Performance & Capacity of Mobile Broadband WiMAX (802.16e) Deployed via High Altitude Platform

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Abstract- **This paper investigates the performance and capacity of a WiMAX 802.16e cellular system deployed via High Altitude Platform (HAP WiMAX) through extensive simulations. HAP WiMAX link performance is evaluated for a wide range of channel conditions in terms of elevation angle and signal to noise ratio (SNR) through a comprehensive link level simulator based on 802.16e. The obtained results are then used to investigate HAP WiMAX cellular system performance in terms of user capacity, cell throughput and Grade of Service (GoS) by modelling a multi cellular scenario. The performance is evaluated for frequency reuse of 1 and 3 with and without Adaptive Coding and Modulations (ACM) for two different user data rates. Simulation results show that, cell throughputs as high as 3.6 Mbps per cell can be achieved for 5MHz channel bandwidth while attaining an acceptable GoS with a minimum frequency reuse of 3 in a HAP WiMAX 802.16e system.**

Keywords: WiMAX, HAP, Capacity, Performance.

I. INTRODUCTION

HAPs are stratospheric platforms deployed at heights ranging between 17 and 30km [1]-[8], [10]. They can be flying air crafts for temporary deployments, or stationary or quasi stationary air borne platforms with a typical life time of weeks to months. Recent advancements in aerodynamics, control systems, avionics and power electronics have made commercial realisation of such platforms more feasible than ever. The main features of HAPs which make them more attractive than terrestrial infrastructures are: their low cost, easy, quick and incremental deployment capability and large coverage area. Other than this, HAPs based cellular deployment also allows for a central resource scheduling in contrast to terrestrial network where these efficient central resource scheduling can not be exploited without heavy signalling overheads. Further HAPs also offer some major advantages over satellite systems that are: low propagation loss, smaller delays, easy and cheaper launching process.

Because of such advantageous characteristics, HAP based cellular deployment can be used to compliment or replace terrestrial and satellite networks. Other than this, HAPs can also be a good solution to replace a failed ground infrastructure, in case of emergency, due to their quick deployment capability.

On the same time WiMAX802.16e has emerged as a new broadband communication standard with a potential to support a diverse range of services in mobile mode with high data rates and fine granularity of QoS.

Deployment of WiMAX via HAP is a concept which has potential to provide high data rates promised by WiMAX combined with all the technical and commercial advantages of HAPs compared to terrestrial and satellite infrastructures.

Instead of all these potential advantages, limited number of studies [1]-[8] has been carried out on performance evaluation of HAP WiMAX system. Studies reported in [1]-[4] are focusing on the link level performance only, in a particular frequency band, mostly at Ka band [1] [3][4]. A few studies that consider performance aspects of HAP WiMAX at system [5]-[8], are based on basic analytical approach. They are mostly limited to derivation of SINR in HAP WiMAX alone or in case of its coexistence with terrestrial networks. None of these studies incorporates in its analysis the link level performance of WiMAX in HAP channel. Further these studies do not include some pragmatic features of a real HAP cellular system namely shadowing and dynamic interference in their assessment of performance. So to the best of our knowledge, no such work has been reported in literature which evaluates HAP WiMAX802.16e performance and capacity for a multi cellular scenario while considering both link level and system level aspects in detail. The study presented in this paper fills this vacuum.

In this paper, performance of WiMAX link is first evaluated in a broadband channel model for HAP at 5 GHz. An 802.16e based simulator is used to evaluate the link level performance. The results obtained are then fed to System Level simulator (SLS) which models a two tier multi cellular WiMAX system deployed via HAP. For a realistic analysis, the SLS models all the important factual features of HAP WiMAX which can potentially affect its performance. These features include correlated shadowing and its strong dependency on elevation angle in HAP scenario; appropriate path loss model, realistic antenna footprints, and dynamically updated interference form the two tiers of cells.

Performance of HAP WiMAX system is studied with frequency reuse of 1 and 3, with and without ACM for two different user data rate. Large number of simulations is run for each system configuration to obtain reliable average results on Monte-Carlo principle. Impact of different system parameters on the overall performance of the system is investigated in detail. Summary of selective results is presented in terms of average user capacity, cell throughput and GoS.

The rest of this paper is organised as follows: Section II describes the details of link level simulation setup. Section III presents link level performance results. Section IV provides brief overview system level simulation setup. Section V presents the results of system level performance and capacity analysis. Finally section VI draws conclusion of study and presents ideas for future work.

II. LINK LEVEL SIMULATION SETUP

Link level performance of HAP WiMAX is investigated using a simulator based on 802.16e PHY [11]. Advance features of WiMAX i.e. Space Time Block Coding (STBC), and Hybrid Automatic Repeat request (HARQ) are not included in this study, for simplicity. Convolution Coding with Tail Biting (CCTB) is used as Forward Error Correction (FEC) scheme. Coding block and corresponding block sizes are allocated to user based on the number of slots assigned to user. The coded bits are punctured and then interleaved. The resulted data are then mapped to one of the constellations (QPSK, 16QAM, and 64 QAM). The constellation data then are mapped into the allocated data region based on the selected subcarrier permutation zone format. The resulted data is then OFDM modulated and transmitted over multi path channel.

Multi path channel model used in the link level simulations is based on Jake's algorithm [9]. Doppler spread and relative delays of multipath components and their relative power levels for various elevation angles are determined according to [10] with one simplification that the scattering object and receiver are assumed to be in the same plane. This is a reasonable assumption because the heights of scatterers (that can be 0 to 50 meter) are negligible as compared to the height of HAP (20km in this study).

At the receiver after OFDM demodulation (guard time removal, FFT, zero depadding) each user's assigned pilot and data subcarriers are extracted. Then the extracted data is soft bit demapped to compute the reliability of the constituent bits of the received constellation symbol. Soft bit demapper requires corresponding subcarrier complex gain value and the additive noise power. In this simulator ideal channel values have been used for detection of data.

Table I shows a summary of WiMAX simulator setup parameters used in this study. For detailed parameter list o 802.16e standard [11]. The Channel parameters used to simulate HAP channel in this study are listed in Table II.

Table I.

WiMAX SIMULATOR SETUP PARAMETERS

BW	5MHz
FFT Size	512
Guard Time	¼ of Symbol duration
Frequency	5GHz
Coding	CCTB
Coding Rate	1/2
Sub-carrier Allocation Mechanism	PUSC
PUSC carrier allocation Type	Distributed Clusters
Modulation Type	QPSK,16QAM and 64QAM
STBC/MIMO	Off
HARQ	Off

Table II.

HAP CHANNEL PARAMETERS

HAP Height	20km
Area Type	Sub urban
User Speed	3Km (Pedestrian)
Number of Multipaths	4
Maximum scatterer distance	100m
Scatter distribution Type	Uniform
Elevation Angle	10^o to 90^o
SNR	2-20dB

III. LINK LEVEL PERFORMANCE RESULTS

Figures 1-3, show the results of link level performance evaluated for HAP WiMAX link at 5GHz. The results are shown in terms of packet error rate (PER) against a wide range or E_b/N_0 for elevation angles from 10 to 90 degree in steps of 10 degree. The link performance for each of three modulations schemes supported by 802.16e i.e. QPSK, 16QAM and 64QAM has been plotted. Results only for down link are shown for brevity. PER curves show, the performance in general is better for higher elevation angles compared to low elevation angles. This trend is consistent for all the three modulations schemes simulated. It is further observed that the change in PER is not simply proportional to change elevation angle. This is because the Rice-factor [2] and power delay profile [10] in HAP channel, both change nonlinearly with the elevation angle. There is another important observation that is crucial to analyse the role of ACM while investigating system level performance later i.e. for large elevation angles (above70) higher order modulations can give an acceptable PER in a HAP channel even for reasonably low E_b/N_o. This is because at high elevation angles (above 70 degree), Line of Sight (LoS) conditions become dominant and multi path interference diminishes; hence a HAP channel behaves more as a rice channel with very large K-factor that is almost an AWGN channel. This observation implies that ACM can be exploited more fully in a HAP links due to the larger probability of LoS conditions compared to a terrestrial links.

It is to be noted that PER curves are plotted against E_b/N_o not SNR. SNR values corresponding to PER will be higher than the Eb/No depending on the modulation scheme.

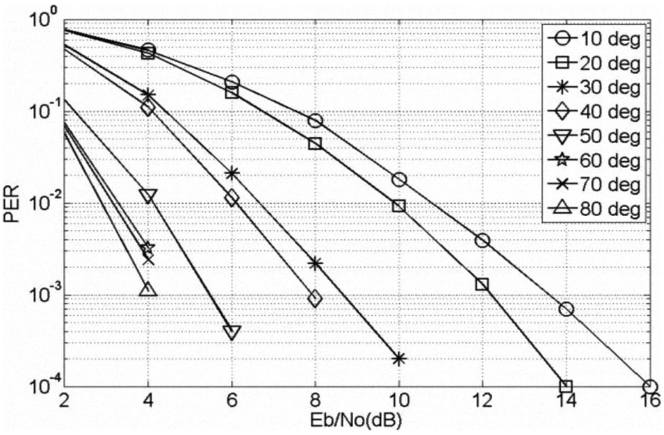

Figure 1: Packet Error Rate in HAP WiMAX down link for QPSK for varying elevation angles (EA).

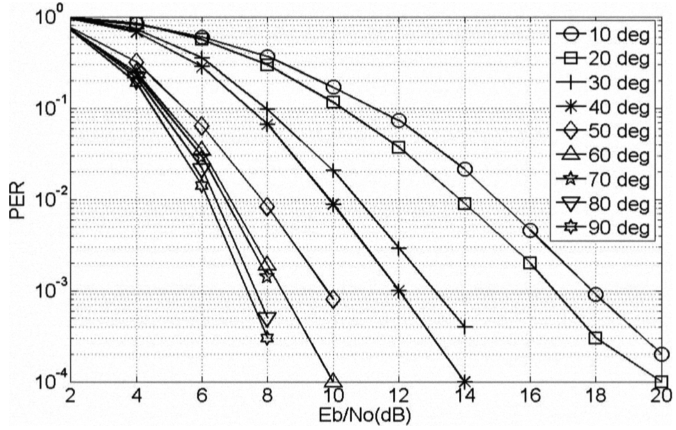

Figure 2: Packet Error Rate in HAP WiMAX down link for 16QAM for varying elevation angles (EA).

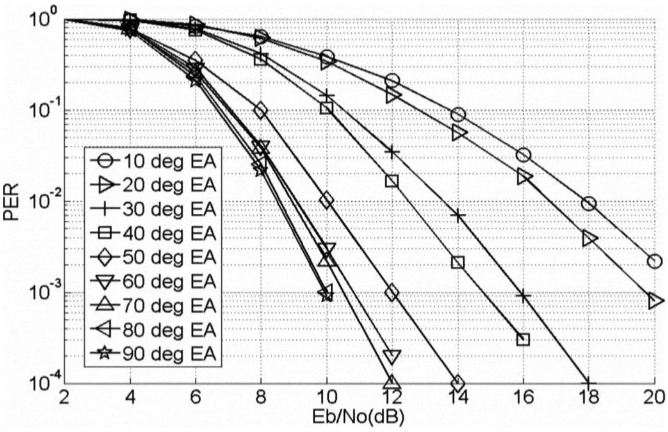

Figure 3. Packet Error Rate in HAP WiMAX down link for 64QAM for varying elevation angles (EA).

IV. SYSTEM LEVEL SIMULATION MODEL

SLS model developed for HAP WiMAX is explained in the following subsections.

A. System Design

A cellular network of 19 cells deployed by antennas mounted on single HAP is modelled in SLS. Thus a realistic level of interference from two tiers of co-channels is considered in this study. Table III shows the system level simulation parameters used in this study.

Table III
SIMULATION PARAMETERS FOR HAP WIMAX SYSTEM

No. of HAP	1
Height of HAP	20km
No. Cells	19 (two tiers)
Frequency Reuse	3
Antenna Type	Parabolic Antenna
Avg Cell radius	5Km
HAP Antenna BW	19.5, 16.5, 14.5 deg for 1st,2nd & 3rd tier[1] antennas
Antenna Gain	Calculated against B.W i.e. 20, 21 and 23 dB
User Distribution	Uniform
Frequency Reuse	1,3
Max Tx power	39dBM
User Antenna Type	Omini directioal
User Antenna Gain	0dB
Shadowing Std.[2]	0 to 8dB
Shadowing Mean	0dB

[1] Calculated against cell radius and tilting angle required for each antenna to project the cell at appropriate place.

[2] Depending on the of elevation angle

B. Propagation Aspects

In order to estimate the propagation loss in a HAP scenario, free space path loss model is used in this study with slight modification to accommodate the additional losses due to air and moisture molecules. Shadowing model inspired by [12, pp29-39] that also incorporate the auto-correlation property of the shadowing dependent on elevation angle, is used in the simulator.

C. System Dynamics

As can be anticipated, the performance of HAP WIMAX cellular systems will depend on a number of factors. For this study we have investigated the over all performance and capacity for the HAP WiMAX system model described above while considering the effect of following two major factors.

Adaptive Coding and Modulation (ACM)

Performance has been investigated with and without ACM. In order to keep the results more deducible, the coding rate is kept fixed in this study and modulations schemes have been changed under the principle of ACM. A measurement of relative usage of each modulation has been carried out. In this study, we have considered, QPSK, 16QAM and 64QAM.

User Traffic

Performance with two different *per user data rates* of 100kbps, and 300kbps has been investigated. Uniformly distributed users have been considered in this study with low mobility. Full buffer traffic model is used.

Users are registered with respective HAP WiMAX cells based on maximum received signal level. When a user in a given cell is selected in a round robin fashion, system checks if the number of free slots (WiMAX radio resource units) available with that particular cell are enough to provide the user with requested data rate. If no free slot is available at all, the user is logged as blocked due to *full hard blocking* (This happens when system is fully loaded i.e. all the radio resources are already occupied). If some free slots are there but are not enough to provide the data rate requested by user, the user is logged as blocked due to *partial hard blocking*. If enough free slots are available, system then calculates the expected packet error rate for that particular link condition of the user (using the look up tables obtained through link level simulation results). The effective SINR is estimated by averaging the SINR on all the subcarriers to be allocated. If user is not expected to achieve a PER <10%, even for the most robust ACM scheme, user is considered softly blocked i.e. blocked due to low SINR or bad signal quality; otherwise user is permitted admission into system and starts receiving using the most efficient possible ACM which allows a PER better than 10%. The particular slots required to meet user transmission rate demand are allocated by resource allocation mechanism in operation. In this study, we have implemented a resource allocation scheme, which randomly allocates the required amount of WiMAX radio resource units to the admitted user by specifying the slots and sub carriers for that particular user. (Such random sub-carrier allocation scheme can approximate PUSC on PHY layer without introducing significant error [13]). The admitted user is then logged as *successful user* and the interference caused by this new user is instantaneously added to respective time slots on all the subcarriers allocated to user.

V. SYSTEM PERFORMANCE EVALUATION

A. Performance Metrics

Our performance analysis is based on the observation of four major system performance metrics namely 1.*soft blocking*, 2. *partial hard blocking*, 3. *full hard blocking* & 4. *spectrum utilisation* i.e. percentage of engaged WiMAX radio resources in a cell. (not to be confused with spectrum efficiency). These parameters are logged throughout the simulations until system becomes fully loaded and stable. The number of successful users determines the performance of the system in terms of effective user capacity against the performance metrics observed for that particular system configuration. For each system configuration simulations have been run for a large number of times to get average results on Monte Carlo principle. Results are logged for the central cell only to include the full interference from two tiers of cells in the analysis. System level performance for down link has been investigated in this study.

B. Performance Results

Table IV shows a representative summary of the average performance results obtained for HAP WiMAX cellular system for Frequency reuse (FR) of 1 and 3. The performance metrics are measured with the ACM on and off, for low and high user data rates i.e. 100, and 300 kbps that represent ordinary data services and video streaming respectively. High level of soft blocking observed in Table IV, for all the cases with frequency reuse of 1 show that an acceptable GoS can not be achieved with frequency reuse 1 due high level co-channel interference. It is worth to point out here, that advance features of WiMAX 802.16e namely Space Time Block Coding STBC, MIMO and partial frequency reuse; might have a potential to improve the GoS with frequency reuse 1. Further radio resource allocation with co-ordination among co-channel cells (i.e. central resource scheduling to minimise interference) that is very much feasible in HAPs can also be exploited to avoid interference and improve the performance with frequency reuse 1 in HAP WiMAX. We would like to point out that these are potential areas to extend this study in future. For now we will focus on results with frequency reuse of 3 which yields acceptable GoS in HAP WiMAX system studied here.

In Table IV, it is quite obvious from the large level of fluctuations in throughput and GoS, that the performance of the HAP WiMAX is strongly dependent on ACM and slightly dependent on per user data rate. It can be seen that ACM brings a large gain in throughput. This gain in throughput can be interpreted by comparing Figure 4 and Figure 5 showing dynamics of system in terms of performance metrics during an arbitrary round of simulation for ACM off and on, respectively. In Figure 4, with ACM off, it can be seen that spectrum utilisation rises to as high as 94 % while only 15 users have been successfully admitted in the HAP cell. Whereas it can be seen in Figure 5 that, with ACM on, around 40 users can be accommodated in the same HAP cell for almost same spectrum utilisation of 96%. This is because ACM allows for the usage of higher order modulations for users with better signal quality (refer to columns in Table IV showing the relative percentage usage of different modulation with ACM on), and thus they occupy lesser spectrum resources in HAP cell for the same data rate. And when more users are accommodated in the spectrum saved by ACM, a gain in user capacity is achieved.

Intuitively speaking, ACM should also improve GoS because with ACM on, the spectrum utilisation is lower for the same number of users. But a comparison of soft blocking values in Table IV show that this is not the case, rather GoS is slightly degraded with ACM on. This observation can also be inferred by careful analysis of system dynamics revealed by Figure 4 & 5.It can be seen that level of *soft blocking* is slightly higher in a system with ACM on, than in system with ACM off. This slight degradation in GoS is a hidden payoff of the large gain in throughput brought by ACM and has following reasoning: Cell edge users' cause more co-channel interference than the users in the centre of cells due to two folded reason; first they have to use large power levels, second, they are relatively closer to co-channel cells. By using robust Modulations and Coding Scheme (MCS), ACM allows admission of many such cell edge users that would have been denied in absence of ACM. Thus all such users now occupy relatively larger bandwidths as they are using robust MCS. Further, higher power levels need to be used for them as they are at cell edge. At the same time, with ACM on, users in the centre of cell that are relatively friendlier to co-channel cells occupy a smaller share of the *spectrum utilisation* compared to the same number of users with same data rate but located at the cell edge. Thus with ACM on, there is slightly more interference due to increased proportion of users transmitting with larger powers at wider bandwidths, located closer to the co-channel cells. Exact value of this increase in interference caused by ACM will depend on different traffic types, user distributions and scheduling and power control algorithm and is beyond the scope of this paper and is a potential topic of future study. The results in Table IV show, for particular scenarios investigated in this study the increase in interference caused by ACM is negligible and is clearly out weighted by the huge gain in throughput it brings.

A second factor that affects the performance of HAP WiMAX and is investigated in this study is traffic type. Simulation results in Table IV, show that, performance both in term of GoS and cell throughput is better for larger data rate per user (i.e. 300kbps) compared to that with smaller data rate(i.e. 100kbps). This is because, for a system with fixed amount of radio resources, instantaneous data rate per user determines the number of simultaneously active users in the system. Greater the number of simultaneously active users; higher is the total interference energy even for same power bandwidth product per user. Lower the interference level better is the performance.

Finally results in Table IV show that a maximum cell throughput of up to 3600Kbps per cell is possible with a the studied HAP WiMAX system model. This performance of HAP WiMAX is close to the performance of a similar terrestrial WiMAX [14]-[15] system. Thus the commercial and technical advantages of HAPs highlighted above make them an attractive alternative solution for deployment of WiMAX.

Table IV

HAP WIMAX SYSTEM PERFORMANCE RESULTS

FR	ACM	User data Rate (Kbps)	No. of Active Users /cell	% of Users using QPSK	% of Users using 16QAM	% of Users using 64QAM	Spectrum Utilisation	% soft blocking	Cell Through put (Kbps)
1	OFF	100	15	100	0	0	94.38	14.5	1500
	ON	100	27	30	11	59	94.54	16.2	2700
	OFF	300	5	100	0	0	94.70	12	1500
	ON	300	9	30	10	60	94.17	15	2700
3	OFF	100	14	100	0	0	96.0	3.55	1400
	ON	100	34	16	9	75	96.2	4.1	3400
	OFF	300	5	100	0	0	94.70	1.0	1500
	ON	300	12	10	4	86	97.0	4.0	3600

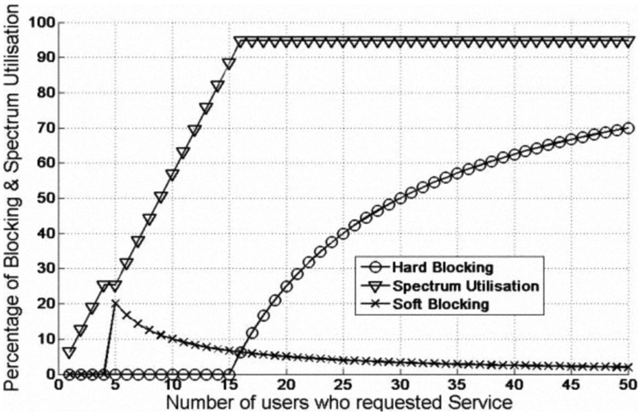

Figure 4: Performance metrics with frequency reuse=3, user data rate=100kbps and ACM=OFF

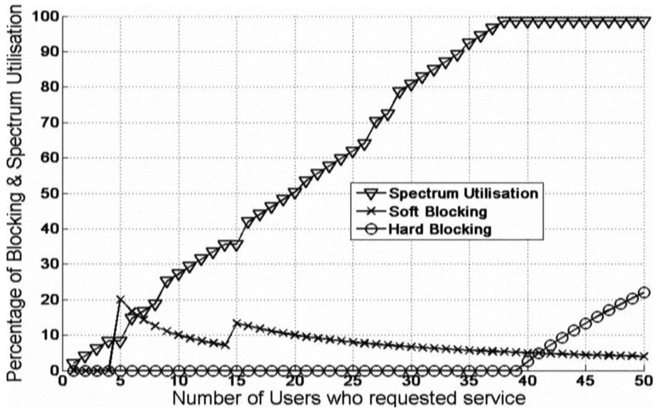

Figure 5: Performance metrics with frequency reuse of 3, user data Rate=100kbps, and ACM=ON

VI. CONCLUSIONS

The investigation of performance and capacity of a multi cellular HAP WiMAX system is carried out using extensive link level and system level simulations. Link level results show that performance of HAP link is strongly dependent on the elevation angle along with SNR.

The results that quantify the performance HAP WiMAX with and without ACM show that ACM can bring a gain in cell throughput up to as high as 140%= (3600-1500)/1500*100, but, also has a potential pay off as a slight increase in interference. System level simulation results further show that performance is also dependent on the user traffic type, with larger data rates per user resulting in slightly better performance. It is also shown that, in the HAP WiMAX system considered in this study, frequency reuse 1 does not yield acceptable GoS yet frequency reuse as tight as 3 can be used to achieve an acceptable GoS. Finally it is concluded that a maximum of up to 12 users with data rate 300kbps per user can be served in a HAP cell with 5 MHz channel bandwidth resulting in a cell capacity of 0.68 b/s/Hz/cell with frequency reuse of 3.

In future, this work will be extended to investigate the improvement that can be achieved in HAP WiMAX system performance using advance WiMAX features i.e. STBC, ARQ, MIMO, and partial frequency reuse. Further it will be interesting to establish a comparison between HAP based and Terristrial WiMAX in terms of performance, capacity & cost to investigate the relative feasibility of two deployment solutions for next generation networks.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Reza Hoshyar, Majid Shateri and Sadegh Fazel-Falavarjani at CCSR, UniS for their valuable support during this work.

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