Simulation and Emulation Approach for the Performance Evaluation of Adaptive Modulation and Coding Scheme in Mobile WiMAX Network

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ABSTRACT

WiMAX is the IEEE 802.16e standard-based wireless technology, provides Broadband Wireless Access (BWA) for Metropolitan Area Networks (MAN). Being the wireless channels are precious and limited, adapting the appropriate modulation and coding scheme (MCS) for the state of the radio channel leads to an optimal average data rate. The standard supports adaptive modulation and coding (AMC) on the basis of signal to interference noise ratio (SINR) condition of the radio link. This paper made an attempt to study the performance of AMC scheme in Mobile WiMAX network using simulation and emulation methods. Different MCS are adopted by mobile subscriber station (MSS) on the basis of the detected instantaneous SINR. Simulation results demonstrate the impact of modulation and coding scheme on the performance of the system and emulation results defend the simulation results.

General Terms

Performance evaluation, WiMAX features, Adaptive modulation and coding schemes.

Keywords

AMC, Modulation and coding schemes, Signal to noise ratio, Simulation and Emulation, WiMAX.

1. INTRODUCTION

Among the upcoming broadband wireless technologies Worldwide Interoperability for Microwave Access (WiMAX) is a promising technology which offers high-speed data services. Mobile WiMAX is the acronym for IEEE802.16e standard, which defines the Air Interface for mobile Broadband Wireless Access (BWA) systems by incorporating seamless handover while maintaining differentiated Quality of Service (QoS) [1-2]. Mobile WiMAX is outfitted with novel technological tools, such as orthogonal frequency division multiple access (OFDMA), time division duplexing (TDD), multi-input multi-output (MIMO), adaptive modulation and coding (AMC), Internet protocol (IP), security and others, which are combined together to offer high data-rate, low-cost, wide-area, secured mobile multimedia services[3].

By introducing Scalable OFDMA (SOFDMA) at PHY architecture, Mobile WiMAX is able to support scalable channel bandwidths of wide range. The scalability is implemented by varying the FFT size 128, 512, 1024 and 2048 to support channel bandwidths of 1.25 MHz, 5 MHz, 10 MHz and 20 MHz respectively [4].

Since radio resources are scarce and wireless channels are unreliable [5], AMC has become optimal approach in recently developed wireless standards, including WiMAX [6]. AMC technique follows the principle that when channel conditions are good, *i.e.*, for a good signal to interference noise ratio (SINR), higher order modulation and coding scheme (MCS) is adapted which improves the data rates over the channel. For degraded channel quality, lower order MCS is adapted. However, the channel is not used when the instantaneous SINR falls below the threshold value [5]. This enables a robust and spectrally efficient transmission over time-varying fading channels: it brings in higher throughput when the channel is in good state and brings in reliable communications when the channel suffers from deep fading [3].

The network simulator can virtually evaluate the behaviour of a network and test combinations of network features that are likely to work. Basically, a network simulator duplicates the behaviour of a real network, but cannot interact with real networks. A simulator uses lower quality reproduction or abstraction of the real system and focuses on simply replicating the real network's behaviour. A network simulation is a very low cost method for developing the early stages of network centric systems. On the other hand, a network emulator imitates the functions of a real network so that it appears, interacts and behaves like the real network. The emulator provides an exact, high quality reproduction of external behaviour so that the emulated system is indistinguishable from the real system. An emulator provides a cost-effective method of evaluating new network technologies before actual systems or networks are built. Network emulation helps in developing a net-centric system by providing an environment in which design decisions can be easily changed and their impact evaluated. Customers of the net-centric system can use the emulated network and see how their applications (such as VoIP, situation awareness, sensor data and streaming video) will perform when the real system is built. This also sets realistic expectations of the communication network, i.e., it provides predictability [7]. In this paper performance of AMC scheme in Mobile WiMAX network is evaluated using simulation and emulation methods.

The rest of the paper is organized as follows: Section 2 outlines the related work in the literature. Section 3 gives an overview of WiMAX and section 4 explains the AMC technique in WiMAX. Section 5 and 6 consolidate the simulation and emulation results respectively, followed by conclusion in section 7.

2. RELATED WORK

The related work in this area is discussed below; authors of [8] studied the impact of AMC on the capacity of the downlink in WiMAX system in the presence of streaming and elastic types of traffic. In [9] authors studied the transition thresholds for ARQ and HARQ retransmission by considering a link adaptation model. H. Kim et.al, [10] have proposed band AMC algorithm with dynamic band selection which is controlled by wireless channel conditions. Authors of [11] evaluated the throughput performance of an OFDM WiMAX with AMC by outdoor measurements. In paper [12], authors studied the effects of MCS on throughput performances of TCP. C Tarhini et.al [13] proposed an AMC-aware QoS proposal that compensates the degradation in modulation to maintain the bit rate of streaming flows at a constant level throughout the whole coverage area. Authors of [14] evaluated the impact of AMC on the performance of adaptive and non-adaptive admission control. In [15] authors proposed an uplink bandwidth allocation algorithm based on AMC to guarantee the delay requirement and full link utilization. L. Zhang et.al [16] proposed a cross layer based modulation adaptation mechanism which incorporates the use of adaptive erasure code with the physical layer information to significantly improve the goodput and transmission efficiency. A latency and modulation aware bandwidth allocation algorithm is proposed in [17] for WiMAX base stations (BS), which considers the AMC, uplink and downlink traffic volume and QoS parameters. In [18-20], performance of WiMAX physical layer is evaluated for AMC techniques. In [18] the authors considered communication channels and fading channels along with AMC. In [19-20] cyclic prefix are considered.

3. AN OVERVIEW OF WiMAX

The WiMAX standard includes MAC and PHY layer specifications and it is designed to achieve goals like easy deployment, high speed data rate, large spanning area and large frequency spectrum. PHY layer uses AMC technique combined with OFDMA to produce variable data rates to support variable channel conditions. A typical 802.16 network consists of a BS and a number of subscriber stations (SS) which communicate with the BS. Communication can happen in two modes: Point to Multi Point (PMP) mode and mesh mode. In mesh mode, SSs can communicate with each other without the need of BS. In PMP mode, the BS schedules the traffic flow for SSs and SSs do not communicate directly. The communication path between SS and BS has two directions: uplink (UL: SS to BS) and downlink (DL: BS to SS), multiplexed either with TDD or frequency division duplex (FDD). The DL channel is in broadcast mode and UL channel is shared by various SS's through time division multiple access (TDMA) manner.

In PMP mode with TDD, each TDD frame is divided into a DL subframe and an UL subframe, the duration and the number of subframe slots is determined by the BS scheduler. Each frame contains DL-MAP and UL-MAP, DL map contains information about the duration of subframes and which time slot belongs to a particular SS as the DL channel and UL map consists of information element (IE) which includes transmission opportunities, based on the bandwidth requests made by each SS. SS uses bandwidth request mechanisms to specify uplink bandwidth requirement to the BS. The BS will grant the bandwidth to SS in Grant per subscriber station (GPSS) mode as it reduces the requesting and granting overhead of the BS and a SS when there are multiple connections at SS. After getting grant from BS, a SS should manage and redistribute the bandwidth among its connections according to the QoS requirements. Transmission parameters, including the modulation parameters and coding schemes, may be adjusted individually for each SS on a frame-by-frame basis [1-2].

The MAC layer is connection oriented i.e. all data communications, for both transport and control, are in the context of a unidirectional connection. Each packet has to be associated with a connection at MAC level. Each connection is assigned a unique Connection ID (CID) and a Service Flow ID (SFID) with an associated service class. The MSS/SS cannot transmit data until it has been allocated a channel by the BS. This provides a way for bandwidth request, association of QoS and other traffic parameters and data transfer related actions. This allows 802.16e to provide strong support for QoS. QoS in 802.16e is supported by allocating each connection (service flow) between the SS and the BS to a specific service type. In 802.16e, there are five distinguished service types have been defined by the standard to handle different multimedia traffic, which are designed to support stringent QoS requirements.

a. Unsolicited grant service (UGS) is intended to support the real time data like voice over IP (VoIP) without silence suppression, T1/E1. This scheduling type has the highest priority and usually constant bit rate (CBR) data is mapped on UGS, BS allocates fixed size data grants without receiving explicit requests from a requesting entity. Grant is based on the maximum sustained data rate of the connection.

b. Extended real time polling service (ertPS) is designed for real time data, such as VoIP with silence suppression. Variable bite rate (VBR) data is mapped on this scheduling service, which is treated in the same manner as UGS. Bandwidth grant can be negotiated on the basis of maximum and minimum sustained data rate of a connection.

c. Real time polling service (rtPS) is meant for VBR real time data like MPEG video data. In this scheduling service requesting entities send a non contention based unicast request periodically and BS allocates a dedicated grant to the requesting stations. All the above services are real time services and hence are delay intolerant.

d. Non real time polling service (nrtPS) is designed to support VBR non real time services like file transfer protocol (FTP). In this service also SS send a contention based unicast request and receives grant at longer intervals. This service is delay tolerant but requires being throughput optimal.

e. Best effort service (BE) is intended for the lowest priority non real time traffic like internet HTTP traffic, which does not require any QoS guarantee for its connection.

4. ADAPTIVE MODULATION AND CODING SCHEME

Adaptive modulation and coding enables robust and spectrally efficient transmission over time-varying channels. The basic premise is to estimate the channel at the receiver and feed this estimate back to the transmitter, so that the transmission scheme can be adapted relative to the channel characteristics. Adapting to the channel fading can increase average throughput, reduce required transmit power or reduce average probability of bit error by taking advantage of favorable channel conditions to send at higher data rates or lower power and by reducing the data rate or increasing power as the channel degrades. AMC technique adjusts the transmission rate by changing the MCS adaptively according to the state of the fading channel.

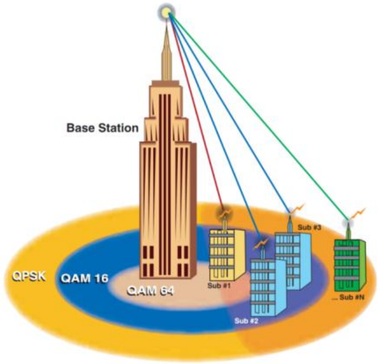

Fig.1 Illustration of Adaptive Modulation and Coding

In order to strengthen the robustness of communications in the mobile wireless environment, channel coding techniques may be employed in conjunction with the modulation techniques. The modulation schemes used in 802.16 are (from high to low modulation order): 64-QAM, 16-QAM, QPSK and BPSK. A higher order modulation scheme can deliver higher throughput. The modulation order can be based on the distance from BS to SS. AMC dynamically changes the modulation and coding techniques depending on the channel status. When the channel condition is good, it selects a high-efficiency modulation (i.e., 64-QAM) and less heavy channel coding technique, but when the channel condition is poor it selects a low-efficiency modulation (i.e., BPSK or QPSK) and heavy channel coding technique to increase the robustness. Fig 1 gives the illustration of AMC. Based on channel measurements at the physical layer, SS adapts the interval usage code (IUC) which defines modulation, rate and forward error correction (FEC) scheme, for both downlink (DIUC) and uplink (UIUC) transmissions. For DL channel quality the SS calculates the SINR and sends this information to BS through channel quality feedback indicator. For the uplink, the BS estimates the channel quality, based on the received signal quality.

For an effective operation of AMC, each MSS reports its channel status to the BS, which is mainly done in terms of SINR or *carrier-to-interference ratio* (CIR or C/I). On receiving this channel status report, the BS decides which modulation and coding techniques to use. Therefore, the AMC technique inherently requires a channel estimation process at the receiver and a mechanism to feed the estimated channel condition back to the transmitter. The CIR value increases as the MSS moves close to the BS and decreases as it moves away from it, so the CIR value becomes small when the MSS approaches the cell boundary. MSS periodically reports such channel status information to the BS through the *channel quality indicator* (CQI) channel, so that the BS can change the MCS dynamically to the most appropriate ones. By taking such adaptive operation, the Mobile WiMAX system can maintain the transmission capacity at a maximum level. Table 1 illustrates the MCS set and the corresponding data rates for the Mobile WiMAX (10 MHz)/WiBro (8.75 MHz) system. Here SINR Threshold describes the minimum required SINR for each MCS level [1].

Table 1: Modulation and coding schemes [21]

Modulation Scheme	Encoding Rate	Number of symbols	Data Rate (Mbps)	SINR Threshold (dB)
QPSK	1/2	2	14.2875	5.6
QPSK	3/4	2	21.4285	9
16QAM	1/2	4	28.5714	11.48
16QAM	3/4	4	42.8570	15
64QAM	1/2	4	42.8570	17.02
64QAM	2/3	6	57.1428	19
64QAM	3/4	6	64.2857	21

5. SIMULATION AND RESULTS

An extensive simulation work is performed to study the QoS Performance of WiMAX network for different service types under different MCS. The simulation tool used for performance evaluation is Qualnet 5.0.2 [21]. A single WiMAX cell is considered in the simulation area of 4Km x 4Km, working at a frequency 2.4 GHz. The pathloss model selected is two-ray with constant shadowing model of shadowing mean of 4dB. The simulation parameters settings are mentioned in Table 2.

Table 2. Simulation parameters

Property	Value
Simulation time	100 Sec
Channel bandwidth	20 MHz
FFT size	2048
Antenna model	Omni directional
BS antenna gain	10 dB
SS antenna gain	0 dB
BS antenna height	12 m
SS antenna height	1.5 m

5.1. Scenario 1

This scenario is designed to evaluate the QoS performance of different services types under different MCS, which consists of single BS and two SSs. Both SS transmit 5 CBR traffic flows (UGS, ertPS, rtPS, nrtPS and BE connections of one each) of 4Mbps data rate each, to other SS. Initially the simulation is carried out by placing both the SSs at the region where the MCS adapted is 64QAM ¾. In the same way the series of simulation study is carried out by placing the SSs in 64QAM 2/3, 64QAM ½, 16QAM 3/4, 16QAM ½, QPSK ¾ and QPSK ½ regions. The QoS metrics considered here are throughput and delay.

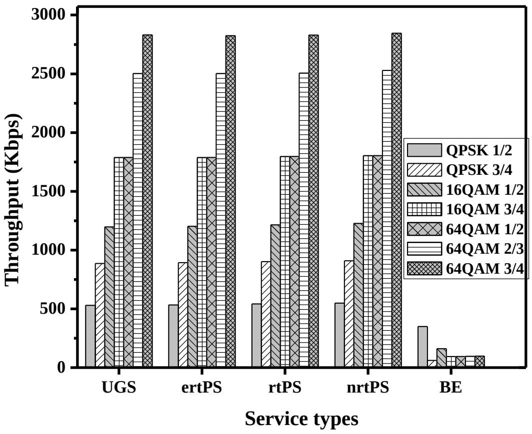

Fig.2 Throughput performances of connections of different service types for various MCS

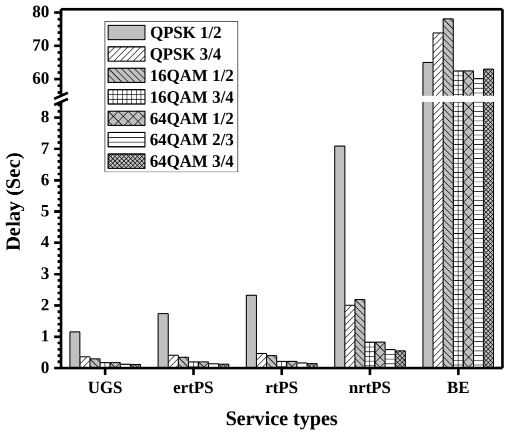

Fig.3 Delay performances of connections of different service types for various MCS

Fig 2 gives the throughput performance of the different service types under different MCS. It can be observed that, throughput performance of all service types except BE increases as the MCS is changed from low modulation and high coding scheme (QPSK 1/2) to high modulation and low coding scheme (64QAM 3/4). The throughputs of 16QAM 3/4 and 64QAM 1/2 are same as they offers same raw data rate (table 1). The throughput of BE is less compared to other service types as it has least priority.

Fig 3 gives the delay performance for different service types for different MCS. It can be seen that, the delay performance of UGS is better compared to other service types, as it has highest priority. The delay performance of service types deteriorates as the priority decreases. In QPSK ½ region delay of all service types is higher compared to other MCS and 64QAM ¾ offers very low delay.

5.2. Scenario 2

In this scenario the simulation design of scenario 1 is retained and instead of keeping the data rate constant as in scenario 1, the data rate of each connection is varied from 200Kbps to 2Mbps in steps of 200Kbps. The simulation study is repeated by placing the SSs in different MCS regions as in scenario 1 and also by varying data rate. Average throughput and average end to end delay are considered as performance metrics.

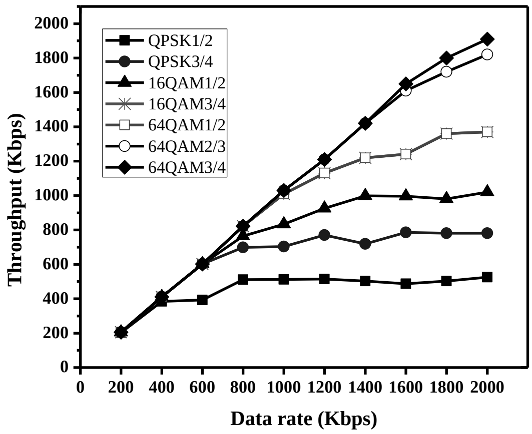

Fig.4 Throughput performances of connections for varying data rate

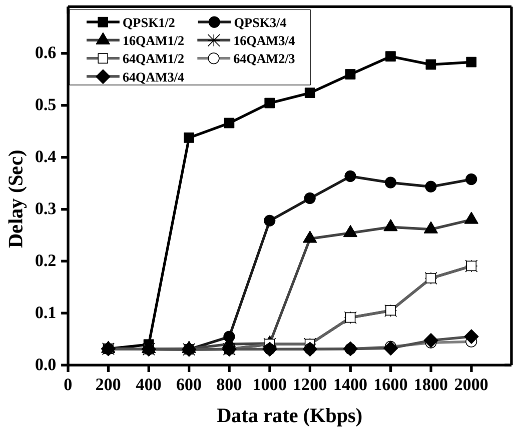

Fig.5 Delay performances of connections for varying data rate

The throughput performance for varying data rate is shown in fig 4. As the data rate increases, the throughput increases for all the MCS. It is observed that the throughput offered by 64QAM 3/4 is more compared to other MCS and QPSK 1/2 offers least throughput. This is because the total data rate offered by WiMAX network depends on MCS used and as order of MCS increases the total data rate increases (table 1). The delay performance for varying data rate is given in fig 5. The delay of QPSK 1/2 is higher compared to other MCS and 64QAM 2/3 and 64QAM 3/4 offers least delay.

5.3. Scenario 3

In this scenario the simulation design of scenario 1 is retained and in contrast to scenario 1, in this scenario only one SS transmits 10 traffic flows in which 5 flows are mapped as real time services (RTS) and other 5 flows are mapped as non-real time services (NRTS) to other SS. Instead of making SSs stationary as in scenario 1, in this scenario Random way point mobility is given to the transmitting SS with the speed of 20m/s. The data rate of each connection is varied from 1Mbps to 6Mbps in steps of 1Mbps. The AMC technique is implemented in WiMAX to overcome the fading effects of the channels, urban and free space environments are considered here to study the effect of fading on the performance of the network. Rayleigh fading model is considered for urban environment. Simulation study is carried out for urban and free space environments for varying data rate and results are obtained for average throughput and average end to end delay.

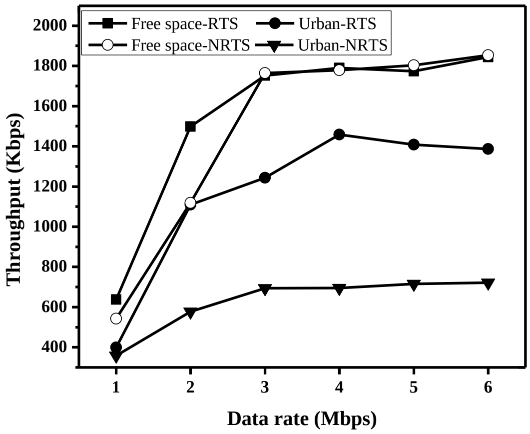

Fig.6 Throughput performances for varying data rate

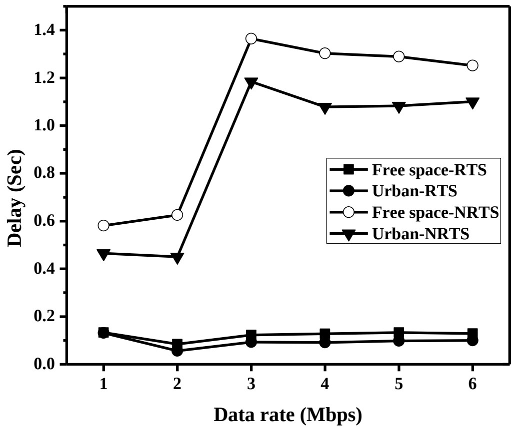

Fig.7 Delay performances for varying data rate

Fig 6 gives the throughput performance for varying data rate in urban and free space environments. The throughput performance in free space environment for both RTS and NRTS is good compared to urban environment. In the urban environment fading channel effect is very high due to obstacles; the throughput performance in urban environment deteriorates compared to free space. The throughput of RTS is more compared to NRTS in both urban and free space environments, as the RTS has higher priority than NRTS.

The delay performance for varying data rate is shown in Fig 7. Delay of RTS is less compared to NRTS in both urban and free space environments. It is observed that delay performance of RTS in free space environment is good compared to urban environment.

5.4. Scenario 4

In this scenario the simulation design of scenario 3 is retained and instead of varying data rate, the data rate of each connection is kept constant at 4Mbps. Speed of transmitting SS is varied from 10m/s to 40m/s in steps of 5m/s and simulation study is carried out for both urban and free space environments.

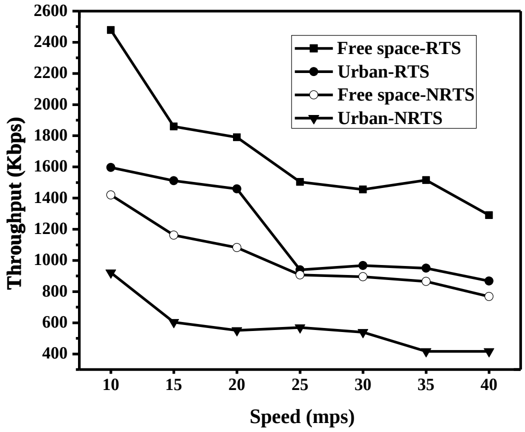

Fig.8 Through performances for varying speed

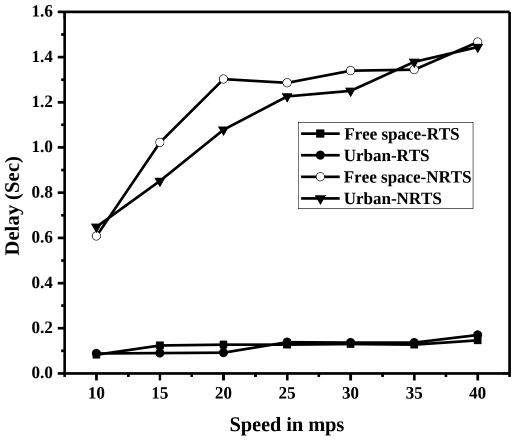

Fig.9 Delay performances for varying speed

Fig 8 gives the throughput performance for varying speed in urban and free space environments. As the speed increases, the throughput performance of both RTS and NRTS decreases for both free space and urban environment. This is due to fast variation of the channel for high mobility. The throughput performance deteriorates in urban environment for both RTS and NRTS compared to free space environment, as in the urban environment fading channel effect is very high. The delay performance for varying speed is shown in Fig 9. As the speed increases, the delay of NRTS increases for both free space and urban environment. The delay of RTS is not affected even with increase in speed, since RTS connections have higher priority. Delay of RTS is less compared to NRTS in both urban and free space environments.

6. EMULATION AND RESULTS

The Emulation test bed has been set up using EXata 2.0.1 tool. A single WiMAX cell scenario consists of a BS and two SSs is considered. One SS is configured as transmitter and another as receiver. The transmitter SS is configured to send a video streaming application and ftp application to other SS.

The video codec rate is 1024Kbps and audio codec rate is 192Kbps.

6.1 Scenario 1

This scenario is designed to evaluate the QoS performance of real time video service under different MCS through emulation. Initially the emulation is carried out by placing both the SSs at the region where the MCS adapted is 64QAM ¾. In the same way the series of emulation study is carried out by placing the SSs in 64QAM 2/3, 64QAM ½, 16QAM 3/4, 16QAM ½, QPSK ¾ and QPSK ½ regions. The QoS metric considered here is packet delivery ratio.

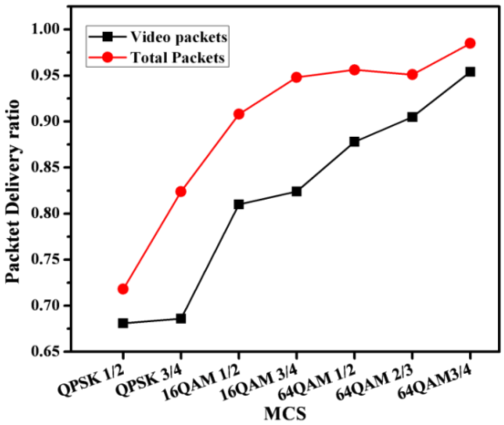

Fig. 10 Packet delivery ratio for different MCS

Fig 10 gives the packet delivery ratio performance of the real time video service under different MCS. It can be observed that, as the MCS is changed from low modulation and high coding scheme (QPSK 1/2) to high modulation and low coding scheme (64QAM 3/4) the packet delivery ratio increases. It is evident from the graph that the packet delivery ratio for real time applications will significantly improved by adopting the MCS in a cell region.

6.2 Scenario 2

The scenario 1 architecture is been retained here and in addition the SSs are assigned with random mobility, in which the SS can move randomly in considered geographical area.

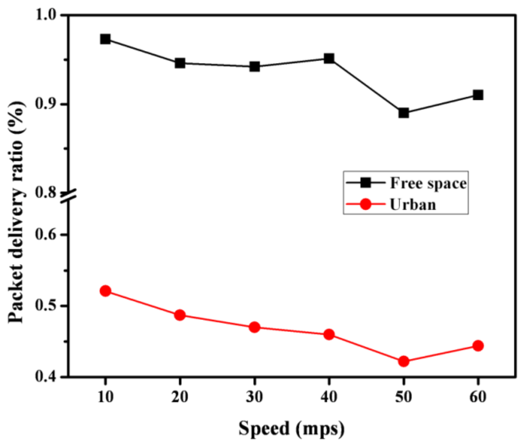

Fig. 11 Packet delivery ratio for different MCS

With these settings the packet delivery ratio has been studied for free space and urban terrain environments by assigning specified speeds for the SS. Speed of transmitting SS is varied from 10m/s to 60m/s in steps of 10m/s and emulation study is carried out for both urban and free space environments. Fig 11 gives the packet delivery ratio performance of the real time video service for varying speed in urban and free space environments. As the speed increases, the packet delivery ratio decreases for both free space and urban environment. This is due to fast variation of the channel for high mobility. The packet delivery ratio performance in free space environment is good compared to urban environment, as in the urban environment fading channel effect is very high.

6.3 MCS for varying data rate

In this scenario the simulation design of scenario 1 is retained and instead of keeping the data rate constant as in scenario 1, in this scenario the data rate of video streaming application is varied as 192bps, 512bps and 1024bps. The emulation study is carried out by placing the SSs in different MCS regions as in scenario 1 and also by varying data rate. Number of packets received is considered as a performance metric.

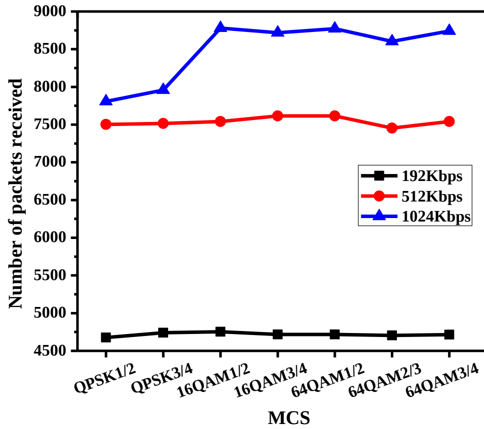

Fig. 12 Packet delivery at different transmission rate for different MCS

Fig 12 gives the Number of packets received for varying data rate. It is observed that for higher data rate services AMC will definitely improves the QOS of the application, rather than lower bit rate application.

7. CONCLUSIONS

The adaptive modulation and coding is a powerful tool in WiMAX technology. Depending on the instantaneous SINR value of SS, the BS will select the appropriate modulation and coding scheme. The performance of AMC for the WiMAX has been thoroughly studied using simulation and emulation tools. The simulation and emulation based approach are the efficient methods for evaluating the performance of a communication network. The emulation studies reveal the real network performance and support the simulation based results. From the graphs it is apparent that AMC will improve the throughput and robust connectivity in communication channel, especially for high data rate networks.

8. ACKNOWLEDGMENTS

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