Radio Network Dimensioning and Planning for WiMAX Networks

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This paper is a high-level introduction to the complexities involved in dimensioning and planning of Worldwide interoperability for Microwave Access (WiMAX) networks, with specific emphasis on key WiMAX features and planning techniques that need to be considered for optimal network coverage, capacity, and service requirements. We introduce Fujitsu's in-house developed WiMAX Network Dimensioning Tool, which contains innovative algorithms for interference margin calculation and capacity analysis. In theory, WiMAX technology allows a huge number of optional and mandatory features and promises larger coverage and higher data throughput in comparison to the existing 2G/3G technologies. This paper explains briefly the challenges involved in network planning due to such features, with a further description on the step-by-step approach to network dimensioning and planning.

1. Introduction

Worldwide interoperability for Microwave Access (WiMAX) has become synonymous with the IEEE 802.16 air interface standard.[1] WiMAX is a broadband wireless access (BWA) technology capable of delivering voice, video, and data over the microwave RF spectrum to stationary or moving users. There are two flavours of WiMAX: Fixed WiMAX and Mobile WiMAX.

IEEE 802.16-2004 or IEEE 802.16d is a fixed wireless access technology, optimised for fixed and nomadic applications in line-of-sight (LOS) and non-LOS (NLOS) environments. It is designed to serve as a wireless digital scriber line (DSL) replacement technology to provide basic voice and broadband access. This standard is also a viable solution for wireless backhaul for WiFi access points or potentially for cellular networks.

IEEE 802.16e is a mobile WiMAX standard targeted primarily for portable and mobile applications in NLOS environments. Mobile WiMAX systems can also provide fixed and nomadic access. Mobile WiMAX incorporates features such as soft/optimised handoff, fractional frequency reuse, features for better NLOS performance, and indoor penetration.

The WiMAX Forum is an organization that promotes WiMAX interoperability between vendors and develops WiMAX system profiles. The system profiles refer to a set of parameters on which a WiMAX network will operate, including the frequency band, channel bandwidth, and duplexing scheme. The profiles do not cover all possible operational parameters, but instead prioritise those with wide support from the industry and those in harmony with various frequency regulations across regions and countries.

The WiMAX standard supports a wide range of features, including multiple input multiple output (MIMO) and adaptive antenna system (AAS) antenna types, operating frequencies in the licensed and unlicensed bands, a wide range of bandwidths, multiple operating modes {time division duplex (TDD) and frequency division duplex (FDD)}, and fractional frequency reuse. The support for these advanced features help in achieving high data throughputs of the order of 70 Mb/s and coverage distances of around 50 km, depending on the spectrum available.

The challenges in WiMAX network dimensioning and planning compared to conventional 2G/3G cellular network planning are to evaluate the implication of each of the optional and mandatory features and then consider the best combination of the supported features to suite the operator's business model. Section 2 of this paper gives a high-level description of the features and application of WiMAX. Section 3 describes an approach for addressing network dimensioning and planning for WiMAX network and gives details of the Fujitsu's in-house dimensioning tool DoORs. Lastly, Section 4 presents our conclusions.

2. WiMAX technology and applications

2.1 WiMAX technology

2.1.1 OFDM and OFDMA

The Fixed WiMAX technology specifies a radio interface that uses orthogonal frequency-division multiplexing (OFDM), and the Mobile WiMAX technology uses a radio interface based on OFDMA.

In an OFDM system, a very-high-rate data stream is divided into multiple parallel low-rate data streams. Each smaller data stream is then mapped to an individual data sub-carrier and modulated using some form of phase shift keying (PSK) or quadrature amplitude modulation (QAM). OFDM systems efficiently overcome the interference and frequency-selective fading caused by multipath propagation. The effect of inter symbol interference (ISI) is suppressed because the parallel OFDM sub-carriers have a longer symbol period than the carrier in a single carrier system. OFDM delivers better performance in NLOS urban environments due to its better resistance to multipath interference.

OFDMA is a variation of OFDM, which provides multiple access to different users by allocating different sub-bands from the total bandwidth. It employs multiple closely spaced sub-carriers divided into groups of sub-carriers called sub-channels. The sub-carriers that form a sub-channel need not be adjacent. In the downlink (DL), a sub-channel may be intended for different receivers. In the uplink (UL), a transmitter may be assigned one or more sub-channels. **Figure 1** shows the sub-carrier arrangement in OFDM and OFDMA systems.

2.1.2 Sub-channelisation in WiMAX

Sub-channelisation defines sub-channels that can be allocated to subscriber stations (SSs) depending on their channel conditions and data requirements. In OFDM, only one SS transmits in a time slot.

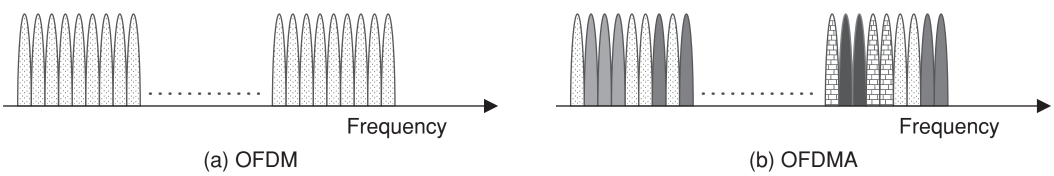


Figure 1
OFDM and OFDMA.

In OFDMA, several SSs can transmit in the same time slot over several sub-channels. **Figure 2** shows the allocation pattern of the sub-carriers to SSs in an OFDM and OFDMA system. By using sub-channelisation, within the same time slot, a Mobile WiMAX base station (BS) can allocate more transmit power to user devices (subscriber stations) with a lower signal-to-noise ratio (SNR) and less power to user devices with a higher SNR. Sub-channelisation also enables the BS to allocate higher power to sub-channels assigned to indoor SSs, resulting in better in-building coverage. Sub-channelisation in the uplink can save a user device transmit power because it can concentrate power to only selected sub-channels allocated to it. This power-saving feature is particularly useful for battery-powered user devices, especially in Mobile WiMAX.

With OFDMA, there are two types of sub-carrier permutation for sub-channelisation: diversity and contiguous. The diversity permutation draws sub-carriers pseudo-randomly to form a sub-channel. It provides frequency diversity and inter-cell interference averaging. The diversity permutations include DL fully used sub-carrier (DL FUSC), DL partially used sub-carrier (DL PUSC), UL PUSC, and additional optional permutations. The contiguous permutation groups a block of contiguous sub-carriers to form a sub-channel. The contiguous permutations include DL adjacent subcarrier allocation scheme (DL AMC) and UL AMC, which have the same structure as each other. AMC permutation enables multi-user diversity by choosing the sub-channel with the best frequency response. In general, diversity sub-carrier permutations perform well in mobile applications while contiguous sub-carrier permutations are well suited for fixed, portable, or low mobility environments. These options enable the network designer to trade-off mobility for throughput.

2.1.3 *Modulation and coding scheme in WiMAX*

WiMAX utilises an adaptive modulation and coding scheme together with BPSK, QPSK, and QAM modulation schemes.[3] The adaptive modulation allows the highest order modulation to be chosen according to the channel conditions. As we increase our range, we step down to lower order modulations, but as we reduce our range, we can use higher order modulations such as QAM for increased throughput. The standard also supports repetition coding of rate 1, 2, 4, or 6. This can, in theory, be used in combination with any modulation and coding scheme. Repetition coding can be used to lower the required receiver sensitivity and hence increase the cell range. However, the penalty will be a reduction in capacity in line with the rate selected because every transmission will be repeated multiple times. The network planner needs to consider the use of repetition coding in line with the deployment requirements (for coverage or capacity).

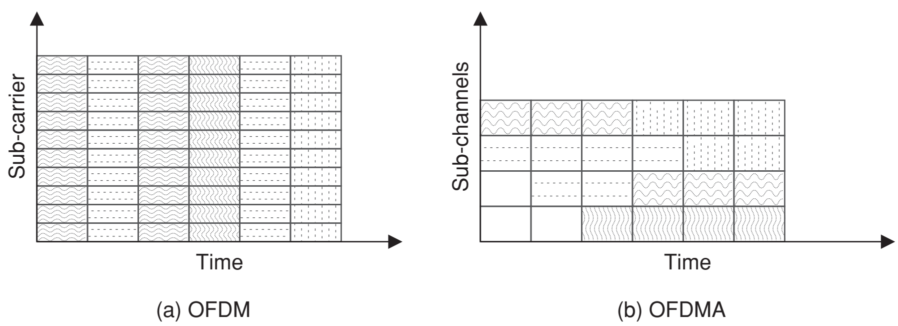


Figure 2
Uplink subchannelisation in WiMAX.

2.1.4 Spectrum

Unlike 2G/3G technologies, where the operating frequency is fairly defined, the WiMAX air interface is designed to operate over a range of frequencies, both in the licensed band (2.5 to 2.69 GHz and 3.4 to 3.6 GHz) and in the unlicensed band (5.725 to 5.850 GHz). The WiMAX Forum has identified several frequency bands for the initial 802.16 products. IEEE 802.16 supports a variable channel bandwidth. The channel bandwidth can be an integer multiple of 1.25 MHz, 1.5 MHz, and 1.75 MHz with a maximum of 20 MHz. WiMAX supports two modes of operation: FDD and TDD. In TDD, the uplink and downlink can be asymmetrical, which means that the percentage of downlink subframe to uplink subframe of one frame can be decided according to the network's uplink/downlink capacity requirement.

2.1.5 Fractional frequency reuse

The operating spectrum is the scarcest resource in network deployment. Mobile WiMAX, which will be deployed like 2G and 3G cellular networks, supports fractional frequency reuse. It works by allowing users at a cell centre to operate on all available sub-channels, while users at a cell edge are only allowed to operate on a fraction of all available sub-channels. A fraction of the total available sub-channels is allocated in such a way that adjacent cell edges will operate on different sets of sub-channels. Fractional frequency reuse takes advantage of the fact that a Mobile WiMAX user transmits on sub-channels (because in OFDMA, a channel is divided into sub-channel segmentation) and does not occupy an entire channel such as in 3G. In **Figure 3**, f1, f2, and f3 represent different sets of sub-channels in the same frequency channel. With the multicell layout shown below for Omni sites, full load frequency reuse is maintained for the users close to the centre of the cell and fractional frequency reuse is implemented for cell edge users. Fractional frequency reuse maximizes spectral efficiency for users at the cell centre and improves signal strength and throughput for users at the cell edge.

2.2 WiMAX application

1) Fixed WiMAX is considered a cost-effective backhauling option for cellular operators where the cost of backhauling represents a

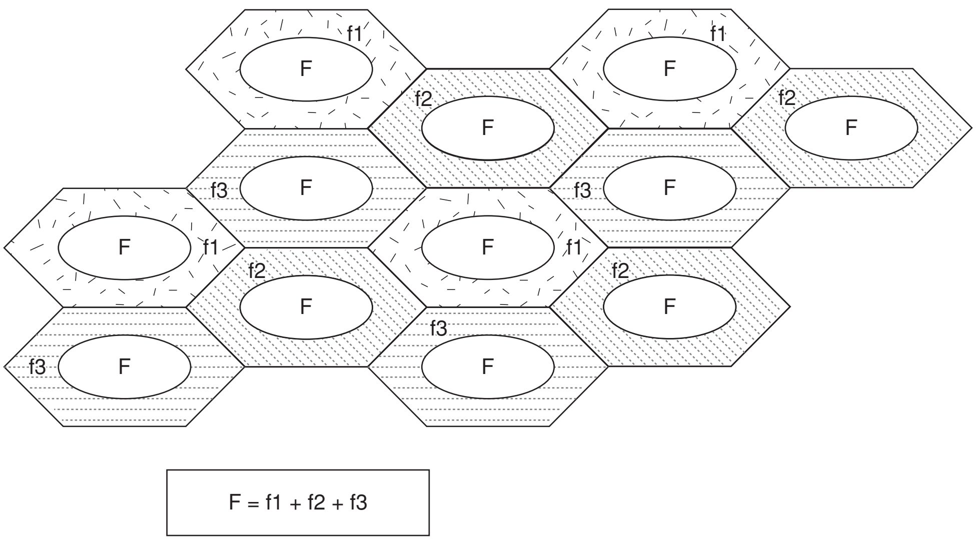


Figure 3
Fractional frequency reuse.

significant portion of their recurring costs. WiMAX can provide point-to-point links of up to 50 km, with data rates capable of supporting multiple E1/T1s. Fixed operators can offer nomadic and portable Internet usage as an addition to their fixed access offering to complement their DSL and WiFi bundle. In developing countries, Fixed WiMAX can be the most cost-effective solution for delivering broadband and VoIP to residential customers where wired infrastructure is lacking.

2) Mobile WiMAX is designed to complement existing 2G/3G access technologies with an "Always Best Connected" experience with voice and data connections. Portable Internet allows session continuity throughout the network. WiMAX can then be positioned as a complementary solution by offering higher bandwidth when required, particularly in dense urban areas. By integrating WiMAX into their networks, mobile operators can boost their service with high bandwidth. **Figure 4** shows that a WiMAX network can be deployed to obtain service while at home, on the move, in the office, or in public places.

3. Radio network dimensioning and planning for WiMAX

3.1 Overview

The objective of the radio network dimensioning and planning activity is to estimate the number of sites required to provide coverage and capacity for the targeted service areas and subscriber forecast. This section describes a methodology that is suitable for dimensioning and planning of a WiMAX network based on utilisation of the OFDM and OFDMA PHY of IEEE 802.16.

Designing, deploying, and managing any cellular system requires clear objectives to be identified from the outset. These include definition of the service area; the projected number

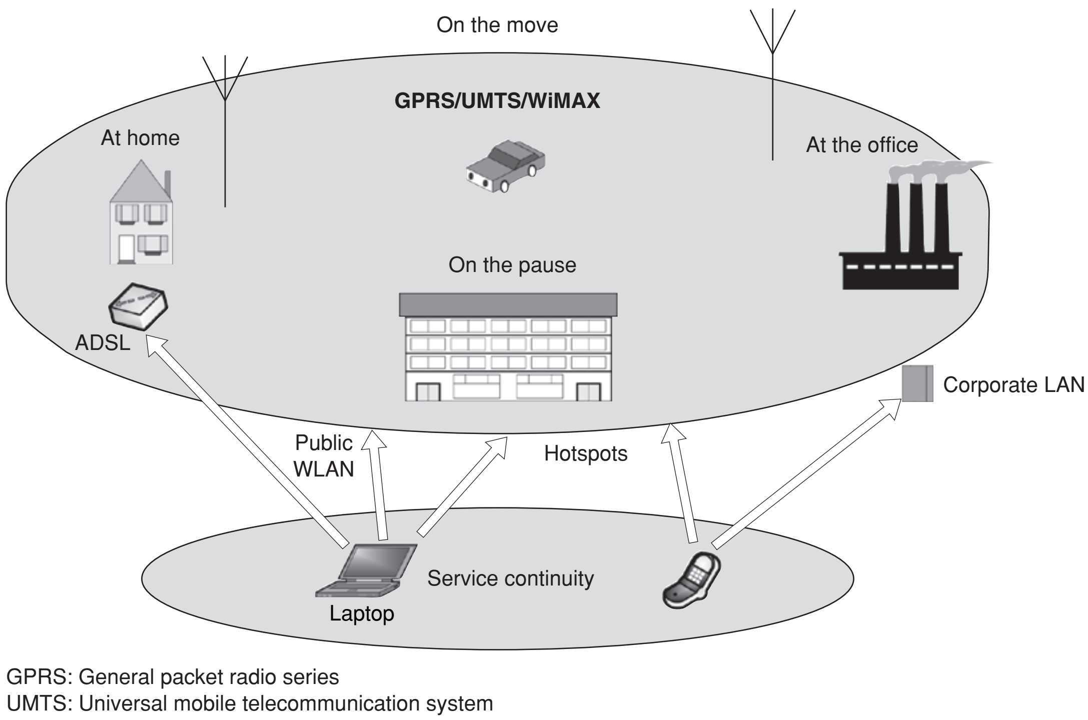


Figure 4
Mobile WiMAX deployment.

of customers; their distribution, spectrum availability, growth rate, and system usage; and the network interconnect agreement, numbering, and routing policy for inter-network access and roaming.

The Quality of Service (QoS) of a WiMAX network is a critical aspect of radio planning, which determines the level of service that users will experience when they access the network for voice or data communication. This is achieved by careful planning that helps to successfully implement different quality and range enhancing features supported in WiMAX. The carefully formulated design criteria such as link-budgets, targeted service classes, coverage threshold levels for different service types, an appropriate propagation model for the available spectrum and an appropriate channel allocation strategy will help in satisfying the technical and business goals.

Figure 5 shows the natural flow of activities performed in network planning, starting from gathering the marketing and design requirement input and satisfying the business model to providing a nominal cell plan using a network planning tool. The next sections describes the process for WiMAX network dimensioning and planning and describes a WiMAX network dimensioning tool called DoORs developed at Fujitsu Laboratories of Europe Ltd.

3.2 Cell dimensioning for WiMAX

Radio network dimensioning aims to estimate the number of required base stations in accordance with the theoretical approach, which is the first step of radio network planning. Network dimensioning process is based on the

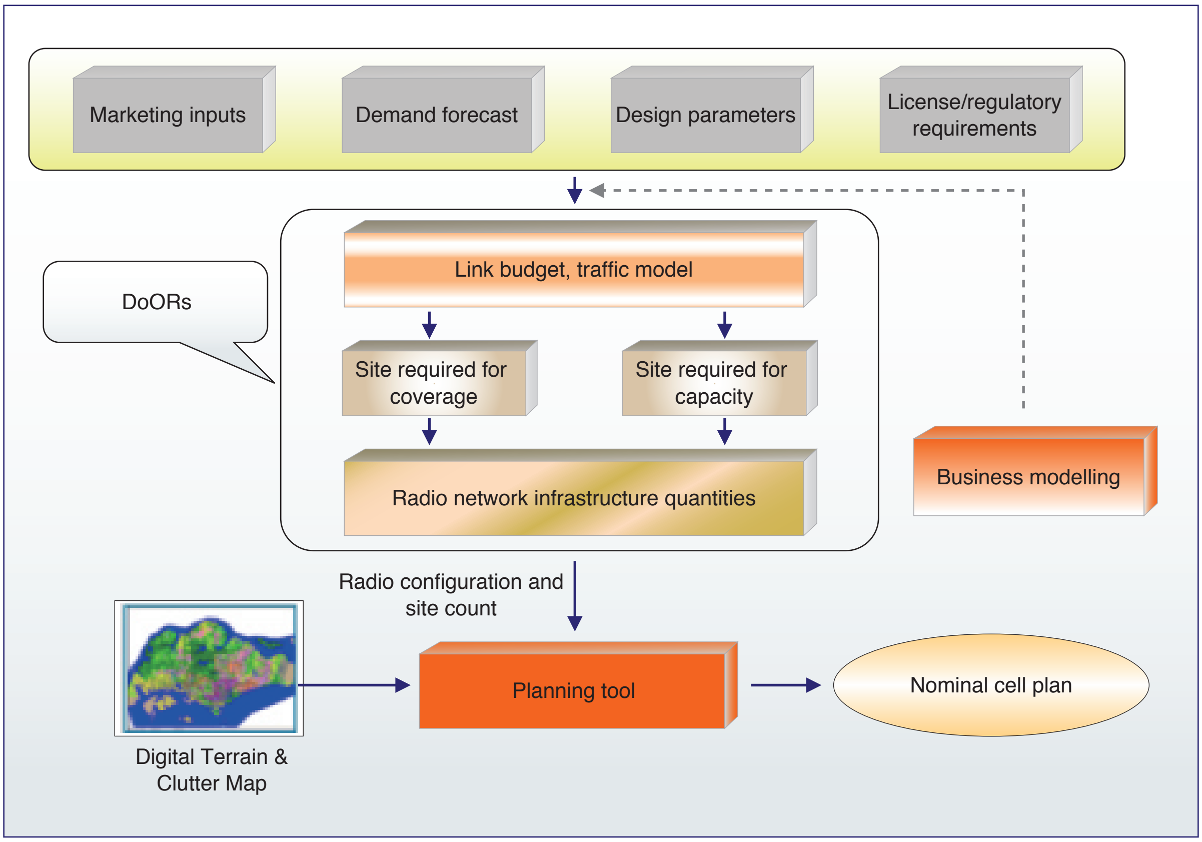


Figure 5
Network dimensioning and planning processes.

assumption of uniform distribution of subscribers, homogenous morphology and ideal site distribution. The outputs of the dimensioning phase are further used in configuring the network planning tool. Digital map containing height and clutter information at pixel level is used in the network planning tool to design a nominal cell plan. The results of network dimensioning activity essentially assist in the business planning and budget planning process for understanding the likely return on investment, which helps in designing the tariff strategy as well. The output of this activity also provides input to the core network team to plan the network topology and to decide the number of backhaul links required for the initial launch of the network.

Since the result of the network dimensioning will significantly impact the network reliability and initial implementation cost, each parameter that is used in the dimensioning process must be thoroughly considered. Due to the large number of optional and mandatory features supported by IEEE 802.16, it may not be possible to obtain a single set of site count values for the scenario to be dimensioned. The difference in site count for the same scenario may be due to assumptions about the frequency reuse scheme, handover mode, and multiple antenna diversity gains being considered and the SNR values (used in calculating the receiver sensitivity of the equipment) assumed for the deployment model.

The main inputs required for network dimensioning are:

- BS and SS equipment-specific parameters: Equipment-specific parameters include the BS and SS transmit powers, antenna gains, feeder losses, BS/SS heights, supported OFDM/OFDMA equipment-related parameter configurations, and other equipment-related features. If the equipment datasheets are available, then parameter values are straightforward. In situations where dimensioning is performed for technology evaluation, the generic or vendor independent parameter values and features are used. In the latter case, most of the parameter values are derived from IEEE 802.16 standards and the technical understanding and simulation results.
- Marketing-specific parameters: The marketing input includes the areas to be serviced, equipment penetration in the market for one year (snapshot analysis) or a forecast for over 5 to 10 years, services to be offered to the subscribers, coverage objective for different clutter categories (e.g., dense urban, suburban or rural), and the over-subscription ratio.
- License regulation and propagation model: Depending on the spectrum allocated to the area to be planned, an appropriate propagation model that suits the allocated spectrum and the propagation environment must be selected or modelled. Statistical/empirical propagation models that implicitly take into account all environmental influences regardless of whether they can be separately recognized are considered for dimensioning. The accuracy of existing models depends on the similarities between the environment to be analysed and the environment to which the standard models relate. Generally, most empirical models have model correction factors that allow the model to be tailored to particular markets using direct knowledge of the area's attenuation factors. Customised continuous wave (CW) propagation measurements for a specific area/frequency help to tailor an accurate propagation model suitable for that deployment. Widely accepted propagation models for WiMAX are the IEEE 802.16 recommended SUI model, the Modified COST231 Hata model, and the ECC 33 model. All these models have correction factors to accommodate the range of frequencies supported by WiMAX.

Once the design requirements are defined, the next step is to perform coverage analysis and capacity analysis to identify the required number of infrastructure quantities satisfying the business model.

3.2.1 Coverage analysis

Coverage analysis fundamentally remains the most critical step in the design of any network. Appropriate selection of the propagation model and the fade margins for the area coverage probability are key factors to eliminate cell design that leads to interference or quality degradation in the network. IEEE 802.16 supports some coverage enhancing features such as UL sub-channelisation (boosts the uplink power budget by 8 to 10 dB or more depending on the amount of sub-channelisation used) and repetition coding (factor of 1, 2, 4, or 6). In OFDM, the UL sub-channelisation factor is fixed to 1, 2, 4, or 6, while it is flexible in OFDMA. Depending on the deployment model, an appropriate sub-carrier allocation scheme needs to be considered. For example, for a nomadic to stationary type of deployment with a BW of 10 MHz, AMC with a FFT size of 1024 and a guard period of 1/8 will be most appropriate due to the advantages the adjacent sub-carrier allocation schemes have for nomadic to stationary deployment. Transmit and receive diversity gains obtained by using advanced antenna techniques help to enhance the range and rate. The mobile WiMAX supports three types of handover modes like hard handover, FBSS handover and Macro diversity handover. The macro diversity handover (MDHO) provides extra gain that helps in range enhancement. The receiver sensitivity of the equipment for all the modulation schemes supported by WiMAX is either obtained from the equipment's datasheet or is calculated from the SNR values of the modulation schemes for a specific antenna type under specific channel conditions (obtained from link-level simulations), along with assumed equipment noise figures and implementation losses. The link budget specifies the maximum path loss between the SS and BS. This gives a limit to the cell range for different configurations in order to maintain a balanced uplink and downlink. The balance must be calculated accurately for full duplex connection to be maintained at all times. If the SS can receive from but not transmit to the BS, the connection will terminate after a period defined by the Radio Link Timeout value. The link budget is a pre-requisite to any cell plan and is one of the vital components of network quality. An example link budget for IEEE 802.16e systems is shown in **Table 1**. **Table 2** shows the parameters used for capacity calculation. The link budget serves to look at the system as a whole and attempts to represent the system as an average (in terms of the derived cell ranges), providing the engineering guidelines to begin cell layout and design.

3.2.2 Capacity analysis

Capacity analysis involves accessing the demanded and available traffic for different service requirements considering the activity factor, overbooking/contention ratio, and TDD ratio for the uplink and downlink. IEEE 802.16 supports an adaptive modulation and coding scheme, which leads to a ring structure for capacity calculation. The cell throughput calculation is based on the area of each modulation scheme. The theoretical throughput calculation per modulation scheme is done using the following formula:.

$$R_b = R_s \frac{MC}{R_r} \tag{1}$$

where M is the modulation gain, which is 2 for QPSK, 4 for 16-QAM, and 6 for 64-QAM; C is the coding rate (1/2, 3/4, etc.); R_r is a repetition rate of 1, 2, 4 or 6; R_b is the bit rate; and R_s is the symbol rate.

The bit rate R_b as derived from Equation 1 is the PHY throughput rate, which accounts only for the pilot overhead. It does not account for the signalling overhead, which includes the preamble, FCH, UL/DL MAP and MAC overhead. The

Table 1
Mobile WiMAX-Link Budget-1/2QPSK Cell edge.

	Uplink	Downlink
Transmitter		
TX power (dBm)	23	40
TX antenna gain (dBi)	0	18
Tx feeder loss (dB)	0.5	1
TX AAS gain (dB)	0	0
Body loss (dB)	0	0
TX diversity gain (dBi)	0	0
Receiver		
Antenna gain (dBi)	18	0
Rx feeder loss (dB)	1	0.5
Rx diversity gain (dB)	0	0
Tx channel combination gain (dB)	0	0
Sub-channelisation gain (dB)	15.44	0
Indoor penetration loss (dB)	3	3
Receiver sensitivity (dBm)	–96.07	–99.67
Max allowed path loss (System link budget) (dB)	148.01	153.17
Co-channel interference margin (CCI)	1.75	1.96
Fast fade margin (FFM) (dB)	5	5
Edge coverange probability (%)	85	85
Fade margin std deviation (dB)	6	6
Prop. loss exponent	3.52	3.52
Log normal fade margin/shadow fade margin (dB)	7	7
Max allowed path loss (with FFM & CCI) (dB)	141.26	146.21
Max allowed path loss (Shadow fade margin + 802.16e gains & losses) (dB)	136.26	139.21
Sectorisation	3	3
Sectorisation factor	1.95	1.95
Clutter correction factor	–7	–7
Propagation model	COST231-HATA	COST231-HATA
Model parameters		
Operating frequency (MHz)	2350	2350
BS antenna height (m)	40	40
SS antenna height (m)	1.5	1.5
Cell radius for dense urban (km)	1.381	1.682
Limiting radius/ultimate cell edge	Cell Radii (km)	Area (km^2)
Dense urban	1.381	3.719

Table 2
Additional parameters for capacity calculation.

TDD UL-DL ratio	1:2
Mode of operation	TDD
Operating BW	10
Sub-carrier allocation scheme	AMC
Nfft	1024
Guard ratio	0.125

maximum throughput will need to be adjusted based on the amount of signalling overhead. The signalling overhead depends on the number of active connections and the service type used by these connections, which makes it a dynamic parameter. Analysis and studies indicate that the signalling overhead may vary from 4 to 10% of the PHY throughput.

Initially the cell radius is determined by the coverage requirement. If the capacity can be handled by that radius, then the final number of cells required for the network is calculated; however, if the number of sites required for capacity exceeds the number required for coverage, an iterative process is performed to check if the cell radius can be shrunk and the required capacity fulfilled.

3.3 A tool for dimensioning of overall radio networks for WiMAX

Dimensioning of Overall Radio networks (DoORs) is a software tool developed by Fujitsu Laboratories of Europe to support dimensioning of WiMAX and 3G UMTS networks. The DoORs tool contains a graphical user interface (GUI) driven front end developed with Visual Basic software and a spreadsheet based data repository. The tool provides the capabilities to simultaneously dimension multiple rollout phases for different environments such as dense urban, urban, suburban, and rural topologies. The WiMAX component of DoORs is compliant with both IEEE 802.16d for fixed broadband standards and IEEE 802.16e for mobile broadband standards, supporting a comprehensive set of optional and mandatory features available in the standard. The DoORs tool forms a repository of parameter values derived from in-house radio link and radio system simulators and from vendor datasheets. **Figure 6** shows the different inputs that are used in the analytical dimensioning process. The radio link simulator provides the SNR values for the different channel conditions and antenna types that are required to calculate the receiver sensitivity of the BS and SS equipment. The radio system simulator helps to cross-validate the different margins and values that are derived from analytical calculations. The tool is enriched with a number of analytical models, for example, an intercell interference margin calculation model and a system throughput calculation model, which along with other parameters are designed to be part of the overall coverage and capacity analysis to provide the total site count required for a specific deployment model.

The DoORs tool can also be used for technology evaluation to analyse the impact of varying the parameter values on the total site count. For example, it can be used to evaluate how the total site count varies when a repetition coding of 2 or 4 is used or evaluate the impact on the total site count when uplink sub-channelisation is enabled or disabled. The tool provides a quick and accurate site count and a firm ground for the next step of network planning. A high-level description of the features modelled in these tools is provided in the sub-sections below.

3.3.1 Design parameters and data management

The WiMAX standard demonstrates a lot of flexibility by encompassing variable parameters. The DoORs tool accommodates these variable parameters and allows the user to make suitable selections. Different modes (FDD or TDD) with bandwidths from 1.25 to 20 MHz and different site configurations (Omni or 3 or 6 sectors) with up to 6 carriers per sector can be configured for any simulation. Thus DoORs enable rapid evaluation of a many "what-if" scenarios and serve as an advantage over manual dimensioning.

Multiple vendor equipment specifications can be stored and reused. The tool has provision for efficient data management where each set of simulations can be saved as a project file and retrieved. The output results including the number of BS sites, the total and average throughput, and the link budget used for analysis are available in graphical and spreadsheet formats.

The propagation models are used for determining cell radius from the maximum allowable path loss (MAPL) value derived in the link budget calculations. As WiMAX networks are deployed worldwide, it is expected that different regions will employ different carrier frequencies. For example, WiMAX networks in the US and the Far East will occupy the 2.4 GHz/2.5 GHz band, while in Europe they will occupy the 3.5 GHz band. In the global context, the optimum propagation model will differ from region to region due to variations in clutter characteristics and the variations in spectrum utilisation. The DoORs tool supports three popular empirical propagation models, COST231-HATA, SUI, and ECC 33. According to the spectrum and terrain in consideration an appropriate propagation model can be used.

3.3.2 Interference margin calculator

An estimation of the interference margins is an important feature because any fully loaded wireless network tends to be interference limited. A brief description of the model that is considered appropriate for analytically modelling interference in a WiMAX network is given below.

Mobile WiMAX employs OFDMA as the multi-access technology, and the main source of interference comes from collisions amongst same sub-carrier and time-slot selections in neighbouring cells/sectors. The first task in interference calculation is thus the determination of collision rates against the cell loading. The sub-carrier mapping from logical to physical channels varies

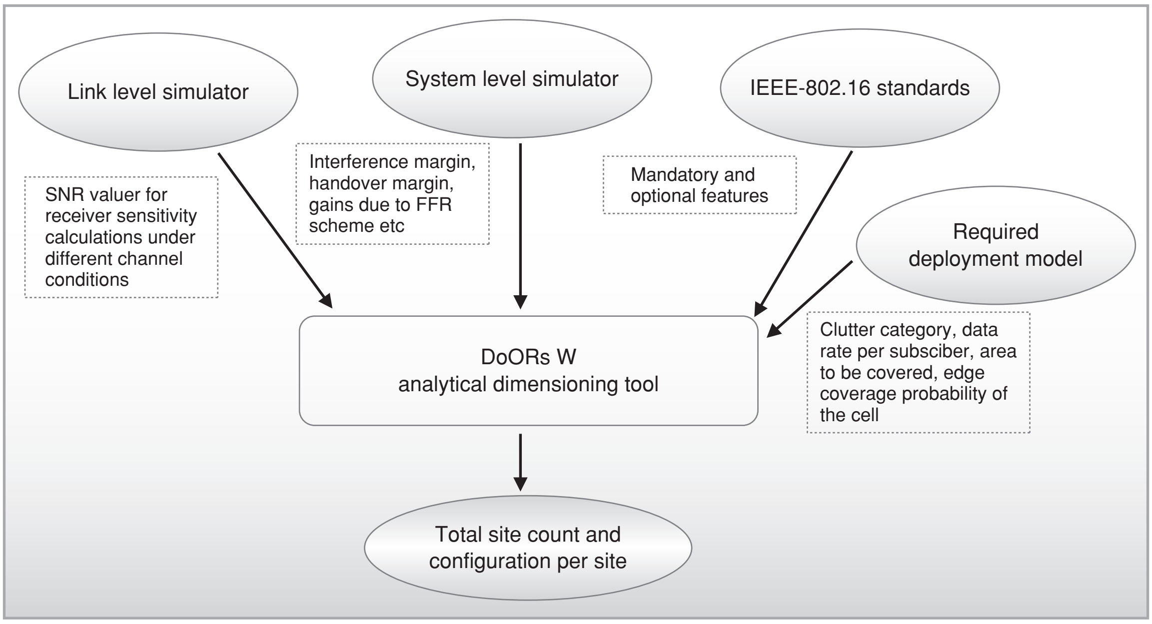


Figure 6
Inputs to the dimensioning tool-DoORs W.

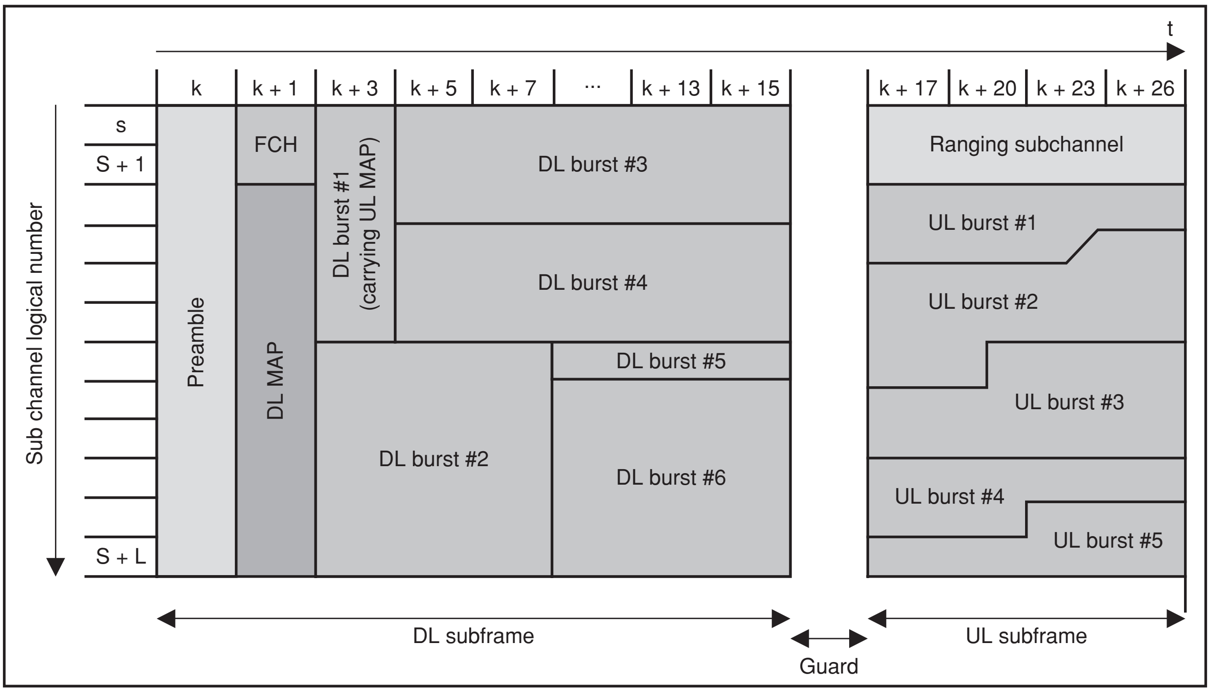
with the sub-carrier allocation scheme. Also, the method of data burst allocation in the uplink and downlink sub-frames impacts the collision rate. An example of data burst allocations for the 5 ms PUSC frame is shown in **Figure 7**.

Due to the nature of data burst allocation in the PUSC downlink, all the sub-carriers can be occupied before the sub-frame is fully loaded. Consequently in low traffic conditions sub-frames may be only partially occupied in time axis. Thus the collision rates at the beginning of sub-frames can quickly reach 100% well before the downlink reaches full load condition and the collision rates drop down in parts of the sub-frame, yielding a collision probability (P_{coll}) function with several maxima and minima across the sub-frame length. In contrast, in the PUSC uplink, the data bursts occupy the minimum number of sub-carriers and the entire sub-frame length. Thus the collisions would increase linearly with the loading for the uplink. The AMC sub-carrier allocations for both the uplink and downlink are similar to the PUSC uplink sub-carrier allocations scheme, where the collision rates are linearly proportional to cell loading.

The interference power I is estimated by assuming uniform hexagonal cell geometry and worst-case interference scenario. Three types of site configurations, omnidirectional, 3-sector, and 6-sector are considered as well as frequency reuse of 1 and 3. For frequency reuse of 1, use of fractional frequency reuse is assumed. The interference power I is a function of transmit effective isotropic radiated power (EIRP), the collision probability, the path loss suffered by each interfering path, and for directional antennas the angle of arrival/departure of interfering signals. Equation (2) below gives the interference power from the above contributions.

$$I = P_T \cdot G_T \cdot P_{coll} \left[\sum_{i=1}^{N} \frac{1}{PL_i} . Cos^{\gamma}\theta_i \right] \qquad (2)$$

$P_T G_T$ represents the EIRP at the transmit-



DL: Downlink FCH: Frame control header
UL: Uplink MAP: Mapping messages

Figure 7
Data burst allocations for PUSC downlink and uplink.[2)]

ter, P_{coll} the collision probability, and PL_i the path loss for the i^{th} interfering user/BS. The path loss is calculated using the assigned path loss model and the cell radii from the link budget. The $Cos^{\gamma}\theta_i$ term represents the antenna directivity for 3-sector and 6-sector deployments. For 3-sector deployments, $\gamma = 1$ is assumed, and for 6-sector deployments (where the roll-off needs to be sharper), $\gamma = 3$ is assumed.

The actual interference margin I_m is calculated as a "noise rise" as shown by Equation (3) below, where the noise power N is already known through link budget calculations.

$$\begin{aligned} I_m &= SNR_{dB} - SINR_{dB} \\ &= \frac{N + I}{N} \end{aligned} \tag{3}$$

3.3.3 Capacity calculator

The system capacity calculator included in DoORs tool estimates the cell capacities based on the summation of the throughputs from each of the 7 adaptive modulation schemes depending on the percentage of the total area covered by each of the schemes. Higher order modulation schemes require a corresponding higher receive SNR. The ring boundaries are determined from MAPL for each of the modulation and coding rate. The outermost ring corresponds to the minimum modulation and coding rate (for example, ½ QPSK modulations in IEEE 802.16e) and yielding the lowest data rate. The innermost ring corresponds to highest modulation and coding rate (for example ¾ rate 64 QAM in IEEE 802.16e) and thus yielding the highest data rate.

The capacity calculator also considers the impact of MIMO antenna structures. Both MIMO-A and MIMO-B schemes as defined in the IEEE 802.16e standard are supported. The MIMO schemes can enhance coverage or capacity or a combination of both.

3.4 Cell design and optimisation for WiMAX

3.4.1 Cell design for WiMAX

Nominal cell planning follows sequentially after cell dimensioning. Cell design is performed with the help of a network planning tool using digital elevation and demographic maps. The elevation maps provide the height of the area at pixel level, where each pixel is of the resolution of the mapping data (5 m, 20 m, or 50 m). The demographic map provides the clutter class of the area at the pixel level. The total demanded traffic can be distributed uniformly or non-uniformly across the target area based on the clutter category. For example, the demanded traffic can be distributed over target area with higher traffic weighting given to clutter classes such as dense urban and urban, whilst less traffic weighting given to classes such as rural and forest, and probably zero weighting to classes such as marsh and water. Snapshot traffic estimation and traffic forecast for consecutive years need to be considered for a successful network rollout.

The dimensioning process simplifies most of the BS and SS equipment configuration stage in the planning tool and moreover provides the initial cell radii to be used as the starting point for deciding site positions on the map. The site positioning not only depends on the intersite distance obtained from dimensioning but also on other factors like the local regulation for site locations, availability of land for site locations, electricity to the BS, and other details. Generally it is very costly to reposition incorrectly positioned sites.

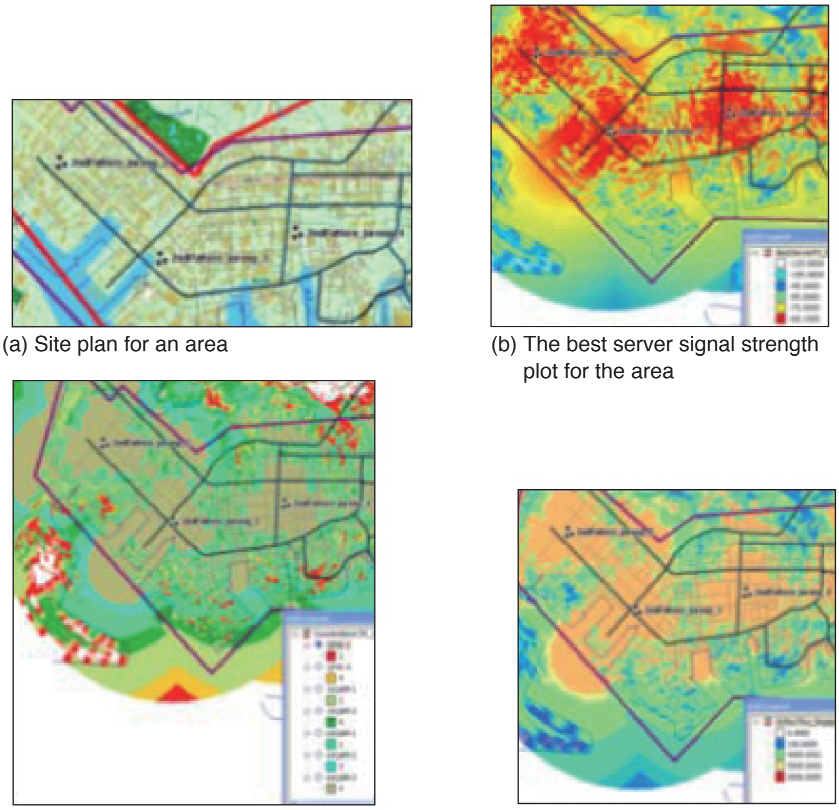
An appropriate antenna pattern and tuned propagation model needs to be used to obtain close to real-life predictions for the BS location. The prediction file contains the path loss values from the BS to the pixel points around the BS. These along with the channel allocation to the sites will help in providing the interference array that determines the cell radii of the modulation schemes. Very high resolution maps with details of building heights and street widths help to achieve a near real-life network plan. With such high-resolution data, the radio propagation pattern, including reflection and diffraction, can be captured in the planning tool using a 3D ray tracing propagation model.

Channel allocation is based on the inter-cell co-channel to interference (C/I) ratio. In a WiMAX system, the co-channel interference is based on the probability of collision and varies depending on factors like the sub-carrier allocation scheme, channel allocation scheme, and cell loading. An efficient segmentation allocation for fractional frequency reuse schemes can provide benefits whenever the spectrum is limited.

The final radio plan consists of the coverage plans, capacity estimations, interference plans, power budget calculations; parameter set plans, channel allocation plans, and other details. Some example outputs are shown in **Figure 8**.

3.4.2 Network optimisation

It is impossible to predict the exact performance of a network once it has been implemented, so it will always be necessary to make minor adjustments to the network. Network optimisation is an important element of a network's lifecycle comprising of prelaunch network optimisation and post launch network performance optimisation. At the initial network launch, there is more focus on the network/radio optimisation to ensure that the network performs as per the design and is free from configura-



(a) Site plan for an area

(b) The best server signal strength plot for the area

(c) Best available DL CPE's for the area

(d) DL maximum throughput plot for the area

Figure 8
Example — Network planning outputs.

tion and implementation faults. The prelaunch network/radio optimisation is performed on a cell-by-cell basis.

Network performance optimisation involves finely tuning the network after the configuration faults are eliminated by selecting appropriate network parameters to achieve the set QoS targets. The main focus of WiMAX radio network optimisation is expected to be on areas such as the sub-carrier allocation scheme, neighbour list definition, zoning definition for the frequency reuse of 1 and channel measurements. The network performance optimisation involves establishing end-to-end key performance indicators to cover service accessibility, availability, retainability, and service integrity for monitoring the network QoS as perceived by the end user. It is always beneficial to have a proactive performance monitoring system in place to ensure the set design standards are always met.

The optimisation process is initiated by collecting and analysing network data from drive testing on selected routes and also data from network nodes by using customised software. The detailed network optimisation and performance process is outside the scope of this paper and what is provided here is a brief overview.

4. Conclusions

This paper presented the challenges in WiMAX network deployment and explained an approach to the network dimensioning and planning process. It also introduced an in-house developed analytical dimensioning tool called DoORs. The tool provides a user-friendly environment for quick and accurate dimensioning that provides a firm ground for the next steps of network and cell design. It enables rapid evaluation and selection of many of the basic parameters and options of the WiMAX radio interface. Consequently, it reduces the time needed for the cell design phase and makes the design is easier to optimise.

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