Comparison between the Performance of PUSC and FFR Network

Kamal Ahmed, Himadri S. Saha, Mustafa M. Hussain, M. R. Amin

Abstract*—This work is an approach to solve the limitations of WiMax with three operational band frequencies. As the license fee of the frequency band goes higher and not easy to get allotment, it is wise to look for solution to make effective use of the available band. This can be done by several features that will lead to a network to the peak of performance with limited resource. One of the proposed solutions to maximize the capacity and upgrading the performance in this literature is using fractional frequency reuse (FFR) with MIMO (Multiple-Input Multiple-Output) technique. MIMO is a revolutionary technique to overcome the limitations of capacity and coverage of a WiMax network. In this paper, first we discuss about the features which will give a perfect overview of this FFR technology. Then a simulator is used to compare the performance of the FFR technology with partial usage of sub-channels (PUSC) technique. The simulation results are compared to find the best feature to see whether this feature really works in a real RF environment. Finally, the whole approach is discussed with the limitations and future proposals.

Index Terms*—WiMax, MIMO (multi-input multi-output), CINR (carrier to interference-plus-noise ratio), RSSI (received signal strength indicator), CAPEX (**capital expenditure**).

I. INTRODUCTION

Mobile WiMax, a broadband wireless access (BWA) technology, is based on IEEE standard 802.16-2005 [1]. Orthogonal frequency division multiple access (OFDMA) is a distinctive characteristic of the physical layer of 802.16e based systems. The underlying technology for OFDMA based systems is orthogonal frequency division multiplexing (OFDM). With OFDM, available spectrum is split into a number of parallel orthogonal narrowband subcarriers. These subcarriers are grouped together to form sub-channels. The distribution of the subcarriers to the sub-channels is done using three major permutation methods called: partial usage of sub-channels (PUSC), full usage of sub-channels (FUSC) and adaptive modulation and coding (AMC). The subcarriers in a sub channel for first two methods are distributed throughout the available spectrum while these are contiguous in case of AMC [2].

As the WiMax features are cost effective solutions of enhancing the performance of a WiMax network, rigorous research works are going on in this field. In the published works [3]-[9], various kinds of features are discussed with possible simulations. From these papers, it can be seen that these are very effective measures to enhance the network performance in terms of cost, quality and time. Being motivated by these works, in this paper, a realistic simulation with a fully professional industrial planning tool of these features is proposed. A comparison study is also done to check the efficiency of these features.

The rest of the paper is organized as follows: Section II gives the system model of the work while Sec. III provides the simulation results of the model. Finally, Sec. IV concludes the entire analysis.

II. SYSTEM MODEL

Frequency spectrum is a limited and increasingly expensive resource. Wireless network operators often have to compete in acquiring licenses to operate on frequencies of their choice which is a very costly process. Of course, they still have another alternative, that is, using free spectrum in license-exempt bands. But then, they have to find the means to control interference from other networks, sharing the same band and to limit spillover to other users of the band.

Mobile WiMax in mobile mode will be deployed like a cellular network (2G, 3G). Therefore, in most cases it will operate in licensed bands. But buying more frequency bands will increase the CAPEX (Capital Expenditure). Unlicensed bands may be considered only for green field deployment where there are no other users of the same spectrum.

Regardless of licensed or unlicensed spectrum, frequencies have to be used efficiently. Therefore, it is crucial to maintain the frequency reuse one. It is to be mentioned here that frequency reuse one is achieved when all sectors within a cell and all cells within a network operate on the same frequency channel. However, frequency reuse one in a cellular network implies that users at cell edges may face degraded signals due to adjacent cell interference.

In PUSC, the used subcarriers (data and pilots) are sequentially divided among a number of physical clusters such that each cluster carriers twelve data and two pilot subcarriers. These physical clusters are permuted to form logical clusters using the renumbering formula [1]. This process is called outer permutation. This permutation is characterized by a pseudo-random sequence and an offset called DL PermBase. But using PUSC, the interference at the cell edges cannot be avoided. Also, this is a simplified scheduler, does not use information about the channel. PUSC requires more redundancy (Overhead) for forward error correction [10].

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FFR is a promising approach for reducing interference at the cell edges. The solution to the interference problem proposed in the standards is FFR. In FFR, the users at the cell/sector edge operate with a fraction of all sub-channels available while the inner cell users operate with all sub-channels available. In Fig. 1, F1, F2 and F3 are different sets of sub-channels in the same frequency channel.

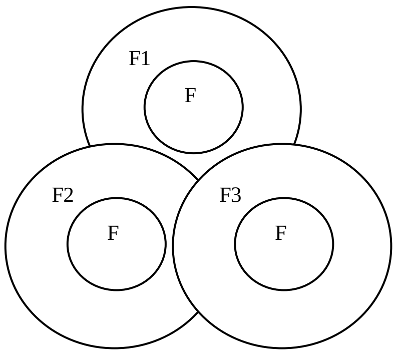

Figure 1: Fractional frequency reuse

Mobile WiMax addresses this issue by "tweaking" the frequency reuse one. It works by allowing users at a cell center to work on all available sub-channels. Cell center is the area closer to a base station (BS) which means, it is particularly immune to co-channel interference [3]. Users at a cell edge are only allowed to operate on a fraction of all available sub-channels. This set of sub-channels is allocated in such a way that adjacent cells' edges will operate on different sets of sub-channels. This is called fractional frequency reuse [2], [6], [10]-[12]. MIMO system consists of several transmit and receive antennas. We can consider a system with n_T transmit and n_R receive antennas. The channel of this system is defined by an $n_R \times n_T$ complex matrix **H** [13] (please see Eq. (5)).

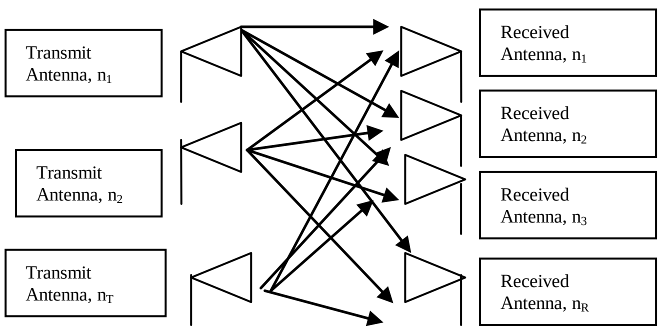

Figure 2: MIMO Technique.

The transmitted signal is represented by an $N_t \times 1$ column matrix, denoted by the symbol **x**, whereas the received signal is represented by an $N_r \times 1$ column matrix, denoted by the symbol **r**. Here, the $N_t \times 1$ vector is as follows

$$\mathbf{x}(n) = [\hat{x}_1(n), \hat{x}_2(n), \ldots\ldots, \hat{x}_{Nt}(n)]^T . \quad (1)$$

The vector $\mathbf{x}(n)$ represents the complex signal vector transmitted by N_t antennas at the discrete time n. Here, the components of the vector $\mathbf{x}(n)$ are assumed to have zero mean and common variance.

The variance of the signal vector $\mathbf{x}(n)$ is given by

$$\sigma_x^2 = \frac{x_i^2}{N_t} = \frac{P_t}{N_t} . \quad (2)$$

Signal received by the first antenna is

$$r_1(n) = \hat{x}_1(n)h_{11} + \hat{x}_2(n)h_{21} + \hat{x}_3(n)h_{31} + \ldots\ldots + \hat{x}_{N_t}(n)h_{N_1} ,$$

which can also be written as

$$r_1(n) = \left[h_{11}\ \ h_{21}\ h_{31} + \ldots\ldots\ldots, h_{N_t 1}\right] \begin{bmatrix} \hat{x}_1(n) \\ \hat{x}_2(n) \\ \hat{x}_3(n) \\ \ldots \\ \ldots \\ \ldots \\ \hat{x}_{N_t}(n) \end{bmatrix} . \quad (3)$$

Signal received by the second antenna is

$$r_2(n) = \hat{x}_1(n)h_{12} + \hat{x}_2(n)h_{22} + \hat{x}_3(n)h_{32} + \ldots\ldots\ldots + \hat{x}_{N_t}(n)h_{N_2} ,$$

which can also be written as

$$r_2(n) = \left[h_{21}\ \ h_{22}\ h_{32} + \ldots\ldots\ldots, h_{N_t 2}\right] \begin{bmatrix} \hat{x}_1(n) \\ \hat{x}_2(n) \\ \hat{x}_3(n) \\ \ldots \\ \ldots \\ \ldots \\ \hat{x}_{N_t}(n) \end{bmatrix} . \quad (4)$$

The channel matrix, $\mathbf{H}(n)$ is expressed by the following $N_r \times N_t$ complex matrix:

$$\mathbf{H}(n) = \begin{bmatrix} h_{11}(n) & h_{12}(n) \ldots\ldots\ldots\ldots & h_{Nt1}(n) \\ h_{21}(n) & h_{22}(n) \ldots\ldots\ldots\ldots & h_{Nt2}(n) \\ \vdots & \vdots & \vdots \\ h_{Nr1}(n) & h_{Nr2}(n) \ldots\ldots\ldots & h_{NrNt}(n) \end{bmatrix} . \quad (5)$$

In matrix form, Eq. (5) can be written as

$$\mathbf{r}(n) = \mathbf{H}(n)x(n) + \mathbf{n}(n) . \quad (6)$$

The $N_r \times 1$ vector denotes the complex noise vector and is given below:

$$\mathbf{n}(n) = \left[\tilde{n}_1(n), \tilde{n}_2(n), \ldots\ldots\ldots, \tilde{n}_{N_r}(n)\right]^T . \quad (7)$$

To simplify Eq. (6), we can suppress the dependence on time n by the following expression:

$$\mathbf{r} = \mathbf{H}\mathbf{x} + \mathbf{n} . \quad (8)$$

The correlation matrix is

$$R_x = E[XX^H] = \sigma_x^2 \mathbf{I}_{N_t} , \quad (9)$$

where $\mathbf{I}_{N_t}$ is the $N_t \times N_r$ identity matrix. The correlation matrix of the noise vector $\boldsymbol{n}$ is given by

$$R_{\mathbf{n}} = E[NN^H] = \sigma_x^2 \mathbf{I}_{N_r}. \qquad (10)$$

where $\mathbf{I}_{N_r}$ is the $N_r \times N_t$ identity matrix.

Finally, the normalized channel capacity is expressed as

$$C = E\left\{\log_2\left[\frac{\det(R_{\mathbf{n}} + HR_{\mathbf{x}}H^H)}{\det(R_{\mathbf{n}})}\right]\right\}. \qquad (11)$$

The IEEE 802.16 defined MIMO configurations are negotiated dynamically between each individual base station and mobile station. The 802.16 specification has the ability to support a mixture of mobile stations with different MIMO capabilities. This helps to maximize the sector throughput by leveraging the different capabilities of a diverse set of vendor mobile stations.

III. RESULTS AND SIMULATION

The simulation is done by a fully practical planning and simulation tool. The name of the tool is "Atoll". The version used here is "2.2". The map provided in Figs. 3,4 and 6 are in 10 m resolution terrain map.

The simulations provided in this paper are based on several realistic criterions/specifications which are elaborate in Tables 1- 4.

Table 1: Network Criterion

Criterion type	Criterion
Clutter type	Dense urban, Urban
Antenna height	24 m
Antenna Tilt	3 degrees (down tilt)
Area	21 square KM
Site to site distance	500 m

The simulation provided in this paper is based on the antenna specification given in Table 2. .

Table 2: Antenna Specification

Specification	Values
Frequency Range	2300 - 2700 MHz / 2300 - 2700 MHz
Gain	17.3 dBi 2.4 GHz, 18.0 dBi 2.6 GHz
Return Loss	> 15 dB
Polarization	Dual Slant ± 45°
Horizontal Beam width	65°
Vertical Beam width	6.5° with null fill
Electrical Down tilt	0° - 10° independently continuously adjustable
Upper Side lobe Level	< -18 dB
Front to Back Ratio	> 30 dB
Isolation Between Ports	> 30 dB
Power Rating	250W
Impedance	50 ohm
Antenna configuration	4T4R

Table 3: Customer Premises Equipment (CPE) Specification

Frequency band	2.3 – 2.4 GHz
Channel Band width	10 MHz
Modulation	DL: QPSK, 16 QAM, 64QAM, UL: QPSK, 16 QAM
MIMO	MIMO supported
Tx power	23 dbm
Receiving sensitivity	-95 dbm
Antenna configuration	1T2R
Antenna gain	1 dbm

Table 4 : Simulation Specification

Name	Longitude	Latitude	Altitude (m)	Cluster
AB0001	91.8786E	24.89272N	[20]	Urban
AB0002	91.883119E	24.895001N	[20]	Urban
AB0004	91.88157E	24.90164N	[29]	Urban
AB0005	91.87698E	24.90641N	[30]	Dense urban
AB0006	91.87197E	24.892N	[20]	suburban
AB0009	91.85801E	24.90754N	[20]	suburban
AB0010	91.88433E	24.88716N	[19]	Urban
AB0011	91.86842E	24.91029N	[30]	Urban
AB0012	91.85076E	24.90515N	[20]	suburban
AB0014	91.849629E	24.910571N	[21]	suburban
AB0015	91.86E	24.913361N	[30]	suburban
AB0016	91.89024E	24.90007N	[23]	Urban
AB0017	91.8895E	24.889167N	[20]	Urban
AB0021	91.855944E	24.897972N	[20]	Urban
AB0022	91.874917E	24.90025N	[29]	suburban
AB0023	91.8676E	24.8973N	[20]	Urban
AB0024	91.86431E	24.90414N	[24]	Urban
AB0025	91.895556E	24.896194N	[20]	Dense urban
AB0026	91.87047E	24.916993N	[30]	Urban

Using MIMO in both PUSC and FFR, the comparison between the Coverage Area is shown in Figs. 3 - 5 both for Channel to Interference Noise Ratio (CINR) and Received Signal Strength Indicator (RSSI) case. In Table 6, the comparison between different parameters of PUSC and FFR are shown for different RSSI values.

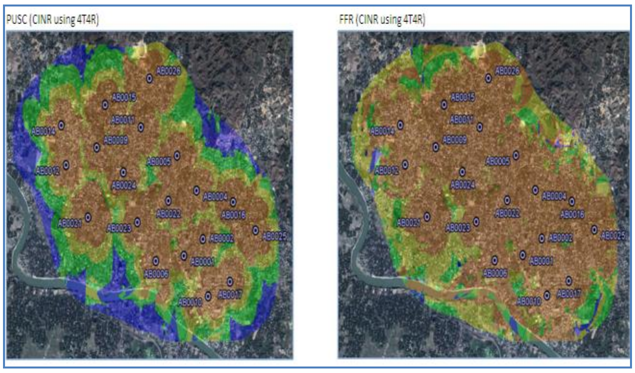

Figure 3 : PUSC vs. FFR (CINR based).

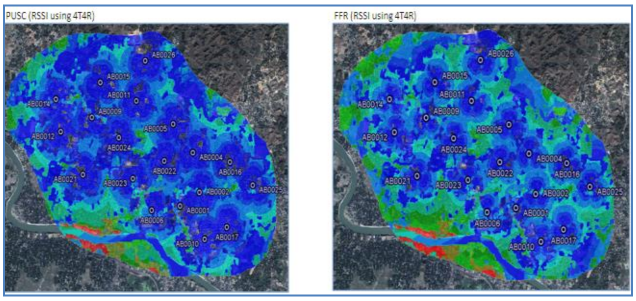

Figure 4: PUSC vs. FFR (RSSI).

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Table 5: Comparison between PUSC and FFR (RSSI based)

RSSI	PUSC			FFR		
	Surface (km²)	% of Covered Area	% Compu-tation Zone	Surface (km²)	% of Covered Area	% Compu-tation Zone
-60 <=RSSI <-40	14.2232	75.3647	66	12.7682	62.6534	59.2
-70 <=RSSI <-60	3.4436	18.2467	16	5.0674	24.8657	23.5
-80 <=RSSI <-70	0.6873	3.6418	3.2	1.9857	9.7438	9.2
-90 <=RSSI <-80	0.3411	1.8074	1.6	0.3496	1.7155	1.6
-110 <=RSSI <-90	0.1773	0.9395	0.8	0.2082	1.0216	1

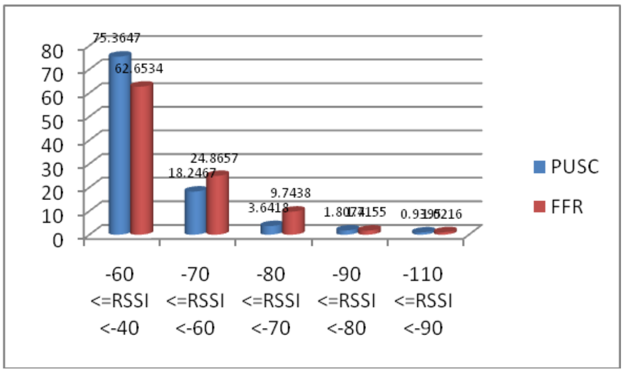

Figure 5: Comparison between PUSC and FFR (RSSI based).

Without using MIMO in both PUSC and FFR, the comparison between the performance of PUSC network and FFR Network is shown in Figs. 6 - 8. In Table 6, the comparison between different parameters of PUSC and FFR are also shown for different RSSI values.

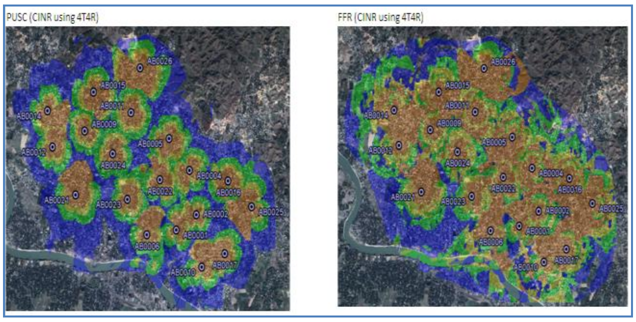

Figure 6: PUSC vs. FFR (CINR based).

Table 6: Comparison between PUSC and FFR (RSSI based)

RSSI	PUSC			FFR		
	Surface (km²)	% of Covered Area	% Compu-tation Zone	Surface (km²)	% of Covered Area	% of Comput-ation Zone
-60 <= RSSI <-40	9.4997	45.8205	44.1	5.5013	25.7883	25.5
-70 <= RSSI <-60	6.9207	33.3811	32.1	8.2343	38.5998	38.2
-80 <= RSSI <-70	3.4622	16.6995	16.1	5.0942	23.88	23.6
-90 <= RSSI <-80	0.7018	3.385	3.3	2.003	9.3894	9.3
-110 <= RSSI <-90	0.148	0.7139	0.7	0.4997	2.3424	2.3

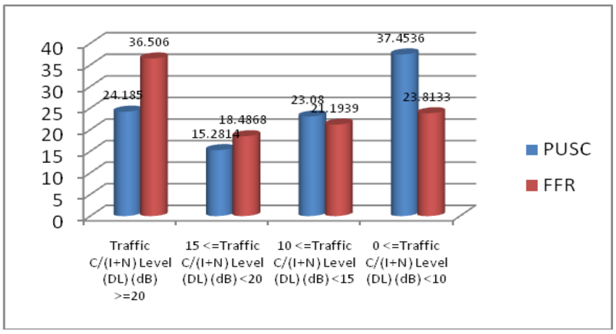

Figure 7: Comparison between PUSC and FFR (CINR based).

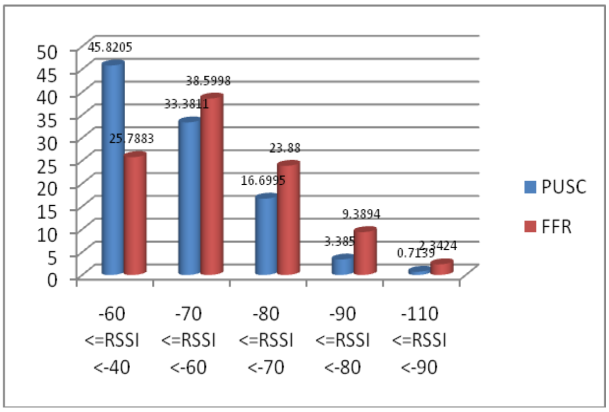

Figure 8: Comparison between PUSC and FFR (RSSI based).

From the figures, a very clear idea about the effects of features can be described. From Table 4, it can be seen that in a MIMO PUSC network, the CINR below 10 is 14.4% whereas in MIMO FFR network, it is only 1.4%. The RSSI is also better in FFR MIMO network. The same result can be seen in the non-MIMO network. Table 6 shows that the CINR drops down in PUSC network vastly which means that the network condition is worse and FFR shows pretty impressive results in terms of both CINR and RSSI. Between the MIMO-PUSC and non-MIMO-PUSC network, MIMO PUSC has better CINR and RSSI than that of non-MIMO network. The MIMO-FFR performs far superior than the non-MIMO version.

IV. CONCLUSION

As the frequency is the most limited, expensive and viable resource of any network, it needs to be used as efficiently as possible. The reason behind the present work is to study the use of features to optimize a wireless network cost effectively. In the present paper, it has been shown how a three band frequency network performance can be optimized by using the features very efficiently.

In world telecom market, the frequency band license has become the most prominent factor of any company's CAPEX. To utilize it more efficiently, features need to be improved as far as possible. To reduce the capacity constraints of FFR, Enhanced FFR can be implemented. MIMO can also be also implemented in the uplink to increase the uplink throughput.

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