

Decentralized Power Control for SIC-Based κ -Max Decoding Slotted ALOHA over Nakagami- m Fading Channels

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Abstract—This paper studies decentralized power control for successive interference cancellation (SIC)-based slotted ALOHA random access systems, extending the framework of Xu *et al* (DOI: 10.1109/JSAC.2013.131113). In this scheme, each active device independently selects its transmit power according to a probability distribution conditioned on its instantaneous channel gain. We introduce a generalized κ -max decoding scheme, where up to κ packets with sufficiently separated received power levels are decodable via SIC, extending the conventional two-packet ($\kappa = 2$) case. We further design channel-adaptive power profiles and derive analytical expressions for the achievable throughput. In particular, for $\kappa = 3$, a closed-form throughput expression is obtained. The analysis is conducted over Nakagami- m fading channels, which provides a flexible model for a wide range of fading conditions. Numerical results demonstrate the throughput gain from $\kappa = 2$ to $\kappa = 3$ and validate the analysis. The optimal conditional transmission probabilities under fading reveal the power control mechanism that suppresses transmission under poor channel conditions while exploiting favorable channel realizations to improve throughput.

Index Terms—slotted ALOHA, successive interference cancellation, decentralized power control, Nakagami- m fading channel, random access

I. INTRODUCTION

Slotted ALOHA (SA), as a fundamental random access protocol widely adopted in wireless communication systems and standards [1], is particularly well suited for grant-free and massive machine-type communications. Early studies of SA relied on the *collision channel model*, where an access point (AP) decode a packet only when exactly one device transmits in a slot. A generalization of this abstraction is the *multi-packet reception (MPR) channel model* [2], which allows multiple packets to be decoded in a slot.

Another research line considers non-orthogonal multiple access (NOMA)-based random access with multiple received power levels. In [3], a NOMA-ALOHA model is studied in which successive interference cancellation (SIC) can resolve multiple packets only when the simultaneously transmitted

packets occupy distinct received power levels, while packets transmitted at the same level are treated as a collision. This abstraction is often referred to as a *MAC-layer power-level collision model*. [3] analyzed the throughput of such NOMA-ALOHA systems and derived bounds on the maximum throughput for a small number (e.g., two) of power levels. However, even for a few power levels, the exact throughput analysis is complicated. [4] further incorporated signal-to-interference-plus-noise ratio (SINR) constraints into the decoding model, where the decoding success depends on both power-level collisions and interference from undecoded signals, requiring enumeration of SIC decoding scenarios.

In this MAC-layer model [3], [4], channel inversion is assumed so that packets transmitted at different power levels arrive at the AP with predefined received powers. However, such schemes may require large transmit power when the channel gain is small. In contrast, a PHY-aware scheme, referred to as decentralized power control for SIC-based random access, was studied in [5]. In such a scheme, each device selects its transmit power according to a predefined distribution conditioned on its channel gain. However, the decoding capability of [5] is limited to two-packet collisions and over Rayleigh fading channels.

To address the above limitations, this paper studies a PHY-aware decentralized power control scheme for SIC-based SA systems. Building upon the framework in [5], we generalize it to κ -collision ($\kappa \geq 2$) and Nakagami- m fading channels. The main contributions of this work are summarized as follows.

- We introduce a generalized κ -max decoding scheme for SIC-based SA, in which collisions involving up to κ packets can be successively decoded when their received power levels are sufficiently separated. The proposed formulation subsumes the scheme in [5] as the special case $\kappa = 2$, thereby providing a unified framework that extends two-collision decoding to higher-order collisions. Under this framework, we derive analytical throughput

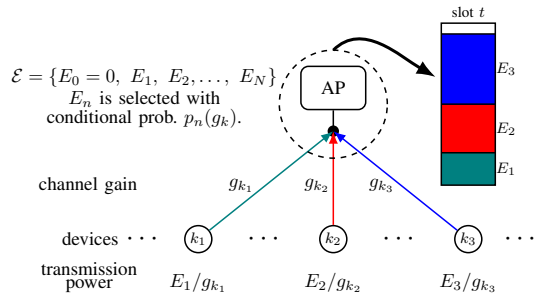


Fig. 1: Example of transmission process: active devices k_i ($i = 1, 2, 3$) select their power levels E_1 , E_2 , and E_3 , respectively, with conditional probabilities $p_1(g_{k_1})$, $p_2(g_{k_2})$, and $p_3(g_{k_3})$.

expressions for decentralized power-controlled SA systems in terms of the transmission probability profile and the received power levels. While the formulation is defined for arbitrary κ , the analysis in this paper focuses on the case $\kappa = 3$.

- We extend the throughput analysis from Rayleigh fading to Nakagami- m fading channels. The extension replaces the exponential channel gain with a gamma-distributed gain, leading to expressions involving incomplete gamma functions while preserving the overall formulation. Moreover, the framework can be extended to mixture-gamma channel models, although this extension is not pursued here due to space limitations.
- Numerical results illustrate the throughput performance of the proposed scheme and provide a comparison with conventional SA and the 2-max decoding scheme.

II. SIC SA WITH DECENTRALIZED POWER CONTROL

A. Transmission Scheme

We consider an SA system with K_T devices, denoted by \mathcal{K}_T , transmitting coded packets to a common AP in a time-synchronized manner. Each packet is encoded at a fixed spectral efficiency R (bits per channel use), representing the overall transmission rate, e.g., a combination of channel coding and modulation. From Shannon theory, this corresponds to a required SINR η_0 satisfying $R = \log_2(1 + \eta_0)$ [6]. Each time slot has a duration sufficient for the transmission of one packet.

In decentralized power control [5], each device adopts a κ -dependent power profile $\mathcal{E}^{(\kappa)}$ with a probability profile \mathcal{P} :

$$\mathcal{E}^{(\kappa)} = \{E_0^{(\kappa)} = 0, E_1^{(\kappa)}, \dots, E_N^{(\kappa)}\}, \quad 2 \leq \kappa \leq N,$$

$$\mathcal{P} = \{p_0, p_1, p_2, \dots, p_N\},$$

where power level $E_n^{(\kappa)}$ is selected with probability p_n , and N denotes the maximum number of discrete power levels. The level $E_0^{(\kappa)} = 0$ corresponds to no transmission.

Each device is assumed to have perfect knowledge of its channel gain. Let g_k denote the channel gain between device k and the AP. In slot t , device k selects power level $E_{n_k}^{(\kappa)}$ with probability $p_{n_k}(g_k)$, conditioned on its channel gain g_k , and transmits its packet \mathbf{x}_k with transmit power $E_{n_k}^{(\kappa)}/g_k$. Here,

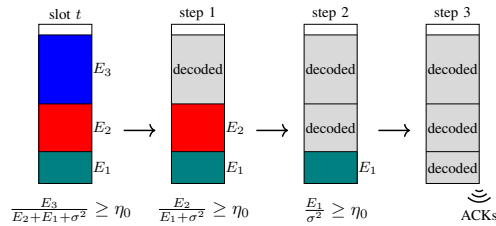


Fig. 2: Example of the SIC procedure for $\kappa = 3$, where three packets are received at distinct power levels and are successively decoded. Here, $\mathcal{E}^{(3)} = \{E_0 = 0, E_1 = \eta_0 \sigma^2, E_2 = \eta_0(E_1 + \sigma^2), E_3 = \eta_0(E_1 + E_2 + \sigma^2), \dots, E_N\}$.

$p_n(g)$ denotes the conditional transmission probability given channel gain g , and the corresponding unconditional probability p_n is defined in (9). Devices with $E_{n_k}^{(\kappa)} \neq 0$ are referred to as *active devices* in slot t . Since the transmit power is $E_{n_k}^{(\kappa)}/g_k$, a small channel gain g_k results in a large transmit power. However, the optimization naturally suppresses transmissions under poor channel conditions. Fig. 1 illustrates an example of the transmission, where the superscript (κ) is omitted for notational simplicity.

For each packet, successful decoding requires that the received SINR exceeds η_0 [6]. At the AP, packets are decoded using SIC according to their received power levels.

Suppose that at most κ packets, $2 \leq \kappa \leq N$, within a slot can be decoded, when their received power levels are distinct. This abstraction assumes that the received power levels are sufficiently separated such that the SINR condition for successive decoding is satisfied. To guarantee successful decoding under this threshold condition, the received power levels are recursively defined as, with $E_0^{(\kappa)} = 0$,

$$E_n^{(\kappa)} = (2^R - 1) \left(\sum_{j=\max(0, n-\kappa+1)}^{n-1} E_j^{(\kappa)} + \sigma^2 \right), \quad 1 \leq n \leq N, \quad (1)$$

where σ^2 denotes the noise power. When $\kappa = 2$, (1) reduces to [5, Eq. (9)]. Throughout this paper, we focus on the case $R \geq 1$. The extension to the case $R < 1$ is straightforward.

After transmission, a device receiving an acknowledgment (ACK) generates a new packet for future transmission. Otherwise, it retransmits the same packet with the same power profile and probability profile until successfully decoded.

B. Decoding Scheme

Packet recovery is performed using *intra-slot* SIC. Consider a single slot at time t . Based on the power control in Section II-A, the AP observes the superimposed baseband signal

$$\mathbf{y} = \sum_{k \in \mathcal{K}_a} \sqrt{g_k} \frac{\sqrt{E_{n_k}^{(\kappa)}}}{\sqrt{g_k}} \mathbf{x}_k + \mathbf{z} = \sum_{k \in \mathcal{K}_a} \sqrt{E_{n_k}^{(\kappa)}} \mathbf{x}_k + \mathbf{z}, \quad (2)$$

where $\mathcal{K}_a (\subseteq \mathcal{K}_T)$ denotes the set of active devices in the slot t . The slot index is omitted for simplicity. Each element of \mathbf{z} is circularly symmetric complex Gaussian (CSCG) noise distributed as $\mathcal{CN}(0, \sigma^2)$.

The collision in (2) involving $|\mathcal{K}_a|$ packets in the slot is referred to as a $|\mathcal{K}_a|$ -collision. To limit receiver complexity and enable analytical tractability, we define κ -max decoding as the case where collisions with $|\mathcal{K}_a| \leq \kappa$ are processed via SIC, whereas collisions with $|\mathcal{K}_a| > \kappa$ are not processed.

Without loss of generality, the packets are ordered such that $E_{n_1}^{(\kappa)} > E_{n_2}^{(\kappa)} > \dots > E_{n_{\kappa_a}}^{(\kappa)}$ ($|\mathcal{K}_a| \leq \kappa$), the AP attempts to decode packets sequentially in this order. At step k , after the first $k-1$ packets have been successfully decoded and removed, the SINR for device k is $\eta_k \triangleq \frac{E_{n_k}^{(\kappa)}}{\sigma^2 + \sum_{u=k+1}^{|\mathcal{K}_a|} E_{n_u}^{(\kappa)}}$. If the SINR η_k exceeds the decoding threshold η_0 , the packet \mathbf{x}_k is successfully decoded, i.e., $\Pr\{\text{packet } \mathbf{x}_k \text{ decoded}\} = \begin{cases} 1, & \eta_k \geq \eta_0, \\ 0, & \eta_k < \eta_0. \end{cases}$

After successful decoding, the recovered packet is subtracted from the received signal. The SIC procedure continues until no further packets can be decoded within the slot. An example of this procedure in slot t is shown in Fig. 2.

III. THROUGHPUT ANALYSIS ($\kappa = 3$)

In this section, we analyze the performance of the K_T -device SA with decentralized power control over fading channels. We focus on the 3-max decoding scheme ($\kappa = 3$). Hereafter, $E_n^{(\kappa=3)}$ is abbreviated as E_n for notational simplicity.

Since each device performs channel inversion in (2), the received power levels are independent of fading gains. Therefore, the throughput formulation depends only on the probability profile \mathcal{P} , and the overall throughput T is given by

$$T(p_0, p_1, \dots, p_N) = \sum_{q=1}^{\kappa} T_q. \quad (3)$$

A. Single-Packet Decoding Case ($q = 1$)

Two scenarios lead to the successful decoding of a single packet. The first scenario occurs when one device selects E_j ($j \geq 1$) and the remaining $(K_T - 1)$ devices select E_0 . The throughput contribution for this event is given by [5, Eq. (22b)]

$$T_{11} = K_T \bar{p}_0 p_0^{K_T-1}, \quad \text{where } \bar{p}_0 \triangleq 1 - p_0. \quad (4)$$

The second scenario occurs when three packets are received in a slot, two with power level E_j and one with E_{j+2} or higher ($j = 1, 2, 3, \dots, N-2$). Since $E_{j+2} = \eta_0(E_j + E_{j+1} + \sigma^2)$ and $E_j < E_{j+1}$, the SINR for the packet with power E_{j+2} exceeds η_0 . Therefore, the packet with E_{j+2} can be successfully decoded. Hence, among three packets consisting of two packets with power E_j and one packet with power E_{j+2} (or higher), only the strongest packet is successfully decoded. The corresponding throughput contribution is

$$T_{12} = 3 \binom{K_T}{3} p_0^{K_T-3} \sum_{j=1}^{N-2} \sum_{i=j+2}^N p_j^2 p_i. \quad (5)$$

Thus, $T_1 = T_{11} + T_{12}$.

B. Two-Packet Decoding Case ($q = 2$)

In this case, two packets can be decoded only when the two received packets have distinct power levels. The corresponding throughput contribution T_2 is given by [5, Eq. (22c)]:

$$T_2 = 2 \binom{K_T}{2} p_0^{K_T-2} (\bar{p}_0^2 - \sum_{n=1}^N p_n^2). \quad (6)$$

C. Three-Packet Decoding Case ($q = 3$)

In this case, three packets can be decoded only when the three received packets have distinct power levels (see Fig. 2). The corresponding throughput contribution is given by

$$T_3 = 3 \binom{K_T}{3} p_0^{K_T-3} (\bar{p}_0^3 - \sum_{n=1}^N p_n^3 - 3 \sum_{n=1}^N p_n^2 (\bar{p}_0 - p_n)). \quad (7)$$

IV. OPTIMIZATION OF TRANSMISSION PROBABILITIES

The channel amplitudes $\sqrt{g_k}$ from devices $k \in \mathcal{K}_T$ to the AP are assumed to be independent and identically distributed (i.i.d.) Nakagami- m random variables. Accordingly, the channel power gains g_k follow a gamma distribution [7] with parameter $m \geq 1$. The probability density function (PDF) of g is given by $\Psi(g) = \frac{m^m}{\Gamma(m)} g^{m-1} e^{-mg}$, with $\mathbb{E}[g] = 1$, where $\Gamma(\cdot)$ denotes the gamma function [8, Eq. 8.310.1].

A. Discretization of Gain & Conditional Probabilities

The analysis in this section follows the discretization framework in [5] for fading channels. Let $p_n(g)$ denote the probability that each device transmits with power level E_n/g at the channel gain g . We optimize the conditional transmission probability profile $\{p_n(g) \mid n = 1, 2, \dots, N\}$ for each g .

Since direct optimization over the continuous channel gain g is analytically intractable, we discretize the support $[0, \infty)$ into L intervals using $L+1$ thresholds $\{g^{(\ell)} \mid \ell = 0, \dots, L\}$, where $g^{(0)} = 0$ and $g^{(L)} = \infty$. In the numerical results in Section V-B, the intervals are chosen to have equal probability mass, i.e., each interval has probability $1/L$. With this discretization, g is approximated as a discrete random variable. Thus, we model the transmission probability as follows [5].

$$p_n(g) = p_n^{(\ell)}, \quad g \in [g^{(\ell-1)}, g^{(\ell)}), \quad \ell = 1, \dots, L. \quad (8)$$

Here, $p_n^{(\ell)}$ denotes the probability of selecting the received power level E_n when the channel gain satisfies $g \in [g^{(\ell-1)}, g^{(\ell)})$. Under this discretized channel model, the unconditional probability of selecting received power level is [5]

$$p_n = \sum_{\ell=1}^L p_n^{(\ell)} q^{(\ell)}, \quad \text{where } q^{(\ell)} = \int_{g^{(\ell-1)}}^{g^{(\ell)}} \Psi(g) dg. \quad (9)$$

When the received power level is E_n and the channel gain satisfies $g \in [g^{(\ell-1)}, g^{(\ell)})$, the corresponding transmit power is E_n/g . This occurs with probability $p_n^{(\ell)} \Psi(g) dg$. Thus, the average transmit power is given as follows.

$$\sum_{\ell=1}^L \sum_{n=1}^N \int_{g^{(\ell-1)}}^{g^{(\ell)}} (E_n/g) p_n^{(\ell)} \Psi(g) dg = \sum_{\ell=1}^L \sum_{n=1}^N p_n^{(\ell)} E_n / \bar{g}^{(\ell)},$$

where

$$\bar{g}^{(\ell)} = \left(\int_{g^{(\ell-1)}}^{g^{(\ell)}} \frac{\Psi(g)}{g} dg \right)^{-1} = \left(\int_{g^{(\ell-1)}}^{g^{(\ell)}} \frac{m^m}{\Gamma(m)} g^{m-2} e^{-mg} dg \right)^{-1} \quad (10)$$

$$\stackrel{(a)}{=} \begin{cases} 1, & m=1, \\ \frac{\text{Ei}(-g^{(\ell)}) - \text{Ei}(-g^{(\ell-1)})}{\Gamma(m)}, & m>1. \end{cases}$$

In (a), we use the exponential integral [8, Eq. 8.214.1]

$$\text{Ei}(x) = -\int_{-x}^{\infty} \frac{e^{-t}}{t} dt = C + \ln(-x) + \sum_{k=1}^{\infty} \frac{x^k}{k \cdot k!}, \quad x < 0,$$

where C denotes the Euler constant, and the lower incomplete gamma function [8, Eq. 8.354.1]

$$\gamma(\alpha, x) = \int_0^x e^{-t} t^{\alpha-1} dt = \sum_{k=0}^{\infty} \frac{(-1)^k x^{\alpha+k}}{k!(\alpha+k)}. \quad (11)$$

The appearance of the incomplete gamma function reflects the extension from Rayleigh fading (with exponential power gain) to Nakagami- m fading (with gamma-distributed power gain), while preserving the overall formulation.

B. Optimization of Probability Profile \mathcal{P}

Let \bar{e} denote the transmit power constraint per device. The throughput maximization problem in (3) over Nakagami- m fading channels can be formulated as follows:

$$\max_{\{p_n^{(\ell)}\}} T(p_0, p_1, \dots, p_N) \quad (12a)$$

$$\text{s.t. } 0 \leq p_n^{(\ell)} \leq 1, \quad n = 0, \dots, N, \quad \ell = 1, \dots, L \quad (12b)$$

$$p_n = \sum_{\ell=1}^L p_n^{(\ell)} q^{(\ell)}, \quad n = 0, \dots, N \quad (12c)$$

$$\sum_{n=0}^N p_n^{(\ell)} = 1, \quad \ell = 1, \dots, L \quad (12d)$$

$$\sum_{\ell=1}^L \sum_{n=1}^N p_n^{(\ell)} E_n / \bar{g}^{(\ell)} \leq \bar{e}. \quad (12e)$$

The average transmit power per slot for the entire system, $E_T \triangleq \bar{e} K_T$, is used as a performance metric. Unlike [5], where the idle probability p_0 is fixed, we optimize p_0 jointly with the remaining transmission probabilities.

Remark 1: Our work builds upon the framework in [5] but differs in two main aspects. First, we consider a κ -max decoding scheme with $\kappa = 3$, which subsumes [5] as the special case $\kappa = 2$. Second, we extend the analysis from Rayleigh to Nakagami- m fading channels, where the channel power gain follows a gamma distribution. Since the gamma distribution is analytically tractable, the framework can also be extended to mixture-gamma distributions that approximate or represent the channel power gain distributions of many fading models [9]. Thus, the proposed framework readily applies to a broad class of fading environments. \square

V. NUMERICAL RESULTS

In this section, we evaluate the performance of the proposed κ -max decoding scheme ($\kappa = 3$). The maximum throughput is obtained by solving the optimization problems in (12). Monte Carlo simulations for $\kappa = 3$ are conducted to verify accuracy of the analytical throughput expression in (3).

A. Optimization Setup

Unless otherwise stated, the spectral efficiency is set to $R = 1$, the noise power is $\sigma^2 = 1$, and the number of received power levels is $N = 6$. Under these parameters, the maximum received power level satisfies $E_N^{(3)} \approx 13$ dB. Since the throughput expression in (3) is generally non-convex with respect to the probability profile $\{p_n\}_{n \geq 0}$, the optimization problems in (12) are non-convex. To solve these problems, we employ the `GlobalSearch` optimization framework implemented in `MATLAB`.

B. Throughput over Nakagami- m Fading Channels

We evaluate the performance of the proposed scheme over Nakagami- m fading channels. To compute the throughput under fading, the channel gain g is discretized into $L = 25$ equiprobable intervals.

Fig. 3 presents the maximum throughput for $E_T = 5$ dB, obtained by solving (12), for $\kappa = 3$ and 2. Monte Carlo simulations ($\kappa = 3$), using the same optimized transmission probability profile as in the analysis, are conducted over $n_s = 10^5$ slots. The close agreement between simulation and analytical results validates the throughput expression in (3).

For comparison, the performance of the 2-max decoding scheme ($\kappa = 2$) is also included. In this case, the number of received power levels is set to $N_{2\text{-max}} = 20$, such that $E_{N_{2\text{-max}}}^{(2)} \approx E_N^{(3)} \approx 13$ dB for comparison. The results over Nakagami- m fading channels confirm that the proposed 3-max decoding scheme achieves consistently higher throughput than the 2-max decoding scheme. Moreover, for $\kappa = 2$, the conventional two-max decoding scheme is evaluated under Nakagami- m fading using the proposed framework, and the resulting non-convex optimization closely matches the convex optimization result with fixed p_0 in [5], thereby validating the proposed framework.

In addition, Fig. 3 shows the maximum throughput of conventional SA without power control, i.e., $\mathcal{E} = \{0, E_T\}$, where the optimal transmission probability is obtained via simulation-based search. All devices transmit with fixed power E_T over Nakagami- m fading channels, and the AP performs SIC for up to three colliding packets. The results show that power control significantly improves the throughput.

In Fig. 4, the achievable throughput increases with E_T , because a larger average power budget allows the optimizer to assign more probability mass to higher received power levels, which facilitates SIC decoding.

Fig. 5 shows the optimal transmission probability profile for $K_T = 5$ under two different average power constraints. As the power constraint increases, the probability mass shifts toward higher power levels, reducing the likelihood that colliding packets arrive with similar received powers and thereby facilitating SIC decoding under the κ -max decoding.

Fig. 6 further illustrates how this optimal distribution is realized under fading through channel-dependent transmission probabilities $p_n^{(\ell)}$. When the channel gain is small (small ℓ), the optimal policy assigns $p_0^{(\ell)} \approx 1$, meaning that devices

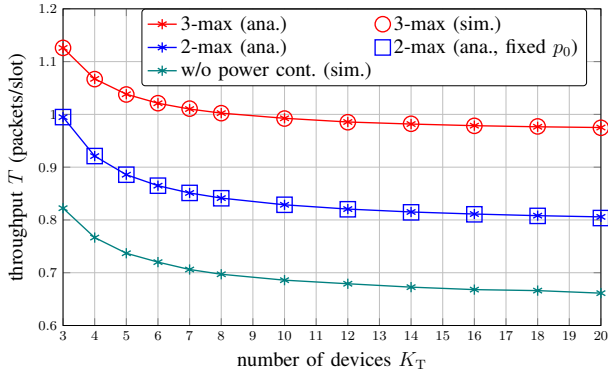


Fig. 3: Maximum throughput versus the number of devices K_T under Nakagami- m fading with $m = 5$ for the average power constraint $E_T = 5$ dB.

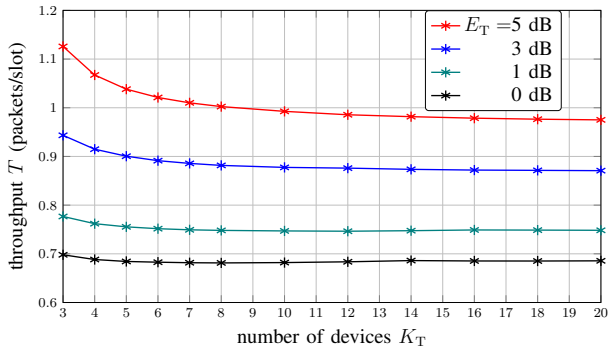


Fig. 4: Maximum throughput vs. K_T for $E_T = 0 - 5$ dB and $\kappa = 3$ under Nakagami- m fading with $m = 5$.

refrain from transmission. As the channel gain g increases, the optimization gradually assigns probability to higher E_n since the required transmit power E_n/g decreases. This behavior reflects the power-control mechanism that suppresses transmission under poor channel conditions while exploiting favorable channel realizations to improve throughput.

VI. CONCLUSION

This paper studied decentralized power control for SIC-based SA over Nakagami- m fading channels. A generalized κ -max decoding scheme was introduced, where up to κ packets with separated received power levels can be decoded within a slot. For $\kappa = 3$, we derived a closed-form throughput expression and optimized the transmission probability profile under an average power constraint, demonstrating throughput gains over the conventional two-max decoding scheme.

Although the analysis focuses on Nakagami- m fading, the proposed framework readily extends to mixture-gamma channel models representing a broad class of fading environments, but is omitted due to space limitations.

REFERENCES

[1] A. Munari, "Modern random access: An age of information perspective on irregular repetition slotted ALOHA," *IEEE Transactions on Communications*, vol. 69, no. 6, pp. 3572–3585, 2021.

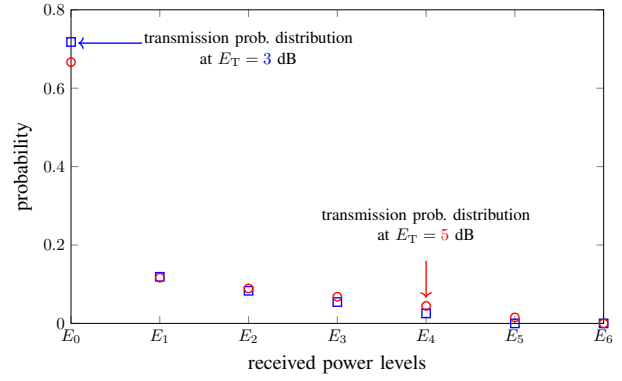
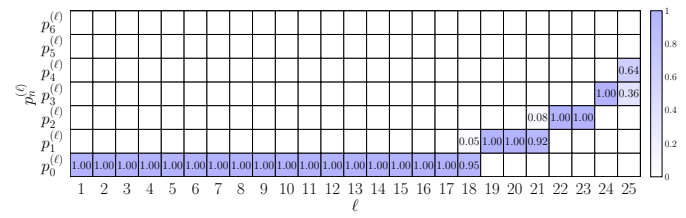
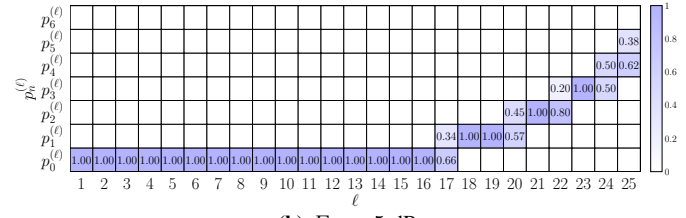


Fig. 5: Optimal transmission probability profile $\{p_0, \dots, p_6\}$ for $K_T = 5$ and $\kappa = 3$ under Nakagami- m fading ($m = 5$) with average power constraints $E_T = 3$ and 5 dB.



(a) $E_T = 3$ dB



(b) $E_T = 5$ dB

Fig. 6: Optimal conditional probabilities $p_n^{(l)}$ for $K_T = 5$ and $\kappa = 3$ under Nakagami- m fading ($m = 5$). Poor channel conditions favor $p_0^{(l)} \approx 1$, while larger gains activate higher levels E_n .

[2] S. Ghez, S. Verdu, and S. Schwartz, "Stability properties of slotted Aloha with multipacket reception capability," *IEEE Transactions on Automatic Control*, vol. 33, no. 7, pp. 640–649, 1988.

[3] Y. Jin and T.-J. Lee, "Throughput analysis of NOMA-ALOHA," *IEEE Transactions on Mobile Computing*, vol. 21, no. 4, pp. 1463–1475, 2022.

[4] L. Mai, Q. Zhang, and J. Qin, "System throughput maximization of uplink NOMA random access systems," *IEEE Communications Letters*, vol. 25, no. 11, pp. 3654–3658, 2021.

[5] C. Xu, L. Ping, P. Wang, S. Chan, and X. Lin, "Decentralized power control for random access with successive interference cancellation," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 11, pp. 2387–2396, 2013.

[6] T. M. Cover and J. A. Thomas, *Elements of Information Theory* (Wiley Series in Telecommunications and Signal Processing). USA: Wiley-Interscience, 2006.

[7] M. K. Simon and M. S. Alouini, *Digital Communication over Fading Channels; 2nd ed.* Newark, NJ: Wiley, 2005.

[8] I. Gradshteyn and I. Ryzhik, "Table of integrals, series, and products," 2007. [Online]. Available: <http://fisica.ciens.ucv.ve/~vincenz/TISPISGIMR.pdf>

[9] S. Atapattu, C. Tellambura, and H. Jiang, "A mixture gamma distribution to model the SNR of wireless channels," *IEEE Transactions on Wireless Communications*, vol. 10, no. 12, pp. 4193–4203, 2011.