On Bounding the Number of Mobiles Sharing a Slot in a Point-to-Multipoint Network

Phani Krishna P
Indian Institute of Technology Madras, India
p.phanikrishna@gmail.com

Siva Ram Murthy C
Indian Institute of Technology Madras, India
murthy@iitm.ac.in

ABSTRACT

Multiple antenna techniques are widely being recognized as front-runners in improving the performance of a wireless network. Sharing a slot between two Mobile Stations (MSs) is defined in a Point-to-Multipoint (PMP) network, independent of the number of antennas at each MS. However, sharing a slot among more than two MSs in a PMP network is not studied in the literature. In this paper, we study if more than two MSs can share a slot for transmission. We find that there exists few realistic scenarios where more than two MSs can share a slot, thus improving the throughput of the network. We observe that the number of MSs sharing a slot is dependent not only on the number of antennas at each MS but also the multiple antenna technique utilized for transmission. When each MS has a constant rate requirement of 2 bps/Hz, we found that 3 MSs can share a slot when each MS uses Spatial Multiplexing techniques, while 4 MSs can share a slot when each MS uses Spatial Diversity techniques for transmission.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication

General Terms

Performance

Keywords

WiMAX, MIMO, Signal to Interference Ratio

1. INTRODUCTION

We consider a Point-to-Multipoint (PMP) network, in which several Mobile Stations (MSs) are directly connected to a Base Station (BS). Orthogonal Frequency Division Multiple Access (OFDMA) technology is considered at the physical layer, so that the multi-path interference can be minimized. In each frame, an MS requests the BS, the number of slots required in the next frame. BS, in response, allocates the available OFDM slots to each of the MSs depending on their individual requirements. An OFDM slot may be allocated to different MSs based on several parameters such as geographical location, channel quality and quality of service requirements of each MS. The problem of choosing MSs that share an OFDM slot is studied by the research community under the name 'pairing' and the technique is termed as Collaborative Spatial Multiplexing (C-SM).

In IEEE 802.16 Networks [1], two MSs with 1 or 2 antennas, can share an OFDM slot for transmission. However, sharing a slot with more than two MSs is not studied for a PMP network by considering the interference limitations. Most of the studies [12, 8, 10] are based on a decentralized network, wherein several user (transmitter-receiver) pairs share the same slot for transmission.

This setup can be mimicked in a PMP network by placing all the receivers of a decentralized network at a centralized location. However, the centralized entity needs sufficient number of antennas to support transmission for all MSs sharing a slot in the network. In such scenario, the signals of different MSs sharing same slot interfere with each other at the receiving antennas. Furthermore, as the number of MSs that share a slot increases, the complexity to decode signals increases at the BS (receiver). Using Interference Alignment (IA), signals are aligned along different vectors at antennas of each MS (thus minimizing the interference).

Interference in a PMP network is caused due to two reasons: a) Inter Carrier Interference (ICI) and b) Multiple Input Multiple Output (MIMO) Interference. Interference contributing factors such as Carrier and Doppler Frequency Offsets, and Synchronization caused due to the relative mobility between transmitter and receiver is accounted as part of ICI. This is highly dependent on the PHY layer technology used, and has a wide range of solutions [14, 9] particularly when OFDM technique is used. However, most of the solutions use the concept of redundancy to eliminate ICI. They transmit same data symbol along a group of adjacent subcarriers [14]. The size of this group containing redundant data is analytically derived to be two [9], when linear combining techniques are utilized at the receiver. In [9], ICI is shown to be a non-Gaussian random process that has higher impact on the network performance.

When several MSs with several antennas share a slot for transmission, interference occurring in the network is accounted as part of MIMO interference. It is the responsibility of the BS to determine which MSs share a slot and which MSs utilize multiple antennas for transmission, such

MSWiM'12, October 21–25, 2012, Paphos, Cyprus.

that the interference can be mitigated. The BS provides the beam vectors along which data is transmitted at each antenna of the MS.

While it has been a working assumption that two MSs can share a slot for transmission in a WiMAX network [1], there has been no theoretical or analytical study to find the maximum number of MSs that can share a slot. We take initial step towards the solution by finding out the maximum MSs that can share a slot, by considering Signal to Interference Ratio (SIR) as a parameter to verify if the data is successfully received. The problem that we consider in this paper can be formally stated as '*What is the maximum number of MSs that can share an OFDM slot in a PMP network given that each MS is equipped with same number of antennas and each MS has equal rate requirements in a realistic scenario?*' This study also points us to probe into several questions such as: Does this number depend on the PHY layer parameters of each MS participating in the share? Does this number vary with the rate requirements of each MS? Does this number vary as the number of antennas at each MS varies? Can we determine the lower bound on number of antennas required at the BS?

We organize the remainder of the paper as follows: In Section 2, keeping the problem statement in view, we review relevant work in the literature that closely addresses the problem. We provide the parameters required for studying the problem and the system model considered for evaluation in Section 3. We analyze the numerical results obtained in Section 4. Finally, we conclude the paper in Section 5 providing pointers towards work for the future.

2. RELATED WORK

IA is a technique in which several user pairs with single antenna transmit and receive data successfully by aligning their data along pre-determined beam vectors [3]. Though IA is proposed for a decentralized network wherein K user-pairs with single antenna share a slot, the technique can be applied in a PMP network where the BS has antennas equal to the number of MSs sharing a slot (wherein each MS is equipped with one antenna). The number of times throughput of the network is improved was shown to be $K/2$ using IA technique. Beam vectors are assumed to be computable and communicated to each MS as and when they are determinable, using the algorithms proposed in [11].

The IA technique is effectively used [6] and experimentally shown to be efficient in designing a protocol for utilizing same slots in an 802.11 network (this work considers the MSs endowed with multiple antennas up to 'K'). The important result being, 'In a distributed network where a transmit-receive pair has equal number of antennas, a pair having more number of antennas than the spatial streams that are being transmitted currently, can utilize the same slot for transmission'. The implications of this result in a PMP network are studied in this paper.

Peters and Heath-Jr. [10] study multiple antenna interference channels and propose a greedy algorithm to partition available users into several groups such that users in a group use IA to transmit data in a single slot, while users across groups use TDMA mechanism to transmit data across different slots. They model users (transmit-receiver pairs) in the network as a connected graph, and partition the graph such that users across groups transmit mutually orthogonally, while users inside a group use IA for transmission.

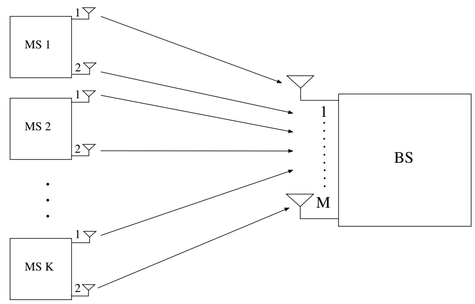

Figure 1: System Model.

The users are partitioned based on the position information of each transmitter and receiver in the network. However, their solution assumes that the user pairs are decentralized in the network, which is not the case in a PMP network under consideration.

When each MS is equipped with only one antenna, receiver filters that mitigate the ICI are designed in [4]. The receiver complexity was proven to be reduced from $O(N^3)$ to $O(N log_2 N)$ using these receiver filters. The complexity of these filters is dependent on the Fast Fourier Transform (FFT) size (N) used in the OFDMA technique. In a typical WiMAX network, the FFT size is constant depending on the bandwidth allocated at the BS [1]. A set of linear filters (MMSE/ML/ZF receivers) that minimize the interference are assumed to be available at the BS so that all the streams are received without errors.

3. SYSTEM MODEL

For a signal to be interference free, the value of SIR should be above a threshold β, where β is dependent on the bit transmission rate. The SIR for a signal can be defined as

$$SIR = \frac{P(R)}{P(I)} \tag{1}$$

where $P(R)$ is the power of the required signal at the receiver and $P(I)$ is the power of interfered signal at the receiver. β can be derived from popular Shannon's theorem as follows: $C = B\ log_2(1 + SIR) \Rightarrow SIR = 2^{(C/B)} - 1$, where C is achieved capacity of the channel given B bandwidth. Similar expression is also used in [12] as $2^R - 1$, where R is the required rate of transmission in bps/Hz.

We use SIR to measure power of the received signal at the BS. Also, average SIR of the signal at each antenna of the BS is measured in one OFDM slot and plotted to determine effective interference for each signal.

Let 'K' MSs share the same OFDM slot for transmitting to the BS. Each MS is equipped with 2 antennas and the BS is equipped with $M(\geq 2K)$ antennas. An antenna at each MS transmits the data that is aligned along a vector, beamed to a specific antenna at the BS. In other words, alignment vectors specific to each antenna of the MS are transmitted by the BS for each frame. The overhead of transmitting these beam vectors in each frame is presumed to be negligible when compared to the achievable data rates. The data received at antenna i of the BS, similar to Equation 6 in [7], can be written as

$$y_i(s) = \sum_{j=1}^{2K} d_{ij}^{-\rho} W_j H_{ij} x_j(s) W_i^H + n_{ij} \tag{2}$$

where W_j is the beam-formed (weighted) vector along which data is transmitted,
W_i^H is the inverse of the beam-formed matrix used at the BS,
$x_j(s)$ is the data transmitted across antenna j on subcarrier s,
H_{ij} is the channel coefficient between the transmitted antenna j and received antenna i,
n_{ij} is the Additive White Gaussian Noise associated with the channel,
d_{ij} is the distance between antenna i and antenna j,
and ρ is the path loss exponent of the channel. The ICI in a channel using OFDM is mainly due to adjacent subcarriers [7]. Also, assuming the channel to be frequency flat fading, Equation 2 can be modified as follows:

$$\begin{aligned} y_i(s) = \sum_{j=1}^{2K} d_{ij}^{-\rho} W_j H_{ij} x_j(s) W_i^H + \sum_{j=1}^{2K} d_{ij}^{-\rho} W_j H_{ij} x_j(s-1) W_i^H \\ + \sum_{j=1}^{2K} d_{ij}^{-\rho} W_j H_{ij} x_j(s+1) W_i^H + n_{ij} \end{aligned} \tag{3}$$

Equation 3 assumes that ICI occurs every time in the network. The probability of occurrence of ICI in a network [13] is shown to be a random number uniformly generated in the range of $[0, 0.1]$.

The SIR of i^{th} stream at antenna i on a OFDM slot using subcarrier s can be determined as

$$SIR = \frac{\left|W_i W_i^H H_{ii}(s)\right|^2}{\sum_{l=s} \sum_{\substack{j=1 \\ j \neq i}}^{2K} \left|W_j W_i^H H_{ij}(l)\right|^2 + \sum_{\substack{l=s-1 \\ l=s+1}} \sum_{j=1}^{2K} \left|W_j W_i^H H_{ij}(l)\right|^2} \tag{4}$$

where $H_{ij}(l)$ is the channel coefficient for the l^{th} subcarrier between transmit antenna j and receiving antenna i ($\because d_{ij},\ \rho$ are constant for all MSs in the system).

From the concept of IA, it is obvious that

$$W_j W_i^H = \left\{ \begin{array}{ll} 1 & \text{if } i = j \\ 0 & \text{otherwise} \end{array} \right\}$$

Hence, $W_j W_i^H$ is always binary (i.e., 0 or 1). However, due to the factors such as imperfections in measured channel conditions and highly varying nature of the channel the IA vectors may not remain fixed even for 20 ms (same as time duration of a typical super-frame in WiMAX Networks [1]) time frame, $W_l \times W_m^H$ will not be zero all the time and is considered to have minute errors in evaluations.

Different MIMO techniques can be achieved by varying the transmitted data $x_j(l)$ across different antennas with alignment vectors W_j. In Spatial Multiplexing technique, two antennas of an MS transmit different data (X_1 and X_2) along IA vectors W_1 and W_2, as shown in Fig. 2. Antennas at the BS receive data aligned along vectors W_1^H and W_2^H. The signals aligned along remaining vectors is considered as interference. In Spatial Diversity technique, two antennas of an MS transmit variants of the same data (X_1 and $\tilde{X}_1$) along IA vectors W_1 and W_1, as shown in Fig. 3. Two antennas at the BS receive data along same IA decoding vector W_1^H. We consider both multiplexing and diversity techniques for determining the maximum number of MSs that can share a slot for transmission. A thorough study on the consequences of using different MIMO techniques is provided in the next section.

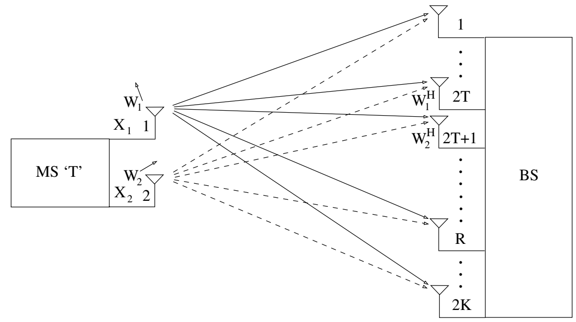

Figure 2: Spatial Multiplexing Technique using IA Vectors for Transmission.

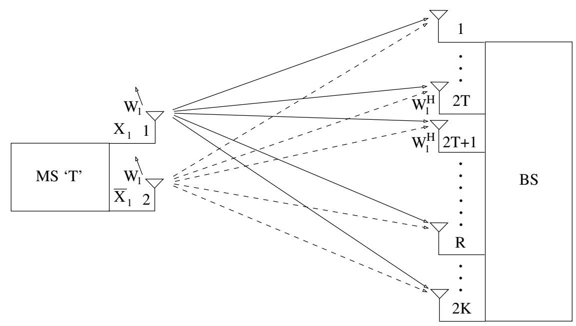

Figure 3: Spatial Diversity Technique using IA Vectors for Transmission.

For the numerical results, initially we place all MSs adjacent to each other as shown in Fig. 1. Since each MS shares approximately the same channel to the BS, the SIR estimate remains same for several MSs (Note: Distance remains the same for all MSs). Later SIR value of each MS is made to be independent of other MSs, representing a more realistic scenario.

4. EXPERIMENTAL DETAILS

We consider only one slot is being used for transmission by all MSs in the network and increase the number of MSs in the network from 1 to 20. The authors in [5] propose a transmitter centric algorithm after realizing that the uplink interference in a multi-user system is highly fluctuant. Since each MS receives different SIR values for each transmission, we calculate SIR of required signal at each antenna of the BS, and plot the average SIR across all antennas observed at the BS. This average SIR is used to determine the achievable transmission rate (in bps/Hz) for each MS in the network.

Table 1: Average SIR determined at different antennas of the receiver when each MS exhibits different channel quality.

Number of MSs Sharing a Slot	No ICI One Antenna	Full ICI One Antenna	Two antennas No ICI Diversity	Two antennas Full ICI Diversity	Two antennas No ICI Multiplexing	Two antennas Full ICI Multiplexing
1	Infinity +/- NaN	4.21 +/- 0.01	Infinity +/- NaN	Infinity +/- NaN	65.64 +/- 0.54	53.88 +/- 0.1
2	59.71 +/- 0.51	3.29 +/- 0.01	19.54 +/- 0.04	10.68 +/- 0.02	5.31 +/- 0.00	8.57 +/- 0.0
3	12.58 +/- 0.40	3.22 +/- 0.03	7.20 +/- 0.00	4.77 +/- 0.03	3.17 +/- 0.01	3.10 +/- 0.0
4	7.06 +/- 0.03	2.67 +/- 0.01	4.32 +/- 0.02	3.02 +/- 0.00	2.30 +/- 0.00	1.63 +/- 0.0
5	5.06 +/- 0.01	2.32 +/- 0.03	2.75 +/- 0.01	2.20 +/- 0.01	1.82 +/- 0.01	1.32 +/- 0.0
6	3.75 +/- 0.01	1.95 +/- 0.00	2.58 +/- 0.00	1.69 +/- 0.01	1.58 +/- 0.00	1.47 +/- 0.0
7	3.07 +/- 0.02	1.74 +/- 0.01	1.81 +/- 0.00	1.55 +/- 0.00	1.46 +/- 0.00	1.13 +/- 0.0
8	2.59 +/- 0.02	1.50 +/- 0.00	1.57 +/- 0.01	1.44 +/- 0.00	1.35 +/- 0.01	0.98 +/- 0.0
9	2.26 +/- 0.01	1.39 +/- 0.00	1.39 +/- 0.00	1.34 +/- 0.00	1.09 +/- 0.00	0.79 +/- 0.00
10	1.99 +/- 0.00	1.24 +/- 0.01	1.31 +/- 0.00	1.11 +/- 0.00	0.97 +/- 0.00	0.80 +/- 0.0
11	1.75 +/- 0.00	1.14 +/- 0.00	1.22 +/- 0.00	1.10 +/- 0.00	0.84 +/- 0.00	0.66 +/- 0.0
12	1.61 +/- 0.00	1.05 +/- 0.00	1.20 +/- 0.00	1.00 +/- 0.00	0.72 +/- 0.00	0.59 +/- 0.00
13	1.47 +/- 0.00	0.99 +/- 0.00	1.11 +/- 0.00	0.89 +/- 0.00	0.66 +/- 0.00	0.57 +/- 0.00
14	1.36 +/- 0.00	0.93 +/- 0.00	0.99 +/- 0.00	0.79 +/- 0.00	0.64 +/- 0.00	0.56 +/- 0.0
15	1.26 +/- 0.00	0.86 +/- 0.00	0.89 +/- 0.00	0.77 +/- 0.00	0.62 +/- 0.00	0.51 +/- 0.0
16	1.17 +/- 0.00	0.82 +/- 0.00	0.89 +/- 0.00	0.76 +/- 0.00	0.54 +/- 0.00	0.45 +/- 0.00
17	1.09 +/- 0.00	0.77 +/- 0.00	0.85 +/- 0.00	0.69 +/- 0.00	0.52 +/- 0.00	0.43 +/- 0.0
18	1.02 +/- 0.00	0.73 +/- 0.00	0.80 +/- 0.00	0.65 +/- 0.00	0.49 +/- 0.00	0.42 +/- 0.0
19	0.97 +/- 0.00	0.70 +/- 0.00	0.74 +/- 0.00	0.63 +/- 0.00	0.47 +/- 0.00	0.39 +/- 0.0

For the sake of numerical calculations, we assume the channel coefficients to be uniformly distributed Gaussian random variables with zero mean and unit variance while noise is circularly symmetric and uniformly distributed with zero mean and 0.1 variance.

Initially, we compute the maximum number of MSs that can share a slot when channel conditions are identical for each MS. Later, we compute the same with channel conditions being completely independent for each MS. Also, a Selection Combining receiver is used at the BS when Diversity techniques are employed.

Considering the total capacity of the network to be constant, the number of MSs sharing a slot is maximized when the requirement of each MS is minimized. We consider 2 bps/Hz as a norm in the analysis for the following reason: It is highly visible in WiMAX networks, even when channel quality is as low as $0-5$ dB for an MS. In a WiMAX network, the rate can scale to higher values as the channel quality increases for each MS (Details in Appendix).

4.1 Numerical Results

When the number of MSs that share a slot is 1, the SIR value is maximum for all the four studied scenarios: Each MS with 1 (2) antennas and ICI can (not) be mitigated completely. As the number of MSs sharing a slot increases, the interference in the network also will increase, and a reduction in SIR value can be observed. The maximum MSs that can share a slot is limited to that number, where the average SIR falls below the threshold $\beta = 3$ (pertaining to R=2 bps/Hz). Also, note that β is calculated from Section 3. The values shown in Table 1 are generated after performing $10,000$ iterations. Since β is dependent on rate requirement of each MS, number of MSs that share a slot depends on rate requirement of each participating MS.

When an MS with one antenna transmits only one stream of data, SIR value would be maximum as there is no interference in the network. Table 1 provides the results for the scenario where the channel quality of each MS is independent of other MSs. Also, unless mentioned, the results are analyzed for a constant rate requirement of 2 bps/Hz and $\beta = 3$. We also observed that with different rate requirements, the number of MSs that can share a slot varies. This is represented for different rate requirements $(1, 2, 3$ bps/Hz$)$ in Table 1 using Plum, blue, and ForestGreen colors to denote the maximum number of MSs sharing each slot.

Though multiplexing techniques multi-fold the achievable transmit rates depending on number of antennas used for transmission, prior work showed that using multiplexing techniques improves performance of the network only in high SIR regions [1]. Thus, it can be misleading to consider that every MS uses multiplexing techniques for transmission. We observed that diversity techniques attain more SIR values compared to that of multiplexing techniques reiterating this notion. Hence, it becomes noteworthy that in a real world scenario, the number of MSs that share a slot also depends on the MIMO technique employed by each MS sharing the slot.

We observed that the number of MSs that can share a slot is 7 when ICI is eliminated and 3 when ICI is not mitigated in the network. Hence, the number of MSs sharing a slot also depends on the mitigating ICI in the network. Also, it can be observed from Table 1 that the SIR values remain almost same when the number of MSs sharing a slot is above 8, irrespective of the number of antennas at each MS and ICI mitigation in the network. This confirms that the upper bound for the number of MSs that can share a slot is bounded to 8 if we plan to exploit MIMO techniques available at each MS.

We can also observe that when 2 MSs with one antenna share an OFDM slot for transmission, the SIR value remains close to the threshold β, conforming to the C-SM specifications in WiMAX standards [1]. However, we observed that more MSs can share a slot when each MS is equipped with multiple antennas. A maximum of 7 MSs can share an OFDM slot for a constant rate requirement of 2 bps/Hz in the best possible settings. Consequently, a BS must need at least 14 antennas to receive data from each MS participating in the share. Thus, we provide a lower bound on the number of antennas required at the BS in a PMP network, such that rate requirements of each MS is satisfied. However, the number MSs sharing a slot is completely dependent on channel characteristics, rate requirements, and number of antennas at each MS participating in the share.

4.2 Discussion

The above study determines the maximum number of MSs that can share a slot. It can be misleading that the throughput of the network increases as the number of MSs sharing a slot increases. This is because of the requirement of IA vectors to be available at each MS before transmission. This calculation of IA vectors is done by the centralized entity (BS), and the BS transmits the IA vectors to each MS participating in the share. Though algorithms to calculate IA vectors are proposed in the literature for different channels, the time and space complexities of those algorithms are very high. Thus, the challenge shifts from *being able to share a slot among many MSs* to *providing on-line algorithms that can schedule many MSs* in a specific network.

5. CONCLUSION

In this paper, we studied the effect of increasing the number of MSs that share a slot in a PMP network using simulations. For a constant rate requirement of 2 bps/Hz, we observed that more than 2 MSs can share a slot when each MS is equipped with multiple antennas, which is in stark contrast to the current wireless network standards [1], that allows only 2 MSs to share a slot for transmission. The number of MSs sharing the slot varies for different rate requirements at each MS and different MIMO techniques applied at each participating MS.

A thorough analysis of the presented system to determine the maximum number of MSs that can share a slot is currently being investigated. The analysis is expected to be robust of any receiver combining techniques when diversity techniques are used for transmission. Studying the performance of a network when number of antennas at each MS is not constant across the network is left for the future work.

6. ACKNOWLEDGEMENTS

The first author would like to thank the timely support of Giridhari while preparing the manuscript. This work was supported by the Department of Science and Technology, New Delhi, India.

7. REFERENCES

[1] IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Broadband Wireless Access Systems. *IEEE Std 802.16-2009 (Revision of IEEE Std 802.16-2004)*, pages 1–2082, May 2009.

[2] K. Balachandran, D. Calin, N. Gopalakrishnan, J. H. Kang, A. Kogiantis, S. Li, L. Ozarow, S. Ramakrishna, A. N. Rudrapatna, and R. Sun. Design and performance analysis of collaborative spatial multiplexing for IEEE 802.16e-based systems. *Bell Labs Technical Journal*, 13(4):97–117, Feb. 2009.

[3] V. Cadambe and S. Jafar. Interference alignment and degrees of freedom of the k -user interference channel. *IEEE Transactions on Information Theory*, 54(8):3425–3441, Aug. 2008.

[4] C.-Y. Hsu and W.-R. Wu. ICI mitigation for OFDMA uplink systems. In *Proceedings of IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, pages 1–5, 2008.

[5] Y. Li, G. Zhu, and S. Zhang. Transmitter centric scheduling in multi-cell MIMO uplink system. In *Proceedings of the IEEE International Conference on Communications*, pages 1–6, 2010.

[6] K. C.-J. Lin, S. Gollakota, and D. Katabi. Random access heterogeneous MIMO networks. In *Proceedings of the ACM SIGCOMM Conference*, pages 146–157, 2011.

[7] C. O. Martin Garcia. Intercarrier interference in OFDM: A general model for transmissions in mobile environments with imperfect synchronization. *EURASIP Journal on Wireless Communications and Networking*, 2009(1):101–111.

[8] P. Mohapatra, K. Nissar, and C. Murthy. Interference alignment algorithms for the K user constant MIMO interference channel. *IEEE Transactions on Signal Processing,*, 59(11):5499–5508, Nov. 2011.

[9] K. W. Park and Y. S. Cho. An MIMO-OFDM technique for high-speed mobile channels. *IEEE Communications Letters*, 9(7):604–606, July 2005.

[10] W. S. Peters and W. R. Heath-Jr. User partitioning for less overhead in MIMO interference channels. *CoRR*, abs/1007.0512, 2010.

[11] M. Shen, A. Host-Madsen, and J. Vidal. An improved interference alignment scheme for frequency selective channels. In *Proceedings of the IEEE International Symposium on Information Theory*, pages 559–563, 2008.

[12] R. Vaze. How many transmit antennas to use in a MIMO interference channel. *CoRR*, abs/1105.6170, 2011.

[13] T. Yucek and H. Arslan. Carrier frequency offset compensation with successive cancellation in uplink OFDMA systems. *IEEE Transactions on Wireless Communications,*, 6(7):3546–3551, Oct. 2007.

[14] Y. Zhao and S.-G. Haggman. Intercarrier interference self-cancellation scheme for OFDM mobile communication systems. *IEEE Transactions on Communications*, 49(7):1185–1191, July 2001.

APPENDIX

Here, we provide a reality check on the of assumptions made in this paper, and argue for their validity in a real world scenario.

A. RATE REQUIREMENT ASSUMPTION

A bit rate requirement of 2 bps/Hz is considered for the numerical analysis in this paper due to the following reasons:

- These rates are highly visible in a WiMAX network even in the SNR range of $0-5$dB [2].

Table 2: Typical CBR requirements for VoIP traffic

	Rate (in bps)	Bandwidth	Rate (in bps/Hz)
CBR	256 Kbps	10 MHz	0.02621
CBR	384 Kbps	10 MHz	0.03932
CBR	512 Kbps	10 MHz	0.05242
CBR	1024 Kbps	10 MHz	0.10485

- The rate requirements of a typical MS in a WiMAX network (that uses 10 MHz bandwidth) are tabulated in Table 2. Clearly, 2 bps/Hz rate requirement is significantly higher than rate requirements in a typical network.

B. ICI REDUCTION

The existing ICI elimination/reduction techniques include: frequency domain equalization, time domain windowing, peak to average power ratio techniques, and self cancellation techniques. In frequency domain equalization techniques, the pattern at which ICI occurs for each OFDM symbol is calculated and estimated for the remaining OFDM symbols. These are used to reduce the fading distortions in the channel. In time domain windowing technique, linear distortions are eliminated by using adaptive filters. In peak to average power ratio reduction technique, the input data block is partitioned into disjoint sub-blocks, and several sub-blocks are combined to minimize peaks. In self cancellation technique, one data symbol is mapped on a group of subcarriers for transmission. However, self cancellation techniques reduce the effective bandwidth of the network by half, thus reducing the network throughput. Since the filters are heuristic in nature, they do not completely eliminate ICI in the network. ICI occurs with probability [0,0.1] in the network [13].