Dimensioning and Cost Analysis of Multihop Relay-Enabled WiMAX Networks

● Bharathi Upase ● Mythri Hunukumbure

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WiMAX networks are intended to cover diverse clutter categories with a higher data range and throughput compared with 2G/3G networks. This paper explains an approach to the analytical dimensioning and possible planning techniques for a cellular network based on IEEE 802.16j technology. The main emphasis is on the methodology used for evaluating the cell edge coverage extension of the base station using a relay station. The paper also highlights the economical feasibility analysis of WiMAX network deployment with and without support for relay stations.

1. Introduction

One of the major challenges for WiMAX wireless network communication is to provide broadband services everywhere. The term WiMAX (Worldwide Interoperability for Microwave Access) has become synonymous with the IEEE 802.16 air interface standard.[1] IEEE 802.16 provides broadband access with performance similar to wired xDSL systems, which surpass current 3G mobile data rates. Every wireless system suffers from challenging radio propagation characteristics, so does WiMAX. The achievable signal-to-noise ratio (SNR) and the data rate decrease with an increasing link distance. Shadowing, which leads to non-line-of-sight (NLOS) communication, further reduces the perceived signal quality. The achievable data rates for WiMAX are in the order of 70 Mb/s depending on the spectrum available. It is unlikely that the high volume of traffic will be entirely used up by the user terminal roaming in the cell leading to low utilization of the spectrum.

The range of radio interfaces like the one envisaged beyond 3G broadband systems as studied by the EU project WINNER[3] and IEEE 802.16-based systems are limited because of the high attenuation at carrier frequencies beyond 2.5 GHz, a limited transmission power owing to regulatory constraints, and unfavorable radio propagation conditions, such as densely populated areas with high inbuilding penetration losses. Conventional cellular radio network deployment concepts would require a very high density of base stations (BSs) to achieve sufficient radio coverage there. As a consequence, the system deployment cost in terms of Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for broadband radio will increase dramatically, resulting in a high cost per bit transmitted. An increased data rate (for a given power and carrier frequency) leads to a reduced radio range and the available data rate decreases with increased distance from the base station. The requirements for 4G radio systems in terms of capacity, delay, user-experienced data rate and deployment cost cannot be met using conventional cellular deployment concepts. Instead, a novel deployment concept is needed.

Changing the network architecture by introducing multihop relay stations may significantly enhance the link quality leading to throughput enhancements and coverage extensions, and may facilitate efficient spectrum usage. The IEEE 802.16j standards will be completed in 2008, and they aim to integrate multihop relay (MR) in WiMAX networks.

A relay station (RS) will be expected to cover regions with a diameter of 200-500 m. This means that the transmission power requirements for such RS are significantly reduced compared with those for a BS. This in turn permits an economical design of the amplifier used in RS. The higher frequency of operating spectrum requires increased density of base sites, and getting a prime site location which requires full planning permission is a bottleneck for any operator. The mast on which the RS is placed does not need to be as high as for a BS, reducing operating expenses such as tower leasing and maintenance costs for the operator. The RS does not have a wired connection to the backhaul. Instead, the data received wirelessly from the BS is buffered and forward to the user terminals, and vice versa. The cost of the backhaul link is eliminated with RS. Relay-enabled WiMAX networks are envisaged to benefit greenfield operators, where providing coverage with low CAPEX and OPEX with the minimum deployment time is of prime importance during the initial rollout phases.

This paper attempts to provide an insight into the complexities involved in coverage dimensioning including the propagation models for different links (BS to RS, BS to SS, RS to SS) in a relay-enabled WiMAX network. Though the generic definitions of the type of MR and its functionality are derived from the IEEE 802.16j standard, emphasis is given in this paper to a more generic type of MR limited to two hops. A number of usage scenarios and their associated assumptions are considered for dimensioning a relay-enabled WiMAX network. A detailed description of the different relay modes and usage scenarios is discussed in section 2 of this paper. An approach for addressing network dimensioning for MR-enabled WiMAX network is addressed is section 3. The economical feasibility analysis of WiMAX network deployment with and without support of MR will be discussed in section 4, and finally conclusions are presented in section 5.

2. WiMAX technology for multihop relays

2.1 IEEE 802.16j WiMAX technology

The IEEE 802.16j standard[2] which will be completed in 2008 is based on the OFDMA physical layer and medium access-control layer enhancements to IEEE 802.16 standards for licensed bands, to enable the operation of RSs. The objective of MR is to enhance the coverage, throughput and system capacity of IEEE 802.16 networks. The introduction of relays in an IEEE 802.16 network is designed to have no impact on the subscriber station (SS) specifications. RS is an optional element that may be used to provide additional coverage or performance advantages in an access network. In MR networks, the BS would be replaced by a multihop relay BS (MR-BS) and one or more RS's. Signaling between the SS and MR-BS are relayed by the RS, thereby extending the coverage and performance of the system in areas where RS's are deployed. Each RS is under the supervision of a parent MR-BS. In a system with more than two hops, traffic and signaling between an access RS and MR-BS may also be relayed through intermediate RS's. The RS may be fixed in a location (i.e. attached to a building), or it may be mobile (i.e. travelling with a transportation vehicle). The SS may also communicate directly with the MR-BS. The various MR features defined throughout the standard permit an MR system to be configured in several modes as described below:

2.1.1 Centralized and decentralized relays

Two scheduling modes, centralized and distributed, are specified for controlling the allocation of resources to an SS. In centralized scheduling mode, the resource allocation for RS's subordinate station is determined at the MR-BS. The MR-BS determines the bandwidth allocations, and generates the corresponding control channel information including MAPs for all the access (MR-BS to SS and RS to SS) and relay (RS to SS) links.

In the distributed scheduling mode, the resource allocation of RS's subordinate station is determined by the RS, in cooperation with the MR-BS. Each RS determines the bandwidth allocations and generates the corresponding MAPs for the access link to and from their subordinate SS's and RS's.

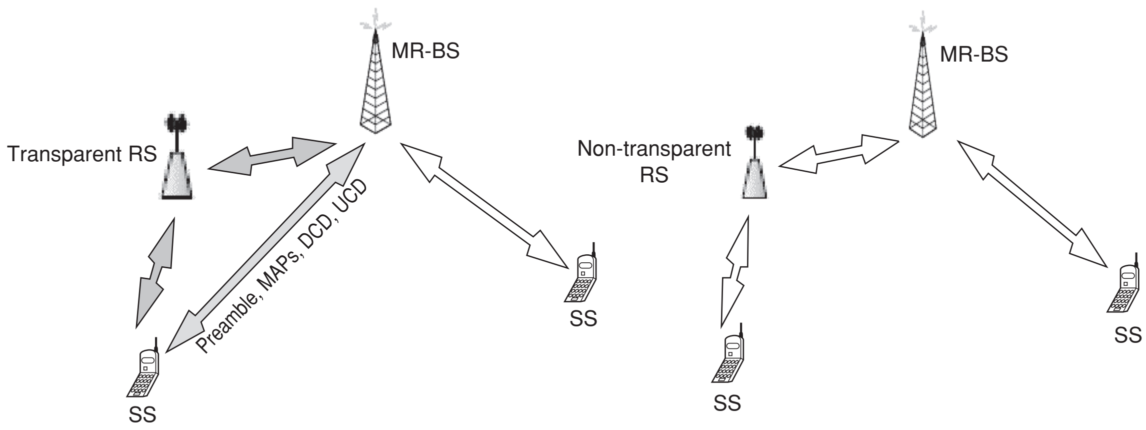
2.1.2 Transparent and non-transparent relays

For non-transparent relays, the RS looks like a base station (BS) to an SS, which means that the RS allocates resources for an SS (does scheduling) and generates the frame header, including the MAP messages as indicated in **Figure 1**. The RS will be a part of the neighbor list scan; a call can be initiated in the RS and handed to the BS. A non-transparent RS can operate in both centralized and distributed scheduling mode.

In the case of transparent relays, the RS is transparent to an SS, which means that the RS does not allocate resources for an SS. Instead, an upstream station (BS or RS) performs these functions and the RS either transmits the same frame header (preamble and MAP messages) as the upstream station, or does not transmit the frame header at all, as indicated in Figure 1. When the RS does not transmit the frame header, the SS receives data from the RS and only receives the frame header from the upstream scheduling station. Transparent relays have to use a centralized scheduling mode. Non-transparent relays with distributed scheduling scheme are considered in all the analyses in this paper.

2.1.3 In-band and out-of-band relays

In the case of in-band relays, the same carrier is segmented to be shared between the MR-BS links and the RS links. In-band relays maximize the spectrum usage. In the case of out-of-band relays, the MR-BS uses one carrier for the SS and the RS, while the RS uses a separate carrier for the subordinate links. Operators having the privilege of an extra spectrum may opt for out-of-band relays. In-band relays will be consid-



(a) Transparent RS (b) Non-transparent RS

Figure 1
Transparent and non-transparent RS.

ered in all the analyses in this paper.

2.1.4 Decode and forward or amplify and forward

In amplify-and-forward schemes, the RS essentially acts as an analog repeater and regenerates the original signal by means of amplification. In doing so, the noise signal is also amplified. In decode-and-forward schemes, the RS regenerates the signal by fully decoding and re-encoding the signals before retransmission. Decoding and forwarding are more beneficial with respect to implementation, and are considered in all the analyses in this paper.

2.2 Deployment models with multihop relays

There are mainly three types of MR stations for different applications in the network. The three types are classified as a fixed RS for outdoor and indoor use, a nomadic RS for temporary events, and a mobile RS for coverage when moving. These three categories of RS can be used to improve system performance including extending coverage, and increasing throughput, depending on their applications in the network. The different scenarios in which RS's can be deployed are as indicated in **Figure 2**.[5] They can be used for anything from improving coverage holes in a shadowed area of the network, to enhancing inbuilding coverage, or to provide coverage extensions to isolated areas. A mobile RS may be installed on the top of a bus or train to provide coverage while travelling.

From the perspective of an SS, the coverage provided within the network with different types of BS and RS remains the same. As an SS moves within a network, it may move from one RS type to another. From a deployment perspective, the mobile RS may be far from being realized because of issues on quantification of interference and also handover issues in a highly mobile environ-

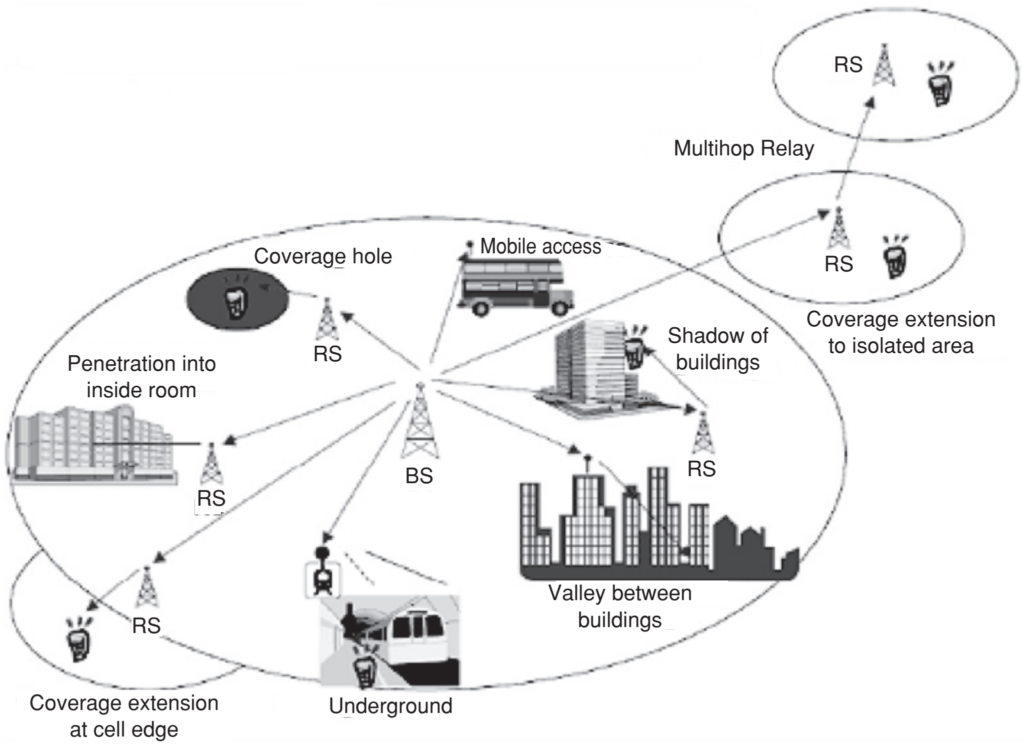


Figure 2
Deployment models for the RS.[5]

ment. Much of the discussion and analysis in this paper is focused on the fixed infrastructure model. The fixed infrastructure RS model can be used for the benefit of greenfield operators (totally fresh network operators) or mature operators (operators with existing wireless networks deployed) in different ways as explained below.

2.2.1 Fixed RS deployment model

In the case of a fixed RS, a service provider deploys RS's and MR-BS's within their network to improve coverage, capacity, or per user throughput in areas which are not sufficiently covered in the MR-BS cell, or to extend coverage to areas that are beyond the boundaries of the MR-BS coverage area. The fixed RS can allow operators to have control on the network capacity and coverage, and also to minimize interference in the network. The RS's can be mounted on street furniture such as towers, poles, tops or sides of buildings, lampposts, or in other locations. As relays do not need to be wired for backhauling, they can be used in places where access to backhauling for a micro/pico station is not cost-effective.

The RS's can either be randomly deployed as a method of network optimization (mature network operators) or their deployment can be preplanned (greenfield operators). The deployment of RS's is very similar to the micro/pico stations, however with the RS's the BS capacity is used efficiently. The RS may have two sets of antenna, a highly directional antenna to have a LOS connection to the MR-BS and another antenna for its subordinate stations. Though the scheme of having two sets of antenna at the RS is beneficial from a radio point of view, it may be less economical and not always practical, so NLOS channel conditions on links between the MR-BS and RS's can also be expected.

RS's can be deployed to provide better coverage and higher throughput in a building, tunnel or underground, such as on a subway platform. Channel conditions between the MR-BS and RS's will generally be NLOS, but it is possible for the RS to have one or more antennas mounted to the exterior of a building to provide a link between it and the MR-BS, and one or more antennas mounted inside a building to provide coverage to downstream RS's and SS's.

2.2.2 Temporary RS deployment model

Nomadic RS's are deployed temporarily to provide additional coverage or capacity in an area where the MR-BS and fixed RS's do not provide sufficient coverage or capacity. The nomadic RS's enter the network when they are deployed, and exit the network when the temporary situation for which they were deployed has ended. Temporary usage may be to cope with disasters where the fixed infrastructure is destroyed or to cover some special events like sports or exhibitions. LOS or NLOS channel conditions can be expected between MR-BS and RS's.

2.2.3 RS Deployment model for greenfield operators

For greenfield operators, during the initial phases of the network launch, the number of subscribers and the traffic per subscriber is estimated to be low. The network is usually coverage limited. Preplanned MR deployment can be beneficial in two ways:

1) The available spectrum is used efficiently.
2) The initial deployment cost is considerably reduced. The cost of deploying an RS may be considerably cheaper than deploying a low-powered BS or micro/pico BS as there is no cost for backhauling.

During the later phases of the network rollout (maybe three or four years after network launch) when parts of the network become capacity-limited, the possible solutions would be to replace the RS with either a micro or pico BS. It is anticipated that products may be available that can be configured to act either as a relay node or as a micro/pico station. This would simplify the upgrade, from RS to a micro/pico station, to installing the backhaul link.

2.2.4 RS Deployment model for mature operators

Mature operators are those who have existing WiMAX networks deployed. Existing operators can use random deployment of RS's to cope with network optimization related to a coverage hole within a cell caused by shadowing (for example, a change in the dense urban clutter owing to a tall building), to cope with a shift of traffic conditions of the existing sites, to handle temporary special events, or to extend coverage in buildings or tunnels. RS's may also be deployed with a cell-coverage extension for rural deployment where capacity limitations are rarely anticipated. In rural deployment, one of the main costs of network deployment is for leasing the backhaul link which otherwise is minimized if combination between MR-BS and RS is used. RS's can also be deployed to deal with an in-cell capacity increase. Having RS's within the coverage of the MR-BS will improve the SINR and provide subscribers with better access capacity.

3. Radio network dimensioning for relay-enabled WiMAX network

3.1 Overview

A network operator always wants to minimize deployment expenditure to provide a satisfactory service. Positioning of the RS will have an impact on the coverage and capacity benefits. As discussed in Section 2.2 above, there are a number of deployment possibilities and advantages with relay-enabled networks. In different scenarios, the RS may be in LOS or NLOS with the serving MR-BS and with its subordinate links. In a conventional WiMAX network, dimensioning the objective means estimating the number of BS sites required to provide coverage and capacity for the targeted service area, and targeted subscriber forecast. Dimensioning of MR-enabled network means considering evaluating the optimal number of MR-BS's plus RS's required for serving the same performance requirements as a network without RS. This section describes one of the methodologies for dimensioning and planning MR-enabled Mobile WiMAX network. The dimensioning approach evaluates the deployment in typical scenarios. Dimensioning of MR-enabled network where the MR for cell edge coverage enhancement is used in preplanned deployment is discussed in this paper.

3.2 Cell dimensioning for relay-enabled WiMAX networks

Cell dimensioning for a relay-enabled network implies evaluating the cell radii of the MR-BS and the RS's, so that the target requirements of the service area coverage and subscriber capacity demands are satisfied. Dimensioning of the network assumes a uniform distribution of users, ideal site locations and homogenous morphology, while network planning using 2D/3D digital maps is performed with the subscribers spread as per the traffic requirements of the area and with consideration given to the natural and man-made topography. Network dimensioning and budgetary analysis for network deployment work hand in hand. For a relay-enabled network, the dimensioning and its impact on the network budget becomes more crucial as the RS in a network may be perceived as necessary for different reasons, depending on the business model of the operator. This is mainly because of the advantages and limitations that are inherent with RS, such as the fact that a wired backhaul is not required for RS, which is advantageous as it lowers the initial CAPEX. However, if the network capacity grows, the RS will need to be replaced by a macro/micro/pico BS. A forecast estimate of the time lag between parts of the network being coverage limited to it becoming capacity limited becomes crucial for a preplanned deployment of RS. Since the result of the network dimensioning will significantly impact the network reliability and initial implementation cost, each parameter and assumption that is used in the dimensioning process must be thoroughly considered. Because of the large number of optional and mandatory features supported by IEEE 802.16e and IEEE 802.16j, it may not be possible to obtain a single set of site count values for the scenario to be dimensioned. The difference in the site count (MR-BS + RS) for the same scenario may be due to assumptions about the frequency reuse scheme, handover mode, multiple antenna diversity gains being considered, the SNR values (used in calculating the receiver sensitivity of the equipment), and the type of RS (transparent - nontransparent, inband - out of band, centralized - decentralized, above roof top - below roof top, LOS-NLOS, different antenna for access link and relay link - single antenna for both the links) assumed for deployment.

An analytical network dimensioning process is based on link budget analysis with consideration of technical requirements, the propagation characteristic and the marketing requirements. For dimensioning MR networks, three link budgets will need to be accessed for the different links of MR-BS to RS, RS to SS, and MR-BS to SS. The inputs required for dimensioning are as follows.

- Equipment specific parameters: equipment specific parameters include MR-BS, RS, SS transmit powers, feeder losses, antenna gains, sector configuration, BW-supported characteristics and the BS/RS/SS deployment heights.
- Marketing specific parameters: The marketing inputs include the area to be served, the subscriber count and traffic demand per subscriber for the first year and subsequent growth for the next 5 to 10 years. The cell edge coverage and minimum data rate requirements.
- Propagation characteristic and spectrum requirements: The empirical macrocellular and microcellular propagation model suitable for the spectrum to be designed has to be selected with appropriate correction factors so that there is minimum discrepancy in the results. The correction factors allow the propagation model to be tailored to a specific deployment clutter using direct knowledge of the area's attenuation factors. For the MR-BS to SS link and MR-BS to RS links, macrocellular propagation models are suitable. However, for the RS to SS link, microcellular propagation models may be suitable especially in situations where the RS height is below rooftop level. Some of the macrocellular empirical models validated for WiMAX frequency ranges are SUI A, B, C model for NLOS and SUI D for LOS; Modified COST231 Hata model for NLOS and COST231 Wallfish Ikegami (COST231 WI) model for LOS and NLOS. The microcellular models considered appropriate are the COST231WI-NLOS model and the Modified BERG model. All the above said models have correction factors to accommodate the range of frequencies supported by WiMAX.

In conventional network dimensioning, 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. In MR-enabled network, the multihop cell (MR-BS + RS's) coverage is closely tied to the cell (MR-BS) capacity, hence it needs to be carefully defined. When a relay is added to MR-BS cell, coverage may increase but capacity may also be affected. For example, relays may be deployed in areas of poor coverage, releasing resources which may be used to enhance capacity elsewhere in the cell.

In this paper, a two-hop inband relay is considered with an MAC frame structure such that, transmissions on the first and second hop are assumed to be perfectly separated in time.

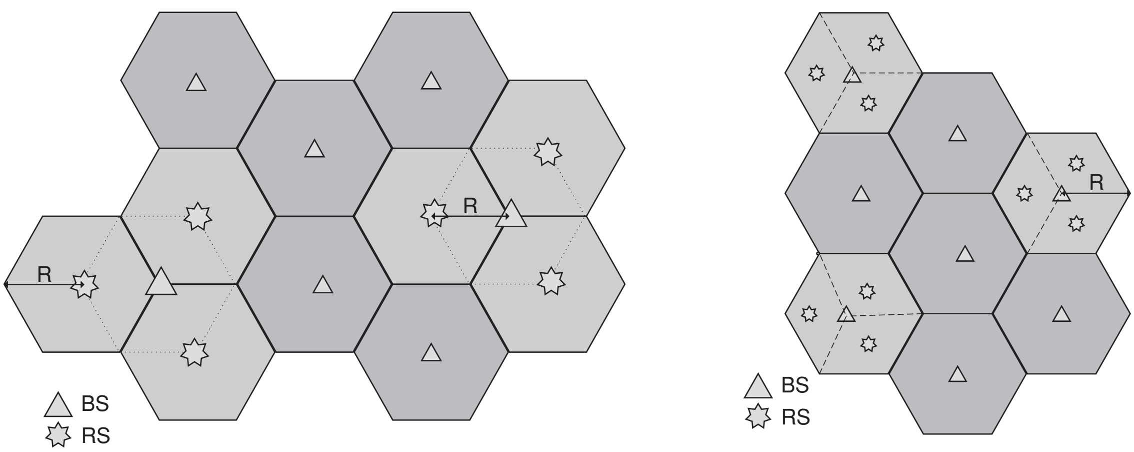
The interference analysis in section 3.2.3 is also based on this frame structure. As explained earlier in this paper, the positioning of RS's may vary according to the intended purpose. Mainly cell edge coverage extension (which can be preplanned) will be discussed in this paper.

3.2.1 Coverage analysis

Coverage is the probability that a randomly placed subscriber is able to communicate reliably at a particular data rate. It may also be expressed as the area of a cell within which signal quality is high enough to support a specified service. Coverage enhancement is the primary objective of relay-based systems. In order to extend the coverage area of the MR-BS, RS's are placed at the border of the transmission range of the MR-BS's. The distance between the MR-BS cell centre and the RS's cell centre depends on the link quality between MR-BS and RS, the degree of overlap for optimum handover and the cell radii of the MR-BS and RS. For theoretical analysis, the distance between the MR-BS and RS's equal to the original MR-BS cell radius is considered. **Figure 3** illustrates this scenario. It indicates the coverage area of the MR-BS's with dotted lines and three relays at the corner extend the coverage area by a factor of three (assuming that the RS cell radii is the same as that of the MR-BS).

To derive the MR-BS and RS's cell radii for a specific clutter category, link budget analysis needs to be performed. The link budget specifies the allowable path loss between the serving and the receiving station under consideration. It provides 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. The link budget is a prerequisite to any network dimensioning activity, and is one of the vital components of network quality.

For relay enabled WiMAX networks, three link budgets are required. The first is for the MR-BS to SS link, which will provide the MR-BS cell radii. The second is for the MR-BS to RS link which will provide the limiting distance for the location of the RS. The third link budget is required for the RS to SS link which will provide the RS cell radii. Though the link budgets are not provided in this paper, **Table 1** tabulates the parameters that are required to perform the analysis:



(a) Cell edge extension scenario

(b) In cell throughout enhancement scenario

Figure 3
Coverage extension and throughput enhancement of the MR-BS with RS's.

From the link budget results, the cell radii of the MR-BS and the RS's are derived, and further the total area coverage of the multihop cell (MR-BS + RS's) is calculated. The multihop cell area depends on the area of overlap between MR-BS and the RS and the total number of RS's supported per MR-BS (with consideration to the MR-BS capacity). The total area to be served is divided by the multihop cell area to derive the total number of MR-BS plus RS's required for providing coverage to the area.

3.2.2 Capacity analysis

Dimensioning for capacity in conventional network involves accessing the demanded and available traffic for different service requirements considering the activity factor, overbooking or contention ratio, and TDD ratio for the uplink and downlink, and then determining the site count required to satisfy the capacity requirements. The primary definition of capacity dimensioning for MR-enabled networks remains the same as for a conventional network. The total capacity of the multihop cell is calculated and the number of sites for capacity derived.

RS can be deployed to enhance the incell throughput, as indicated in Figure 3. Placing RS's within the BS's coverage helps to improve the SINR and thereby increase the link capacity. The SS/MS battery power is also saved because of improved signal quality at the cell edge. A detail analysis of the capacity enhancement of incell relays is beyond the scope of this paper.

3.2.3 Interference analysis for MR-enabled networks

This section provides a brief introduction for calculating interference margins for the RS-SS link of MR-enabled WiMAX networks. The basic approach follows the same definitions of interference margin as adapted for the interference calculations for the BS-SS single hop scenarios

Table 1
Parameters for link budget analysis.

Parameters between MR-BS and SS	Parameters between MR-BS and RS	Parameters between RS and SS
Path loss model (COST 231Hata for NLOS)	Path loss model (COST 231Hata for NLOS/SUI-D for LOS, COST 231 WI for LOS/NLOS) depending on whether the RS is ART or BRT	Path loss model (COST 231 WI for LOS/NLOS, Modified BERG's model for NLOS) depending on whether the RS is ART or BRT
MR-BS, SS Tx power	MR-BS, RS Tx power	RS, SS Tx power
MR-BS antenna gain	RS antenna gain (if RS has a directional antenna for the relay link, the antenna gain will be high compared to when it has a common antenna for access link and relay link)	Omni antenna gain
MR-BS site configuration (omni, three-sectored)	Omni configuration for RS unless directional antenna is specified	Omni configuration for RS
MR-BS, SS-equipment RX-sensitivity	RS equipment RX-sensitivity	RS equipment RX-sensitivity
Cell edge coverage probability	99% coverage probability for high reliability	Cell edge coverage probability
MR-BS antenna height	RS antenna height for the MR-BS and RS link	RS antenna height for the RS-SS link
Diversity gains	Diversity gains	Diversity gains
Outdoor or outdoor to indoor (penetration loss to be considered)	Outdoor	Outdoor or outdoor to indoor (penetration loss to be considered)
Clutter category-DU, UR, SU, R	Clutter category-DU, UR, SU, R	Clutter category-DU, UR, SU, R
Operating frequency	Operating frequency	Operating frequency
Bandwidth supported	Bandwidth supported	Bandwidth supported

in Reference 6). The BS-RS links and the RS-SS links are considered separately.

The main assumption considered is that the RS's are used for coverage extension and are placed at fixed locations at the cell boundaries. The analysis is based on the assumption that each MR-BS is connected to three RS's. The three RS's are served by the MR-BS through sharing of the time and frequency resources in the relay link, and no spatial division multiplexing is considered. As such, no interference is generated within the three RS's from the same MR-BS; however, interference originates from similar RS deployments in adjacent cells. The RS's are assumed to be placed outside of the fractional frequency reuse (FFR) zone; the RS's are subjected to an effective frequency reuse of three, even if the re-use pattern is one. The antenna coverage is assumed to be omni-directional at both the RS and MR-BS. This basic model of MR-BS and RS placement is shown below in **Figure 4**, for a cell deployment with omni-directional antennas.

The BS-RS link can be broadly categorized into two sections. The first is where the RS is deployed above the local clutter (i.e., on a building top or a tall mast), this makes a LOS connection to the MR-BS possible. The second scenario is when the RS is deployed at a much lower height (about 5 to 7 m) for example on top of a lamppost. With this type of deployment it is highly unlikely that the RS will be able to achieve a LOS connection with the MR-BS, so an NLOS connection is evaluated. Different path-loss models are considered in these two scenarios. For example the NLOS considers COST231-HATA and COST231WI-NLOS models, and the LOS scenario considers SUI-D and COST231WI-LOS models.

As described in Reference 6), the interference is considered as a 'noise rise' above the thermal noise level. The interference power I is calculated as:

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

Where P_T is the transmission power of the interfering terminal (BS, RS or MS) and G_T is the relevant antenna gain. P_{coll} is the average collision probability for the Uplink or Downlink and PL_i is the path loss for the interference source. $\cos^{\gamma}\theta_i$ is the term used to model antenna directionality in three-sectored and six-sectored deployments.

Selected results for the RS-SS link interference analysis for the NLOS scenario are shown in **Figure 5**. The results indicate that the interference margins are almost identical for the two RS-SS path loss models considered. This is due to the fact that the major contribution of interference is coming from the serving MR-BS cell (with higher MR-BS power) and the BS-SS path loss model has the dominant effect, which is taken to be COST231-HATA. With a larger cell radius from the serving MR-BS, the interference margins for the RS-SS link reduce considerably. Hence the MR-BS cell radius is of prime concern in deciding the RS-SS interference margins.

3.2.4 DoORs for MR-enabled WiMAX network dimensioning

DoORs W (Dimensioning of Overall Radio networks for WiMAX) are a series of software

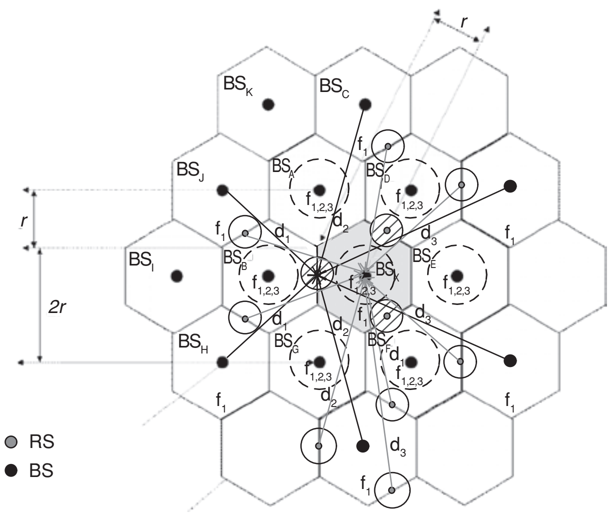


Figure 4
BS-RS deployment scenario when effective frequency reuse = 3.

tools developed by Fujitsu Labs of Europe to support dimensioning for WiMAX networks. DoORs W have a graphical user interface (GUI) driven front-end, developed with Visual Basic software and a Microsoft Excel data repository. They provide capabilities to simultaneously dimension multiple roll-out phases for different environments. It is compliant with IEEE 802.16d for fixed broadband, IEEE 802.16e for mobile broadband and IEEE 802.16j for MR support. Because of the large number of optional and mandatory features supported in WiMAX, the tools are a repository of parameters with values for the parameters derived either from FLE's link and system simulator, or from the vendor datasheets, or from the understanding of the technology and standards. The MR module of the tools is designed to determine the number of RS and MR-BS infrastructure count for the cell edge coverage extension scenario. It can also be used for technology evaluation to analyze the impact of varying the parameter values on the total number of MR-BS + RS site count. The tools are enriched with a number of analytical models like an intercell interference-margin calculation model and a system-throughput calculation model, which along with other parameters are designed to a part of the overall coverage and capacity analysis. A detailed description of the features modeled in the tools is provided in Reference 6).

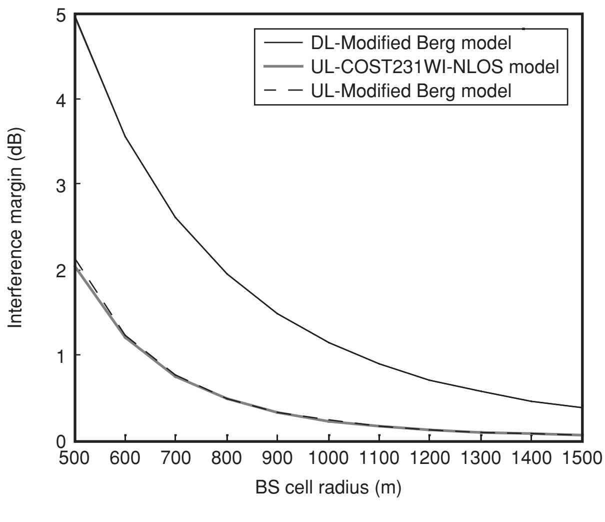


Figure 5
Simulation results for the RS-SS interference model.

4. Economical feasibility analysis of MR-based WiMAX network

4.1 Overview

The assessment of deployment cost for cellular networks has always been a topic of interest for network operators, and has recently gained more importance as advanced radio technologies, mobile services and new deployment strategies (e.g. infrastructure sharing, coexistence with legacy systems, network architecture change by having MR-enabled network) are introduced, which in turn makes the investment decision more complex. To justify the benefits of MR in the network, cost analysis or an economical feasibility analysis needs to be performed which considers the fact that if the original system consists of macro BS's, the savings from having a lower number of BS's because there are additional RS's for the same network performance could be substantial, since the costs associated with equipment in a macro BS site is higher than that of the RS's. If the original system consists of micro or pico BSs, the cost savings of having RS instead of a micro/pico station may consist basically of the wired backhauling which is not required for RS's.

4.2 Cost analysis methodology

Evaluating the economical feasibility of a hybrid network (MR-enabled network) compared with a conventional network may not be straightforward in a general case, since the results may depend on whether the old infrastructure can be reused. The particular case of a greenfield operator is considered to be more appropriate. The general scenario with a greenfield operator considers that the network is coverage limited (either the customers do not demand services with high bit-rates or the number of customers is simply very low) for the initial phases of network rollout, and later as the traffic load increases, the operator may update the network by having additional BS/RS/micro/pico stations in the network or by turning some of the already existing RS's into micro/pico stations. When building the network from scratch, the operator has the option of deploying a traditional (single hop) cellular system with macro BSs, or a hybrid system with macro BSs and fixed wireless relays.

The different stages of cost analysis can be explained with the help of a flow diagram as shown in **Figure 6**.

As indicated in Figure 6 the first stage is to derive the count of the network infrastructure elements required for different cases (for example, a network with only BS's, a network with a BS and micro/pico station and a network with MR-BS's and RS's) which satisfy the same network performance requirement in terms of the service coverage and throughput. Network dimensioning for MR-enabled network is addressed in Section 3.2. The cost associated with the deployment of each of the network types is derived independently by using the cost values as explained in Section 4.2.1. Comparing the cost results will provide the best system for that one scenario.

4.2.1 COST components of network

The different cost component of the network needs to be identified and classified as either a candidate of CAPEX or OPEX. The once-only costs that usually have to be paid at the time

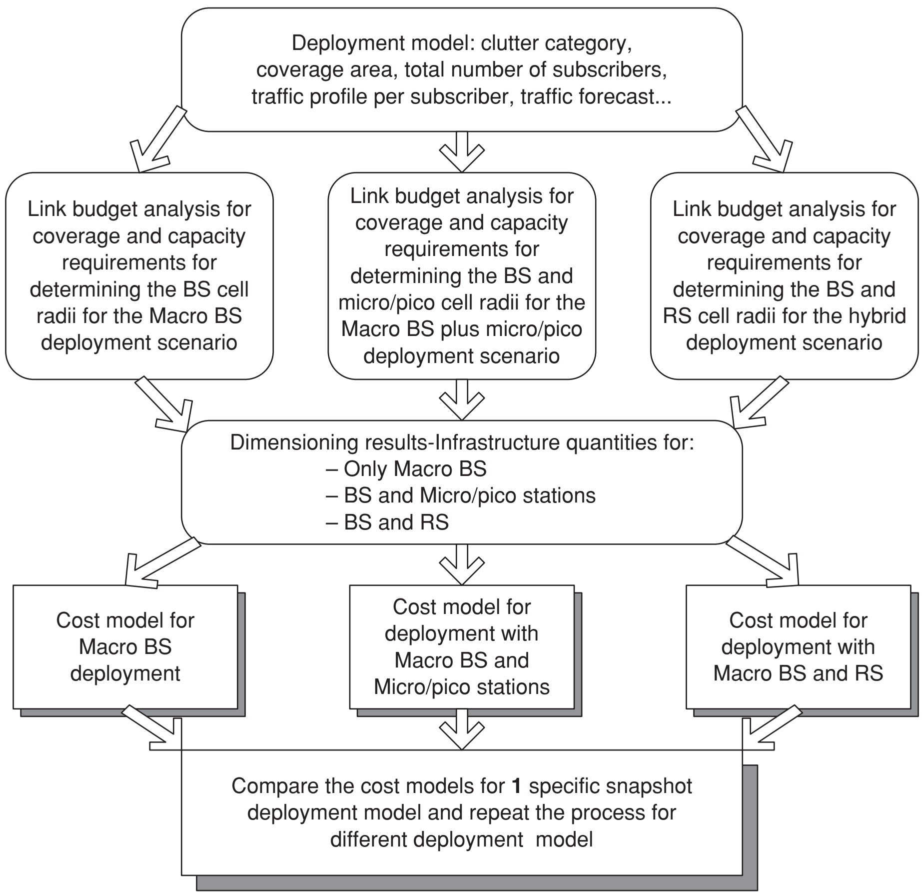


Figure 6
Flow diagram indicating the flow of economical feasibility analysis.

of deployment are called capital expenditures or CAPEX, and costs that occur periodically are classified as operational costs or OPEX.

Costs assessments based on comparisons of a conventional network (consisting of Macro BS, micro/pico BS) and a hybrid network implicitly assume that the operator bears the CAPEX and OPEX including payment for the spectrum access, network deployment, operation and maintenance as well as the subscriber acquisition, marketing and terminal subsidies. Operators get their income from the offered services. For a greenfield operator the CAPEX and OPEX for a specific clutter category will depend on a number of factors like:

- Site share availability, percentage of sites with microwave links (LOS) for backhauling, and whether the CPE has outdoor antenna or is indoor self-installable.

The Capex and Opex for the same deployment scenario will vary for different Clutter categories (Dense Urban, Urban, Sub Urban or Rural) and also will vary from region to region depending on the economics of the region (country of deployment). When using a cost model for comparison with analysis done by another party, an error may arise because of this.

Though an elaborate classification of all the network elements is beyond the scope of this paper, **Table 2** indicates some of the network elements classified as CAPEX and OPEX.

Table 2 does not consider the one-off cost related to spectrum licenses, or system-specific costs related to standardization and research, or costs related to marketing.

With the knowledge of the absolute cost associated with each of the CAPEX and OPEX elements for any infrastructure deployment, the total cost of network deployment can be evaluated.

4.2.2 Cost analysis with example

Cost analysis of a network with a BS only and a combination of MR-BS and RS's is explained here with an example. The Capex and Opex figures in the example are not specific to any area or vendor or technology and should be considered at face value. The Capex and Opex calculation for the MR-BS and RS is shown in **Table 3**, the RS deployment cost is considered as a percentage of the total cost of the MR-BS deployment.

The table below is an example of the dimensioning result for a specific scenario:

Using the final cost values in Table 3 and the total infrastructure count from **Table 4** will provide the total cost of network deployment with and without an RS. The total cost benefit of having hybrid network is around 10 percent of the total cost of a conventional network for this specific example of site count and cost.

For a preplanned RS deployment, it is obvious that the ratio of MR-BS to RS cell radii will be a determining factor for cost benefit of MR-enabled network. As explained earlier, the cost of the RS depends on the type of power amplifier of the RS, since a high-powered RS can be used to reduce the number of BS's substantially. Cost saving may also come from saving on the wired backhaul and also on the ability to have the RS on street furniture which may not require full planning permission. The number of RS's that can be supported by the BS also determines the maximum number of RS's that can be supported for a specific network performance. The parameters that determine the MR-BS to RS cell radii are:

- Path loss models, equipment EIRP, equipment height, cell edge coverage probability, equipment receiver sensitivity and antenna configuration.

For the same network performance, the ratio of MR-BS to RS may vary for the above reasons. The breakeven point for the combination of MR-BS and RS in MR-enabled network is best shown with the help of an indifference curve as studied in the WINNER project.[4] The indifference curve as shown in **Figure 7** is a powerful technique for illustrating the trade-off between BS and RS density in terms of total network cost. Each point on the indifference or iso-performance curve represents a different multi-hop system, each having identical performance. A tangent to the iso-performance curve is the equal cost line, such that any point on the line represents the same total cost of the BS's plus RS's.

The gradient of the iso-performance curve represents the change in the RS density required to compensate for a change in BS density. The point at which the equal-cost line is tangent to

Table 2
Classification of cost components into CAPEX and OPEX.

CAPEX	OPEX
Cost of the MR-BS (three-sectored site including cost of cabinets, cables, antenna and feeders)	Power supply cost (BS and RS)
Cost of the RS (omni, diversity antenna, cost of cabinets, cables, antenna and feeders)	Site rent and maintenance cost (BS and RS)
Civil works cost for BS and RS (acquisition, cabling, power)	Rent for RAN connectivity
New tower or rooftop deployment (or percentage mix, cost of new tower is substantial)	Power supply cost (BS and RS)
RAN connectivity (wireline or microwave backhauling) costs for MR-BS	Network operations
Centralized RRM servers, gateways	Terminal device costs and subscription
Initial network optimisation	Software upgrades

Table 3
Example calculation of CAPEX and OPEX for BS-RS.

CAPEX

MR-BS	
Three-sectored BTS Tx + Rx + antenna + cables	$70 000
Site acquisition + preparation + cabling + power	$50 000
Backhauling to the core network	$30 000
New Tower-deployment	$80 000
Total BS CAPEX	$230 000
Total RS CAPEX	40% of the BS

OPEX

BS	
Backhauling cost-(T1/E1 yearly cost-DU)	$6000
Site lease expense per year	$13 200
Maintenance cost per year	$9200
Installation and commissioning	$2500
Power per year	$2400
Total BS OPEX	$33 300
Total RS OPEX	40% of the BS

SUMMARY: CAPEX + OPEX	
Per BS Capex + Opex per year	$263 300
Per RS Capex + Opex per year	40% of the BS

Table 4
Example dimensioning results for a specific scenario.

Network	BS site count	RS site count
BS only	22	0
MR-BS + RS	11	33

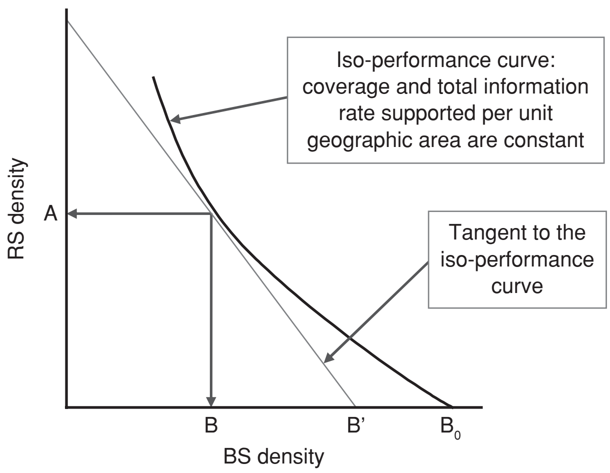


Figure 7
Iso-performance curve showing the different BS densities and RS densities required to maintain constant capacity and coverage.[4)]

the indifference curve is the least-cost combination of the BS's and RS's for a specific BS/RS cost ratio. If the BS/RS cost ratio varies, the corresponding equal-cost line will be tangent to the indifference curve at a different point, leading to a different combination of BS's and RS's.

5. Conclusions

This paper presents a detailed description of the technology that enables relays in a WiMAX network with emphasis on the different deployment models that are possible with RS. It highlights the dimensioning approach for a preplanned RS-deployed WiMAX network focusing on the cell edge coverage scenario. Interference analysis for cell edge coverage extension cases is explained. The output of the interference analysis is a key input parameter in the MR-BS and RS cell radii calculation.

Because of the inherent advantages and limitations of having RS's in the network, it becomes crucial to perform economical feasibility analysis. This paper describes the cost elements involved in the network deployment further classified under CAPEX and OPEX. An example is used to show the results of cost analysis for one specific scenario. Indifference curves can be used to generalize the interaction of the BS to RS ratio and its cost implications.

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Bharathi Upase
Fujitsu Laboratories of Europe Ltd.
Ms. Upase received the B.E and M.E degrees in Electronics and Communication Engineering from Karnataka University, India in 1992 and 1994, respectively. She joined SDM College of Engineering, India, as a Lecturer. From 1998, she was a consultant in the Wireless Division of Marconi (UK), mainly working with a number of wireless operators such as O2 and Vodafone in the UK and Vodacom in South Africa on wireless network planning involving cell planning, frequency planning, site survey, KPI evaluation and optimisation for GSM, GPRS, and WCDMA networks. She also worked in the product development division of Marconi defining requirement specification for modules in the network planning tool Planet. In 2003 she joined Bechtel Telecommunication UK, where she was involved in intense drive testing and KPI evaluation for improved GPRS coverage on high-speed rail routes for the Vodafone network. In 2004 she joined Fujitsu Laboratories of Europe Ltd., where she has been involved in radio network planning research; assisting Fujitsu business groups with cell design for Fujitsu's customers; and design and development of a radio network dimensioning tool for WCDMA, HSDPA, wireless LANs, and WiMAX.

E-mail: bharathi.upase@uk.fujitsu.com

Mythri Hunukumbure
Fujitsu Laboratories of Europe Ltd.
Dr. Hunukumbure received the B.Sc. degree in Electronics and Telecommunications Engineering from the University of Moratuwa, Sri Lanka, in 1998. He completed his M.Sc. and Ph.D. studies at the University of Bristol, UK. He is now employed at Fujitsu Labs. of Europe Ltd., as a senior research engineer. His research studies have encompassed the appraisal of code orthogonality and space-time signal processing technology for 3G mobile systems. He has been actively involved in the European COST273, IST-Saturn, and Mobile VCE research programs. At Fujitsu, he is involved in 4G WiMAX-related research, mainly concentrating on network dimensioning and planning for the evolving WiMAX architecture and standardization aspects of WiMAX.

E-mail: mythri.hunukumbure@uk.fujitsu.com