Technology White Paper
WiMAX Uplink and Downlink Design Considerations

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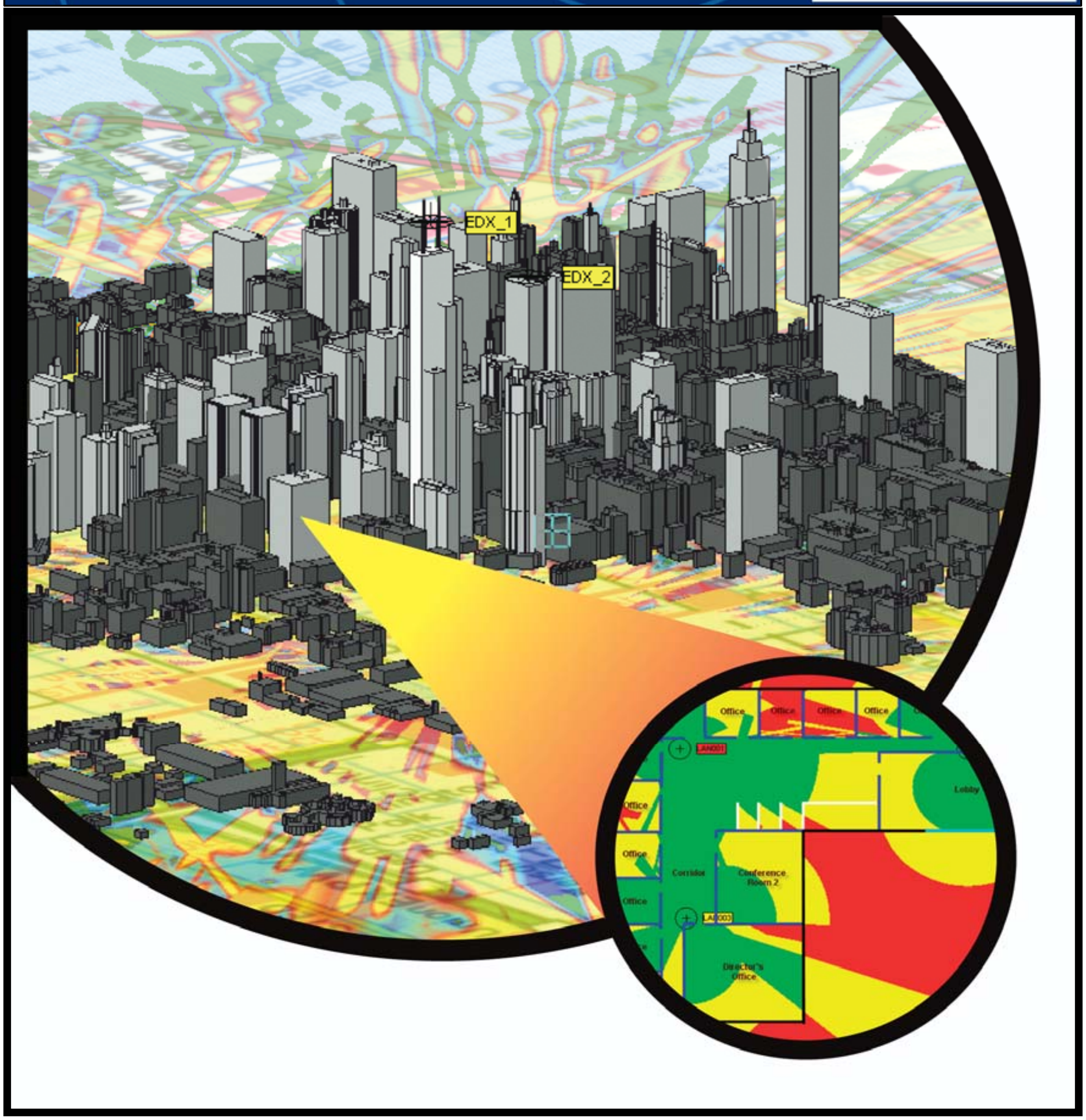

The Power of Planning

WiMAX Uplink and Downlink Design Considerations

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The flexibility of the WiMAX standard allows the designer of a network to plan a system even with a limited amount of spectrum. Service providers can choose to design a network that best suits their needs by balancing spectral efficiency, number of supported users, reliability, and coverage through the setting of the various WiMAX system parameters. This paper addresses some of the tradeoffs that are encountered in the process of planning a network.

Introduction

WiMAX promises to deliver high data rates to subscriber stations (SS) through an efficient use of its system resources. This efficiency is achieved by means of an adaptable physical layer that tries to maximize the use of the available spectrum by using higher modulation orders on connections to users that have better received signal-to-interference and noise (SINR) ratios. Not all subscribers are received with the same intensity; the adaptive modulation and coding scheme takes advantage of this fact and transmits more data per OFDM sub-carrier to users that receive more reliable signals (with better SINRs) while applying the more robust and less efficient modulations schemes to users that have poor SINRs. This method increases the capacity of a wireless system over conventional fixed modulation wireless systems. WiMAX also offers the flexibility to accommodate a variety of applications through a scheduling algorithm that assigns data allocations to the various subscriber stations based on their needs. The demand is allocated to each user on a frame by frame basis in order to maximize system resources. If the application requires it, a subscriber can be allotted a fixed amount of resources periodically using the unsolicited grant service (UGS). Variable rate applications (rtPS, nrtPS, ertPS) employ a polling based system and resources are allocated for these services on a frame by frame basis according to the instantaneous needs of the users. Some applications like VoIP have additional strict latency and jitter requirements that have to be met to achieve acceptable QoS to maintain a circuit switched type quality. Other services such as web browsing have no such timing restrictions and can be met on a best effort (BE) basis. The scheduler is making decisions on a frame-by-frame basis to ensure demand is being met while factoring the individual applications needs and requirements to meet adequate QoS. When overloaded, a site might have to make judgments on which applications or users should get priority. The WiMAX standard does not specify the functionality of the scheduler; its design is left up to the hardware developers as a means to differentiate vendors. This creates an additional challenge to the operator in that the scheduling algorithms are usually proprietary and not known to the system design engineer. This makes it difficult if not impossible to predict in advance the exact behavior of the installed system.

In a WiMAX system, the base station (BS) performs most of the system decisions. It decides the modulation used on the uplink and downlink (from measurement and/or customer device feedback), the number of resources allocated to each user in both directions, and when and what physical slots are assigned to each user. The BS conveys its resource assignments in the uplink (UL) and downlink (DL) MAPs at the beginning of each frame following the preamble. The subscribers decode the MAPs to determine when and where information directed to them is located within the frame and to determine which UL slots have been allocated to them for transmission. It is very important that these MAPs are protected and received correctly by the SS to prevent missed opportunities. Any failed attempts would have to be retransmitted and/or re-allocated in subsequent frames bringing down the efficiency of the system. In a TDD (Time Division Duplexing) system, a *frame* (typically 5 ms in duration) is subdivided into uplink and downlink portions over which the base station either transmits or receives information from the users. The fraction of the frame assigned to UL and DL can be adjusted to meet that particular frame's needs but most likely will remain fixed on a system wide level.

The main unit of allocation within a frame is the *slot* which consists of 48 *tones* spanning the sub-carriers in the frequency/time space that make up each OFDMA *channel* (typically 5 or 10 MHz of spectrum). The 48 tones that make up each slot are picked according to a pre-determined sub-channelization scheme. These schemes are further divided into *diversity* or *adjacent* sub-channelization methods. PUSC (Partial Usage of Sub-channels) and FUSC (Full Usage of Sub-channels) fall under the first category of schemes that attempt to pseudo-randomly pick tones that make up any given slot from across the entire sub-carrier space to ensure healthy frequency diversity. Diversity sub-channelization schemes help minimize errors due to sub-carrier collisions (from interfering stations) and mitigate instantaneous frequency selective fading which is helpful in mobile applications. AMC is an adjacent sub-carrier sub-channelization method where a contiguous set of sub-carriers are combined to form slots. AMC is used in conjunction with advanced antenna systems to reduce the number of weights that need to be computed when using adaptive antennas. Regardless of the permutation scheme, a subscriber can be assigned several slots for each application on the DL and UL dependent on demand and availability.

WiMAX System Design Parameters

Regardless of the robust RF and data handling features built into the WiMAX standard, a WiMAX system still needs to be first carefully designed with respect to RF coverage and interference. Poorly planned networks will exhibit interference limited performance. Under these conditions, increases in overall transmit power lead to proportionate increases in system wide interference resulting in no added capacity or reliability. In order to reduce this interference floor, BS using the same channels should be separated as far away as possible to minimize the network from becoming interference limited. The use of directional antennas is also a typical technique used to isolate co-channel sectors. There are times, however, when only limited spectrum is available and the tradeoff between reliability and added capacity might have to be relaxed.

A potential source of interference in WiMAX systems can occur when there is a loss in frame synchronization between the base stations using the same channels or when the UL/DL ratio in a TDD system is different for each BS. Both these scenarios cause BS to BS interference. In these situations, a base station that is trying to listen to its subscribers could also receive large signals from a neighboring interfering site which is likely to be in unobstructed view and transmitting at higher power than a normal subscriber station. The potential for large system wide interferences from unsynchronized BS are a concern that could trump the spectral efficiency gained by having an adjustable UL/DL frame at each BS.

Minimizing interference requires proper RF frequency planning. Channel planning in WiMAX is performed in a similar manner as traditional cellular systems. The channels (5 or 10 MHz) are allocated to sectors with a certain frequency reuse factor across the service area. What is unique about WiMAX is that it has a built in method that tries to minimize the sub-carrier collisions from interfering cells using the same channels. The PUSC and FUSC sub-channelization schemes randomly form slots from the available sub-carriers based on a predetermined permutation (each BS can be assigned a different permutation). This reduces the chances that interfering cells are using the same sub-carriers even when they are operating on the same channel. However, the reduction in interference achieved through the diversity sub-channelization methods rapidly becomes less effective as the system becomes more loaded.

WiMAX also has provisions set up to support channel frequency re-use factors of one for operators that have a limited amount of spectrum. The OFDMA physical layer allows a channel to be parsed and redistributed. Support for a frequency re-use of one is achieved by dividing up the available sub-carriers of a channel among the sectors in the cell; this will be discussed in more detail in the following sections that discuss the downlink and uplink separately.

Scheduling can also be performed in different ways and has system wide consequences in performance. The base station makes the decisions on what modulation is used to communicate to and from each of the subscribers in its cell. These decisions are based on estimates of the uplink and downlink SINR for each connection. The UL and DL SINR are usually different. For negligible interference levels, the base station might be able to infer the strength with which the signal is received by a user from an uplink measurement in a TDD system (using reciprocity). Under more realistic conditions, the base station can query the SS for an estimate of its received SINR which is transmitted back to the BS scheduler in order to assign an appropriate modulation type. The BS could also intentionally leave sections of the frame empty and use them to measure interference levels and improve SINR estimates. The scheduler has to constantly track the changes in the channel to ensure that proper modulation orders are assigned to each of its connections. The updates of the modulation have to track the channel which varies with the rate that the users are moving through the service area. In fixed/nomadic networks, the updates don't need to be as regular as in the mobile scenarios. Ideally the scheduler would have knowledge of the instantaneous SINR of all its connections. However, the best a BS can do is base its estimates of the current frame on information gathered on the previous frame. From one frame to the next, connections can be added or dropped and the mobile could have moved changing the interference and signal environment. When the BS request SINR measurements from the SS, it takes at least two frames to receive feedback. The scheduler has to decide how many past frames it should take into account to make its decision of the modulation type. It could take an average SINR estimate, pick the worst, or use the best SINR over a predetermined number of frames to set the modulation order for the present frame. A pessimistic estimate of SINR could lead to everybody operating with lower than optimal link modulations (reducing capacity) while an optimistic estimate could result in less robust modulations that lead to data errors that require retransmission. There is a system wide optimal decision metric that takes into account the mobility distribution and the dynamics of the network that maximizes the capacity of the system. It is important to note that scheduling cannot overcome the limitations of improper RF planning but it can maximize the capacity potential of the designed network.

Initially, WiMAX was designed for fixed/nomadic wireless subscribers as a way to provide alternatives to wired DSL and T1 lines for homes and businesses. The idea was that fixed or nomadic users would have a directional antenna that could be pointed in the direction of strongest received power. As the WiMAX standard moves toward mobile applications, the integration of the antenna into the units for compactness will lead to the use of smaller lower gain omni-directional antennas. This loss in antenna gain can be ameliorated through the use of sub-channelization. The mobile could be instructed by the scheduler to transmit on less sub-carriers which effectively concentrates the available power on transmit to fewer data streams instead of over the entire band. This results in a boost in power (similar to an antenna gain) on the sub-carriers in use. This 'thinning' of the pipe can be applied to extend the service area of the sector or it could permit the use of higher modulation orders on the uplink.

Downlink Considerations

As mentioned earlier the available channels should first be divided among the sectors in the network and reused throughout the service area with a given channel re-use factor (CRF). The CRF should be as large as possible but constraints such as sector demand and spectrum availability put a limit on this value. Large numbers of users require that more channels be allocated per sector forcing channels to be reused more often resulting in greater interference.

Downlink coverage is easier to plan than uplink because of its deterministic nature. On the downlink (not so on the uplink) the sources of interference are always coming from the same location - the neighboring BSs that are using the same channels. Estimating or measuring the C/(I+N) can be done for every point in space to establish an interference matrix for each BS. Based on the received RF signal-to-interference and noise ratio, an optimal modulation to service a user in that location can be found. As mentioned earlier, the actual modulation is decided by the scheduler and is based on what performance metric it chooses to employ. As an example, Figure 1 shows the OFDM adaptive modulation zones that can be achieved based on the received downlink SINRs. From the figure, most of the users in the service area can be reached using 64 QAM on the downlink which is the most efficient modulation order in WiMAX.

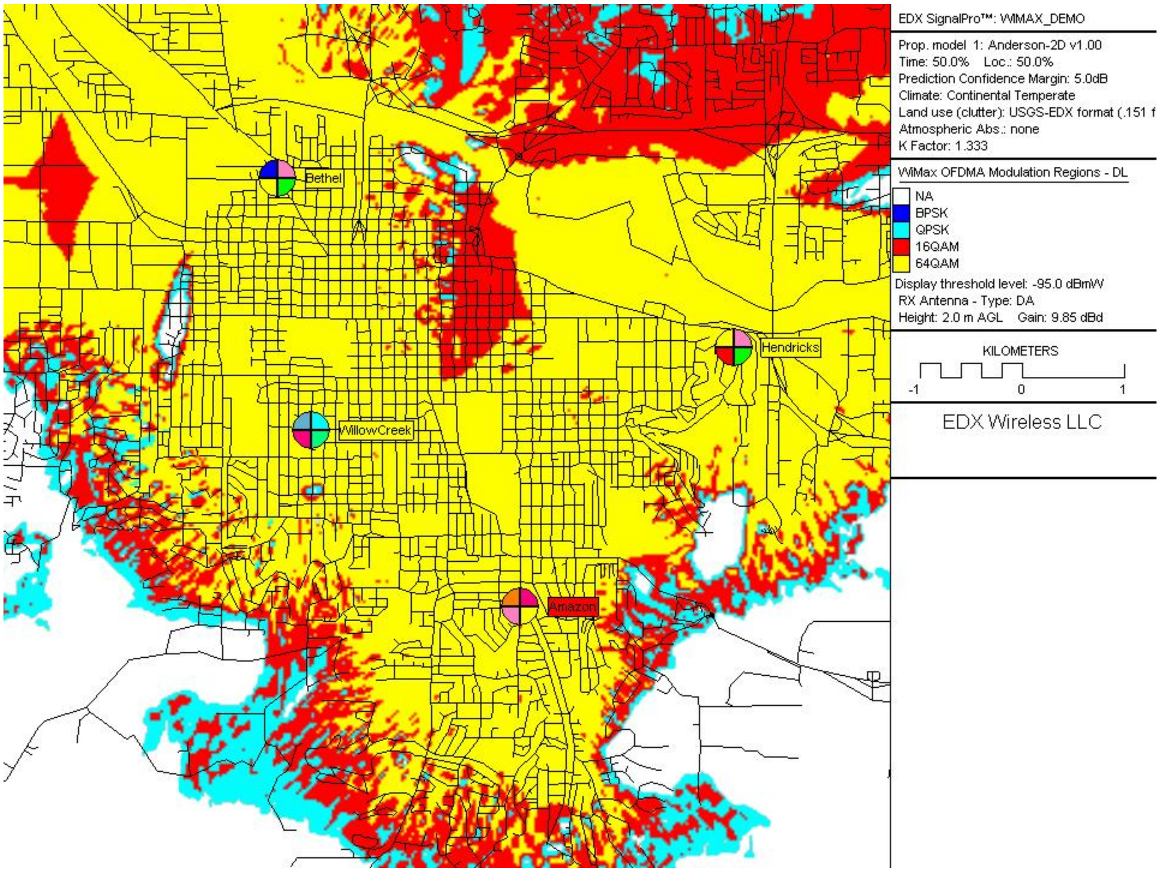

Figure 1. WiMAX Downlink Adaptive Modulation Study Produced in EDX® SignalPro®

In the above example the large areas of 64QAM modulation order were achieved because of the low downlink interference levels in the system resulting from a good frequency re-use plan. The use of an efficient automatic frequency assignment process in an RF planning tool is valuable (and in large systems vital) in creating an effective frequency plan.

WiMAX can also consider the more spectral efficient case with a CRF of one for a three sector base station. This can be achieved efficiently using a provision in the PUSC sub-channelization method sometimes referred to as PUSC-3. Under these circumstances, the available sub-carriers of a channel are distributed among the sectors of the cell. Effectively, this results in each sector transmitting on different sub-carriers so as to not interfere with adjacent sectors. This method is more efficient than traditional channel planning in that there are no guard bands separating the frequencies in each sector and all sectors have sub-carriers that span the whole channel bandwidth to enjoy the advantages of frequency diversity. Also the DL and UL MAPs can be received more reliably by the SSs since they are transmitted on different frequencies on all three sectors.

Most of the interference problems on the downlink occur at the edges of the cell. This is also true for the CRF of one provision. To further improve the spectral efficiency of a network employing PUSC-3, multiple zones within a frame can be employed to communicate to different users in the system based on their location in the cell. Since most of the interference problems occur at the edges of the cell, the system could connect to the users located around the cell service borders using PUSC-3 in a first part of the downlink frame. On the second part of the downlink frame, the SS that are closer to the base station can be serviced using all sub-carriers of the channel since these users are not prone to be interference limited. The usage of zones allows the base station to switch from one sub-channelization method to another within a single WiMAX frame. It is up to the scheduler prerogative to resort to different zones on the downlink to maximize spectral efficiency if needed.

Uplink Considerations

Uplink interference is less predictable and random in nature. Uplink interference is a function of the location of the SS in the interfering cells which (unlike the BS) could be located anywhere in their service area. Additionally, the desired SS could also be in any location within its service area which makes it even more difficult to accurately estimate the uplink SINR. Because of the intricacies of the WiMAX standard, a particular user's signal could be interfered with by several SS from any given interfering cell. The amount with which any given interfering SS affects the reception at the base station is a function of its location in the interfering cell and the number of slots it transmits on. The pseudo-random allocation of sub-carriers to slots has an effect of averaging the collective interferences from a given cell weighted by their demand.

However, the worst case interference is worth considering since a single interfering SS can bring down all of the desired SS uplink SINR estimates in a sector. A reduction in the SINR results in a decrease in system capacity and reliability on the uplink. To be the worst uplink interferer it not only has to be located in the appropriate spot in a neighboring cell but it also needs to have a large transmit allocation. The more slots it transmits on, the larger the number of users and sub-carriers it will interfere with in the affected cell on the uplink. The interfering SS locations that cause the most problems are unobstructed hill tops or SS in tall buildings. But once identified their destructive effects can usually be mitigated through antenna down tilting or frequency planning. Figure 2 shows an example of the uplink SINR considering the worst case interferences in the neighboring cells.

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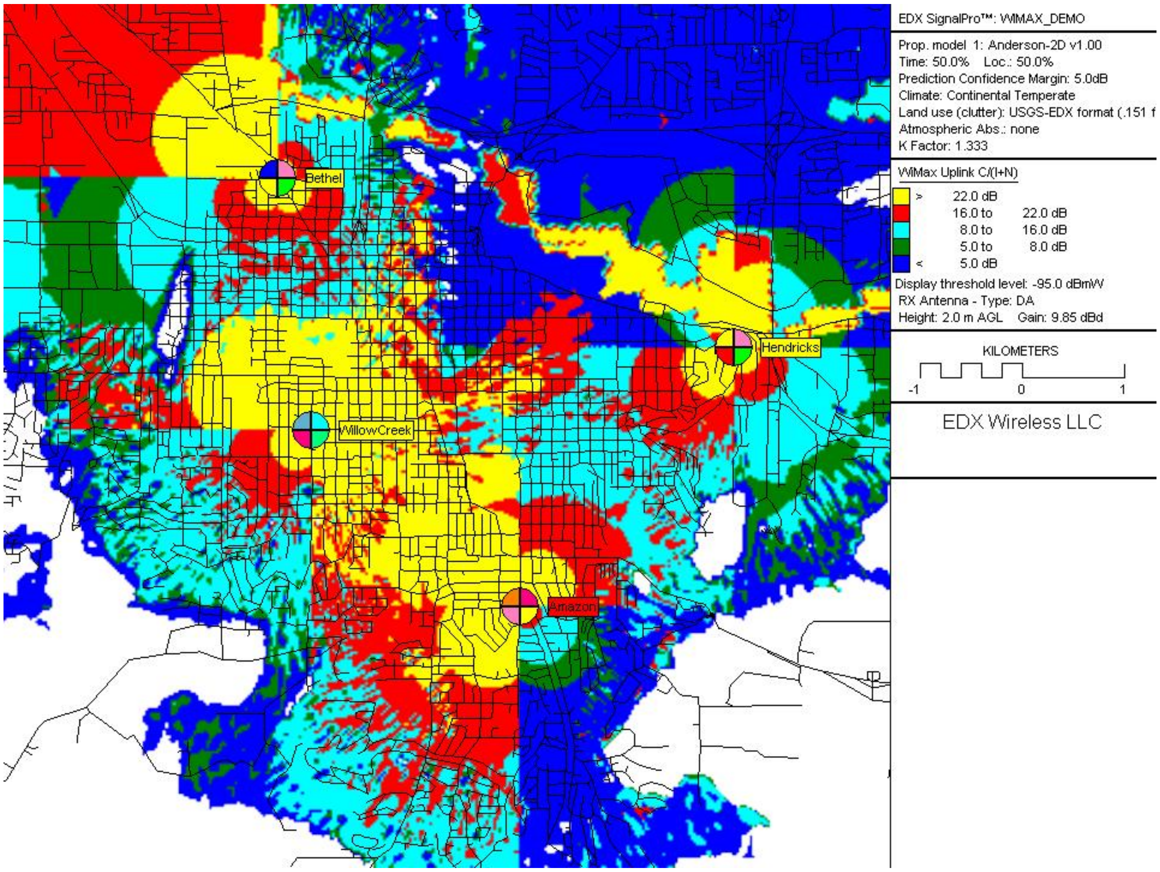

Figure 2. WiMAX Uplink Carrier-to-Interference and Noise (C/(I+N)) Study Produced in EDX® SignalPro®

Unlike with PUSC-3 on the downlink, there are no special options supported for channel frequency reuse factors of one for the uplink. WiMAX counts on the averaging effects of the sub-channelization schemes to combat interference on the uplink. The interleaving of bits across sub-carriers and error correction coding are the only methods relied on for protecting data on the uplink when opting for this high spectrally efficient provision. Figure 3 shows the resulting uplink modulation areas used to connect with users within the cell based on the worst case interference. Note that the connections of the uplink and downlink are not reciprocal when it comes to SINR and the base station modulation zones are significantly different.

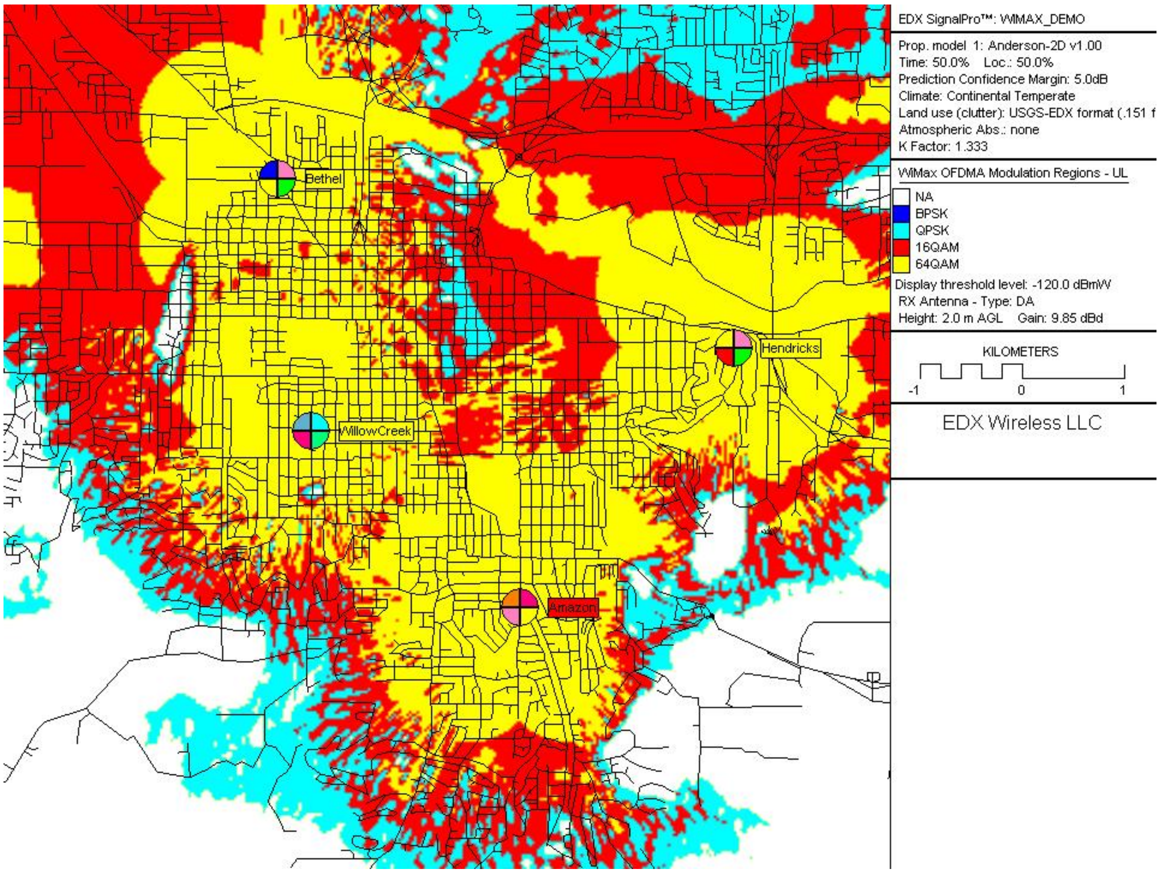

Figure 3. WiMAX Uplink Adaptive Modulation Study Produced in EDX® SignalPro®

Conclusions

Traditional RF planning remains the fundamental limiting factor in system performance in WiMAX. Proper system design can be performed by appropriately locating base stations and finding an adequate channel re-use factor that accommodates both demand and reduces interference. At the base station level, site sectoring, antenna down-tilt, MIMO, can all be used to improve the capacity and performance of the system. The scheduler can only try to maximize and more efficiently manage the resources in the system but can do very little in terms of improving the RF environment. The WiMAX standard has within it a number of provisions that allow the network designer to perform tradeoffs of capacity and reliability. It is up to the service provider to pick the appropriate mix that will best match its network needs.

References

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