Evaluation of 5G New Radio Non-orthogonal Multiple Access Methods for Military Applications

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Abstract—Non-orthogonal multiple access (NOMA) is an enabling technique to support massive connectivity and utilize the radio resources more efficiently. A number of novel NOMA schemes have been proposed for 5G New Radio (NR) standards. In this study, we evaluate various 5G NOMA methods for different military communications scenarios. We also propose a novel, simple NOMA scheme based on separation of users via frozen bit signatures in polar codes. First, we provide the description of basic principles in each evaluated scheme, then we investigate and compare their performances under different system parameters such as spectral efficiency, overload factor and antenna number in various channel models. Finally, we provide the discussions and insights on the suitability of the evaluated schemes for the considered military scenarios based on simulations.

Index Terms—Non-orthogonal multiple access (NOMA), 5G, satellite communications, military networks, polar codes.

I. INTRODUCTION AND MOTIVATION

NOMA schemes are based on the idea that multiple users share the same resource block (e.g. time slot, subcarrier group) via non-orthogonal resource allocation. The main motivation behind NOMA is to increase system capacity by utilizing the resources more efficiently and/or provide enhanced connectivity [1]. The idea of users sharing the same resource blocks has been used in previous commercial wireless systems and military waveforms. For example, Wideband Code Division Multiple Access (WCDMA), which depends on the idea of spreading the data symbols using specific channelization and scrambling codes, has famously been employed in 3G. Also, Mobile User Objective System (MUOS) has been introduced for military UHF satellite communication (SATCOM) systems targeting worldwide coverage and increased communications capacity by employing Spectrally Adaptive Wideband Code Division Multiple Access (SA-WCDMA) [2].

Starting with LTE (4G), Orthogonal Frequency Division Multiple Access (OFDMA) has replaced WCDMA for cellular mobile communications and it will also be employed in 5G [3]. One of the main service scenarios in 5G is massive machine type communications (mMTC), which requires the connection of massive number of low-cost, energy-efficient devices sending sparse, small packets in the uplink communication. A number of novel NOMA schemes have been proposed for mMTC scenario [4]. The main evaluation scenario of the proposed techniques is communications with low spectral efficiency in channels with slow fading and short RMS delay spread (30 – 300 ns,) as it targets commercial use [5].

The refined, novel NOMA schemes potentially be employed for certain military communications scenarios as well. An example is the satellite communications, in which the efficient use of bandwidth becomes more and more necessary with the increasing number of terminals and unmanned aerial vehicles (UAVs) using the satellite links. Especially, using NOMA schemes for channel requests and synchronization signaling would be a more efficient alternative to OMA and/or dynamical channel allocation methods by reducing delay and overhead. Another example is the military sensor networks, in which the sensors are used as assets for Command and Control applications such as border safety and threat detection. Also, military Internet of Things (IoT) will find applications in human performance and medical tracking or advanced situational awareness through manned/unmanned sensors [6].

For example, in covert military operations, the soldiers can send various types of data supplied by sensors and cameras to the team leader in close-range and indoor communications scenarios [7]. NOMA techniques can be employed in such scenarios to send information from large number of monitoring devices to a fusion/command center similarly to the mMTC scenario considered in 5G. In tactical area communications, the increased number of connected radios in a network lead to a clustering based network structure rather than a flat network [8]. For the uplink communications inside the cluster, members can send packets to the cluster-head by NOMA schemes, which will potentially increase the total spectral efficiency and simplify the link scheduling algorithms. Furthermore, contention based access methods used for channel allocation requests in tactical area networks can be replaced by NOMA schemes to allow non-orthogonal access in a more controlled way, which in turn reduces the packet collisions and increases the system...
capacity.

In this work, we investigate different NOMA schemes in the scope of military scenarios mentioned above. We also propose a NOMA scheme, namely Polar Code Based Multiple Access (PCBMA) and compare its performance with the other NOMA schemes considered in this work.

II. BACKGROUND

A. Basic Principles

The novel NOMA schemes proposed for 5G share the common idea to superpose different users’ signals in the same orthogonal resource block in a controlled manner so that they can be recovered using advanced receiver structures. The ratio of the number of users to the number of resource blocks is called the overload factor. In order to limit the multi-user interference and distinguish between the users, user-specific signatures need to be used. The proposed NOMA schemes for 5G are classified depending on the type of signatures, which can be in power-domain or in modulation and symbol level processing including spreading, repetition, interleaving and codebook mapping [9].

A general description of NOMA transmitter and receiver structures considered in this study are depicted in Fig. 2. At the transmitter side, the encoded user data are modulated and repeated/spread with user-specific sequences. Then, the user signals are superposed in specific resource blocks. It should be noted that modulation and spreading operations are performed jointly in some of the considered NOMA schemes.

At the receiver side, advanced receiver structures, such as Successive Interference Cancellation (SIC) or Message Passing Algorithm (MPA) are employed depending on NOMA schemes to recover user data under multi-user interference. In SIC, the received signal is first filtered by Matched Filter (MF) or Minimum Mean Squared Error (MMSE) filter. For soft input FEC decoding, the log-likelihood ratios (LLR) are calculated in accordance with [10]. After LLR calculation, the user data are first decoded, then reconstructed and subtracted from the received signal until all user data has been processed. The processing order of users can be formed according to their post filter signal to noise-interference ratio (SINR) or any other criteria. This procedure can be performed for several iterations if necessary. On the other hand, MPA is a generic algorithm providing near Maximum Likelihood (ML) detection performance and working on a factor graph representation. It calculates the probability of the codewords for each user by iteratively passing messages in a bipartite graph.

B. Evaluated Methods

In this study, we evaluate 4 different 5G NOMA schemes in addition to a simple, novel polar code frozen bits based NOMA scheme that we propose. We briefly describe each method as follows:

1) Sparse Coded Multiple Access (SCMA): SCMA is a codebook-based NOMA method which performs modulation and spreading jointly [11]. Particularly, each user has a different codebook which contains $J$ different sparse codewords with length $M$. At the transmitter, a user maps $\log_2 J$ bits to a specific codeword in the codebook and codewords are sparse in the sense that the number of nonzero elements in a codeword is much less than $M$. The sparse structure of SCMA codewords allows MPA to be a suitable receiver to detect user data. For SCMA, the codebook available in [12] has been used in this study.

2) Pattern Division Multiple Access (PDMA): PDMA is a codebook-based NOMA scheme employing a user-specific pattern mapping of the modulated user symbols to resource blocks for differentiating the user data. PDMA patterns are selected to offer different orders of transmit diversity. To recover the user data, a receiver based on MMSE filter working together with SIC algorithm iteratively or MPA is proposed in the literature [13], [14].

3) Repetition Division Multiple Access (RDMA): RDMA is an interleaver based NOMA scheme introduced in [15]. The scheme separates the user data and utilizes time and frequency diversity by assigning distinct cyclic shift repetition patterns in frequency domain to users. Due to the RDMA pattern, the interference level between users can be limited and randomized so that an SIC receiver with MF or MMSE filtering can distinguish the user data.

4) Multi User Shared Access (MUSA): MUSA is a spreading sequence-based NOMA method as proposed in [16]. In this method, each user’s modulated symbols are spread by short, user-specific codes and transmitted in the same resource blocks.

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1The blocks with * are optional in some schemes, even though they are included in this study.
At the receiver, each user’s data can be detected using SIC procedure. In [17], a receiver structure employing CRC-based SIC and user-specific MMSE filtering is proposed and it has been used in this study as well.

5) Polar Code Based Multiple Access: PCBMA is a simple NOMA scheme based on separation of users via signatures over the redundant bits of polar codes used for FEC. Instead of setting the frozen bits to 0 (or 1) as in conventional polar coding [13], each user embeds a predetermined signature that is composed of specific numbers of 0’s and 1’s. In other words, each user is assigned a different codebook separated by the frozen bit signatures. An SC-based (e.g. SC, SCL, etc.) decoder can separate the users in codebook domain during the decoding operation given these signatures. The LLR values for decoding are obtained using CRC-based SIC algorithm with MMSE filtering described in [17]. PCBMA brings no additional algorithmic complexity at the transmitter side since it does not require any additional operations (e.g. spreading, scrambling, etc.) other than FEC encoding. Transmitting the identification numbers of wireless transmit/receive units over frozen bit signatures has been proposed in [19]; however, this is the first time it has been employed to separate users in codebook domain in a NOMA scheme to the best of our knowledge.

III. Numerical Results

A. Scenarios

In satellite communications, high Doppler and phase errors can be observed due to high dynamics of satellite and terminals. Additionally, satellite systems are based on line-of-sight (LOS) communications [20]. Therefore, it is possible to model the received signal with Additive White Gaussian Noise (AWGN) channel when no interference in the received signal is assumed. Due to the long distance communications between satellite and terminals, the received signal strength level for different received power levels uniformly distributed in 2 dB interval around the mean SNR value.

For sensor networks/military IoT and covert operation/indoor communications, the environmental conditions are similar to those in mMTC scenario. For example, in [7], statistics for RMS delay spread for soldier to soldier links are provided where most of the energy of the signal arrives in 25 ns, and occasional multipath components arrive between 100 and 150 ns. Therefore, for close-range/indoor communications and sensor networks, we use TDL-A channel which has an RMS delay spread of 30 ns to evaluate NOMA schemes, which is also one of the selected channels for the evaluation of NOMA schemes in 5G [5].

For tactical area communications, various channel models can be adopted depending on the considered scenario. In this work, we assume a communications requirement in a densely built urban area and consider the COST207 Bad Urban (BU) wideband channel model [21].

B. Simulation Results

The system parameters and the receiver structures for the schemes are given in Table I. First, we test the NOMA schemes described in Section II-B with 150% and 300% overload factors and compare their performances with an OFDM scheme in which the user signals are simply superposed without any processing. In the simulations, the user spectral efficiency (SE) is set to 1/4 and 1/6 bits/s/Hz for all evaluated schemes. Therefore, the number of information bits transmitted per user is constant for all compared schemes. Note the change in the code lengths and code rate when NOMA schemes are used with respect to PBCMA and OFDM in Table I. The channel estimation is assumed to be ideal in all cases but the AWGN scenario with CFO errors for which MMSE based channel estimation is performed. The user signatures in PCBMA are selected randomly.

In Figures 3 and 4, the performances of the considered NOMA schemes are provided in AWGN channel for 1/4 and 1/6 bits/s/Hz SE per user, respectively. It is observed that in AWGN, the schemes except MUSA and PDMA do not perform well with 300% overload factor. On the other hand, when the SE per user is 1/6 with 150% overload, most schemes perform well with varying successes. We note that MUSA has the best overall performance in the investigated overload factors and SE combinations whereas OFDM fails in all of them. The results show that NOMA methods are necessary in AWGN channel with close user received powers. Also, lowering the SE improves the performances of the schemes. For example, PCBMA reaches the performance of MUSA when the SE per user is 1/6 with 150% overload.

In Fig. 5 we observe the effects of CFO errors. For 150% overload scenario, PDMA and MUSA provide the best performance, however none of the schemes can operate with 300% overload. This implies that CFO estimation and correction are necessary in high overload scenarios.

**Note that SCMA codebook in [12] supports 6 users using 4 resources, therefore we evaluated SCMA in only 150% overload factor.**

### Table I: Simulation Parameters

| Parameter                          | RDMA               | SCMA               | MUSA               | PCBMA             | OFDM               |
|------------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| **Codebook Length (bits)**         |                    |                    |                    | 512 – (1/2, 1/3)  |                    |
| **Code Rates**                     | RDMA               | SCMA               | MUSA               | PCBMA             | OFDM               |
|                                    | SCMA               | MUSA               | OFDM               |                    |                    |
| **CRC Length (bits)**              | 512                | 2048 – (1/8, 1/12) |                    |                    |                    |
| **FEC Decoder**                    | SCL-16             |                    |                    |                    |                    |
| **Antenna Number**                 | 1×1 (SISO), 1×2 (SIMO) |                    |                    |                    |                    |
| **Channel Estimation**             | Ideal, MMSE        |                    |                    |                    |                    |
| **Receiver**                       | RDMA               | SCMA               | PDMA               | MUSA               | PCBMA             |
|                                    | MF-SIC-CRC         |                    |                    | MMSE-CRC          |                    |
|                                    |                    |                    |                    |                    |                    |
| **Monte Carlo**                    | 10000              |                    |                    |                    |                    |
In Figures 6 and 7, we investigate the performances of the schemes in BU channel for 1/4 and 1/6 bits/s/Hz SE per user, respectively. We observe that the schemes perform much better compared to the AWGN case. The performance improvement is due to the fact that BU is a highly frequency selective channel, and it differentiates users via frequency diversity. We note that in both figures, PCBMA and OFDM give the best performance in 150% overload. Their performances are almost the same as the differentiation of the user codewords is primarily handled by the channel and frozen bit signatures do not provide any further performance gains. However, in Fig. 6 the performances of the NOMA schemes except RDMA surpass those of OFDM and PCBMA with 300% overload factor (see also, Fig. 12).

In Fig. 8 we investigate the performances of the schemes in TDL-A channel with 1/4 bits/s/Hz SE per user. Note that TDL-A is a less frequency selective channel than BU. The diversity difference in the channels can be observed from the slopes of BLER curves in Figures 6 and 8. However, TDL-A
channel naturally provides a received power difference, which enables easier separation of users compared to BU and AWGN channels. Owing to this fact and CRC-based SIC algorithm at the receiver, high overload factors can be supported in TDL-A channel. For example, in Fig. 8 we observe that there is no performance gap between 150% and 300% overload factors for MUSA, OFDM and PCBMA.

So far, we only considered SIMO configuration in our simulations. In Fig. 9 we focus on a SISO setting which may be the case for certain military communications scenarios. The diversity gain by multiple receive antennas can be observed by comparing Figures 8 and 9. An important observation for the SISO case is the performance degradation with 300% overload factors can not be supported in this specific case. In Fig. 10 we consider a scenario, in which the SNR of each user is uniformly distributed in $[-7, +17] \text{ dB}$. One can observe that, in low overload factors, PCBMA gives the best performance, but the performance of MUSA surpasses those of other schemes especially after 250% overload factor. Note that OFDM still performs poorly and RDMA performs worse than MUSA and PCBMA even though it still performs better than OFDM.

In Figures 11 and 12 the performances of the schemes for TDL-A and BU channels at specific SNR values are provided. Note that in both channels, MUSA gives the best performance in high overload values. In Fig. 11 we observe that the performance of MUSA is almost identical up to 500% overload, showing its robustness to high interference in TDL-A channel. In Fig. 12 it can be observed that the performances of all schemes become worse as the overload factor increases. Note that it is possible to support larger overload factors in TDL-A channel compared to BU. The performances of PCBMA and OFDM are similar in both channels, and even though their performances are the best among all schemes in low overload factors, they are quickly surpassed as the overload factor increases. The reason behind that is the fact that in low overload factors, using low code rates instead of repetition/spreading based methods provides coding gain; however as the overload factor increases, specific NOMA processing techniques help decrease the effects of interference. Therefore lowering the code rate in high overload scenarios is not a solution anymore, and NOMA methods are required.

### IV. Discussion and Conclusion

In this study, we investigated the performances of 5G NOMA schemes for certain scenarios in military communications. We also proposed a simple method based on user signatures carried on frozen bits in polar codes. The key observations in this study are as follows:

- In satellite communications (AWGN), it is not possible to support high overload factors compared to other scenarios, assuming the user received powers are close to each other. Also, superposing users with low code rate is not a valid solution, and NOMA schemes are required as the channel
does not naturally separate the users. It is also observed that NOMA schemes are sensitive to CFO errors, and CFO correction is required in general.

- For tactical area communications (BU), it is observed that NOMA schemes exploit the high frequency selectivity of the channel to create diversity and randomize the interference. The schemes are especially useful in high overload scenarios.

- For close-range/indoor communication scenarios (TDL-A), as the channel has larger coherence bandwidth compared to BU, less frequency diversity is observed. However, the channel creates a received power difference between the users so that they are separable in power domain. By using SIC based receivers, it is possible to support overload factors up to 500% (and possibly higher) via NOMA schemes.

- OFDM with loading provides good performance in low spectral efficiency and overload factors due to advanced MMSE-SIC-CRC receiver. However, in order to support larger overload values, specific NOMA schemes need to be used.

- PCBMA based scheme is especially useful and improves the performance of OFDM when the channel does not provide any diversity or power level differentiation.

- SIMO technology is key in many scenarios as it provides an additional source of diversity.

- For SCMA, the specific codebook design should be further studied for better performance. Note that advanced soft receivers can improve SCMA performance [22]. For PDMA, it is known that MPA based receivers can provide performance gains over SIC-based receivers [13]. For RDMA, the performance can be improved by using block based MMSE-SIC receivers at the expense of increased complexity.

REFERENCES

[1] F. Luo and C. Zhang, Signal Processing for 5G: Algorithm and Implementations, Wiley-IEEE Press, 2016.
[2] J. D. Oetting and T. Jen, “The mobile user objective system,” in Johns Hopkins APL Tech. Dig., vol. 30, no. 2, pp. 103–112, 2011.
[3] 3GPP TS 36.211 V15.1.0, “NR: Physical channels and modulation (Release 15),” (2018-03)
[4] 3GPP “Final report of 3GPP TSG RAN WG1 #66”, August 2016.
[5] 3GPP RP-171997, “Summary of workshops on NOMA,” ZTE, Sanechips, Sep. 2017.
[6] P. Lamas et al., “A review on Internet of Things for defense and public safety,” in Sensors, vol. 16, no. 16, pp. 1644–1687, Oct. 2016.
[7] L. C. Cotton, W. G. Scanlon and B. K. Madahar, “Millimeter-wave soldier-to-soldier communications for covert battlefield operations,” in IEEE Communications Magazine, vol. 47, no. 10, pp. 72–81, Oct. 2009.
[8] J. Y. Yu and P. H. J. Chong, “A survey of clustering schemes for mobile ad hoc networks,” in IEEE Communications Surveys & Tutorials, vol. 7, no. 1, pp. 32-48, First Qtr 2005.
[9] 3GPP RP-171724, “Status report on study of 5G non-orthogonal multiple access,” ZTE, Sep. 2017.
[10] D. Seethaler, G. Matz and F. Hlawatsch, “An efficient MMSE-based demodulator for MIMO bit-interleaved coded modulation,” Global Telecommunications Conference (GLOBECOM), 2004, IEEE, 2004, pp. 2455–2459 Vol.4.
[11] H. Nikopour and H. Baligh, “Sparse code multiple access,” 2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), London, pp. 332–336, 2013.
[12] Altera Innovate Asia FPGA Design Contest, 5G Algorithm Innovation Competition. [Available: http://www.innovateasia.com/5g/images/pdf/1st 5G Algorithm Innovation Competition-ENV1.0 - SCMA.pdf]
[13] S. Chen, B. Ren, Q. Gao, S. Kang, S. Sun and K. Niu, “Pattern division multiplex access – A novel nonorthogonal multiple access for fifth-generation radio networks,” in IEEE Transactions on Vehicular Technology, vol. 66, no. 4, pp. 3185-3196, April 2017.
[14] D. Kong et al., “Multiuser detection algorithm for PDMA uplink system based on SIC and MMSE,” 2016 IEEE/CIC International Conference on Communications in China (ICC), Chengdu, 2016, pp. 1-5.
[15] 3GPP R1-167535, “New uplink non-orthogonal multiple access schemes for NR”, MediaTek Inc., August 2016.
[16] Z. Yuan, G. Wu, W. Li, Y. Yuan, X. Wang and J. Xu, “Multi-user shared access for Internet of Things,” 2016 IEEE 83rd Vehicular Technology Conference (VTC Spring), Nanjing, 2016, pp. 1-5.
[17] 3GPP R1-180123, “Receiver algorithms of linear spreading based NOMA”, ZTE, Sanechips, Jan. 2018.
[18] E. Arinik, “Channel polarization: A method for constructing capacity-achieving codes for symmetric binary-input memoryless channels,” IEEE Trans. Inform. Theory, vol. 55, no. 7, pp. 3051–3073, July 2009.
[19] S. Hong, J. AHN, “Wtru identification using polar code frozen bits,” WO/2017/106246, June 22, 2017.
[20] A. P. Neira et al., “Signal processing for high throughput satellite systems: Challenges in new interference-limited scenarios,” arXiv:1802.03958v1 [cs.IT], Feb. 2018.
[21] M. Patzold, “Mobile fading channels,” John Wiley & Sons, New York, NY, 2003.
[22] B. Xiao et al., “Iterative detection and decoding for SCMA systems with LDPC codes,” 2015 International Conf. on Wireless Comm. & Signal Proc. (WCSP), Nanjing, 2015, pp. 1–5.