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Improving Throughput For Mobile Receivers Using Adaptive Beamforming

Jaspreet Kaur
Electrical and Electronics Engineering
University of Glasgow
Glasgow, United Kingdom
2585552k@student.gla.ac.uk

Olaoluwa R Popoola
Electrical and Electronics Engineering
University of Glasgow
Glasgow, United Kingdom
Olaoluwa.Popoola@glasgow.ac.uk

Muhammed Ali Imran
Electrical and Electronics Engineering
University of Glasgow
Glasgow, United Kingdom
Muhammad.Imran@glasgow.ac.uk

Qammer H Abbasi
Electrical and Electronics Engineering
University of Glasgow
Glasgow, United Kingdom
Qammer.Abbasi@glasgow.ac.uk

Hasan T Abbas
Electrical and Electronics Engineering
University of Glasgow
Glasgow, United Kingdom
Hasan.Abbas@glasgow.ac.uk

***Abstract*— In anticipation of a rapid increase in wireless communication, MIMO is one key technology to be explored for 5G. Conventional approaches are unable to predict many of the key characteristics for MIMO channels, and more detailed methods suffer from significant computational complexity due to the number of antennas in a MIMO array. In this work, the beamforming performance for moving users in a large cell with effective channel throughput has been explored. The Glasgow University campus model is used to estimate channel properties when various beamforming techniques are implemented. The techniques explored are Maximum Ratio Transmission (MRT) (for transmitter), Equal Gain Combining (EGC), Selection Combining (SC), and Max Ratio Combining (MRC) (for receiver) beamforming in 3GPP Long Term Evolution (LTE). Throughput, received signal strength, and signal to noise interference ratio (SINR) are determined. By implementing the beamforming techniques, on average, we are able to improve the throughput from 9 Mbps to 14 Mbps. The best throughput/SINR has been observed with MRT-MRC in comparison to No-beamforming.**

Keywords*— *MIMO, Beamforming, Maximum Ratio Transmission (MRT), Selection Combining (SC), Equal Gain Combining (EGC), and Max Ratio Combining (MRC).

I. INTRODUCTION

Over the next decade, the telecommunication sector expects a substantial increase in wirelessly connected devices and mobile data-rate consumption. Networks will need to support greater data (used per region) than what is currently available, hundreds of connected devices, and much greater data rates, according to most estimates [1]. To address these expectations, the telecommunications industry is focused on several solutions for 5G, including additional spectrum and more efficient use of that spectrum. In terms of improving the infrastructure efficiency of a wireless network, the antenna design and performance are essential where enormous antenna arrays can be combined with beamforming techniques to send high bandwidth data streams to multiple users on the same frequency band. Due to the huge amount of multipath (the propagation of radio signals occurs from transmitters to receivers by two or more paths) in urban areas, using these techniques properly is difficult. Standard tools and methods for channel modelling are simply unable to forecast many of the critical channel properties for MIMO antennas.

As a result, this problem has developed into an active area of research with essential channel model requirements set out in METIS standards in [2]. An overview of the mathematical framework of beamforming is discussed in [3]. It has been demonstrated that the general beamforming optimization problem is an NP-hard computational problem [4]. It is a problem in which each solution's accuracy can be validated and a search algorithm finds a solution from all possible solutions. In the context of a wireless network having a user that frequently changes locations, this means the beamforming weights are not available as the amount of time required to compute the beamforming weights is longer than the user moving to a new location. As a result, the development of efficient yet approximate or heuristic beamforming algorithms is a hot topic of research [5]–[8]. In order to support beamforming techniques in these research domains, a channel model must calculate appropriate channel data. The state-of-the-art in the field of predicting or analysing the wireless channel characteristics with the help of ray-tracing and other wave propagation techniques has been used by researchers. Ray-tracing is a popular approach for forecasting wireless channel power and path gain. It is especially good at forecasting multipath in urban or indoor settings, where surface reflections, diffractions at corners, and transmissions through materials provide a lot of propagation paths between transmitters and receivers. Fig. 1 shows the set-up for the investigation of the effect on beamforming, showing the position of a transmitting MIMO antenna array and multiple receivers. In this paper, we present complicated channel characteristics between a MIMO base station and multiple mobile devices within the Glasgow University campus with considerable multipath. The set-up for this investigation is shown in Fig. 1. This is followed by a prediction of beamforming's capacity to deliver signals to numerous users utilizing approaches such as maximum ratio transmission (MRT) beamforming. The findings shed light on some of the major issues and complications that huge MIMO systems encounter. The rest of this work is arranged in the following manner. The system model and problem formulation are

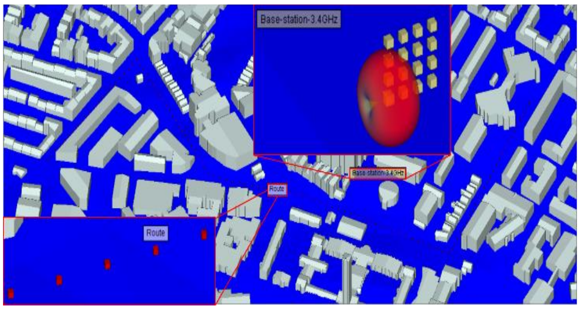

Fig. 1. Base Station with MIMO antenna and users within Glasgow university campus in Glasgow, UK

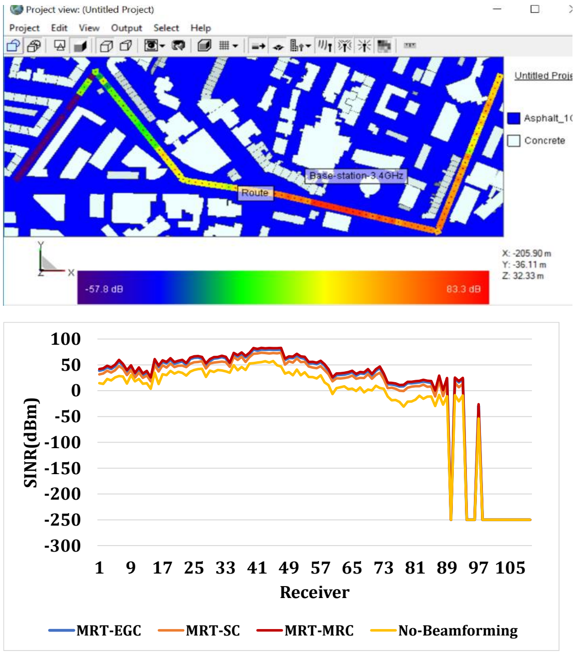

Fig. 2. SINR comparison of receiver diversity methods

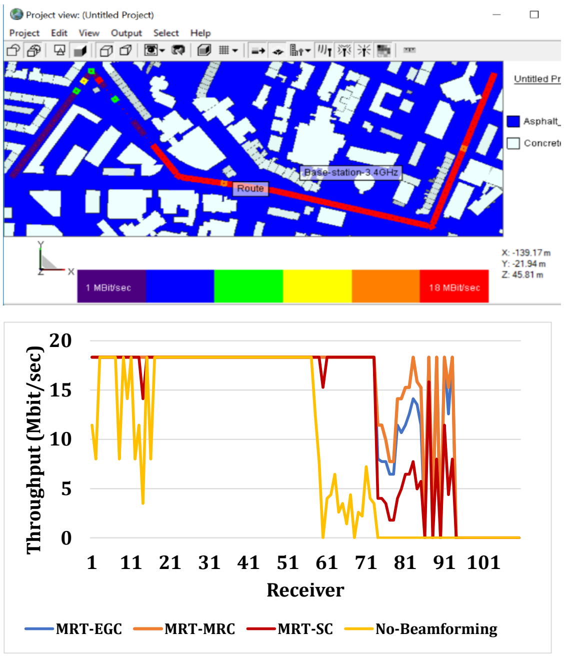

Fig. 3. Throughput comparison of receiver diversity methods

introduced in Section II. The simulation findings are presented in Section III, and the paper is concluded in Section IV.

II. SYSTEM MODEL

A. *Beamforming Techniques: MRT, EGC, MRC, SC*

Optimal beamforming strikes a balance between giving maximum power to a single user while decreasing or eliminating signal interference at other users. If user k receives the maximum power, interference to other users is uncontrolled and likely to be relatively strong for users near to user k. However, if other users' interference is reduced, the power reaching user k may be reduced as well, for a given overall transmit power. The ideal solution lies somewhere in the middle, making these two extremes valuable as limiting instances. The rest of this section gives a quick review of the mathematical beamforming approach used in this work. The summary uses the mathematical development in [3]. In the discussion, n represents antenna elements of the base station and k symbolizes user. $G_k[n]$ is the ratio of the power received by user k divided by the power radiated by element n with all other elements radiating zero power. $\theta_k[n]$ is the phase in radians of the voltage across a matched load at k under the same conditions. Note that $G_k[n]$ and $q_k[n]$ include all of the propagation paths in a complex urban environment from antenna element n to user k summed coherently. The propagation factor, $g_k[n]$, is defined as

$$g_k[n] \equiv \sqrt{G_k[n]}e^{j\theta_k[n]} \tag{1}$$

When written in bold without the [n], g_k is an N-dimensional complex row vector (1×N). Closely associated with g_k is the channel vector $\mathbf{h}_k$, an N-dimensional complex column vector (N×1) given by

$$\mathbf{h}_k = \mathbf{g}_k{}' \tag{2}$$

where $'$ denotes the conjugate transpose. The antenna element weight vector for user k is w_k, which is also an N-dimensional complex column vector. Maximum power to user k is achieved when the weights of the antenna elements are proportional to the channel values of the respective elements. This arrangement is known as maximum ratio transmission, or MRT, and is a relatively simple beamforming solution [9].

Antenna diversity methods use variances in the signal received by antennas spaced half a wavelength or more apart to generate a more robust signal with less fading at the receiver. MRC, EGC and SC are the most broadly utilized receiver diversity techniques [10]. These methods are designed to identify a collection of weights that optimizes a given function. To reduce the impact of fading on multiple received signals, the weights are selected for each user. The weighted received signals, in MRC, are used so that the SNR equals the sum of the average SNRs of each branch. In EGC, on contrary, the evenly weighted received signals are summed up. The selection combiner chooses the highest SNR [10]. The ith branch's received signal is given by

$$r_i(t) = g_i S(t) + n_i, \tag{3}$$

Where $i = 1,2,\dots,M$, S(t) is the unit-power transmitted signal and g_i is gain.

Selection Combining

The highest SNR is selected as the output SNR in selection combining (SC):

$$\omega_i = \begin{cases} 1 & \gamma_i = \text{Max} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

SNR is:

$$\gamma_T = \Gamma \sum_{i=1}^{M} \frac{1}{i} \cong \Gamma\left(C - \ln M + \frac{1}{2M}\right) \tag{5}$$

where C is Euler's constant, Γ is average SNR, M is the diversity branches.

Equal Gain Combining

To improve the average SNR, an equal gain combiner (EGC) sets unit gain at each branch. In EGC,

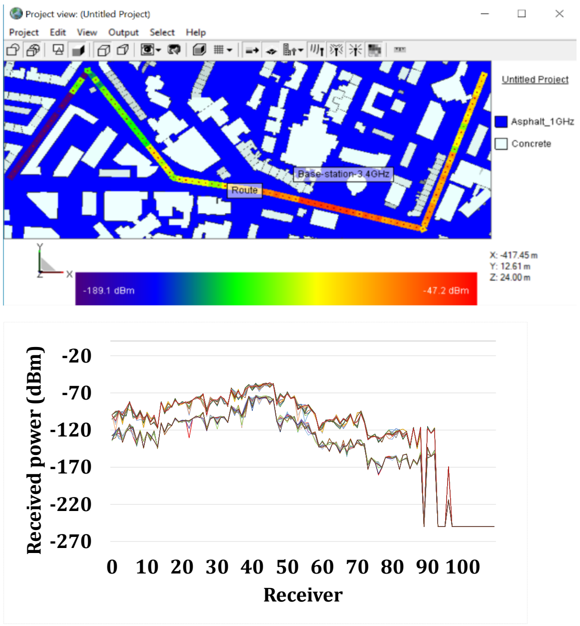

Fig. 4. Receiver Power to receivers along Route for all 32 MIMO Sub-channels

$$\omega_i = e^{j\angle g_i} \Rightarrow \omega_i * g_i = |g_i| \Rightarrow \boldsymbol{\omega}\mathbf{G}^T \quad (6)$$

$$= \sum_{i=0}^{M-1} |g_i|, \mathbf{G} = [g_1, g_2, \dots, g_M] \quad (7)$$

$$\gamma_i = \frac{\left[\sum_{i=0}^{M-1} |g_i|\right]^2}{M\sigma_n^2} \quad (8)$$

$$\gamma_T = \frac{E\left\{\left[\sum_{i=0}^{M-1} |g_i|\right]\right\}^2}{M\sigma_n^2} = \left[1 + (M-1)\frac{\pi}{4}\right]\Gamma \quad (9)$$

$\sigma_n^2 = N_0/2$ is the variance.

Maximal Ratio Combining

The receiver in MRC linearly joins the received signal $r_i(t)$ with ω (i) that is i^th branch's weighting coefficient. The linear diversity combiner's output signal r(t) is therefore provided by

$$r(t) = \sum_{i=1}^{M} \omega_i r_i(t) = S(t)\sum_{i=1}^{M} \omega_i g_i + \sum_{i=1}^{M} \omega_i n_i \quad (11)$$

As S(t) is unit power, SNR is

$$\gamma_T(\boldsymbol{\omega}) = \frac{1}{\sigma_n^2}\frac{\left|\sum_{i=1}^{M} \omega_i g_i\right|^2}{\sum_{i=1}^{M} |\omega_i|^2} = \frac{|\boldsymbol{\omega}\boldsymbol{G}^T|^2}{E\{|\boldsymbol{\omega}\boldsymbol{N}^T|^2\}} \quad (12)$$

$$E\{|\boldsymbol{\omega}\boldsymbol{N}^T|^2\} = E\{|\boldsymbol{\omega}\boldsymbol{N}^T\boldsymbol{\omega}^T\boldsymbol{N}|\} = \boldsymbol{\omega}^2\sigma_n^2 \quad (13)$$

If $\boldsymbol{\omega}$ is directly proportional to **G**, MRC with ideal channel estimation has the highest output SNR of amongst three approaches, as per Cauchy-Schwarz inequality equation. If $\boldsymbol{\omega} = \boldsymbol{G} \Rightarrow \gamma_T = |\boldsymbol{G}\boldsymbol{G}^T|/\sigma_n^2\boldsymbol{G}^T\boldsymbol{G} = \boldsymbol{G}\boldsymbol{G}^T/\sigma_n^2 \Rightarrow \sum_{i=1}^{M} |\gamma_i|$, the overall SNR is the summation of the SNR at each element [10].

B. Received Power, SINR, and Throughput

When the MRT beamforming technique is used in a MU-MIMO system, the transmitter transmits a beam to every user, k, according to its weight vector. The resultant power received by each user for the signal intended for that user is calculated as the product of the channel gain and this weight vector:

$$\mathrm{Pr}_k = |\mathbf{g}_k\mathbf{w}_k|^2 = |\mathbf{h}_k * \mathbf{w}_k|^2 \quad (14)$$

Because the MIMO system transmits to multiple users at the same frequency, a critical performance metric for the system is the signal-to-interference-plus-noise ratio (SINR) for each user. This is calculated as:

$$\mathrm{SINR}_k = \frac{|\mathbf{g}_k\mathbf{w}_k|^2}{\sum_{i=k}^{K} |\mathbf{g}_k\mathbf{w}_i|^2 + \sigma^2} = \frac{|\mathbf{h}_k * \mathbf{w}_k|^2}{\sum_{i=k}^{K} |\mathbf{h}_k * \mathbf{w}_i|^2 + \sigma^2} \quad (15)$$

The first term in the denominator represents interference from transmissions to other users, and the second represents random noise.

Throughput and SINR are connected as:

Throughput = Bandwidth * $\log_2$(1+SINR) (16)

one can achieve high throughput with low SINR if the bandwidth is large and low throughput and high SINR if the bandwidth is small.

III. Results and Discussion

To demonstrate MIMO simulation concepts described in Section II, a small cell scenario that is University of Glasgow campus was set up in a dense urban environment, in Glasgow, Scotland, UK. The layout of the university campus was obtained with the assistance of the REMCOM team from a third party (open street map). Fig. 1 shows the base station, positioned near the university library. This was defined to have a 4x4 array with both vertically and horizontally polarized antennas, with a total of 32 elements for 3.4 GHz. 110 route receivers were positioned 10 m apart from each other considered as moving vehicles along a route through the scene, shown as a red line (Fig. 1). The "Route" feature is available in Wireless Insite. There exist multiple receivers (red points in Fig. 1) on the route: some receivers correspond to the NLOS path and others correspond to the LOS path. For simplicity, these devices were specified to have half-wave dipole array antennas and the specifications are shown in Table I. Next, Intel(R) Core (TM) i7-10850H CPU @ 2.70GHz 2.71 GHz, 16GB RAM, Wireless InSite® MIMO version 3.3, was used to simulate the scenario. There are two clusters of received power curves that are separated in Fig. 4. The cluster with higher received power is from transmitting antennas that were vertically polarized (matching the polarization of the receiver). The cluster with lower received power is from transmitting antennas that were horizontally polarized. Each curve (Fig. 4) represents the power received from each element of the transmitter antenna array to receivers. The sudden drop in power represents the shadow area for receivers to receive the signal from a transmitter. The reason for shadowing is the distance between a base station (transmitter) and receivers on the route and also the height of buildings in the path of them. To analyze the effects of SC, EGC, and MRC for the receivers three communication systems in Wireless Insite was created. The throughput and SINR were calculated from the simulation results and used to observe beam patterns using the MRT (for transmitter), EGC, MRC, and SC (for receiver) beamforming techniques. MRT was used to calculate the best beam for every receiver on the route. Results in Fig. 2 and Fig. 3 show the sky view and curves, there is a slight difference between the three diversity methods for improving SINR and throughput. However, in comparison to No-beamforming, on average, we are able to improve the throughput from 9 Mbps to 14 Mbps. The 14.43 Mbps has been achieved through MRT-MRC beamforming implementation on transmitter and receiver side antenna array. The SINR has also improved from -24 to 1 dBm after implementing beamforming in comparison to No-beamforming. MRT-MRC has contributed the best SINR/throughput as shown in Table II.

TABLE I. ANTENNA SPECIFICATIONS FOR GLASGOW UNIVERSITY CAMPUS

Parameter	***Definition***
Frequency	3.4 GHz
Base Station Antenna	4x4 cross-polarization, 32 elements MIMO array
Base Station Height	10 m
Receiver Height	2 m
Receiver Antenna	Half-wave vertical dipole

TABLE II. BEAMFORMING TECHNIQUES

Beamforming	***Throughput (Mbps)***	***SINR (dBm)***
MRT-EGC	14.07	-1.54
MRT-MRC	**14.43**	**0.88**
MRT-SC	13.03	-7.71
No-Beamforming	9.43	-23.81

IV. CONCLUSION

The results of wave propagation for forecasting multipath and channel parameters for massive MIMO systems are reported in this study. We showed how complicated channel data from simulations can be retrieved and used to examine MIMO performance using beamforming techniques and estimating the resulting received power, SINR and throughput. By implementing beamforming techniques, on average, our results show a 53% increment in the throughput in comparison to No-beamforming. In future, we can improve further by implementing more robust adaptive beamforming algorithms. These findings reveal a novel capability that can be utilized to conduct research and estimate the performance of large MIMO antenna arrays in future 5G mobile networks.

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