21

Multi-hop Relay Networks

David Soldani
Huawei Technologies, European Research Centre
Germany

1. Introduction

The current outlook for the overall wireless broadband market worldwide shows that mobile data traffic will double every year through 2013, and mobile broadband handsets with higher than 3G speeds and laptops with air cards will drive over 80% of global mobile traffic by 2013. About 1.2 billions of new users are expected on top of the current 200 millions. The expansion of wireless broadband ubiquity will allow the convergence of the "3 Screens" (TV, PC & mobile handset) with exciting opportunities for always-on networking and an increased volume of consumers who will access and rely on mobile networks, thus creating a need for greater economies of scale and lower cost per-bit.

Today cost of 2G/3G network transmission accounts for approximately 19% of the overall cost for delivering a bit of data to an end user. Analyses of Tier 1 European mobile carriers suggest that, given the current backhaul architectures, which are based primarily on leased lines, operational expenditure (OPEX) for transmission would increase to around 80% of the spending per cell site, if the cell exploited its maximum capacity. Therefore, it is not feasible to offer mass market mobile data services using the existing backhaul networks, mainly based on leased lines.

The broadband radio interfaces for next generation mobile networks (NGMN), such as 3G Long Term Evolution (LTE) and mobile WiMAX 802.16e and beyond, will be characterized by a very limited range due to their high operating frequencies, which are expected to be in most of the cases above the 2 GHz band currently used for the 3G systems. For example, WiMAX 802.16e is expected to be the Time Division Duplex (TDD) technology for 2.5 GHz and 3.5 GHz bands (Andrews et al., 2007). In a suburban environment, a wireless solution for good quality indoor coverage would take nearly four times as many sites to deploy at 2 GHz than at 1 GHz, and ten times as many for 3.5 GHz. On the other hand, at a given power and carrier frequency, the available data rate decreases if the distance from the access node (AN) increases and Quality of Experience (QoE) must not depend on where the terminal is located in a cell. Hence, the deployment of a conventional cellular network would require a very high density of access nodes to achieve a satisfactory radio coverage, capacity and QoE, resulting in a very high costly solution per delivered bit.

Consequently, to meet the goal of low cost radio network deployment, for both, short-range and wide-area coverage, the deployment concept based on layer 2 (multi-hop) relay nodes is currently one of the most promising solutions (Soldani & Dixit, 2008).

Wireless relays help overcome the current dependencies on wired backbones and enable cost-effective enhancement of coverage, throughput and system capacity. In fact, relay nodes do not need a wired (e.g. copper or fibre) backbone access, reducing deployment costs, and offer high flexibility in placing the stations, allowing fast network rollout and adaptive traffic capacity engineering. Further, multi-hop relaying gives better trunking efficiency at aggregation points and site acquisition and antenna structures are much less expensive. A relay augmented network is thus expected to provide an improved Return on Assets (RoA), which means higher average revenue per user (ARPU) with superior grade of service at lower overall incremental cost. Such networks are well suited for deployments in emergency and disaster scenarios. Also, in rural areas, where the traffic density is low and population sparsely distributed, it may not be economically viable to build traditional cellular access networks with full fledged base stations; rather a network architecture with a single base station (BS) flanked by relay nodes to improve capacity and range extension may be a more economical and flexible approach.

This chapter presents an overview of the concept of relaying and specifically targets a system that utilizes the WiMAX technology and related standards.

1.1 Concept of Relaying

The classical *three-node relaying* model is a network consisting of only one *Source* (mobile multi-hop relay-base station, MMR-BS or MR-BS), one *Relay* (fixed, nomadic, or mobile relay station, F/N/M-RS) and one *Destination* (mobile station, MS, or user terminal, UT). (In the rest of the chapter, the nomenclature "UT" is used for both fixed and mobile station.) The model was originally introduced by Van der Meulen (1971).

The three-node relay network can be seen as a primitive building block for larger relaying systems. As illustrated in Figure 1, the destination can receive the signal from the source via two paths: the two-hop relaying link (first and second hop) and the one-hop *direct link* (third hop). In the two-hop relaying link, the physical channel between the source and the relay is called *relay link* and the physical channel between the relay and the destination is called *access link*.

A *relay path* is by definition a concatenation of consecutive relay links between the source and the designated access relay station.

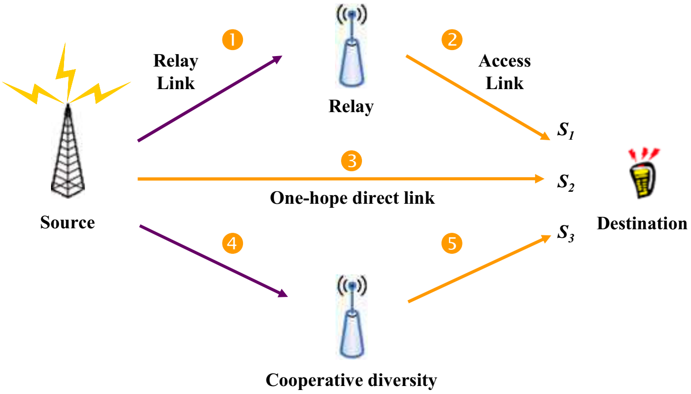


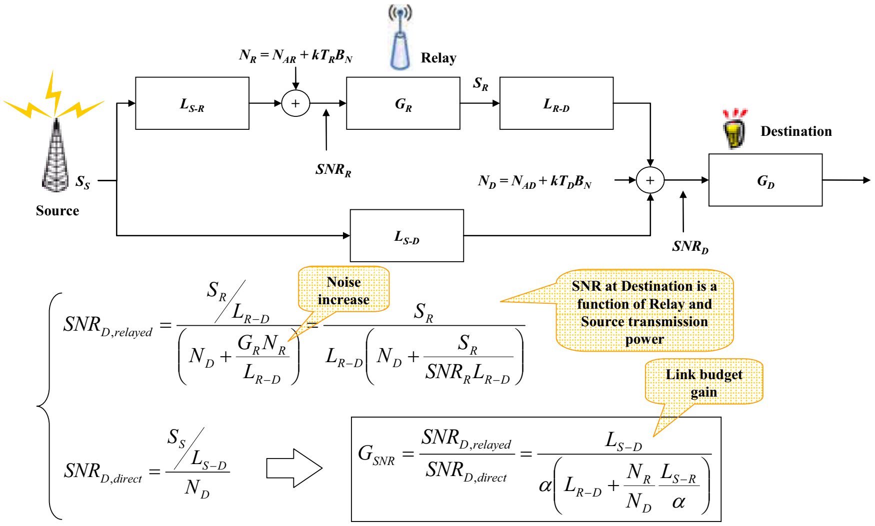
Fig. 1. Three node relay network and cooperative relaying (Soldani & Dixit, 2008)
Reproduced by permission of © IEEE 2008

The relay normally works in half-duplex mode, which means that the station does not receive and transmit using the same channel simultaneously. This is because it would be difficult to separate the received signal from the transmitted one. For this reason, the channel allocated for the relay operation consists of two (ideally) orthogonal sub-channels. For example, in TDD, the orthogonal sub-channels are two consecutive time slots: the relay receives during the first time slot and uses the second slot for retransmitting. Frequency or code division duplex is also possible (Pabst et al., 2004).

The relay may operate in three possible schemes, depending on how the received signal is processed: *Amplifying and Forwarding* (AF), *Decoding and Forwarding* (DF) or *Estimating and Forwarding* (EF).

In the AF scheme (*analogue repeaters*), the relay node just amplifies and retransmits the input symbols. The received signal is deteriorated by relay link fading and additive receiver noise. The degraded signal and noise are amplified and forwarded, thereby increasing the system noise level. This is demonstrated in Figure 2, where S_S is the Source transmit power, S_R is the Relay transmit power, $L_{S\text{-}R}$ the Source-Relay path loss (includes antenna gains), $L_{R\text{-}D}$ is the Relay-Destination path loss (includes antenna gains), $L_{S\text{-}D}$ is the Source-Destination path loss (includes antenna gains), G_R is the Relay gain, G_D is the Destination gain, B_N is the equivalent Noise bandwidth, T_X is the effective noise temperature referred to the input, N_{AX} is the Antenna noise temperature (includes interference), k is the Boltzmann constant (1.3806 x 10^{-23} J/K), F_0 is the noise figure (Noise Factor), i.e. $F_0 = (1 + T_X/T_A)$, when $T_A = T_0 = 290$ K (standard room temperature), and α is the Source-Relay transmit power ration, i.e. $\alpha = S_S / S_R$. From the basic theoretical analysis showed in the figure results that multi-hop techniques enable a link budget gain, which can provide an improvement in coverage, throughput and reduction in transmission power.

In the DF scheme (*digital repeaters*, or *layer 2 relays*), the relay demodulates and decodes the received signal before the retransmission. In this case, the forwarded signal does not contain additional degradation, but only symbol errors resulting from it.



$$SNR_{D,relayed} = \frac{S_R / L_{R-D}}{\left(N_D + \frac{G_R N_R}{L_{R-D}}\right)} = \frac{S_R}{L_{R-D}\left(N_D + \frac{S_R}{SNR_R L_{R-D}}\right)}$$

$$SNR_{D,direct} = \frac{S_S / L_{S-D}}{N_D} \Rightarrow \boxed{G_{SNR} = \frac{SNR_{D,relayed}}{SNR_{D,direct}} = \frac{L_{S-D}}{\alpha\left(L_{R-D} + \frac{N_R}{N_D}\frac{L_{S-R}}{\alpha}\right)}}$$

Fig. 2. Impact of relaying on received SNR for an Amplifying & Forwarding (AF) relay

In the EF scheme (*hybrid relays*), the relay does not decode the input data, but it source codes the received signal (after quantization) and transmits it to the destination. In this case, the forwarded signal contains possible estimation errors. The destination uses the relay estimation as side information while coding the actual direct link signal.

The concept of *cooperative relaying* is based on the fact that a signal, once transmitted, can be received (and usefully forwarded) by multiple terminals (Pabst et al., 2004). In general, cooperative relaying systems have a source node multicasting a message to a number of cooperative (helping) relays, for example, two in Figure 1, which in turn resend a processed version to the intended destination node. The destination node combines and exploits the inherent diversity of the signals received from the relays and, possibly, the source signal, as illustrated in Figure 1.

The coverage area of an MMR-BS cell and all its subordinate RS cells constitutes a *multi-hop relay cell* (MMR-Cell). The MMR-BS manages all resources within an MMR-cell through a *centralized* or *decentralized* control function. Resource management and control of UTs within an MMR-cell may be via direct radio links or via relayed messages.

1.2 The State of the Art

The DF concept has been studied widely and many results are available in the literature. The most relevant research contributions are from the Wireless World Initiative New Radio (WINNER) project, and its continuation (WINNER+), which is an EU-funded consortium with strong participation from the academia and the industry, working towards enhancing the performance of mobile communication systems (WINNER, 2008).

Wireless relays are also being specified in the standards. For instance, at the time of writing, relaying is studied as an enhancement of 3GPP LTE and planned to be standardized in LTE-Advanced by the end of 2010, with mesh extensions in later releases. The IEEE 802.16j amendment (IEEE 802.16j, 2009) provides specifications for mobile multi-hop relay features, functions, and interoperable relay stations, to enhance coverage, throughput and system capacity of WiMAX networks. The document specifies orthogonal frequency division multiple access physical layer (OFDMA-PHY) and medium access control protocol (MAC) enhancements to the IEEE 802.16e to enable the operation of relay stations for licensed bands. The standard does not require any modification to the mobile stations (including subscriber stations, SS) and provides full backward compatibility with 802.16-2004 (fixed) and 802.16e-2005 (mobile) WiMAX systems. Mesh extensions are specification items for IEEE 802.16m system (IEEE 802.16m, 2008). A key differentiator between 802.16m and 802.16j is that the former is not constrained by any legacy issue and hence is at liberty to design an entirely new radio access system within the ITU IMT-Advanced initiative.

2. Multi-hop Relaying for WiMAX Networks

This section provides a comprehensive description of the IEE 802.16j relays-based wireless access networks; it covers the different usage scenarios, network topologies, frame structure, radio interface protocols, relay path management and routing, radio resource management (RRM) functions, quality of service (QoS), and cooperative relaying. More information on the radio interface protocols and MMR frame structure can be found in the Multi-hop Relay Specification (IEEE 802.16j, 2009) and in (Chen & De Marca, 2008).

2.1 The 802.16j Specifications

In 802.16j, the RS is supposed to work in line of sight (LOS) and non-LOS propagation conditions and to support UT handover. The relay link can operate either in TDD or frequency division duplex (FDD) mode. The MMR-BS supports bandwidth requests and allocation mechanisms for RS and maintains full compliance with legacy standard. QoS for multi-hop is supported as defined for legacy 802.16 systems and delivery of unicast data, via RS and UT connections, is based on connection identifiers (CIDs). Security procedures are compulsory between MMR-BS and RS, between relay stations, and between RS and UT.

Both *in-band* and *out-of-band relaying* are possible. In *in-band relaying*, MMR uses the same RF channels on relay (MMR-BS-to-RS or RS-to-RS) and access links (MMR-BS-to-UT or RS-to-UT), and in *out-of-band relaying*, the MMR uses different RF channels on relay (i.e., MMR-BS-to-RS or RS-to-RS) and access links (i.e., MMR-BS-to-UT or RS-to-UT).

Other relevant functionalities, such as automatic repeat-request (ARQ) of UT via RS, RS with mobility and its subordinate UTs, multiple antennas (MIMO, beam forming, transmit diversity, etc.), RS to support feedback mechanisms and to participate in cooperative relaying, mechanism to support various forms of radio resource assignment, RS to process and forward the DL and UL control information, mechanisms for both MMR-BS and RSs to learn the topology of the MMR-cell in which they operate, are optional requirements (IEEE 802.16j, 2009).

The next sections give more insights into usage scenarios and basic functionalities of mobile multi-hop relay (MMR) networks.

2.2 Use Cases

The most important use cases for MMR are illustrated in Figure 3. The RSs can be owned by either the infrastructure provider or by the customer, depending on the usage scenario.

In the infrastructure with *fixed relay stations* (F-RSs), RSs and MMR-BSs are deployed to improve coverage, capacity, or user bit rate, in areas not sufficiently covered (e.g., indoor, in shadow, tunnels or underground), or to provide access for clusters of users outside the coverage area of the MMR-BS.

A *nomadic relay stations* (N-RS) can be temporarily deployed to provide additional coverage or capacity in an area where MMR-BSs and/or fixed RSs do not provide good coverage or capacity. For instance, temporary coverage could be required in emergency or disaster recovery situations, or in sporting occasions or fairs, where coverage is required only for the duration of that particular event. Furthermore, nomadic (portable) relay stations can provide access to subscribers within a room or to a large building, such as a multi-tenant dwelling or office building.

A *mobile relay station* (M-RS) can be mounted on a vehicle and connected to an MMR-BS or RS via a mobile link. In this case, the RS provides a fixed access link to terminals residing on the platform.

Enhancements in throughput, capacity and reliability can be achieved by providing higher signal interference noise ratio (SINR) to users at the edge of the cell, so that higher bit rates can be used, or by deploying RSs and MMR-BSs in a dense topology (small cells). The latter scenario may also provide a higher degree of routing diversity. For example, traffic from a given UT can be routed to avoid a congested relay link or to save power at a particular node.

For coverage and/or range extension the RSs can be deployed to provide higher signal level to users in low lying or isolated areas, beyond the MMR-BS coverage. Coverage can also be extended to UTs riding on mobile vehicles and to areas frequently travelled.

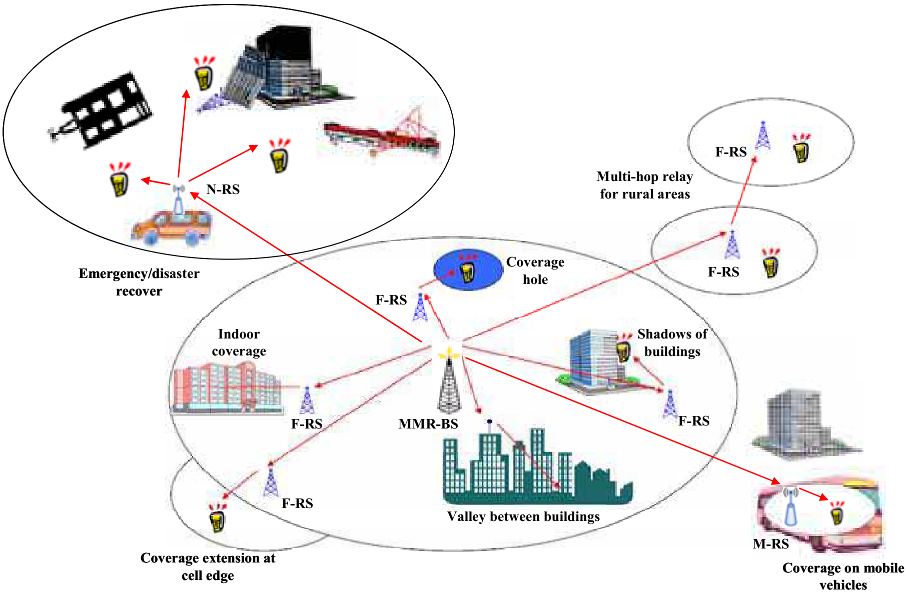


Fig. 3. Examples of usage scenarios for fixed, nomadic and mobile relay stations (Soldani & Dixit, 2008) Reproduced by permission of © IEEE 2008

2.3 Network Topology

The topology follows a *tree structure*, point to multipoint (PMP) compatible, neither ad hoc nor mesh. The interconnections between nodes include the following types of links: MMR-BS to UT, where the MMR-BS can connect to multiple UTs; RS to UT, where RSs can associate with multiple UTs; MMR-BS to RS, where the MMR-BS can connect to multiple RSs; and RS to RS, where RSs can associate among themselves.

For instance, in all usage models described in Section 2.2, all data transmission may occur between MMR-BS and mobile stations directly, or through one or more relay stations.

Downlink (DL) and uplink (UL) connectivity between the MMR-BS and UT can be provided via either symmetric or asymmetric routes. Multiple routes between one MMR-BS and one UT are also possible, e.g., as shown in Figure 4, where there are two routes (one through RS1 and the other through RS3) between the MMR-BS and UT5, which is served by RS4.

2.4 Radio Interface Protocols

An example of MMR data protocol stack for simple relay stations is depicted in Figure 4.

MAC-Convergence Sublayer (MAC-CS) constitutes the interfaces to upper layers (e.g. IP, Ethernet). This protocol is also responsible for: (i) classifying and mapping the MAC-Service Data Units (MSDUs) into appropriate CIDs for QoS management, routing and forwarding; (ii) processing (if required) the higher-layer PDUs based on their classification; and (iii) delivering CS PDUs to the appropriate MAC SAP and receiving the CS PDUs from the peer entity. An optional function of the CS is payload header suppression (PHS), the process of suppressing repetitive parts of payload headers at the sender and restoring these headers at the receiver.

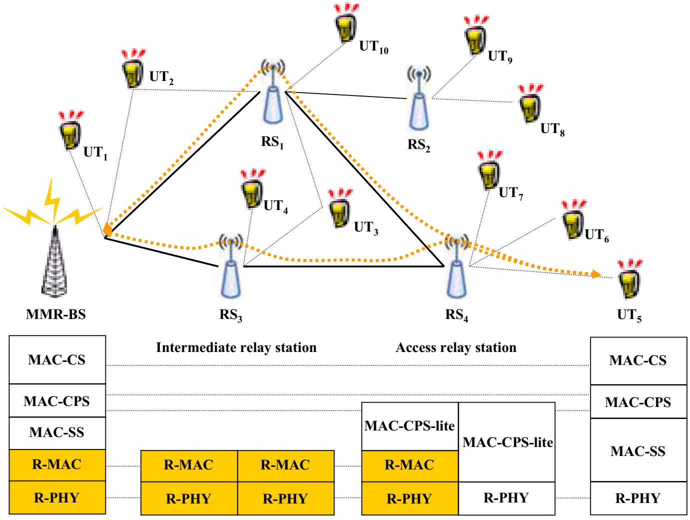


Fig. 4. Example of network topology and MMR data protocol stack for simple relay stations (Soldani & Dixit, 2008) Reproduced by permission of © IEEE 2008

Main functions of *MAC-Common Part Sublayer* (MAC-CPS) are: connection establishment and maintenance of the connection between the two peer entities; relay path management and routing; network entry and initialization; UL/DL hybrid ARQ (HARQ); handover procedures; multicast and broadcast services (MBS); relay station neighbourhood discovery; scheduling of bandwidth allocation and QoS management. *MAC-Security Sublayer* (MAC-SS) is mainly responsible for authentication, secure key ex-change, and encryption and integrity control procedures. *Relay-MAC* (R-MAC) takes care of concatenation and fragmentation of forwarded MAC PDU and control functions, such as scheduling, routing, flow control, etc. It also supports the use of the generic MAC header. *Relay-Physical* (R-PHY) implements all physical layer functionalities and procedures, such as sub-channelisation, modulation and coding for links between MMR-BS and RS and between RSs.

2.5 Frame Structure

The standard defines two different modes of operation for relaying: *transparent* and *non-transparent*; and the frame structure configuration depends on the type of relaying.

A *transparent relay station* (T-RS) does not transmit the preamble, frame control header (FCH) and MAP at the beginning of the frame. Instead, it receives the preamble, FCH and MAP, and an optional R-MAP transmission from the MMR-BS, as explained later. In transparent relaying, RSs do not forward framing information, and hence do not increase outer MMR-BS coverage; consequently, the main use case for transparent mode relays is to increase capacity within the MMR-BS coverage area. This type of RS is of lower complexity, and only operates in a centralized scheduling mode and for topology up to two hops. A simulation study on the gain in throughput that is possible to achieve in transparent mode relay-based 802.16j systems can be found in (Genc et al., 2008).

In a *non-transparent relay* (NT-RS), the contents of the FCH, DL-MAP and UL-MAP in the relay frame may be different from those in the MMR-BS frame. The frame header contains essential scheduling information that nodes use to determine when they can transmit and receive data. Related to the modes of relaying are two different options for scheduling: *centralized* and *distributed*. In the former, all scheduling for all nodes in the MMR-Cell takes place in the MMR-BS; in the latter, the RSs have some autonomy and can make scheduling decisions for the nodes which they communicate with, as explained in detail later. In non-transparent relaying, RSs generate their own framing information or forward those provided by the MMR-BS depending on the scheduling approach (i.e., distributed or centralized). They can provide a wider coverage area and, therefore, are mainly used for increasing coverage. On the other hand, the transmission of the framing information can result in high interference between neighbouring RSs; hence, the capacity enhancement that can be achieved using these relays is rather limited. Also, they can operate in topologies larger than two hops, leading to different levels of complexity at the RS (Genc et al., 2008).

As transparent and non-transparent relays have different advantages, there can be some scenarios in which it makes sense to associate both with a single MMR-BS (Genc et al., 2008).

The *Frame Structure* required to support relay network architectures, similarly to the legacy 802.16 frame, is divided into two subframes (DL/UL). These subframes are further divided into different *zones* for MMR-BS-RS and RS-UT connectivity. The *access zones* are defined for supporting MMR-BS/NT-RS communications with the UT/T-RS. In transparent mode, a *transparent zone* is defined for T-RS communications with the UT; in non-transparent mode, *relay zones* are defined for MMR-BS/NT-RS communications with NT-RS.

As illustrated in Figure 5, for transparent mode (with two-hop topologies) it is only necessary to have a single access zone and one transparent zone in both DL and UL. The RSs switch mode (transmit ↔ receive) when the system switches zone; therefore, it is necessary to have a receive/transmit transition gap (R/TTG) between the two zones. The scheduling is performed via MAPs that are transmitted by the MMR-BS. Data can be transmitted from the MMR-BS to the RS in one frame and forwarded from the RS to UT in the subsequent frame.

An example of non-transparent mode frame structure (two-hop case) is shown in Figure 6. The MMR-BS and RS must be synchronized to transmit the frame preamble at the same time, and both the DL and UL subframes must be synchronized in both the MMR-BS and RS. The DL subframe includes at least one DL access zone and, optionally, one or more relay zones. The UL subframe may include one or more UL access zones and one or more relay zones. The system behaviour depends on the scheduling mode of operation; though, in both modes (centralized or distributed), the MMR-BS transmits two MAPs for scheduling transmissions to and from UTs to which connects directly, and one R-MAP for scheduling MMR-BS-RS communications. In centralized mode, the MMR-BS generates the MAP (or R-MAP, in topologies with more than two hops) for the RSs to schedule transmissions to/from their subordinates. The RSs transmit the received MAP messages at the start of its DL access zone. In distributed scheduling the RSs can perform their own scheduling; hence, they do not need these messages. Furthermore, non-transparent mode provides support for both single- and dual-radio RSs. For single-radio RSs, is necessary to introduce transition gaps between zones within the subframes, which are not necessary in the latter case. In the dual radio case, the RS communicates with its parent via one radio, and the other radio is used for communicating with its subordinates; typically, these radios would operate using different channels.

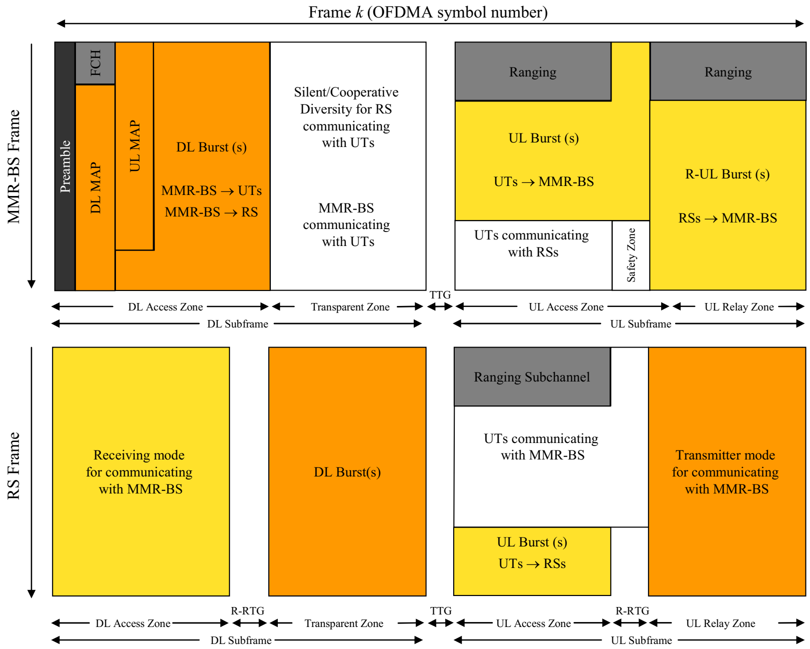


Fig. 5. Transparent mode frame structure as viewed at MMR-BS and at RS

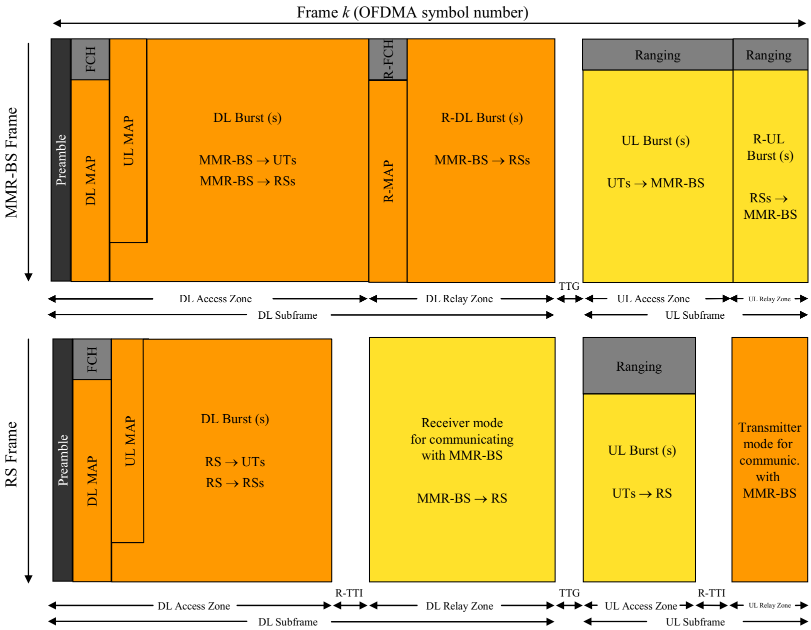


Fig. 6. Non-transparent mode frame structure (two-hop) as viewed at MMR-BS and at RS

2.6 Forwarding Schemes

Two different forwarding schemes are defined: the *tunnel-based* scheme and the *connection ID (CID)-based* scheme. As showed in Figure 7, both schemes are intended to maximize system efficiency by aggregating traffic wherever possible and requiring less signalling information, as groups of flows can be handled together. These schemes can be differentiated in terms of QoS management functionality, error handling, and overhead.

The tunnel-based scheme provides support for *explicit management tunnel connections* (bi-directional MT-CID) and *transport tunnel connections* (unidirectional T-CID), which are characterized by a unique CID, two specific endpoints, and QoS requirements. The tunnels aggregate traffic from disparate UTs on the MMR-BS-RS connection for either management or transport connections with similar QoS requirements. As depicted in Figure 7, the access station at the ingress of the tunnel adds a so-called *relay MAC header* to a packet or group of packets indicating the CID of the tunnel that the packet(s) should traverse. This header is removed when the packet arrives at the destination RS. It is worthwhile noting that *tunnel-in-tunnel* is also possible, which is essentially a recursive tunnel encapsulation, where a tunnel is constructed using a mix of individual connections and tunnels. In both centralized and distributed scheduling modes, the use of the tunnel requires some intelligence at the RSs along with the distribution of different service flows parameters to the RSs for *traffic prioritization*. In an MR network, where tunnels are established for traffic of the same service type, e.g. voice, 3 bits can be taken from the reserved bit field in the relay MAC header to implement the traffic prioritization function, especially when the scheduling is performed in a distributed manner at each RS. The tunnelling mechanism improves the efficiency of relay links application and can significantly simplify routing, QoS management and RS handover at the intermediate RSs along the relay path (Chen & De Marca, 2008).

The CID-based scheme has no such tunnels and supports only the legacy management and transport connections, as defined in the 802.16e-2005 standard. The packets are forwarded based on the CID of the destination station, which is contained in the MAC-PDU header. In centralized scheduling, the MMR-BS sends a message to the RSs describing the relay link channel characteristics, including an extra field specifying the delay associated with each packet in either the DL or UL. Thus, the RS knows in which frame each packet should be transmitted. This is necessary in order to meet the QoS requirements of each connection. In the distributed case, the RS has knowledge of the QoS requirements of each connection and can therefore make its own scheduling decisions (Genc et al., 2008).

The CID-based approach must be used in transparent relaying, whereas both schemes can be used in non-transparent mode, depending on the system configuration. The difference in terms of MAC efficiency provided by these schemes is accentuated as the number of hops increases in the system. Thus, the tunnel mode eventually leads to higher system efficiency as the number of hops in the system increases (Chen & De Marca, 2008).

2.7 Routing and Path Management

Routing and path management functions handle multi-hop paths between the MMR-BS and UT. As explained in Section 2.3, *routing* is tree-based, and algorithms for deciding which RS a particular UT should be associated with (routing/path selection) are left to vendors. The decisions are made at the MMR-BS based on information provided by the RSs. They may be based on metrics such as radio resource availability, radio link quality and traffic load at the RSs. *Path management* relates to path establishment, maintenance, and release.

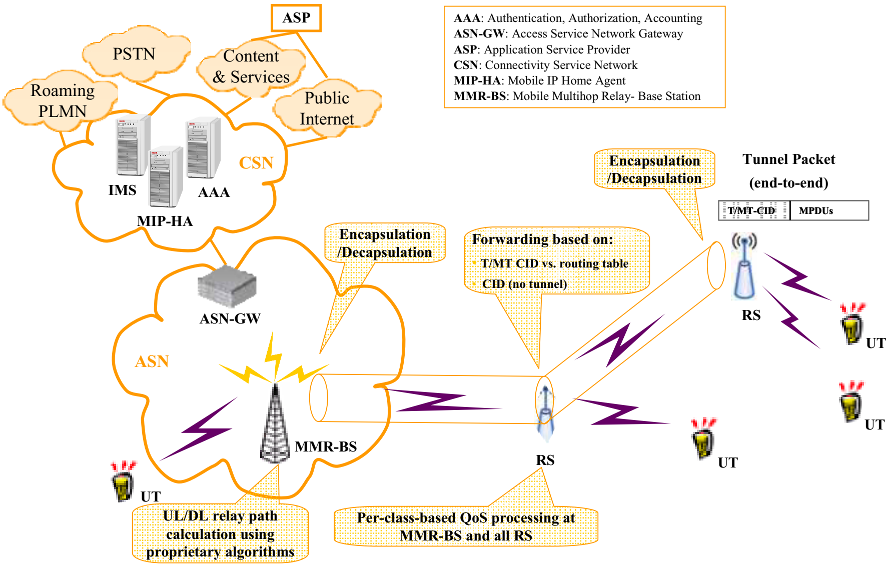


Fig. 7. WiMAX network architecture and an example of relay path management and routing (Soldani & Dixit, 2008) Reproduced by permission of © IEEE 2008

The standard defines two path management mechanisms for creating the most appropriate path: *embedded* and *explicit*. The main difference between the approaches is how signalling information to manage the path is distributed in the system (IEEE 802.16j, 2009).

In the *embedded path management* approach, a hierarchical CID allocation scheme is used in the MMR-Cell. The MMR-BS allocates CIDs to its subordinate stations such that the CIDs allocated to all subordinate RSs of any given station are a subset of the allocated CIDs for that station. In this way, there is no need of a specific routing table in each RS and very little signalling is required to update the path information.

The *explicit path management* mode uses an end-to-end signalling mechanism to distribute the routing table along the path. When a path is created, removed, or updated, the MMR-BS sends the necessary information to the RSs involved in the path. Each path is identified by a path ID, which the CIDs are bound to. This leads to smaller routing tables at the RSs and a reduction of the overhead required to update these tables. In distributed scheduling mode, to allow the RSs to make an independent decision regarding how to schedule the packet, the MMR-BS may optionally send (include) the QoS requirements associated with each CID.

The key difference of the two path management mechanisms stands in signalling overhead. The embedded scheme simplifies operation at the RS with no routing table, allows fast data forwarding, and generates less overhead and delay in route update than the explicit scheme. Thus, the embedded scheme is very suitable for managing paths in centralized scheduling. The explicit scheme should be used in distributed scheduling, as it allows the distribution of the routing table and service flow parameters to the RSs along the path.

An example of distributed path selection method for NT-RSs can be found in (Ann et al., 2008). The proposed method allows the NT-RS to select the optimal path using a path cost function with the PHY-layer loss rate, link bandwidth and hop count, as input performance metrics.

2.8 Initial Ranging and Network Entry

The network entry procedure for the UT remains unchanged. Some additional functions are introduced in the MMR-BS and RSs, in order to determine which node should be the access node for the UT. The initial ranging process depends on the scheduling and relay modes. In transparent relaying, the RSs monitor the ranging channel in the UL access zone (see Figure 5) and forward the ranging codes they receive to the MMR-BS. The MMR-BS determines the most appropriate path (i.e., direct or via an RS) from the messages with the same ranging code received from other RSs and sends a response directly, or indirectly via the RS, to the UT, depending on the path chosen. In non-transparent relaying, the UT selects the MMR-BS or NT-RS with the strongest preamble. The RS communicates with the MMR-BS only to ensure that the UT is "permitted network entry". The information exchanged with the MMR-BS depends on the scheduling mode.

The initial ranging process for RSs is similar to that for UTs in non-transparent mode relay. The MMR-BS (or NT-RS) can determine whether a node performing ranging is an RS or a UT based on the ranging code it receives, since specific set of codes are reserved for RSs. (In this way, transparent mode RSs can easily ignore ranging performed by other RSs, and RSs performing ranging can be also prioritized with respect to UTs.) In the RS network entry procedure, after the initial ranging, authentication, and registration processes, the MMR-BS may request the RS to provide the MMR-BS the signal strength of each of its neighbouring RSs. The MMR-BS can then determine the most suitable access station with which to associate the RS based, e.g., on traffic load, signal strength, and other relevant parameters. The final stage of network entry is then the configuration of the RS parameters, including its operation (e.g., transparent or non transparent) and scheduling modes (Genc et al., 2008).

2.9 Radio Resource Management

As already pointed out in the previous sections, bandwidth requests and allocations can be either distributed or centralized.

In *distributed scheduling*, see Figure 8 a), each MMR-BS and RS individually determines the bandwidth allocations on the links they control (i.e., downlinks to and uplinks from its immediate downstream stations) and create their own MAPs reflecting these decisions. Along a relay path, the MMR-BS and RSs must guarantee the performance of the following service flows: unsolicited grant services (UGS), real-time polling services (rtPS) and extended real-time variable rate (ERT-VR) services. Scheduling comprises bandwidth requests (including contention based CDMA bandwidth requests) from the immediate downstream stations, and grants and polling from the corresponding upstream stations.

In *centralized resource partitioning*, see Figure 8 b), the MMR-BS determines the bandwidth allocations for all links (access & relay) in its MMR-cell. Hence, before a station can transmit a packet to the MMR-BS, the bandwidth request from that station must first reach the MMR-BS, which in turn creates bandwidth allocations on the links along the path from the RS to the MMR-BS. The centralized scheduling encompasses the following procedures: contention-based CDMA bandwidth requests for relaying, continuous bandwidth allocation mechanism, dedicated uplink channel allocation, dedicated channel between MMR-BS and RS, and service flow based dedicated resource update.

An example of resource scheduling with directional antennas for multi-hop relay networks in a Manhattan-like environment can be found in (Chen & De Marca, 2008). Both MMR-BS and RSs were equipped with directional antennas. By taking advantage of the effect of high degree of shadowing, the proposed methods could increase the system throughput up to 12 times, as compared to the system with omni-directional antennas.

The choice of a centralized or distributed system has profound ramifications throughout the entire network. For larger systems, in which there are more than two hops to the MMR-BSs, the benefits of distributed systems are most probably larger. However, many deployments are likely to be smaller topologies in which most communications will be via one or two hops; in these cases the centralized mode of operation seems preferable as it results in lower-complexity RSs, ultimately leading to lower overall costs (Genc et al., 2008).

Network coverage and cell throughput for transparent relaying system and non-transparent relaying system with centralized and distributed scheduling mode were compared in (Zeng & Zhu, 2008). The basic IEEE 802.16e system (with only BS, i.e. 1 hop system) was used as a comparison base line. Different RS configurations (1 or 3 RSs per sector) were considered. Performance results showed that the largest network coverage and highest system capacity were both achieved by the non-transparent relay system with 3 RSs per sector with distributed scheduling.

In IEEE 802.16j, the MMR-BS controls the *handover* (HO) process – centralized multi-hop relay network (MR network) control – and an RS relays HO associated messages between a UT and the MMR-BS, independent of the scheduling mode. After HO, the routing and QoS information along the old and new path is updated as described in Section 2.7.

The RS HO process hands off all the UTs attached to itself, along with the RS, to a target MMR-BS (see Figure 3, in the M-RS use case). It supports the same procedures as described for an UT HO process in the 802.16e with the following additional functionalities:

- *Access station selection*, which enables the target MMR-BS to indicate access station reselection.
- *RS operational parameters configuration*, which enables the target MMR-BS to reconfigure RS operational parameters.
- *Tunnel connection re-establishment*, which enables the target MMR-BS to re-establish tunnel connections for an RS.
- *UT CID mapping* (only for CID-based forwarding). This stage is used for the target MMR-BS to inform the RS, which is performing the handover, about the mapping of new CIDs and old CIDs of its subordinate UTs. The RS uses this information to swap the new CIDs with the old CIDs before forwarding the MAC PDUs to the subordinate UTs after the handover.

Quality measurements for each active UT that can be used form making an HO are: *received signal strength indicator* (RSSI), *carrier interference noise ratio* (CINR) and *timing adjust* (TA). The HO is executed after the signal strength from neighbour cell exceeds the signal strength of the current cell for a certain period of time (IEEE 802.16j, 2009).

A simulation study on the performance of HO techniques for IEEE 802.16j MR networks can be found in (Sultan et al., 2008). Simulation results, at the considered UT speeds, showed that Macro Diversity HO (MDHO) performed better than Fast Best Station Switching (FBSS) and Hard Handover (HHO). Also, the MDHO gain decreased as UT speed increased. FBSS performed slightly better than HHO. However, the overall average DL CINR decreased for the three handover techniques, as the UT speed increased.

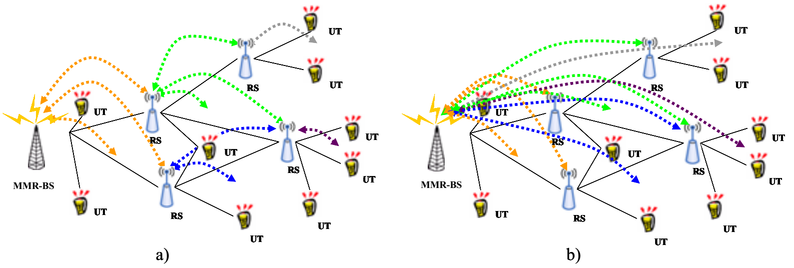


Fig. 8. Bandwidth request / allocation: a) distributed scheduling; b) centralized scheduling

MR networks support a *power control* algorithm for the uplink channels from RSs and UTs with both initial calibration and periodic adjustment procedure without loss of data. Power control of the RS downlink channels is supported as well. In the case of RSs operating in centralized scheduling mode, the UL power control algorithm is located in the MMR-BS and the MMR-BS controls the transmission power of all uplink channels served by the MMR-BS and its subordinate RSs. In distributed scheduling, an UL power control algorithm is located in both the MMR-BS and RSs to control the uplink channels they serve (see Figure 8).

For more information on the procedures described above the reader is referred to the Multi-hop Relay Specification (IEEE 802.16j, 2009).

Admission control (AC), caching of subscriber profiles and encryption keys, AAA client functionality, establishment and management of mobility tunnel with base stations, QoS and policy enforcement, mobile IP foreign agent (FA) functionality for mobile IP (MIP), and routing to the selected connectivity service network (CSN) are a part of the functionalities of the access service network gateway (ASN-GW). Load Sharing or balancing can be seen as an integral part of the proprietary algorithms for relay path management and handover control (Navaie et al., 2006).

2.10 Cooperative Relaying

In an MMR-Cell, cooperative relaying can be achieved using either an MMR-BS and one or more RSs or multiple RSs transmitting in cooperation. These RSs are either transparent RSs or non-transparent RSs transmitting the same frame start preamble, FCH and MAPs, or non-transparent using a common permutation zone during the transmission. Diversity gains and pilot collision mitigation are achieved by sending appropriately coded signals (correlated signals) to subordinate stations (e.g., S1, S2 and S3, in Figure 1) across different MMR-BS and RS transmit antennas.

In 802.16j, three modes of operation for cooperative relaying are possible: *cooperative source diversity*, *cooperative transmit diversity*, and *cooperative hybrid diversity*, which is a combination of the previous cooperative relaying schemes (IEEE 802.16j, 2009).

In *cooperative source diversity* (CSD), transmitting antennas simultaneously transmit the same signal using the same time-frequency resource. In practice, the transmission timing differences from multiple signal sources need to be within a cycling prefix (CP) period. An example of CSD is illustrated in Figure 9. In the simulation, the signals (2hop SISO and CSD) arriving at the UT were of the same power, and the signal noise ratio (SNR) on the relay link (MMR-BS – RS) was 30 dB. The channel model used in the simulation was SUI-4 model and the signal was transmitted using QPSK modulation with 1/2 convolution code.

In *cooperative transmit diversity* (CTD), space-time block coded (STBC) signals are transmitted across the transmitting antennas using the same time-frequency resource. The transmit structure is identical to the cooperative source diversity. However, in this diversity scheme, the main idea is that both the source and the relays transmit a part of the codeword symbols. Diversity is achieved based on the fact that a portion of the code word symbol arrives at the destination through a different and independent fading channel. An example of CTD is depicted in Figure 10. (The simulation assumptions were as for Figure 9.)
Cooperative hybrid diversity (CHD) is identical to cooperative transmit diversity except that at least one value for virtual antenna assignment is assigned to multiple physical antennas. An example of CHD is showed in Figure 11. (The simulation assumptions were as for Figure 9.)

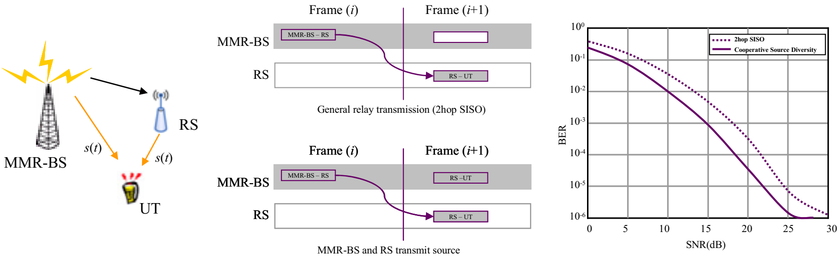


Fig. 9. Example of Cooperative Source Diversity (CSD): the received signals from different sources (MMR-BS and RS) is exactly the same

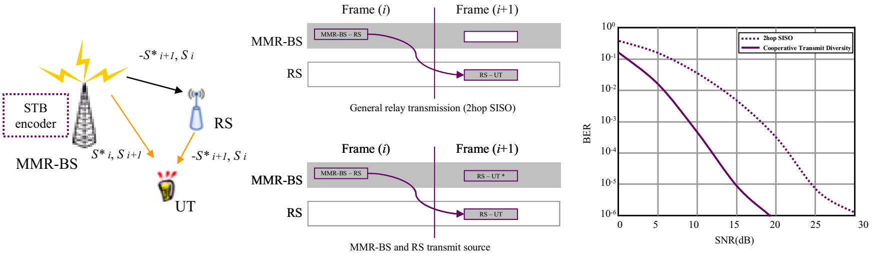


Fig. 10. Example of Cooperative Transmit Diversity (CTD) with full encoding in the MMR-BS (STB encoder): the received signal from different sources (MMR-BS and RS) is different

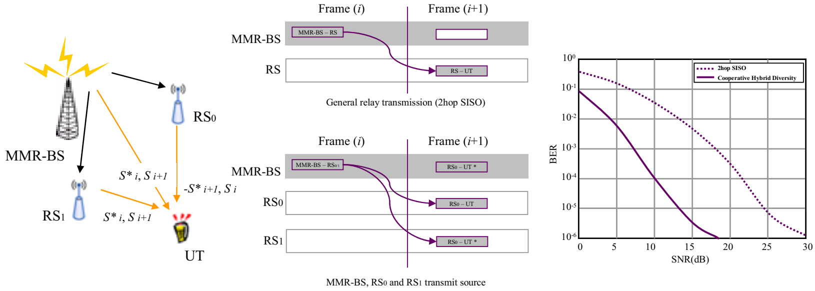


Fig. 11. Example of Cooperative Hybrid Diversity (CHD): multiple signal sources (MMR-BS and RS_1) can transmit the same STBC encoded signal to implement an Mx1 STBC scheme

3. Impact on Network Planning

The network planning process consists of the following phases: *preplanning*, *planning*, *detailed planning*, *acceptance*, and *optimization*.

In the preplanning phase, criteria for deploying wireless relays are agreed with customers. This encompasses the definition of traffic, services, network topology and deployment scenarios; coverage, throughput and system capacity requirements, relay type and usage model are discussed and agreed as well.

In the dimensioning phase, coverage range and an estimate of the number of MMR-cells based on the average SINR distribution in the cell is calculated. The noise limited maximum allowed path loss is a combination of link budgets calculated separately for RS to MMR-BS link, RS to UT link and MMR-BS to UT link, e.g., link 1, 2 and 3 in Figure 1. An example of link-budget for DL is illustrated in Figure 12. This assumes a sector antenna gain of 15 dBi and a maximum transmission power of 42.3 dBm at the MMR-BS antenna port, which yields an effective isotropic radiated power (EIRP) of 57.3 dBm.

The detailed network planning makes use of a tool for combined coverage and capacity computation. The tool usually supports traffic models, propagation and RRM models, and all necessary radio parameters for the MMR Cells.

In the network configuration and optimization phases, the additional MMR parameters are set and fine tuned based on service and network performance measurements. The latter activities depend heavily on the self-organizing capabilities of the network.

The following sections present some key indicators for link and system level performance assessment and an example of deployment cost analysis in different traffic scenarios and propagation conditions. For more information on evaluation methodologies and models, dimensioning and capacity evaluation for multi-hop WiMAX networks, and methods for cost analysis, the reader may consult the following relevant references (Puthenkulam et al., 2006; Hart et al., 2007; Hoymann et al., 2007; and Moberg et al., 2007).

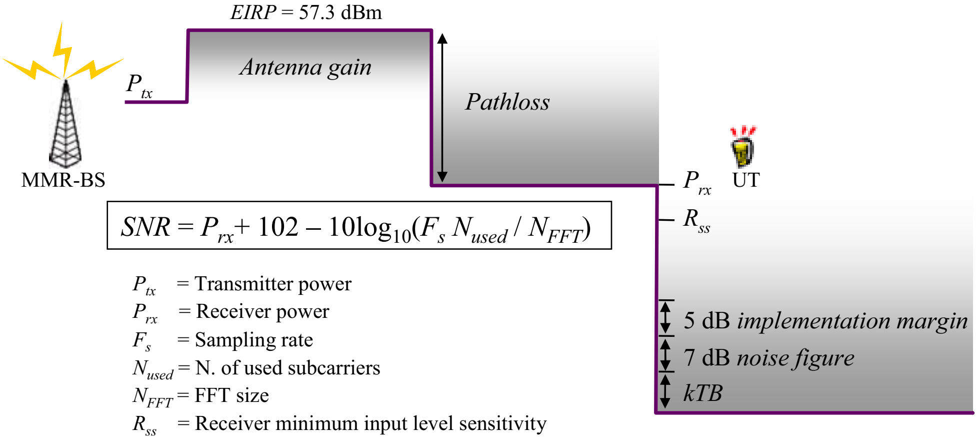


Fig. 12. Example of DL link budget

3.1 Key performance metrics

In order to obtain a viable metric for performance assessment, *coverage* (allowable outage probability) must be coupled with *capacity* (# of admissible UTs at a given min bit-rate).

This is due to the fact that, although a user may be covered for a certain percentage area (e.g. 99%) for a given service, the resources (time, frequency, power) are to be shared among UTs in a sector/MMR-BS. It can be expected that the UT average throughput may be reduced by a factor of *N*, when there are *N* active users compared to a single user rate (assuming no multi-user diversity gain and resources equally shared). On the other hand, the total cell throughput could be adversely affected if users having poor channel quality were provided more resources for better QoE. Thus, there is a trade-off between coverage and capacity, and any measurement of capacity should be provided with the associated coverage and quality of end user experience.

The combined index for *coverage & capacity* (CC) assessment is given by the number *N* of simultaneous UTs per cell (e.g. MMR-cell or legacy cell) that can be supported achieving a target information throughput R_{min} with specified coverage reliability.

The *packet call throughput* (PCT) is given by

$$PCT = \frac{1}{K}\sum_{k=1}^{K}\frac{BitsPacketCall(k)}{t_{end}(k) - t_{arrival}(k)} \tag{1}$$

where *K* is the total number of packet calls.

The *system data throughput* of a MMR-BS is defined as the number of information bits per second that a site can successfully deliver or receive using scheduling algorithms.

The corresponding *effective system spectral efficiency* (ESSE) is calculated as:

$$ESSE = \frac{SystemDataThroughput}{TotalSiteBWallocted} \tag{2}$$

In an MR network, a key performance indicator for quantifying the end-to-end quality of an *M*–hop routing path in terms of throughput is given by:

$$EtoET = \left(\sum_{m=1}^{M}\frac{1}{LinkThroughputHop(m)}\right)^{-1} \tag{3}$$

where *LinkThroughputHop*(*m*) is the throughput per link over the *m*–hop.

Another end-to-end PHY abstraction metric is given by the harmonic mean of the capacities (*C*) over individual wireless links, as a function of the SINR:

$$C = \left(\sum_{m=1}^{M}\frac{1}{C_m}\right)^{-1} = \left(\sum_{m=1}^{M}\frac{1}{\log_2(1+SINR_{eff,m})}\right)^{-1} \tag{4}$$

where

$$SINR_{eff} = 2^{C} - 1 \tag{5}$$

is the effective SINR for the multi-hop route; C the effective end-to-end capacity for the multi-hope route; C_m the effective capacity over hop m, $m = 1, \ldots, M$; $SINR_{eff,m}$ the effective SINR over hop m; and M the number of hops over the established route between MMR-BS and UT. (The above formula is valid in the case of orthogonal channels (e.g. slots) for inter-relay communication. This relay capacity model applies only for small M (1-3). For large M, the same resource (e.g. slot) can be reused in the relays farther a part, and, hence, this needs to be accounted for in the capacity calculation.)

An example of multi-hop wireless networks capacity is illustrated in Figure 13. The capacity is related to a one-dimensional network, where an MMR-BS and UT communicates through multiple intermediate relay stations located equidistantly, as depicted in the figure.

In the simulations, the channel model included path loss and lognormal shadowing. No spatial reuse, no interference, no synchronization error were considered. Outage was defined as the event in which the achieved end-to-end data rate felled below the target data rate. In Figure 13, the Spectral Efficiency, i.e. C_m, denotes the maximum achievable rate per Hz on hop–m, and d is the inter-relay stations distance.

As shown in Figure 13, the deployment of relay stations improves the spectral efficiency. Also, the simulation results demonstrate that *a MR network with maximum 2-3 hops provides the best network performance*. More hops in the MR network would not improve the situation.

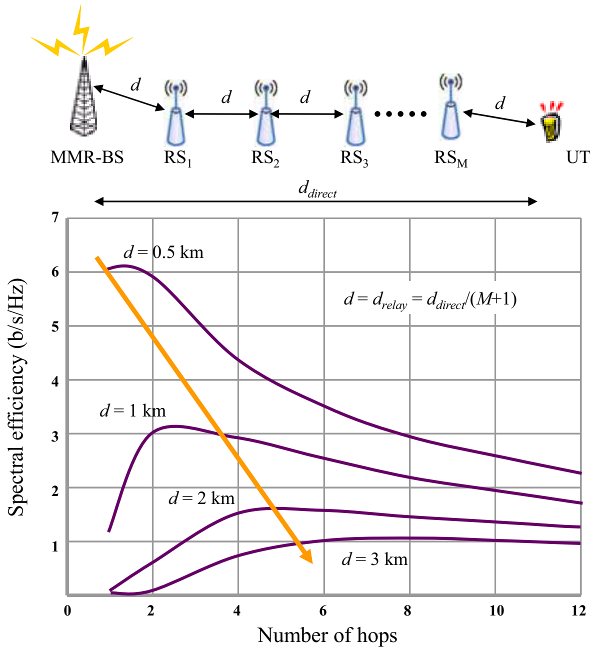


Fig. 13. Example of example of capacity of multi-hop wireless networks

3.2 Example of Deployment Cost Analysis

This section discusses the relative CAPEX and OPEX (total cost of ownership) of an MMR approach versus a conventional WiMAX deployment at 3.5 GHz, to meet the same coverage and capacity requirements. This is studied for the urban environment with heavy traffic, and for the urban, suburban and rural environments with light traffic.

The cell structures are dimensioned for a minimal SINR of 3.7dB at the edge. The cell split for conventional WiMAX is based on capacity demand, whereas the MMR system is dimensioned for heavy load. The channel bandwidth is 30, 20 and 10 MHz for conventional WiMAX, MMR-BS and RS, respectively. The spectral efficiency is 5 b/s/Hz for conventional WiMAX and MMR-BS, and 2 b/s/Hz for the RS.

In the analyzed deployment scenarios, the MMR-BS to RS ratio is 1:56, 1:33, and 1:12. CAPEX consists of site acquisition and construction costs per cell, wired backhaul costs and station costs (e.g., hardware, software).

Backhauling and station costs for a MMR-BS are assumed to be higher than for a conventional BS. Civil work expenditures are supposed to be the same for base stations and much lower for deploying a RS, which is also considered much cheaper than any BS.

OPEX comprises all administrative costs for backhaul, access points, and network. This expenditure is considered to be the same for the base stations and much lower for a RS.

A sample of the analyzed networks and the resulting deployment costs normalized and relative to the MMR CAPEX value with RS to MMR-BS ratio 56 are showed in Figure 14.

In the conventional WiMAX deployment, CAPEX is a significant cost with respect to OPEX. In the MMR approach, CAPEX decreases if the MMR-BS to RS ratio increases and it is considerably less than OPEX in the capacity limited scenario (heavy traffic).

Further, the total costs of the MMR approach are always less than those for the conventional WiMAX, and savings in expenditure from capacity improvement in heavy traffic scenarios, e.g., in urban environment, is significantly higher than those from range extension.

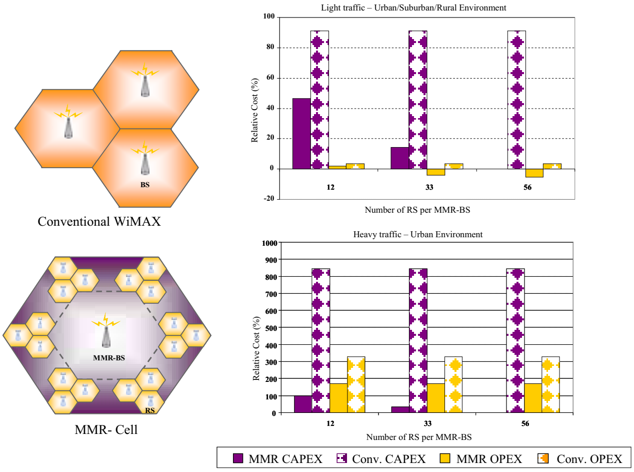


Fig. 14. Results of deployment cost analysis normalized and relative to MMR CAPEX with RS to MMR-BS ratio 56, for urban environment with heavy traffic and for urban, suburban, and rural environment with light-traffic density (Soldani & Dixit, 2008) Reproduced by permission of © IEEE 2008

4. Conclusions and Future Work

Relay technology to extend coverage and range has been receiving a lot of attention due to its simplicity, flexibility, speed of deployment, and cost effectiveness. This is particularly so in scenarios where first responders need to communicate in the disaster and emergency situations. Relaying also offers a cost-effective way to deliver broadband data to the rural communities where the distances may be large and population density sparse.

Some key advantages of relays are: (a) they do not require backhauling resulting in lower CAPEX and OPEX, (b) flexibility in locating relay stations, (c) when located in a cell, relays can enlarge the coverage area and/or increase the capacity at cell border, (d) decrease transmit power and interference, and (e) mobile relays enable fast network rollout, indoor-outdoor service, and macro diversity by way of cooperative relaying.

However, relaying is not without drawbacks, namely increased use of radio resources in in-band relaying (time domain) and need for multiple transceivers in out-of-band relaying (frequency domain). Relays also introduce additional delays.

Overall, the substantial amount of choice, coupled with a general lack of understanding of the impact of the different design decisions, makes the system design difficult, and much research remains to be carried out, in order to understand how 802.16j systems perform under different configurations and at what cost compared to 802.16e systems.

As a matter of facts, the MR network architecture is currently a relatively new design and introduces many complexities within the already challenging environment of radio access networks with mobility support. Many of the issues remain still unsolved, and more work is necessary to really understand the cost/benefit trade-offs that arise in IEEE 802.16j systems. Also, resource allocation in MR networks requires the design of novel scheduling algorithms with QoS differentiation for improving QoE, e.g., in terms of reliability, fairness, and latency. In this respect, there are many aspects that require further investigation; these include the approaches to realize distributed systems, ways to maximize spatial reuse, and dynamic mechanisms to control the amount of resources allocated to each of the zones in both the transparent and non-transparent relaying modes.

Fast-forwarding into the future, the relay stations will not be confined to just decode and forward, but will also support additional capabilities, such as being able to connect to more than one RS both in the downstream and upstream direction, support routing, multicasting, and dynamic meshing. (These are a part of the advanced relay station (ARS) characteristics defined in IEEE 802.16m (IEEE 802.16m, 2008). The ARS supports procedures to maintain relay paths, mechanisms for self configuration and self optimization and multi-carrier capabilities.) When such evolution will have occurred, the relay network beyond the MMR-BS will mimic a mesh topology and the MMR-BS will simply function as a gateway to the Internet core while connecting to the nearest relay nodes in the downstream direction. Mesh and self organizing capabilities will enable connection reliability, traffic load balancing, and proactive topology management.

Ultimately, it remains to be seen how wireless relays will compete against other important solutions, such as femto base stations, and conventional broadband networks that will use lower carrier frequencies and optimized backhauling, for example, using digital subscriber lines (xDSLs), passive optical networks (xPONs), and broadband meshed microwave links.

Overall, wireless relays offer great advantages and will continue to receive a lot of attention both in the research and business communities.

5. References

Andrews, J. G.; Ghosh, A. & Muhamed, R. (2007). *Fundamental of WiMAX – Understanding Broadband Wireless Networking*, Prentice Hall, ISBN: 0132225522, USA

Ann, S.; Lee, G. K. & Kim, S. H. (2008). A Path Selection Method in IEEE 802.16j Mobile Multi-hop Relay Networks, *Proceedings of the 2nd International Conference on Sensor Technologies and Applications*, pp. 808-812, ISBN: 978-0-7695-3330-8, Cap Esterel, Aug. 2008, IEEE

Chen, K. C. & De Marca J. R. B. (2008). *Mobile WiMAX*, Wiley & Sons and IEEE, ISBN: 978-0-470-51941-7, UK.

Genc, V.; Murphy, S. & Murphy, J. (2008). Performance analysis of transparent relays in 802.16j MMR networks, *Proceedings of the 6th international Symposium on Modeling and Optimization in Mobile*, Ad Hoc, and Wireless Networks, pp. 273-281, ISBN: 978-963-9799-18-9, Berlin, Apr. 2008, IEEE

Genc, V.; Murphy, S.; Yang, Y. & Murphy, J. (2008). IEEE 802.16j relay-based wireless access networks: an overview, *IEEE Wireless Communications Magazine*, Vol., N. 15, (October 2008), pp. 56-63

Hart, M. et al. (2007). Multi-hop Relay System Evaluation Methodology (Channel Model and Performance Metric), *Contribution to the IEEE 802.16 Broadband Wireless Access Working Group*, IEEE 80216j-06/013r3, http://www.ieee802.org/16/relay/

Hoymann, C.; Dittrich, M. & Goebbels, S. (2007). Dimensioning and capacity evaluation of cellular multihop WiMAX networks, *Proceedings of the Mobile WiMAX Symposium*, pp.150-157, ISBN: 1-4244-0957-8, Orlando, Mar. 2007, IEEE

IEEE 802.16j Draft Standard P802.16j/D9 (delta), *Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Multihop Relay Specification*, Feb. 2009, IEEE, http://www.ieee802.org/16/published.html

IEEE 802.16m Draft Standard 802.16m-08/003r6, *IEEE 802.16m System Description Document*, Dec. 2008, IEEE, http://www.ieee802.org/16/published.html

Moberg, P.; Skillermark, P.; Johansson, N. & Furuskar A. (2007). Performance and cost evaluation of fixed relay nodes in future wide area cellular networks, *Proceedings of the 18th International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 1-5, ISBN: 978-1-4244-1144-3, Athens, Sept. 2007, IEEE

Navaie, K.; Liu, Y.; Abaii, M.; Florea, A.; Yanikomeroglu, H. & Tafazolli, R. (2006). Routing mechanisms for multi-hop cellular communications in the WINNER air interface, *Proceedings of the 64th Vehicular Technology Conference*, pp. 1-4, Montreal, Sept. 2006, IEEE

Pabst, R.; Walke, B. H.; Schultz, D. C.; Herhold, P.; Yanikomeroglu, H.; Mukherjee, S.; Viswanathan, H.; Lott, M.; Zirwas, W.; Dohler, M.; Aghvami, H.; Falconer, D. D. & Fettweis, G. P. (2004). Relay-based deployment concepts for wireless and mobile broadband radio, *IEEE Communications Magazine*, Vol., N. 42, (Sept 2004), pp. 80-89

Puthenkulam, J. et al. (2006). Tutorial on 802.16 Mobile Multihop Relay, *Contribution to the IEEE 802.16 Broadband Wireless Access Working Group*, 802 Plenary, Mar. 2006, IEEE 802.16mmr-06/006, http://www.ieee802.org/16/sg/mmr/

Soldani, D. & Dixit, S. (2008). Wireless relays for broadband access, *IEEE Communications Magazine*, Vol. 46, March 2008, pp. 58-68, ISSN: 0163-6804

Sultan, J.; Ismail, M. & Misran, N. (2008). Downlink performance of handover techniques for IEEE 802.16j multi-hop relay networks, *Proceedings of the 4th IEEE/IFIP International Conference on Internet*, pp. 1-4, ISBN: 978-1-4244-2282-1, Tashkent, Sept. 2008, IEEE/IFIP

Van Der Meulen, E. C. (1971), Three-terminal communication channels, *Advances in Applied Probability, Applied Probability Trust*, Vol. 3, N. 1, spring 1971, pp. 120-154

WINNER and WINNER+, http://projects.celtic-initiative.org/winner+/index.html

Zeng, H. & Zhu C. (2008). System-level modelling and performance evaluation of multi-hop 802.16j systems, *Proceedings of the International Wireless Communications and Mobile Computing Conference*, pp. 354-359, ISBN: 978-1-4244-2201-2, Crete Island, Aug. 2008, IEEE

WIMAX New Developments

Edited by Upena D Dalal and Y P Kosta

ISBN 978-953-7619-53-4
Hard cover, 442 pages
Publisher InTech

Published in print edition December, 2009

WiMAX (Worldwide Interoperability for Microwave Access) is a wireless broadband access network named by industry group called the WiMAX forum formed in June 2001. It is Wireless MAN with IEEE 802.16 family standards. Loosely, WiMAX is a standardized wireless version of Ethernet that enables the last mile, intended primarily as an alternative to wire technologies (such as Cable Modems, DSL and T1/E1 links) to provide broadband access to customer premises. Mission of the WiMAX forum is to promote and certify compatibility and interoperability of broadband wireless products. This book touches most of the above issues in form of 22 individuals' papers containing research work in WiMAX domain in particular. WiMAX has two important standards/usage models: a fixed usage model IEEE 802.16-2004 for Fixed Wireless Broadband Access (FWBA) and a portable usage model IEEE 802.16e-2005, which is mainly concentrated on Mobile Wireless Broadband Access (MWBA). Both are released as standards and amendments are available in form of drafts. Higher data rate transmissions (@ 100 Mbps) are achieved in IEEE 802.16-2004 WiMAX through LOS communications which incorporate a stationary transmitter and receiver but IEEE 802.16e supporting NLOS communication is much complicated and little less bit rate is achieved. 2-11 GHz licensed band is the range of frequencies with TDD and FDD supports. The book will provide a wide horizon to visualize the WiMAX technology and its developments leading towards 4G systems. It will provide a good platform to the researchers with clues to the innovative ideas in WiMAX domain. I wish all the best to the authors and readers of this book in their successful research of WiMAX technology.

David Soldani (2009). Multi-Hop Relay Networks, WIMAX New Developments, Upena D Dalal and Y P Kosta (Ed.), ISBN: 978-953-7619-53-4, InTech, Available from: http://www.intechopen.com/books/wimax-new-developments/multi-hop-relay-networks

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821