

Slow, Fast and Opportunistic FAMA: A Spatial Block-Correlation Analysis under Nakagami- m Fading Channels

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Abstract—This paper studies slow, fast and opportunistic fluid antenna multiple access (FAMA) under the effect of Nakagami- m fading channels, considering the new and realistic spatial block-correlation model. Expressions for the outage probability (OP), based on the signal-to-interference ratio (SIR), are derived for slow FAMA. Interestingly, we provide mathematical relationships that allow the expressions of fast FAMA to be obtained from slow FAMA. Multiplexing gains for an opportunistic FAMA (O-FAMA) network are presented for both slow and fast FAMA scenarios. Our analytical results are validated through Monte Carlo simulations, under various channel and system parameters. All expressions derived in this work are original.

Index Terms—FAMA, multiplexing gain, Nakagami- m fading, opportunistic FAMA, spatial block-correlation.

I. INTRODUCTION

FLUID antenna systems (FAS) is a disruptive technology that promises to help to achieve the demand for massive connectivity of emerging mobile communication systems [1], [2]. A fluid antenna (FA) is a flexible, electronically reconfigurable antenna structure based on liquid or pixel technology. In its canonical form, it consists of a linear structure with pre-defined positions, known as ports, where the radiating element is switched to optimize a reception metric. The performance benefits of FAS have been extensively analyzed in various operational modes and channel fading scenarios [2]–[4].

Extending the concept of FAS, fluid antenna multiple access (FAMA) introduces multiple users equipped with FAs [5]–[7] sharing the same resources. In an FAMA scheme, FAs dynamically reconfigure their ports to mitigate interference in a shared spectrum scenario and maximize the signal-to-interference ratio (SIR) or signal-to-interference-plus-noise ratio (SINR). By leveraging the fading depth across the FA space, user equipments (UEs) can select ports that enhance performance in interference-limited environments. The literature identifies two primary FAMA operating modes: fast FAMA (f -FAMA) [5], [6] and slow FAMA (s -FAMA) [7]. While f -FAMA provides substantial performance gains, its practical applicability is constrained by the requirement to switch FAs at symbol time [6]. In turn, s -FAMA offers a more

feasible alternative, requiring switching only between channel coherence times, when significant channel variations occur [7].

Recently, another proposed approach for FAMA is based on opportunistic scheduling. This technique relies on the dynamic allocation of resources to a subset of UEs from a large user pool based on their channel conditions [8]. The so-called opportunistic-FAMA (O-FAMA) integrates opportunistic scheduling with either f -FAMA or s -FAMA, leveraging their respective advantages to improve network performance [8]. Using a reinforcement learning approach, it is shown in [9] that it is possible to select the best users and FAS ports to reach a network sum rate close to the ideal, which makes O-FAMA an interesting option for multiple access.

In the literature, [5], [7]–[9] assume Rayleigh fading channels and [6] considers the finite-scatterer channel model. Despite serving as a fundamental benchmark, the Rayleigh distribution offer no additional degrees of freedom (DoF), significantly limiting the applicability of their results. More recently, only [10] extended the analysis of s -FAMA to Nakagami- m fading. Furthermore, the correlation models originally used in the analysis of [5], [7], [8] are based on restricted forms of the correlation matrix [11], [12] for easy mathematical tractability. However, they do not capture well the physical behavior of FAS. New correlated channel models are also presented in [13] and [14], that have been proven to be prohibitively complex, resulting in intractable analysis in FAS and FAMA [13]–[15], due to multi-folded integrals involved.

In this context, we study for the first time the performance of s -FAMA, f -FAMA and O-FAMA under Nakagami- m fading channels considering a spatial block-correlation analysis. We adopted the Nakagami- m fading since it is a well-established and relevant model for evaluating the performance of current and emerging systems, providing greater flexibility compared to Rayleigh fading. We also adopted the spatial block-correlation model recently proposed in [16], which accurately characterizes the correlation, as predicted by classical realistic models such as Jakes's, while maintaining analytical tractability and simplicity of the constant correlation model presented in [12]. To the best of our knowledge, the analyses and all the expressions presented here are novel in the literature.

The main contributions of this article are summarized as:

- Novel and more precise expressions are derived for outage probability (OP)-based on SIR for s -FAMA under the effect of Nakagami- m fading, considering the spatial block-correlation model.

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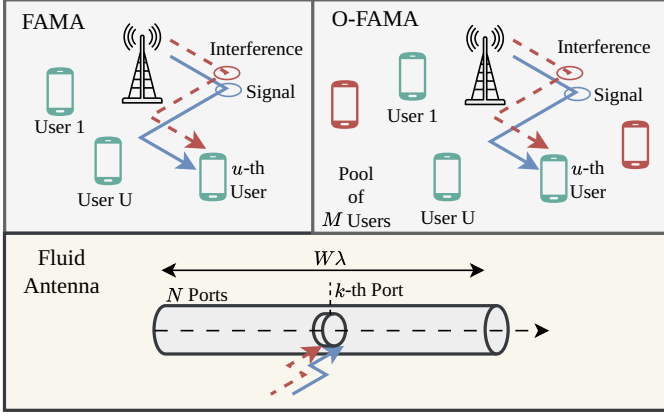


Fig. 1. FAMA and O-FAMA systems.

- A new and approximate expression is derived for the SIR-based OP under s -FAMA, over Nakagami- m channels with spatial block-correlation. Furthermore, an upper bound for the SIR-based OP is also deduced.
- Interesting similarities between fast and slow FAMA are identified, where mathematical relationships are presented. These relationships allow expressions of one type of FAMA to be obtained from the other.
- O-FAMA is analyzed for fast and slow FAMA, under Nakagami- m channels and spatial block-correlation, where results are provided for the multiplexing gain.

II. FAMA MODEL

A. System Model

The downlink FAMA network considered in this work is illustrated in Fig. 1 and consists of a BS equipped with U antennas. In this system, each antenna of BS transmits a signal destined to a specific user of the network, thus constituting a network with U users, and each UE contains an FA with N ports. The received signal at the n -th port, of a FAS for a given user u , is modeled as

$$r_n^{(u)} = s_u h_n^{(u,u)} + \sum_{\tilde{u} \neq u} s_{\tilde{u}} h_n^{(\tilde{u},u)} + \eta_n^{(u)}, \quad (1)$$

in which s_u denotes the transmitted symbol intended for the u -th user, $h_n^{(u,u)}$ is the corresponding complex fading channel experienced at n -th port of user u , and $h_n^{(\tilde{u},u)}$ denotes the fading channel from the BS antenna transmitting user $\tilde{u}$'s signal, $s_{\tilde{u}}$, which acts as an interference at n -th port of user u . Furthermore, $\eta_n^{(u)}$ is the complex additive white Gaussian noise (AWGN), at the n -th port for user u , with zero mean and variance σ_η^2 . Note that each BS antenna is assigned to transmit the signal for a given user on the downlink. The average power of the transmitted symbol is $\sigma_s^2 = \mathbb{E}[|s_u|^2]$, $\forall u$, in which $\mathbb{E}[\cdot]$ is the expectation operator. In this paper, we assume that the UEs have perfect knowledge of the channel, so the best ports are selected; and also that the switching delay between ports is negligible.

B. Channel and Spatial Correlation Models

The channel envelope for the one-dimensional (1D) FAs under Nakagami- m fading is expressed as

$$|h_n^{(u,u)}| = \sqrt{\sum_{l=1}^m |g_{nl}^{(u,u)}|^2}, \quad (2)$$

where m is the fading severity and $\{g_{nl}^{(u,u)}\}$ is a set of mutually correlated complex Gaussian random variables (RVs) with zero mean and $\mathbb{E}(|g_{nl}^{(u,u)}|^2) = 2\sigma_u$. In general, the mutual correlations between the channel coefficients of any pair of ports are described by the spatial correlation matrix $\Sigma \in \mathbb{C}^{N \times N}$. For one-dimensional FAs in an isotropic scattering environment, under the Jakes model, the elements of the correlation matrix are given by $[\Sigma]_{nk} = J_0\left(\frac{2\pi(n-k)W}{N-1}\right)$, where W denotes the normalized antenna size and $J_0(\cdot)$ is the zeroth-order Bessel function of the first kind. Alternative spatial correlation models have been proposed in the literature to account for various antenna geometries and multipath scattering distributions [17]. While these models effectively capture the mutual correlation properties between ports, the analytical tractability of the FAS and FAMA systems performance is prohibitively complex [13]–[15].

To mitigate this complexity while preserving the correlation effects along the FAs, we adopt the methodology proposed in [16], which approximates the correlation matrix by a block-diagonal matrix with constant correlation coefficients δ , denoted by $\hat{\Sigma}$. In this approach, the N ports of a FA are partitioned into B blocks, where each block has length of L_b ports, with $b \in [1, \dots, B]$ and $\sum_{b=1}^B L_b = N$. According to the algorithm in [16], both L_b and $\hat{\Sigma}$ are determined from the dominant eigenvalues of the reference spatial correlation matrix Σ with respect to a threshold ρ_{th} . Consequently, $\hat{\Sigma}$ is constructed as a block-diagonal matrix consisting of B equi-correlation submatrices of size $L_b \times L_b$. Based on this representation, the OP of the FAMA system can be evaluated as B independent blocks, while approximately retaining the correlation properties. There is no closed-form solution for the best choice of δ and ρ_{th} to optimize $\hat{\Sigma}$, but in [16] it is suggested to choose $\delta \in (0.95, 0.99)$ and $\rho_{th} = 1$. In principle, this method is applicable to any reference correlation matrix, providing flexibility across different scattering scenarios.

III. SLOW FAMA UNDER NAKAGAMI- m CHANNELS WITH SPATIAL BLOCK-CORRELATION MODEL

A. Channel Model

Based on Section II, the channel coefficients are defined as

$$g_{nl}^{(u,u)} = \sigma_u \left(\sqrt{1-\delta} x_{nl}^{(u,u)} + \sqrt{\delta} x_{b(n)l}^{(u,u)} \right) + j\sigma_u \left(\sqrt{1-\delta} y_{nl}^{(u,u)} + \sqrt{\delta} y_{b(n)l}^{(u,u)} \right), \quad (3)$$

where $x_{b(n)l}^{(u,u)}$, $x_{1l}^{(u,u)}, \dots, x_{Nl}^{(u,u)}$ and $y_{b(n)l}^{(u,u)}$, $y_{1l}^{(u,u)}, \dots, y_{Nl}^{(u,u)}$, with $l \in [1, \dots, m]$, are zero mean and unit variance independent Gaussian RVs. The RVs $x_{b(n)l}^{(u,u)}$ and $y_{b(n)l}^{(u,u)}$ are referenced to the block index $b(n)$, which is defined as $b(n) = 1$, for $n = 1, \dots, L_1$, $b(n) = 2$, for $n = L_1 + 1, \dots, L_2$ and so on.

It is assumed that $\sigma_u = \sigma$, $\forall \tilde{u}$. In (3), δ is the common power correlation coefficient between any two ports in a block.

Note that the expressions (2) and (3) are also suitable for interfering users. In this case, the distribution parameters are indicated by $m_{\tilde{u}}$, with $l \in \{1, \dots, m_{\tilde{u}}\}$, $\sigma_{\tilde{u}} = \sigma \forall u$, and the superscripts are denoted by $(\tilde{u}, u)$.

B. SIR Model

Assuming an interference-dominated scenario, where noise can be neglected in (1), a s -FAMA UE selects the port where the SIR is maximized, such as

$$\text{SIR} = \max_n \frac{\sigma_s^2 |h_n^{(u,u)}|^2}{\sigma_s^2 \sum_{\tilde{u} \neq u} |h_n^{(\tilde{u},u)}|^2} = \max_n \frac{X_n}{Y_n}, \quad (4)$$

in which

$$X_n = \sum_{l=1}^m \left(x_{nl}^{(u,u)} + \varphi x_{b(n)l}^{(u,u)} \right)^2 + \left(y_{nl}^{(u,u)} + \varphi y_{b(n)l}^{(u,u)} \right)^2 \quad (5)$$

and

$$Y_n = \sum_{\tilde{u} \neq u} \sum_{l=1}^{m_{\tilde{u}}} \left(x_{nl}^{(\tilde{u},u)} + \varphi x_{b(n)l}^{(\tilde{u},u)} \right)^2 + \left(y_{nl}^{(\tilde{u},u)} + \varphi y_{b(n)l}^{(\tilde{u},u)} \right)^2 \quad (6)$$

with $\varphi = \sqrt{\delta/(1-\delta)}$.

C. Outage Probability Analysis

1) Exact Expression

The OP, considering that the blocks are independent, is given by

$$P_{\text{out}} \triangleq \Pr[\text{SIR} \leq \gamma] = \prod_{b=1}^B P_{\text{out};b}(\gamma), \quad (7)$$

in which $P_{\text{out};b}(\gamma)$ is the OP of the b -th block and γ is the SIR threshold.

Replacing [10, Eq. (23)] into (7), the SIR-based OP results in

$$P_{\text{out}} = \prod_{b=1}^B \int_0^\infty \int_0^\infty \frac{r_b^{m-1} \tilde{r}_b^{\tilde{U}-1} e^{-\frac{r_b + \tilde{r}_b}{2}}}{2^{m+\tilde{U}} \Gamma(m) \Gamma(\tilde{U})} \times [G(\gamma; r_b, \tilde{r}_b)]^{L_b} dr_b d\tilde{r}_b, \quad (8)$$

where $G(\gamma; r_b, \tilde{r}_b)$ is given by (12), $(x)_j$ denotes the Pochhammer symbol, $Q_\nu(\cdot)$ is the ν -th order Marcum-Q function and $I_\nu(\cdot)$ is the ν -th order modified Bessel function of the first kind.

2) Approximation

Applying the generalized Gauss-Laguerre quadrature [18] in (8), we have a simple approximation for the SIR-based OP, as

$$P_{\text{out}} \approx \prod_{b=1}^B \frac{1}{\Gamma(m) \Gamma(\tilde{U})} \sum_{i=1}^{n_I} \sum_{j=1}^{n_J} w_i w_j [G(\gamma; 2x_i, 2x_j)]^{L_b}, \quad (9)$$

where x_i , for $i \in [1, \dots, n_I]$, and x_j , for $j \in [1, \dots, n_J]$, are, respectively, the roots of the generalized Laguerre polynomials $L_{n_I}^{m-1}(x_i)$ and $L_{n_J}^{\tilde{U}-1}(x_j)$, with weights $w_i = \frac{\Gamma(n_I+m)x_i}{n_I!(n_I+1)^2 [L_{n_I+1}^{m-1}(x_i)]^2}$ and $w_j = \frac{\Gamma(n_J+\tilde{U})x_j}{n_J!(n_J+1)^2 [L_{n_J+1}^{\tilde{U}-1}(x_j)]^2}$.

It should be mentioned that the use of the quadrature technique reduces computational time while maintaining an acceptable accuracy in the OP calculation.

3) Upper Bound

The upper bound for the OP can be derived using the fact that for $\delta \rightarrow 1$, the exponential in (12) tends to zero, and then the OP is approximated only by the term $Q_{\tilde{U}}(\cdot)$. Furthermore, for very large N that results in large L_b for most dominant eigenvalues, it follows that $[Q_{\tilde{U}}(\cdot)]^{L_b}$ tends to a Heaviside step function, shift by a threshold $f(\tilde{r}_b)$. Thus, $[G(\gamma; r_b, \tilde{r}_b)]^{L_b} = 1$ for $r_b < f(\tilde{r}_b)$ and $[G(\gamma; r_b, \tilde{r}_b)]^{L_b} = 0$ for $r_b > f(\tilde{r}_b)$, so (8) is approximated by

$$P_{\text{out}} \approx \prod_{b=1}^B \int_0^\infty \frac{\tilde{r}_b^{\tilde{U}-1} e^{-\tilde{r}_b/2}}{2^{m+\tilde{U}} \Gamma(m) \Gamma(\tilde{U})} \int_0^{f(\tilde{r}_b)} r_b^{m-1} e^{-\frac{r_b}{2}} dr_b d\tilde{r}_b. \quad (10)$$

Setting the threshold as $f(\tilde{r}_b) = \gamma \tilde{r}_b$ and using [19, Eqs. (3.351-1) and (3.351-3)], the integrals in (10) are solved, which results in the upper bound

$$P_{\text{out}}^{\text{UB}} \approx \left(1 - \sum_{i=0}^{m-1} \frac{\gamma^i (\tilde{U})_i}{i! (\gamma+1)^{\tilde{U}+i}} \right)^B. \quad (11)$$

It can be shown that (11) is also the OP of B independent antennas under Nakagami- m channels.

D. Multiplexing Gain

The multiplexing gain for s -FAMA, denoted as $\mathcal{G}_m$, can be defined as [7, Eq. (29)]

$$\mathcal{G}_m = U(1 - P_{\text{out}}). \quad (13)$$

IV. FAST FAMA UNDER NAKAGAMI- m CHANNELS WITH SPATIAL BLOCK-CORRELATION MODEL

A. Channel Model

For f -FAMA, the total interference in the received signal is treated as a single RV $\tilde{h}_n^{(u)} = \sum_{\tilde{u} \neq u} s_{\tilde{u}} h_n^{(\tilde{u},u)}$. Considering the seminal work of Nakagami [20], the sum of the complex Nakagami- m interference RVs is approximated by another Nakagami- m RV, with average power $\tilde{\Omega}$ and fading parameter $\tilde{m}$ given by [20, Eq. (96)]

$$\tilde{\Omega} = \sum_{\tilde{u} \neq u}^U \Omega_{\tilde{u}} \sigma_s^2 = 2\sigma^2 \sigma_s^2 \tilde{U} \quad (14)$$

and

$$\tilde{m} = \frac{\left(\sum_{\tilde{u} \neq u}^U m_{\tilde{u}} \right)^2}{\sum_{\tilde{u} \neq u}^U m_{\tilde{u}} + \sum_{\tilde{u} \neq u}^U \sum_{i \neq \tilde{u}}^U m_{\tilde{u}} m_i}, \quad (15)$$

in which $\Omega_{\tilde{u}} = \mathbb{E}[|h_n^{(\tilde{u},u)}|^2] = 2m_{\tilde{u}}\sigma^2$ and $\mathbb{E}[s_{\tilde{u}}^2] = \sigma_s^2$, $\forall \tilde{u}$. Therefore, the total interference power is modeled as $|\tilde{h}_n^{(u)}|^2 = |\sum_{\tilde{u} \neq u}^U s_{\tilde{u}} h_n^{(\tilde{u},u)}|^2 \approx \sum_{l=1}^{\tilde{m}} |\tilde{g}_{nl}^{(u)}|^2$ with $\tilde{g}_{nl}^{(u)}$ being expressed similarly to (3), with Gaussian components denoted as $\tilde{x}_{b(n)l}^{(u)}, \tilde{x}_{1l}^{(u)}, \dots, \tilde{x}_{Nl}^{(u)}$ and $\tilde{y}_{b(n)l}^{(u)}, \tilde{y}_{1l}^{(u)}, \dots, \tilde{y}_{Nl}^{(u)}$ and $\mathbb{E}[|\tilde{g}_{nl}^{(u)}|^2] = 2\tilde{\sigma}$ and $\tilde{\Omega} = \mathbb{E}[|\tilde{h}_n^{(u)}|^2] = 2\tilde{m}\tilde{\sigma}^2$.

$$G(\gamma; r_b, \tilde{r}_b) = Q_{\tilde{U}} \left(\sqrt{\frac{\delta \gamma \tilde{r}_b}{(1-\delta)(\gamma+1)}}, \sqrt{\frac{\delta r_b}{(1-\delta)(\gamma+1)}} \right) - \left(\frac{1}{\gamma+1} \right)^{m+\tilde{U}-1} \left(\frac{r_b}{\gamma \tilde{r}_b} \right)^{\frac{1-m}{2}} \exp \left(-\frac{\delta}{2(1-\delta)} \frac{\gamma \tilde{r}_b + r_b}{\gamma+1} \right) \\ \times \sum_{k=0}^{m+\tilde{U}-2} \sum_{j=0}^{m+\tilde{U}-k-2} \frac{(m+\tilde{U}-(j+k)-1)_j}{j!} \left(\frac{r_b}{\tilde{r}_b} \right)^{\frac{j+k}{2}} (\gamma+1)^k \gamma^{\frac{j-k}{2}} I_{1-m+j+k} \left(\frac{\delta \sqrt{\gamma r_b \tilde{r}_b}}{(1-\delta)(\gamma+1)} \right) \quad (12)$$

B. SIR Model

The SIR for f -FAMA is given by

$$\text{SIR} = \max_n \frac{\sigma_s^2 |h_n^{(u,u)}|^2}{|\tilde{h}_n^{(u,u)}|^2} = \max_n \frac{X_n}{\tilde{U} Z_n} \quad (16)$$

in which $\tilde{U} = \tilde{U}/\tilde{m} = \tilde{\sigma}^2/\sigma_s^2$, X_n is given by (5) and Z_n is defined as

$$Z_n = \sum_{l=1}^{\tilde{m}} \left(\tilde{x}_{nl}^{(u)} + \varphi \tilde{x}_{b(n)l}^{(u)} \right)^2 + \left(\tilde{y}_{nl}^{(u)} + \varphi \tilde{y}_{b(n)l}^{(u)} \right)^2. \quad (17)$$

Remark 1: Comparing the SIR for f -FAMA in (16) and the SIR for s -FAMA in (4), note that the expressions are similar, except for the constant $\tilde{U}$ and the upper limits of the sum of Y_k and Z_k . As a consequence, the SIR-based OP for f -FAMA can be obtained from the SIR-based OP for s -FAMA in (8) substituting γ by $\tilde{U}\gamma$ and $\tilde{U}$ by $\tilde{m}$.

Remark 2: The multiplexing gain for f -FAMA is calculated as (13), but considering the OP particularities of f -FAMA.

V. OPPORTUNISTIC FAMA UNDER NAKAGAMI- m CHANNELS WITH SPATIAL BLOCK-CORRELATION MODEL

In opportunistic scheduling, the best U users are selected from a pool of $M(\geq U)$ users to maximize network capacity. We combine in this section opportunistic scheduling with FAMA, operating in either fast or slow modes, referred to as O-FAMA. In FAMA, the BS performs no pre-processing, and a user's OP is independent of the others. Consequently, in O-FAMA, the BS can identify the top users by sequentially activating and deactivating them until the best set is found. In this paper, we assume that the strongest U UEs are selected as an ideal condition. In [9], it is shown that it is possible to select the best users and FAS ports to reach a network sum rate close to the ideal based in a reinforcement learning approach, which makes O-FAMA an interesting option for multiple access.

Based on the selection of the U users with better channel conditions from a pool M users, the multiplexing gain of an O-FAMA network is given by [8, Eq. (21-a)] $\mathcal{G}_m = \sum_{u=M-U+1}^M \mathcal{I}_{1-P_{\text{out}}}(M-u+1, u)$, where $\mathcal{I}_x(a, b)$ is the regularized incomplete beta function. Note that $\mathcal{G}_m$ depends on the OP, so the multiplexing gain is dependent on whether it is operating in fast or slow mode. Moreover, $\mathcal{G}_m$ can be approximated by [8, Eq. (46)] $\mathcal{G}_m \approx \min\{U, M(1-P_{\text{out}})\}$.

VI. NUMERICAL RESULTS

This section presents the numerical results for the performance metrics developed in this work. Monte Carlo simulations are also employed to validate the derived analytical expressions¹. The Gauss-Laguerre quadrature approximations

are evaluated with $n_I = n_J = 50$ roots. In addition, the block-correlation analysis is based on a reference correlation matrix derived from the Jakes model. Our results compare the exact OP with the analytical approximation obtained via Gauss-Laguerre quadrature and the Monte Carlo simulations. All curves exhibit a strong overlap, validating our analysis.

Fig. 2 shows the OP curves as a function of the number of ports N for both s -FAMA and f -FAMA systems, considering different values of the normalized antenna length W . The remaining parameters are fixed at $U = 5$ users, $m = 2$ and $\gamma = -3$ dB. This result highlights the impact of different correlation models on OP, comparing Jakes-based block correlation with constant correlation across ports, presented in [12]. The results indicate that, for equivalent systems, FAMA achieves considerably better performance in fast mode, owing to port selection optimization at the symbol time scale. Increasing the number of ports also improves performance by reducing OP. However, this gain is significantly diminished under a more realistic block-correlation model. The constant-correlation model reproduces a non-realistic scenario with rapid signal fluctuations across ports, offering more opportunities for SIR maximization and thus leading to an overestimation of performance. Conversely, with the block-correlation model, spatial fluctuations are slower, reflecting the practical characteristics of spatial correlation, where fewer opportunities for SIR maximization occurs and consequently limiting the OP improvement achievable with larger N . Finally, it is noted that for both the FAMA systems and the adopted correlation models, the OP improves with the increase of W since a larger W reduces the spatial correlation among ports.

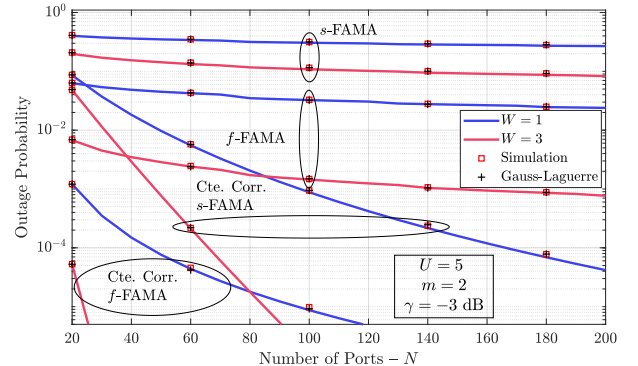


Fig. 2. OP curves for s -FAMA and f -FAMA systems, considering different W and correlation models, with $U = 5$, $m = 2$, and $\gamma = -3$ dB.

Fig. 3 presents the OP curves as a function of the SIR threshold for s -FAMA and f -FAMA under different values of the fading parameter m and the number of users U . The antenna parameters are fixed at $N = 100$ and $W = 1$. As a benchmark, the Rayleigh case ($m = 1$) is included.

¹The code is available at: <https://github.com/HigoTh/famabl>.

As expected, the OP increases with higher SIR threshold requirements. Moreover, f -FAMA consistently outperforms s -FAMA under the same system configuration. The impact of m differs across the evaluated cases. For s -FAMA, under low SIR threshold requirements, the Rayleigh case ($m = 1$) represents the worst performance. However, at higher SIR thresholds, the case with $m = 3$ becomes the worst. For f -FAMA, the OP exhibits a general improvement as m increases. Furthermore, U worsens the OP since higher interference leads to higher outage levels.

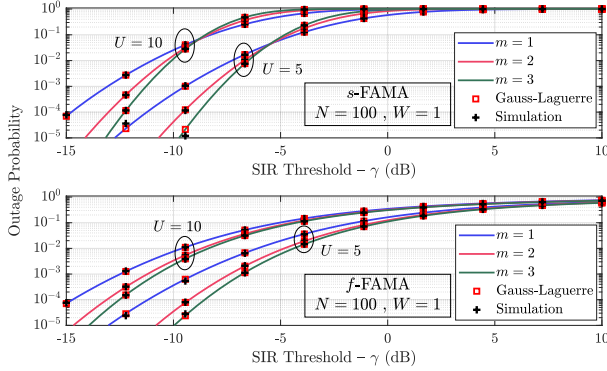


Fig. 3. OP curves as a function of the SIR threshold for s -FAMA and f -FAMA considering different values of m and U , with $N = 100$ and $W = 1$.

Fig. 4 depicts the multiplexing gain curves as a function of the number of users for s -FAMA, f -FAMA, and O-FAMA (in slow and fast modes). The system parameters are set to $N = 100$ ports, $m = 2$, $\gamma = -3$ dB, and $W = 1$. The performance of O-FAMA is evaluated under different user pool sizes M . As observed, increasing M while keeping U fixed enhances the multiplexing gain, indicating that a larger number of users can be served without experiencing outage. Conversely, for FAMA in slow mode, an inflection point emerges, beyond which further increases in network size reduce the multiplexing gain. In contrast, in fast mode this effect does not occur, and the multiplexing gain exhibits a consistently increasing trend with network scaling. This notable performance advantage is attributed to the ability to maximize the SIR at symbol time, thereby offering more optimization opportunities compared to the slow mode.

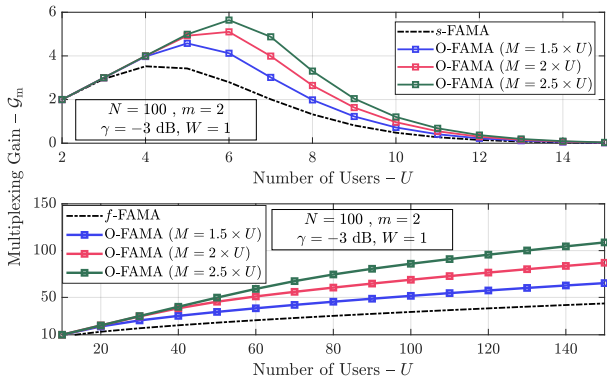


Fig. 4. Multiplexing gain curves as a function of the number of users U for s -FAMA, f -FAMA and O-FAMA under different settings of M , considering $N = 100$, $W = 1$, $m = 2$, and $\gamma = -3$ dB.

VII. CONCLUSION

This paper studied slow, fast, and opportunistic FAMA under Nakagami- m fading channels, considering the spatial block-correlation model, where OP expressions and bounds for slow and fast FAMA were derived and applied to the study O-FAMA. We obtained multiplexing gain results for O-FAMA over fast and slow FAMA. Numerical and simulation results confirmed the accuracy of the proposed analytical framework. Our work extends FAMA analysis to more general fading and correlation conditions, providing practical insights.

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