A Slotted Unsourced Random Access Scheme with a Massive MIMO Receiver

Mert Ozates, Mohammad Kazemi and Tolga M. Duman
Dept. of Electrical and Electronics Engineering, Bilkent University, Bilkent 06800, Ankara, Turkey
Email: {ozates, kazemi, duman}@ee.bilkent.edu.tr

***Abstract*—We consider unsourced random access over fading channels with a massive number of antennas at the base station and propose a simple yet energy-efficient solution by dividing the transmission frame into slots where each slot is also divided into pilot and data parts. We utilize non-orthogonal pilot sequences selected based on part of the information bits, and encode the remaining message bits with a polar code for transmission. At the receiver side, we first detect the transmitted pilot sequences by employing generalized orthogonal matching pursuit, and utilize a linear minimum mean square error solution to estimate the channel vectors. We perform symbol estimation by maximal ratio combining, and pass the symbol estimates to a single-user polar decoder to recover the data bits with successive cancellation list decoding, with successive interference cancellation at the end of each iteration. Numerical examples demonstrate that the proposed scheme either outperforms the existing schemes in the literature, or has a lower complexity while achieving a comparable performance.**

***Index Terms*—Unsourced random access, massive MIMO, polar codes, generalized orthogonal matching pursuit.**

I. Introduction

Emerging Internet-of-Things (IoT) applications require sporadic communication of a massive number of devices with a common access point. In order to address this problem, Polyanskiy introduced the unsourced random access (URA) paradigm in [1], where an unbounded number of devices with short payloads communicate with a common base station (BS) in an uncoordinated fashion, while only a subset of them are active at any given time. The devices share the same codebook, which allows for the operation of the system irrespective of the total number of devices, and the decoding is only up to a permutation of the transmitted messages. In addition, per-user probability of error (PUPE) is adopted as a performance criterion rather than the global error probability. These are the two main aspects making URA different than the traditional multiple access channel (MAC) scenario.

A random coding achievability bound is derived for Gaussian MAC in [1]. Since then there have been substantial efforts to develop low complexity coding schemes to approach that bound. The main approaches for this purpose are splitting the payload [2]–[4], sparsifying the collisions [5]–[8], and spreading of the LDPC or polar encoded codewords using random signatures [9]–[11].

A practical wireless channel model is quasi-static Rayleigh fading, where the transmitted signals are attenuated by random fading coefficients. For this model, in the context of URA, [12]–[14] study the completely synchronous scenario, while [15] focuses on the asynchronous case.

Massive multiple-input-multiple-output (MIMO) systems provide high spectral efficiencies and data rates as well as spatial multiplexing gains, which make them suitable candidates to solve some bottlenecks in URA systems. With this motivation, several recent studies consider a massive number of antennas at the BS. A non-Bayesian activity detection (AD) algorithm combined with an outer tree code to detect the active messages is proposed in [16], and the authors of [17] show that its performance can be improved by using successive cancellation list decoding. The authors in [18] propose to use rank-1 tensors constructed from Grassmannian sub-constellations as transmitted signals, which exhibit good performance up to around 600 active users. Furthermore, a pilot-based scheme is proposed in [19], where non-orthogonal pilots are transmitted in the pilot phase, and the data payload is encoded by a polar code. At the receiver side, a multiple measurement vector approximate message passing (MMV-AMP) algorithm is used to recover the active pilot sequences followed by a linear minimum mean square error (LMMSE) channel estimation, data detection by maximal ratio combining (MRC), and single-user polar decoding.

In this paper, we consider URA over Rayleigh block fading channels, and develop a low complexity and high performing solution based on slotted transmissions to reduce the multiuser interference. We employ generalized orthogonal matching pursuit (gOMP) [20] for AD assuming a massive number of antennas at the BS. The slot length is smaller than the channel coherence time, and each slot is also divided into pilot and data parts. Each user transmits a pilot sequence from a common non-orthogonal codebook followed by its polar encoded and modulated codeword. At the receiver, we first detect the active pilots by a gOMP algorithm, then estimate the channel vectors by employing LMMSE in each slot. Next, we perform iterative decoding by estimating the user symbols with MRC, passing these estimates to a polar decoder, and subtracting the effects of the successfully decoded messages by successive interference cancellation (SIC). Our proposed scheme is similar to that

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of [19]. However, in contrast to [19], we employ a slotted transmission to reduce the multiuser interference, in addition to employing a simpler AD algorithm, which makes our scheme suitable even for fast fading scenarios. Furthermore, we provide a complexity analysis and investigate the effect of the pilot collisions to the system performance.

The rest of the paper is organized as follows. We describe the system model in Section II, and the proposed scheme in Section III. We present a set of numerical results in Section IV, and conclude the paper in Section V.

II. System Model

We consider a massive random access scheme where K_a out of K_{tot} active users ($K_a \ll K_{tot}$) transmit B bits of information over a Rayleigh block-fading channel to a common BS equipped with M antennas. Assuming that the channel coherence time is larger than L, we divide the length-n channel frame into V slots of length L. Each user transmits its signal in a randomly selected slot. Then, the received signal in the s-th slot can be written as

$$\mathbf{Y}_s = \sum_{k \in \mathcal{K}_s} \mathbf{x}(\mathbf{m}_k)\mathbf{h}_k^T + \mathbf{Z}, \tag{1}$$

where $\mathbf{Y}_s \in \mathbb{C}^{L \times M}$, $\mathcal{K}_s$ is the set of active users transmitting in the s-th slot, $\mathbf{m}_k$ is the message of the k-th user, $\mathbf{x}(\mathbf{m}_k)$ is the transmitted signal of the k-th user corresponding to the message $\mathbf{m}_k$, $\mathbf{h}_k \in \mathbb{C}^{M \times 1}$ is the channel vector of the k-th user with independent and identically distributed elements $h_{k,i} \sim \mathcal{CN}(0,1)$, and $\mathbf{Z} \sim \mathcal{CN}(0, N_0\mathbf{I}_L)$ is the circularly symmetric complex white Gaussian noise, where $\mathbf{I}_L$ is an $L \times L$ identity matrix. Assuming that the elements of $\mathbf{x}(\mathbf{m}_k)$ have an average power of P, the energy-per-bit of the system can be defined as

$$\frac{E_b}{N_0} = \frac{LP}{BN_0}, \tag{2}$$

where E_b is the energy-per-bit. The receiver aims to produce a list of the decoded messages $\mathcal{L}$. The PUPE of the system P_e is defined as the sum of misdetection and false alarm probabilities, namely, $P_e = P_{\text{md}} + P_{\text{fa}}$. Let $n_{\text{md}} = \sum_{k \in \mathcal{K}_a} \mathbb{1}_{\{\mathbf{m}_k \notin \mathcal{L}\}}$ be the number of misdetections and $n_{\text{fa}} = |\mathcal{L} \setminus \{\mathbf{m}_k : k \in K_a\}|$ be the number of the false alarms, where $|\mathcal{L}|$ is the cardinality of set $\mathcal{L}$ and $\mathbb{1}_{\{.\}}$ is the indicator function. Then, P_{md} and P_{fa} are defined as

$$P_{\text{md}} = \frac{\mathbb{E}[n_{\text{md}}]}{K_a}, \quad P_{\text{fa}} = \mathbb{E}\Big[\frac{n_{\text{fa}}}{|\mathcal{L}|}\Big], \tag{3}$$

where $|\mathcal{L}| = K_a - n_{\text{md}} + n_{\text{fa}}$ is the size of the output list $\mathcal{L}$. Our objective is to design a URA scheme minimizing the required E_b/N_0 with $P_e \leq \epsilon$, where ϵ is the target PUPE of the system.

III. Proposed Scheme

A. Encoding

In this section, we describe the encoding process performed in each slot. We first divide the transmission slot into pilot and data parts of lengths n_p and n_d, respectively. In the pilot phase, each user picks one of the non-orthogonal pilot signatures from a common codebook $\mathbf{A} \in \mathbb{C}^{n_p \times N}$ based on first J message bits $\mathbf{m}_p$ where $N = 2^J$, and the corresponding pilot index is $b(\mathbf{m}_p)$. The columns of $\mathbf{A}$ are normalized as $\|\mathbf{a}_i\|^2 = n_p P$ and the received signal of the pilot part in the s-th slot can be written as

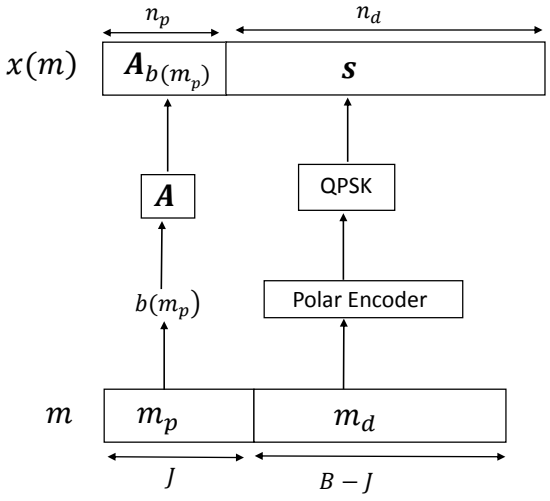

Fig. 1. Encoding process of the proposed scheme for a user.

$$\mathbf{Y}_{p,s} = \mathbf{A_s}\mathbf{H} + \mathbf{Z}_{p,s}, \tag{4}$$

where $\mathbf{Y}_{p,s} \in \mathbb{C}^{n_p \times M}$, $\mathbf{A}_s \in \mathbb{C}^{n_p \times K_s}$ is the submatrix of $\mathbf{A}$ including the selected pilot sequences in its columns, $\mathbf{H} = (\mathbf{h}_1, \mathbf{h}_2, \ldots, \mathbf{h}_{K_s})^T \in \mathbb{C}^{K_s \times M}$ is the channel matrix including channel vectors of the users transmitting in the s-th slot, K_s is the number of transmitting users in the s-th slot, and $\mathbf{Z}_{p,s}$ is the additive white Gaussian noise (AWGN) matrix.

The remaining $B - J$ message bits $\mathbf{m}_d$ are encoded using a $(2n_d, B - J + r)$ polar code and modulated using quadrature phase shift keying (QPSK), where r is the number of cyclic redundancy check (CRC) bits. Then, the received signal of the data part in the s-th slot can be written as follows:

$$\mathbf{Y}_{d,s} = \sum_{k \in \mathcal{K}_s} \mathbf{s}_k \mathbf{h}_k^T + \mathbf{Z}_{d,s}, \tag{5}$$

where $\mathbf{Y}_{d,s} \in \mathbb{C}^{n_d \times M}$, $\mathbf{s}_k \in \{\sqrt{P/2}(\pm 1 \pm j)\}$ is the transmitted symbol of the k-th user, and $\mathbf{Z}_{d,s}$ is the AWGN matrix. The encoding process is depicted in Fig. 1, where $\mathbf{A}_{b(\mathbf{m}_p)}$ is the pilot sequence corresponding to $b(\mathbf{m}_p)$.

B. Activity Detection and Data Decoding

At the receiver side, we perform an iterative decoding by first detecting the selected pilot sequences and estimating the corresponding channel vectors followed by decoding of the data part in each slot. We also use successive interference cancellation at the end of each iteration to improve the performance. In the following, we explain these processes in detail. Note that we drop the slot index s for the rest of subsection to simplify the notation.

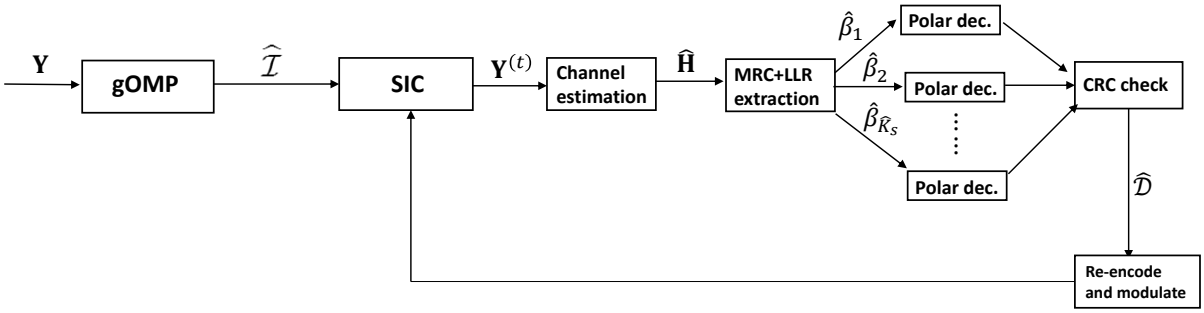

Fig. 2. Decoding process of the proposed scheme in a slot.

We first need to detect the selected pilots in each slot, which is an activity detection problem determining the columns of $\mathbf{A}$ that are active. Since $K_a \ll N$, this problem can be regarded a compressed sensing problem for which $\mathbf{A}$ is the measurement matrix. We propose to employ the gOMP algorithm [20] to solve this problem, which is a lower complexity generalization of orthogonal matching pursuit (OMP). In gOMP, multiple indices are added to the list of detected indices at each iteration, while in OMP, only one index is added to the list. In order to minimize the complexity, we employ gOMP with a single iteration.

In order to implement gOMP with one iteration, we first perform the following multiplication to calculate the correlation between the columns of $\mathbf{A}$ and the pilot part of the received signal:

$$\mathbf{R} = \mathbf{A}^H \mathbf{Y}_p, \tag{6}$$

where $\mathbf{R} \in \mathbb{C}^{N \times M}$ and $\mathbf{A}^H$ denotes the Hermitian of $\mathbf{A}$. Then, we sum the absolute values of the elements of each row of $\mathbf{R}$ to get the $N \times 1$ vector $\mathbf{C}$, where we exploit the receive (antenna) diversity. We then sort the elements of $\mathbf{C}$ and take i_{OMP} indices corresponding to the maximum i_{OMP} elements of $\mathbf{C}$. We explain the choice of i_{OMP} for the single iteration case in the next paragraph.

Since the number of transmitting users in a slot is not known at the receiver, we need its estimate to determine the number of pilot sequences to be recovered. To do this, we first set $i_{\text{OMP}} = \frac{K_a}{V} + \Delta$, where $\frac{K_a}{V}$ is the average active user load in a slot and Δ is an integer which may be taken sufficiently high to make the probability of undercounting the number of the transmitting users in the slot negligible. However, setting i_{OMP} to a high value leads to a high number of overcounts. In order to reduce them, we first calculate the least square (LS) channel vector estimates corresponding to the detected indices as follows

$$\hat{\mathbf{H}}_{LS} = \mathbf{A}^{+}_{\hat{\mathcal{I}}_{id}} \mathbf{Y}_p, \tag{7}$$

where $\hat{\mathcal{I}}_{id}$ is the set of initially detected indices, $\mathbf{A}_{\hat{\mathcal{I}}_{id}}$ denotes the submatrix of $\mathbf{A}$ obtained by taking the columns in $\hat{\mathcal{I}}_{id}$, and $\mathbf{A}^{+}_{\hat{\mathcal{I}}_{id}}$ is its pseudo-inverse. We then calculate the average absolute value of the row elements of $\hat{\mathbf{H}}_{LS}$, and take the indices of $\hat{\mathcal{I}}_{id}$ corresponding to the LS channel vector estimates with an average absolute value of greater than a threshold δ to obtain the finalized set of detected signature indices $\hat{\mathcal{I}}$. Our extensive simulations show that setting δ to a proper value according to the active user load while taking Δ sufficiently high gives an accurate estimate of the active users in each slot. We also note that even if the users are overcounted, the corresponding decoded message in the data part is unlikely to satisfy the CRC check, which ensures that false alarms will not be a problem, while undercounting the users will lead to significant number of misdetections.

Once the set of the detected indices are available, the channel vector of the i-th user can be estimated via LMMSE as:

$$\hat{\mathbf{h}}_i = \mathbf{A}^H_{\hat{\mathcal{I}}(i)} (\mathbf{A}_{\hat{\mathcal{I}}} \mathbf{A}^H_{\hat{\mathcal{I}}} + N_0 \mathbf{I}_{n_p})^{-1} \mathbf{Y}^{(t)}_p, \tag{8}$$

where $\mathbf{Y}^{(t)}_p$ is the received pilot signal at the t-th decoding iteration. Note that the LS channel vector estimates obtained in (7) can also be used as the estimated channel vectors, which decreases the complexity by eliminating the LMMSE step at the cost of a slightly lower performance.

The decoding of the data part is done by first performing MRC to separate the users, and then passing the symbol estimates to a single-user polar decoder. Namely, the symbol estimates of the i-th user are obtained as

$$\hat{\mathbf{s}}_i = \hat{\mathbf{h}}_i (\mathbf{Y}^{(t)}_d)^H, \tag{9}$$

where $\mathbf{Y}^{(t)}_d$ is the data part of the received signal at the t-th decoding iteration. The bit-wise log-likelihood ratio (LLR) values $\hat{\beta}_i$ are then extracted from the complex symbol estimate $\hat{\mathbf{s}}_i$ as in [22], which are treated as the output of a virtual single-user channel and are fed to a single-user polar decoder. If the decoded sequence satisfies the CRC check, it is assumed as successfully decoded and added to the output list $\hat{\mathcal{D}}$. Once this step is completed, we know the successfully decoded messages and the corresponding pilot signatures as well as the channel vector estimates. We then re-encode and modulate the successfully decoded messages to obtain the actual symbols, and perform interference cancellation as follows:

Algorithm 1 Receiver operation of the proposed scheme

Input: $\mathbf{Y}_p$, $\mathbf{Y}_d$, $\mathbf{A}$, δ, Δ, n_{max}
gOMP activity detection algorithm:
$\mathbf{R} = \mathbf{A}^H \mathbf{Y}_p$.
Sum the absolute values of the elements of each row of $\mathbf{R}$ to get $\mathbf{C}$ and sort its elements.
Take $i_{\text{OMP}} = K_a/V + \Delta$ indices corresponding to the maximum elements of $\mathbf{C}$ and put them into the set $\hat{\mathcal{I}}_{id}$.
$\hat{\mathbf{H}}_{LS} = \mathbf{A}^{+}_{\hat{\mathcal{I}}_{id}} \mathbf{Y}_p$.
Calculate the average absolute values of the row elements of $\hat{\mathbf{H}}_{LS}$.
Take the indices of $\hat{\mathcal{I}}_{id}$ corresponding to the rows of $\hat{\mathbf{H}}_{LS}$ having an average absolute value greater than δ to get $\hat{\mathcal{I}}$.
Channel estimation and decoding:
for $j = 1, 2, \ldots n_{max}$ **do**
    Initialize $\hat{\mathcal{D}} = \emptyset$, $\hat{K}_s = \left|\hat{\mathcal{I}}\right|$
    Estimate the channel vectors $\hat{\mathbf{h}}_i$ by Eq. (8)
    for $i = 1, 2, \ldots, \hat{K}_s$ **do**
        MRC: Estimate $\hat{\mathbf{s}}_i$ by (9).
        LLR extraction + polar decoding $\rightarrow \hat{\mathbf{m}}_i$
        If CRC check is satisfied, $\hat{\mathcal{D}} = \hat{\mathcal{D}} \cup i$
    end for
    SIC:
    for k in $\hat{\mathcal{D}}$ **do**
        Re-encode and modulate $\hat{\mathbf{m}}_k \rightarrow \mathbf{s}_k$
    end for
    Interference cancellation by Eq. (10) and (11)
    if $\left|\hat{\mathcal{D}}\right| = 0$ **then**
        Terminate the algorithm.
    end if
end for
$\mathbf{Output}$: List of messages

$$\mathbf{Y}_d^{(t+1)} = \mathbf{Y}_d^{(t)} - \sum_{d \in \hat{\mathcal{D}}} \mathbf{s}_d \hat{\mathbf{h}}_d^T, \tag{10}$$

$$\mathbf{Y}_p^{(t+1)} = \mathbf{Y}_p^{(t)} - \sum_{d \in \hat{\mathcal{D}}} \mathbf{A}_{\hat{\mathcal{I}}(d)} \hat{\mathbf{h}}_d^T, \tag{11}$$

where we initialize $\mathbf{Y}_d^{(0)} = \mathbf{Y}_d$ and $\mathbf{Y}_p^{(0)} = \mathbf{Y}_p$. We then pass the residual signals to the decoder and start another iteration until there is no improvement between two consecutive iterations, i.e., when no message satisfies the CRC check in the current iteration, or a maximum number of iterations is reached. An illustration of the decoding process in a slot is depicted in Fig. 2, and a pseudo-code for the receiver operation is provided in Algorithm 1, where $\hat{\mathbf{H}}$ is collection of the channel vector estimates, $\hat{K}_s$ is the estimated number of transmitting users in the s-th slot, and $\mathbf{Y}$ is the received signal.

C. Complexity Analysis

In this subsection, we provide a complexity analysis of the proposed scheme for the average number of multiplications in each slot. The total complexity of the scheme can be calculated by summing this quantity over V slots.

The complexity of gOMP is dictated by the correlation step in Eq. (6), with a complexity of $\mathcal{O}(Nn_pM)$, which can be further reduced to $\mathcal{O}(MNlogN)$ by employing a sub-sampled DFT matrix as pilot codebook and converting matrix multiplications in the gOMP algorithm to FFT operations [21]. The complexity of LMMSE channel estimation is dominated by matrix inversion, which is $\mathcal{O}(n_p^3)$[1]. The complexity of the matrix multiplication in the MRC step is $\mathcal{O}(\hat{K}_s M n_d)$, and single-user decoding has a complexity of $\mathcal{O}(\hat{K}_s n_d \log n_d)$. Therefore, the overall complexity of the proposed scheme is dominated by the complexity of the gOMP step, which is $\mathcal{O}(MNlogN)$ and independent of the number of the active users.

We now compare the complexity of the proposed scheme with two very recent schemes proposed in [22] and [23] for URA with a massive number of antennas at the receiver. The authors in [22] consider a slotted structure, and use multiple stages of orthogonal pilots instead of a single non-orthogonal pilot. For this scheme, the LS channel estimation at the end of each iteration of [22] has a complexity of $\mathcal{O}(L^2 K_s)$, which is clearly higher than the complexity of the newly proposed scheme. On the other hand, the authors of [23] study an unslotted structure and propose the idea of spreading the random sequences with channel coded bits. The complexity of the matrix multiplication in channel estimation within its additional decoding step is $\mathcal{O}(K_a^2 n)$, which is much higher than the complexity of our scheme.

D. Collisions

In this subsection, a brief analysis on the effect of the pilot collisions on the system performance is provided. In URA, it is impossible to assign fixed pilot sequences to the users due to the massive number of users, hence collisions can happen when the pilot bits of multiple users are the same. We can calculate the average number of the collisions of u users on a pilot sequence as

$$\mathbb{E}\{C_u\} = \frac{\binom{\frac{K_a}{V}}{u}}{N^{u-1}}, \tag{12}$$

where $\frac{K_a}{V}$ is the average active user load in a slot. Since the operations in the slots are identical yet independent, we can consider the collision probability in one slot. The collisions of more than two users are much smaller than 1, so they can be ignored. For instance, for $K_a = 600$, $V = 8$ and $N = 2^{13}$ (13 pilot bits), the average number of users involved in a collision of order two is about 0.68, which leads to an error probability of 0.0090 if none of the users involved in the collision cannot be recovered.

If a suitably designed polar code of less than rate $1/2$ is used over a Gaussian MAC, then both of the colliding users can be recovered. For our case, at least the user having the channel vector with the higher Euclidean norm will be recovered with a high probability. So, if we assume that one of the colliding users would result in error, this leads to

[1]This complexity can be reduced to $\mathcal{O}(n_p^{2.8})$ by the Strassen algorithm.

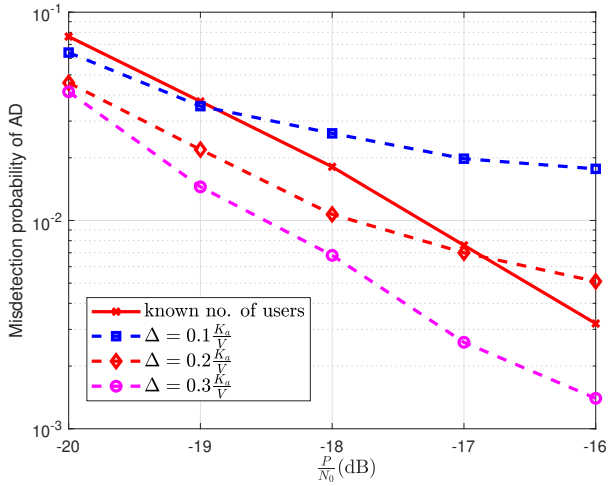

Fig. 3. Misdetection probability of activity detection with different Δ values for $K_a = 300$, $N = 2^{13}$, $M = 50$ and $n_p = 144$.

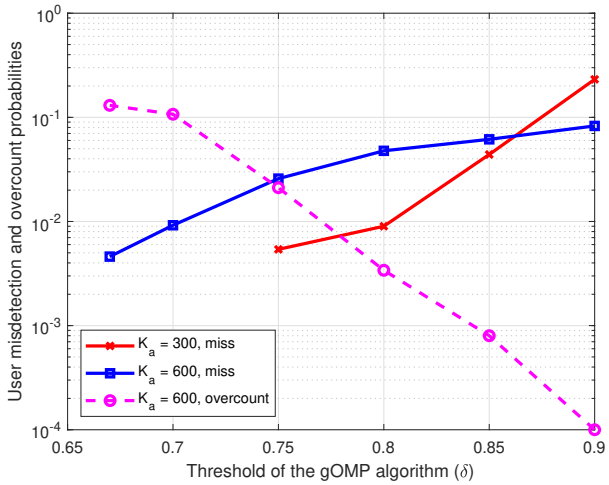

Fig. 4. Misdetection and overcount probabilities of gOMP with respect to δ.

an overall error probability of 0.0045. Note that (12) is a decreasing function of V, hence the collision probability can be decreased by increasing V for a fixed number of pilot sequences; however, it also decreases the packet lengths which can degrade the system performance. There is also a trade-off between the number of pilot sequences N and complexity, namely, increasing the number of pilot sequences decreases the collision probability but it increases the system complexity at the same time. Therefore, an investigation of how small the number of the pilot sequences can be made without significantly deteriorating the system performance would be interesting.

IV. Numerical Results

We now present a performance evaluation of the proposed URA scheme. We choose $n = 3200$ for a fair comparison with the available results in the literature, $B = 100$, $J = 13$, $M = 50$ and $\epsilon = 0.05$. We have tried two different slot sizes $L = 640, 400$ which lead to 5 and 8 transmission slots, respectively, and observe that $L = 400$ outperforms the other choice in a wide range of active user loads. Based on that, we take $n_p = 144$ and $n_d = 256$. We employ 5G polar codes with length 512, set the CRC length to 16 and employ successive cancellation list decoding (SCLD) with a list size of 128. Furthermore, we use a randomly sub-sampled DFT matrix of size N for the pilot codebook, and run the gOMP algorithm with $\delta = 0.75, 0.67$ according to the number of active users.

We first evaluate the performance of gOMP with different Δ values with respect to the average active user load as well as for the case that the number of active users in each slot is known. The results in Fig. 3 depict that taking Δ as 30% of the average active user load in the first step of gOMP leads to a good AD performance. Also, it performs even better than knowing the exact number of the users in the slots since some users with weak channel vectors can be missed around K_s users, but they can be detected when the indices are selected from a larger set.

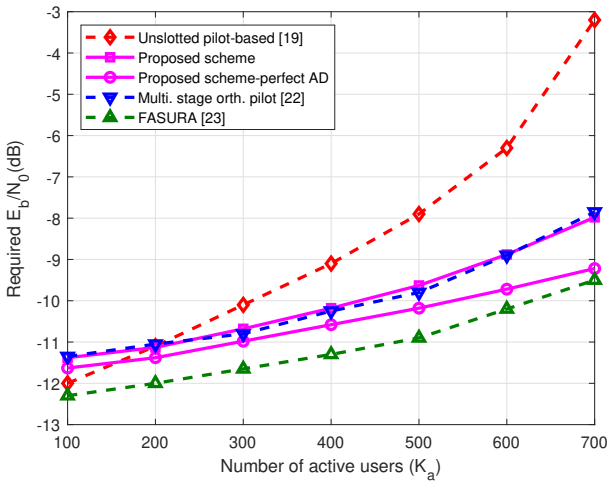

Fig. 5. Required E_b/N_0 versus number of active users for $M = 50$, $n = 3200$, $B = 100$ and $\epsilon = 0.05$.

Note that Δ is rounded to the nearest integer if it is not equal to an integer.

We then investigate the effect of the choice of threshold δ for the gOMP algorithm on the system performance by calculating the misdetection (undercount) and overcount probabilities for $K_a = 300, 600$ and $P/N_0 = -15$ dB with $\Delta = 0.3\frac{K_a}{V}$. Among 500 trials, there are no false alarms when $K_a = 300$ for the considered regime. Fig. 4 illustrates that in order to have a misdetection probability of about 0.0050, the threshold should be approximately set to 0.75 for $K_a = 300$ and 0.67 for $K_a = 600$, respectively.

Finally, we assess the energy efficiency of the proposed scheme by calculating the minimum E_b/N_0 for a system error probability of 0.05. We first compare the performance of our scheme with the one proposed in [19]. Fig. 5 demonstrates that the proposed scheme substantially outperforms the scheme

in [19] for $K_a \geq 200$. We observe that the performance gap increases with the number of active users, for instance, the proposed scheme requires almost 5 dB less power when $K_a = 700$. We also observe that the performance loss at the AD step is at most 1 dB by comparing our result with that of the perfect AD case. Furthermore, we compare the performance of the proposed scheme with the schemes in [22] and [23] and observe that the proposed scheme offers competitive performance with the one in [22] and its performance is slightly inferior to that of [23]. However, both of these two schemes have higher complexity as demonstrated in Section III-C and Table I. In Table I, we calculate the complexity orders of the proposed scheme and the schemes in [22] and [23] for different active user loads using the parameters in Fig. 5. We observe that the proposed scheme provides substantial complexity advantage, which increases with increasing the number of active users.

TABLE I
COMPARISON OF COMPLEXITY ORDERS ($\times 10^6$ MULTIPLICATIONS)

URA scheme	$K_a = 200$	$K_a = 400$	$K_a = 600$
Proposed	3.69	3.69	3.69
Scheme in [22]	69.9	139.8	209.7
FASURA [23]	128	512	1152

V. SUMMARY AND CONCLUSIONS

We consider unsourced random access over Rayleigh block fading channels where the BS is equipped with a massive number of antennas. We propose a slotted scheme to decrease the multiuser interference, and divide each slot into pilot and data parts. After randomly selecting a slot, each user transmits a pilot sequence from a non-orthogonal set in the pilot part and a polar encoded and modulated signal in the data part. We employ a gOMP algorithm for activity detection, and an iterative decoding algorithm based on the LMMSE channel estimation and MRC-based polar decoding of data symbols at the receiver.

Our results demonstrate that the proposed scheme substantially outperforms the scheme in [19] for a wide range of active user loads, which implies that the trade-off between decreasing multiuser interference and packet lengths due to the slotted structure favors the newly proposed scheme. Furthermore, the new approach offers similar performance to the state-of-the-art schemes while having less complexity. Note that since we exploit a slotted structure in contrast to [19] and [23], the proposed approach may even be suitable for fast fading scenarios.

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