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Key Factors for IEEE 802.16e 2.5 GHz WiMAX Deployments for Fixed Access Service Applications

By WCA's Global Development Committee (GDC)

Executive Summary

Cellular telephony has successfully spread voice services virtually everywhere in the world. WiMAX has the potential to do the same for Internet access.

A key factor in WiMAX's success will be the ability to take advantage of the technology's capability to deliver the lowest possible data transfer cost per megabyte while achieving the expected quality of service goals. Minimizing investments is mandatory, but it is also important to maximize the next generation growth opportunity to open new data market segments.

One of the most important aspects of WiMAX technology is its flexibility in addressing different markets' needs. The IEEE 802.16e version can be used to provide not only mobility, but also fixed and nomadic services, satisfying both highly sophisticated markets and underserved populations.

Many analysts predict that this technology will grow faster in places with no or scarce access to service. Developing countries need very low-cost services, furthermore required in low-cost CAPEX and OPEX.

Very soon, by the 2009/2010 time frame, embedded chips in laptops, personal devices and home appliances will drive the cost even lower, accelerating the path to a more competitive market share. Creating differentiated new alternatives based on wireless technology will allow the offering of several services (not yet available) based on those embedded chips.

WiMAX is already a catalyst for new disruptive initiatives in developed countries. Small operators are now able to build their business models around the disruptive capabilities of this new technology and improve their market penetration by providing new applications.

WiMAX opportunities are generating enormous momentum globally.

WiMAX Activities in Brazil

Neotec, a Brazilian association of 2.5 GHz operators, has been involved in broadband wireless business models for years. Since 2005, WiMAX has become a promising technology for 2.5 GHz spectrum owners and most of the association's efforts were devoted to the study and research of how best to implement this technology in the most cost-effective way. Morphology of the most important target cities was analyzed and Internet traffic monitored, as these two parameters are key factors in building a reliable model.

Even though IEEE 802.16e is a standard, there are several ways to implement it.

Understanding the differences and identifying the best alternative for a low-cost infrastructure implementation was one of the main purposes of this study. The objective was ***to maximize coverage and throughput of a WiMAX network while keeping CAPEX and OPEX contained.*** The next paragraphs are dedicated to describing what was considered.

Providing fixed services was the initial target. As the market grows, portability and mobility will certainly become an important priority for users. Deployments are scheduled to start in 2008 and mobility services are expected to be introduced by 2010/2012 in Brazil, when embedded WiMAX chips become a reality for mass markets. Until then, the main devices to be offered to fixed service users will be CPEs (Customer Premise Equipment) to provide access and affordable fixed telephony services (VoIP – Voice over IP).

A consistent business model requires exploring answers to the following questions:

1. How is the market distributed geographically?
2. What is the traffic demand?
3. What are the propagation conditions?
4. How can interference between cells be minimized?
5. What is the base station throughput?
6. What are the spectrum requirements?
7. What percentage of the broadband market can be service by the system?

The study's answers are provided below.

How is the Market Distributed Geographically?

In developing countries most of the population is concentrated in a few very large and dense cities. Brazil's two largest cities -- São Paulo and Rio de Janeiro -- were evaluated and the results are presented in Table 1. These two cities alone (not considering their surrounding metropolitan areas) have almost 5 million homes, which is equivalent to more than 10% of the Brazilian households.

AREA	DENSE URBAN	URBAN	SUB-URBAN
Average Density Residential (HH/km2)	10000	3500	350
Percentage of Total Area (%)	10	20	70
Percentage of Total HH (%)	50	35	15

Table 1 – Morphology Model of a large cities (**)

More than 50% of the total population (representing less than 10% of the total municipal area) lives in dense urban areas. Some neighborhoods have more than 13,000 HH (households) per square kilometer. Suburban areas, although occupying 72% of the total municipal area, have only 14% of the total population.

For this business model we focused on dense urban areas and used 10,000 HH/km2 as a market density. Assuming 3.5 to 4.0 habitants per house, between 35,000 to 40,000 people per sq. km live in those areas.

Besides consumers, it is useful to also consider commercial users in broadband Wireless Access (BWA) service rollouts. In very large cities in Brazil, especially in city centers, homes and offices coexist in the same neighborhood. The relationship between homes and commercial buildings is shown in Table 2.

USERS	DENSE URBAN	URBAN	SUB-URBAN
Homes (%)	85	90	95
Commercial (%)	15	10	5

Table 2 – Residential x Commercial users (**)

The total potential market is demonstrated in Table 3, with results obtained by adding the corporate and residential markets together.

AREA	DENSE URBAN	URBAN	SUB-URBAN
Average Density Total Market (HH/km2)	11765	3889	368

Table 3 – Total Market

It is assumed that Brazilian population grows at an average rate of 1.2% per year.

What is the Traffic Demand?

Most of the models currently published are adopting oversubscription rates of 20:1 (5%) for a residential market and 5:1 (20%) for a commercial market.

Because these are important numbers, they required testing before inclusion in our model. About 80,000 Internet users (92% residential and 8% commercial customers) were monitored for several months. The result of this work showed a very close set of numbers for the assumed subscription rate: 4% for home users and 15% for commercial users during peak hours of a day.

A major question is: what services does the market demand? According to IDC Brazil (www.idc.com), 59% of the Brazilian market was concentrated around 512kbps services and 27.6% above 1Mbps in Q3/07. For the sake of our model we will adopt 500kbps for downlink (DL) and 250kbps for uplink (UL) for residential customers and 1,000kbps DL and 500kbps UL for commercial users, considering that traffic demand continues to grow at a rate of 15% per year.

While in the developed countries the main application may be small devices with low traffic requirements (with much more DL than UL traffic (rate 3:1)), in the developing countries WiMAX may be the only available option for broadband access, which may be shared among many users or dedicated to much heavier traffic conditions. This might be the biggest difference between networks designed for developed and developing countries. The asymmetry between the downlink and uplink traffic is also different, normally 2:1.

The research showed that in the case of high-speed Internet users (residential users) the limitation factor is not access but the ISP's (Internet Service Providers) capability to provide throughput capacity. There is a correlation between the efficiency of the desired DL/UL access rate and the QoS (Quality of Service) provided by ISPs in the market. An average DL & UL per residential user will increase as ISP server capacity increases. That means should ISPs improve their servers, the average traffic requirements will certainly increase.

Knowing the market size and the service parameters it is possible to calculate the average DL and UL throughput per user. Table 4 shows these calculations.

Commercial users generate most of the traffic. While residential users generate on average an equivalent traffic of 25x12.5kbps (DLxUL), commercial users generate eight times more, equivalent to an average of 200x100kbps (DLxUL). As previously stated, both types of traffic increase at a rate of 15% per year.

TRAFFIC	DENSE URBAN	URBAN	SUB-URBAN
Average Density (HH/km2)	11765	3889	368
Average DL Residential Users (kbps)	500	500	500
Average DL Commercial Users (kbps)	1000	1000	1000
Over Subscription Rate - Residential (%)	5	5	5
Over Subscription Rate - Commercial (%)	20	20	20
Total DL Traffic per km2 (Mbps)	**603**	**165**	**12**
Average DL Traffic per User (kbps)	**51**	**43**	**34**
Total UL Traffic per km2 (Mbps)	**301**	**83**	**6**
Average UL Traffic per User (kbps)	**26**	**21**	**17**

Table 4 – DL/UL Traffic Demand

What are the Propagation Conditions in Different Areas?

The link budget calculations we performed showed that the *Maximum Allowable Path Loss* is 119dB for 64QAM5/6 and 136dB for QPSK1/2 -- a range of approximately 15 dB, depending on the expected modulation. That means at the edge of a cell, the path loss should not exceed 136 dB.

After conducting careful cell planning exercises, we defined the radius of a cell as 600 meters for a dense urban area, 1.0km for an urban area and 2.6km for a suburban area.

Depending on the propagation model used, for dense urban areas the attenuation at 600 meters from the base station lies between 127 to 133 dB.

It is now possible to calculate the required throughput at a cell in different areas. Table 5 shows the results.

CELL TRAFFIC	DENSE URBAN	URBAN	SUB-URBAN
Average Density (HH/km2)	11765	3889	368
Cell Radius (km)	0,6	1,0	2,6
Cell Area (km2)	1,1	3,1	21,2
Cell Density (HH/km2)	13306	12217	7824
Average DL Traffic per User (kbps)	51	43	34
Total DL Cell Traffic (Mbps)	**682**	**519**	**264**
Average UL Traffic per User (kbps)	26	21	17
Total UL Traffic per km2 (Mbps)	**341**	**260**	**132**

Table 5 – Total Predicted DL/UL traffic in a cell

How to Minimize Interference Between Cells?

Since WiMAX is a flexible technology it allows several ways of using spectrum. Depending on the available band (size of the spectrum) and channel width, there are many ways of reusing a given channel.

There are several reuse alternatives: N=1, when all base stations are using the same frequency; N=2, when two different frequencies are used in a cell; and N=3, where each of the three sectors operates in a different given frequency. The most common configurations are N=1 and N=3.

Some vendors claim that a single frequency network (N=1) is possible. Trials conducted in some countries with N=1 demonstrated that this is possible, but the interference level might be too high, especially in dense urban areas due to high multipath interferences, compromising the throughput of a system. That means N=1 represents a less efficient network and a larger number of base stations is required to compensate for the effect of interference. In order to have an efficient network, N=3 should be adopted for a low infrastructure cost. At first glance one might think that reuse factor N=1 will utilize the spectrum more efficiently. This is not always true, because interference will reduce the modulation level, more base stations will be required to meet traffic demand and overall, more spectrum will be used to carry the same amount of traffic. Generally, frequency reuse N=3 requires three times more spectrum, but it is more efficient as higher modulation levels can be consistently used.

What is the Base Station's Throughput?

This is the most difficult question to answer. In an adaptive modulation system the throughput is predictable but depends on the minimum signal level (Smin) and a signal to noise ratio (SNR). Table 6 shows both parameters for a single antenna, 10 MHz channel system according to IEEE 802.16e specifications. Actual performance in a real environment may differ.

Modulation & Coding	SNR (dB)	Smin AWGN (dBm)	Smin Ped-B @3km/h (dBm)	Maximum DL (Mbps)	Maximum UL (Mbps)
QPSK 1/2	2.9	-88.5	-83.9	3.17	1.68
QPSK 3/4	6.3	-85.1	-78.9	4.75	2.52
16QAM 1/2	8.6	-82.8	-78.4	6.34	3.36
16QAM 3/4	12.7	-78.7	-73.4	9.50	5.04
64QAM 1/2	13.8	-77.6	-73.9	9.50	5.04
64QAM 2/3	16.9	-74.5	-69.9	12.67	6.72
64QAM 3/4	18.0	-73.4	-67.9	14.26	7.56
64QAM 5/6	19.9	-71.5	-65.9	15.84	8.40

Table 6 – Maximum DL/UL according to Modulation

The maximum DL/UL throughput was calculated for a 10 MHz channel, DL/UL rate of 2:1, 22 effective symbols for DL and 15 effective symbols for UL.

Smin AWGN (Additive White Gaussian Noise) represents the minimum signal level in the presence of only Gaussian Noise, while Smin Ped-B @ 3km/h (ITU's model) is based on an International Telecommunications Union model's requirement for a minimum signal level in the presence of Gaussian Noise and some degree of interference, adopted by the WiMAX Forum.

It is important to take into consideration that depending on the received channel conditions, the throughput may vary significantly. Within 17 dB variation on SNR or Smin the DL throughput may vary five times. Increments of 2 – 3 dB represent 50% more throughput.

Fixed service provided by CPE devices is much more predictable, since the devices are fixed, have their own power supply and have more power available for the uplink signal. They may also be equipped with a much higher gain directional antenna (3 to 8 dB gain) that reduces the interference, which is unavoidable when using omnidirectional antenna in mobile devices. At least two antennas may be used to allow diversity gain. Fixed devices can present a link budget that is up to 10 dB better than mobile devices. A network with only fixed devices may have 2.5 to 3 times more capacity, compared to a system with only mobile devices.

In our model we are assuming a fixed service using SISO (Single Input Single Output) 500mW CPEs and a reuse factor of N=3 that may give us 8 Mbps per sector for DL and 3 Mbps per sector for UL. Hence, aggregate throughput of a base station would be 24Mbps for DL and 9Mbps for UL.

What are the Spectrum Requirements?

WiMAX is a recent technology and the combination of beamforming signal processing and/or MIMO (Multiple Input Multiple Output) smart antennas will certainly improve the Base Station DL/UL data throughput and link range without requiring any additional bandwidth or transmitting power. Table 7 shows the actual numbers and the expected numbers for the DL/UL throughput within the 2007 – 2012 timeframe.

BASE STATION THROUGHPUT	DL (Mbps) (2007)	DL (Mbps) (2012)	UL (Mbps) (2007)	UL (Mbps) (2012)
1 Sectror (10MHz)	8	12	3	5
1x3 Sectors (30MHz)	24	36	9	14
2x3 Sectors (60MHz)	48	72	18	27
3x3 Sectors (90MHz)	72	108	27	41

Table 7 - Expected DL/UL throughput 2007/2012

Knowing the capacity of the system and the market requirements, it is possible to calculate the size of the market that can be served by the system.

What Percentage of the Market can be Served by the System?

Knowing the size of the market, future growth rate (1.2%), current traffic demand and traffic increase rate (15%), it is possible to calculate the total traffic within the area of a cell. Table 8 shows the results.

MARKET SERVED	DENSE URBAN	URBAN	SUB-URBAN
Cell Density 2007 (HH/km2)	13306	12217	7824
Cell Density 2012 (HH/km2)	14123	12968	8305
Average DL Traffic per User 2007 (kbps)	51	43	34
Average DL Traffic per User 2012 (kbps)	103	85	68
Total DL Cell Traffic 2007 (Mbps)	**682**	**519**	**264**
Total DL Cell Traffic 2012 (Mbps)	**1456**	**1109**	**564**
Average UL Traffic per User 2007 (kbps)	26	21	17
Average UL Traffic per User 2012 (kbps)	52	43	34
Total UL Cell Traffic 2007 (Mbps)	**341**	**260**	**132**
Total UL Cell Traffic 2012 (Mbps)	**728**	**554**	**282**

Table 8 – Total DL/UL traffic in the area of a cell 2007/2012

Table 9 shows the percentage of the market that can be served by a system with 10, 30, 60 and 90 MHz of spectrum based on the current market demands.

(%) MARKET SERVED (2007)	DENSE URBAN	URBAN	SUB-URBAN
DL 1x3 Sectors (30MHz)	4	5	9
UL 1x3 Sectors (30MHz)	3	3	7
DL 2x3 Sectors (60MHz)	7	9	18
UL 2x3 Sectors (60MHz)	5	7	14
DL 3x3 Sectors (90MHz)	11	14	27
UL 3x3 Sectors (90MHz)	8	10	20

Table 9 – Percentage of market served in 2007

Currently, WiMAX Forum does not require modulation levels higher than 16QAM for the uplink. Table 6 shows the maximum possible UL bit rate at those modulation levels, but they are not currently available. This might change soon, since some vendors are implementing the capability to modulate to 64QAM. Keeping the TDD DL/UL rate (2:1) constant due to traffic demand, UL throughput is the limiting factor. Currently, 30MHz could serve only 3% of the total households and 90MHz could provide the same service to up to 8% of the total households. The good news is that in suburban areas with few service providers the system could cover up to 20% of the households.

As the market and traffic grow, the percentage of the market served will decrease. However, there will be some compensation with the introduction of MIMO and beamforming antennas.

Table 10 shows the predictions of the market served in 2012.

(%) MARKET SERVED (2012)	DENSE URBAN	URBAN	SUB-URBAN
DL 1x3 Sectors (30MHz)	2	3	6
UL 1x3 Sectors (30MHz)	2	2	5
DL 2x3 Sectors (60MHz)	5	6	13
UL 2x3 Sectors (60MHz)	4	5	10
DL 3x3 Sectors (90MHz)	7	10	19
UL 3x3 Sectors (90MHz)	6	7	14

Table 10 - Percentage of market served in 2012

As long as 64QAM in the uplink is not implemented, UL is still the limiting factor. Depending on the available spectrum, 2, 4, 5, 6 or 7% of the total households will be served by a system in 85% of the equivalent households in very large cities situated in dense urban and urban areas. It is important to remember that this exercise is valid only for fixed service. Since mobile devices will require less traffic but will most certainly use low modulation level, one factor may compensate the other.

Final Remarks

Most of the numbers used in this paper were taken from real world conditions, based on the results of several studies and trials conducted by Neotec's operators. Those numbers are valid for Brazilian conditions but the concept may be applied in other environments as well.

The main differences might be:

1. *Fixed vs. Mobile applications*: traffic and modulation level will be lower in mobile applications.

2. *DL vs. UL Rate*: for fixed applications the choice was 2:1, while for mobile services most of the vendors' papers are using 3:1. This would increase the DL capacity to improve video downlink services, while uplink traffic might be lower in this situation.

3. *Business vs. Residential Customers*: commercial customers require more bandwidth and are more demanding in terms of service than residential customers. Should the rate be lower from the one adopted (15% of business customers in dense urban areas) the traffic demand will also decrease.

4. *Channel Width*: we are using a 10MHz channel bandwidth, which is the largest channel available today. (3.5/5.0/7.0MHz channels are also available). It is clear that the maximum efficiency of the infrastructure (base station) will be achieved when the maximum bandwidth available is used. Most manufactures believe that base stations are able to process all the traffic generated in a 10.0 MHz channel width. Should a lower bandwidth be used, the system will not utilize the total capacity from the system. In 2009, we expect that this limit will be extended to 20 MHz.
   Doubling the channel bandwidth does not mean that the capacity will double, because the link budget will change. But the larger the available channel bandwidth is, the higher the network efficiency and the lower the implementation cost will be.

5. *Infrastructure Cost*: WiMAX network business models show that base station costs are not the most important factor. What drives the investment analysis are the additional costs associated with infrastructure, mainly microwave links (backhaul cost), base station installation, maintenance and space rental. Lack of sufficient spectrum to implement an efficient network means a larger number of cells needs to be deployed. Also, higher infrastructure costs compromise the implementation viability. Adding more base-station sectors to an existing cell tower to accommodate higher traffic throughput is always cheaper than deploying a new cell, but requires more spectrum.

6. *Users' Traffic Demand*: According to the most recent work conducted by Ibope Net Ratings (www.ibope.com.br), a Brazilian research institute, the number of Internet users grew 48.4% during the year, reaching 21.4 million in December 2007. Unfortunately, only 7 million had access to broadband. An interesting number to note is the time spent by a residential user online -- 22 hours and 59 minutes per month. This number grew 1 hour and 20 minutes in only 12 months.

This is the world record. By comparison, France is in the second place with 20 hours and 34 minutes and USA in the third place with 19 hour and 47 minutes. As the number of Brazilian subscribers grows, this number may decrease as it happened with cellular telephony. This cannot be predicted today.

Although 30 MHz is often cited as the minimum required spectrum for an IEEE 802.16e system, 60/90 MHz should be considered whenever possible in order to reduce infrastructure costs and allow operators to grow system capacity and support market demand in a cost-effective way.

Regulators often divide spectrum among players to increase competition. At some point, however, this does not make sense because operators have too little spectrum to become profitable and meet demand.

Instead of allocating small portions of spectrum in the same band to several operators, different bands should be considered to improve competition. There are many spectrum alternatives available, including at 2.3 GHz, 2.5 GHz, 3.3-3.8 GHz, and 5.1-5.8 GHz. Also, there are almost 700MHz of spectrum below 4GHz and 700MHz in the 5GHz band available, in addition to the possible 700MHz band, which is currently allocated to TV broadcasters.

As it happened with cellular telephony, tri-band and quad-band devices will soon (2008/2009) provide the ability to connect users to different operators, allowing migration and roaming.

U.S. operators like Sprint Nextel and Clearwire are ranking spectrum as the key element for a successful WiMAX deployment. A recent Yankee Group report* states that Sprint has at least 100MHz of spectrum in 85% of their launch cite cities.

We hope to have contributed to a better understanding of the key elements that drive major parameters of a WiMAX business model. Naturally, there are different opinions about this subject and we welcome comments and contributions.

(*) “Modest WiMAX Market Grows Despite Uncertainty” January 2007 (yankeegroup.com)

(**) Morphology studies were developed by Neotec based on the year 2000 Census data base provided by IBGE (Brazilian Geographic and Statistics Institute) www.ibge.org.br

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