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Adaptive Spatial Multiple Access (SMA) for millimeter waves 28 GHz Outdoor Channel

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Abstract

Using Spatial Multiple Access (SMA) jointly with Adaptive Modulation, we propose a low complexity and spectral efficient Non-Orthogonal Multiple Access (NOMA) scheme. The traditional Spatial Multiple access overcomes the complexity of traditional NOMA receiver known as Successive Interference Cancellation (SIC). However, a fixed data rate is archived. On the other hand, the Adaptive SMA technique is introduced in this paper in order to achieve high data rates while keeping the ABER below a certain threshold. In addition, we investigate the performance of this proposed technique in the 28 GHZ outdoor channel using the fluctuating two ray (FTR) model. Using Monte-Carlo simulations, the average bit error rate (ABER) and the average spectral performance results are presented.

1 Introduction

One of the goals of the fifth generation (5G) is to enable large numbers of devices to be connected with large bandwidth [1]. To meet this requirement, Non-Orthogonal Multiple Access (NOMA) is considered as the multiple access scheme for this generation. However, traditional schemes such as Power-domain NOMA [2] or Code- Domain NOMA [3,4] requires complex receivers such as Successive Interference Cancellation (SIC) or message passing algorithm (MPA) respectively.
In order to avoid the implementation of such complex receivers, spatial multiple access (SMA) was proposed in [5]. It allocates different users in different domain as shown in Figure 1, One user's data is responsible for antenna selection (spatial domain) and the other user's data is transmitted via the selected antenna. At the receiver side, it tends to use and tends to use either maximal ratio combining (MRC) or maximal likelihood (ML) as a receiver. In addition, this scheme limits the number of operating RF chain to only one. This leads to archive a higher increase in the energy efficiency (EE) of the system. However, this technique provides a fixed data rate of each user.
Adaptive modulation [6] can be used to increase the spectral efficiency of the SMA. Based on multiple thresholds, the system can adapt the modulation parameters, such as constellation size, to the fading channel conditions while respecting the average bit error rate (ABER) requirements.
The millimeter-waves band is a candidate for 5G deployment due to the spectrum scarcity in the traditional microwave bands. The 28 GHz band is considered for an initial deployment of mm-waves cellular, given their relatively lower frequency within the mm–waves range which leads to lower attenuation [7].

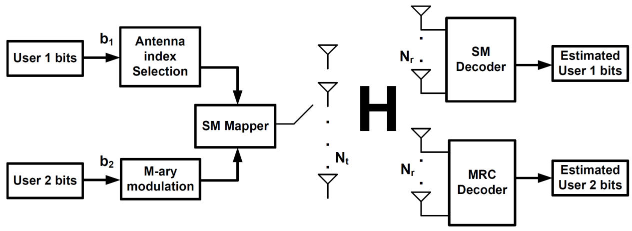

Figure 1. Spatial Multiple Access scheme.

In this paper, a proposed adaptive SMA scheme is investigated to achieve higher data rates while maintaining the ABER below a certain threshold with the study of its performance under the 28 GHz outdoor channel.
The rest of paper is organized as follows. In section 2, system model is described adaptive scheme is presented. In section 3, the performance analysis of the adaptive SMA system is discussed in terms of in terms of the average SE (ASE) and the ABER. Section 4 shows the numerical results to verify the analytical expression.

2 System Model and Adaptive Scheme

2.1 System and channel model

We consider a downlink system consists of a base station (BS) equipped with multiple transmit antennas N_t and serving two users' equipment (UE). Each UE is equipped with N_r receiving antennas. Let the bits of UE-1 b_1 is transmitted via space shift keying (SSK) where antenna j is used for transmission. The selection process is based on SSK modulation for b_1 and the data of UE-2 b_2 is transmitted via M-ary modulation. In that case UE-1 is called the Spatial Modulation user (SM user) and UE-2 is called M-ary user. The transmitted vector takes the form $x_j \in C^{N_t \times 1}$

$$x_j = \begin{bmatrix} 0 & 0 & \dots & \underbrace{f_{M-ary}(b_2)}_{j^{th}\text{ antenna}} & \dots & 0 & 0 \end{bmatrix}^T \quad (1)$$

Where the j^{th} antenna is selected for transmission and $f_{M-ary}(.)$ is the constellation mapping operation for M-ary modulation.
The multipath fading channel model for 28 GHz is the Fluctuating Two-Ray (FTR) fading [8]. It consists of two fluc-

tuating components plus random phase and diffuse components. It arose as the generalization of the two-wave with diffuse power (TWDP) fading model proposed by in [9]. The FTR fading distribution provides a much better fit than Rician fading to the 28 GHz field measurements results in [10].
In FTR model, Assume the complex baseband receive signal as

$$V_r = \sqrt{\zeta} V_1 \exp(j\phi_1) + \sqrt{\zeta} V_2 \exp(j\phi_2) + X + jY \tag{2}$$

Where $V_n e^{j\varphi_n}$ represents the n^{th} component with constant amplitude V_n and uniformly distributed phase φ_n. $X + jY$ is a complex Gaussian random variable with $N(0,\ \sigma^2)$ which represents the diffuse received signal component.

The FTR model is defined by the following parameters

$$k = \frac{{V_1}^2 + {V_2}^2}{2\sigma^2} \tag{3}$$

$$\Delta = \frac{2V_1V_2}{{V_1}^2 + {V_2}^2} \tag{4}$$

k represents the ratio of the average power of the dominant components to the power of the remaining diffuse multipath. Δ represents the similarity between the received powers from the dominant components and it ranges from zero to one. $\sqrt{\zeta}$ is a Gamma distributed random variable and has the following probability density function.

$$f_\zeta(x) = \frac{2(m^m)x^{(2m-1)}}{\Gamma(m)} e^{(-mx^2)} \tag{5}$$

The FTR fading model is suitable for many propagation channels. Table 1 summarizes the relationship between FTR model and classical fading channel models (Rayleigh, Rician and Nakagami–m).

Table 1. the relation between FTR model parameters and classical fading channel

Fading Channel	FTR model parameters (Δ,k,m)
Rayleigh	$\Delta = 0, k \to \infty, m = 1$
Ricean-(k)	$\Delta = 0, k = k, m \to \infty$
Nakagami-(m)	$\Delta = 0, k \to \infty, m = m$

The PDF and CDF of the received SNR for multiple branch receiver for this model can be found in [11].

2.2 Proposed Adaptive Modulation Scheme

We consider an adaptive modulation scheme as illustrated in Figure 2. in order to send more data for better channel conditions. In that case, the MRC receiver feeds back the modulation mode for the transmitter after estimating the channel state information. We consider the constant-power variable-rate uncoded M-QAM [6] as an adaptive modulation system. With this adaptive modulator, the SNR range is

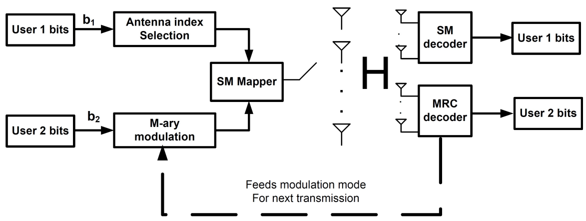

Figure 2. Proposed adaptive modulation scheme

divided into $N+1$ fading regions and the constellation size $M = 2^n$ is assigned to the n^{th} region ($n = 0, 1, \ldots, N$). The BER of coherent 2^n-QAM with two-dimensional Gray coding over an additive white Gaussian noise (AWGN) channel with a SNR of γ can be well approximated as

$$P_{bn}(\gamma) \cong \frac{1}{5}\exp\left(\frac{-3\gamma}{2(2^n-1)}\right) \tag{6}$$

Given a target instantaneous BER equal to P_{b0}, the adaptive modulator switching thresholds γ_n for $n = 0, 1, \ldots, N$ are given by:

$$\gamma_n = -\frac{2}{3}\ln(5P_{b0})(2^n-1) \tag{7}$$

2.3 Detection

The received signal vector after the channel is given by:

$$\mathbf{y_i} = \sqrt{\varepsilon}\mathbf{h}_{j,i}x_n + \rho_i \tag{8}$$

Where ε represents the transmitted energy,$h_{j,i}$ is the fading channel coefficient between antenna j at the transmitter to user i . $\mathbf{h}_{j,i} \in C^{N_r \times 1}$ and $i \in \{1,2\}$. ρ_i is the additive white Gaussian noise (AWGN) vector. $\rho_i \in C^{N_r \times 1}$

1. UE–1: since the data of UE-1 is transmitted via the antenna index. The function of the detector is to obtain which antenna index is used for transmission. The optimal detector is ML which is given by [12]

$$\hat{j} = \arg\min_{j,n} \left\| \mathbf{y_1} - \sqrt{\varepsilon}\mathbf{h}_{j,1}x_n \right\|^2 \tag{9}$$

2.UE – 2: since the data of UE-2 is transmitted via M-ary modulation and it is equipped with N_r antennas for reception. Hence, it implements a maximal likelihood (ML) receiver with Maximal ratio combining (MRC) based detection.

$$\hat{x_n} = \arg\min_{n} \left\| \mathbf{y_2} - \sqrt{\varepsilon}\mathbf{h}_{j,2}x_n \right\|^2 \tag{10}$$

Where $x_n = f_{M-ary}(b_2)$

3 Performance Analysis

3.1 Average Spectral Efficiency

The average spectral efficiency for the SM- user is given as

$$\eta_{SM} = \log_2 N_t \tag{11}$$

Thus, spectral efficiency for the SM- user depends only on the number of transmit antennas.

For the M-ary user, the modulation mode n is used if the output SNR falls between the switching thresholds γ_n and γ_{n+1}. Thus the average link spectral efficiency is given by the sum of the data rates of each of the $N+1$ regions, weighted by the probability that the output SNR falls in the nth region. Thus, it can be written as

$$\eta_{M-ary} = \sum_{n=1}^{N} n \times P_n \quad (12)$$

Where P_n denotes the probability that the n^{th} constellation is used. It can be calculated as

$$\begin{aligned} P_n &= \Pr[\gamma_n < \gamma_s < \gamma_{n+1}] \\ &= F_{\gamma_s}[\gamma_{n+1}] - F_{\gamma_s}[\gamma_n] \end{aligned} \quad (13)$$

Where $F_{\gamma_s}[\gamma_n]$ is the CDF of the received SNR γ_s given in [11]. Thus; the average spectral efficiency for the M-ary user:

$$\eta_{M-ary} = N - \sum_{n=2}^{N} F_{\gamma_s}[\gamma_n] \quad (14)$$

3.2 Average BER

1.SM user: For SM user, the average bit error probability (ABEP) is calculated via the upper bound technique [13] which is given by

$$ABER = \frac{1}{N_t \log_2 N_t} \sum_{t_1=1}^{N_t} \sum_{t_2=1}^{N_t} N_H(t_1,\ t_2) PER(t_1 \to t_2) \quad (15)$$

Where $N_H(t_1,\ t_2)$ is the hamming distance between the antenna indexes $t_1$and t_2 and $PER(t_1 \to t_2)$ represents the pairwise error probability of antenna indexes t_1 and t_2 Using the moment generating function (MGF) approach, the $PER(t_1 \to t_2)$ can be formulated as

$$PER(t_1 \to t_2) = \frac{1}{\pi} \int_0^{\pi 2} \prod_{l=1}^{N_r} M_{t_1,t_2}\left(\frac{E_m}{4N_o} \frac{1}{2\sin^2\theta}\right) d\theta \quad (16)$$

Where $\frac{E_m}{N_o}$ is the energy to noise spectral density ratio and $M_{t1,t2}(.)$ is the MGF of the fading channel.

2.M-ary user: For M-ary user, the ABEP is given as

$$P_M = \frac{1}{\eta_{M-ary}} \sum_{n=1}^{N} n\overline{P_{bn}} \quad (17)$$

Where $\overline{P_{bn}}$ is the average BER for constellation size n, and is given by

$$\overline{P_{bn}} = \begin{cases} \int_0^{\gamma_2} P_{b1}(x) f_{\gamma_s}(x)\, dx & n = 1 \\ \int_{\gamma_n}^{\gamma_{n+1}} P_{bn}(x) f_{\gamma_s}(x)\, dx & n>1 \end{cases} \quad (18)$$

Where $f_{\gamma_s}[\gamma_n]$ is the PDF of the received SNR γ_s given in [11].

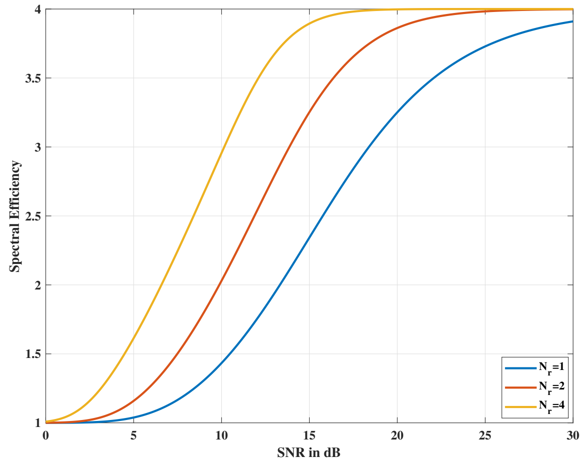

Figure 3. Average spectral efficiency of the M-ary user versus the SNR

4 Numerical Results

Figure 3 shows the average spectral efficiency for the M-ary user under FTR model with $(m = 2, k10; \Delta = 0.3)$ with different N_r antenna receiver. It is clear that as the number of receiver antennas increases, better spectral efficiency is achieved. These results aim to achieve a target BER $P_{b0} = 10^{-3}$ with $N_t = 2$. The adaptive scheme with $N_r = 2$ guarantees spectral effiency $= 3$ for $SNR \geq 10$ dB and $= 4$ for $SNR \geq 14$ dB.

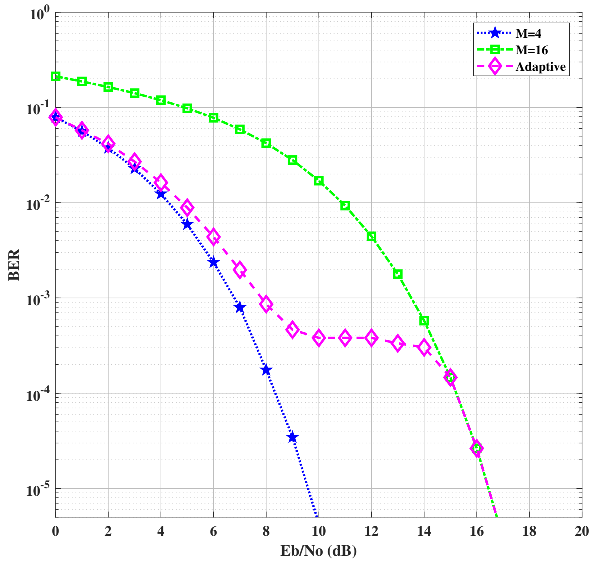

Figure 4. Average BER for the M-ary user under the FTR model $(m = 2, k = 8, \Delta = 0.3)$ with $N_r = 2)$

Figure 4 Shows the average BER for the M-ary user under FTR model with $(m = 2, k = 10; \Delta = 0.3)$ with $N_r = 2$. In the lower SNR values, the proposed adaptive scheme experiences performance similar to the performance of $M = 4$. In the middle region of the SNR values, there is variation in the slope of the BER curve. That is mainly due to increasing the modulation order while keeping the average BER below10^{-3}. In higher SNR regions, the performance converges to the same performance of $M = 16$.

Figure 5 shows the average BER for the SM user under FTR model with $(m = 2, k = 8; \Delta = 0.3)$ with $N_t = 2$ And $N_r = 2$. The slope of the BER curve for that user is unaffected by the adaptive modulation of the M-ary user. The slope of the BER curve for that user is unaffected by the adaptive modulation of the M-ary user. This is because its information bits are conveyed by the spatial dimension.

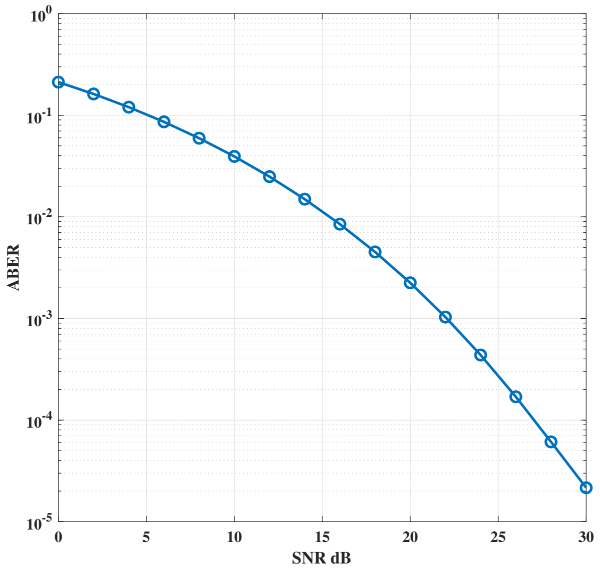

Figure 5. Average BER for the SM user under the FTR model $(m = 2, k = 8, \Delta = 0.3)$ with $N_r = 2)$

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