Interference-aware Multi-User, Multi-Polarization Superposition Beamforming (MPS-Beamforming)

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Abstract—**Wireless technology has witnessed a massive amount of attention in communication domain, not only in industrial field, but in academia field as well. Multiple-input multiple-output (MIMO) systems among them has emerged itself as a promising future technology. Few of the properties of MIMO include diversity, spatial multiplexing, and beamforming. Exploiting these properties can lead us to improve the data rate. Among these properties lies polarization diversity which has large potential to improve the performance in wireless technologies. This paper contributes in investigating and implementing interference-awareness to multiple users with the help of dual polarized MIMO schemes at ±45º. Various factors such as Cross-polarization Discrimination (XPD), Signal to Interference noise ratio or SINR have been viewed that utilizes multi-polarization superposition beamforming (MPS-Beamforming) to optimize the system design. Simulation results are provided which shows improvement of the performance in terms of the Symbol Error Rate (SER) for the users. The polarization diversity with beamforming has high potential for the next generation wireless technologies.**

I. Introduction

Wireless Communication is one of the areas which has seen a surge of new technologies. These technologies have emerged since the time when the third generation (3G) of cellular networks were introduced, and these standards have been evolved, since the optimization of technologies and with the increase in the number of smart phone devices. The ability to connect to the internet has led the 4G Long-Term Evolution (LTE) and 5G New Radio (NR) cellular standards to thrive for better performance.

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Wireless communication mainly focuses on the reliability of the users and/or the Base Stations (BS). This can be achieved by multiple-input multiple-output (MIMO) communication. To increase the performance and to have a reliable communication, techniques such as spatial multiplexing and diversity are utilized.

Spatial multiplexing utilizes the technique of rendering the data to be divided into several streams called sub-streams; and those sub-streams are transmitted via different transmit antennas [1-2]. On the other hand, MIMO diversity is a technique where the information is spread across multiple transmit antennas to maximize the diversity advantage in fading channels.

Diversity can be obtained in a few ways such as time, frequency, space, and polarization. It is known that massive MIMO use an extra dimension of space and separate different receivers at the same time serving massive number of users. This advantage of massive MIMO thus becomes an answer to industrial revolution. Conventional space diversity is usually obtained by having very less space between the antennas. However, space diversity, when the base station is elevated would require the spacing of the antenna in the order of 30 wavelength. polarization diversity, on the other hand would not require any antenna spacing, with or without the elevated base station as the electromagnetic waves arrive at the antennas at different angles [3]. For this reason, polarization domain can be regarded as the key to mitigate interference as well as improve the Symbol Error Rate (SER).

Recent literature work shows that radio signals are susceptible to degradation and fading. To combat these effects, diversity may be incorporated at the Base Stations. These techniques include time, frequency, space diversity, and polarization diversity. However, multiple antennas become unsuitable in space diversity if the antenna spacing between them is too large. Several polarization

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diversity models have embedded the minimum acceptable Base Station antenna separation into them [4-7]. Mounting an antenna thus becomes difficult. This is when polarization diversity at the Base Station becomes an advantage. The polarization diversity overcomes the limitations because the antenna is positioned at an angle ±θ° [7]. Suppose if the Base Station transmits a signal at either of the angles, the mobile can receive either with the same polarization or different polarization, based on line of sight communication. Studies have shown that the polarization reception improves the capacity of wireless system [8-13].

Even with the potential that polarization domain has, it has not been fully utilized. It is seen that the channel capacity improves and the SER reduces [14-15]. Based on the 5G standard society, it has been agreed that the next-generation Node B (gNB) which is also equivalently known as the Base Station is fixed with either polarization of ±45°. The receiver, however, based on the hand-tilting or due to the movement of the users themselves, can receive the signal from both negative and positive polarization from the transmitter [13-14]. The use of a dual-polarized antenna thus becomes a cost-effective and space-efficient alternative where the antenna structure employs two orthogonal polarizations.

Contributions: Using the convenience and the purpose served in the prior literature, this paper provides some contributions as follows:

- We introduce a system model that employs a dual-polarized Transmitter antenna (Tx) positioned at an angle of ±45º.
- Taking in account, the Cross-Polarization Discrimination (XPD), we introduce a new scheme that analyses the influence of the transmit beam by allocating the power to it on the receiver end.
- Theoretical study and simulation results for an OFDM based system that utilizes Superposition Beamforming. The performance is measured in terms of Symbol Error Rate (SER) for different power at the polarized transmitter antenna.

Organization of the paper: The rest of this paper is organized as follows. Section II introduces the system model and states our assumptions. In Section III, the proposed scheme and its interpretation are provided. The analysis of the schemes are verified in section IV via simulation results. Section V concludes the paper.

II. System Model

The system model is shown in Fig.1 where we consider, one next-generation Node B (gNB), formerly known as the Base station (BS) that consists of a fixed dual-polarization antenna at ±45º. These antenna elements can be extended to an array of multiple antennas spatially separated, where the antenna elements of one column represent either of the two polarizations from +45° or −45°. The User Equipment (UE), formerly known as the Mobile Stations have flexible polarization due to the movement of the users and change in polarization angle caused by the hand-tilting of the phone. While transmitting, the users will get signals from the same Tx polarization antenna (shown in solid lines), called the co-polarized components and from other polarization as well (shown in dotted lines). These are the cross polarized components. Because of these components, a new theory is unfolded leading to interference mitigation between the users.

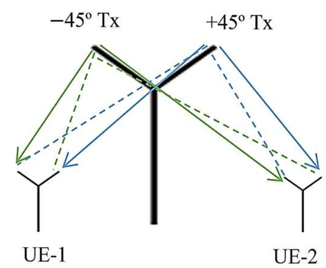

Fig. 1. 5G beamforming structure

A downlink cellular network structure for dual beamforming, supported by 5G is shown in Fig. 2, where, $h_m^{(N_{Rx.}/P_{Rx.})(N_{Tx.}/N_{Tx.})}$, $\{Tx, Rx\} \in$ {N,P} and m ∈ {1,2} represents the channel impulse response from the gNB to MS polarized antenna. ϕ is the angle between the Transmitter-Receiver (Tx-Rx) boresight line and the street line.

We have assumed that both the users are in the same street line but standing apart from each other. Due to the formation of the superposition of the channel impulse at −45° and +45°, there exists 2 signals having co and cross polarization components.

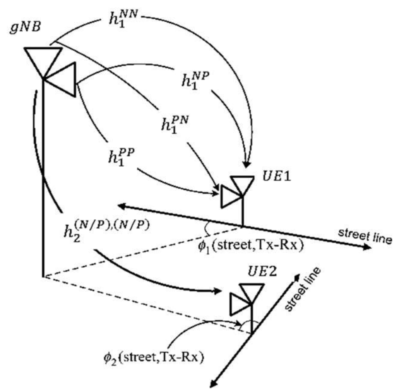

Fig. 2. Downlink Cellular structure of a dual Beamforming for 2 users

The Degree of Depolarization is measured in terms of Cross-polarization discrimination (XPD). Thus, XPD is defined as the ratio of co-polarized average received power to cross-polarized average received power.

$$XPD_{aa-bc} = \frac{<P_{aa}>}{<P_{bc}>}; \tag{1}$$

Where a, b, c= Negative or positive polarized and $b \neq c$. Thus, substituting a, b, c as N/P, we get

$$XPD_{NN-NP} = \frac{<P_{NN}>}{<P_{NP}>}, \tag{2}$$

$$XPD_{NN-PN} = \frac{<P_{NN}>}{<P_{PN}>}, \tag{3}$$

A. *Optimal Transmission Power Allocation*

Orthogonal frequency division multiplexing (OFDM) is a prevalent component of the current wireless communication system; consequently, the system model and the associated simulations in this paper assume OFDM system. Firstly, baseband signal processing for the demodulation is fulfilled at the Rx, where the cyclic prefix is removed (which is initially applied at the Tx); then, the discrete Fourier transform (DFT) of the demodulated signal is taken into account.
Hence, the received signals are as follows,

$$R_1^{N,(N,P)} = \sqrt{\alpha E_{s,N}} H_n^{(N,N)} s(n) + \sqrt{\beta E_{s,P}} H_n^{(N,P)} s(n) + v_n^N, \tag{4}$$

$$R_2^{P,(N,P)} = \sqrt{\alpha E_{s,N}} H_n^{(P,N)} s(n) + \sqrt{\beta E_{s,P}} H_n^{(P,P)} s(n) + v_n^P, \tag{5}$$

where $E_{s,N/P}$ is the transmitted information symbol energy,
$H_n^{(N/P,N/P)}$ is the channel frequency response at Negative/Positive polarized Rx. polarized due to Negative/Positive polarized Tx. antenna. v_n^N is the noise at the receiver at -45° polarization and v_n^P is the noise at the receiver at 45° polarization. The term α and $\beta = (1-\alpha)$ are the transmit power allocation ratio ranges between $0 \leq \alpha \leq 1$ and consequently, $0 \leq \beta = (1-\alpha) \leq 1$. The XPD for the received signal using MPS beamforming [13] is given by

$$\overline{XPD} \triangleq \frac{E[|R_1^{N,(N/P)}|^2]}{E\left[|R_2^{P,(N,P)}|^2\right]} \tag{6}$$

$$\overline{XPD} = \frac{\alpha + \beta/XPR^N}{\alpha/\overline{XPD}^{(N)} + \beta/(\overline{XPD}^{(N)} XPR^N)} \tag{7}$$

The term $\overline{XPD}^{(N/P)}$ is the received signal polarization without using MPS beamforming and it defined as following

$$\overline{XPD}^{(N/P)} \triangleq \frac{\sum_{n=1}^{N} |H_n^{(N,N/P)}|^2}{\sum_{n=1}^{N} |H_n^{(P,N/P)}|^2} \tag{8}$$

and XPR^N is defined as following

$$\overline{XPR}^{(N)} \triangleq \frac{E[|H_n^{(N,N)}|^2]}{E[|H_n^{(N,P)}|^2]} \tag{9}$$

where n is the subchannel index and $\overline{XPR}^{(N)}$ is the cross polarization ratio which is defined as the received signal power ratio at Rx antenna at $-45°$ polarization from Tx antennas with $\pm 45°$ polarization.

The transmitter allocates some transmission power (α and β) to the $-45°$ polarization and +45° polarization, respectively. The main reason for the allocation of the power ratio is to align the Rx signal polarization to that of the Rx antenna polarization. Rx antenna polarization can be changed because of the hand-tilting phenomenon of the phone and the movement of the user. Fig. 3 shows the schematic diagram of the alignment of the received signal to receive antenna polarization.

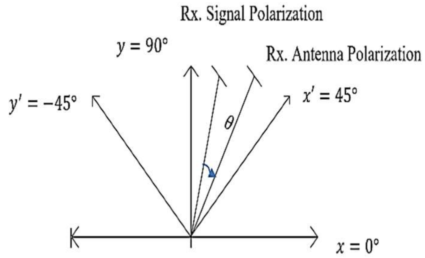

Fig. 3. Receive signal Polarization Alignment

B. Adjustment of Power Allocation

The gNB can adjust $(\alpha,\ \beta)$ by assigning different power ratio to $-45°$ and $+45°$ polarization to its antenna such that the receive signal polarization aligns with the received antenna polarization. Until the optimal Rx XPD is obtained, the power allocation ratio is varied. For the adjustment of optimal rotation angle to obtain the Rx. XPD, the α and β are taken as follows: [0 0.2 0.5 0.8 1] and [1 0.8 0.5 0.2 0] respectively. This means that if gNB with $-45°$ polarization has power 0, then the gNB with $+45°$ polarization will have power 1 and so on for different cases. Allocating such powers will ensure interference between two (or more) users is as little as possible.

Another important concept in beamforming is the null steering. Null steering becomes an advantage when one UE is placed in the sight of the beamforming and the other user is placed at the nulls. One user will receive the signal from either a different gNB or at a different Tx power allocation ratio. So, the system is engineered in a way where both the users receive the signals at the same time, without causing any interference to each other. The users having 2 polarization antennas, are either in the same vicinity or at different locations from each other.

III. Results and Discussions

This section provides comprehensive simulation results and the corresponding analysis for different power allocation ratio at the transmitter; and for different receive antenna polarization angles. The parameters used in the simulations are demonstrated in Table I.

TABLE I. Parameters Setup For The Simulation

Parameters	Value
Number of subchannels	$2^{11} = 2048$
Modulation method	4-PSK
Channel center frequency (f)	2.48 GHz
Channel Length	32
Number of Transmit Antennas	2
Number of Receive Antennas	4 (2 for 2 UEs)

A. Receiver Angle Polarization vs. Cross Polarization Discrimination (XPD)

Table II. presents the XPD for both the users with different receive polarizations angle from $-90°$ to $0°$. The movement of the tilting of the phone is incremented every 10 degrees.

TABLE II. Classification Results For Rx. Antenna Polarization Angle vs The XPD For Both Users

Rx. Ant. Pol.	XPD for UE-1 [dB]	XPD for UE-2 [dB]
$-90°$	8.7981	3.3407
$-80°$	12.0450	3.5527
$-70°$	14.4360	3.7748
$-60°$	8.8578	4.0588
$-50°$	8.2023	4.2741
$-40°$	4.0976	12.4402
$-30°$	3.8549	11.3214
$-20°$	3.5937	9.5396
$-10°$	3.3324	8.0114
$0°$	3.2491	6.6381

B. Signal to Intereferncе Noise Ratio Vs. Symbol Error Rate (SER)

From Table II, it can be seen that when the receive antenna polarization angle is $-70°$, XPD for UE-1 is higher than UE-2. SER is measured for both the users when power is allocated to both the Tx antenna polarization.

The SER of the Rx antenna while allocating the power at 0.8 at $-45°$ polarized Tx antenna is 2.2×10^{-3} and the SER of the Rx antenna while allocating the power at 0.2 at $+45°$ polarized Tx antenna is 4.4×10^{-3} for UE-1. Similarly, the SER of the Rx antenna while allocating the power at 0.8 at $-45°$ polarized Tx antenna is 4.2×10^{-3} and the SER of the Rx antenna while allocating the power at 0.2 at $+45°$ polarized Tx antenna is 8.7×10^{-3} for UE-2. It is seen that the SER is much lower for UE-1 as compared to UE-2 as shown in Figs 4 and 5. The UE-2 is placed at the nulls of the UE-1, where even though both the users receive some signals at the same time, from the same gNB, they do not experience any interference.

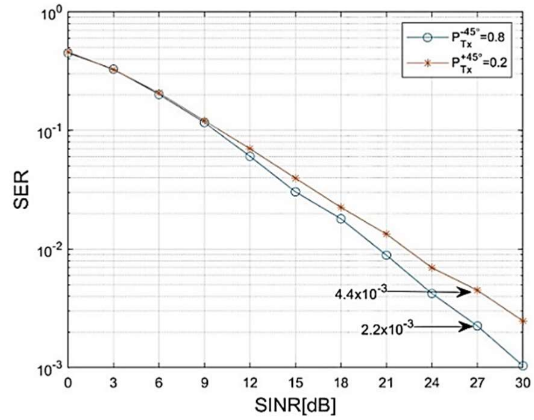

Fig. 4. SER for UE-1 in the scenario of Rx. antenna Polarization of $-70°$

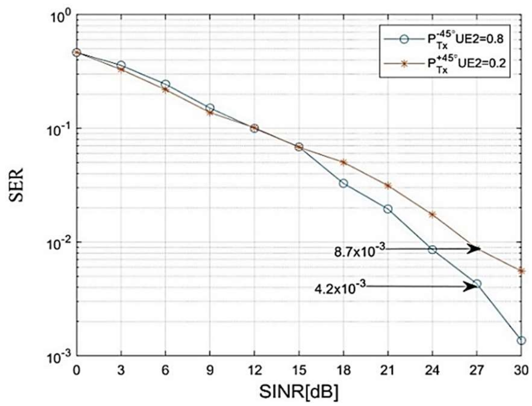

Fig. 5. SER for UE-2 in the scenario of Rx. antenna Polarization of $-70°$

If the power allocated to the $-45°$ polarized Tx antenna is changed from 0.8 to 0.2 and the orientation of the hand is changed from -70º to -40º, the SER for UE-1 becomes 3.8×10^{-2} and for UE-2, it is 3.6×10^{-2}. Changing the power allocation from 0.8 to 0.2 at the $+45°$ polarized Tx antenna, the SER for UE-1 is 7.3×10^{-3} and for UE-2, the SER is 2.1×10^{-3}. This shows that the performance of UE-2 is much better than the first one by looking at drop in the SER as shown in Figs. 6 and 7. This again verifies from Table II that the XPD of UE-2 is higher than UE-1.

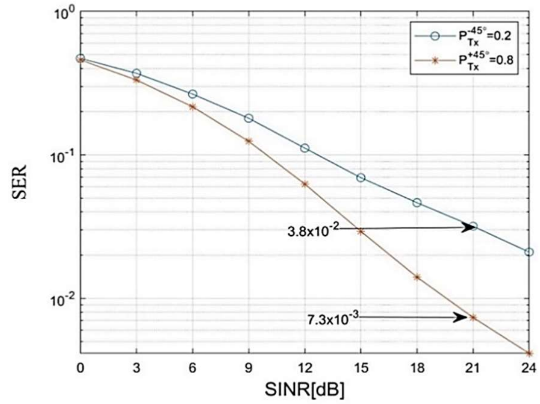

Fig. 6. SER for UE-1 in the scenario of Rx. antenna Polarization of $-40°$

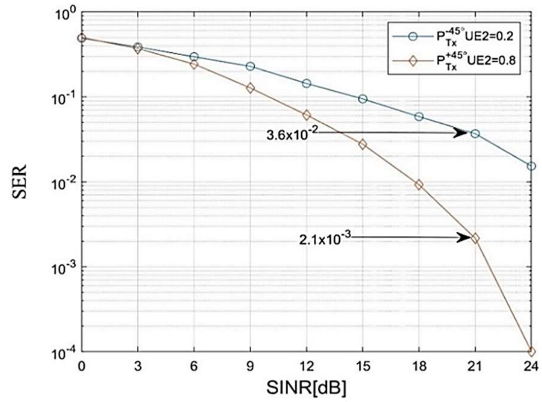

Fig. 7. SER for UE-2 in the scenario of Rx. antenna Polarization of $-40°$

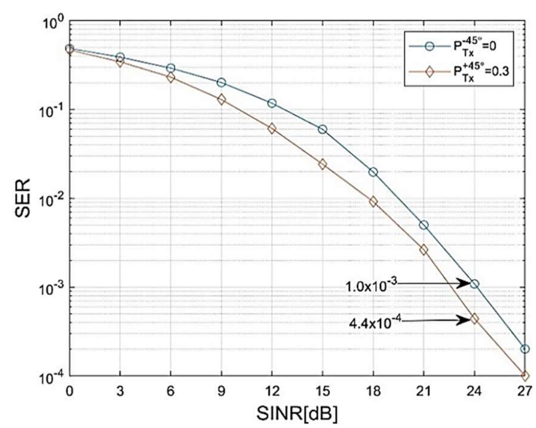

Fig. 8. SER for different Tx power allocation in the scenario of Rx antenna polarization of $+20°$ for UE- 1

Figs. 8 and 9 show that SER is significantly low while using MPS-Beamforming as compared to when whithout using Beamforming ($\alpha = 0$). When the Rx antenna polarization angle is $+20°$ for user 1, the SER at 24dB is 1×10^{-3} when no beamforming is used and the SER is 4.4×10^{-4} when beamforming is used ($\alpha = 0.3$). For UE-2, at the same polarization angle, $+20°$, the SER at 21dB when using beamforming ($\alpha = 0.5$) is 9×10^{-4} and without using beamforming , the SER is 1.8×10^{-2}.

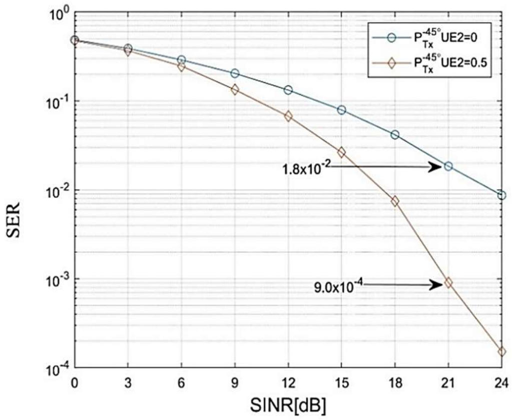

Fig. 9. SER for different Tx power allocation in the scenario of Rx antenna polarization of $+20°$ for UE- 2

IV. Conclusion and Future Work

This paper presents an interference-aware, multi-user, multi-polarization superposition beamforming (MPS) system. Due to the presence of channel depolarization, a method to evaluate the XPD is achieved as well as analyzing the performance of polarization diversity. One gNB and two users, whose structure is based on 5G standards scheme is used which shows improvement in the Symbol Error Rate (SER). It can be seen from the simulated results that there is a significant amount of improvement in terms of SER when beamforming is used as compared to when no beamforming is used, reducing the interference in all possible ways. One of our future scopes would be adding multiple antenna panels as well as adding more users and further research can be done to study the impact of these parameters on this scheme and make a way that is approachable, practical and can be used in real life.

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