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***Abstract*—3.65 GHz Mobile WiMAX spectrum is often a better commercial solution due to its attractive licensing requirements, in spite of the slightly lower coverage area. However, no significant performance data has been reported for 3.65 GHz equipment behavior. In this paper, we have presented an in-depth analysis of a 3.65 GHz Mobile WiMAX solution. Our reported data can also contribute in performing link budget analyses and benchmarking similar equipment.**

Keywords-MobileWiMAX; 3.65 GHz; Equipment Test; Channel Emulator; Throuhgput; RSSI; CINR

I. INTRODUCTION

Our team at the University of Nebraska-Lincoln's Advanced Telecommunications Laboratory has been actively engaged in investigating broadband solutions for railroads. Our research process includes four essential stages -- test bed design and testing, computer simulation based performance analysis, theoretical analysis and equipment testing in real-world settings. To design a resource-constrained but reliable and cost-efficient network, conducting a detailed analysis of all four aspects of network design is an essential component and ignoring any one of them leads to an inefficient system.

Quantitative performance evaluation is very important in many aspects. Firstly, simulation results, though important for initial planning and relatively easy and flexible to obtain, are seldom accurate enough to properly design an entire network infrastructure with. The primary reason behind this lack of accuracy is that simulation is based on well-accepted but idealized theoretical communication models, whose assumptions rarely match the observations made in practical systems. Also, it is an impossible task to modify the model to fit every real-world test condition. Hence, actual equipment testing is necessary to get reliable results and also verify the accuracy of the simulation for specific conditions. Secondly, the results of detailed equipment testing provide benchmarks to verify the quality of the equipment itself. Finally, such results are essential to determining whether the equipment is suitable to be implemented in the target network environment.

A considerable number of studies have been conducted by us and other researchers and industries in the area of broadband networking using Mobile WiMAX [1]. The application area includes broadcasting, VoIP operations, multimedia transmission and even as broadband solution for defense forces. All these activities establish WiMAX as a popular and efficient broadband networking protocol. However, it is seen that most studies focused on equipment in the 2.5 GHz frequency band, and no significant work has been published on the analysis of devices operating at 3.65 GHz. This 3.65 GHz spectrum is a very important band of WiMAX broadband solutions, with many technical and non-technical advantages over the 2.5 GHz spectrum. The most attractive reason that Wireless ISPs, looking for a broadband solution for their customer services, or any company looking for a communication infrastructure solution for its own managerial and control operations, will consider the 3.65 GHz spectrum is the licensing requirement for it. The affordable licensing requirements of 3.65 GHz spectrum make it a favorable prospect for small WISPs and other companies looking to deploy their own wireless infrastructure on a local level [2]. These companies and their network requirements can also tolerate the fact that higher carrier frequencies will have a lower coverage due to the more rapidly increasing path loss. This alternative to costly operation and licensing in 2.5 GHz then necessitates a detailed evaluation of the performance of 3.65 GHz equipment. In this paper, we have presented the results of our evaluation of a commercial 3.65 GHz solution under a broad range of channel conditions.

II. EQUIPMENT AND TEST CONDITIONS

We utilized our lab's ACE-400WB [3], a Wireless Channel Emulator from Azimuth Systems, to emulate the wireless channels for our experiments. A channel emulator is a sophisticated software controlled device able to emulate real physical channels. Use of channel emulator provides us several advantages in equipment testing. The most important advantage of using channel emulation is the complete control over the test environment and test conditions it affords us. A wireless channel is easily and severely affected by a plethora of environmental factors, most of which are outside of our control (rain, temperature, moving cars and people, etc.). This makes it very difficult to get reliable and repeatable results as it is impossible to recreate channel conditions for any form of comparison. Further, as a result of this inherent randomness, it becomes difficult to ascertain what aspect of the performance of the devices is being affected by which specific factor and to what extent, since we cannot isolate individual factors to identify their impact. A channel emulator can be used to realistically recreate virtually any environment under which the devices may operate, and experience their effects on the device performance. We used PureWave's Quantum 1000 outdoor device [4] as the base station. It uses an advanced four-element antenna array for MIMO. Two antennas are used for transmission and all four are used for reception, using MRC receiver diversity. Similarly, we used Gemtek's ODU-series CPE [5] as the subscriber station. It employs a dual polarization

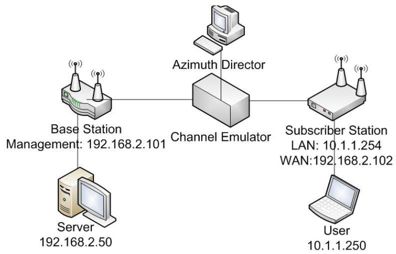

Figure 1: Network Topology Diagram

antenna to support MIMO. Both devies are Mobile WiMAX (IEEE 802.16e) Wave-2 compliant.

Figure 1 shows the network setup for our equipment evaluation. The data server, essentially representing a very simplistic yet functional core services network (CSN) is connected to the base station via the serial (RS-232) management interface for configuration and control of the device and the RJ-45 Ethernet interface for telnet sessions and, most importantly, data transfer. The base station is connected to one of the two MIMO port sets of the channel emulator. Since the base station has four antennas and subscriber station has two antennas, the channel emulator is configured for 4x2 MIMO. The other port set of the channel emulator is connected to the subscriber station. With this setup the channel emulator can now create virtual wireless channels as specified by the software installed in the Azimuth director, between the base and subscriber stations. To complete this setup the subscriber station is connected to the client computer. The data server and client computer are the two data endpoints for our downlink and uplink data tests. Table 1 shows the various link and channel parameters used for evaluating the equipment.

The channel emulator can create both ITU standard channels and user defined channels. In this work, we have limited ourselves to ITU-defined channels – Butler, Pedestrian A and B and Vehicular A and B. Using the channel emulator, the MIMO antennas were configured to have no correlation.

III. PERFORMANCE RESULTS

The results of the tests are shown in figures 2-7. Due to limitation of space and for the sake of clarity, some results have been omitted from the graphs. However, the omitted results are also following the trend of the presented results.

Table 1: Channel conditions for performance measurement

Channel/Link Parameter	Value
Central Frequency	3.66 GHz
Bandwidth	10 MHz
Frame Duration	5 ms
Downlink/Uplink Ratio	35/12
Transmit Transition Gap (TTG)	296 ps
Receive Transition Gap (RTG)	168 ps
Uplink Channel Descriptor (UCD) Interval	1000 ms
Downlink Channel Descriptor (DCD) Interval	1000 ms
CBR traffic generation rate (UL)	10 Mbps
CBR traffic generation rate (DL)	25 Mbps
CBR Packet Size	1400 bytes
Base station transmission power	15 dBm
Subscriber station transmission power	27 dBm (max)
Channel Path Loss	80 - 115 dB
ARQ	User Defined
HARQ	User Defined
Power Control	ON
Adaptive Modulation and Coding	ON
Antenna Configuration	4x2 MIMO

Figures 2 and 3 show the end-to-end uplink and downlink throughput results with respect to the path loss under channel parameters as specified in Table 1. Under these conditions, the maximum achievable uplink and downlink throughputs are 5 Mbps and 21 Mbps, respectively. The downlink direction shows a much higher throughput due to the 3:1 DL/UL ratio configured in the MAC layer. This configuration correlates well with typical real-world network deployments for which a higher bandwidth in the downlink direction is preferred. It is seen that the throughput curves for downlink are monotonic but the uplink curves are not. This phenomenon can be attributed to uplink power control.

Figures 4 and 5 show the uplink RSSI and CINR. We can see that for path loss values up to ~92 dB, the uplink RSSI remains approximately constant in spite of the increase in path loss. This is a result of the power control in Mobile WiMAX: When the uplink RSSI decreases, the BS directs the SS to transmit using a higher transmit power, if possible. As a result, this power increase raises the CINR and hence the throughput, while also stabilizing the RSSI. The SS tries to maintain an optimal level of uplink RSSI until its transmission power

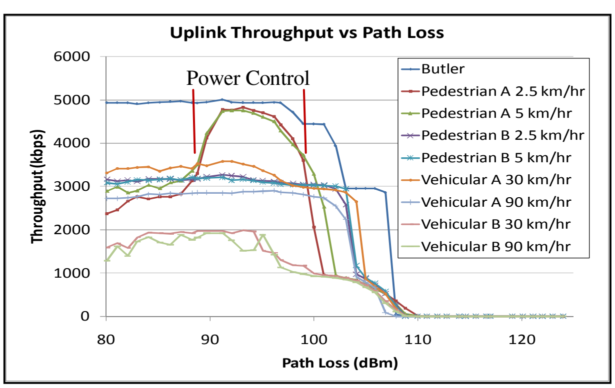

Figure 2: End-to-end uplink throughput

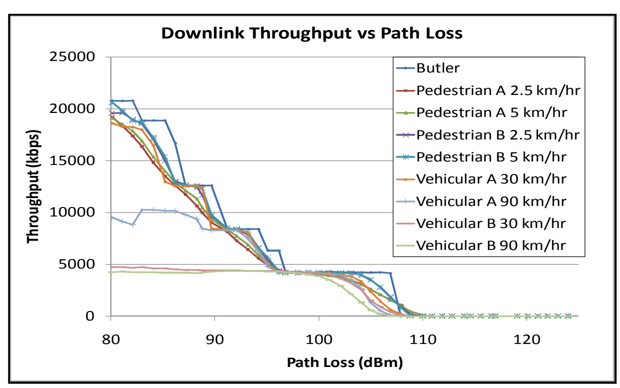

Figure 3: End-to-end downlink throughput

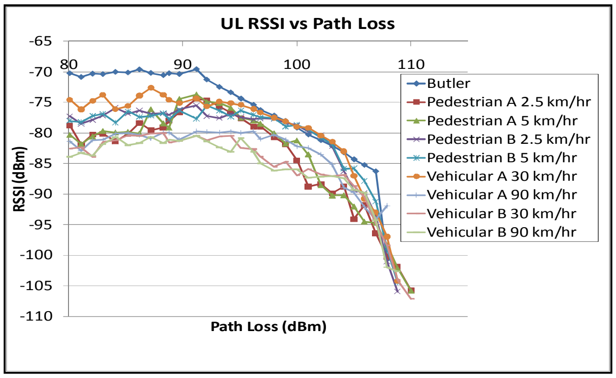

Figure 4: RSSI in uplink direction

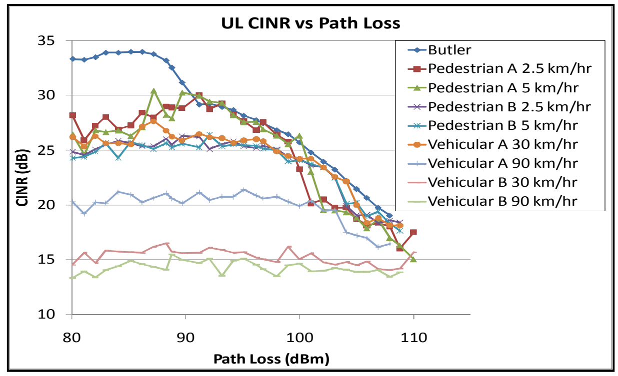

Figure 5: CINR in uplink direction

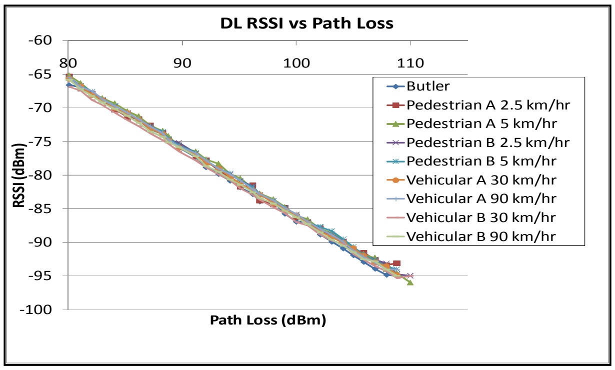

Figure 6: RSSI in downlink direction

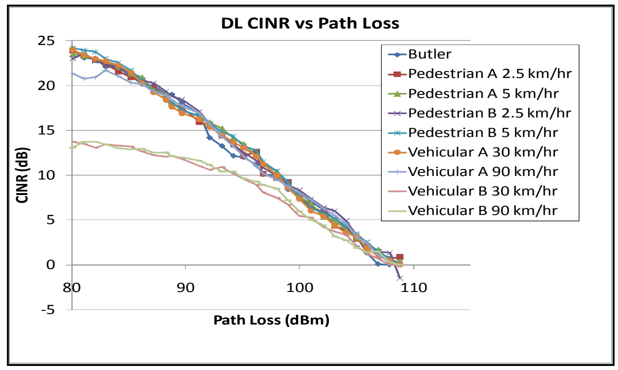

Figure 7: CINR in downlink direction

increases to the maximum possible value, after which it is no longer able to increase transmission power and the RSSI decreases rapidly until link failure occurs.

The result of increasing path loss is remarkably different for the downlink, however. Figures 6 and 7 show the effect of increasing path loss on downlink RSSI and CINR, respectively. Since the BS's transmission power is a fixed configuration value, the RSSI falls linearly with path loss and is the same for all channel models. However, CINR is very low for poor channels, especially Vehicular-B. This is because the CINR takes into account the noise and interference power present in the channel, which is highest for the Vehicular B channel model. This clearly demonstrates that RSSI alone cannot be utilized as a communication link quality descriptor.

IV. Conclusions

To put our results in perspective, if the BS transmits at its full power of 30 dBm, it can support an area with a radius of approximately 11.5 km under free space propagation and 0.2 km under severe multipath conditions of an urban environment, represented by a path loss exponent of 2.8 [18], as measured in our Crete, Nebraska field test bed. Therefore, assuming an average utilization of 1 Mbps by each user, a maximum of 21 users can be supported simultaneously in optimal channel conditions.

One interesting feature of all of our results is how all curves for each channel model tend to be grouped closely together to form a set. This indicates that in a mobile radio network the impact of multipath is actually much more severe than the impact of velocity. The effect of tripling the velocity from 30 km/hr to 90 km/hr in the Vehicular B model seems to have only negligible impact compared to the impact when the channel model is changed from Butler to Vehicular B, representing a significant increase in multipath with a high maximum path delay.

Future work will include continuation of comparing 2.5 GHz and 3.65 GHz Mobile WiMAX equipment, as well as comparison of different vendors' solutions for either frequency band. Similarly, additional performance results regarding latency and jitter, Error Vector Magnitude (EVM), spectral analysis and different types of antenna (MIMO and beamforming) will also be studied in details.

V. Acknowledgement

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