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Selection Criteria for Implementing Optimum WIMAX Frequency Spectrum

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ABSTRACT

This paper is about a work that was carried out by the authors in an attempt to identify technologically robust and economically viable solution for commercial implementation and installation of WIMAX optimal frequency spectrum. A variety of broad band working spectrums are discussed. This paper especially focus' on parameters which play an important role in the selection process. Some of these parameters include Data rate, available Modulation Techniques, Competitive services in the particular spectrum, Interference Issues, Power requirements, Environmental effects, Quality of services, Security, Applications, World wide support, Available Vendors and so on.

This work compares various WIMAX comparable standards and frequencies spectrum and provides a associative criteria with respect to band width losses, interference factors, power coverage area, Capital Expenditure (CAPEX) & Operational Expenditure (OPEX). This work also highlights pros & cons associated with successful implementation of WIMAX. After studying various parameters & indicators for an optimal implementation the study suggests that 2.5 GHz is the preferable choice for WIMAX.

Key words: Optimal Frequency Spectrum; Capital Expenditure; Operational Expenditure
Jel Classification: M11; M59

INTRODUCTION

WiMAX (Wiley, 2006) is defined as Worldwide Interoperability for Microwave Access by the WiMAX Forum, formed in June 2001 to promote conformance and interoperability of the IEEE

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802.16 standard, officially known as Wireless Metropolitan area network (MAN). The Forum describes WiMAX as last mile wireless broadband access through standard based technology and an alternate for cable and DSL local loop. WiMAX is not a technology, but rather a certification mark, or 'stamp of approval, given to equipment that meets certain conformity and interoperability tests for the IEEE 802.16 family of standards. Additional possibilities for introducing WiMAX as a substitute for Mobile Ad hoc Networks (MANET) are also being explored (Sandor, 2006; Shaikh,2005). However, the robust security measures (Shaikh, 2005) that MANET offers without the need of infrastructural requirements is attracting a WiMAX based MANET, especially since MANET can operate by IEE 802.11b at 2.4 GHz.

Typically, broad band air interface as identified in various sub classes of IEEE 802.16 is derived from a relatively wide frequency range of 2-66 GHz. Thus, IEEE 802.16a addresses 2-11 GHz standard while IEEE 802.16.2 addresses 10-66 GHz range. While the commercial and technical feasibility of various optimal ranges are being studied by many researchers, the early indications are that selection of a suitable frequency range within 2-11 GHz band is found to be most attractive (Agrawal, 2004; Shaikh 2001, 2005).

In Dec 2001, IEEE 802.16 allocated 10 to 66 GHz spectrum for fixed wireless broadband air interface dedicated for line of sight and point to point applications. In January 2003, IEEE started working for point to multipoint applications and for non line of sight applications. Thus the IEEE 802.16a standard and the spectrum dedicated for this, is from 2 to 11 GHz.

In July 2004 a new extension has developed came in to being and this is the WIMAX start. This 802.16d was a revision for 802.16 and 802.16a but it was for fixed application. In 2005, some amendments were made which were suitable for Mobile wireless broadband up to vehicular speed in license bands from 2 to 11GHz. This standard enabled roaming for portable clients within & between service areas.

Frequency Spectrum

A quick study of the characteristics of the available frequency spectrum for wireless solutions will reveal that frequencies in GHz are Microwave frequencies. Frequencies below 10 GHz are referred to as in centimeter bands and those above 10 GHz are in millimeter bands. Wider channel bandwidths accommodate large data capacities. So, millimeter bands are generally most suitable for very high data rate, line of sight backhauling applications (major pipelines), while centimeter bands are well suited for multipoint, non line of sight (NLOS), tributary and last mile distribution.

Microwaves have wavelengths approximately in the range of 30 cm (frequency = 1 GHz) to 1 mm (300 GHz). However, the boundaries between far infrared light, terahertz radiation, microwaves, and ultra-high-frequency radio waves are fairly arbitrary and are used variously between different fields of study. The term microwave generally refers to "alternating current signals with frequencies between 300 MHz (3 × 108 Hz) and 300 GHz (3 × 1011 Hz)."(Agrawal, 2004) This range of wavelengths has led to many questions. The existence of electromagnetic waves, of which microwaves are part of the frequency spectrum, was predicted by James Clerk Maxwell in 1864 from his Maxwell's equations.

Above 300 GHz, the absorption of electromagnetic radiation by Earth's atmosphere is so great that it becomes effectively opaque, until the atmosphere becomes transparent again in the so-called infrared and optical window frequency ranges. Microwave frequency bands are shown below in table 1.

Table 1:

Microwave frequency bands

Microwave frequency bands		Microwave frequency bands		Microwave frequency bands	
Bands	Frequency range	Bands	Frequency range	Bands	Frequency range
L band	1 to 2 GHz	Q band	30 to 50 GHz	K band	18 to 26.5 GHz
S band	2 to 4 GHz	U band	40 to 60 GHz	Ka band	26.5 to 40 GHz
C band	4 to 8 GHz	V band	50 to 75 GHz	F band	90 to 140 GHz
X band	8 to 12 GHz	E band	60 to 90 GHz	D band	110 to 170 GHz
Ku band	12 to 18 GHz	W band	75 to 110 GHz		

Microwaves are used in broadcasting transmissions because microwaves pass easily through the earth's atmosphere with less interference than longer wavelengths. There is also much more bandwidth in the microwave spectrum than in the rest of the radio spectrum. Metropolitan Area Networks: MAN protocols, such as WiMAX (Worldwide Interoperability for Microwave Access), are based on the IEEE 802.16 specification. The IEEE 802.16 specifications were designed to operate between 2 to 11 GHz.The commercial implementations are in the 2.5 GHz, 3.5 GHz and 5.8 GHz ranges.

Wide Area Mobile Broadband Wireless Access - MBWA protocols, based on standards specifications such as Alliance for Telecommunications Industry Solutions (ATIS) / American National Standards Institute - (ANSI) High Capacity Spatial Division Multiple Access (HC-SDMA), for example Wide Area Mobile Broadband Wireless Access products like iBurst that are designed to operate between 1.6 and 2.3 GHz to give mobility and in-building penetration characteristics similar to mobile phones but with vastly greater spectral efficiency.

This paper mainly focus' the frequency bands which exist in the 2 GHz to 6 GHz portion of the spectrum, where allocated bandwidths are relatively narrow comparing to those which are available in the 10 GHz to 66 GHz range.

Available Competitive Services in WIMAX Frequency Spectrum

Selection of various characteristics for comparison depends upon many factors, notably:

Licensing

Feasibility of applicability of a certain frequency spectrum range depends upon its availability and licensing and regulatory requirements. Between 2 to 6 GHz, there are some license free bands. These unlicensed bands are freely available for any experimental or enterprise application, as opposed to the licensed bands which are currently owned by carriers and users who have paid for the use of these bands.

3.5 GHz band is licensed spectrum, available for Broad band Wireless Access (BWA) and is used in many European and Asian countries, but not in the US. It is the most heavily allocated band, representing the largest global BWA market. Covering 300 MHZ of bandwidth, from 3.3 GHz to 3.6 GHz, this band offers great flexibility for large pipeline back hauling to WAN services. With this license spectrum, major carriers could be able to offer competitive subscriber fees through the economy of scale and the lower equipment costs that is achieved through WIMAX certification.

The 5 GHz Unlicensed National Information Infrastructure (UNII) bands are in three major frequency groups:

- Low and middle U-NII bands in the 5150 MHz-5350 MHz frequency range, included in IEEE 802.11a
- Newly adapted World Radio Conference (WRC) in the 5470 MHz - 5725 MHz frequency range
- Upper U-NII / Industrial, Scientific and Medical (ISM) band in the 5725 MHz - 5850 MHz frequency range

Most WiMAX services are in the upper U-NII band because there are fewer competing services and hence less interferences (Salvekar, 2004). There are many other operational frequency bands that are being considered for a variety of domain specific applications. The two Wireless Communications Services (WCS) bands are twin 15 MHz slots, 2305 MHz to 2320 MHz and 2345 to 2360 MHz. 2.4 GHz band is dedicated to ISM band. It is also an unlicensed band and offers roughly 80 MHz of Bandwidth for BWA deployment. Another option, the Multichannel Multipoint Distribution Services (MMDS) Spectrum include 31 channels of 6MHz is also considered as viable solution within the 2-10 GHz range. Spacing in the 2500 MHz to 2690 MHz range and include the Instructional Television Fixed Service (ITFS). IEEE 802.15.3a, Ultra Wideband (UWB), also uses 3.1 GHz to 10 GHz spectrum. However, It is well established that there are two main working Spectrums for WIMAX which are 2.5 GHz and 3.5 GHz.

RF Interference

An interfering RF source disrupts a transmission and decreases performance by making it difficult for a receiving station to interpret a signal. Problems in RF communication which frequently encounter are interference and attenuation. When same signal receives from various paths then multipath errors are encountered.

Bluetooth offers short-range radio frequency (RF) technology that operates at 2.4 GHz and is capable of transmitting voice and data. Some times at 2.4 GHz, Bluetooth networks also create Interference problem in Wireless MAN, working in this particular range.

Attenuation

Attenuation occurs when an RF signal passes through a solid object, such as a tree, the strength of signal reduces and subsequently its range. It is critical to identify inherent interference sources in the spectrum range under consideration.

Discussions and Consideration

Here we describe at length the comparison criteria and modeling approaches that were employed to reach to an assertive conclusion.

Comparison Criteria

The two main working spectrums of WIMAX are compared on the basis of various important parameters as shown below.

$f_n = \max (\Sigma a_n x, \Sigma b_n y)$, Where,

F = Most suitable Spectrum for WIMAX = max (f_1,……..,f_n), f = Leading Spectrum with respect to any one comparing parameter

n = 1,2,… Parameter number

x = 1 to 7, Weight of importance of 2.5 GHz Spectrums with respect to the comparing parameters

y = 1 to 7, Weight of importance of 3.5 GHz Spectrums with respect to the comparing parameters

a = 2.5 GHz Spectrum

b = 3.5 GHz Spectrum

The next several tables indicate some of the most critical factors & their corresponding weights. These values then are introduced in the above analytical model to derive a winning solution.

Comparison With Respect To Losses (f1)

The 1st comparable factor between the 2.5 GHz & 3.5GHz spectrums is the effective Range or Coverage area. For large coverage, it is necessary that the losses are small.

Table 2:

Shows factors affecting the Coverage and range in Mobile WIMAX deployment.

Factors	Variation With Freq.	Impact at higher frequency	2.5GHz Weight	3.5 GHz Weight
Receiver Sensitivity	No	None	5	5
Shadow Margin (Additional loss to account for shadowing by terrain and building).	Yes	Shadow margin is related to path loss & shadow variance. Both these parameters increases as frequency increases.so 3.5GHz gives 2dB more losses than2.5 GHz spectrum	5	3 (More loss so less range)
Free Space Loss	Yes	Free Space Losses enhance as frequency goes up. ,FSL of 3.5GHz is 3dB larger than 2.5GHz. FSL (dB) = 32.4 + 20LOG dist (m) + 20LOG freq (GHz)	5	2
Path Loss	Yes	lower the frequency , smaller will be the path loss and greater will be the distance which a signal will propagate. Higher frequencies experience greater path loss And therefore a reduction in signal range.	5	2.5 (More loss so less range)
Physical Environment	Yes	Higher frequency bands tend to experience higher losses in metal and concrete surfaces but lower losses through glass.	5	2.5 (More loss so less range)
Cable Loss	Yes	Cable loss increases as frequency increases In a 30m cable, ,the loss of 3.5GHz is about 0.58dB more than 2.5GHz	5	4 (0.58dB more loss)

Using :

$f_n = \max (\Sigma a_n x, \Sigma b_n y)$

$f_1 = \max (\Sigma a_1 x, \Sigma b_1 y)$, where f_1 is the leading spectrum with respect to losses or range,

$f_1 = \max (30x, 19y)$

Hence, $f_1 = 2.5GHz$

Comparison With Respect To Interference Factors

Since an interfering RF source disrupts transmission and decreases performance by making it difficult for a receiving station to interpret a signal, this factor has a great significance in

developing a comparison model. Forms of RF interference frequently encountered are Multipath interference and attenuation. Multipath interference is caused when signals are reflected off objects resulting in reception distortion. Attenuation occurs when an RF signal passes through a solid object, such as a tree, the strength of the signal reduces and subsequently its range. The comparison details are given below in table 3.

Table 3:

Comparison details with respect to Interference.	
2.5 GHz	3.5 GHz
1) Multichannel Multipoint Distribution Services (MMDS) Spectrum includes 31 channels of 6MHz spacing in the 2500 MHz to 2690 MHz range and includes the Instructional Television Fixed Service (ITFS).	1) IEEE 802.15.3a, UWB, also uses the 3.1 GHz to 10 GHz spectrum. 2)The band, 3400-4200 MHz is heavily used by FSS (Fixed Satellite Station) satellites for many essential telecommunication needs, and its use is constantly developing in Asia, the Pacific, Africa, the Arab States, parts of Europe and the Americas • Co-frequency interference o WIMAX 3496-3596MHz o Satellite 3400-4200MHz • Adjacent frequency interference o WIMAX 3496-3596MHz; o Satellite 3600-4200MHz
5	2.5

Using :

$f_n = \max (\Sigma an\ x,\ \Sigma bn\ y)$

$f_2 = \max (\Sigma a_2\ x,\ \Sigma b_2\ y)$, where f_2 is the leading spectrum with respect to Interference sources

$f_2 = \max (5x, 2.5y)$

Hence, $f_2 = 2.5GHz$

The required distance between Fixed Satellite Services (FSS) and WiMAX Base station is at least 30KM. For a clear resolution of issues resulting from adjacent frequency interference and co-frequency problems space isolation is one popular way since WiMAX can't share the same 3.4 GHz ~ 3.6 GHz band with satellite.

Adjacent Frequency Interference Effects

Possible solutions to the problem of Frequency Interference Effects may include:

- WiMAX base station needs to use narrow band filter to attenuate the interference

- FSS needs additional high performance band-pass filter to enhance the receiver capability
- Add 25MHz protected band between WiMAX and FSS frequency band

Comparison With Respect To Power And Coverage Area

The important factors for the comparison with respect to Power and Coverage area are shown below in table 4.

Table 4:

Comparison with respect to Power and coverage area.

Factors	Weight 2.5GHz	Weight 3.5 GHz
3.5GHz just have 35dBm output power in the antenna as defined by ETSI, but 2.5GHz can reach larger output value.	5	2.5
3.5GHz has the less coverage area compare to 2.5GHz for urban area, when using indoor CPE	5	2.5
3.5GHz has less coverage area compare to 2.5GHz in outdoor dense urban area when using PCMCIA	5	2.5
3.5GHz has the worst coverage area compared to 2.5GHz in outdoor dense urban area as using PCMCIA.	5	2.5
Total	20	10

Using :

$f_n = \max (\Sigma a_n x, \Sigma b_n y)$

$f_3 = \max (\Sigma a_3 x, \Sigma b_3 y)$, where f_3 is the leading spectrum with respect to Power & Coverage

$f_3 = \max (20x, 10y)$

Hence, $f_3 = 2.5GHz$

Comparison With Respect to CAPEX and OPEX Area

The critical factors for the comparison with respect to CAPEX and OPEX area are shown below in table 5.

Table 5:

Comparison with respect to CAPEX and OPEX area.

Factors	Weight 2.5 GHz	Weight 3.5 GHz
Cost to build a 3.5 GHz network is 2 times than that of 2.5 GHz network in the same coverage area.	5	2.5
CPE Cost is from $ 500-300 for 3.5 GHz And for 2.5 GHz it is approximately $100.	5	2.5
Total	10	5

Using :

$f_n = \max (\Sigma a_n x, \Sigma b_n y)$

$f_4 = \max (\Sigma a_4 x, \Sigma b_4 y)$, where f_4 is the leading spectrum with respect to Cost

$f_4 = \max (10x, 5y)$

Hence, $f_4 = 2.5GHz$

Comparison With Respect To Cell Radius & Range

As is shown under, most mobile applications are best adapted in the < 3GHz bands range. However, for fixed applications typically 3.5 GHz spectrum is mostly adopted. Thus IEEE 802.16-2004 mainly focuses on 3.5 GHz spectrum while IEEE 802.16e standard works with 2.5 GHz spectrum.

The important factors for the comparison with respect to Cell radius and range, are given below in table 6.

Table 6:

Comparison with respect to cell radius & range.

2.5 GHz	3.5 GHz	Weight (2.5 GHz)	Weight (3.5 GHz)
Cell Size is 1-5 KM	Cell Size is 4-6 KM	2.5	5
Range 2-5 Km	Range 7-10 Km, max 50	2.5	5
According to Standard for mobile application, standard cell radius is 1-3 miles	According to Standard for fixed application standard cell radius is 3-5 miles.	-	-
Total Score on the basis of Cell Radius & Range		5	10

Using :

$f_n = \max (\Sigma a_n x, \Sigma b_n y)$

$f_5 = \max (\Sigma a_5 x, \Sigma b_5 y)$, where f_5 is the leading spectrum with respect to Cell Radius

$f_5 = \max (5x, 10y)$

Hence, $f_5 = 3.5$ GHz

Comparison with respect to Mobility

For mobile networks and mobile applications including MANET based systems it is necessary to remain connected at the least above the Transport layer. For this purpose the 802.16e is the standard which supports mobility and its main focus is on the 2.5 GHz frequency spectrum. The important factors for the comparison with respect to Mobility are shown below in table 7.

Table 7:

Comparison with respect to Mobility.			
2.5 GHz	3.5 GHz	Weight 2.5 GHz	Weight 3.5 GHz
Diversified terminal: Modem, PCMCIA, Handset, PDA	Low quantities Terminal: desktop Modem, PCMCIA.	5	2.5
75-93 miles / Hr OR 120 KM / Hr	For fixed applications Only	5	2.5
Total Score with respect to Mobility		10	5

Using :

$f_n = \max (\Sigma a_n x, \Sigma b_n y)$

$f_6 = \max (\Sigma a_6 x, \Sigma b_6 y)$, where f_6 is the leading spectrum with respect to Mobility

$f_6 = \max (10x, 5y)$

Hence, $f_6 = 2.5$ GHz

Comparison With Respect to Data Rates

The important factors for the comparison with respect to Data Rates are given below in table 8.

Table 8:

Comparison with respect to data rates.		
Factors	Marks (2.5 GHz)	Marks (3.5 GHz)
Data rate is dependent on the channel Bandwidth so for 5MHz Channels.	This band is mostly used for 802.16e applications and Data rate is 15 Mbps @ 5 MHz	This band is mostly used for 802.16-2004 applications and Data rate is 15-18 Mbps @ 5 MHz
Total	2.5	5

Using :

$f_n = \max (\Sigma a_n x, \Sigma b_n y)$

$f_7 = \max (\Sigma a_7 x, \Sigma b_7 y)$, where f_7 is the leading spectrum with respect to Cost

$f_7 = \max (2.5x, 5y)$

Hence, $f_7 = 3.5$ GHz

Licensing Issues and Technical Limitations

While WiMAX spectrum is mostly unlicensed, WiMAX also offers operability with a licensed band, specifically in the 5GHz range for WIMAX. So, the designers and engineers have choice to select licensed or unlicensed frequency spectrum for implementing and installation of application adaptable suitable solutions. One important point is that the total avoidance of license free band may not offer the quality that a licensed solution may provide. This is further shown in table 9.

Table 9:

Comparison with respect to License and unlicensed solution.

Licensed Solution	License-Exempt Solution
Better QoS	Poor Qos with lots of Interference Issues
Better NLOS reception at lower frequencies	Poor NLOS reception at lower frequencies as compare to Licensed Spectrum
Better Security	Poor Security

Aggregated Result:

Using:

fn = max (Σ a_n x, Σ b_n y) Where, F = Most suitable Spectrum for WIMAX = max (f1,……..,fn),
f = Leading Spectrum with respect to any one comparing parameter

F = max (Σ a_n, Σ b_n)

F = max (x,y) ($f_1 \ldots f_7$)

F = max (82.5x, 56.5y)

F = 2.5 GHz = the most suitable Spectrum for WIMAX

CONCLUSION AND RECOMMENDATIONS

We have shown that the most suitable and preferable spectrum for WIMAX implementations appears to be in the 2.5 GHz range. The 2.5 GHz range promises to provide most if not all the features which are required to compete with most current wireless technologies and has a prospective to go a long way in the future. This is particularly true in the cases where mobile applications or MANET installations have to be augmented by some sort of gateway based solutions between fixed and ad hoc infrastructures. However, since WIMAX is still in its infancy, it is important to consider the following factors before a full blown commitment is made:

- Compatibility issues between different (2.5 GHz, 3.5 GHz) bands equipment
- Interference issues throughout the 2-11 GHz spectrum.
- Issues of frequencies allocations
- Wireless Local loop still using the frequencies in the 3.5 GHz frequency band

More work is needed, especially in the areas of building models that can be employed to provide real time design specifications in a simulated environment for specific custom services and applications with an emphasis on mobility and MANET.

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