Evaluating the Performance of WiMAX Network with Smart Antenna Systems

Mohammed A. Abdala and Naiam W. Alsamaraie

Abstract— Smart Antenna Systems (SAS) is an additional feature in WiMAX technology IEEE 802.16e. SAS have the capability in focusing on the energy in a certain direction. This helps in achieving higher data rate transmission and improving system capacity. In this paper, WiMAX network is integrated with SAS in order to study and analyze its performance. WiMAX network is simulated using OPNET 14.5 simulator while the SAS system is implemented using MATLAB (R2013a). Then, OPNET 14.5 is integrated with MATLAB (R2013a) through MX/MEX interface to evaluate the performance of a WiMAX network that uses SAS installed at the Base Station (BS) or Subscriber Station (SS). The designed SAS consists of 8 Uniform Linear Array (ULA) and the adaptive beamforming algorithm used is Constant Modulus Algorithm (CMA). The performance of the modeled network evaluated in term of overall network delay, throughput, Downlink Signal to Noise Ratio (DL SNR), Downlink Block Error Rate (DL BLER) and Downlink Packets Dropped.

Index Terms— BS, CMA, integrating MATLAB and OPNET, SAS, SS, ULA, WiMAX.

1 Introduction

The ultimate objective of wireless communication is to host large number of users in a wide coverage. Initial deployment of wireless networks has dated back to 1924 with one base station providing a city-wide coverage. Although achieving very good coverage, the network can only host a few users simultaneously. Another base station using the same spectrum and serving the same area cannot be placed since that would result in interference [1].

With the rapid growth of the internet market and the (WWW) World Wide Web became richer in content and more complicated, higher bandwidth with faster speed for connection was needed [2].

The researchers and technologists have forced to develop better transmission methods with greater efficiency. Broadband wireless is one of the solutions designed to meet those needs. Broadband and wireless have enjoyed a massive mass market adoption in the past twenty years [3].

Broadband wireless services has started with fixed wireless broadband which is similar to the traditional fixed line broadband access technology like DSL or cable modem but using wireless as a medium of transmission. Mobile broadband service, is one of broadband wireless services that has additional functionality in providing mobility and nomadicity.

IEEE 802.16 and its Worldwide Interoperability for Microwave Access (WiMAX) technology designed to accommodate both fixed and mobile broadband application. WiMAX is a wireless alternative to DSL and cable on the last mile [4].It provides similar speeds to DSL and is deployed mostly in regions (such as rural areas) with no access to broadband access networks like DSL and cable [5]. WiMAX promises to offer higher peak data rates and greater flexibility than 3G networks [4].

The use of SAS is envisioned to take advantage of Space Division Multiple Accesses (SDMA) to increase network efficiency by directing the transmitted power in the desired direction. SAS allows the energy to be transmitted or received in a particular direction as opposed to disseminating energy in all directions; this helps in achieving significant spatial re-use and thereby increasing the capacity of the network [7].

Many researchers focused their work on evaluating the performance of WiMAX network with SAS. In [8] examined the processing requirement for implementing SAS in WiMAX network and the effectiveness of SAS in enhancing the coverage and capacity as well as spectral efficiency of the network. The performance of mobile and fixed WiMAX networks that use SAS evaluated using OPNET 14.5 in [9] and [10] respectively. Both of these studies show that the link capacity of WiMAX nodes increased when integrated with smart antennas than with omni-directional antennas even if distance between the nodes increased. Also, the throughput and SNR are higher in the case of smart antennas. The performance of fixed WiMAX (IEEE 802.16d) with and without SAS using the MATLAB presented in [11] using MATLAB. Both transmitter and receiver supposed to be fixed and SAS installed at the receiver. The results show the performance of WiMAX with SAS is better than without SAS. Also, it has proved the performance of the system increased when the number of antennas increased at receiver.

The rest of paper organized as follows: overview of WiMAX network presented in section 2, section 3 discusses the design of SAS, the simulation tools viewed in section 4, the proposed model discussed in section 5, section 6 contains results and the conclusion presented in section 7.

2 WiMAX Network

Different standards are provided by IEEE 802.16 family. IEEE 802.16d-2004, also known as fixed WiMAX, is the initial feasible criterion of the IEEE 802.16 stock published and approved in December 2004 [12]. Since the mobility became necessary, an amendment to this standard that added mobility backup known as "IEEE 802.16e-2005" or mobile WiMAX was published in December 2005 [2].The IEEE 802.16 standard is still a new standard when compared to existing standards such as the more mature IEEE Standard 802.11, the standard used for Wi-Fi networking commonly seen in home and business. However, WiMAX and Wi-Fi aim to provide Internet access and wireless connectivity, where they designed for several application scenarios, thus, become less competitive than complementary, so they are not straight competitors for wireless broadband subscribers. The Wi-Fi provides a bounded LAN's coverage area, such as an office or a home, whereas WiMAX is deliberated to render a MAN coverage area with a large range of kilometers. WiMAX uses licensed spectra, while Wi-Fi uses unlicensed one. Furthermore, they have various QoS (Quality of Service) conservation techniques [12]. The IEEE 802.16/WiMAX network look like a cellular network, which means that each cell includes WiMAX Base Station (BS) and WiMAX Subscriber Station (SS). The WiMAX BS can connect directly to the Internet by the use of a high-bandwidth, wired connection. It can also connect to another WiMAX BS using Line of Sight (LoS) microwave link. This connection to a second BS called (a backhaul), therefore, the coverage area of a single BS approximately 3000 square miles. This makes the WiMAX provide coverage to remote rural areas. However, it is possible to connect several BSs using backhaul microwave links. Thus, permits a WiMAX SS to moves from one coverage area of one BS to another area served by another BS without losing the connection as presented in fig.1 [13].

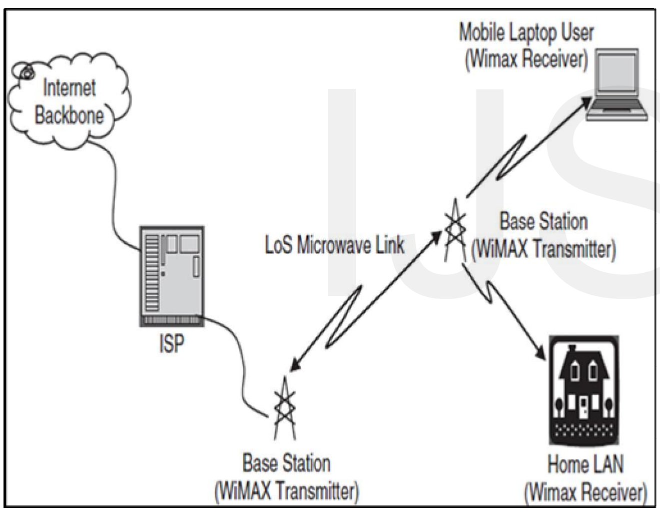


Figure 1: Operational principles of WiMAX technology [13].

Like any wireless network, IEEE 802.16 specifies two types of propagations depending on the frequency range: LoS for frequency range between 10-66 GHz and Non-Line of Sight (NLoS) for frequency range between (2-11) GHz [4].
The physical layer of fixed WiMAX network is established on Orthogonal Frequency Division Multiplexing scheme (OFDM) [14] which is based on the partitioning the input bit stream into several parallel bit streams and which then used to modulate various subcarriers. The space between these subcarriers is formed in an orthogonal way and the signals are still received without neighboring carrier interference. This close spacing tools up the system with more spectral efficiency in transmitting the same amount of data as in FDM but with lower bandwidth [15]. While Mobile WiMAX based on the OFDMA modulation technique that divides the available frequency spectrum into several orthogonal subcarriers. These subcarriers can be dynamically assigned to different users for transmission, both in frequency and time dimensions. This flexibility provides a way of boosting system performance, at the cost of increasing the challenge of resource allocation [14].
One of the most attracting technology, is the use of adaptive modulation technique for different throughput and range. Depending on the SNR condition of the radio link, WiMAX system is free to switch between QAM, QPSK and BPSK as its modulation technique. This kind of adaptive modulation gives the system more stable links and good connection quality [16].
For each station, concurrent transmission and reception is possible since the physical layer supports two Duplexing schemes. Time Division Duplexing scheme (TDD) allows stations to transmit and receive or vice versa simultaneously in a different time while in Frequency Division Duplexing scheme (FDD), the transmission and reception take place on different frequency channels. TDD is used only Mesh network while PMP supports both TDD and FDD [17].
The WiMAX physical layer has the ability to support advanced antenna techniques, such as beamforming, space-time coding, and spatial multiplexing. These technologies based on the idea of multiple antennas can be implemented at transmitter/receiver that helps to increase the overall capacity and spectral efficiency of the network [14].

3 Smart Antenna Systems

One of the most promising techniques for increasing capacity in cellular systems is through the use of Smart Antenna System (SAS). SAS incorporates all situations in which a system is using an antenna array and the antenna pattern is dynamically adjusted by the system as required [18].
An essential component of SAS is its sensors or antenna elements. Just as in humans the ears are the transducers that convert acoustic waves into electrochemical impulses, antenna elements convert electromagnetic waves into electrical impulses. These antenna elements play an important role in shaping and scanning the radiation pattern and constraining the adaptive algorithm used by the digital signal processor [19].
However, the term smart refers to the signal processing capability that forms vital part in controlling the antenna pattern by updating a set of antenna weights. Smart antenna, supported by signal processing capability, points narrow beam towards desired users but at the same time introduces null towards interferers, thus optimizing the service quality and capacity [20].
Beamforming which is also known as spatial processing technique [21], it is a technique applied to array of antenna elements in order to produce the pencil beam in the direction of the desired user and at the same time attenuate signals coming from other directions. The spatial properties of the signal of interest distinguished from interference/noise by weighting the output of array with a complex number according to a certain criterion. [22].
Based on the used beamforming algorithm, two types of beamforming exist fixed and adaptive beamforming. In fixed beamforming, the weights applied to the array output is pre-

defined and not changed in the application while in adaptive the weights adjusted automatically according to specific criteria. Thus, the interference suppression in adaptive beamforming outperforms fixed beamforming with cost higher cost of implementations [22].
For wireless cellular communication systems which are considered as time-varying signal environments where statistics change with time as the target mobile and interferers move around the cell. Recursive update of the weight vector is needed to track a moving mobile so that the spatial filtering beam will adaptively steer to the target mobile's time varying DOA for the time-varying signal propagation environment, thus resulting in optimal transmission/reception of the desired signal [21]. A generic adaptive beamformer presented in fig. (2), consists of N-antenna elements with Digital Signal Processor (DSP) containing an algorithm which controls the update criteria of the complex weight. The antenna array collects the applied data samples, fed these data to the signal processing unit to compute the weight vector according to adopted algorithm [21].

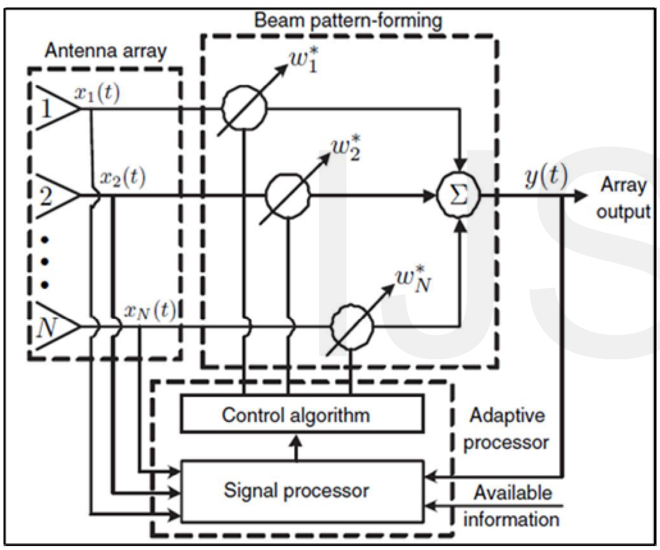


Figure (2): Adaptive antenna array of N-elements [21].

The weight vector w (n) is calculated using the signal x (n) received by multiple antennas. An adaptive processor will minimize the error e (n) between a desired signal d (n) and the array output y (n) [7]. The output of the beamformer can be obtained by taking the inner product of the signal and weight vectors, as given by:

$$y(t) = w^H x(t) \qquad (1)$$

Where superscript H, denotes the complex conjugate transposition of a vector or matrix. w and x (t) are referred to as the weight vector and the signal vector, respectively, and n= [1, 2, 3,…, N] represents the number of antenna elements [18].
One of the blind algorithms which does not require training signals for its guidance is Constant Modulus Algorithm (CMA). When comparing with non-blind algorithms like Least Mean Square (LMS) there is a lot of energy conserved by LMS since the receiver requires to know training signals, in advance, to train the adaptive weights for convergence.
CMA, based on reducing the system overheads while maintaining gain on the signal with total power similar to the omnidirectional antenna. As a result, the number of bits used for transmitting the information is increased which in turn the system capacity [20]. A signal with a constant magnitude is the required signal to implement the CMA [20]. The signals that are phase or frequency modulated, such as in radar systems should have a constant magnitude or modulus.
In fading channels, the received signal is the composite of different signals from different paths. Thus, the channel introduces an amplitude variation on the signal magnitude which destroy the constant modulus property of the signal. If the arriving signals of interest have a constant modulus, an algorithms can be devised to restore or equalize the amplitude of the original signal [22]. CMA adjusts the weight vector to minimize the difference at the array output and steer the beam to the required direction. This is done by the minimization of a cost function in the form of [21]:

$$J(n) = E[(|y(n)|^p - 1)^q] \qquad (2)$$

Where p and q are positive integers. p and q, must be selected in a good way to give a specific cost function called the CM (p,q) cost function. The most popular cost functions are (1,2) and (2,2). The (1,2) case has been proven to converge much more rapidly than the (2,2) case [22]. CMA beamforming goal is restoring the output of the array y (n) to a constant envelope signal. By the use of steepest descent, the weight vector is updated using the following recursive equation [21]:

$$w(n+1) = w(n) - \mu\, \nabla_{w,w^*}(J_{p,q}) \qquad (3)$$

Using CMA (1, 2), the weight gradient vector becomes:

$$\nabla_{w,w*(\hat{J}_{1,2})} = \frac{\partial J_{1,2}}{\partial w^*} = \mathcal{E}\left[x(n)\left(y(n) - \frac{y(n)}{|y(n)|}\right)^*\right] \qquad (4)$$

Therefore, for each n the resulting output signal y(n), error signal e(n) and the weight vector w(n) represented by [21]:

$$y(n) = w^H x(n) \qquad (5)$$

$$e(n) = \left(\frac{y(n)}{|y(n)|} - y(n)\right) \qquad (6)$$

$$w(n+1) = w(n) + \mu e^*(n) x(n) \qquad (7)$$

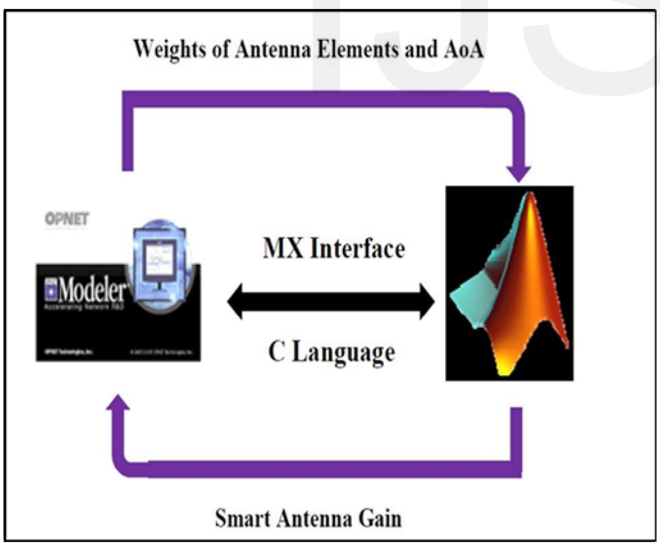
Where μ represents the rate of adaptation, controlled by the processing gain of the antenna array. If a large value of μ is taken then convergence becomes faster but makes the array system unstable/noisy. Conversely if a small value is taken then convergence becomes slow that is also not desirable. Therefore, value of μ is taken in between that satisfy the following conditions for good convergence and to avoid instability [20].
Comparing the CM and the LMS algorithms, the term y(n)/|y(n)| in CM plays the same role as the desired signal

d(*n*) in the LMS. However, the reference signal *d* (*n*) must be sent from the transmitter to the receiver and must be known for both the transmitter and receiver if the LMS algorithm is used. The CM algorithm does not require a reference signal to generate the error signal at the receiver [21].

4 Simulation Tools

A number of network simulators that are available to simulate different wireless as well as wired networks. The design requires modeling WiMAX network using OPNET simulator and study the network performance with and without SAS. The design of SAS in OPNET has some limitations, since the antenna pattern, in OPNET, is restricted to static antenna patterns which means it is not easily to change its state during the simulation time. Also, physical layer modeling is time-driven and OPNET is an event driven simulation tool. Therefore, it is necessary to explore a platform that supports the investigation of the physical layer simulation, implemented in MATLAB or C, into the OPNET to perform the necessary cross layer simulation requirements [23].
Furthermore, MATLAB offers a way for numerous programs in C/C++ languages to call its functions by its external MX/MEX interface [23]. Since OPNET is based on C++, it is possible to integrate the best of both OPNET and MATLAB with the use of an interface between them as explained in fig. (3).

Figure (3): OPNET MATLAB Interfacing.



5 Network design and Simulation parameters

The purpose of this work, is to examine and compare the behavior of a WiMAX network that support voice application which is delay sensitive application in three cases: the first case when using omnidirectional antenna, the second case when SAS installed at the MSs and the last case applying SAS at BSs. The proposed WiMAX network presented in fig. (4) and the configuration parameters that required to design a WiMAX topology in OPNET summarized in table (1).

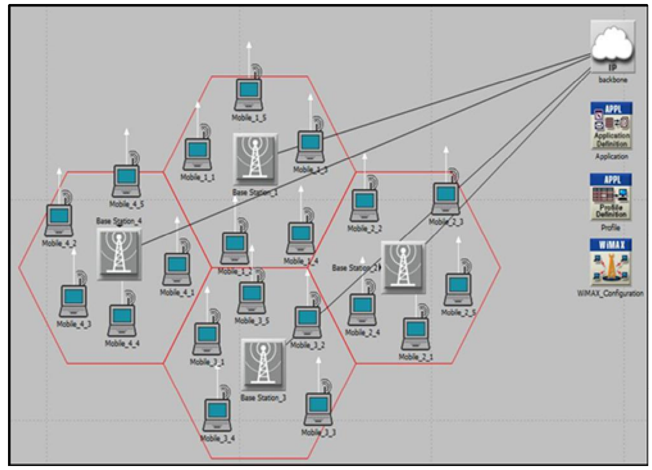


Figure (4): WiMAX network supports voice application.

Table (1): WiMAX Network Parameters.

Parameter	Value
Cell Radius	3 km
PHY Layer Profile	OFDMA
Carrier Frequency	3.5 GHz
Channel Bandwidth	5 MHz
Number of Subcarriers	512
Modulation and Coding	64 QAM, 16 QAM, QPSK
Duplexing Scheme	TDD
BS/SS Antenna Gain	15 dBi
BS/SS Transmission Power	0.5 W
Multipath Channel Model	ITU Vehicular

In this paper, MATLAB was chosen to implement the additional feature provided in WiMAX physical layer named Adaptive Antenna Systems (AAS). The nominated algorithm for AAS design is CMA (described previously in section 3). Table (2) summarize the parameters needed for the design and simulation of SAS in MATLAB.

Table (2): SAS parameters.

Parameter	Value
Number of antenna elements	8
Step size	0.01
Type of array	ULA
Carrier frequency	3.5 GHZ
Angel of arrival	Change with the node mobility (From OPNET)
Initial weights	From OPNET

6 Simulation Results

A set of global and node statistics were selected to measure and compare the performance of WiMAX network with and without SAS. The global statistics include:
Network delay represents the time taken by the packets to travel from source to destination measured in seconds [24].
Network throughput is the total data reaches the receiver from the sender. It is the measurement of data rate or how fast the data can be sent. The common units used to measure throughput is: bits per second (bps) or packets / seconds [24].
On the other hand, node statistics include:
Downlink Signal to Noise Ratio (DL SNR) is the ratio of the mean power of the signal of the packet being received by the receiver to the average power of the background noise that corrupts the signal [25].
Downlink Block Error Rate (DL BLER) is the ratio of received erroneous blocks to the total number of data blocks transmitted.
Downlink Packets Dropped "DL Packets dropped" records the number of the dropped packets (packets / second) in the downlink due to physical layer weakness. Fig. (5) shows the delay of a WiMAX network when the SAS installed at the BS and fig. (6) shows the delay when SAS installed at the MS. As illustrated in the figures, the use of SAS decreases the delay values by 31% and 22% when SAS installed at BS and MS respectively when compared with omnidirectional antenna.

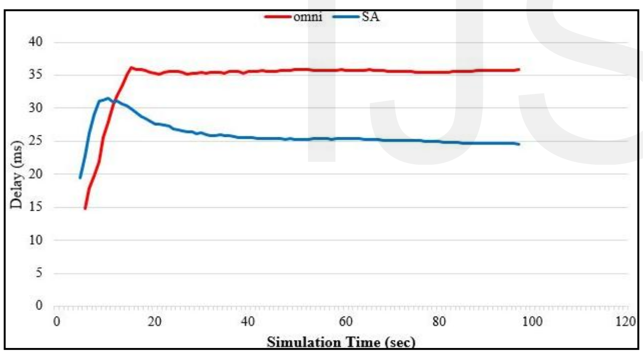


Figure (5): delay of WiMAX network supports voice with SAS at BS.

Fig. (7) shows the throughput for voice project when the SAS installed at BS compared with omnidirectional antenna and fig. (8) shows the throughput when the SAS at MS compared with omnidirectional antenna. It can be noticed from the figures that a higher throughput achieved when SAS integrated with WiMAX BS compared with SAS installed at MS and with omnidirectional antenna. On average the throughput increased by 40% when SAS insatalled at BS and increased by 25% when SAS integrated with MS for both cases compared with omnidirectional antenna. Since the use of SAS of eight ULA, increase the gain of SAS in the desired direction eight times than omnidirectional antenna. Therefore, an increase in the number of antenna by N results in gain improvements by N times.

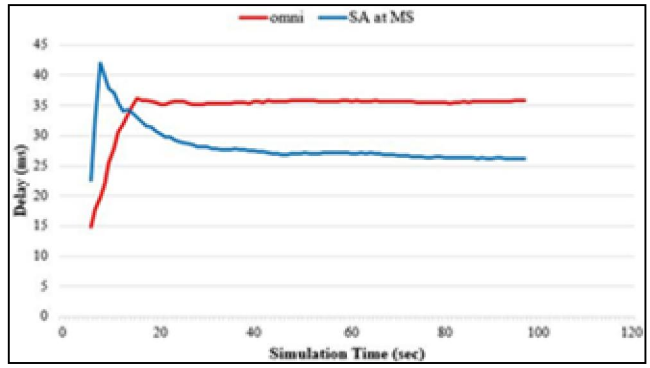


Figure (6): delay of WiMAX network supports voice with SAS at MS.

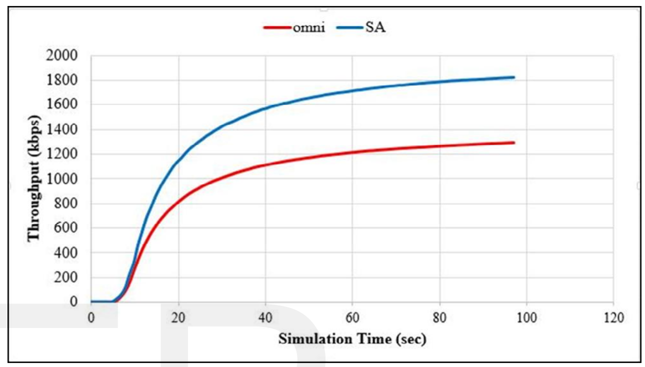


Figure (7): The throughput for voice project when the SAS installed at BS.

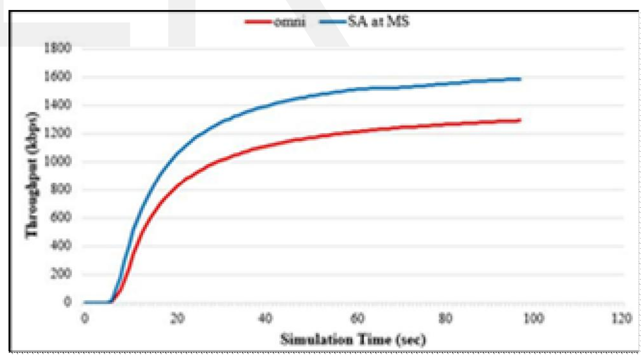


Figure (8): The throughput for voice project when the SAS installed at MS.

The following figures (9), (10a, b) and (11) shown the DL SNR, DL BLER and DL packets dropped respectively in the simulated WiMAX network with SAS at the BS compared with omnidirectional case. SAS focuses the main beam in the direction of user (SOI) and nulls towards interferes (SNOI) leads to an increase SNR and security of the system since it rejects signal from other directions other than the target direction. Therefore, the value of DL SNR increased by 77%, 61%, 87% and 57.6% for BS1, BS2, BS3 and BS4, respectively, compared to omnidirectional antenna. The maximization in DL SNR values results in DL BLER improvement and reduction in the number of lost packets. As presented in fig. (10a, b), DL BLER for BS1, BS2, BS3 and BS4 decreased by 95.6%, 84% 94% and 90% respectively. Also, the average number of packets dropped decreased by 68.4%.

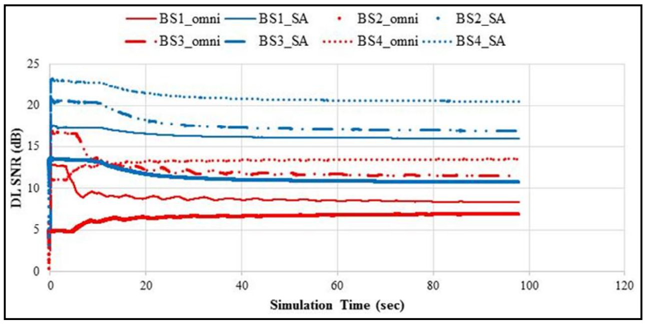
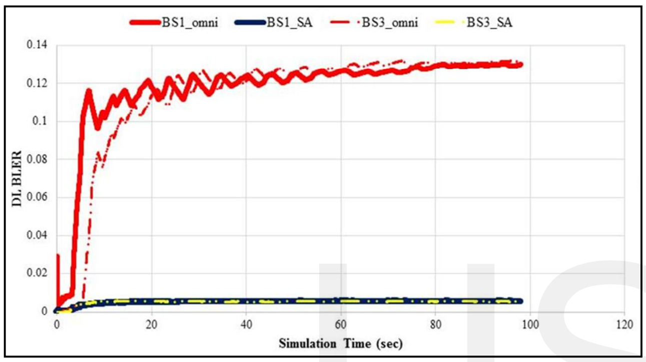
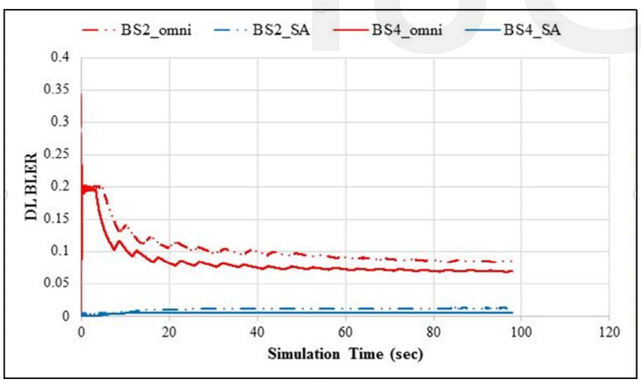


Figure (9): Average DL SNR for WiMAX with Voice Application.



(a) Average DL BLER BS1 and BS3.



(b) Average DL BLER BS2 and BS4.

Figure (10): Average DL BLER for WiMAX with Voice Application.

7 Conclusion

The evaluation of WiMAX network that uses SAS is proposed in this paper. The main objective of this paper is to compare the performance of the WiMAX network with and without SAS.OPNET 14.5 and MATLAB was interfaced to address the effects of SAS in WiMAX network performance. Integrating WiMAX network with SAS boosting up the system performance by decreasing delay and throughput enhancement due to the use of antenna array consists of eight elements will increase the gain of SAS eight times in a certain direction between transmitter and receiver. Thus, the main narrower beam is focused towards AoA between transmitter and receiver leads to higher transmission rate in that direction which results in a higher throughput compared with omnidirectional antenna. While omnidirectional antenna radiates the signal in all direction so most if the energy is wasted and that would result in a low throughput as shown in previous figures. Because the main objective of beamforming is to place the maximum radiation pattern toward Signal of Interset (SoI) and nulls in other directions Signal Non-of Interest (SNoI) according to AoA thus leads to maximize the SNR by ignoring signals from other directions except the target direction. DL SNR improvements result in DL BLER reduction and reduce the number of lost packets compared to WiMAX network with traditional omnidirectional antenna. Also, the simulation of a WiMAX network with SAS equipped at BSs demonstrate higher network capacity and lower delay than installing SAS at MSs.

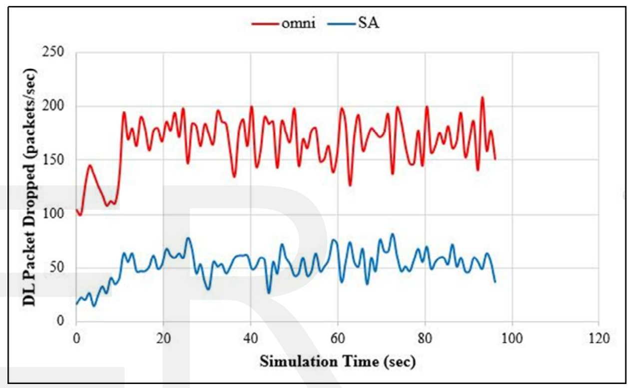


Figure (11): Average DL Packets Dropped for WiMAX with Voice Application.

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