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WiMax Linkbudget Calculations for Airport Surface Communications in the C Band

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ABSTRACT

This paper deals with the Dimensioning of a WiMax wireless system from the physical layer perspectives that requires accurate knowledge of the radio propagation channel characteristics combined to system parameters such as the required number of channels, power, antenna gains and heights, cable losses, receiver sensitivity, and the required BER for a given Quality of Service (QoS).

Keywords—*Linkbudget, Radiowave Propagation, Maximum Allowable Path Loss, Effective Sensitivity, Cell range.*

1. INTRODUCTION

WiMax system as it is specified in the Standards employs multi-carrier transmission using OFDMA with different bandwidth options and two duplexing schemes: TDD and FDD. For the Aviation needs, and for the time being, the study focuses on a 10 MHz bandwidth and exclusively on TDD duplexing. Besides, according to the WRC07 [1] assignments for aviation, the operating frequency will be using the 5 GHz band. As a consequence, propagation models in the 5GHz band have been investigated [2] and results are now available within the aviation community. Therefore, these results will be used in this study as input to derive the linkbudget of the WiMax Mobile system in the Airport surface environment. This document however focuses on the use and adaptation of these results for typical large ECAC airports such as Paris Charles De Gaulles or London Heathrow. Perspective work could be the completion of the other medium-sized and small airports.

Section II provides a brief overview on radio propagation work for the C Band and the justification of use of specific C Band model, which will be used as input for the linkbudget calculation.

This paper is organized as follows: Section II explains the concept of dimensioning and details the required input parameters both system specific and general radio parameters. In this Section we will outline the methodology of the cell count by using the notion of Maximum Allowable Path Loss (MAPL) and the Equivalent Isotropic Radiated Power (EIRP) in both uplink and downlink. The radiowave propagation models that are valid in the range of 5000 MHz bands will also be detailed. Section III deals with the system specific input parameters inherent to WiMAX system such as SNR requirements, supported service types, QoS requirements (such as BER, and BLER), static sensitivities as defined in the ETSI Technical Specifications and other RF parameters. Section IV is nothing but the results of network dimensioning, whereas Section V summarizes the discussions and concluding remarks with the perspective work.

2. RADIO PROPAGATION CHANNEL DESCRIPTION

Several studies have been dedicated to radio propagation in VHF and UHF [3] but very few in the C Band, especially in Airport surface environments. The most well known path loss model in mobile communication systems is Hata–Okumura model [4] However for BWA systems the Erceg proposed a model, which was accepted for WiMAX forum for GHz frequency band [5][6]. The Erceg path loss model has been initially designed for suburban areas, receiver antenna heights close to 2 meters, base station heights between 10 and 80 meters and for frequency bands at 1,9 GHz. The model distinguishes three different terrain types, A, B and C. Terrain type A is a hilly terrain with moderate-to-heavy tree density and is associated with the highest path loss. Terrain type C is a flat terrain with light tree densities, producing the lowest path loss. Terrain type B is in between, characterized as either a mostly flat terrain with moderate-to-heavy tree densities or a hilly terrain with light tree densities.

For the airport surface case in the C Band, the complexity of this environment makes a deterministic propagation model quasi-impossible to derive and use. From one hand the moving aircrafts and vehicles and from the other hand the buildings morphology and material structures pushes for a statistical model use rather than a site-general or deterministic model. In land mobile communications several models have been utilized in the 900-1800 and 2000MHz bands but none of them could be adapted to the aviation environment. Even ray tracing techniques using the Uniform Theory of Diffraction, with accurate clutter information, cannot be used because of the dynamic characteristics of the Airport surface. Therefore, a statistical model using real measurements is needed. This report uses the propagation model derived from studies performed in the US in the C-Band [2]. The path loss formula is applicable to a large airport with a stochastic component of Gaussian distribution and zero mean value. The expression for this path loss is given by:

$$PL(dB) = A + 10.n.\log_{10}(d) + X \qquad (1)$$

where A is set to 103 dB, derived from measurements in Miami airport; n is found to be equal to 2.23; and X is a random variable of Gaussian distribution (standard deviation σ= 5.53dB, and zero mean value) and accounts for shadowing and obstructions losses. The distance d is expressed in km. In our example a 10 dB value for X has been assumed.

This propagation model is similar to Erceg extended model [5][6]. The latter was, however, limited to 3.5GHz. The US study made use of Erceg concept and derived the adequate parameters for the C-Band. The measurements were collected at Miami and JFK Airports, representing large and high density environment.

3. REQUIRED INPUT PARAMETERS

A. Receiver Sensitivity

For either uplink or downlink receiver sensitivity is defined as the minimum received signal below which the system is considered to be non operational. This parameter is highly important in the design of any wireless system as its value influences the coverage range in either up or down direction. To derive the sensitivity one needs to first estimate the thermal noise that is present in the receiver.

B. Thermal Noise

For the effective thermal noise, the bandwidth needs to be scaled to the effectively used bandwidth. Therefore, the bandwidth value has to be multiplied to the ratio between the number of used sub-carriers (Nused)[1] and the total FFT window size (NFFT), and the sampling rate (n).

For example, in the case of a 10 MHz overall physical bandwidth the Table below illustrates the subcarriers breakdown per category.

TABLE I

PARAMETERS PER CHANNEL BANDWIDTH

BW	N_{FFT}	N_{used}	N_{DataDL}	N_{DataUL}	$N_{subChDL}$	N_{SubUL}
10 MHz	1024	840	720	560	30	35

The effective Thermal Noise is thus given by:

$$N(dBm) = -174 + 10\log\left(BW \times n \times \frac{N_{used}}{N_{FFT}}\right) \qquad (2)$$

The sampling rate (n) is a fixed figure given by 28/25 = 1.12 and will be used throughout this document. SNR is provide in in Table II and for different modulation schemes and forward correction model.

C. Effective Sensitivity Calculation

Given the effective Thermal noise at the receiver the effective sensitivity can be derived and is written as follows:

$$\begin{aligned} &EffSensitivity(dBm) = N(dBm) + SNR + NF + \\ &Lcable - RxAntGain - Rx\_AntDivGain \end{aligned} \qquad (3)$$

The required SNR is tabulated and depends on the modulation type. Table II below summarizes the figures for QPSK and QAM, for CC and CTC correction schemes.

The green-shaded values in table II are the ones used in our calculations.

TABLE III

SNR VERSUS MODULATION AND FEC MODEL

Modulation Scheme	SNR CC (AWGN, BER 10^{-6}) (dB)	SNR CTC (AWGN, BER 10^{-6}) (dB)	Data bit per symbol
QPSK 1/2	5	2.5	1
QPSK 3/4	8	6.3	1.5
16QAM 1/2	10.5	8.6	2
16QAM 3/4	14	12.7	3
64QAM 1/2	16	13.8	3
64QAM 2/3	18	16.9	4
64QAM 3/4	20	18	4.5

D. Implementation Margin

The implementation margin is set to 3 dB (accounts for a safety margin to cope with potential interference)

E. Uplink Sub-Channelization Gain

In the Uplink it is unlikely that data is sent over the overall physical bandwidth. Sub Channelization in the uplink is an option within WiMAX. Without sub channelization, typically causes the link budget to be asymmetrical, this causes the system range to be up link limited. Sub-channelling enables the link budget to be balanced such that the system gains are similar for both the up and down links. Sub channelling concentrates the transmit power into fewer OFDM carriers; this is what increases the system gain. The use of sub channelling is further expanded in orthogonal frequency division multiple access (OFDMA) to enable a more flexible use of resources that can support nomadic or mobile operation, such in Airport surface domain. Therefore, the uplink sub-channel gain is taken into account in our calculation. This gain is given by:

$$UL\_SubChan\_Gain = -10\log\left(\frac{N_{usedSubChUL}}{N_{SubChUL}}\right) \qquad (3)$$

NSubChUL is already provided in Table I and NUsedSubChUL is based on the number of subchannels required for the offered uplink data rate per user, and will also depend on the modulation scheme.

F. Bit Rate per Cell (or Sector)

The bit rate is dependent upon several parameters amongst them is the bandwidth, the modulation scheme and the FFT window size. The general formula for the bit rate is given as follows:

$$BitRate = BW \times n \times \frac{N_{Data}}{N_{FFT}} \times DataBitsPerSymbol \times \frac{1-Overhead}{1+GuardTime} \times TDD(down/up)Ratio \qquad (4)$$

BW: accounts for the Bandwidth (Hz)
n: is the sampling rate that is fixed to 28/25 = 1.12
NData: user data channels
NFFT: FFT window size (1024)
Overhead: percentage of time when no data is sent (approx. 20%)

Guardtime: intented to overcome multipath effects (1/8 as specified)

TDD Down/up ratio: the ratio between up and down link time (3 and higher, up to 5). The TDD Down/up conversion is typically 3 :1 but for Aviation needs this figure might reach 5 as the ground stations will simultaneously serve many aircrafts and vehicles with large amounts of data.

Bit rate (or Throughput) : is expressed in bits per second

G. *General Mobile WiMax Radio Parameters*

The following three tables include the PHY layer parameters and assumed radio parameters that have been used in our linkbudget calculations.

TABLE IIIII
RADIO PARAMETERS IN A TYPICAL AIRPORT ENVIRONMENT

Parameters	Values	Units	Notes
Operating Frequency	5100	MHz	C-Band
Channel Bandwidth	10	MHz	typical value
BS Antenna Aperture (3dB)	70	°	
BS Antenna Front/back ratio	20	dB	
BS Antenna Height	40	m	Typical ATC Tower Control
MS Antenna Height	1,5	m	Typical Aircraft bottom-mounted antenna. For top-mounted antennas this figure could be 6 m
BS Antenna Gain	12	dBi	
MS Antenna Gain	-1	dBi	
BS Maximum PA Power	33	dBm	could be less
MS Maximum PA Power	23	dBm	could be less
# of BS TRX antennas	Tx: 2, Rx: 2		could be more depending on expected traffic
# of MS TRX antennas	Tx: 1, Rx: 1		no diversity on aircrafts
BS Noise figure	4	dB	to be confirmed with manufacturers
MS Noise figure	7	dB	to be confirmed with manufacturers

TABLE IVV
PHY LAYER OFDMA PARAMETERS

Parameters	Values
System Channel Bandwidth	10 MHz
Sampling Frequency	11,2 MHz
FFT Size (NFFT)	1024
Sub-Carrier Frequency Spacing	10,94 kHz
Useful Symbol Time (Tb = 1/f)	91,4 µs
Guard Time (Tg= Tb/8)	11,4 µs
ODMA Symbole Duration (Ts = Tb + Tg)	102,9 µs
Frame Duration	5 ms
Number of OFDMA Symbols	48

TABLE V
WIMAX CARRIER STRUCTURE

Parameters		Values
DL PUSC	Null sub-carriers	184
	Pilot sub-carriers	120
	Data sub-carriers	720
	Sub-channels	30
UL PUSC	Null sub-carriers	184
	Pilot sub-carriers	280
	Data sub-carriers	560
	Sub-channels	35

The maximum allowable path loss is the maximum loss (MAPL) that is tolerated by the system given the TX power, cable losses, and the RX sensitivity. The higher the MAPL the larger is the extent of the coverage. The MAPL is calculated using the formula below:

$$MAPL(dB) = EiRP(dBm) - EffSensitivity(dBm) \qquad (4)$$

EiRP per link is the effective link power scaled to one sub-carrier whereas the Effective Sensitivity accounts for the scaled sensitivity to this channel.

H. Maximum Cell Range Calculations

The maximum range is derived from eqn. (1) and (4) (see linkbudget spreadsheet in Annex1 and Annex2)

4. CONCLUSIONS

It has been shown through the linkbudget calculations that the Mobile WiMax could well be adapted to the Airport surface with high DL bit rates and keeping the uplink balanced. Channelling (or Channelization) gain is of paramount importance to keep the balance between up and down coverage ranges. However, several issues still to be investigated such as the adjustment of propagation model parameters to different airport types and sizes. The calculations provided did not consider fading losses, which still need to be investigated in the C Band through extensive channel impulse measurements. Further still some figures need to be confirmed like the noise figures for both ground and vehicle/aircraft from the manufacturers.

REFERENCES

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APPENDIX 1

WIMAX IEEE802.e LINKBUDGET FOR THE DOWNLINK									
Modulation Scheme		**QPSK 1/2**		**16QAM 1/2**		**64 QAM 1/2**			
Link Direction		**DL (CC)**	**DL (CTC)**	**DL (CC)**	**DL (CTC)**	**DL (CC)**	**DL (CTC)**		
TX Parameters	**Unit**							**Governing Equation**	**Notes**
# of antenna elements		2	2	2	2	2	2		
TX Power per Antenna Element	dBm	33,00	33,00	33,00	33,00	33,00	33,00	A1	Tx_Pout = (UL: 1W) / (DL: 2W)
Maximum TX Antenna Gain	dBi	12,00	12,00	12,00	12,00	12,00	12,00	A2	
Tx Cable loss	dB	5,00	5,00	5,00	5,00	5,00	5,00	A3	
TX EiRP	dBm	40,00	40,00	40,00	40,00	40,00	40,00	A4=A1 + A2 - A3	TX EiRP = TX_Pout + TX_AntGain - TX_CableLoss
# of occupied sub-carriers		840	840	840	840	840	840	A5	
NFFT Window size		1024	1024	1024	1024	1024	1024	A6	
TX EIRP per sub-carrier	dBm	15,94	15,94	15,94	15,94	15,94	15,94	A7 = 10*log(1000*A1/A5)	
System Parameters									
Required SNR	dB	**5,00**	**2,50**	**11,00**	**8,60**	**16,00**	**13,80**	A8	
Bandwidth	MHz	10,00	10,00	10,00	10,00	10,00	10,00	A9	
sub-carrier spacing	kHz	10,94	10,94	10,94	10,94	10,94	10,94	A10	
Transmit upper Frequency	MHz	5120	5120	5120	5120	5120	5120	A11	
Margins									
Interference Margin	dB	0	0	0	0	0	0	A12	
Implementation Margin	dB	3	3	3	3	3	3	A13	
Safety Margin	dB	0	0	0	0	0	0	A14	
Banking Loss Margin	dB	0	0	0	0	0	0	A15	
RX Antenna Diversity Gain	dB	0	0	0	0	0	0	A16	
RX Parameters									
Maximum RX Antenna Gain	dBi	-1	-1	-1	-1	-1	-1	A17	
Rx Cable loss	dB	3	3	3	3	3	3	A18	
Thermal Noise Density@290K	dBm/Hz	-174	-174	-174	-174	-174	-174	A19	No = kTo
Receiver Noise Figure	dB	7	7	7	7	7	7	A20	
Composite Noise Figure	dB	10	10	10	10	10	10	A21 = A18 + A20	F = Cable loss + Manufacturer Noise figure
RX Sensitivity (per sub-carrier)	dBm	-114,6	-117,1	-108,6	-111,0	-103,6	-105,8	A22=A8 + A12 + A13 + A14 + A15 - A16 - A17 + A19 + A21 + 10log(1000*A10)	S = kT + BW + F + all margins - Diversity Gain(if any) - Rx Antenna Gain
RX Sensitivity (composite)	dBm	-89,4	-91,9	-83,4	-85,8	-78,4	-80,6	A23 = A8 + A12 + A13 + A14 + A15 - A16 - A17 + A19 + A21 + 10log(1000*A5*A10)	same as A22 except that the all the sub-carriers are included in the calculation
Maximum Allowable Path Loss	dB	**130,6**	**133,1**	**124,6**	**127,0**	**119,6**	**121,8**	A24 = A7 - A22	MAPL = EIRP(per sub-carrier) - Sensitivity (at sub-carrier level)
Achievable maximum range - NLOS-S Model	km	**6,1**	**7,9**	**3,3**	**4,2**	**2,0**	**2,5**	A25 = 10^((A24 - 103 - 10)/22,3)	custom model PL = A + 10*n*log(range) + X; A=103dB; n = 2,23, X = 10 dB

APPENDIX2

WIMAX IEEE802.e LINKBUDGET FOR THE UPLINK									
Modulation Scheme		QPSK 1/2	QPSK 1/2	16QAM 1/2	64QAM 1/2	QPSK 1/2	QPSK 1/2		
Link Direction		UL (CC)	UL (CTC)	UL (CC)	UL (CTC)	UL (CC)	UL (CTC)		
TX Parameters	**Unit**							**Governing Equation**	**Notes**
# of antenna elements		1	1	1	1	1	1		
TX Power per Antenna Element	W	0,20	0,20	0,20	0,20	0,20	0,20	A1	Tx_Pout = (UL: 200mW) / (DL: 2W)
Maximum TX Antenna Gain	dBi	-1,00	-1,00	-1,00	-1,00	-1,00	-1,00	A2	
Tx Cable loss	dB	3,00	3,00	3,00	3,00	3,00	3,00	A3	
TX EiRP	dBm	-3,80	-3,80	-3,80	-3,80	-3,80	-3,80	A4=A1 + A2 - A3	TX EiRP = TX_Pout + TX_AntGain - TX_CableLoss
# of occupied sub-carriers		240	240	240	240	240	240	A5	Multipe of 48, here a figure of 5*48 is considered
NusedChUL		1	1	1	1	1	1	A6	
NSubChUL		5	5	5	5	5	5	A7	5 Subchannels required and 1 used as an assumption
NFTT Window size		1024	1024	1024	1024	1024	1024	A8	
TX EIRP per sub-carrier	dBm	-0,79	-0,79	-0,79	-0,79	-0,79	-0,79	A9 = 10*log(1000*A1/A5)	
System Parameters									
Required SNR	dB	**5,00**	**2,50**	**10,50**	**8,60**	**16,00**	**13,80**	A10	
Bandwidth	MHz	10,00	10,00	10,00	10,00	10,00	10,00	A11	
sub-carrier spacing	kHz	10,94	10,94	10,94	10,94	10,94	10,94	A12	
Uplink Sub-Channelization Gain	dB	7,0	7,0	7,0	7,0	7,0	7,0	A13 = -10*log(A6/A7)	Sub-Channelisation gain = -10*log(Nused/Nrequired)
Transmit upper Frequency	MHz	10	10	10	10	10	10	A14	
Margins									
Interference Margin	dB	0	0	0	0	0	0	A15	
Implementation Margin	dB	3	3	3	3	3	3	A16	
Safety Margin	dB	0	0	0	0	0	0	A17	
Banking Loss Margin	dB	0	0	0	0	0	0	A18	
RX Antenna Diversity Gain	dB	3	3	3	3	3	3	A19	
RX Parameters									
Maximum RX Antenna Gain	dBi	12	12	12	12	12	12	A20	
Rx Cable loss	dB	5	5	5	5	5	5	A21	
Thermal Noise Density@290K	dBm/Hz	-174	-174	-174	-174	-174	-174	A22	No = kTo
Receiver Noise Figure	dB	4	4	4	4	4	4	A23	
Composite Noise Figure	dB	9	9	9	9	9	9	A24 = A21 + A23	N = Cable loss + Manufacturer Noise figure
RX Sensitivity (per sub-carrier)	dBm	-132,6	-135,1	-127,1	-129,0	-121,6	-123,8	A25 = A10-A13+A15+A16+A17+A18-A19+A22+A24-A20+10*log(A12*1000)	S = kT + BW + F + SNR - RxAntenna Gain + all margins - Diversity Gain(if any) - Sub-Cahanellizaation Gain
RX Sensitivity (composite)	dBm	-89,8	-92,3	-84,3	-86,2	-78,8	-81,0	A26 = A10-A13+A15+A16+A17+A18-A19+A22+A24-A20+10*log(A5*A12*1000)	same as A25 except that the all the sub-carriers are included in the calculation
Maximum Allowable Path Loss	dB	**131,8**	**134,3**	**126,3**	**128,2**	**120,8**	**123,0**	A27 = A9 - A25	MAPL = EIRP(per sub-carrier) - Sensitivity (at sub-carrier level)
Achievable maximum range - NLOS-S Model	km	**7,0**	**9,0**	**4,0**	**4,8**	**2,2**	**2,8**	A28 = 10^((A27 - 103 - 10)/22,3)	custom model PL = A + 10*n*log(range) + X; A=103dB; n = 2,23, X = 10 dB
Achievable maximum range - NLOS-S Model without sub-channelization gain	km	**3,4**	**4,4**	**1,9**	**2,3**	**1,1**	**1,4**		

APPENDIX 3

Downlink and Uplink Ranges with and without Sub-Channelization Gain