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Throughput and Coverage Evaluation of a Deployed WiMAX Network in Ghana

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***Abstract*– The massive development and investment in the Ghanaian telecommunication sector and the act of deregulation in the industry has necessitated the deployment of Worldwide Inter-operability for Microwave Access (WiMAX) in the 2500-2690 MHz band to help serve the ever increasing needs of broadband internet subscribers in the country. In order to achieve the goal of providing comprehensive network coverage and high capacity WiMAX networks, a realistic physical layer performance evaluation of WiMAX has to be done to enable network operators understand WiMAX performance and provide a guide for future network deployment in Ghana. This paper undertakes a realistic performance evaluation of a pilot WiMAX network in the urban centers of Accra in Ghana. The physical layer performance of the deployed WiMAX systems is evaluated in terms of measured throughput and received power (RSS). This allows for a direct comparison with simulated results. Due to inherent system losses, it was realized that, not even a system with an optimum 2x2 adaptive MIMO antenna configuration was able to achieve the simulated throughput of 8.45Mbps. The results in the study show that, it is possible achieve a throughput of approximately 6.10Mbps downlink and 2.08Mbps uplink with the most robust modulation scheme, and a speed of 60mph in a densely populated urban environment making WiMAX a bright prospect for large-scale deployments in Ghana.**

***Index Terms*– Coverage, MIMO, Throughput and WiMAX**

I. INTRODUCTION

IN a developing country like Ghana, Third generation (3G) cellular and IEEE802.11based Wi-Fi systems are the common solutions for delivering mobile broadband services. Typical outdoor throughput performance of deployed 3G networks measures average rates that users obtain are in the range of 250 kbps to 750 kbps. 3G however, supports high-speed mobility and good coverage distances. Deployed Wi-Fi system supports data rate a little below that of 3G networks mostly over a distance of 500m [1].

The recent exponential increase in the demand for video and multimedia applications in the Ghanaian telecommunication market requires a high speed mobile broadband technology that can support high data rates and mobility. WiMAX technology is a wireless technology that promises high throughput broadband access over long distances. It provides high data rate, coverage, quality of service (QoS) and mobility that users need for video and multimedia services [2].

Since WiMAX promises last mile broadband solution at cheaper cost due to its simple internet protocol (IP) architecture, network operators and government have started its deployment in Accra inthe 2.50GHz-2.69GHz frequency band. Both network operators and subscribers in Ghana are keenly expecting high performance from the newly deployed pilot WiMAX networks [3]. Their anticipation is based on theoretical performance values and documented performance field data from deployed WiMAX sites in US, Europe and Asia. There is, however, lack of availability of performance data in Sub-Saharan Africa. It is therefore necessary to know the basic capabilities of the newly deployed WiMAX network in Ghana.

This paper therefore seeks to evaluate the throughput performance and undertake a coverage analysis of deployed WiMAX network in Ghana through simulation and field measurements. This work will make available performance data that will enable network service providers, planners and designers to make informed decision when deploying and integrating WiMAX into their network infrastructure.

The paper is organized as follow; Section II of the paper presents a review of relevant literature, the measurement setup and procedure, the physical performance and throughput performance are presented and analyzed in Sections III and IV respectively.

II. LITERATURE REVIEW

With the ever-increasing need for mobile communication and the emergence of many systems, it is important to design WiMAX networks that will conform to the performance it promises. There have been numerous simulation studies and field measurement trials of WiMAX network which involves system coverage, signal strength and available transmission rate done in US, Europe and Asia.

In [4], real time images and Voice over IP (VoIP) were transmitted through Skype software by using WiMAX deployed in the 2.50GHz-2.69GHZ band, and this information are connected to exchange wireless monitoring servers to execute data monitoring and analysis. Comparative analysis was then made and the maximum measured throughput was 3.86Mbps as compared to the simulated throughput of 10Mbps.

The authors in [5] realized that the real field performance was different from the documented performance. At about 1km away from the Base Station (BS), the network connection dropped. Even though higher throughputs were measured up to about 1km away from the BS, the evaluated network couldn't help deliver WiMAX promise of providing last mile broadband solution.

In [6] an evaluation was carried out on a 3.5MHz channel bandwidth typical for the 3.5GHz WiMAX band in Europe. The maximum measured downlink and uplink throughput were 11.95Mbps and 8.9Mbps respectively. Measurements were taken from 95 out of 152 locations and the results analyzed. The results of the field experimental work indicated a moderate correlation between network performance, distance and Carrier to Interference plus noise ratio (CINR). A model relating to the Critical CINR to measured data rate was developed that greatly helped WiMAX operators in Europe to enhance network performance.

The authors in [7] also conducted an extensive field parameter measurement and the results showed a wide disparity between the coverage promised by WiMAX in the two separate deployment scenario. It is worth mentioning that all the measurements and simulation works done in these studies were done in USA, Europe and Asia as stated before. The authors in [7] established that environmental conditions play an important role in network performance. It is imperative for us to do an independent evaluation of the pilot WiMAX network deployed in Ghana to come out with the correct performance parameters pertinent to the Sub-Saharan environment to enable our network operators effectively deploy WiMAX to afford subscribers the chance to benefit from this open standard.

III. SIMULATION ANALYSIS

This section discusses the simulation model and theoretical foundations used in estimating the coverage range and throughput of the deployed WiMAX network.

A. Coverage Estimation

The simulation model adopted for analyzing the capacity and coverage range of the deployed WiMAX network is based on the behavior of users and the distribution of Customer Premise Equipment's (CPEs) in the cell. The simulation was done using the stochastic distribution of CPEs within the cell site as shown in Fig. 1. The model consists of a circular placement of nodes in a hexagon with one WiMAX Base Station and ten (10) Subscriber Stations (SS) which were 2.91km and 3.0km respectively apart from the BS. These nodes are fixed and mobile nodes since mobility has been configured.

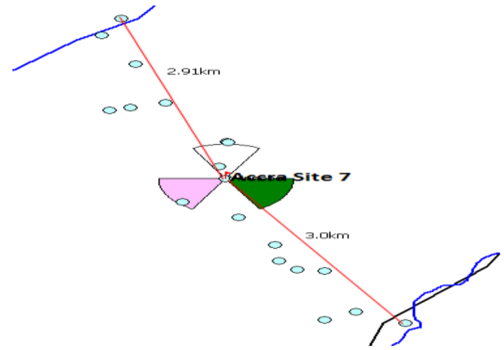

Fig. 1. Dispersion of CPE in the pilot network

In the coverage modeling, a system which employs Adaptive Modulation and Coding (AMC) is considered. The network has different physical layers *(i=1…N)*, where the first physical layer (i=1, BPSK for WiMAX) is the most robust one and the last physical layer (i=N, 64 QAM 3/4) is the most spectral efficient one. The probability of using a certain physical layer i, if it is the only one, in a cell with a radius R (as shown in Fig. 2) is given by [8]:

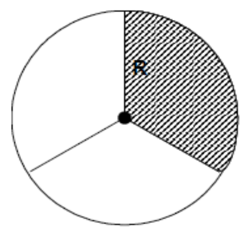

Fig. 2. Single cell scheme with a 3 sectors sector

$$P_i = \frac{2}{R^2}\int_0^R p\left(P_r(x) > P_{s,i}\right).xdx \qquad (1)$$

Where $P_r(x)$ is the received power and $P_{s,i}$ is the threshold received power of the physical layer i.

For a system employing Adaptive Modulation and Coding the effective utilization of a physical layer is given by the difference between the probability of using that physical layer and the probability of using the less robust one ($i+1$). The received power $P_r(x)$ is given by the following relationship [9]:

$$P_{rx} = P_{tx} + G_{tx} + G_{rx} - PL \qquad (2)$$

P_{rx} is the power received and G_{rx} is the receiver's antenna gain in the direction of the transmitter. Here, the P_L term includes all attenuation due to path loss. Eq. (2) describes the aggregate gain and attenuation of many competing signals. It also assumes that the radio link is isolated from any sources of external noise in the environment (thermal noise and interference from other transmitters). Commonly, the signal quality at a given point is written as the ratio between Signal and Noise. Alternately, if interference from a known set of interferers is included, the Signal to Interference and Noise Ratio (SINR) is defined as [10]:

$$SINR = P_{rx} - \left(N + \sum_{j}^{n} I_j\right) \quad (3)$$

For a given real design and modulation scheme, there is a known relationship between Signal to Noise Ratio (SNR) and bit error rate. Using this relationship, we can determine the minimum detectable signal for a given radio as a function of the acceptable error rate: P_e, where P_e is the probability of bit error. Then, determining the points that are covered is simply the set of receiver locations that satisfy the inequality [10]:

$$P_{tx} + G_{tx} + G_{rx} - PL \geq MDS(P_e) \quad (4)$$

Because the P and G terms are known for a network under evaluation, the coverage simulation becomes predicting the quantity PL given what is known about the environment, the distribution of users and the radio link.

B. Capacity Analysis

In order to effectively estimate the average user throughput, the system deployment in terms of Base Station placements, sectorization and frequency reuse planning has to be taken into consideration. The number of users, placed throughout the cellular area, is considered and the effect of channel variations such as path loss and shadow fading are incorporated into the analysis. Frequency reuse scenarios may be described by denotation "NcxNsxNf", where Nc is number of independent frequency channels in the WiMAX network, Ns is the number of sectors per cell and Nf is the number of segments in exploited frequency channel is used for the system level simulation. For example Fig 3 shows the WiMAX network deployment for 1x3x1 frequency reuse planning.

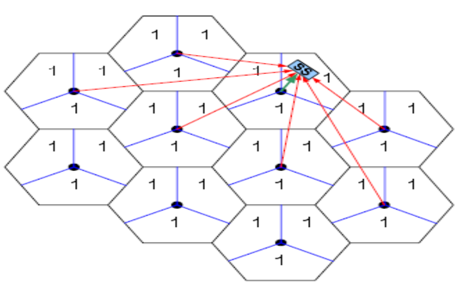

Fig. 3. Deployment scenario

A single sub-carrier in the downlink mode is considered in the analysis. If a user M_i is attached to a BSF_i, it will be denoted by $F_i = \Phi(M_i)$. The propagation path gain $g_{F,M}$designates the inverse of the path-loss (PL) between F_i and user M_i, $g_{F,M} = \frac{1}{\mathrm{PL}_{F,M}}$. It is assumed that $g_{F,M} = Ar_{g_{F,M}}^{-n}$, where A is a constant, $r_{F,M}$is the distance between F_i and user M_i and $n\,(> 2)$is the path-loss exponent. The terms are defined as follows:

- P_{Tx} is the transmitted power per sub-carrier. We assume that the output power per sub-carrier is constant.
- $P_r = P_{Tx} g_{F,M}$is the useful power received at user M_i from station F_i.
- $B$is the total system bandwidth and $B_{Fi}$is the bandwidth dedicated to userM_i.
- R, $R_c$and $R_u$are respectively the cell radius, half distance between base stations and network range.
- P_M, P_{Fi}, and N_M, are respectively the user density, BS density and number of users per cell.
- D_u, is the data rate allocated to a user and D_T, is the total cell data rate, such that $D_T = N_u D_u$,
- N_{BS}, represents the total number of base stations in the network.
- Shannon capacity in bps/Hz is a measure of spectral efficiency.

The total amount of power experienced by a user u in a cellular system can always be split up into three parts: useful signal P_r, interference and noise. It is common to split the system power into two terms [11]:

$$I_u = I_{int} + I_{ext} \quad (5)$$

Where I_{int} is the internally received power and I_{ext} is the external interference. The useful signal P_r is considered to be included in theI_{int}. In a CDMA network, the lack of orthogonality induces intra-cell interference. In an OFDMA network, there is a perfect orthogonality between users and thus $I_{int} = P_r$. The authors in [12] have defined the interference factor for M_i, as the ratio of total power received from other BSs to the total power received from the serving $F_i = \Phi(M_i)$

$$f_u = \frac{I_{ext}}{I_{int}} \quad (6)$$

The quantities f_u, I_{ext}, and I_{int} are location dependent and can thus be defined at any location r as long as the serving BS is known. In an OFMDA network, I_{ext} is the total interference, and thus f_u, is the inverse of the signal to interference ratio (SIR) per sub- carrier. In order to simplify the analysis noise will be neglected. This is a common assumption for macro-cells in dense urban areas. In this case, the signal to interference plus noise ratio (SINR), Υ_u can be approximated by the SIR [13]:

$$\Upsilon_u \approx \frac{P_r}{I_{ext}} = \frac{1}{f_u} \quad (7)$$

As a consequence, it is clear that the approach developed in [13] can be adapted to OFDMA networks, as soon as the orthogonality factor considered in CDMA networks is zero. In this case, SIR per sub-carrier is simply the inverse of the interference factor considered.

$$\Upsilon_u = \frac{r_u^{-\eta}(\eta - 2)}{2\pi\rho_{BS}(2R_c - r_u)^{2-\eta}} \quad (8)$$

Eq. (8) gives the expression for SIR of a subcarrier for a user at distance r_M. Since SINR, capacity, and r_M are always specific to a user, in the rest of the analysis, the subscript M is omitted for these three parameters. With $P_{Fi} = \frac{1}{2\sqrt{3}{R_c}^2}$ and introducing the normalized distance r such that $r = \frac{r}{R_c}$, the expression for SINR can be rewritten as

$$\gamma IFR1(r) = \frac{\sqrt{3}}{\pi}(\eta - 2)(2 - r)^{-2}\left(\frac{2}{r} - 1\right)^{\eta} \qquad (9)$$

By using Shannon's capacity formula, capacity (in bps/Hz) as a function of variable r in a reuse K scheme is given as:

$$C_{IFR1}(r) = \log_2[1 + \gamma IFRK(r)] \qquad (10)$$

It is assumed that a scheduler guarantees throughput fairness among users of the cell. Users are assigned the bandwidth in a way that resultant data rate for every user, D_u, is the same. The further the distance of a user from the BS, the lower the available capacity, and as such a higher number of sub-carriers is allocated to it. As SINR and capacity depend on r, let B_u be the bandwidth allocated by the scheduler to a user at distance r from the BS. User data rate, B_u, can now be written for any r:

$$D_u = B_u(r)C(r) \qquad (11)$$

Under the constraint that total cell bandwidth B cannot be exceeded, that is:

$$B = \iint_{cell\ area} B(r)\rho_u ds \qquad (12)$$

Integration is done and the total bandwidth can be re-written as:

$$B = 12\int_0^{\pi/6}\int_0^{R_c/\cos\theta} B_u(r)\rho_u r\, dr\, d\theta \qquad (13)$$

If N_u is the number of users in a cell, user density is $P_{Fi} = \frac{N_u}{2\sqrt{3}{R_c}^2}$. Using Eq. (11) and Eq. (13), the user data rate is given as:

$$B_u = \frac{\frac{\sqrt{3}B}{6}}{N_u\int_0^{\frac{\pi}{6}}\int_0^{1/\cos\theta}\frac{r}{C_{IFR1}(r)}dr d\theta}$$

Where $C_{IFR1}(r)$ is given by Eq. (10).Since all users receive same data rate and there are N_u users in the cell, total cell data rate is $D_T = N_u D_u$ and can be written using previous result as:

$$D_{T,IFR1} = \frac{\frac{\sqrt{3}W}{6}}{\int_0^{\frac{\pi}{6}}\int_0^{1/\cos\theta}\frac{r}{C_{IFR1}(r)}dr d\theta} \qquad (14)$$

It can be seen from Eq. (14) that, the total cell data rate neither depend upon the number of users in the cell nor upon the value of R_c. The change of variables $\theta = z$ and $r = \frac{y}{\cos z}$, provides the equivalent equation:

$$D_{T,IFR1} = \frac{\frac{\sqrt{3}W}{6}}{\int_0^{\frac{\pi}{6}}\int_0^1((y/\cos\theta)/\cos z C_{IFR1}\left(\frac{y}{\cos z}\right))dy\, dz}$$

To avoid the complexity of calculating double integral, it is also possible to integrate B_u over a disk, whose area equals the hexagon area. Such a disk has a radius, $R_e = \sqrt{\frac{2\sqrt{3}}{\pi R_c}}$. Using the above approach, total cell data rate can be approximated as:

$$D_{T,IFR1} = \frac{\sqrt{3}W/\pi}{\int_0^a\left(\frac{r}{C_r}\right)dr} \qquad (15)$$

For PUSc with reuse higher than one, the analytical study is very similar to the reuse 1 case above. The difference lies in the fact that co-channel BS are considered in interference calculation and thus the half-distance between BS and BS density have to be modified. As a consequence, previous analysis results are still valid provided that $R_c$is replaced by $\sqrt{K}R_c$ and BS density is divided by K, that is,P_{Fi} is replaced by $\frac{P_{Fi}}{K}$. Hence usingEq. (9), SINR is given as:

$$\Upsilon(r) = \frac{r^{-\eta}(\eta - 2)}{2\pi\,.\,\frac{\rho BS}{K}(2\sqrt{K}R_c - r)^{2-\eta}} \qquad (16)$$

Using the same distance normalization as before and after few manipulations, SINR can be written as:

$$\Upsilon PUSC(r) = \frac{K\sqrt{3}}{\pi}(\eta - 2)(2\sqrt{K} - r)^{-2}\left(\frac{2\sqrt{K}}{r-1} - 1\right)^{\eta}.$$

Hence capacity (in bps/Hz) for PUSc with reuse K can be given as:

$$C_{PUSc}(r) = \log_2[1 + \gamma IFRK(r)] \qquad (17)$$

For total cell data rate, Eq. (14)is still valid provided that $C_{IFR1(r)}$ is replaced by Eq. (17) and cell bandwidth is divided by 3.

C. Simulation set up

The simulation parameters are summarized in Table I. Genex-Unet Modeler was used with MATLAB tool to facilitate the usage of in-built models of commercially available network elements, with reasonably accurate emulation of various real life network topologies.

Table I: Simulation Parameters

Resource frequency	2.5-2.53GHz
Channel Bandwidth	10MHz
Frequency reuse scheme	FFR, PUSC
Average users per sector	10
Fast Fourier Transform (FFT) Size	1024
Subcarrier spacing	10.93 kHz
Useful symbol time	91.4µs
Guard time	11.4µs
OFDMA symbol time	102.8µs
Gain	18dBi
Horizontal Beamwidth (3dB)	60°
Vertical Beamwidth (3dB)	8°
Maximum power	43dBm
Antenna height	40m
CPE Antenna Config	2T2R
Height of CPE Antenna	2m

Different frequency reuse scenarios have been designed in our simulation with different FFR and PUSC schemes to measure the performance of some parameters such as throughput and network coverage. The coverage simulation of the site has also been done to help analyze the strength of the received power within the site. The capacity with different reuse factors and various Downlink/Uplink (DL/UL) schemes have been simulated. The final site radio Link budget was done with Genex-Unet and discussed in the subsequent sections.

IV. FIELD MEASUREMENT

A. Setup

The main objective of this research is to make a performance comparison between simulation results and field experimental data. In order to achieve that objective, the performance evaluation of a WiMAX network deployed in the urban center of Accra has been done. The distance and coverage testing is one of the most significant tests which has been done, since this test is of very high importance to subscribers in the study area. The measurement setup comprises; GPS, Dongle XCAL-X, Laptop with a XCAL-X software, Van.

In order to increase the subscriber unit's distance from the BS and measure the link quality and throughput performance for all locations, variable downlink/uplink ratios were chosen to balance the downlink and the uplink throughput, while the other parameters remained the same.

B. Field Measurements Summary

The field measurement was carried around the University of Ghana Campus. This area provides a measure of the WiMAX network's radio distance in a typical urban area. This particular location was chosen because of its representative nature of urban complications in deploying outdoor wireless networks. Most areas within the measurement areas are fairly obstructed, with a few segments surrounded by dense foliage. There are high buildings in the vicinity of the test road in this area.

V. SIMULATION AND MEASUREMENT RESULTS

A. Throughput Simulation

The capacity simulation of the WiMAX Base Station based on the simulation parameters is summarized in Fig 4 and Table 2. The results in Fig 4 show the theoretical performance of the MIMO configuration whiles Table 2 show the simulated performance of the MIMO configurations based on the network simulation parameters used at the site under consideration.

In Fig 4, With 10 MS, received antenna gain of the base station of $18dBi$ and with maximum transmitted power and equivalent radiated power of 18dBm and 21dBm respectively, the theoretical capacity of the 4*4 MIMO System for SNR value of $30dB$ is around 35 Mbps.

Different frequency reuse scenarios have been designed in our simulation with different PUSC schemes to measure the performance of some parameters such as throughput and network coverage. The result in Fig 4 is similar and complements the results obtained for the theoretical performance of MIMO in outdoor environments in [14].

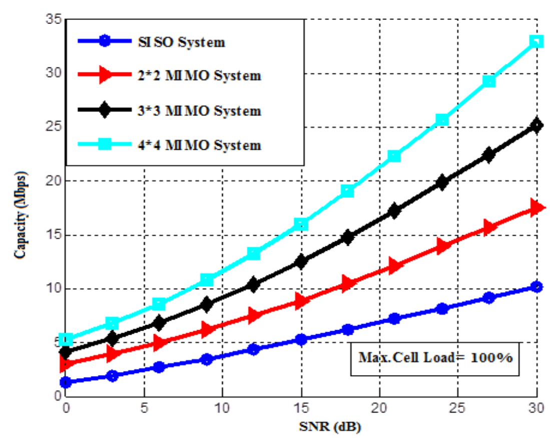

Fig. 4. Open Loop simulation results

Table II: Open Loop Throughput Simulation Results

Bandwidth	Permutation	TDD Split Ratio	WiMAX Carrier Average Throughput per sector			
			2T2R Adaptive MIMO(Mbps)		4T4R adaptive MIMO(Mbps)	
			DL	UL	DL	UL
10 MHz	PUSC with all SC 1x3x3	26:21	5.73	2.18	5.99	2.76
	PUSC with all SC 1x3x3	29:18	6.64	1.81	6.93	2.30
	PUSC with all SC 1x3x3	31:15	7.24	1.45	7.56	1.84
	PUSC with all SC 1x3x3	35:12	8.45	1.09	8.82	1.38

B. Coverage Simulation

The coverage simulation of the site has also been done to help analyze the strength of the received power within the site. The capacity with different reuse factors and various Downlink/Uplink (TDD split) schemes have been simulated. The final site radio Link budget was done with Genex-Unet.

Table 1 shows that at 10MHz the OFDMA symbol time is 102.8 microseconds and so there are 48.6 symbols in a 5 millisecond frame. These symbols will be used for the DL/UL split ratios which will be used for the average throughput per sector simulation. Out of the 48.6 symbols, 1.6 symbols are used for Transmit-Transmit Gap and Receive-Transmit Gap leaving 47 symbols which will be split for the DL/UL ratios. Path loss simulation using SUI with Multiuser Detection (MUD) at a cell range of 1.357 km was around $110.67dB$. It was also realized that as the cell range and allowable path loss in dB decreases, the cell load increases dramatically. Interestingly, similar results were obtained in [15] where they further observed that BS with multiuser detection (MUD) receivers can provide good coverage even with high system load after initial deployment and, finally, concluded that the effect of MUD on cell range depends on propagation environment. It worth noting that the performance of the of the 3x3 MIMO configuration is just below that of 4x4, hence, it could be used when the 4x4 is not available because for signal to noise ratio of 30dB, it is possible to achieve a capacity of 25 Mbps. The capacity performance for SISO as well as the 2x2 system is not encouraging as for SNR of 30dB the capacity is 10 Mbps and 17 Mbps respectively.

The link budget for the network site under study is done using Genex-Unet. The final radio (link budget) is simulated using $Eqn.(2)$ and $Eqn.(4)$

The link budget for the area under study is shown Fig. 5.

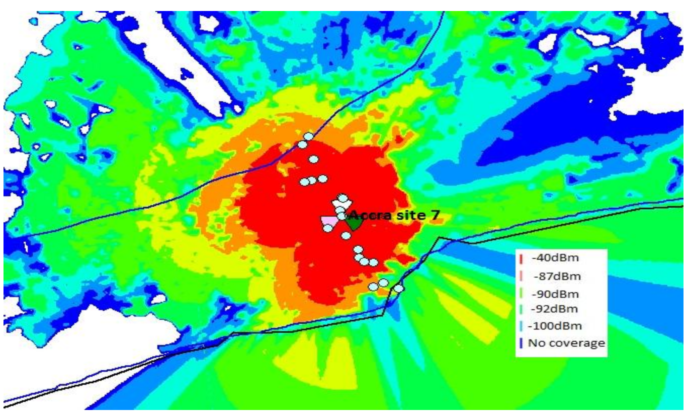

Fig. 5. Radio network simulations

The simulated center RSS of -40dBm was obtained at a modulation scheme of 64-QAM up to about 620m away from the BS. The simulated cell edge RSS value was -92dBm at a modulation scheme of QPSK at a distance of about 4km away from the BS.

C. Coverage Measurement

The Received Signal Strength (RSS) and Carrier to Interference plus Noise ratio (CINR) was done in over 16,000 locations within the cell site.

The measured RSS and CINR values were mapped with the GPS information of the area with the color path showing the amount of measured RSS as shown in Fig 6. The highest RSS value of -45dBm was measured at a distance of 500m away from the base station as compared with the simulated value of -40dBm. The measured cell edge RSS value was -100dBm at about 4km away from the BS.

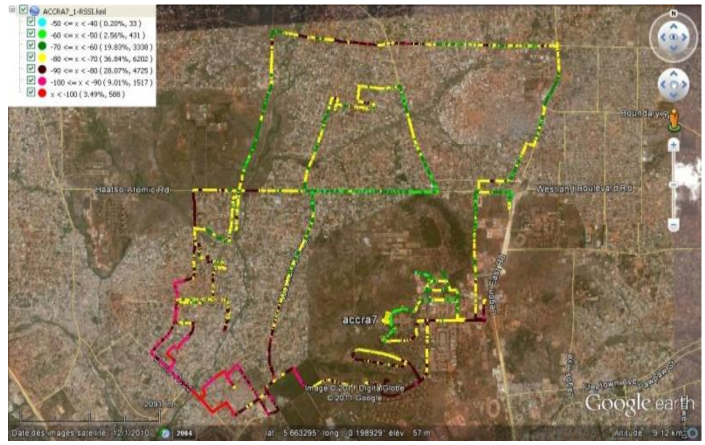

Fig. 6. Locations of RSS measurement within the BS

The summary of the RSS measurement is shown in Fig. 7.

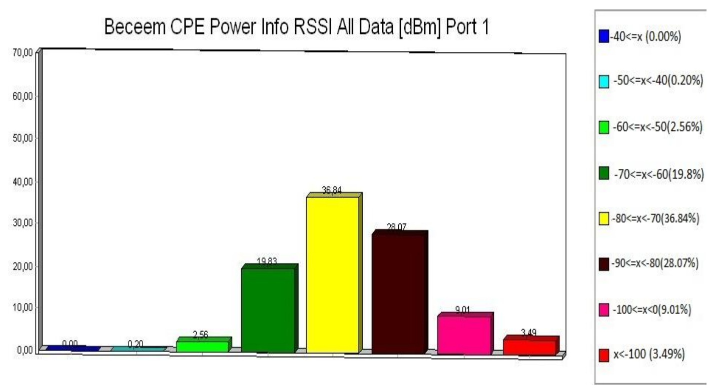

Fig. 7. Summary of RSS measurements within the site

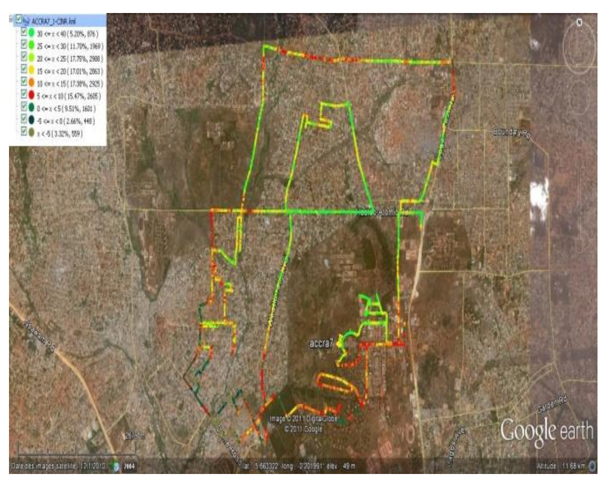

Fig. 8. Location of CINR measurements within the site

The CINR values measured between the base station and the mobile client are shown in Fig. 8 and Fig. 9. The highest measured CINR of 35 dB was measured at a modulation of 64-QAM. This value was measured from the BS to a distance of 500m at 876 locations along the route.

The CINR measurement with respect to the measured distances is summarized in Fig. 10. These parameter measurements will form the basis for determining the critical CINR.

About 79.29 % of the measured CINR values were between 25dB to 5dB. The least measured value of -6dB was obtained at a modulation of QPSK at a distance of 4km before connection was dropped.

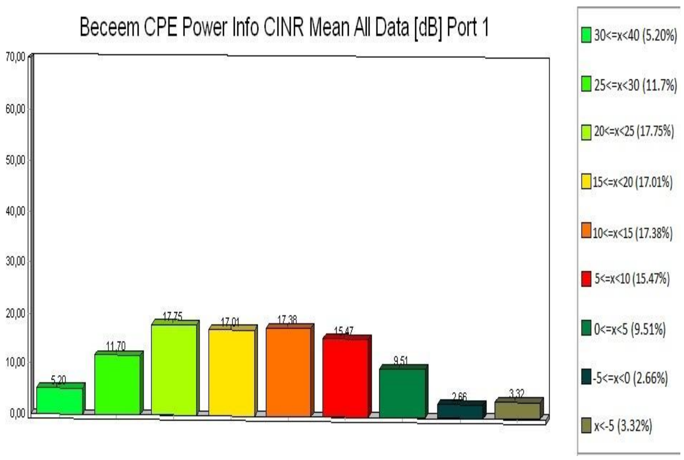

Fig. 9. Summary of CINR measurements within the BS

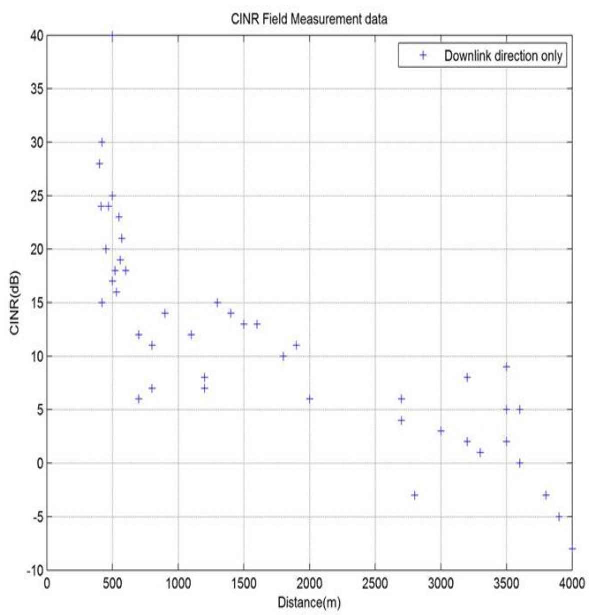

Fig. 10. Summary of CINR measurements

D. Throughput Measurement

The subsequent tests focused on the network's throughput performance. 20Mb FTP packet traffic was transmitted from a remote server to the subscriber unit, which was located in the drive test Van. The Base station's transmit power was set to 30dBm. At the beginning of throughput test, the Van was close to the Base station, and then moved away along drive test route. After the subscriber unit was out of communication range and lost the connection, the van was turned around and moved back towards the location of the Base station. The Van was kept at a steady velocity of 60 mph during the test. Fig. 11 summarizes the throughput measurement and illustrates the downlink and uplink throughput measurement within the site with respect to CINR. The maximum measured DL and UL throughput values of 6.10Mbps and 2.08Mbps respectively were obtained at a distance of 400m away from the BS.

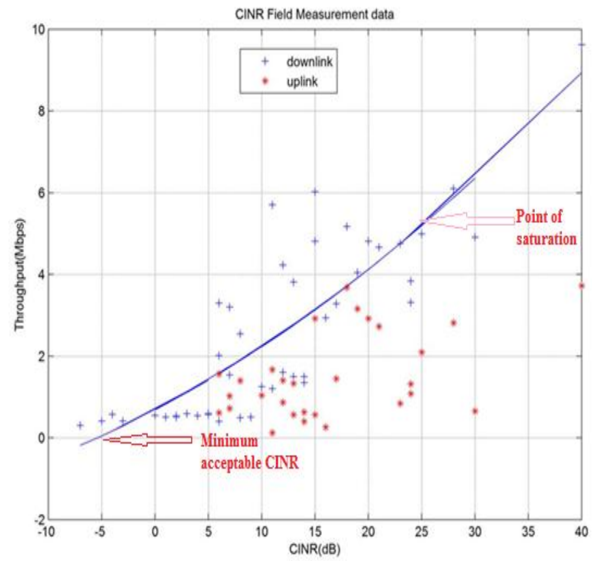

Fig. 11. Throughput measurement within the site

It was observed that, the downlink performance was quite stable at 5.6 Mbps within the range of 500m to 1.5km as shown in Fig. 11.The least measured DL and UL throughput of 300kbps and 156kbps respectively were measured at a distance of about 4km away from the BS. From the field measurement results, the RSS value of -100dBm was measured at a distance of 4km at a modulation scheme of QPSK as against the simulated distance of 5km. This measured distance is adequate to provide ubiquitous coverage to all the CPEs in the service area. From the US Federal Communication Commission's broadband speed guide and similar work done in [4] in Europe and United states, the measured cell edge DL throughput of 300kbps is adequate to support standard video conferencing applications, hence, the network performance of the deployed network is adequate enough to serve its intended purpose.Analysis of coverage of the network conducted in this research has revealed that the propagation environment affects the cell range with a given cell loading. The stimulated results shows a maximum RSSI value of -40dBm at a distance of 500 meters close to the BS as compare to field measured value of -45dBm at the best modulation scheme of 64QAM and minimum simulated RSS value of -92dBm at a distance of 4km as against -100dBm at robust modulation scheme QPSK at the cell edge. The maximum field measured downlink and uplink throughput are

6.1Mbps and 2.08 respectively as compare to the maximum simulated downlink and uplink throughput value of 8.45Mbps and 2.18Mbps respectively for an adaptive 2x2 MIMO antenna configuration.

VI. CONCLUSION

In this study, we have used simulations and field measurement data to evaluate the coverage and throughput performance of a deployed WiMAX network in the urban centers of Accra in Ghana. Results from the simulation stage results showed that, the deployed 2 x 2 MIMO system could support a maximum downlink and uplink data rate of 8.45 Mbps and 2.18 Mbps respectively at a maximum distance of 4km. The results obtained from field measurements were maximum downlink and uplink rate of 6.1 Mbps and 2.08Mbps. The results in the study shows that, the deployed mobile WiMAX network with 1 x 3 x 3 frequency reuse scheme with adaptive 2 x 2 MIMO system provides throughput and coverage values comparable to simulated values. From the analysis of field measured results, the greatest advantage of the deployed WiMAX BS over existing mobile broadband systems is the high throughput measured over longer distances. Even in its early deployment stage in the sub-region, WiMAX is providing 5 times the throughput performance of existing 3G networks in the country. With the next iteration of the standard, 802.16m, WiMAX will evolve and offer even greater speeds. From the evaluation, it can be seen that the WiMAX networks can serve the insatiable demand for wireless broadband services in Ghana.

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