INTERNATIONAL JOURNAL OF COMMUNICATION SYSTEMS
Int. J. Commun. Syst. 2011; **24**:1087–1104
Published online 30 January 2011 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/dac.1217

Performance study of mobile WiMAX network with changing scenarios under different modulation and coding

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SUMMARY

WiMAX—the Worldwide Interoperability for Microwave Access is a promising technology for offering high-speed data, video and multimedia services over mobile platform evolving toward all IP networks. The increasing demand of WiMAX for VoIP and high-speed multimedia is due to the simplicity of installation and cost reduction compared with the traditional wired DSL cable. The challenges to service providers lie with the Quality of Service (QoS) under varying fading environment while at the same time maximizing for resource utilization. In this paper, a rigorous and comprehensive performance study of mobile WiMAX has been made with respect to adaptive modulation and coding techniques considering the variation in the speed of the mobile, path-loss, scheduling services and application type for comparing with the fixed type of modulations. The OPNET 14.5.A modeler for WiMAX platform has been used as simulator for adaptation at the physical layer of the transmission in WiMAX OFDMA structure. Observation reveals that dynamic adaptation of modulation and coding schemes based on channel condition enables better QoS while consuming low overall bandwidth of the system.

Received 5 August 2010; Accepted 2 November 2010

KEY WORDS: mobile WiMAX; adaptive modulation and coding; performance study; quality of service

1. INTRODUCTION

Conventional high-speed broadband solutions are based on wired digital subscriber line (DSL). This type of a solution is not suitable in remote places and also mobility of the users is not supported due to wired connection. High data rate services, such as multimedia applications, for mobile users are increasing. However, low-cost solutions for such application are preferable in light of the existing cable solution. The IEEE 802.16 family of standards [1–3] supported by WiMAX commercial consortium is the outcome of continuous research in wireless communication to address the problem of broadband wireless access (BWA). It specifies the physical (PHY) and medium access control (MAC) layers for BWA communication protocol. The IEEE 802.16/WiMAX is a promising technology for broadband wireless metropolitan area networks (WMANs). WiMAX supports both packet-oriented data transmission and standard mobile telephony over a large coverage with better performance particularly in terms of throughput than traditional wireless communication standards especially for applications that require high and stable throughput. It can be used to deliver backhaul services, enterprise campus and Wi-Fi (local area) hot-spots. The original WiMAX was meant for fixed and nomadic users and reviewed to address the mobility in the IEEE 802.16e standard, known as mobile WiMAX [2]. Very soon it became a competitor to 3G cellular communication systems

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for delivering high-speed data applications [4]. Owing to its ease of deployment and integration with other existing networks, mobile WiMAX will evolve toward the all-IP networks for BWA. The WiMAX PHY layer is based on orthogonal frequency division multiplexing (OFDM). OFDM is the transmission technology to enable high-speed data, video and multimedia communications and is used by a variety of commercial broadband system including DSL and Wi-Fi, besides WiMAX. OFDM is also an efficient technique for high-rate data transmission in a non-line-of sight (NLOS) or multi-path radio environment [5]. It can mitigate the adverse effects of frequency selective multi-path fading and efficiently can contrast the inter-symbol and inter-carrier interferences. The multi-carrier nature of OFDM transmission is helpful in adaptation of modulation and coding technique for improved bit error rate and throughput. This adaptation is fully based on the dynamic channel condition in a fading environment. The PHY features of IEEE 802.16e include scalable orthogonal frequency division multiple access (OFDMA) to carry data supporting channel bandwidth (BW) between 1.25 and 20 MHz with up to 2048 sub-carriers [2].

In wireless communication, the nodes with high mobility experience random fluctuation of received signal due to different fading that occurred in the multi-path propagation. Adaptive modulation and coding (AMC) allows the WiMAX system to select the most appropriate modulation and coding scheme (MCS) depending on the communication channel condition. For example for high data rate transmission, a higher order modulation scheme with low coding redundancy is required in good propagation condition; on the contrary in a fading environment, a modulation scheme and coding of lower order are needed to maintain the quality of link connection without increasing the signal power. Variation in the modulation scheme leads to change in the amount of data transferred through a single channel. To enhance the throughput, therefore AMC has become a standard approach in the WiMAX PHY layer [6, 7]. The performance of WiMAX systems is sensible to the speed of the subscriber station (SS) [8] as the channel condition in terms of attenuation change with respect to speed. Here lies the requirement of adaptation techniques. Again the performance is also varied in different path-loss condition in contrast to free space path-loss model in an idealistic situation. With the larger number of consumers of QoS-enabled high data rate services, it is required to have knowledge of performance parameters over mobile WiMAX networks under fixed type of modulation and coding along with the adaptation to select the best combination. Recently, there have been some works based on performance studies on mobile WiMAX. In [6], capacity study of OFDM-based WiMAX is done considering AMC and Inter Cell interference, while Shuaib [8] examines the performance with changing PHY layer parameters under single cell environment. In paper [9], efficient AMC techniques for WiMAX OFDMA are given. Two techniques have been proposed by taking channel behaviors into consideration in terms of user's mobility. The first technique keeps the error rate within a limit and then employs suitable MCS. The second method aims to maximize the system throughput with MCS among the available ones for each signal to interference and noise ratio (SINR). Both techniques are advantageous over fixed type of modulation and coding. Paper [7] provides performance evolution of WiMAX PHY layer under AMC and channels with different types, such as AWGN, Rayleigh and Rician. The effect of the forward error correction on different channels is evaluated in terms of BER.

In the present paper, an in-depth performance evaluation for mobile WiMAX is carried out using adaptive modulation and coding under the real-like simulation environment of OPNET [10]. OPNET provides the comprehensive development of network models including all the necessary parameters that need to be reflected in the design procedure of PHY and/or MAC layers. Series of simulation scenarios under OPNET 14.5.A PL8 for broadband wireless communication are developed. The different types of data services with QoS requirements that are supported by mobile WiMAX are suitably configured in the OPNET for performance evaluation. We have evaluated the performance parameters for mean opinion score (MOS), upload data burst usage, data dropped, throughput etc. by varying the speed of the mobile nodes and also using different path-loss models under both AMC and fixed types of modulation techniques.

The remainder of the paper is organized as follows. Section 2 provides the relevant background behind this work. In Section 3, the simulation environment is described in brief. The details of simulation scenarios for mobile WiMAX networks performance measurement along with the observation of the outcome have been described in Section 4. Finally, Section 5 concludes the paper.

DOI: 10.1002/dac

2. BACKGROUND LITERATURE

Depending on the channel conditions, WiMAX supports a variety of MCSs and allows for the schemes to change on a burst-by-burst basis per link. Using the channel-quality feedback indicator (CFI), the mobile can provide the base station with feedback on the down-link (DL) channel quality. For the up-link (UL), the base station can estimate the channel quality, based on the received signal quality. In the DL, BPSK, QPSK, 16-QAM and 64-QAM are mandatory for both fixed and mobile WiMAX; 64-QAM is optional in the UL. These modulation techniques can be used in the PHY layer design [2]. WiMAX PHY uses AMC that takes into account the channel SINR to dynamically select the proper modulation technique appropriate for that channel condition to deliver the maximum throughput. Serial to parallel conversion of the incoming bit becomes the critical set of operation that determines the parallel transmission of data bits. OFDM modulation being the key multiplexing technique in WiMAX helps the transmission of data bits at a very high rate with a negligible amount of inter symbol interference (ISI) with minimal amount of packet loss and bit error. The data transmitted through wireless channel reach the receiver. The channel that might be additive Gaussian White noise (AWGN), Rayleigh or Rician, determines the effective channel impairment introduced in the receiver. The receiver section does exactly the opposite to the transmitter.

IEEE 802.16 uses an outer Reed–Solomon (RS) block code concatenated with an inner convolutional code (CC). If the input to CC is k bits/s and the output is n bits/s, the rate of coding is k/n, which has the value equal to $\frac{1}{2}$, $\frac{2}{3}$ and $\frac{3}{4}$ in general. Constraint length m, similar to the memory in the system, can be depicted as preceding k bits used in the encoding process. Table I gives the peak UL and DL data rates for mobile WiMAX with different information bits/symbol [1]. In our case, we have studied the performance under mobile WiMAX scenario in OPNET simulator for QPSK and QAM with different coding rates. BPSK has been excluded from our discussion since OPNET does not support the specific coding. Changes are made in OPNET to achieve proper modulation for evaluation purpose.

Communication systems have two main resources such as transmission power and channel BW. Adaptive modulation allows the WiMAX system to adjust the signal modulation scheme depending on the SINR condition of the radio link. When the radio link is high in quality, the highest modulation scheme is used to increase the system capacity. During a signal fading, the WiMAX system can shift to a lower modulation scheme to maintain the connection quality and link stability. Bit rate determines the channel BW efficiency. If two or more bits are combined, the signaling rate would reduce. Accordingly, the frequency of the carrier is reduced as well. The channel BW reduces with the reduction in frequency of the carrier. This specific scheme of two successive bits grouped together to form a data sequence in order to reduce the BW of channel is called as quadrature phase shift keying (QPSK). The combination of two bits forms four distinct symbols. When the symbol is changed to the next symbol, 45° ($\pi/4$ radian) phase shift occurs [11]. Signal compression can be avoided if the linear region of a power amplifier is selected as the point of operation. Quadrature amplitude modulation (QAM) fits exactly to this requirement. For this reason as far as QAM signaling scheme is concerned, the waveform designers critically examine the power efficiency for the total channel BW. For M-array-QAM ($M=4$, 16, 64), the

Table I. Mobile WiMAX PHY data rates for 5 MHz channel.

Modulation scheme	Information bits/symbol	Down-link rate (Mbps)	Up-link rate (Mbps)
QPSK-1/2	1	3.17	2.28
QPSK-3/4	1.5	4.75	3.43
16-QAM-1/2	2	6.34	4.57
16-QAM-3/4	3	9.50	6.85
64-QAM-1/2	3	9.50	6.85
64-QAM-2/3	4	12.6	9.14
64-QAM-3/4	4.5	14.26	10.28

DOI: 10.1002/dac

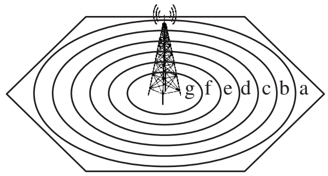

Figure 1. Annuls area that can be served by different modulation schemes.

Table II. AMC profile selected for simulation.

	AMC-1		AMC-2	
Modulation and coding	Mandatory exit threshold (dB)	Minimum entry threshold (dB)	Mandatory exit threshold (dB)	Minimum entry threshold (dB)
QPSK 1/2	−20	2.0	−20	2.0
QPSK 3/4	5.0	5.9	11	11.9
16QAM 1/2	8.0	8.9	14	14.9
16QAM 3/4	11	11.9	17	17.9
64QAM 1/2	14	14.9	20	20.9
64QAM 2/3	17	17.9	23	23.9
64QAM 3/4	19	19.9	25	25.9

number of grouped bits varies from 2, 4 and 6, respectively. The 64-QAM has a higher data rate compared with 16-QAM. However, outside interference or imperfections such as phase noise, I/Q (Inphase/Quadrature) imbalance, etc. have an adverse effect on QAM [12]. Figure 1 shows the different modulation schemes used depending on the location of the mobile from the WiMAX base station. The key feature of adaptive modulation is that it increases the range over which a higher modulation scheme can be used, since the system can flex to the actual fading conditions, as opposed to having a fixed scheme that is budgeted for the worst case conditions [5].

Two sets of AMC schemes, AMC-1 and AMC-2, are considered. Each AMC is basically characterized by two threshold parameters, one is mandatory and the other is minimum entry threshold for different modulation schemes. The mandatory exit threshold is the SINR at or below where this burst profile can no longer be used and where a change to a more robust (but also less frequency-use efficient) burst profile is required and the minimum entry threshold is the minimum SINR required to start using this burst profile when changing from a more robust burst profile [13].

The determination of the threshold is a challenging problem because its value strongly influences the nature of the adaptation algorithm during the measurement of performance parameters. Two techniques for the determination of thresholds are given in [7]. The first one is the target block error rate (BLER) for which the error rate under a target limit is maintained for certain QoS and the second one is the Maximum Throughput algorithm that maximizes the total link throughput for a certain SINR value. QPSK-1/2 is a conservative MCS that reduces BLER at the cost of 0BW consumption [14]. Papers [14–16] provide performance analysis of the WiMAX network with respect to AMC in fixed and single cell environments. It shows that a more aggressive AMC (i.e. using higher order modulation scheme at low SINR value) scheme gives less BW consumption at the expense of increased BLER. We have used the same AMC profile as in [14, 15] for our simulation as given in Table II. Here, AMC-2 is conservative AMC as it is using lower order MCS most of the time.

WiMAX is expected to provide high mobility support to mobile users. However, increase in the mobile speed decreases the performance of the WiMAX network substantially [8]. The WiMAX forum sets requirement guidelines for different applications that can be run over WiMAX [1]. Mobile WiMAX can support varied data services and applications with stringent QoS requirements, high system throughput, symmetric UL, DL capacity and flexible resource allocation as summarized

DOI: 10.1002/dac

Table III. Mobile WiMAX scheduling services.

QoS category	Applications	QoS specifications
UGS—unsolicited grant service	VoIP	• Maximum sustained rate • Maximum latency tolerance • Jitter tolerance
rtPS—real-time polling service	Streaming audio or video	• Minimum reserved rate • Maximum sustained rate • Maximum latency tolerance • Traffic priority
ertPS—extended real-time polling service	Voice with activity detection (VoIP)	• Minimum reserved rate • Maximum sustained rate • Maximum latency tolerance • Jitter tolerance • Traffic priority
nrtPS—non-real-time polling service	File transfer protocol (FTP)	• Minimum reserved rate • Maximum sustained rate • Traffic priority
BE—best-effort service	Data transfer, web browsing, etc.	• Maximum sustained rate • Traffic priority

in Table III [2]. WiMAX QoS is specified for each service flow. The connection-oriented QoS thereby provides strong control over the air interface. It can effectively enable the QoS control by overcoming the bottleneck situation of air interface. The MAC layer manages the service flow parameters and thereby accommodates the dynamic service demand. The same control mechanism is provided in both UL and DL so that QoS improves greatly in both directions. Thus, the BS scheduler controls both the UL and DL.

In voice and video communication, quality usually means whether the hearing experience is good or bad. Besides this qualitative description, there is also a numerical way of representation for voice and video quality known as MOS. MOS gives the numerical representation of the perceived quality of the medium of transmission and eventually compresses using codec. MOS ranges from 1 (unacceptable) to 5 (excellent). The MOS values need not to be a whole number. A value of 3–4.5 is referred to as satisfactory and is normally used in public telephone services. MOS is inversely proportional to delay and packet dropped by the network. The E-model is an analytical model defined in ITU-T recommendation, providing a framework for an objective online quality estimation, based on network performance measurements such as delay and loss and application-level factors like low bit rate codec. The result of the E-model is the calculation of the R-factor [17] given in Equation (1) (best case: 100, worst case: 0).

$$R = R_0 - I_s - I_d - I_e + A \tag{1}$$

where R_0 groups the effects of noise, I_s includes the effects of the other impairments related to the quantization of the voice signal, I_d represents the impairment caused due to delay, I_e covers the impairments caused by the low bit rate codec and packet losses. The advantage factor A compensates for the above impairments under various user conditions. A is 10 for mobile telephony but for VoIP A is 0. The value of R_0 is considered to be 94.77 and the value of I_s is considered to be 1.43 in OPNET. The relation between MOS and R-factor is given as follows [17]:

$$\mathrm{MOS} = 1 + 0.035R + 7R(R-60)(100-R) \times 10^{-6} \tag{2}$$

For VoIP operations, MOS is used to judge the VoIP services from the network provider. Within a certain environment, MOS value assesses the work of codecs used for compression for saving the BW utilization.

In wireless communication systems, information is transmitted between the transmitter and the receiver antenna by electromagnetic waves. During propagation, electromagnetic waves interact

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Table IV. Various path-loss models used for the simulation.

Propagation model	Mathematical formulation	Description
Free space [20]	$P_{rx}(r) = P_{tx} G_{tx} G_{rx} \lambda^2/((4\pi)^2 r^2 L)$. P_{rx} and P_{tx} are received power and transmitted power in watts, respectively; G_{rx} and G_{tx} are the gain of the receiving and transmitting antennas, respectively; L is the system-loss factor	It is a mathematical model and hardly applicable in real-life scenario. It does not consider the fading effect due to multi-path propagation
Erceg's suburban fixed model [19, 21, 22]	$\mathrm{PL} = H + 10\gamma \log_{10}(d/d_0) + X_f + X_h + s$. PL is the instantaneous attenuation in dB, H is the intercept and is given by free space path-loss at the desired frequency over a distance of $d_0 = 100\,\mathrm{m}$. γ is a Gaussian random variable over the population of macro cells within each terrain category. X_f and X_h are the correlation factors of the model for the operating frequency and for the MS antenna height, respectively	It is based on extensive experimental data collected at 1.9 GHz in 95 macro cells of suburban areas across the United States. Very large cell size, base stations with high transmission power and higher antenna height. Subscriber stations are of very low mobility
Outdoor-to-indoor and pedestrian path-loss environment [23]	$\mathrm{PL} = 40 \log_{10} R + 30 \log_{10} f + 49$. PL is the instantaneous attenuation in dB, R is the distance between the base station and the mobile station in kilometers and f is the carrier frequency	Small cell size, base stations with low antenna heights and low transmission power are located outdoors while pedestrian users are located on streets and inside buildings and residences
Vehicular environment [24]	$\mathrm{PL} = 40(1 - 4 \times 10^{-3} \times \Delta h_b) \log_{10} R - 18 \log_{10} \Delta h_b - 21 \log_{10} f + 80\,\mathrm{dB}$. R is the distance between the base station and the mobile station, f is the carrier frequency and Δh_b is the base station antenna height in meters	Larger cells and higher transmitter power. All subscriber stations have high mobility

with the environment, thereby causing reduction of signal strength. In a communication system, the term path-loss (sometimes called path attenuation) means the attenuation undergone by an electromagnetic wave in transit between a transmitter and a receiver [18]. WiMAX system can operate in NLOS condition. In this regard, the receiver exploits reflected, diffracted and scattered components of the transmitted signal that reach the receiving antenna through multi-path propagation. For the purpose of wireless network planning, propagation models are used for the electric field strength calculation [19]. These models require detailed geometric information on terrain profile, location and dimensions of buildings. Empirical models based on measurements predict mean path-loss as a function of various parameters, e.g. antenna heights, distance, frequency, etc. Path-loss is highly dependent on the propagation model.

The salient features of the common propagation models namely Free Space, Suburban Fixed (Erceg), Outdoor to Indoor and Pedestrian Environment and Vehicular Environment are given in Table IV. These models are used in mobile WiMAX performance evaluation through OPNET simulation.

3. THE SIMULATOR

Optimized network engineering tool (OPNET) [10] provides a comprehensive development environment supporting the modeling of communication networks and distributed systems. Both behavior and performance of the modeled systems can be analyzed by discrete event simulation. Tools

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for all phases of our study including model design, simulation, data collection and data analysis are incorporated in the OPNET environment. Various constructs pertaining to communication and information processing are provided by OPNET. Thus, it provides high leverage for modeling and distributed systems. Graphical specifications of a model are provided by OPNET most of the time. It provides a graphical editor to enter the network and model details. These editors provide an intuitive mapping from the modeled system to the OPNET model specification. OPNET provides four such types of editors namely the network editor, the node editor, the process editor and the parameterized editor organized in a hierarchical way. It supports model-level reuse i.e. models developed at one layer can be used by another model at a higher layer. All OPNET simulations automatically include support for analysis by a sophisticated interactive debugger. Technology developers leverage advanced simulation capabilities and rich protocol model suites to design and optimize proprietary wireless protocols.

The topology of a network is defined in the network domain. The properties of the node including their models are specified in this domain. Multiple instances of the same node models can coexist in one network domain. Geographic context can be provided to the network to analyze real-time deployment situation. Varieties of point-to-point links are provided by the OPNET model library and are used to build the links of the topology. The layer model of a node is viewed in the node domain. It is in this domain that the architecture of a specific node can be modified. Modules such as transmitter receiver, processor, queues and external systems are highly programmable and are the basic components of the node. Packet streams and static wire form the logical association of this module in the node domain. In process editor, we can modify the processes or algorithms of a node using a language called Proto-C, which is based on a combination of state transition diagrams, a library of high-level commands and general facilities of C++ programming language. Through parameterized editor, we can fix the perfect value for the whole network or each node present in the network. With the help of this editor, we can set the overall network configuration such as fading environment, path-loss model, etc.

In this paper, we take the advantages of OPNET Wireless modeler suites (OPNET 14.5.A), particularly the WiMAX platform for our performance study. We have performed a series of simulation with the help of the WiMAX model of PL8 that provides very reliable results for Broadband Wireless communication. Figure 2 presents the screenshot of the SS node's attributes table providing the list of MCS that we can use for our simulation.

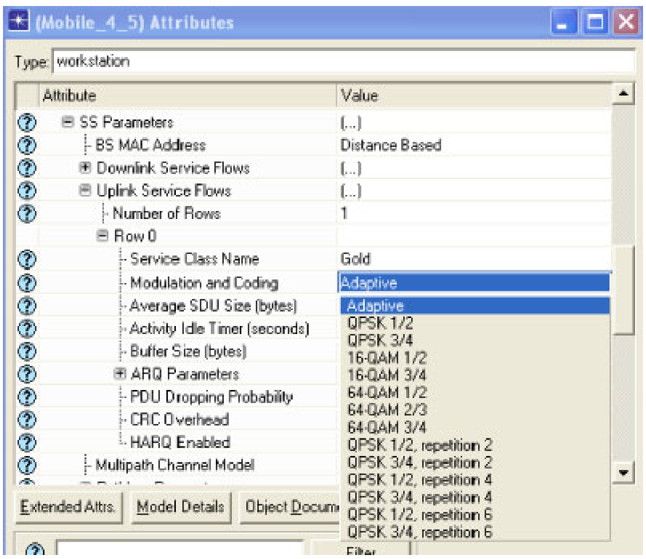

Figure 2. Typical screenshot of the attribute table of SS node.

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4. SIMULATION SCENARIOS

For simulation purpose, scenarios are deployed with 7-Hexagonal celled WiMAX using omni-directional antenna (A typical scenario is shown in Figure 3.). We have used two SS nodes with varying speed. These two nodes (mobile_2_1 and mobile_2_2) move along the trajectories indicated by green and blue lines, respectively. All SS nodes have an UL application load of 96 kbps. The common attributes for simulation used are highlighted in Table V. Although WIMAX standard [2] claims that WiMAX would support a very large coverage area, Andrews *et al.* [25] show that mobile WiMAX typically supports a cell radius of approximately 3 km. Accordingly a 3-km cell radius has been considered for our simulation. The objective of the paper is to make an in-depth study of the various performances such as throughput, data drop, MOS value, BS UL data burst usage, etc. over mobile WiMAX network extensively using the fixed and adaptive modulation and coding techniques. We have constructed various scenarios by varying speed, path-loss models, application type and scheduling services.

Four sets of simulation scenarios are considered: first for varying speed of the mobile node, second for varying path-loss models, third for different types of services with constant bit rate (CBR) traffic, and the fourth is similar to the third scenario except that it uses non-CBR traffic. For each set again the types of modulation is chosen one by one to take the simulation results for a particular output parameter. All the necessary configurations required for different scenarios in OPNET simulator have been implemented. The outcome of the simulation is exhibited in MOS

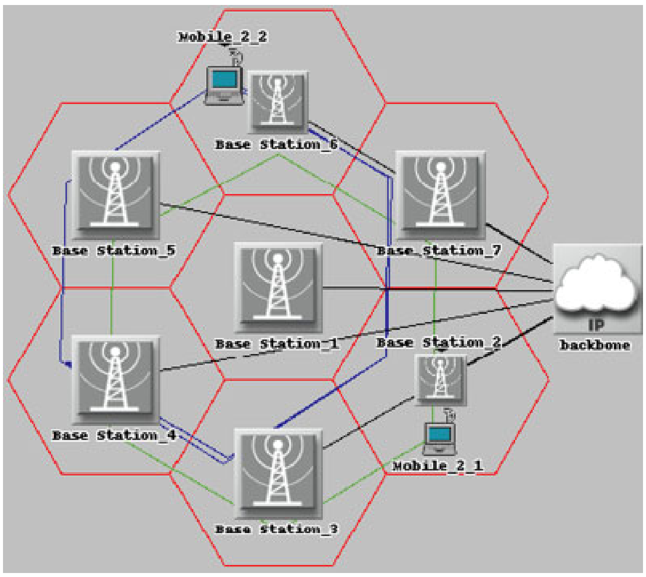

Figure 3. WiMAX network used for simulation.

Table V. Common attributes for simulation.

Attributes	Values
Cell structure	Hexagonal
Cell radius	3 km
No. of cells	7
Base station model	Wimax_bs_router
Subscriber station model	Wimax_ss_wkstn
Link model	PPP_DS3
IP Backhaul model	Router_slip64_dc
Voice codec	G 711

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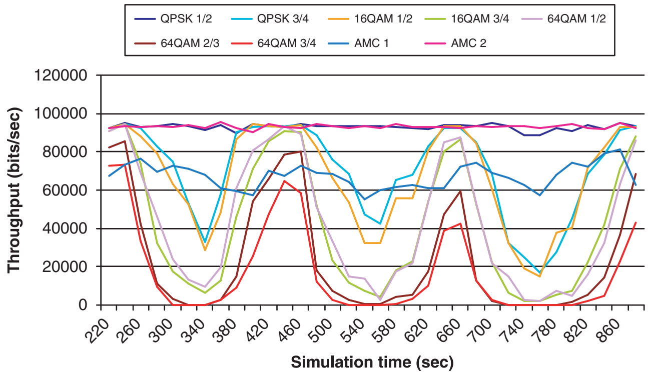

Figure 4. Throughput of SS node during its journey.

value, throughput, data dropped and the UL data burst usage at every instant of time. We consider the average of the statistics obtained over the period of the simulation time for performance studies under different scenarios. We have used VoIP services as the application traffic. G711 [26] is used for digital conversion (sampling, quantization and encoding) of voice. The load of VoIP application is 64 kbps and adding the required headers at transport and network layer, it becomes 96 kbps at WiMAX PHY layer. However, considering the initialization time for simulation, the effective load over the simulation period is 90 kbps.

Scenario 1. Mobile node with varying speed

Under this scenario, path-loss model and scheduling service are kept constant. Path-loss model is chosen as free space while CBR traffic with an average load of 90 kbps and service class as ertPS are considered. We provide the speed of the mobile in kmph. The performance parameters for this scenario are data drop; MOS value of the voice call, throughput of the mobile node and UL burst usage (%) for BS, which is a measure of the utilization of UL BW of a particular WiMAX BS. Figure 4 gives the throughput of Mobile_2_1 during the simulation time. As it moves from one cell to another cell, it faces different SINR values depending upon its current distance from the BS of that cell. As it moves toward the cell boundary, the SINR gradually decreases that results in decreasing the throughput. We can see from Figure 4 that using QPSK-1/2 as MCS, the node experiences maximum throughput the entire path. For higher order MCS such as 64-QAM-3/4, as the SS node moves toward the cell boundary, the throughput falls drastically. The AMC profile adopts the suitable MCS dynamically according to the received SINR value and thus it keeps approximately constant throughput throughout its trajectory.

The average data dropped, throughput, MOS value and UL data burst usage with fixed and adaptive modulation have been implemented in Figures 5(a)–6(b). As the speed of SS increases, the hand-off frequency increases, which results in increased packet loss (data dropped) and thereby decreased throughput and MOS value. As can be viewed from Figure 5(a), the average data drop is significantly high when SS moves with a greater speed (180 kmph). The effect of data drop naturally decreases the average WiMAX throughput as shown in Figure 5(b).

From Figure 5(a) it is observed that the data dropped are almost constant for each modulation scheme and varies with speed.We know that a higher order modulation scheme is more sensible to SINR [11]. As the SS is moving through the cell, it faces a different SINR value depending upon the distance from the BS and the propagation environment. With increasing distance, the SINR decreases and the higher order MCS gives more BLER than the lower order MCS for the same SINR value. The average throughput is taken as a measure that will give the average of observed throughput throughout the simulation. Thus, as the order of MCS increases, the average throughput will decrease which is observed from Figure 5(b). For example, a 64-QAM-3/4 has an average throughput of just 12 kbps compared with 90 kbps in case of QPSK-1/2 under the SS speed of 18 kmph. AMC-1 is an aggressive AMC i.e. SS node tends to use a higher order of MCS compared

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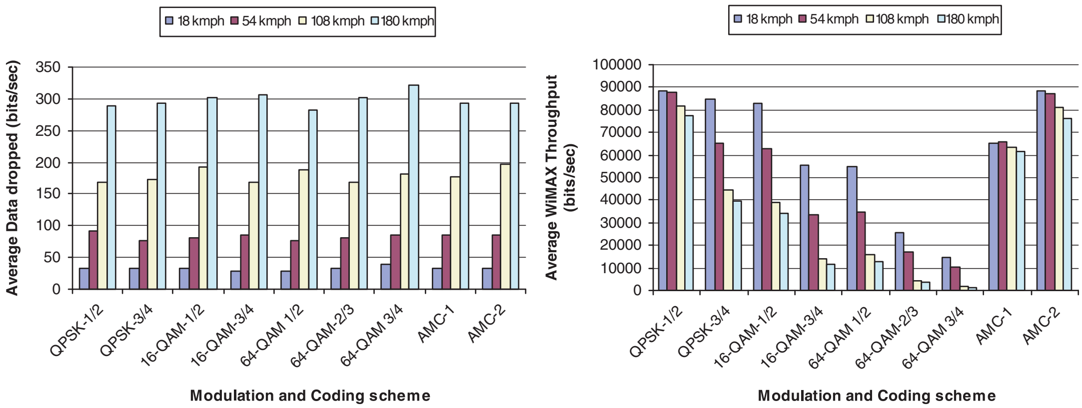
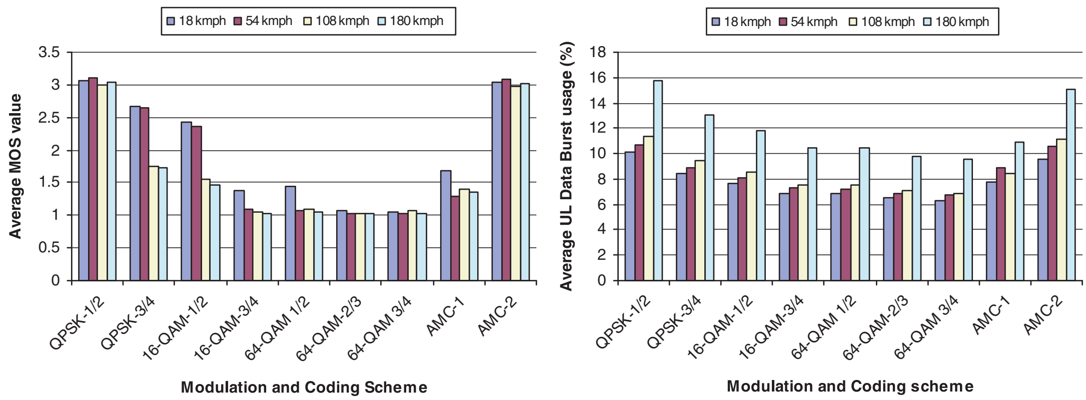


(a) (b)

Figure 5. (a) Average data dropped for SS node and (b) average WiMAX throughput of SS node.



(a) (b)

Figure 6. (a) Average MOS value for voice application and (b) average UL data burst usage of WiMAX BS.

with what AMC-2 uses at the same value of SINR. Thus, it gives comparably a lower value of average throughput than AMC-2. The bit error probability of QPSK is less in noisy environment at the cost of high BW usage. Voice is retrieved efficiently in noisy environment if QPSK is used. This is reflected in the graph shown in Figure 6(a).

From the results (Figures 5(a)–6(b)) it is observed that WiMAX using QPSK as modulation technique shows better performance (i.e. high throughput and greater MOS value) compared with QAM. This indicates that increase in the number of bits per symbol decreases the QoS. But when we see the UL data burst usage, it implies that increase in information bits per symbol decreases the data burst usage, thereby, increasing the system capacity. System capacity is always compromised with system quality.

The average MOS value (Figure 6(a)) indicates that a very poor performance is obtained for higher rate coding schemes such as 16-QAM 3/4 and 64-QAM. Voice quality with MOS above 3 is considered to be of acceptable quality [17]. Hence, only QPSK-1/2 seems to satisfy the user demand of the voice quality, thereby giving a better performance. From Figure 6(b), we observe that increase in information bits per symbol decreases the average UL data burst usage which implies less BW consumption. The AMC profile in each case shows substantial better performance compared with the conventional fixed coding schemes. As we see, the AMC-2 gives similar performance for average throughput and MOS value, but the UL data burst usage is less. This implies that AMC implementation minimizes the overall system BW usage irrespective of system performance and QoS.

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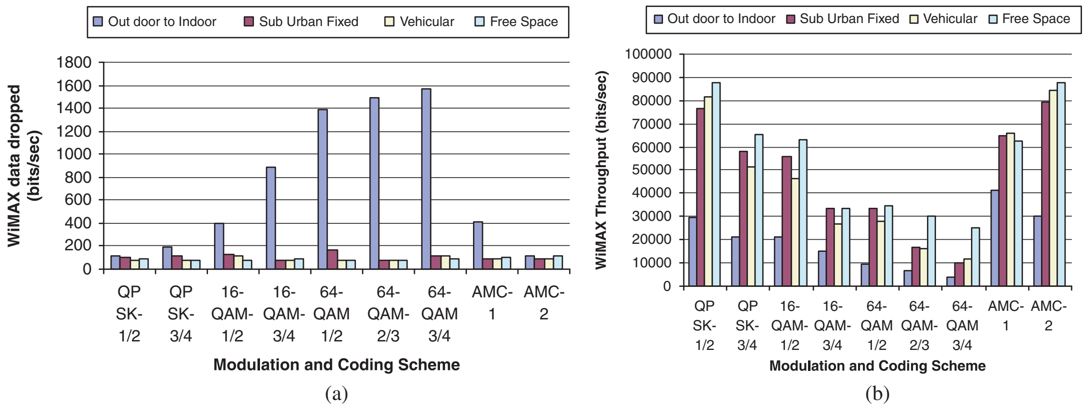


Figure 7. (a) Average data dropped for SS node and (b) average WiMAX throughput of SS node.

From these results, we can conclude that conservative AMC scheme i.e. AMC-2 improves the performance of the WiMAX network over the aggressive AMC scheme i.e. AMC-1 at the expense of system capacity i.e. using higher BW. The application performances for AMC-2 and QPSK-1/2 are almost the same, but the average UL data burst usage for AMC-2 is a bit less than QPSK 1/2, implying more system capacity. The results show that we gain an acceptable MOS value for AMC-2 keeping the BW usage less than that of the QPSK-1/2.

Scenario 2. Different path-loss models

We have considered this scenario keeping the speed of SS and scheduling service constant. Speed of SS is chosen as 54 kmph, application as CBR traffic with average load of 90 kbps, service class as ertPS. In this scenario, the performance of WiMAX network is observed for various modulation and coding schemes with respect to various path-loss models. We know that outdoor to indoor and pedestrian path-loss model is designed for small and micro cell WiMAX network. However, for our study we have considered fixed radius WiMAX network for all the path-loss models.

For outdoor to indoor and pedestrian propagation model, as SS node that moves away from BS will encounter a significant drop in SINR and as the higher order MCS (such as 64-QAM-3/4) requires high value of SINR to give a good throughput, higher order MCS will face a very large amount of data drop as revealed from Figure 7(a). Path-loss for free space is lowest; hence, reduction of SINR with the distance from BS is less which leads to better throughput. Again, as the reduction of SINR with distance from BS is less, the SS has to change its modulation scheme less frequently which results in very high throughput for AMC as shown in Figure 7(b). In free space propagation model, we do not consider fading and multi-path propagation phenomena. Thus, path-loss would be very nominal and the received SINR would be ideal as we can see from Figure 7(b) that the throughput for free space propagation model is highest for all MCS. We have considered the suburban fixed model as hilly terrain with high tree density that implies very high path-loss due to scattering and multi-path propagation of radio signals while for vehicular model, we consider a moderately flat terrain so the path-loss would be less than that of the suburban fixed model. As outdoor to indoor and pedestrian propagation model experiences very high packet drop compared with the others, it gives the lowest throughput compared with other propagation model as can be observed from Figure 7(b). For free space propagation model, QPSK-1/2 and AMC-2 give almost the same throughput, but for other propagation models, AMC-2 performs better, which implies that in idealistic condition AMC-2 performs as good as fixed coding but in noisy area and considering fading environment, AMC-2 performs better than the fixed type of coding scheme.

From Figure 8(a) we can see that only QPSK-1/2 and AMC-2 provide satisfactory results (i.e. MOS>2), but other MCSs give very poor performance as MOS value of 1 is considered to be the worst condition. We can see from Figure 8(b) that for all the path-loss models, AMC-1 consumes

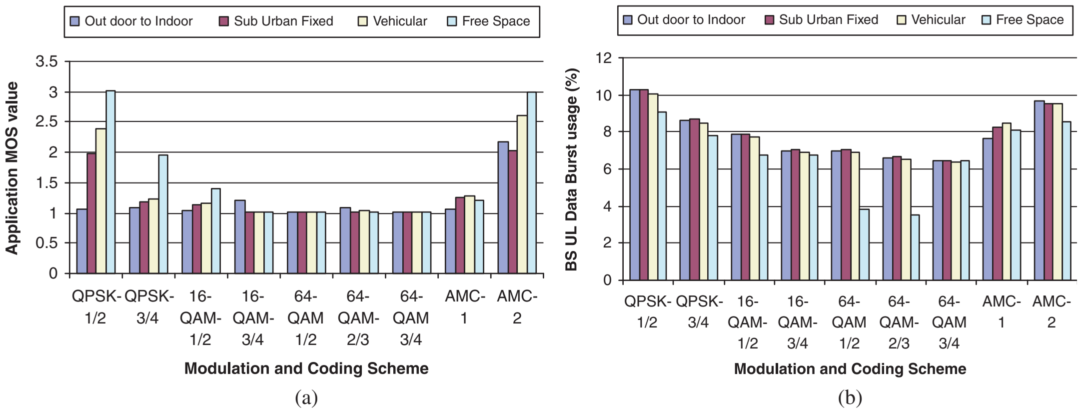


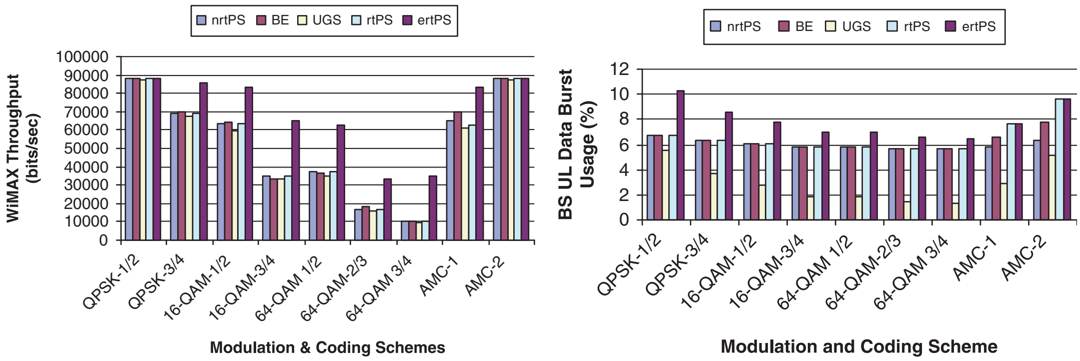
Figure 8. (a) Average MOS value for voice application and (b) average UL data burst usage of WiMAX BS.

less BW than QPSK-1/2 whereas AMC-1 gives almost the same throughput as QPSK-1/2. Thus, we can conclude by comparing Figures 7(b) and 8(b) that AMC improves the system performance while consuming less BW as frequent changes of the scheme is not required.

Scenario 3. Service Class with CBR traffic

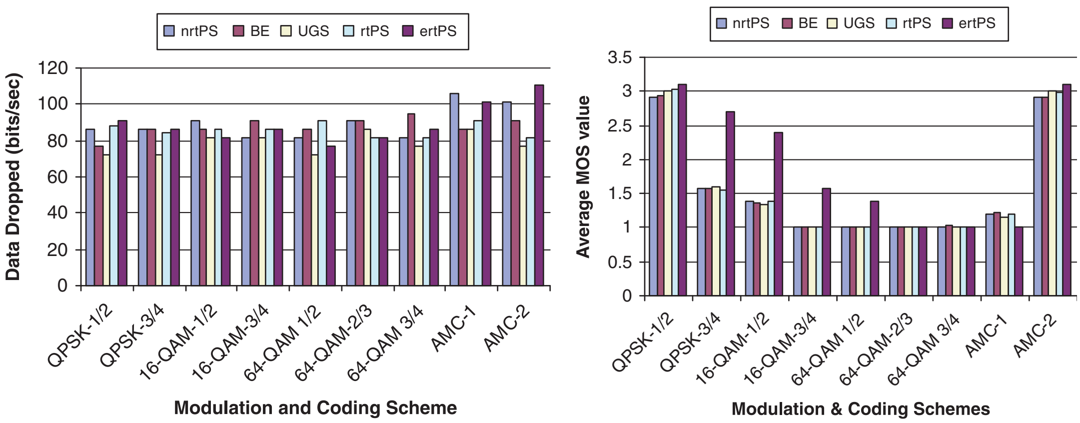
Under this scenario speed of SS, path-loss model are kept constant. The speed of SS is chosen as 54 kmph while path-loss model as free space and CBR traffic with average load of 90 kbps are considered. Though different scheduling types are designed to support different types of traffic, in this work we configure a CBR traffic between the two SS nodes for comparing the performance of different scheduling types for CBR. As for UGS, a fixed amount of BW on the periodic basis is requested at the setup phase of UL. Then BW is never requested explicitly [4]. Thus, UGS gives the best result (good throughput and less consumed BW) for CBR traffic, which is revealed from Figure 9(a) and (b). ertPS is designed to support real-time applications generating variable bit rate traffic periodically [27, 28]. It offers periodic opportunities to request BW consumption comparably high BW for CBR traffic as shown in Figure 9(b). For QPSK-1/2 and AMC-2, all scheduling types give the same result, which reveals that for lower order of MCS and good SINR, all service classes give equal throughput but as the order of MCS increases, throughput falls drastically while consuming nearly the same BW. nrtPS and BE give comparatively the same throughput for almost every coding scheme as these two service classes are designed to handle delay tolerant data packets i.e. data packets arriving aperiodically. Hence, these service classes will consume higher BW than the UGS uses to give the same throughput, which can be seen in Figure 9(b). For fixed coding scheme, there is hardly any difference in the BW utilization; however, using the AMC the nrtPS consumes less BW compared with BE. This is because the BE allocates the requested BW for every arrived data packet whereas nrtPS is designed for services that require variable size data grant burst type on a regular basis [4]. As we have used CBR application, the overall BW consumption of nrtPS is lower.

From Figure 9(a), we see that ertPS provides greater throughput than nrtPS, UGS and BE. The simple reason behind this is that ertPS is designed for VoIP application where CBR traffic is used. From Figure 10(a) it is observed that UGS gives fewer amounts of data dropped compared with other service classes because UGS allocates fixed amount of BW whereas ertPS allocates BW dynamically on the basis of traffic demand BW so that it gives the highest average data dropped. From Figure 10(b) it is observed that the ertPS scheme gives considerable performance (i.e. MOS.2) for QPSK, 16-QAM-1/2 and AMC-2 whereas other service classes give acceptable quality for QPSK-1/2 and AMC-2 only. It is also observed that using AMC-2 and ertPS as scheduling service class, we get the best quality of voice performance.



(a) (b)

Figure 9. (a) Average WiMAX throughput of SS node and (b) average UL data burst usage of WiMAX BS.



(a) (b)

Figure 10. (a) Average data dropped for SS node and (b) average MOS value for voice application.

Scenario 4. Service class with non-CBR traffic

Under this scenario the speed of SS, path-loss model are kept constant. The speed of SS is chosen as 54 kmph while path-loss model as free space and non-CBR traffic with a average load of 36 kbps are considered. In this scenario, we have configured voice traffic with silence suppression traffic between the SS nodes. Voice traffic with silence suppression means that the node will not send traffic while the user is silent i.e. it is sensing the user's voice amplitude all the time and sending traffic according to it. The simulator uses a default value of silence period of 65% [26]. But when the user would be silent, it is unknown to the user and data packet can arrive at any time. Thus, it is not CBR traffic. We simulated this scenario with every scheduling type to compare the results.

As we can see, from Figure 11(b), that UGS gives best throughput irrespective of MCS but from Figure 12(b) we see that it consumes very high BW. This is because UGS uses fixed slots for voice call; hence, it is giving good performance at the cost of high BW. On the other hand, ertPS is designed for VoIP service with activity detection; hence, it is giving comparatively better throughput than nrtPS, BE and rtPS while consuming slightly greater BW than these schemes. rtPS and ertPS consume nearly the same BW but ertPS gives very good performance (in terms of MOS and throughput). Thus, ertPS enhances the system capacity. nrtPS and BE are used for non-real-time traffic; hence, their performance is poor compared with the others.

Finally, we have checked whether a change in the starting position of the node or the trajectory of the nodes affect the performances. If we change the starting position of the nodes or the trajectory such that the mobile node remains close to the BS for most of the time, then the average throughput

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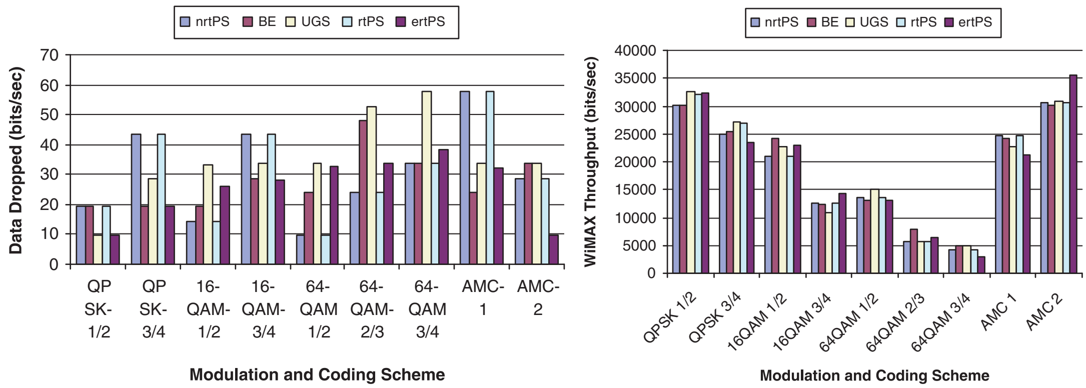
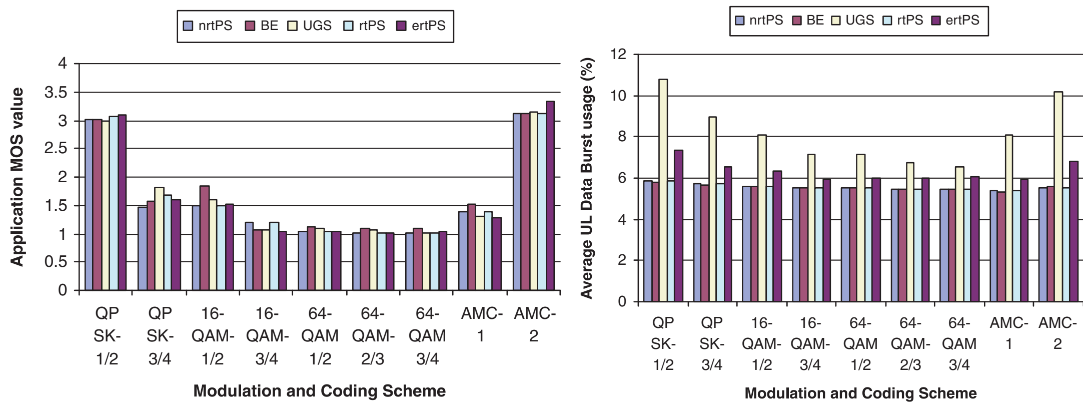


(a) (b)

Figure 11. (a) Average data dropped for SS node and (b) average WiMAX throughput of SS node.



(a) (b)

Figure 12. (a) Average MOS value for voice application and (b) average UL data burst usage of WiMAX BS.

and MOS increase with significantly less data drop. But the effects of speed, path-loss and the scheduling services are in the same order as we have discussed previously.

MOS of 3.5 and above are considered as of very good quality for VoIP services [29] and MOS below 1.5 is unacceptable. Hence, we categorize MOS values as: very good (MOS$\geqslant$3.5), good (3.5>MOS$\geqslant$3), average (3>MOS$\geqslant$2), poor (2>MOS$\geqslant$1.5) and unacceptable (MOS<1.5). For throughput, we have considered that a node achieving throughput that is not less than 95% of its load or desired throughput experiences very good quality of performance. A node achieving throughput that is less that 60% of its load is considered as unacceptable. We have categorized this accordingly as: A ($\geqslant$95%), B ($\geqslant$85%), C ($\geqslant$75%), D ($\geqslant$60%) and E (<60%). With the variation of speed, the UL data burst usage also varies. We consider the performance as very good where the variation is nominal and as very poor where the variation is the most. The results are summarized in the Table VI where A = Very good quality, B = Good quality, C = Average quality, D = Poor quality and E = Very Poor quality.

5. CONCLUSION

In this paper, we made an in-depth study of the performance of the mobile WiMAX network with respect to different modulation and coding schemes. The PHY layer parameters that have been taken into consideration include speed of mobile node, path-loss models, MAC service classes and the type of the traffic. The performance has been evaluated in terms of average throughput, average

DOI: 10.1002/dac

Table VI. Comparative performance of mobile WiMAX network for VoIP application.

Modulation/ coding	Mobile node with varying Speed				Different path-loss models				Service class with CBR traffic				Service class with non-CBR traffic			
	Data dropped	Throughput	UL data burst usage	MOS value	Data dropped	Throughput	UL data burst usage	MOS value	Data dropped	Throughput	UL data burst usage	MOS value	Data dropped	Throughput	UL data burst usage	MOS value
QPSK-1/2	A	A	E	B	A	A	E	B	A	A	E	B	A	B	E	B
QPSK-3/4	B	B	C	C	B	C	D	C	B	B	D	B	C	C	D	E
16-QAM-1/2	C	B	C	C	C	C	C	C	B	B	C	C	B	D	C	E
16-QAM-3/4	D	E	B	D	D	E	B	D	C	C	B	D	C	E	B	E
64-QAM 1/2	B	E	B	E	E	E	B	E	C	C	B	E	C	E	B	E
64-QAM-2/3	D	E	A	E	E	E	A	E	D	E	A	E	D	E	A	E
64-QAM 3/4	E	E	A	E	E	E	A	E	D	E	A	E	E	E	A	E
AMC-1	A	C	C	C	C	C	C	C	D	B	C	E	E	D	C	E
AMC-2	A	A	D	B	A	A	D	B	E	A	D	B	B	A	D	B

data-dropped, MOS value of voice application and the BW usage in terms of UL data burst usage. The simulation is based on OPNET 14.5.A modeler. It has been observed that using lower order modulation and coding schemes, the system provides better performance in terms of throughput, data dropped and MOS at the cost of higher BW usage. The simulation results also show that AMC-2 as considered in this paper give almost the same performance as QPSK-1/2, which is the best performance among all the coding schemes while consuming less overall BW than the QPSK-1/2. The work of this paper validates the reason of using AMC for mobile environment as we observe the better performance while using AMC with high mobility users. Simulation also reveals that ertPS scheduling service class is best suitable for VoIP application with silence suppression. If proper design consideration such as cell size, power control etc. can be done for vehicular model, better VoIP service can also be provided to the high-speed users.

ACKNOWLEDGEMENTS

The authors deeply acknowledge the support from DST, Govt. of India for this work in the form of FIST 2007 Project on 'Broadband Wireless Communications' in the Department of Electronics and Telecommunication Engineering, Jadavpur University.

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