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WiMaX Capacity Enhancements introducing Full Frequency Reuse using MIMO Techniques

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***Abstract-* This paper focuses on WiMaX performance presenting capacity for both SISO advanced MIMO scenarios . In this paper a full frequency reuse concept in sectored cells and point out the limitations due to overlapping of antenna radiation patterns of adjacent sectors and the resulting interference , which is based on MIMO techniques, is introduced and analyzed for both uplink and downlink. This techniques are half rate providing spatial diversity. The Simulation results indicate significant increase of cell capacity.**

***Index Terms* – WiMaX,MIMO,STBC,BER,CellSectoring, Frequency reuse**

1. Introduction

In cellular communications systems, cell sectoring is commonly used to increase cell and network capacity [1]. This consists of replacing the omnidirectional base station (BS) antenna by several directional antennas each radiating within a specified sector. With hexagonal cell patterns, the most common sectoring schemes employ 120° or 60° sectors. The conventional approach is to allocate a different channel to each sector.

Multiple-input multiple-output (MIMO) techniques have been incorporated in all of the recently developed wireless communications system specifications including the IEEE 802.11n standard for local area networks and the IEEE 802.16e-2005 standard [1] for mobile broadband wireless access systems. Mobile WiMAX systems are based on the scalable OFDMA mode of IEEE 802.16e-2005 specifications and use a subset of the different options included in them.

The WiMAX Forum has specified two mandatory MIMO profiles for use on the downlink of WiMAX systems. One of them is based on the space–time code (STC) proposed by Alamouti for transmit diversity [2]. This code provides perfect second-order diversity when used with a single receive antenna and fourth-order diversity when used with two antennas at the receiver. But it is only half-rate, because it only transmits two symbols using two time slots and two transmit antennas. (In this paper, we define the rate as the number of symbols transmitted per antenna use.) The other profile is spatial multiplexing (SM), which uses two transmit antennas to transmit two independent data streams. This scheme is full-rate, but it does not benefit from any diversity gain at the transmitter, and, at best, it provides second-order diversity with two antennas at the receiver [3].

For future evolutions of the WiMAX standard, it is highly desirable to include a new code combining the respective advantages of the Alamouti code and the SM while avoiding their drawbacks. Such a code actually exists in the IEEE 802.16e-2005 specifications, where it is referred to as Matrix C. The matrix C is a variant of the Golden code [4], which is known to be one of the best STCs of size 2×2. However, this code has a tremendous decoding complexity which grows with the fourth power of the signal constellation size, and this makes it impractical for low-cost wireless systems. IEEE 802.11 Wireless Local Area Networks (WLANs) have been employed in offices, homes, campuses successfully. Although many wireless networking technologies, such as IEEE 802.16 wireless metropolitan area networks and 3G networks are deployed for wireless internet services.

In addition to MIMO techniques, another hot topic in wireless communications systems is frequency reuse in sectored cells. Cell sectoring, which is commonly used to increase cell and network capacity [6], consists of replacing the omnidirectional base station (BS) antenna by several directional antennas each radiating within a specified sector. With hexagonal cell patterns, the most common sectoring schemes employ 120° or 60° sectors. The conventional approach is to allocate a different channel to each sector. Fig. 1 shows a hexagonal cell pattern with 120° cell sectoring and the corresponding frequency allocation to different sectors. Splitting each cell into three sectors multiplies the cell capacity by three, but since a separate channel is allocated to each sector, three channels are needed to serve the entire cell and the spectral efficiency remains unchanged

As is well known, frequency is a rare and expensive resource, which needs to be utilized efficiently. Therefore, there is a significant interest to use the same channel in different sectors of a cell. This would not be a problem if the radiation diagrams of adjacent sector antennas did not overlap. However, in practice, the radiation diagrams of the sector antennas used exceed the sector boundaries and there is a significant overlap region between adjacent sectors. This prohibits full frequency reuse (FFR). One way to handle this problem in cellular systems based on orthogonal frequency-division multiple access (OFDMA) [1] is to reserve a group of subcarriers to serve users located in overlap regions. With 120° sectors, the reserved subcarrier group is divided into three subgroups, and one subgroup is allocated to each overlap region. The remaining subcarriers are reserved for the non-overlap regions and they are reused in all sectors. Since only one part of the subcarriers is reused, this scheme ensures partial frequency reuse (PFR). In a recent paper [7], the present authors described a full frequency reuse technique, which uses existing MIMO concepts to serve the users located in the overlap regions. More specifically, while two users located in the overlap region of two sectors, say A and B, are served by these two sectors, the third sector C serves a user located in its overlap-free region. Thus, three users are simultaneously used and full frequency reuse is achieved.

In this paper, we go one step forward and consider the partitioning of each cell in four sectors. For both uplink and downlink, we describe several frequency reuse concepts. Note that for interference reasons, sectoring of the cells must follow the cell pattern as long as different sectors use different
frequencies. Therefore, 120° sectors are commonly used in hexagonal cell patterns. However, the number of sectors per cell does not have to follow any rule when all of the sectors use the same frequency.

2 . MIMO Techniques in WiMaX systems

A. Transmit Diversity: The first MIMO profile is the simple STC scheme proposed by Alamouti [3] for transmit diversity. In the IEEE 802.16e-2005 specifications, this scheme is referred to as Matrix A. Originally, Alamouti's STC was proposed to avoid the use of receive diversity and keep the subscriber stations simple. In OFDMA-based WiMAX systems, this technique is applied subcarrier by subcarrier and can be described as follows: Suppose that ($s1$, $s2$) represents a group of two consecutive symbols in the input data stream to be transmitted. During a first symbol period $t1$, transmit (Tx) antenna 1 transmits symbol $s1$ and Tx antenna 2 transmits symbol $s2$. Next, during the second symbol period $t2$, Tx antenna 1 transmits symbol and Tx antenna 2 transmits symbol.

B.Spatial Multiplexing:The second multiple antenna profile included in WiMAX systems is the 2x2 MIMO technique based on the so-called matrix **B** = ($s1$, $s2$)T. This system performs spatial multiplexing and does not offer any diversity gain from the Transmitter side. But it does offer a diversity gain of 2 on the receiver side when detected using maximum-likelihood (ML) detection.

C. Matrix C **:**Matrix C was included in the IEEE 802.16–2005
specifications to enhance the performance of Matrix A and B
while providing full-rate and full-diversity with a higher coding gain. This code leads to a spatial diversity of order 4 for 2 receiver antennas and achieves substantially better performance than the SM code (Matrix B) whose spatial diversity is limited to 2 (for this number of receive antennas). Matrix C results in the same bit error probability as the Golden code.

D. Matrix D:This code is a simple linear combination of two Alamouti schemes. Here.

$$|a|^2+|b|^2=|c|^2+|d|^2=1$$
$$|a|^2+|c|^2=|b|^2+|d|^2=1$$

The first condition ensures the transmission of equal average power at each symbol time, while the second condition ensures that equal average total power is transmitted for each symbol. A simple manipulation can show that the magnitudes
of a and c must be equal for reduced complexity optimum detection.

2.1. Full Frequency reuse on the uplink

Sectoring of a cell into 4 sectors is illustrated in Figure 1. It is assumed that the antenna radiation diagrams are as large as those used in 120° sectoring, which means that the angular overlap of adjacent antenna radiation diagrams is larger than 30°. Here, we are not trying to reduce the overlap between adjacent sectors, because our goal is to have these sectors cooperate to serve users located in their overlap regions.

We first consider the uplink case. Since two users can not cooperate and exchange any information, no space-time coding between user terminals can be performed in that direction. Instead, user signals can be transmitted in parallel using spatial multiplexing. Suppose that user u_1 wants to transmit symbol s_1, user u_2 wants to transmit symbol s_2, user u_3 wants to transmit symbol s_3, and user u_4 wants to transmit symbol s_4 to the BS. Suppose further that user u_1 is located in the overlap region of sectors A and B, user u_2 is located in the overlap region of sectors B and C, user u_3 is located in the overlap region of sectors C and D, and user u_4 is located in the overlap region of sectors D and A. We will now describe two techniques for frequency reuse on the uplink.

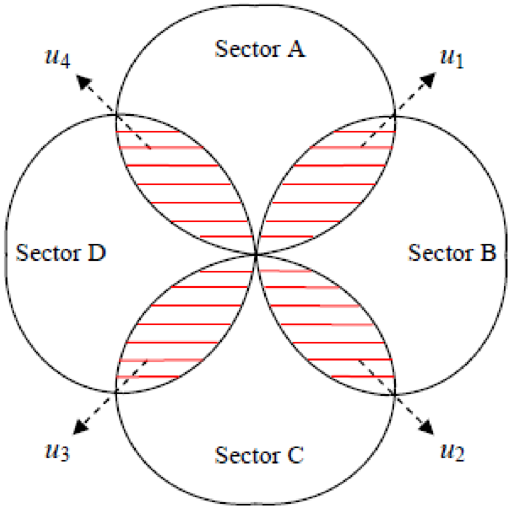

Fig.1.Cell Sectoring into overlapping 90 degree cells

We first consider the uplink case. Since two users can not cooperate and exchange any information, no space-time coding between user terminals can be performed in that direction. Instead, user signals can be transmitted in parallel using spatial multiplexing. Suppose that user $u1$ wants to transmit symbol $s1$, user $u2$ wants to transmit symbol $s2$, user $u3$ wants to transmit symbol $s3$, and user $u4$ wants to transmit symbol $s4$ to the BS. Suppose further that user $u1$ is located in the overlap region of sectors A and B, user $u2$ is located in the overlap region of sectors B and C, user $u3$ is located in the overlap region of sectors C and D, and user $u4$ is located in the overlap region of sectors D and A. We will now describe two techniques for frequency reuse on the uplink.

A. Rate-1/2 Code: Denoting by h_1 the channel response from user u_1 to the receiver (Rx) of sector A and by h_2 the channel response from that user to the Rx of sector B, by h_3 the channel response from user u_2 to the Rx of sector B and by h_4 the channel response from that user to the Rx of sector C, by h_5 the channel response from user u_3 to the Rx of sector C and by h_6 the channel response from that user to the Rx of sector D, and finally by h_7 the channel response from user u_4 to the Rx of sector D and by h_8 the channel response from that user to the Rx of sector A, a simple technique works as follows: During the odd channel use intervals, users u_1 and u_3 transmit their symbols s_1 and s_3, while users u_2 and u_4 remain silent.

During the even channel use intervals, the opposite occurs. That is, users u_2 and u_4 transmit their symbols s_2 and s_4, while users u_1 and u_3 remain silent. Symbol s_2 is received by sectors B and C, and symbol $s4$ is received by sectors D and A as described above. For space limitations, we will not write the corresponding equations, which are straightforward.

In this way, the four users transmit their symbols benefiting from second-order diversity, but the rate of this technique is only one half, because the 4 symbols are transmitted using 4 antennas and two time intervals.

B. Full-Rate Code: In this case, all users transmit simultaneously and their signals overlap. The signals received by the 4 sectors can be written as:

$$
\begin{aligned}
r_A &= h_8 s_4 + h_1 s_1 + n_1 \\
r_B &= h_2 s_1 + h_3 s_2 + n_2 \, . \\
r_C &= h_4 s_2 + h_5 s_3 + n_3 \\
r_D &= h_6 s_3 + h_7 s_4 + n_4 \, .
\end{aligned}
$$

The receivers of the 4 sectors detect jointly the transmitted symbols (s_1, s_2, s_3, s_4). Assuming ML detection, they compute the following metric for all combinations of (s_1, s_2, s_3, s_4) and select the one which corresponds to the smallest metric value.

2.2.Full Frequency reuse on the downlink

On the downlink too, a rate-1/2 code is easily designed to serve users located in the sector overlap regions and offer second-order transmit diversity. Let us consider the same four users $u1$, $u2$, $u3$, $u4$, located in the same regions as in the uplink case. Simple full-rate and rate-1/2 codes are as follows:

A. Rate-1/2 Code: At odd time intervals, sectors A and B cooperate to serve $u1$, and sectors C and D cooperate to serve $u3$. During these periods, no symbols are transmitted to users $u2$ and $u4$. To do so, assuming channel state information is available at the transmitter.. The signal received by user $u1$ will be:

$$r_1 = \left(|h_1|^2 + |h_2|^2\right) s_1 + n_1$$

The same type of equations hold for symbol $s3$ and both symbols are thus received with second-order diversity without any interference.Similarly, at even time intervals, sectors B and C cooperate to serve $u2$, and sectors D and A cooperate to serve $u4$. During these periods, no symbols are transmitted to users $u1$ and $u3$.

The same type of equations as for $s1$ and $s3$ hold for the transmission and reception of symbols $s2$ and $s4$, and both symbols are recovered with second-order diversity.If the channel state information is not available at the transmitter, Alamouti encoding can be used to provide the same diversity order, symbol rate, and performance.

B. Full-Rate Code

On the downlink, simultaneous transmission of symbols to 4 users located in the overlap regions as described above leads to interference. Since each user receives signals from two sectors, the symbol intended to that user will be corrupted by symbols intended to other users. One way to solve this problem is to apply the same type of technique as in the rate- 1/2 code; i.e., serve users $u1$ and $u3$ during two consecutive time intervals $t1$ and $t2$ using a full-rate 2x2 STC as that proposed in [5] and not transmit any signals to users $u2$ and $u4$ during these two intervals.

The code matrix is given by equation (3), where the first row of this matrix represents the signals transmitted from the first sector, and the second row represents the signals transmitted from the second sector serving the user at hand. Next, the first column of this matrix represents the signals transmitted during the first channel use, and the second column represents the signals transmitted during the secondchannel use.

Assume that a symbol quadruplet (*s*1, *s*2, *s*3, *s*4) is transmitted in this way to user *u*1 from sectors A and B. During the same time intervals, sectors C and D cooperate to transmit 4 symbols (*s*5, *s*6, *s*7, *s*8) to user *u*3 using the same code matrix. As for users *u*2 and *u*4, they are served during the next two intervals using the same code matrix, while no symbols are transmitted to users *u*1 and *u*3. In this way, the base station transmits 16 symbols using 4 Tx antennas and 4 time intervals (each user getting 4 symbols), and the coding scheme described is therefore full-rate. We will not write the detector equations, which can be found in [5], where it was shown that optimum decoding of the transmitted symbols can be performed with a complexity on the order of *M*2, where *M* is the constellation size

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3.Perfrormance Analysis

We have analyzed the performance of the proposed frequency reuse scheme using the QPSK and 16-QAM signal formats and independent Rayleigh fading channels. The reference performance against which performance of the proposed scheme should be benchmarked is the single-input single-output (SISO) transmission scheme used in the nonoverlap regions of the 4 sectors. Indeed, since we are assuming that user terminals have a single antenna and also a single base station antenna is used in each sector, non-overlap regions of the four sectors can only use SISO transmission, and this is our basic reference scheme.

Figure 2 shows the BER performance results on the uplink using the proposed rate-1/2 code and uncoded QPSK. The results show that the proposed frequency reuse scheme and rate-1/2 code lead to a tremendous performance improvement compared to that of the SISO scheme used in the non-overlap regions of the sectors. The SNR improvement is as high as 12 dB at the BER of 10^{-3}, and it increases at lower BER values.

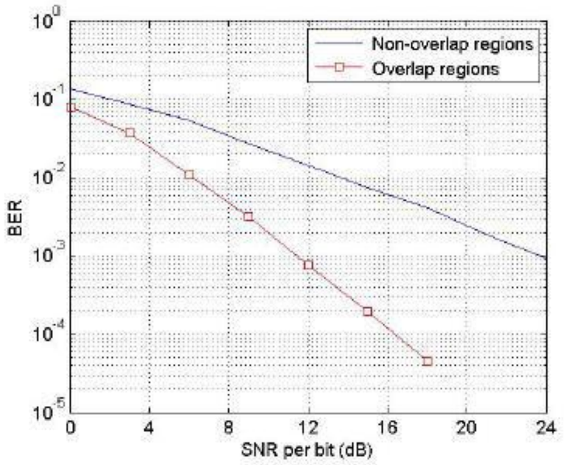

Fig.2. **Performance of the rate-1/2 code on the uplink proposed for users in the sector overlapping regions (the modulation is QPSK).**

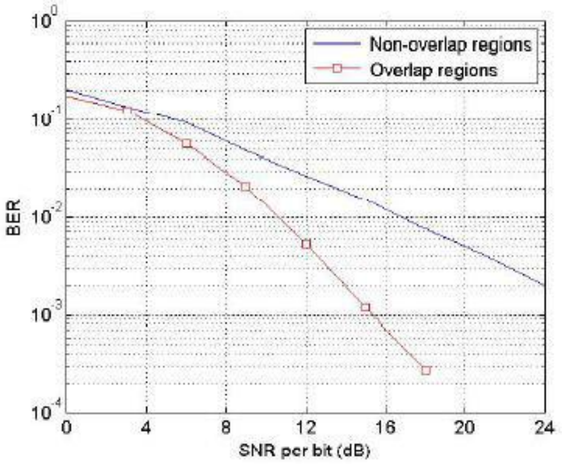

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Fig.3. **Performance of the rate-1/2 code on the uplink proposed for users in the sector overlapping regions (the modulation is 16-QAM).**

Similarly, Figure 3 shows the same type of performance results with 16-QAM modulation. Here too, the proposed technique leads to a tremendous performance improvement over SISO transmission used in the non-overlap regions. Of course, the code used here is only half rate, while the SISO scheme used in the non-overlap regions is full rate. However, a half-rate code with 16-QAM achieves the same bit rate as a

full-rate code with QPSK. This means that an objective comparison consists of comparing the red curve of Fig. 3 with the blue curve of Fig. 3. This comparison reveals that at the BER of 10-3, the proposed rate-1/2 code with 16-QAM achieves over 9 dB performance improvement compared to SISO transmission with QPSK. The given performance figures are also valid for the fullrate code of the uplink as well as for the rate-1/2 code on the downlink. There will be some performance degradation with the full-rate code of the downlink, but with the same modulation format, that code doubles the bit rate

6.Conclusions

In this paper, we have first reviewed the recent developments in MIMO techniques for mobile WiMAX and discussed full frequency reuse in sectored cells. We have proposed to split the cells in 4 overlapping sectors and use MIMO techniques to serve users located in the sector overlap regions. Full-rate and half-rate codes were described for both the uplink and downlink and their performance was analyzed.

It was shown that in addition to achieving full frequency reuse, the users located in the sector overlap regions benefit from spatial diversity and achieve substantially higher performance than those located in overlap-free regions. Since higher performance can be traded off against higher data rate,

the proposed cell sectoring and frequency reuse technique multiplies the cell capacity by a factor higher than 4.

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