High Efficient Mobile WiMAX with MIMO and Multihop Relay

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***Abstract*— MIMO and relay technology is currently being promoted within the IEEE to enhance performance of broadband wireless standards such as WiMAX. However, due to licensed spectrum, it is necessary to implement highly efficient radio resource management. For optimal system design, it is beneficial to achieve higher system data throughput with fewer radio resources employed. This paper presents a comprehensive study of MIMO mobile WiMAX with multihop relay technology for high efficient multiuser transmission. A directional distributed relaying architecture is introduced in order to leverage link-level and system-level capacity. Practical applications are also demonstrated for an example urban environment.**

***Index Terms*—WiMAX, MIMO, multihop relay, spectral efficiency, radio resource sharing, interference, ray tracing, subchannel allocation**

I. INTRODUCTION

WiMAX (World Interoperability for Microwave Access) continuous its development to achieve high capacity services with large cell coverage. Considerable interest currently exists in the exploitation of mobile WiMAX; this is mainly a result of lower infrastructure costs and higher data transfer rates compared to current 3G. The mobile WiMAX air interface adopts a technology known as Scalable Orthogonal Frequency Division Multiple Access (SOFDMA) to achieve enhanced multiuser performance in non-line-of-sight (NLoS) multipath environments. The SOFDMA provides additional resource allocation flexibility. 802.16e [1] transmits using a group of sub-channels, and these can be adaptively optimized to maximize performance. For cellular Mobile Wireless Access (MWA) applications, power and spectral efficiency is key to a successful deployment. The system performance of the mobile WiMAX based on currently published IEEE 802.16 standard has been widely evaluated in [2][3][4].

In a practical urban environment, the radio channel linking a Base Station (BS) to a Mobile Station (MS) is more unpredictable. Multiple-Input Multiple-Output (MIMO) systems have ability to exploit such NLoS channels, and hence increase spectral efficiency [5]. The inclusion of MIMO techniques alongside flexible sub-channelization and Adaptive Modulation and Coding (AMC) enables mobile WiMAX technology to improve system coverage and capacity. If systems are correctly configured, these benefits will result in power and spectrum efficient terminals.

Radio relays can also address many of challenges faced in mobile WiMAX deployments. Relay technology is being promoted in the IEEE 802.16j multi-hop project [6]. It is well-known that multihop relay can be deployed to enhance coverage and capacity [7]. Relays can be used to fill 'holes' in coverage map and thus enhance coverage and data rate at (or even beyond) the BS cell-edge. Multi-hop can be formed between the BS and a distant MS using a number of intermediate Relay Stations (RS). Fundamentally, if no constraints on radio resource, it is relatively simple to implement relay transmission. The simplest approach is to assign a unique radio resource to each link, in order to avoid interference between the links. However, using this approach, the multi-hop users will rapidly drain the system valuable radio resource. This results in poor radio resource efficiency, and hence low system capacity [8]. Given its commercial applications, relaying in the context of WiMAX must conserve radio spectrum and emphasize the need for high spectral efficiency.

This paper focuses on the above challenges, and emphasizes MIMO enabled mobile WiMAX with multihop relay. Efficiency of relay transmission is studied, and then a directional distributed relay topology is proposed. Within this method, interferences are controlled by spatial separation and dynamic channel allocation. This leads to a high data throughput with reduced demands on radio resources. This effective MIMO WiMAX deployment with high efficient relays presents high potential to achieve truly cost-effective and ubiquitous manner. The paper also provides a numerical analysis of capacity and coverage expected for, e.g., urban deployments.

Based on "Study of radio resource sharing for future mobile WiMAX with relay", by Yong Sun, Yan Q. Bian, Andrew R. Nix and Paul Strauch; "Performance Evaluation of Mobile WiMAX with MIMO and Relay Extensions", by Yan Q. Bian, Yong Sun, Andrew R. Nix and Paul Strauch; which appeared in the Proceedings of IEEE mobile WiMAX'07 and IEEE WCNC'07, on March 2007 © 2007 IEEE.

The remainder of this paper is organized as follows. Section II presents mobile WiMAX system performance. Section III discusses the relay efficiency in presence of MIMO correlation, interference and multiuser transmission. In section IV, directional distributed relay architecture is introduced. Then, case studies for a practical urban environment are demonstrated in section V. Finally, the paper is concluded in section VI.

II. ENHANCEMENT WITH MIMO LINK ADAPTATION

It is well-understood that spectral efficiency is the key to good system design. Without loss of generality, the normalized effective system efficiency can be written as

$$\zeta_{sys} = \frac{\textit{system data throughput}}{\textit{total radio resouces allocated}} \quad (1)$$

Two clear approaches emerge to improve the effective efficiency. Firstly the system data throughput can be improved by using methods such as high level AMC and MIMO. Secondly, improvements can be made to reduce the amount of radio resource required in the system. This section focuses on the system performance enhancements with MIMO Link Adaptation (LA) in combination with OFDMA. Using a statistical approach, it is possible to demonstrate the potential benefits of a relay enhanced mobile WiMAX deployment.

A. MIMO-OFDMA PHY model

For a MIMO OFDMA transmission, space-time coding (e.g., Space Time Block Coding (STBC) or Spatial Multiplexing (SM)) is performed before OFDMA symbol mapping. Antenna separations at the BS and MSs were set to 10 and 0.5 wavelengths respectively. Following the WirelessMAN-OFDMA PHY air-interface [1], three sectors are employed at BS and a frequency reuse factor of one is used between the sectors. A number of initial operational profiles have been defined within the WiMAX Forum Technical Working Group [9]. This paper focuses on the exploitation of 512-FFT downlink (DL) PUSC (Partial Usage of Sub-Channels) OFDMA Time Division Duplex (TDD) profile operating with a 5MHz channel bandwidth. For the 512-FFT DL PUSC OFDMA, a total of 15 sub-channels are mapped (after renumbering and permuting) in one OFDMA symbol. Each sector has access to one third of the total number of subcarriers. There are 3 groups (one per sector), with 5 subchannels in each group, and each sub-channel comprises 24 data subcarriers and 4 pilot subcarriers. Since the subchannel is the smallest allocation unit for a user on the DL, this profile can support up to 15 users per slot. A CP length of 1/8th of the OFDMA symbol period is defined to ensure that up to 11.2μs of delay spread can be tolerated [10]. A detailed list of the PHY parameters can be found in [4].

Since mobile terminals are allowed to move freely at street level in the MWA scenario, local surrounding buildings result in deep shadowing and severe multipath. To represent this situation, WINNER channel model [11] is used for the above PHY simulator. The WINNER model builds on the well known 3GPP2 spatial channel model (SCM) [12], which defines three basic environment scenarios, namely urban micro (cell radius: r ≤ 0.5km), urban macro and sub-urban macro (r ≈ 1.5km).

B. Throughputs and coverages for WiMAX system

It is well-known that MIMO promises transmission efficiency enhancement which achieves one aspect of efficiency enhancement. IEEE 802.16e standard supports a full range of smart antenna technologies. Together with modulation and coding, the link throughput for each user can be calculated from Packet Error Rate (PER) by

$$C_{link} = \frac{N_D N_b R_{FEC} R_{STC}}{T_s} \times (1 - PER) \quad (2)$$

where, T_s, N_D, N_b, R_{FEC} and R_{STC} denote the OFDMA symbol duration, the number of assigned data subcarriers, the number of bits per subcarrier, FEC coding rate, and space-time coding rate for the user. Equation (2) implies that, a combination of MIMO, AMC and flexible sub-channelization is required to maximize the link performance.

Figure 1 illustrates STBC and SM performance for a 2x2 MIMO-OFDMA system, in an urban macro cell. Although the SM combined with higher order modulation schemes can increase peak throughput of a link, such schemes require extremely high SNR levels, thus difficult to exploit (especially near the cell edge). In contrast, the STBC exploits the MIMO structure to offer high levels of spatial diversity. Results show that, at an SNR of 32dB, all modes can be used with STBC, however SM can only use the ½ rate QPSK scheme. It implies that, a suitable MIMO orientated LA strategy is critical to fully exploit the wide range of MIMO systems and channel conditions. To generate capacity improvements, the STBC should combine with AMC together.

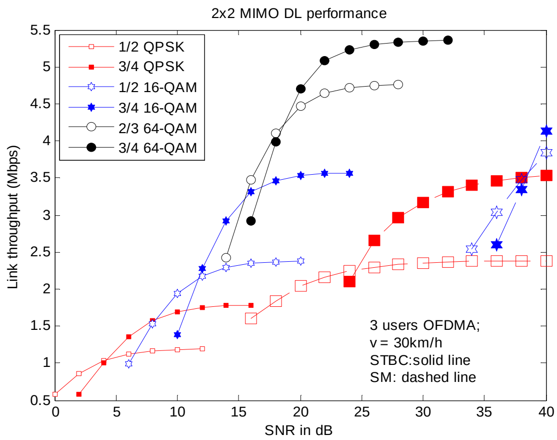

Figure 1 Comparison of STBC and SM for urban macro environment

To evaluate the area coverage and system throughput, 300 MSs were uniformly deployed within an urban macro and an urban micro cellular area. An effective isotropic radiated power (EIRP) of 57.3dBm is applied (assuming 15dBi sector antenna gain) [2]. Each BS-MS link undergoes fast fading, with statistics based on 1000 channel snap-shots. Fair scheduling is assumed such that all users have an equal opportunity to access the BS.

Table 1 compares the system performance for the micro and macro-cell cases. For the LA we choose the modulation and coding mode that maximizes the throughput while maintaining a $PER < 10\%$. Results demonstrate that an approximate 3Mbps throughput improvement can be achieved by the 2x1 STBC in the micro-cell. This gain arises since more users (49%) are able to operate with the highest throughput mode (3/4 rate 64-QAM) compared to Single-Input Single-Output (SISO) case (where only 29% of users support this mode). When 2x1 STBC is employed, the outage probability falls to 5% in the micro-cell. However, large BS-MS separation distance in the macro-cell degrades the level of WiMAX coverage and throughput. Even with the application of transmit diversity, the macro-cell still experiences a 25% outage probability. Average throughputs of just 5.4Mbps and 6.3Mbps are provided by the SISO and 2x1 STBC systems, respectively.

TABLE I. SYSTEM PERFORMANCE IN MICRO AND MACRO CELL

	Urban micro		Urban macro	
	SISO	2x1	SISO	2x1
1/2 QPSK	23%	7%	21%	20%
3/4 QPSK	-	9%	13%	15%
1/2 16-QAM	16%	10%	11%	14%
3/4 16-QAM	11%	14%	8%	9%
2/3 64-QAM	6%	6%	4%	3%
3/4 64-QAM	29%	49%	10%	14%
Outage probability	15%	5%	33%	25%
System throughput (Mbps)	8.7	11.7	5.4	6.3

If the macro-cell radius is reduced to 1km, the 2x1 STBC achieves a throughput of 9.24Mbps with an 8% outage probability as shown in Figure 2. These results indicate that the cell radius has significant impact on system performance. For users exceed 1km from the BS, it is no longer possible to meet a 90% coverage target using this profile.

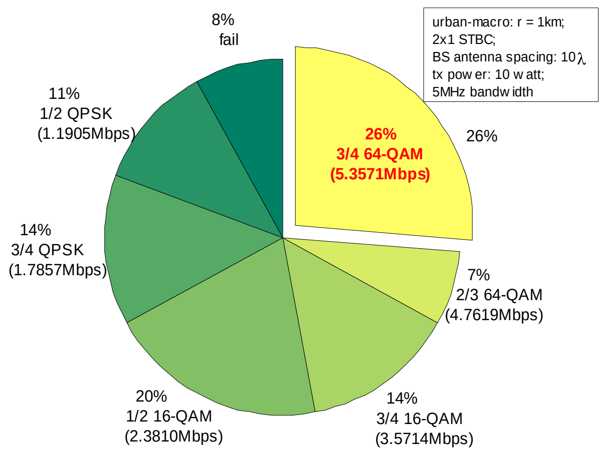

Figure 2 Performance for 1km cell radius (throughput = 9.24Mbps)

Figure 3 shows spectral efficiencies in terms of bps/Hz/km^2 over the cell area. The 2x1 STBC system provides a greater spectral efficiency than the SISO system, especially in the urban micro-cell, which shows a 32% improvement. As the cell radius is increased, the diversity gain is degraded. For example, only an 18% improvement is seen in the 1.5km radius macro-cell.

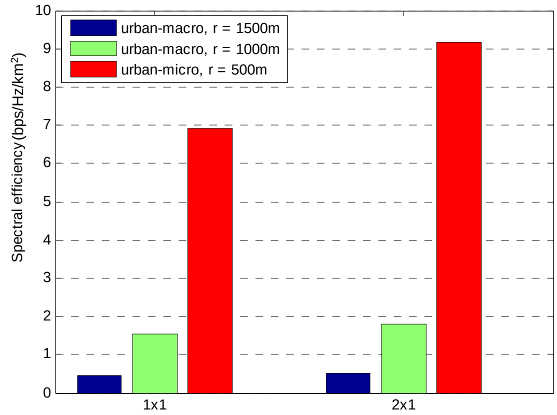

Figure 3 Comparison of spectrum efficiencies

To realize coverage up to a cell radius of 1.5km in a macro-cell, relay and MIMO techniques are required in order to enhance the coverage and capacity. However, it is more critical to investigate resource efficiency of relay deployment.

III. ANALYSIS OF RELAY EFFICIENCY

Ideally, for an *n*-hop relay, it is necessary to provide *n* unique radio resource units to avoid interference between each hop. It is clear that the success of relaying is intimately related to the radio resource reuse efficiency.

A. Formulation of Relay Efficiency

In order to measure the efficiency of a relay deployment, we now introduce an effective system capacity metric (C_{eff}). This is intended to leverage link level capacity gain and system capacity gain. Assuming there are a total of s MSs to be allocated, and p of these users are served via multi-hop relays, C_{eff} can be expressed as

$$C_{eff} = \sum_{i=1}^{s-p} C_i^{BS} + \frac{\sum_{j=1}^{p} C_j^{RS}}{N_{rc}} \quad (3)$$

where, C^{BS} and C^{RS} denote the capacity without relaying (BS access capacity) and the capacity with relaying (relayed capacity). $N_{rc} \in \{1, \ 2, \ \ldots \ n\}$ is the number of radio resource employed in the relays. For simplicity, we assume that the BS-RS and/or RS-RS links are ideal (no 'bottle neck' problems). Under these assumptions, the effective relay efficiency is derived as

$$\xi_c = \frac{\sum_{i=1}^{s-p} C_i^{BS} + \left(\sum_{j=1}^{p} C_j^{RS} \right) \Big/ N_{rc}}{\sum_{k=1}^{s} C_k^{BS}} \quad (4)$$

From a system-level point of view, the effective relay efficiency must be greater than one. In the case where $\xi_c < 1$, radio resource sharing should be considered. However, resource sharing may introduce interference. If no prior channel knowledge is available at the transmitter, then theoretic channel capacity for a MIMO system with M transmit and N receiver antennas is given by [5]

$$C = \log_2 \det\left[\mathbf{I}_N + \frac{1}{M}\cdot\frac{P_s}{P_I + P_n}\cdot\mathbf{H}\mathbf{H}^H\right] \quad (bps/Hz) \tag{5}$$

where, P_s, P_I and P_n represent the power of received signal, interference and noise, respectively. $\mathbf{I}_N$ is an $N \times N$ identity matrix, $\mathbf{H}$ is the normalized channel matrix and $(\cdot)^H$ denotes the transpose conjugate. Equation (4) can now be re-written for the DL case, as

$$\xi_c = \left[1\Big/\sum_{k=1}^{s}\log_2\det\left(\mathbf{I}_N + \frac{1}{M}\cdot\frac{P_{s,k}^{BS}}{P_{I,k}+P_{n,k}}\cdot\mathbf{H}_k\mathbf{H}_k^H\right)\right]\times$$
$$\left[\sum_{i=1}^{s-p}\log_2\det\left(\mathbf{I}_N + \frac{1}{M}\cdot\frac{P_{s,i}^{BS}}{P_{I,i}+\sum_{ii=1}^{l_i^{RS}}P_{I,i,ii}^{RS}+P_{n,i}}\cdot\mathbf{H}_i\mathbf{H}_i^H\right)+\right.$$
$$\left.\frac{1}{N_{rc}}\sum_{j=1}^{p}\log_2\det\left(\mathbf{I}_N + \frac{1}{M}\cdot\frac{P_{s,j}^{RS}}{P_{I,j}+P_{I,j}^{BS}+\sum_{\substack{jj=1\\ jj\neq j}}^{q_j^{RS}}P_{I,j,jj}^{RS}+P_{n,j}}\cdot\mathbf{H}_j\mathbf{H}_j^H\right)\right] \tag{6}$$

where, P_s^{BS} and P_s^{RS} represent the signal power received from the BS and RS. P_I^{BS}, P_I^{RS} and P_I denote the Co-Channel Interference (CCI) power received from the BS, RS and any other resources (e.g., from other cells), respectively. l_i^{RS} denotes the number of RSs that use the same radio resource as the i-th user (BS-MS), and q_j^{RS} represents the number of RSs that use the same radio resource as the j-th user (RS-MS). From (6) we deduce the impact of interference and radio resource usage. Increasing any of the interference terms or the value of N_{rc} could reduce the relay gain. Reducing N_{rc} could also increase the CCI. Also, the channel correlation is an important factor for MIMO transmissions.

Without radio resource sharing, the system relies on the use of unique radio resources for each link, including the BS-RS, BS-MS, RS-RS and RS-MS. We define the relay SNR-gain as $G_{SNR} = SNR_{relay} - SNR_{access}$, where the SNR_{relay} and SNR_{access} represent the signal to noise ratio of the last hop between the RS and MS (shortened to relay-SNR) and the BS-access link (directly between the BS and MS, shortened to access-SNR) respectively.

B. Impacts on MIMO Configurations

Using equation (6) it is possible to produce a comparison of the required relay SNR-gain for different MIMO configurations, as shown in Figure 4. Note that in this study the MIMO channels are uncorrelated. It is interesting to note that higher level of MIMO configuration is more efficient for relay deployments. Compared to low level configurations, higher level MIMO requires a lower relay SNR-gain to achieve a given level of relay efficiency. Increasing the number of antennas at each node can therefore increase the relay efficiency. This implies that the combination of MIMO and relaying form an effective solution for enhanced system efficiency and capacity. In addition, we also observed steeper slope between low and high level MIMO configurations when SNR_{access} is high (e.g., SNR_{access} = 10dB). For low SNR_{access} (e.g., SNR_{access} = 0dB), the differences are small. This implies that relay gain becomes dominant for those links with fairly high probability of outage (e.g., coverage hole, cell edge, etc.).

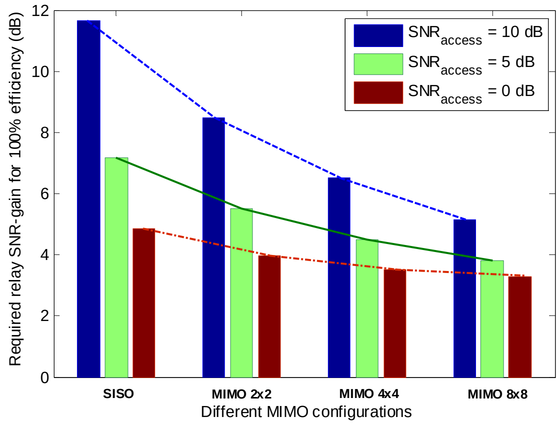

Figure 4 Comparison of required relay SNR-gain for different MIMO configurations (2-hop with two radio resource, no resource sharing)

Given the scarcity of radio resources, to achieve a highly efficient relay deployment it is necessary to implement radio resource sharing. With resource sharing, the critical issue is the interference introduced into the system. Figure 5 presents the impact of interference on MIMO systems with 2 hop relays. We have defined two thresholds: one is at 100% efficiency (which is required to compute the minimum SIR value), and the other is at 200% efficiency, which implies the relay deployment has doubled the capacity of the direct BS-MS link. It is interesting to note that the high level MIMO configuration is more tolerant to interference. For example, the SISO system requires 4.5dB more SIR than an 8x8 MIMO approach at 200% relay efficiency.

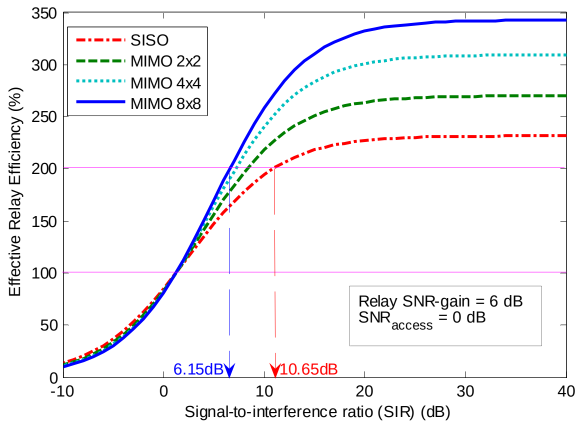

Figure 5 Analysis of relay SIR required for high relay efficiency

As mentioned before, MIMO channel correlation is detrimental to MIMO systems, especially on high order MIMO transceivers with small antenna separations. In order to study this degradation, three extreme scenarios are now considered: 1) the BS-MS link is correlated but the RS-MS link is uncorrelated; 2) both the BS-MS and the RS-MS links are correlated with identical correlation values, and 3) the RS-MS link is correlated but the BS-MS link is uncorrelated.

The effective relay efficiency *vs*. channel correlation value is shown graphically in Figure 6. For a 2x2 MIMO system we deliberately set both the SNR_{access} and the relay SNR-gain to 6dB (since this produces a 100% effective relay efficiency for a SISO system when the BS-MS link and the RS-MS link are uncorrelated [8]). For the first scenario, the relay improves link channel properties and consequently improves the relay efficiency. In contrast, for the third scenario the correlated RS-MS link severely degrades the relay efficiency. However, it is interesting to see that the second scenario shows that a high channel correlation value (greater than 0.6) can destroy the relay gain and dramatically decrease the relay efficiency.

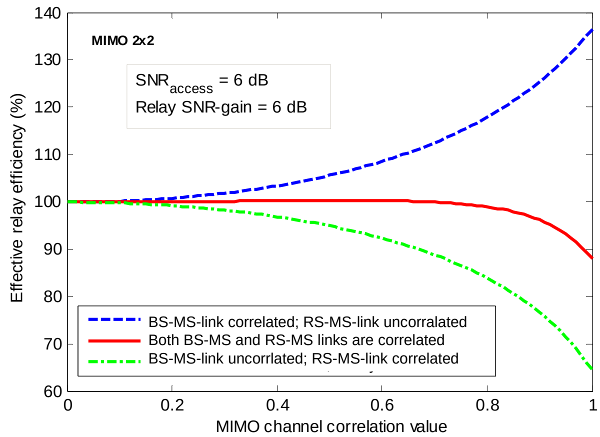

Figure 6 Channel correlation impacts on relayed MIMO system

Fundamentally there are two basic factors that affect MIMO relay applications and must be taken into account when quantifying a MIMO relaying application; 1) the value of the relay SNR-gain, and 2) the condition of the MIMO channel matrix.

C. Effects of Multiuser Transmission

To investigate the relay capacity gain with multiuser transmission, we consider equivalently equal relay efficiency, which is defined as that each user's relay in multiuser transmission achieves equal efficiency for both with and without radio resource sharing. With resource sharing deployment, single user relay efficiency can be expressed as

$$\xi_{ws} = \frac{C^{RS}_{i\_ws}}{C^{BS}_{i\_ws}} \tag{7}$$

where $C^{RS}_{i\_ws}$, $C^{BS}_{i\_ws}$ represent the relayed capacity and BS access capacity of i^{th} user respectively, within the radio resource sharing deployment.

For the relay without resource sharing but to achieve the same efficiency as that in (7), it has to meet either

$$C^{RS}_{i\_wo} = n_{i\_rc} \cdot C^{RS}_{i\_ws} \tag{8}$$

or

$$C^{BS}_{i\_wo} = C^{BS}_{i\_ws} / n_{i\_rc} \tag{9}$$

where n_{i_rc} is the number of resources for case of radio resource sharing, $C^{RS}_{i\_wo}$, $C^{BS}_{i\_wo}$ denote relayed capacity and BS access capacity of i^{th} user. The above two equations have shown that the efficiency loss by employing more resources could be recovered by relay capacity gain. These represent two realistic application scenarios and considerations. Firstly it is dependent on relay link capacity with n_{i_rc} times the capacity of relay with resource sharing. Alternatively, the equal system gain could be achieved when the relay employed in a system where the BS-access link has much low capacity. All these are the cases for single user relay deployment.

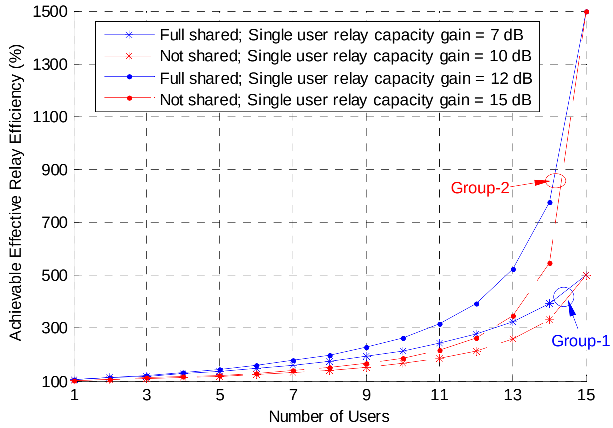

Figure 7 Relay efficiency with multi-users

For multiuser application, it would be interesting to show the different gain achieved from each single user to the system capacity gain. In general, if all users in multiuser transmission are through relays, all cases can achieve the same capacity gain. However, with some users through relaying, multiuser achieves capacity gain which is not linear with number of users. Compared between relay with and without resource sharing, with the first case as that in (8) we observed that the multiuser achieve the equal relay gain. In contrast with the second case as that in (9), multiuser relay gain is different to the first case. We assume 15 users to form an OFDMA transmission (as specified, up to 15 users for the 512 FFT DL PUSC OFDMA profile). Figure 7 presents the achievable effective relay efficiency *vs.* number of users for a 2-hop relaying, where the 'number of users' is defined as the number of users through relaying. For the results presented in Figure 7, it assumes that all the BS-access capacities are equal. The single user relay capacity gain without resource sharing is 3dB higher than the one with resource sharing as it is a 2-hop relaying. Two group typical results show that the relay with resource sharing achieves higher multiuser relay efficiency.

The analysis of efficiency gain for the two groups is shown in Figure 8. The defined efficiency gain is the difference between the relay with and without resource sharing. Based on previous assumptions, both achieve highest relay efficiency when all users are through relaying (see Figure 7). While evaluating the system efficiency with a few users through relaying, it is shown clearly that each single relayed transmission contributes more to system efficiency with radio resource sharing.

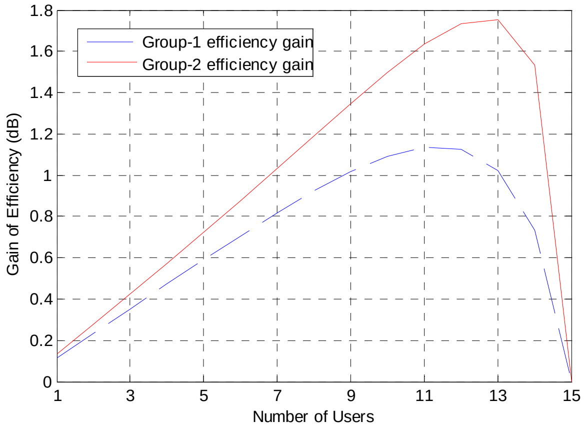

Figure 8 Efficiency gain between sharing and non-sharing relay

From this study it is shown that, in any case, the relay with radio resource sharing has potential to achieve optimal multiuser relay gain. With an OFDMA multiuser application, it is ideal to adopt flexible channelisation, AMC on each user and efficient radio resource management. It could be complicated for statistic studies as the performance is fully dependent on deployment scenario. However, it is much feasible in ray-tracer with realistic application environment (see section V).

IV. Directional Distributed Relay Architecture

Results presented in previous sections have demonstrated the high potential benefits for relay deployment with radio resource sharing in terms of MIMO combination, multiuser transmission, interference environment, etc. However, it is a challenge to implement the resource reuse, which needs careful system design. To achieve highly efficient relay deployments for practical applications, appropriate frequency reuse and multi-user access strategies are required to share the valuable and limited radio resource. As discussed before, the main concern with resource sharing is interference. Relay system must be based on a topology that fully exploits effective resource assignment based on the spatial separation of nodes.

We now introduce a directional distributed relaying architecture based on a paired radio resource transmission scheme. With our proposed direction distributed relay architecture, it is possible to achieve one radio resource to one user (or one group of users) in average even with multihop relay. This approach is depicted in Figure 9. The radio resource can be defined as either frequency (e.g., subcarries in an OFDMA symbol) or time (e.g., OFDMA time slots). Transmissions in the BS coverage are the same as the IEEE 802.16e standard. For relay links, paired transmissions are applied, where the BS forms two directional beams, or uses two sector antennas to communicate with RS1 and RS2 simultaneously. A paired radio resources are required: f_1 and f_2. The first radio resource (f_1) is applied to the BS-RS1 link and also to the RS2-MS links (in the RS2 coverage); while the second resource (f_2) is applied to the BS-RS2 link and also to the RS1-MS links (in the RS1 coverage). Radio resources are shared between the RSs and MSs. Each end-user employs a single pair of radio resources, on average. Figure 9 demonstrates the DL transmission. For UL, the same concept can be applied by another pair of radio resource [8].

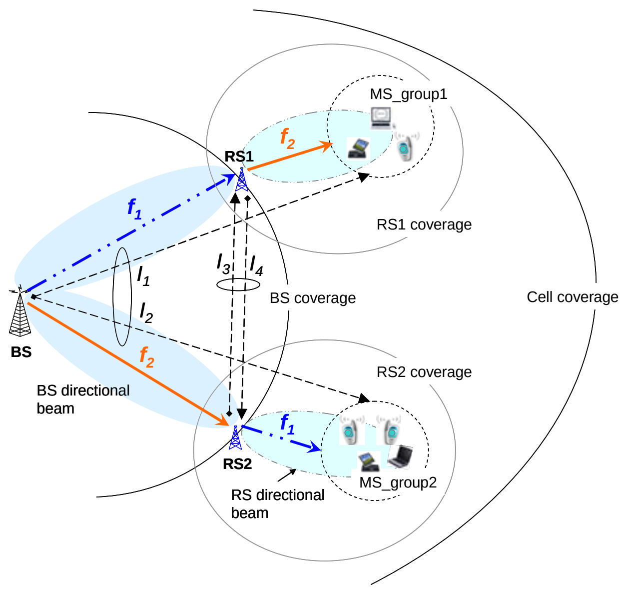

Figure 9 Directional distributed relaying with paired radio resource

Using the sharing scheme outlined above the interference can be controlled at the BS and RS nodes. In this relay configuration there are only two sets of interference, as also illustrated in Figure 9. The interference between the BS and MS-groups (I_1 & I_2) can be detected and controlled by the BS. Firstly, the BS could employ an adaptive array to exploit the spatial separation of the groups. Secondly, since the received power by each MS in each MS-group is known to the BS, the BS can apply interference avoidance [13][14] between the two groups based on measured SINR (Signal to Interference plus Noise Ratio) and power control. The transmit power of the two RSs are controlled for balancing the SINR according to the service requirement. Furthermore, in this scenario the expected level of interference is small since the BS connects to the MSs through a relay, which means the relay SNR-gain will be much higher than the SNR_{access} level. Interference between RSs (I_3 & I_4) can be reduced by array processing (including the use of sector antennas) at the RSs. Interference measurement for the efficient resource assignment can be achieved during neighborhood discovery procedure, which has being developed and specified in IEEE 802.16j [15][16].

This proposed topology is fully compatible with the existing 802.16e standard and no modifications are required at MSs. Alternative deployments topologies are also possible based on the same concept, such as a single RS to cover a ‘coverage hole’ (see Figure 10 in next section). But these will result in different interference modes as the radio resource sharing is performed between the RS and its BS. The interference mode and its impact on system performance are actually highly dependent on the application environment. From our experience, given an acceptable SINR level (e.g., 10dB), interference management can be achieved by spatial separation in the relaying system. To achieve high levels of SINR (e.g., 10-25dB), array processing (including the use of sector antennas at the RS) is desirable. If required, interference cancellation can be used to further enhance system performance.

V. Case Study with Ray-tracer

A. Simulated WiMAX senario

To demonstrate the potential of the proposed resource sharing framework, a site specific ray-tracing propagation model is used in this section to provide realistic environment specific propagation data for the BS-MS, BS-RS and RS-MS links. The ray tracing model takes individual buildings, trees and terrain contours into account and determines specific multipaths based on scattering and diffraction. The ray tracing tool was verified with measurement data in [17], and has been used in many previous WLAN and WiMAX system evaluations [18][19].

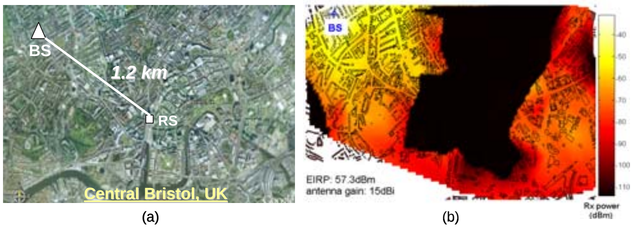

Figure 10 Simulated a macro-cell in Bristol, UK

A realistic MWA scenario is now analyzed based on a region of central Bristol, UK (see Figure 10 (a)). A single BS location was chosen on the roof-top of a tall central building (30m above ground level). 100 MS units were distributed over this geographic area at street level with heights of 1.5m. The BS was assigned an EIRP of 57.3dBm (based on a 15dBi 120^0 sector BS antenna). The raw Multi-Path Components (MPCs) are created using the ray tracing tool. Based on isotropic ray traced channel data, the ETSI specific antenna beam patterns (including their side lobes) [20][21] are incorporated via spatial convolution. Figure 10(b) presents the distribution of received power from the BS to the surrounding region at street level. A severe coverage hole is clearly visible, and this is caused by variations in the terrain height.

Two methods could be used to achieve acceptable WiMAX coverage in this macrocell. Firstly, a second BS could be deployed in the coverage hole. However, this would add to the infrastructure costs and hence it may be more effective to deploy an RS node.

B. Radio resource assignment with interference control

Figure 11 shows the locations of MSs and affiliation to either BS or RS. The locations of BS, RS and MSs are overlaid on a terrain map of Bristol city centre. For each MS a line is drawn to indicate whether communication occurs via the BS or RS. The choice of connection type depends on the received SINR. At a given location, signal power is obtained by sum of all received MPCs, which are transmitted by an assigned BS sector. Interferences are caused by MPCs who comes from either RS (for BS access) or BS (for RS access) if interfering users occupy same frequency resource as the detect user. It should be noted that in NLoS conditions the MS may connect to an adjacent sector since this is determined by the direction of the strongest path.

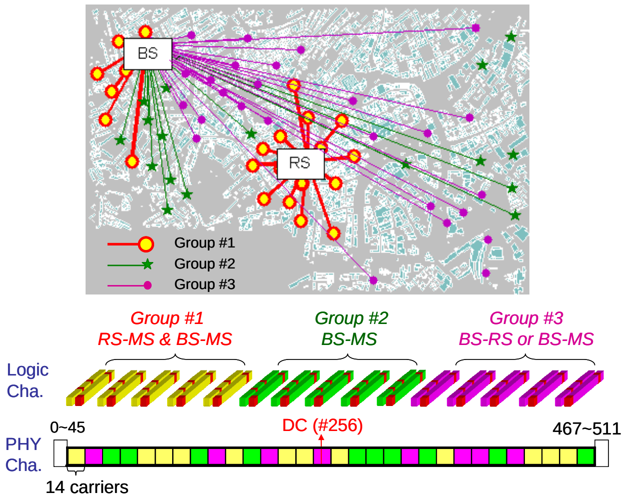

Figure 11 BS and RS radio resource location

When radio resource sharing is applied, a number of RS-MS and BS-MS links are supported simultaneously using the same resources. For simplicity, in this study we assume there are a total of three groups for three users, and each group comprises 5 subchannels, as shown in Figure 11. Each group is made up of 140 physical subcarriers, resulting in a total of 420 subcarriers in each OFDMA symbol (360 data bearing carriers and 60 pilot carriers). When RS is used to connect to an MS, a certain number of timeslots (or alternatively subchannels) must be assigned in the covering sector to support the BS-RS link. Here we assume that BS-RS link and BS-MS link (taken from the sector covering the RS) in group #3. For all the RS-MS links, and also the BS-MS links where the antenna beam is steered away from the RS, it is possible to share group #1. Group #2 is used for those MSs that connect to one of the BS sectors (i.e. but not the sector coving the RS); these can be located near to the RS if required.

C. Numerical results

Transmit powers of 42.3dBm and 23dBm are applied respectively at the BS and RS, and an identical three sector antenna is used at the RS. The MS units are assumed to employ omni directional antennas. Figure 12 presents the SINR contribution within the BS coverage hole for the assumptions made above. As expected, the RS improves the coverage, although users now suffer CCI from the BS because of radio resource sharing. Results show that without the relay, around 60% of users have an SNR value less than 15dB. In contrast, only 10%

of users have an SINR less than 15dB when the relay is applied.

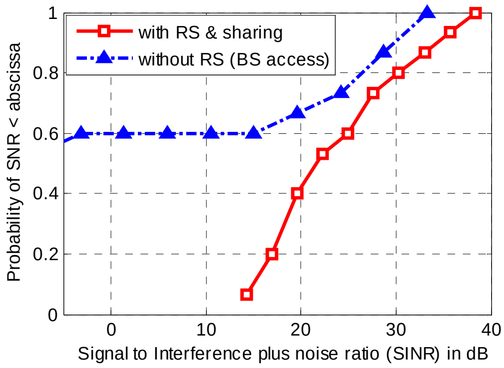

Figure 12 SINR in directional relaying system

Based on optimal AMC as mentioned before, Figure 13 compares the spectral efficiency (in terms of bps/Hz) for three types of deployment. The deployments are named ‘without RS’, ‘with RS, but no sharing’ and ‘with RS and sharing’. Results indicate that without relay the capacity is just 1.14bps/Hz in this area. Using directional relaying to reduce the interference by exploiting spatial separation, the system is able to share radio resource and hence increase the spectral efficiency (e.g., to more than 3.5bps/Hz in the case of sharing).

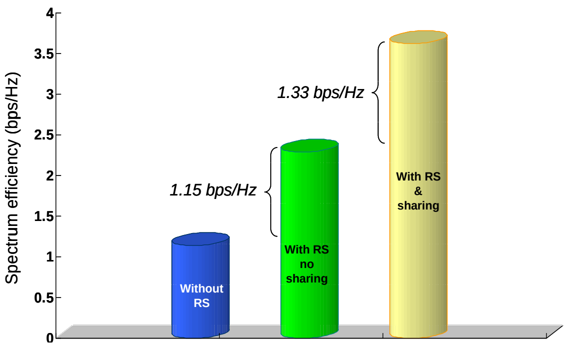

Figure 13 Spectrum efficiency comparisons (SISO)

VI. CONCLUSIONS

This paper highlighted a technical overview and presented design strategies to achieve high efficient mobile WiMAX. We have presented a range of results based on environmental assumption taken from 3GPP2 and the IST-WINNER project. Results show that while MIMO increases the capacity of a single link, it is constrained to wireless channel conditions and received signal strength. To generate capacity improvements, the STBC should combine with AMC together. The STBC system provides a greater spectral efficiency than the SISO system, especially in the urban micro-cell.

Achieving high throughputs with low outage probability in a large cell is a challenge but bring in effective deployment with MIMO and multihop relay, which have been intensively explored in this paper. We have analyzed the effective relay efficiency. For relay systems without radio resource sharing, a higher relay SNR-gain was required. This implies that the system requires a higher transmit power at the RS. In contrast, radio resource sharing offers high potential for a mobile WiMAX network when relays are deployed. Radio resource sharing is very applicable to MIMO relaying. In addition to multiuser transmission, the relay with radio resource sharing is potential to achieve optimal multiuser relay gain.

In order to achieve the practical application of radio resource sharing, relay system must be based on a topology that fully exploits effective resource assignment based on the spatial separation of nodes. Directional distributed relay topology was introduced for highly efficient relay deployment. This scheme is fully backward compatible with the current mobile WiMAX standard. Compared to a relay system without resource sharing, the implementation of resource sharing improved capacity significantly in a realistic urban scenario. For the OFDMA multiuser transmission, it is ideal to adopt flexible channelization and MIMO LA on different users, and multihop relay with efficient radio resource management.

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