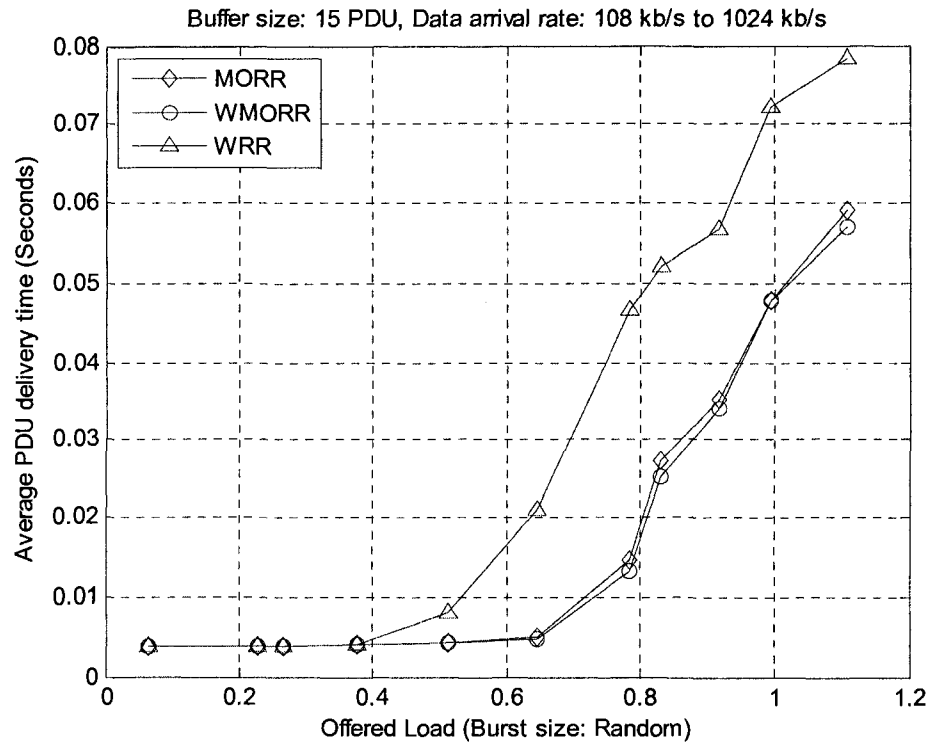


Figure 5.69. Average PDU delivery time vs offered load for buffer size 15 at random burst.

Fig. 5.70, 5.71 and 5.72 show average PDU delivery time in seconds as a function of offered load for the buffer sizes 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. All the figures show that with the increase of buffer size average delivery time also increases as PDUs have to wait long in the buffer to get the transmission opportunity. In the figures we also notice that for load lower than 0.7 for MORR and WMORR and 0.4 for WRR scheme PDU delivery time remains constant and it does not depend on buffer size.

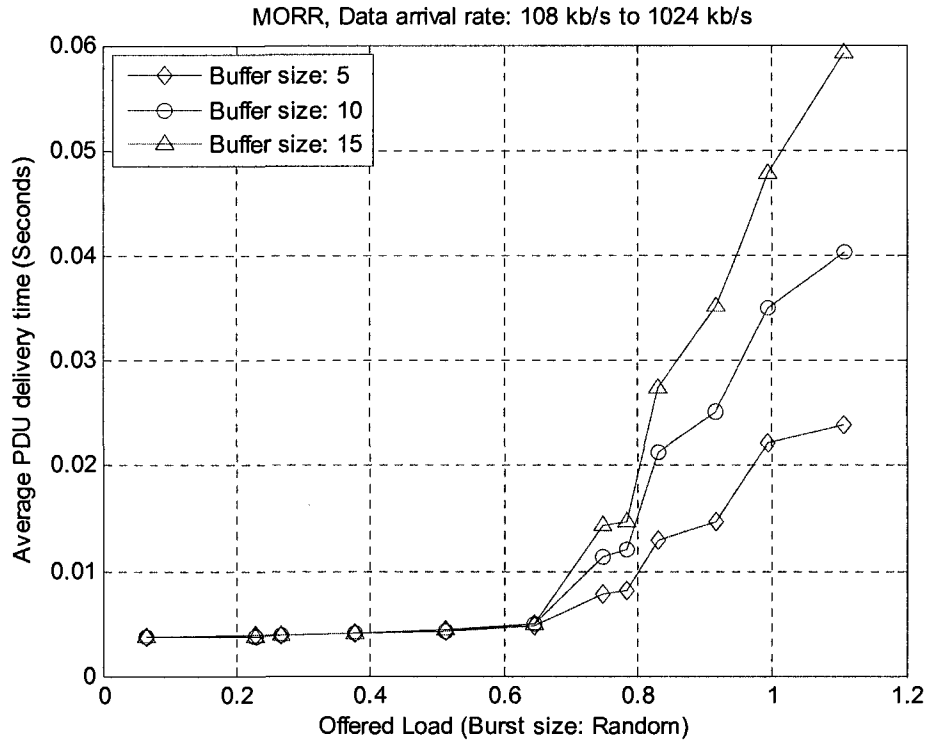


Figure 5.70. Average PDU delivery time vs offered load for MORR scheme at random burst.

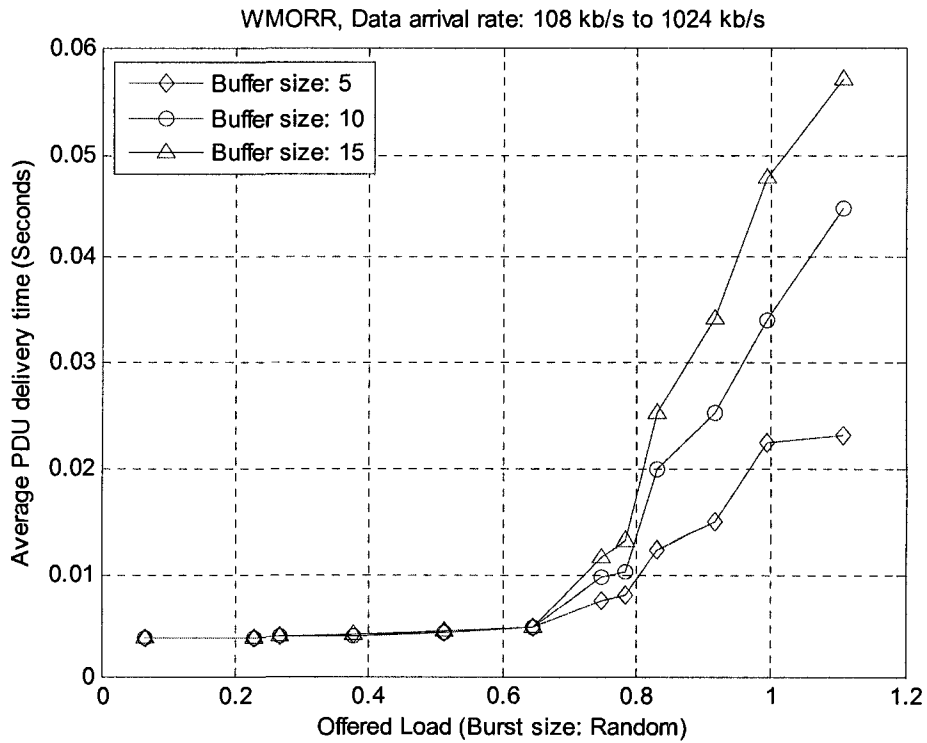


Figure 5.71. Average PDU delivery time vs offered load for WMORR scheme at random burst.

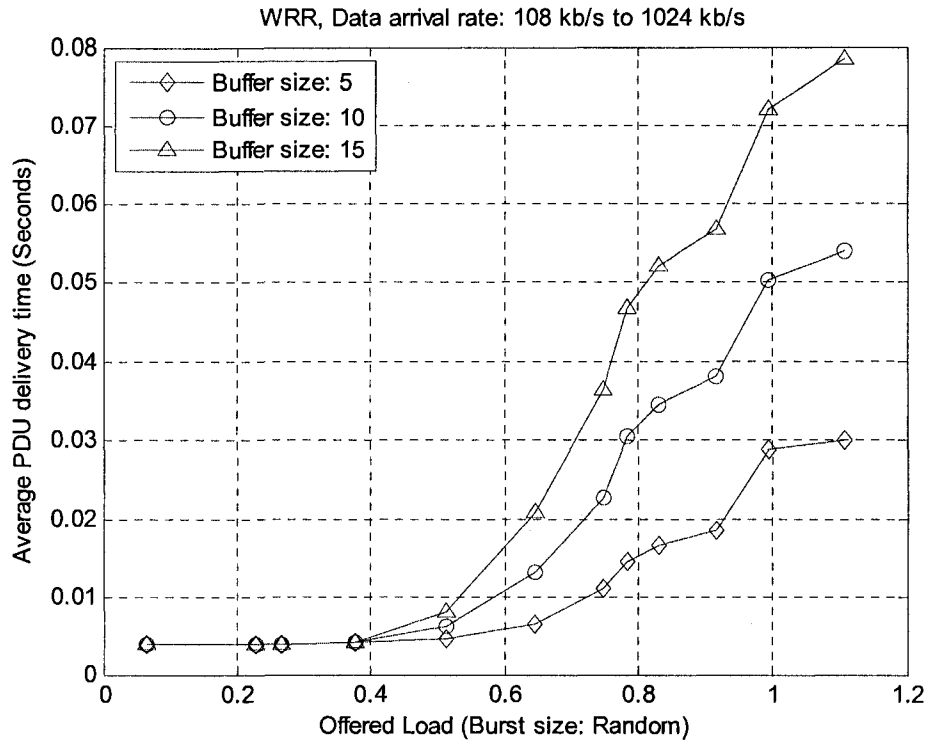


Figure 5.72. Average PDU delivery time vs offered load for WRR scheme at random burst.

Variance in the PDU delivery time is shown in the fig. 5.73, 5.74 and 5.75 as a function of offered load for the three resource allocation schemes and the figures represent the results when the buffer size is 5, 10 and 15 PDUs respectively. For all the curves the variance of PDU delivery time is zero when offered load is below 0.8. But for very high value of offered load variance in delivery time becomes high. We also notice that the variance for WRR scheme is very high and it is out of the range used in the figure.

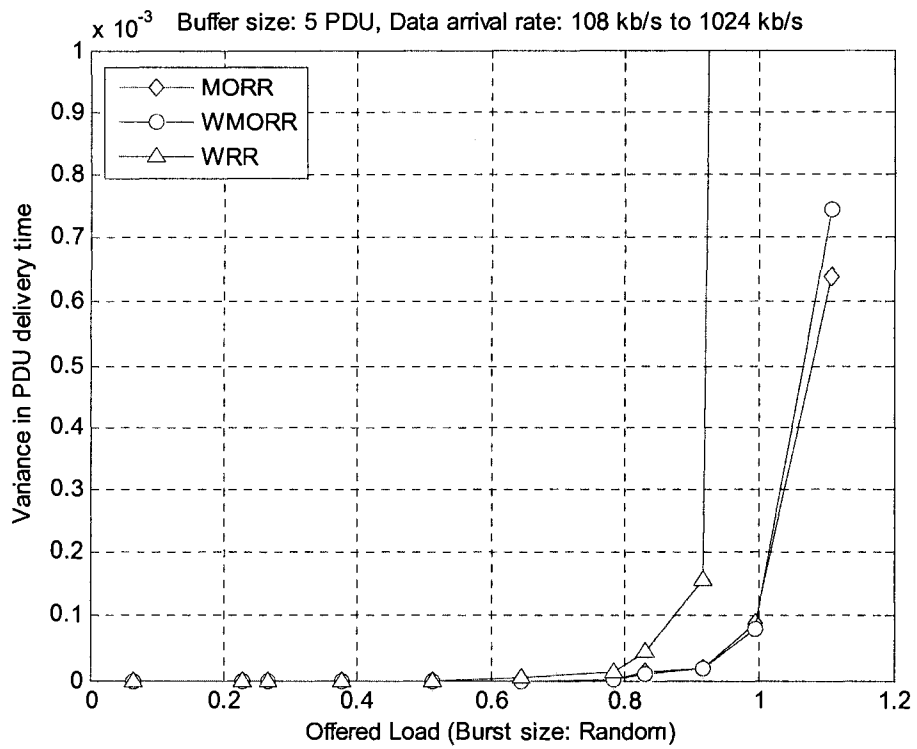


Figure 5.73. Variance in PDU delivery time vs offered load for buffer size 5 at random burst.

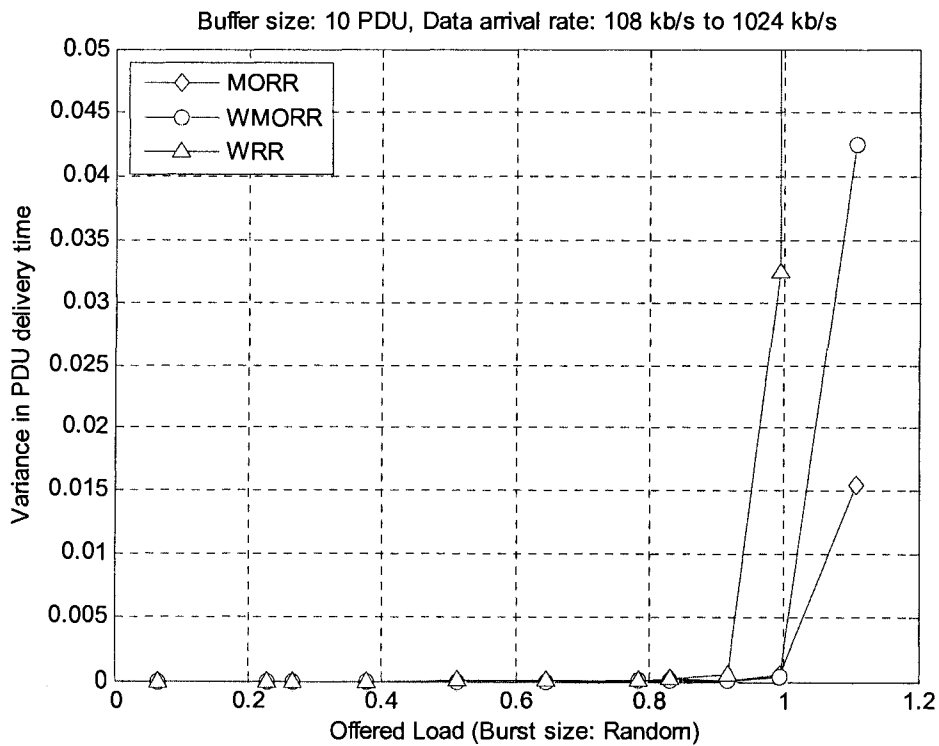


Figure 5.74. Variance in PDU delivery time vs offered load for buffer size 10 at random burst.

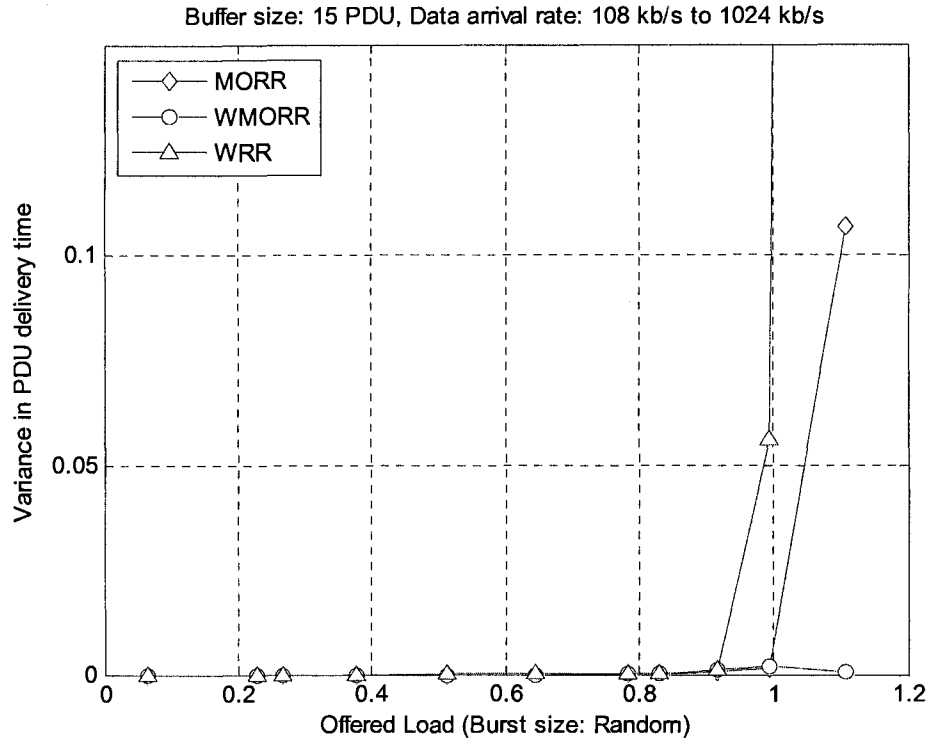


Figure 5.75. Variance in PDU delivery time vs offered load for buffer size 15 at random burst.

o **Average Overhead in Uplink Phase and its variance**

Fig. 5.76, 5.77 and 5.78 depict the average overhead (Percentage of total uplink time) in uplink phase as a function of offered load for the three resource allocation policies, where buffer size is 5, 10 and 15 PDUs respectively. The figures show that the MORR and WMORR schemes have low overhead compared to the WRR allocation scheme. For low value of offered load the uplink overhead is large as all the arrived PDU gets the transmission opportunity and overhead of all the user add up to give a large overhead. But as the load increases arrival rate becomes higher than the service rate and very few users get the transmission opportunity. This results a very low overhead for MORR and WMORR scheme as when ever an user is visited, maximum capacity is assigned to it according to these schemes. But for the WRR scheme as all the user buffer is visited during a TDMA frame, overhead of all the user adds up and the summaion continue to increase with the increase of load.

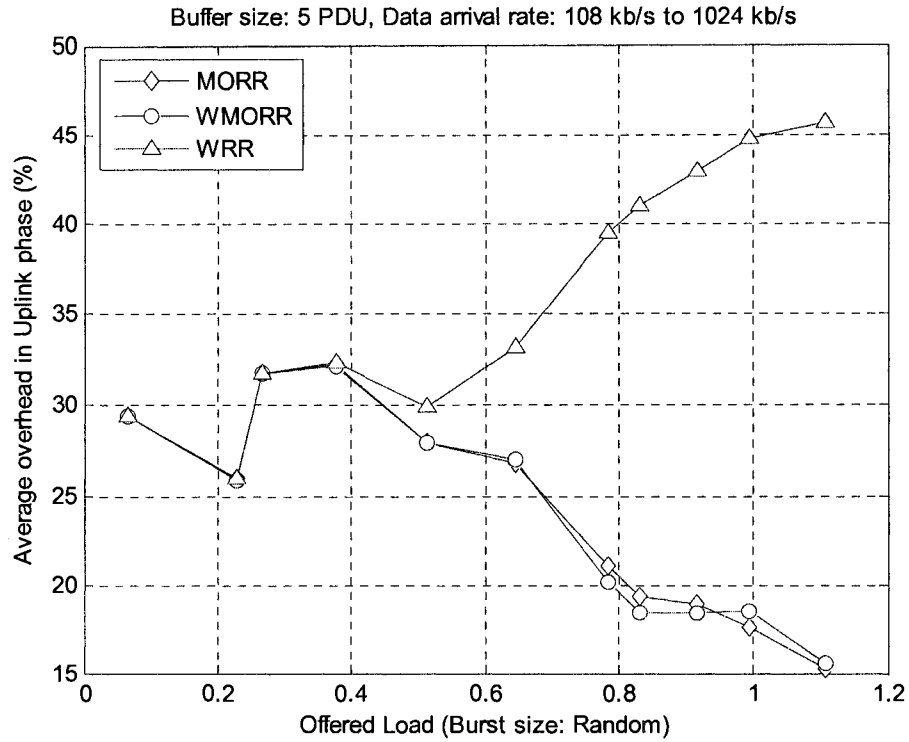


Figure 5.76. Average overhead in uplink phase vs offered load for buffer size 5 at random burst.

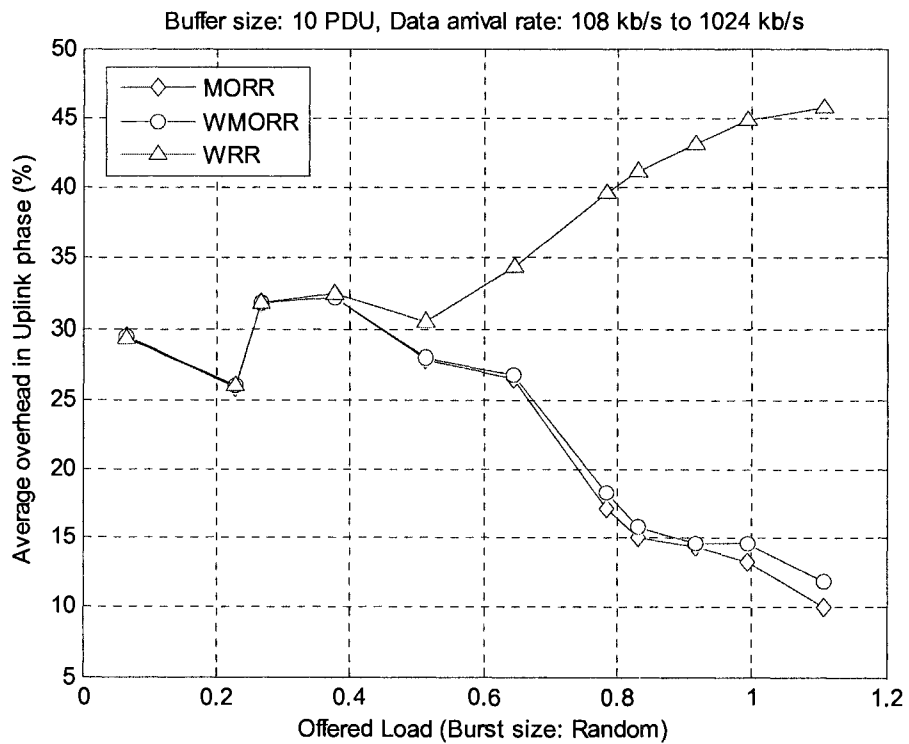


Figure 5.77. Average overhead in uplink phase vs offered load for buffer size 10 at random burst.

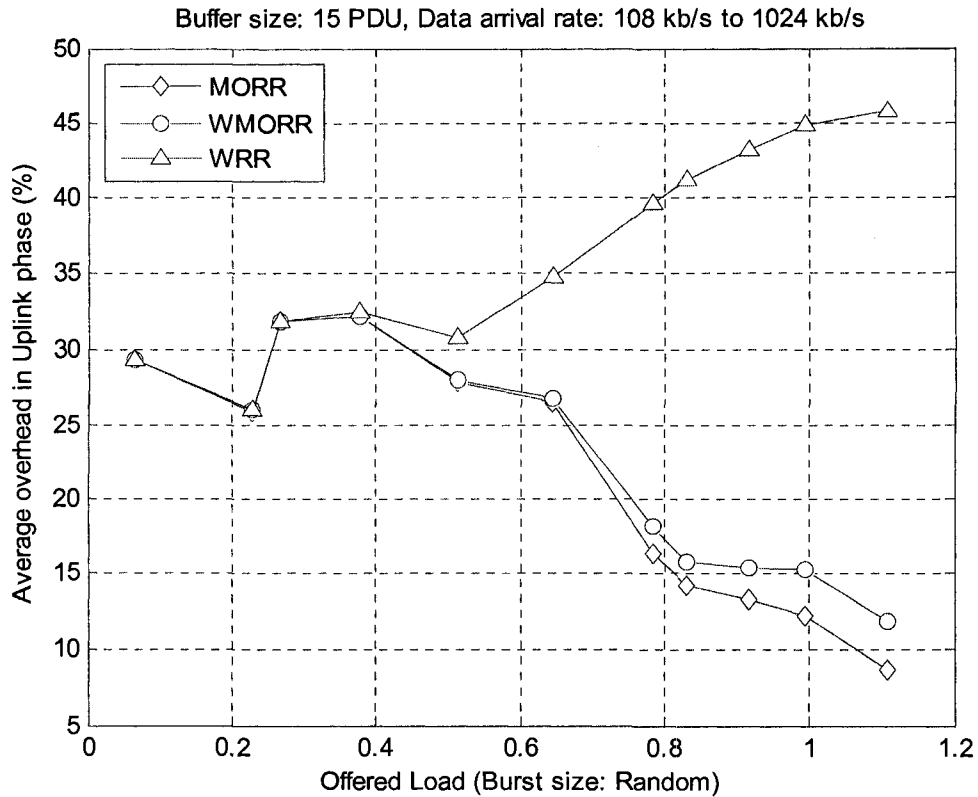


Figure 5.78. Average overhead in uplink phase vs offered load for buffer size 15 at random burst.

Fig. 5.79, 5.80 and 5.81 shows the average overhead in uplink phase (Percentage of total uplink time) as a function of offered load for buffer sizes 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. We notice that for WMORR and MORR schemes overhead decreases with the increase of buffer size at high load. This change in overhead corresponds to the allocation scheme, as for low load all MTs are scheduled for transmission in the TDMA frame but at high load a few of the MTs are scheduled for transmission. Also in these schemes, at high load the number of MTs to be scheduled for transmission depends on the buffer occupancy i.e. buffer size of the MTs. For the WRR scheme overhead remains same for all buffer sizes because in this scheme all the MTs are scheduled for transmission in the TDMA frame and overhead does not depend on the buffer size

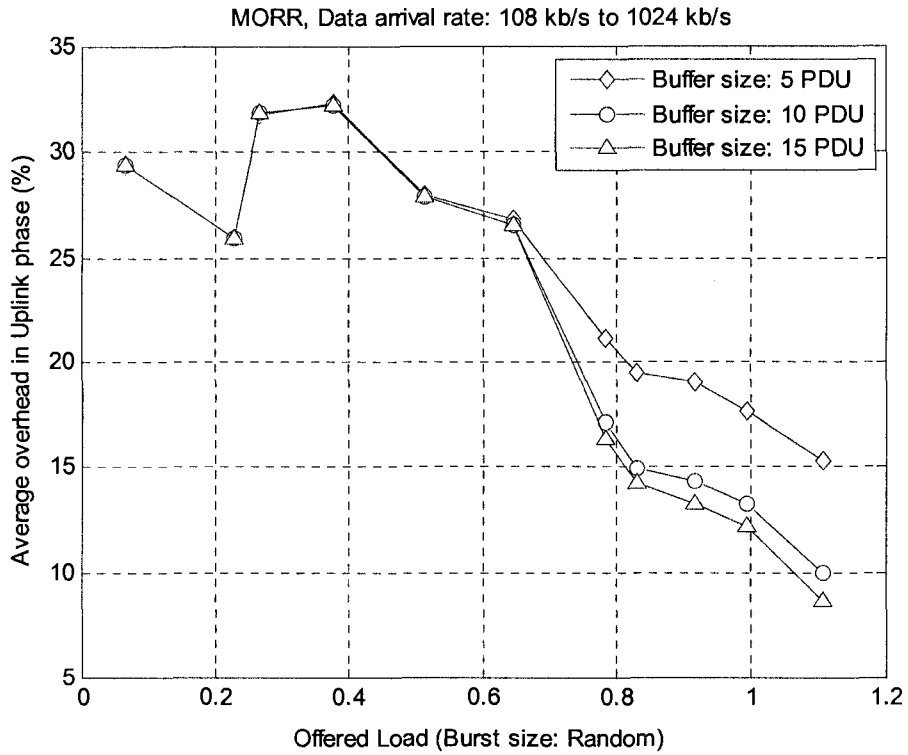


Figure 5.79. Average overhead in uplink phase vs offered load for MORR scheme at random burst.

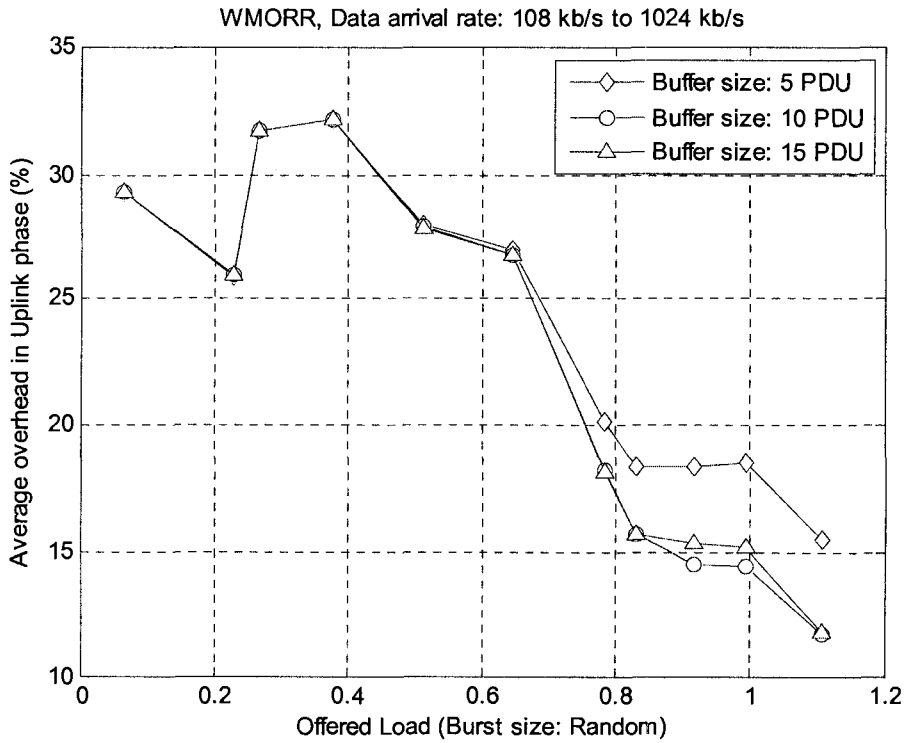


Figure 5.80. Average overhead in uplink phase vs offered load for WMORR scheme at random burst.

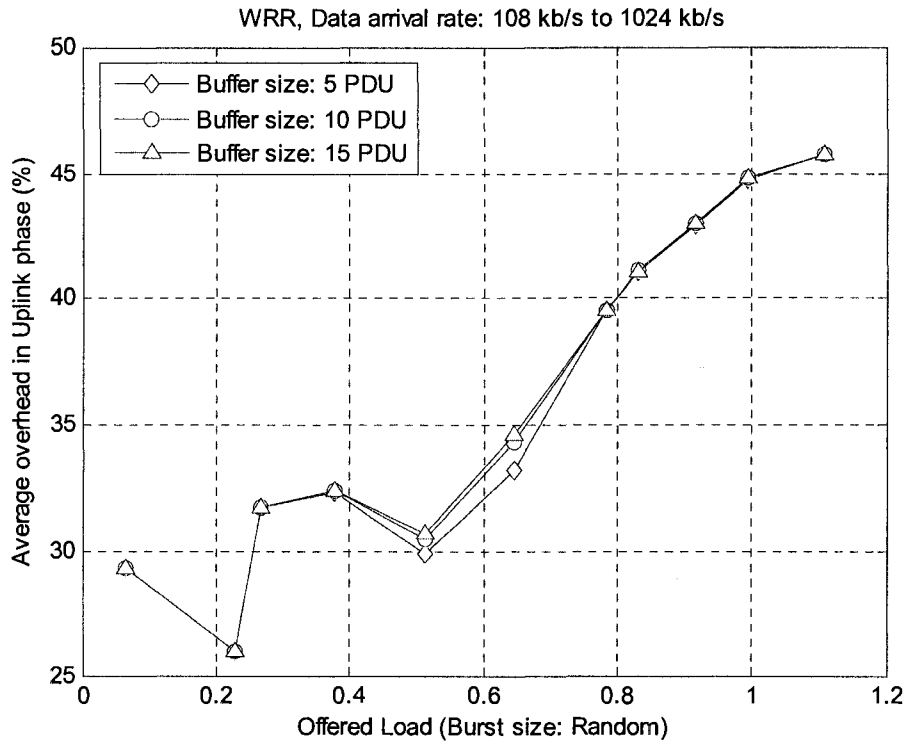


Figure 5.81. Average overhead in uplink phase vs offered load for WRR scheme at random burst.

Variance in overhead of uplink phase is shown in fig. 5.82, 5.83 and 5.84 as a function of offered load for the three resource allocation schemes and the figures represent the results when the buffer size is 5, 10 and 15 PDUs respectively. We notice that change in variance corresponds to the change in the curves of fig. 5.76 – 5.81.

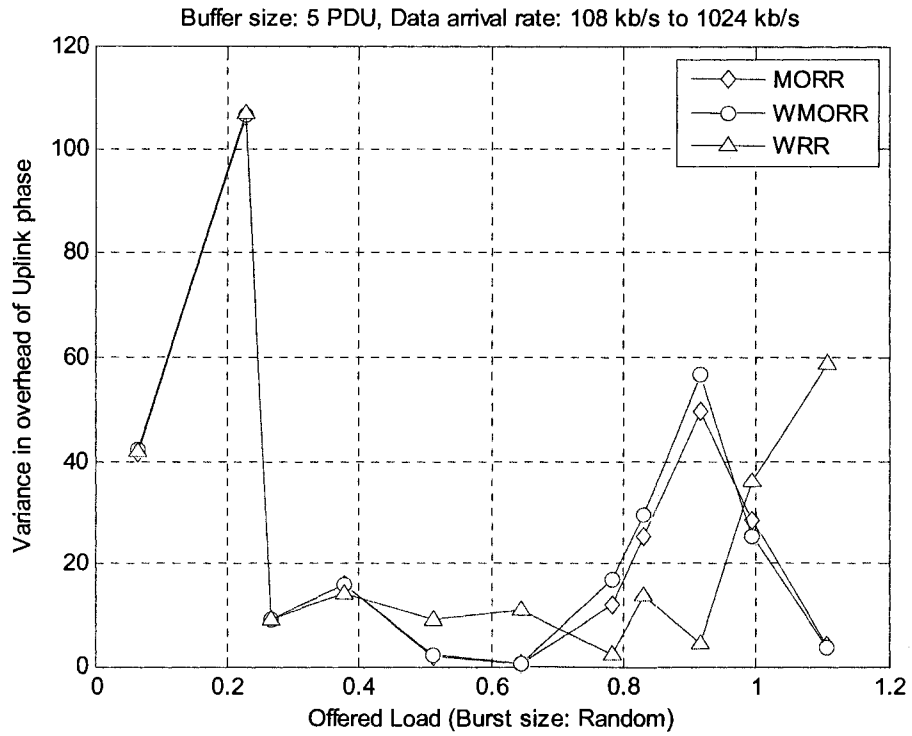


Figure 5.82. Variance in overhead of uplink phase vs offered load for buffer size 5 at random burst.

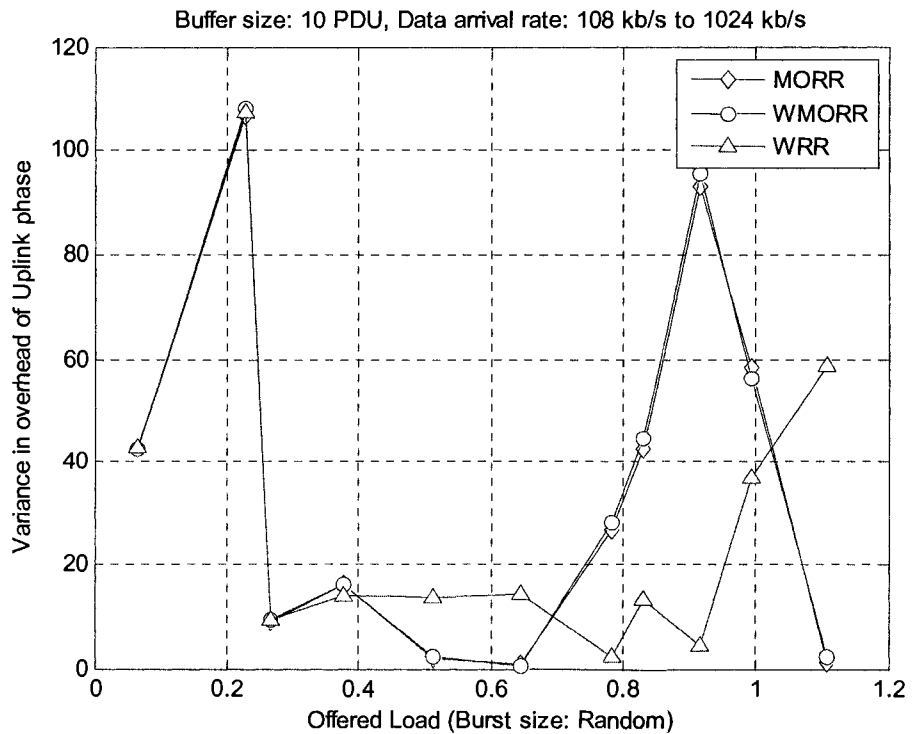


Figure 5.83. Variance in overhead of uplink phase vs offered load for buffer size 10 at random burst.

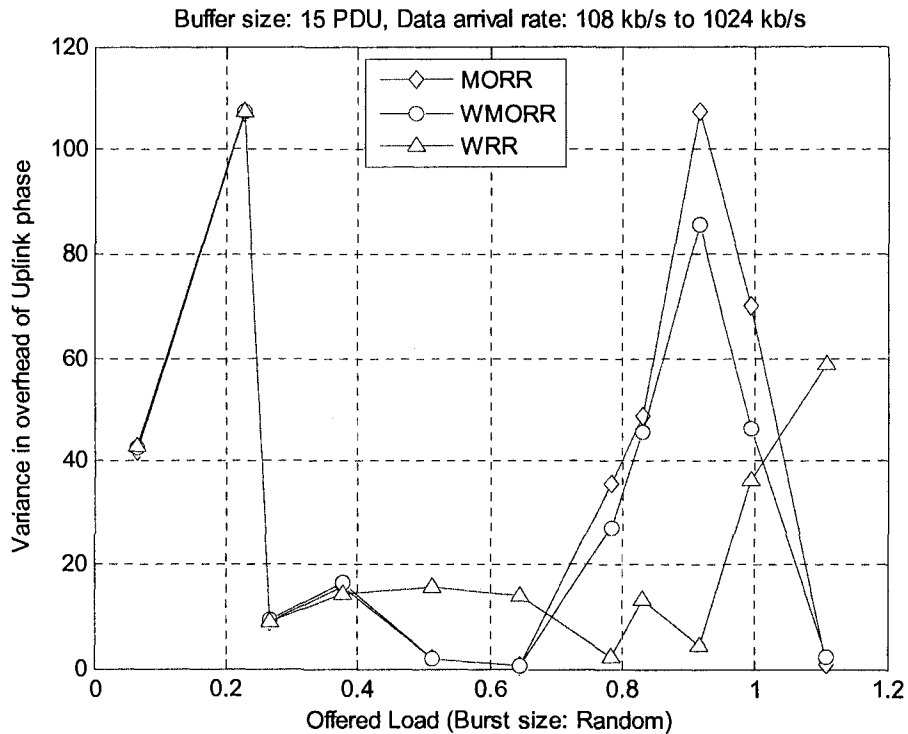


Figure 5.84. Variance in overhead of uplink phase vs offered load for buffer size 15 at random burst.

o **Average Overhead in Downlink Phase and its variance**

Fig. 5.85, 5.86 and 5.87 depict the average overhead in downlink phase (Percentage of downlink time) as a function of offered load for the three resource allocation policies, where buffer size is 5, 10 and 15 PDUs respectively. The figures show that the MORR and WMORR policies have low overhead compared to the WRR allocation scheme. For low value of offered load the downlink overhead is large as all the arrived PDU gets the transmission opportunity and overhead of all the user add up to give a large overhead. But as the load increases arrival rate beomes higher than the service rate and very few of the user get the transmission opportunity. This results very low overhead for MORR and WMORR scheme as according to these schemes when ever an user is visited, system capacity is assigned to it in these schemes. But for the WRR scheme as all users is visited during a TDMA frame, overhead of all the user adds up and the summaion continue to increase with the increase of load.

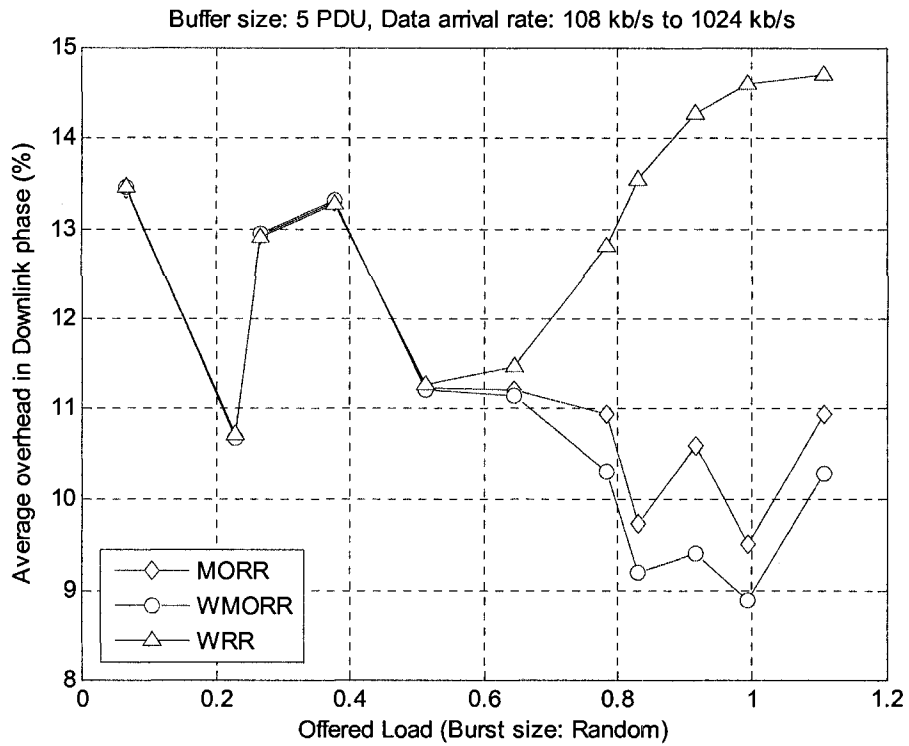


Figure 5.85. Average overhead in downlink phase vs offered load for buffer size 5 at random burst.

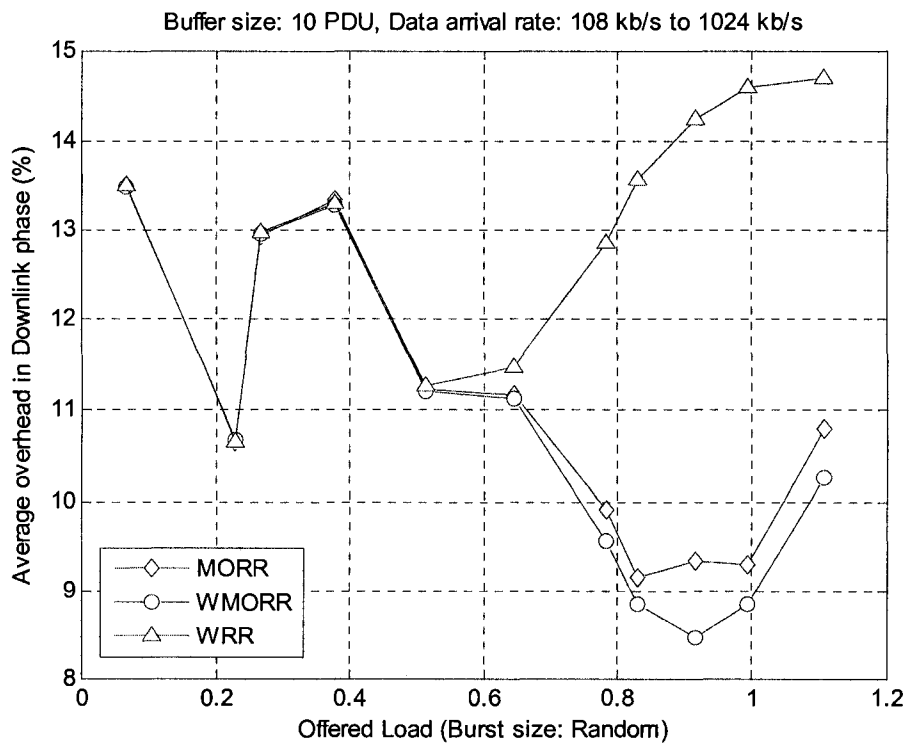


Figure 5.86. Average overhead in downlink phase vs offered load for buffer size 10 at random burst.

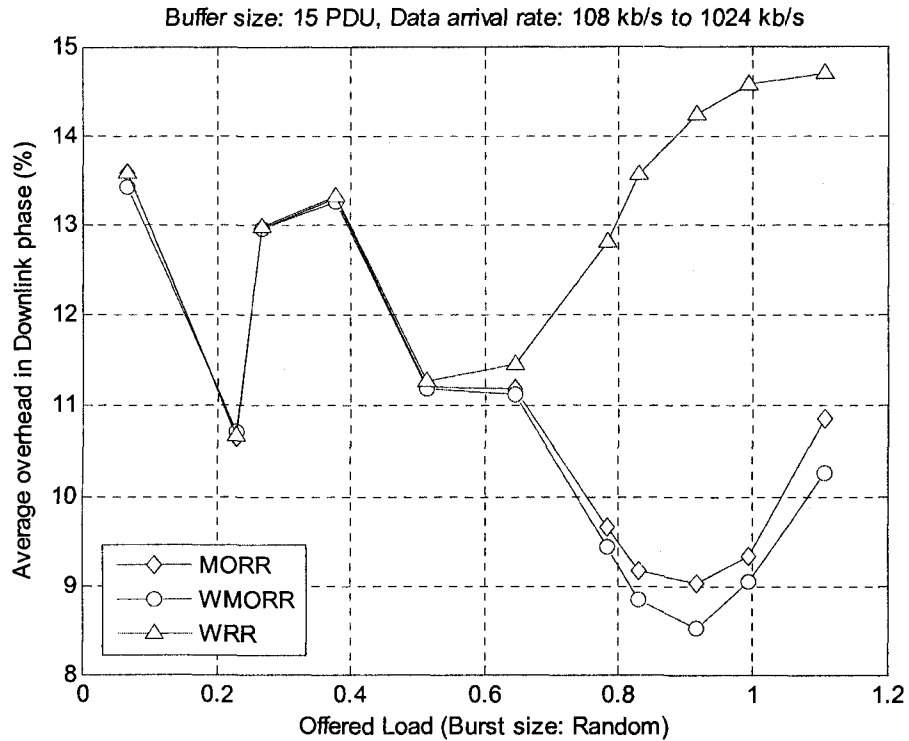


Figure 5.87. Average overhead in downlink phase vs offered load for buffer size 15 at random burst.

Fig. 5.88, 5.89 and 5.90 shows the average overhead (Percentage of total downlink time) in downlink phase as a function of offered load for buffer sizes 5, 10 and 15 PDUs and the figures are for the MORR, WMORR and WRR resource allocation schemes respectively. We notice that for all the schemes change in overhead does not depend on buffer size of the MT. It is due to the fact that here resource is allocated using the number of PDUs for the MTs in the buffer of AP not using the buffer occupancy of MTs.

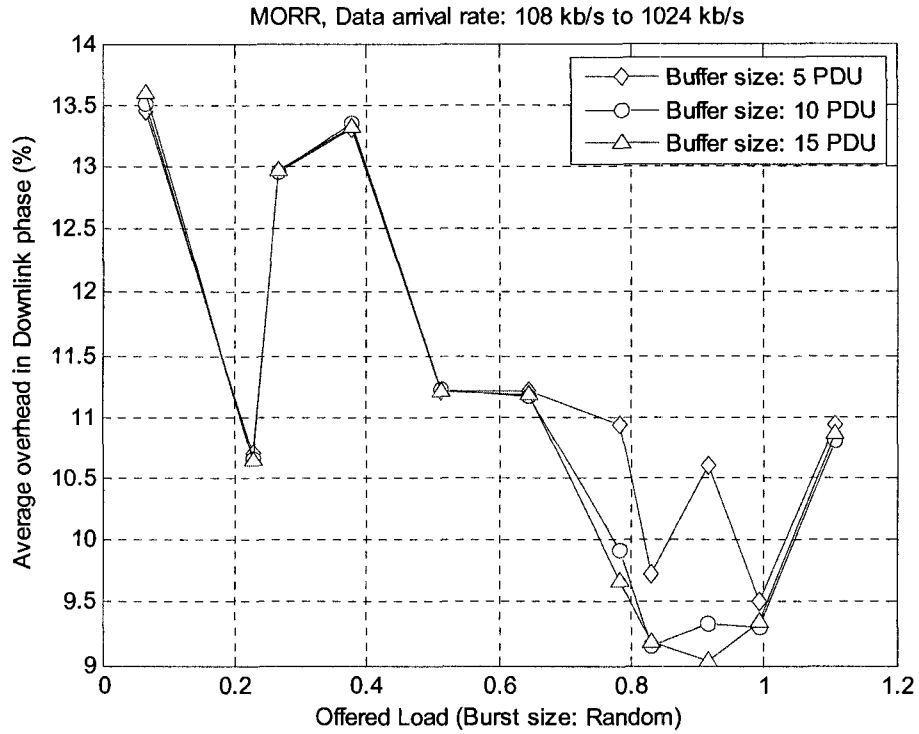


Figure 5.88. Average overhead in downlink phase vs offered load for MORR scheme at random burst.

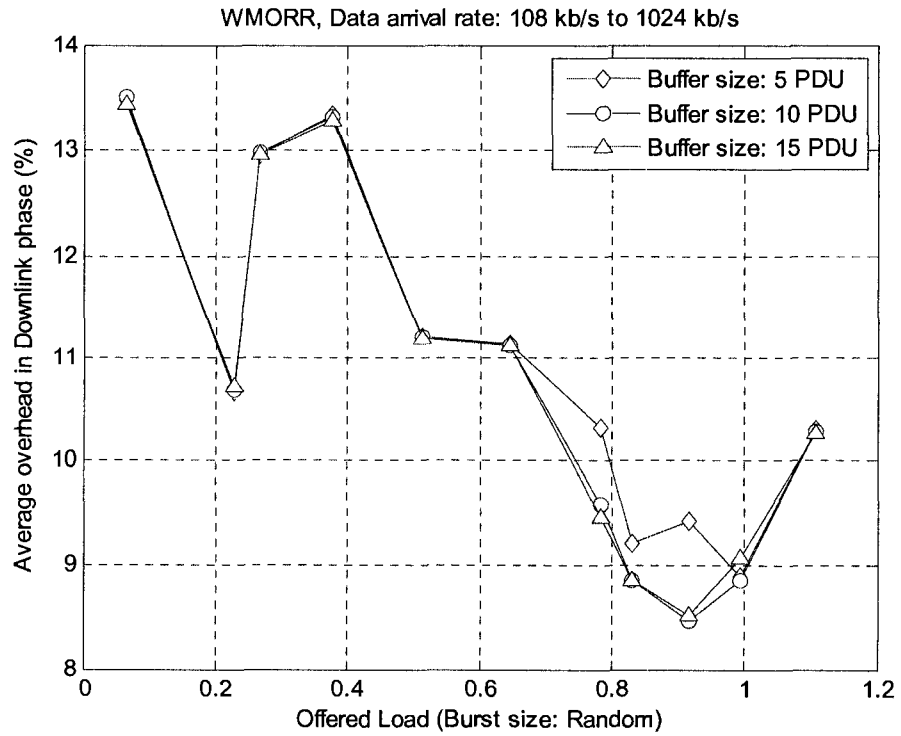


Figure 5.89. Average overhead in downlink phase vs offered load for WMORR scheme at random burst.

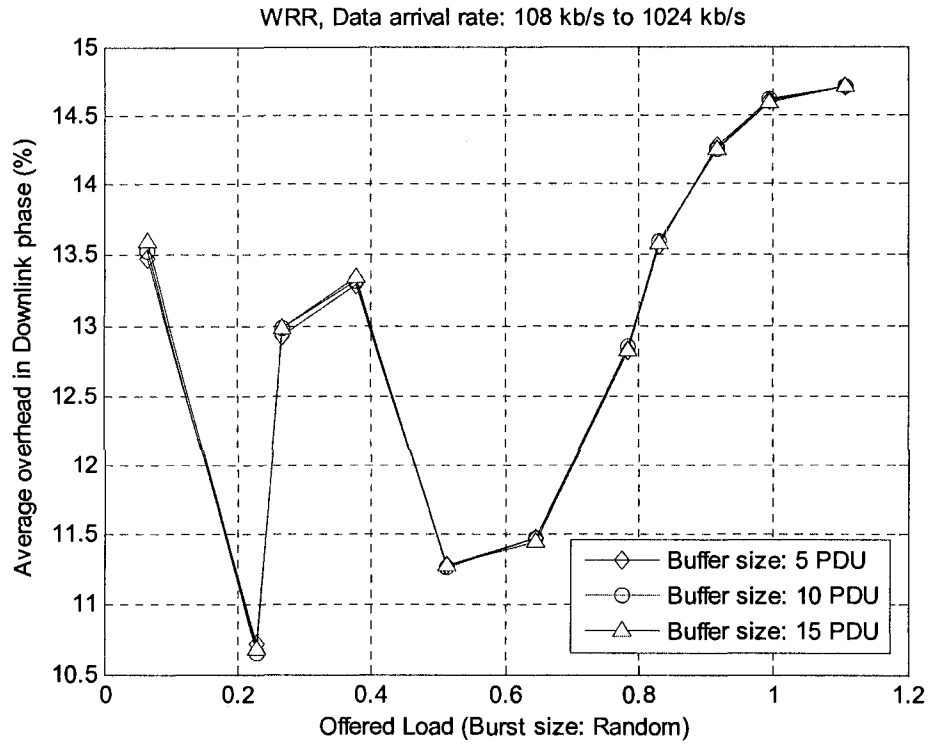


Figure 5.90. Average overhead in downlink phase vs offered load for WRR scheme at random burst.

Variance in overhead of downlink phase is shown in fig. 5.91, 5.92 and 5.93 as a function of offered load for the three resource allocation schemes and the figures represent the results when the buffer size is 5, 10 and 15 PDUs respectively. In the figures we noticed that change in variance corresponds to the change in curves of fig. 5.85 – 5.90.

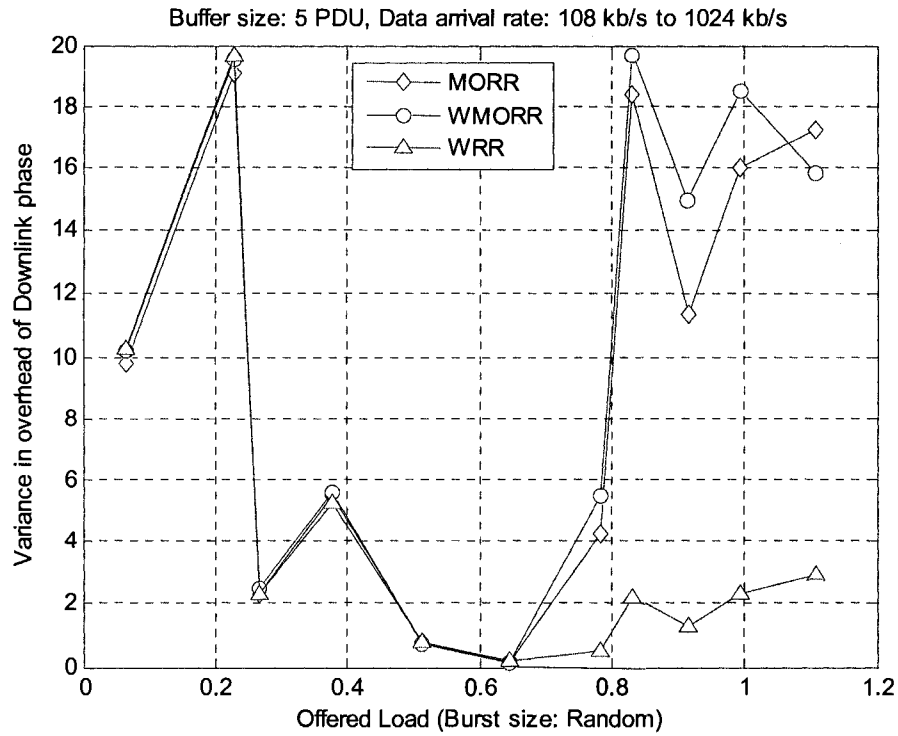


Figure 5.91. Variance in overhead of downlink phase vs offered load for buffer size 5 at random burst.

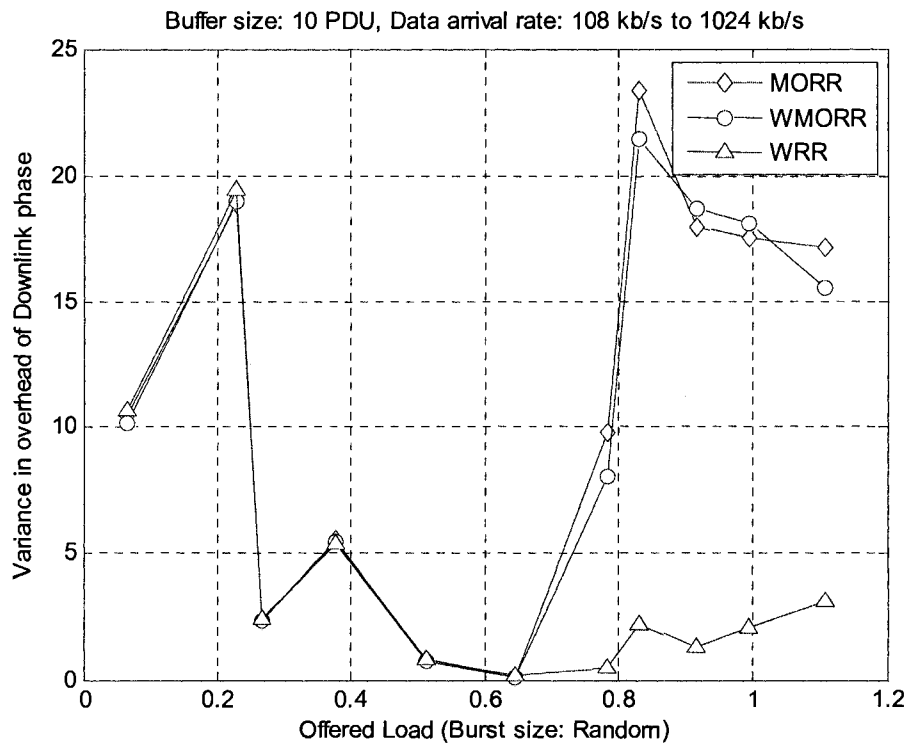


Figure 5.92. Variance in overhead of downlink phase vs offered load for buffer size 10 at random burst.

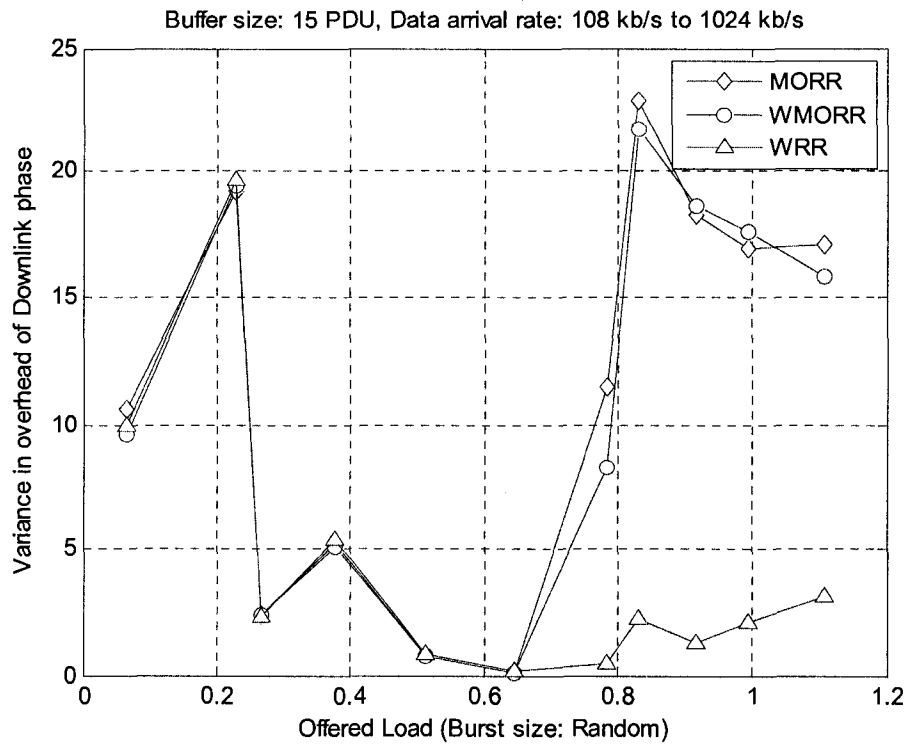


Figure 5.93. Variance in overhead of downlink phase vs offered load for buffer size 5 at random burst.

Chapter 6: Conclusion

In this thesis we have simulated a large private WLAN to provide service in a metropolitan area. Our system is cellular in type and we have distributed the users randomly inside each cell. We have considered mobile users with dynamic transmission rates. We have proposed three resource allocation policies to distribute system resource among the users. To measure the performance we have generated a generic simulation program and run a large number of iterations using some realistic assumptions to make our system simple.

We have measured the performance of the system where we used buffer occupancy, probability of buffer overflow, average packet delivery time, overhead in uplink and in downlink phase as performance criteria. From the results we have found that the WRR policy makes lower PDU delivery time for some instance but it has highest overflow, overhead and buffer occupancy. But the WMORR scheme shows lowest buffer occupancy, overhead, overflow and moderate PDU delivery time. Another important thing is that in the WMORR scheme the system is operable at load higher than the WRR scheme. The WMORR also yields the lowest buffer occupancy, an important feature in case of receiving large bursts. So we can conclude that WMORR has the best performance among the three resource allocation policies. These results are also applicable to other high performance TDMA/TDD system such as WiMAX.

6.1. Major Contributions

The major contributions of this thesis are as follows:

- Design of infrastructure multi-clustered private WLAN for urban area.
- Determine physical layer data rate of users depending on distance from Access Point.
- Setting up new rules for resource allocation.
- Evaluating the useful operating region of the network.
- Performance study of HiperLAN/2 and resource allocation schemes.

6.2. Suggested Future Work

We suggest the following for future research work:

- For simplification we made assumption that mobile terminal cannot move from its associated access-point. In practice it happens and it can be studied in future.
- Serving a mobile node outside the service area of the Access Point using a gratuitous node can be an interesting point to discover in future and resource allocation for this node can be challenging.
- In this thesis we considered best effort packet delivery for simplicity but in the HiperLAN/2 standard packet delivery with ARQ is also supported, which can be an interesting topic for future research.
- We considered the case where no packet loss in between AP and CC. But as the link is wireless, packet loss may occur and this can be also included for future study.

- The effect of other networks in the same service area can also be considered.

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