Capacity Analysis for Non-orthogonal Overloading Transmissions under Constellation Constraints

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***Abstract*—In this work, constellation constrained (CC) capacities of a series of non-orthogonal overloading transmission schemes are derived in AWGN channels. All these schemes follow a similar transmission structure, in which modulated symbols are spread on to a group of resource elements (REs) in a sparse manner, i.e., only a part of the REs have non-zero components while the others are filled with zeros. The multiple access schemes follow this structure is called sparse code multiple access (SCMA) in general. In particular, a complete SCMA scheme would combine multi-dimensional modulation and the low density spreading (LDS) together such that the symbols from the same data layer on different REs are different but dependent. If the spread symbols are the same, it is a simplified implementation of SCMA and is called LDS. Furthermore, depending on whether the numbers of non-zero components for each data layer are equal or not, there are regular LDS (LDS in short) and irregular LDS (IrLDS), respectively. The paper would show from theoretical derivation and simulation results that the complete SCMA schemes outperform the simplified version LDS/IrLDS. Moreover, we also show that the application of phase rotation in the modulator can significantly boost the link performance of such non-orthogonal multiple access schemes.**

***Keywords*—SCMA, LDS, IrLDS, Constellation Constrained capacity, Non-orthogonal multiple access**

I. Introduction

When the 4th generation (4G) wireless networks started to be deployed worldwide, the research for the 5th generation (5G) networks has already been in full swing. The 5G networks set its goal to connect not only people to people, but also people to things and things to things, thus building a *full connected world*. It is not hard to imagine that when cars, machines, robots, sensors are all end equipments in the wireless networks, we will see steep rise in the number of connections and hence highly increased requirement for system capacity, 100 to 1000 times more. [1].

The current orthogonal frequency division multiple access (OFDMA) techniques used in 4G systems today are inadequate to meet such challenging 5G requirement. Instead, non-orthogonal multiple access techniques have been considered as potential solutions to achieve higher spectrum efficiency, throughput and larger connectivity, by packing more data streams or users into the same amount of resources [2]. Such systems are called *overloaded* system, and the *overloading rate* is defined as the ratio between the number of data layers and the number of orthogonal resources, in which each layer stands for one data stream and multiple layers can be assigned to one user or different users.

One intuitive idea to realize overloading transmission is to add code division multiple access (CDMA) on top of OFDMA directly. The major problem with such idea is the high receiver complexity due to the adoption of CDMA style long and full spreading sequences. Further, data stream on each resource element (RE) is interfered by all other streams. Instead, in this paper, we consider a series of overloading schemes in which modulated symbols are spread on to a group of resource elements (REs) in a sparse manner, i.e., only a part of the REs have non-zero components while the others are filled with zeros. With the pre-designed sparsity, the data symbols after superposition on each RE is greatly reduced so that at the receiver end, multi-user decoder with affordable complexity and near optimum performance, such as the message passing algorithm (MPA) [3] [4], can be applied, even for a high overloading rate.

The multiple access schemes follow this structure is called sparse code multiple access (SCMA) in general. In particular, a complete SCMA scheme would combine multi-dimensional modulation and the low density spreading (LDS) together such that the symbols from the same data layer on different REs are different but dependent. In this sense, the coded bits from any given error correction encoder will be directly mapped as multidimensional codeword, with the modulation symbols on the two non-zeros REs different but dependent with each other. The motivation for such correlated design is to introduce diversity in the distance between any two constellation points, reducing the probability of having small constellation distance on both REs, which in turn results in more robust link performance. On the other hand, if the spread modulation symbols for a data layer are exactly the same, it is a simplified implementation of SCMA and is called LDS. Furthermore, depending on whether the numbers of non-zero components for each data layer are equal or not, there are regular LDS (LDS in short) and irregular LDS (IrLDS), respectively.

The contribution of this paper is to examine the link level performances of those schemes mentioned above by calculating their constellation constrained (CC) capacities [5]. Moreover, based on the derivation of their CC capacities, the phase rotation impact is also discussed which gives us a guidance of codebook design.

The rest of the paper is organized as follows. First of all, the unified system model for different overloading transmissions is introduced as the framework for further analysis in Section II. In section III, the closed form CC capacities are mathematically computed for the general framework. With the examples of codebooks given for each scheme, the CC capacities for

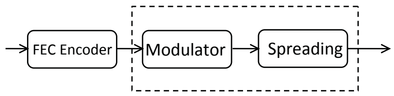

Fig. 1. General SCMA transmitting structure, where the modulator supports phase rotation.

each scheme are derived. On top of it, the impact of phase rotation on the capacity is analyzed as a guideline for optimal overloading codebook design. After that, simulation results in full communication links are provided and compared in Section IV. Finally, Section V concludes the paper.

II. SYSTEM MODEL

A basic non-orthogonal transmission model is assumed in this work, comprising 6 users sharing 4 REs with 150% overloading rate. In contrast with the previous mechanism in LTE, the proposed model enables a joint processing of modulation and spreading by a codebook mapping procedure, as shown in the dashed box of Fig. 1. Specifically, each user has a pre-defined codebook, which determines the codewords to be sent depending on the incoming channel-coded bits. The codebook mapping procedure is shown in Fig. 2. In this paper, we consider 4 point constellation for each layer, namely the maximum capacity equals to 2 bits/sec/Hz for each user. For instance, when coded bit sequence (1,1) comes at UE 1, the 4-th column of its codebook is selected, where the colored REs are spread to while the blank ones are not. By following the same principle, the selected codewords from 6 users are finally overlapped at corresponding REs. Such non-orthogonal transmission schemes can also be represented by the well known factor graph [6], as shown in Fig. 3 for example. Binary data set $\mathbf{b}_i$ (i=1,2,...,6) of length 2 from the $i\text{-}th$ user are encoded to a codeword vector $\mathbf{x}_i$ (i=1,2,...,6) of length 4, and x_{ik} (k=1,2,3,4) further defines the codeword spread to the $k\text{-}th$ RE.

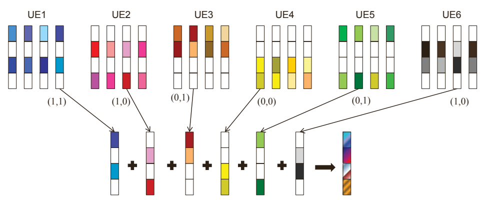

Fig. 2. Diagram of codebook mapping.

As mentioned in the introduction, any non-orthogonal transmission scheme following the above structure is called SCMA in general, and all differences will appear in the codebooks. In particular, we consider the following three types of codebooks in the paper, namely

- Complete SCMA (SCMA in short) codebook: The constellation on the non-zero tones REs are jointly optimized following the multi-dimensional constellation design. Taking UE 1 for example, $x_{11} \neq x_{13} \neq 0$ and $x_{12} = x_{14} = 0$. Usually, if signals are spread to less than half of the total REs, it is called sparse spread. The factor graph matrix F_1 shown below illustrates the spreading density. In F_1, two '1' elements within a column indicate the 2 REs used by each user, and three '1' elements in a row denote that each RE is shared by 3 corresponding users.

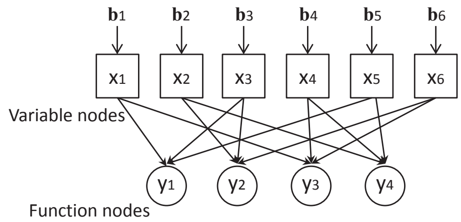

Fig. 3. Factor graph of a SCMA encoding example.

- LDS codebook: LDS can be regarded as a special case of SCMA with the same factor graph shown in Fig. 3. However, its codewords are normal QPSK symbols with simple repetitions while mapping to different REs. Taking UE 1 for example, $x_{11} = x_{13} \neq 0$ and $x_{12} = x_{14} = 0$.

- IrLDS codebook: Both SCMA and LDS regularly spread signals to a fixed amount of REs for each user, with the same factor graph matrix F_1. However, for IrLDS, the spreading can be sparse or dense depending on users, and the factor graph matrix is irregular compared to the other two schemes shown in F_2. For instance, UE 1 will spread its codewords to all REs while UE 5 and 6 only spread to one RE. Taking UE 1 for example, $x_{11} = x_{12} = x_{13} = x_{14} \neq 0$, while for UE 5, $x_{51} \neq 0$ and $x_{52} = x_{53} = x_{54} = 0$.

$$F_1 = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix} F_2 = \begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 \end{bmatrix}.$$

Fig. 4 illustrates the constellation points of UE 1 for three mentioned schemes over 4 REs. It can be seen that UE 1 of SCMA and LDS only spread their codewords to RE1 and RE3, but IrLDS spread its codewords to all REs, which coincides with the first column of factor graph matrixes F_1 and F_2.

As is known that the non-orthogonal codebook design should guarantee user constellations being uniquely decodable, so that the sum constellations can distinguish from which user (or data layer) it is constituted. For the complete SCMA, the designed codebooks already contain phase rotations for different users. For the same purpose, in LDS and IrLDS, users' codebooks can also be phase-rotated from a basic one with certain angles, in order to avoid this problem.

Taking SCMA as an example, with the factor graph and matrix defined above, the received signals $y_k \in \mathbf{y}(k = 1, ..., 4)$

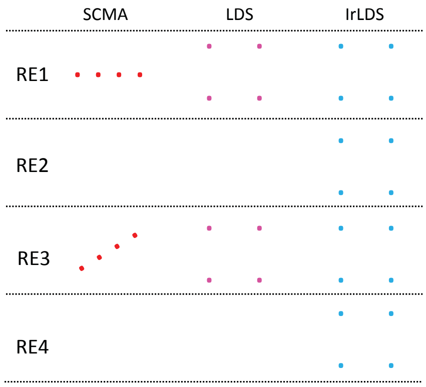

Fig. 4. Constellation schematic of UE 1 for SCMA, LDS and IrLDS.

on the k-th RE over AWGN channels can be expressed by

$$\begin{aligned} y_1 &= x_{11} + x_{31} + x_{51} + z_1, \\ y_2 &= x_{22} + x_{32} + x_{62} + z_2, \\ y_3 &= x_{13} + x_{43} + x_{63} + z_3, \\ y_4 &= x_{24} + x_{44} + x_{54} + z_4, \end{aligned} \tag{1}$$

where x_{ik} is the codeword from the i-th user spread to the k-th RE, and $z_k \in \mathbf{z}$ denotes the complex AWGN noise vector with zero mean and variance $\sigma^2/2$ for each dimension.

III. Constellation Constrained Capacity

A. CC capacity analysis framework

The constellation constrained (CC) capacity is measured by the mutual information between the input and the output of a Gaussian channel, where modulated symbols belong to a finite set with uniform distribution. First of all, we calculate $I(\mathbf{x}_1 : \mathbf{y})$ for UE 1 by taking other users as additive noises, shown as

$$I(\mathbf{x}_1 : \mathbf{y}) = H(\mathbf{y}) - H(\mathbf{y}|\mathbf{x}_1), \tag{2}$$

where $H(\mathbf{y})$ is given by

$$H(\mathbf{y}) = -\int p(\mathbf{y}) \log_2(p(\mathbf{y}))d\mathbf{y}, \tag{3}$$

and

$$p(\mathbf{y}) = \frac{1}{\prod_{i=1}^{6} N_i} \sum_{\mathbf{x}} p(\mathbf{y}|\mathbf{x}), \tag{4}$$

where $N_i(i = 1, 2.., 6)$ is the modulation order of the i-th user, which is equal to 4 in this paper, and $\sum_{\mathbf{x}} = \sum_1^{N_1} \sum_1^{N_2} ... \sum_1^{N_6}$, covering all codewords options of 6 users. Based on the derivations above, $H(\mathbf{y})$ can be expressed by

$$\begin{aligned} H(\mathbf{y}) &= -\int p(\mathbf{y}) \log_2 \left(\frac{1}{\prod_{i=1}^{6} N_i} \sum_{\mathbf{x}} p(\mathbf{y}|\mathbf{x}) \right) d\mathbf{y} \\ &= -\int p(\mathbf{y}) \left[\log_2 \left(\sum_{\mathbf{x}} p(\mathbf{y}|\mathbf{x}) \right) - \log_2 \left(\prod_{i=1}^{6} N_i \right) \right] d\mathbf{y} \\ &= \log_2 (\prod_{i=1}^{6} N_i) - \frac{1}{\prod_{i=1}^{6} N_i} \sum_{\mathbf{x}} \int p(\mathbf{y}|\mathbf{x}) \log_2 \left(\sum_{\mathbf{x}} p(\mathbf{y}|\mathbf{x}) \right) d\mathbf{y}. \end{aligned} \tag{5}$$

After deriving $H(\mathbf{y})$, $H(\mathbf{y}|\mathbf{x}_1)$ can be expressed as follows

$$H(\mathbf{y}|\mathbf{x}_1) = \frac{1}{N_1} \sum_{j=1}^{N_1} H(\mathbf{y}|\mathbf{x}_1 = \mathbf{x}_1(j)), \tag{6}$$

where $\sum_{j=1}^{N_1}$ takes the accumulation with regard to all possible values of $\mathbf{x}_1$, and

$$H(\mathbf{y}|\mathbf{x}_1 = \mathbf{x}_1(j)) = -\int p(\mathbf{y}|\mathbf{x}_1 = \mathbf{x}_1(j)) \log_2(p(\mathbf{y}|\mathbf{x}_1 = \mathbf{x}_1(j)))d\mathbf{y}, \tag{7}$$

$$p\left(\mathbf{y}|\mathbf{x}_1 = \mathbf{x}_1(j)\right) = \frac{1}{\prod_{i=2}^{6} N_i} \sum_{\mathbf{x}/\mathbf{x}_1} p\left(\mathbf{y}|\mathbf{x}/\mathbf{x}_1, \mathbf{x}_1 = \mathbf{x}_1(j)\right), \tag{8}$$

where $\sum_{\mathbf{x}/\mathbf{x}_1}$ is with regard to all users except UE 1. Therefore, $H(\mathbf{y}|\mathbf{x}_1)$ is given by

$$\begin{aligned} H(\mathbf{y}|\mathbf{x}_1) = \log_2(\prod_{i=2}^{6} N_i) - \\ \frac{1}{\prod_{i=1}^{6} N_i} \sum_{x} \int p(\mathbf{y}|\mathbf{x}/\mathbf{x}_1, \mathbf{x}_1) \log_2 \left(\sum_{\mathbf{x}} p(\mathbf{y}|\mathbf{x}/\mathbf{x}_1, \mathbf{x}_1) \right) d\mathbf{y}. \end{aligned} \tag{9}$$

For SCMA and LDS which are on the basis of factor graph matrix F_1, we have

$$\begin{aligned} & p\left(\mathbf{y}|\mathbf{x}\right) \\ =& p\left(y_1|\mathbf{x}\right) p\left(y_2|y_1, \mathbf{x}\right) p\left(y_3|y_1, y_2, \mathbf{x}\right) p\left(y_4|y_1, y_2, y_3, \mathbf{x}\right) \\ =& p\left(y_1|x_{11}, x_{31}, x_{51}\right) p\left(y_2|x_{22}, x_{32}, x_{62}\right) \cdot \\ & p\left(y_3|x_{13}, x_{43}, x_{63}\right) p\left(y_4|x_{24}, x_{44}, x_{54}\right) \\ =& \mathcal{CN}\left(y_1; x_{11} + x_{31} + x_{51}, \sigma^2\right) \mathcal{CN}\left(y_2; x_{22} + x_{32} + x_{62}, \sigma^2\right) \cdot \\ & \mathcal{CN}\left(y_3; x_{13} + x_{43} + x_{63}, \sigma^2\right) \mathcal{CN}\left(y_4; x_{24} + x_{44} + x_{54}, \sigma^2\right). \end{aligned} \tag{10}$$

$$\begin{aligned} & p\left(\mathbf{y}|\mathbf{x}/\mathbf{x}_1, \mathbf{x}_1 = \mathbf{x}_1(j)\right) \\ =& \mathcal{CN}\left(y_1; x_{31} + x_{51}, \sigma^2\right) \mathcal{CN}\left(y_2; x_{22} + x_{32} + x_{62}, \sigma^2\right) \\ & \mathcal{CN}\left(y_3; x_{43} + x_{63}, \sigma^2\right) \mathcal{CN}\left(y_4; x_{24} + x_{44} + x_{54}, \sigma^2\right). \end{aligned} \tag{11}$$

where $\mathcal{CN}$ denotes the complex Gaussian distribution. Finally, $I(\mathbf{x}_1 : \mathbf{y})$ can be expressed in Eq. 15, with Δ equal to the sum of codewords part of the received signal minus the codewords for corresponding users, given the codewords indexes. For example, Δ_{146} is the sum of codewords difference from UE 1, 4 and 6. The expectation is with respect to the complex Gaussian distributions of z_1, z_2, z_3 and z_4. Moreover, the expressions of $I(\mathbf{x}_2 : \mathbf{y}|\mathbf{x}_1)$ is shown in Eq.16, and it is straightforward to obtain the sum CC as follows

$$\begin{aligned} I(\mathbf{x}, \mathbf{y}) =& I(\mathbf{x}_1 : \mathbf{y}) + I(\mathbf{x}_2 : \mathbf{y}|\mathbf{x}_1) + I(\mathbf{x}_3 : \mathbf{y}|\mathbf{x}_1, \mathbf{x}_2) \\ &+ I(\mathbf{x}_4 : \mathbf{y}|\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3) + I(\mathbf{x}_5 : \mathbf{y}|\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3, \mathbf{x}_4) \\ &+ I(\mathbf{x}_6 : \mathbf{y}|\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3, \mathbf{x}_4, \mathbf{x}_5) \end{aligned} \tag{12}$$

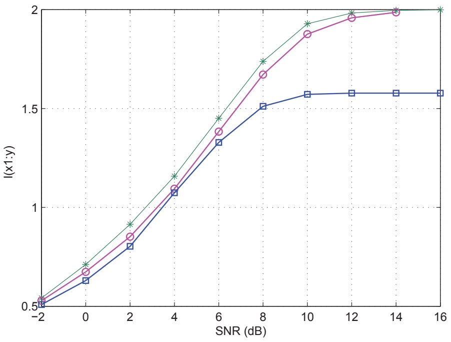

Fig. 5. One user capacity $I(\mathbf{x}_1 : \mathbf{y})$ for SCMA and LDS.

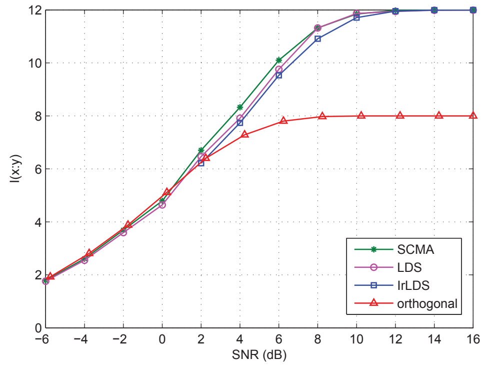

Fig. 6. Total capacity $I(\mathbf{x} : \mathbf{y})$ for SCMA, LDS, IrLDS and orthogonal case.

Similarly, for IrLDS which is based on F_2, we have

$$\begin{aligned} & p\left(\mathbf{y}|\mathbf{x}\right) \\ =& \mathcal{CN}\left(y_1; x_{11}+x_{21}+x_{51}, \sigma^2\right)\mathcal{CN}\left(y_2; x_{12}+x_{22}+x_{42}, \sigma^2\right)\cdot \\ & \mathcal{CN}\left(y_3; x_{13}+x_{33}+x_{43}, \sigma^2\right)\mathcal{CN}\left(y_4; x_{14}+x_{34}+x_{64}, \sigma^2\right). \end{aligned} \tag{13}$$

$$\begin{aligned} & p\left(\mathbf{y}|\mathbf{x}/\mathbf{x}_1, \mathbf{x}_1 = \mathbf{x}_1(j)\right) \\ =& \mathcal{CN}\left(y_1; x_{31}+x_{51}, \sigma^2\right)\mathcal{CN}\left(y_2; x_{22}+x_{32}+x_{62}, \sigma^2\right) \\ & \mathcal{CN}\left(y_3; x_{43}+x_{63}, \sigma^2\right)\mathcal{CN}\left(y_4; x_{24}+x_{44}+x_{54}, \sigma^2\right). \end{aligned} \tag{14}$$

The CC capacity expression for IrLDS can be obtained in the same way, which are omitted in this paper.

B. Numerical comparisons for 3 schemes

By adopting Monte Carlo integration method, the approximated numerical results of $I(\mathbf{x}_1 : \mathbf{y})$ for both SCMA and LDS are compared in Fig. 5, of course with per-user power normalized to unit as assumed in this paper. Note that the SCMA codebooks used here were pre-designed in our previous work [7], and the LDS codebooks are based on QPSK with and without phase rotation. It is clear that SCMA can achieve higher CC capacity than that of the LDS scheme (with phase rotation) when signal-to-noise power ratio (SNR) is larger than 2 dB, and finally they converge to two. However, without phase rotation, it is shown that the LDS CC capacity is unable to reach the value larger than 1.578, even though the SNR continually increases.

In addition, we compute the CC sum capacities for 3 non-orthogonal schemes, as well as the orthogonal case shown in Fig. 6. Both LDS and IrLDS adopt phase rotation in the calculations. It is found that at very low SNR, all schemes have similar performances. However, as SNR increases, SCMA becomes superior to the other schemes while IrLDS performs worst. Three non-orthogonal schemes can finally achieve maximum capacity 12, indicating 150% throughput increase comparing to the orthogonal one.

C. Effect of phase rotation

The equations derived above provide us an approach for SCMA codebook design [7] by comparing their CC capacities. This paper represents a special evaluating case by rotating users' codebooks with different angles from a pre-designed basis. The superiority of phase rotation is initially shown in Fig. 5. In the following discussions, we take SCMA as an example with the factor graph matrix F_1. In F_1, there are 3 orthogonal pairs (UE 1, UE 2), (UE 3, UE 4) and (UE 5, UE 6). In other words, no RE is shared by users within one pair so that they do not impact each other. Hence, it is reasonable to manipulate codebooks belonging to the same pair in a same way. First of all, a basic codebook is chosen from a 4-PAM constellation set for every user (with different RE mapping for each user) , where all constellation points are in a line. Then, we keep the first orthogonal pair the same, and rotate the second pair with θ degrees and the third pair with 2θ degrees, with θ value being selected from $0°$ to $60°$ in steps of $6°$. Here, $60°$ is set as the maximum angle due to that at this point, the constellations from 6 codebooks are maximally separated. By fixing the SNRs equal to 6 dB, the CC capacities with different rotated angles are listed in Table.I as follows

TABLE I. CC CAPACITIES WITH PHASE ROTATIONS

Rotated angles	CC capacities (6 dB)
$0°$	0.7464
$6°$	0.7528
$12°$	0.8621
$18°$	0.9934
$24°$	1.1493
$30°$	1.2414
$36°$	1.2936
$42°$	1.3437
$48°$	1.3754
$54°$	1.3775
$60°$	1.3845

It can be observed from Table.I that, higher CC capacities can be achieved with θ value goes larger until the maximum. In other words, it is better to spread the constellation points as much as possible. It has to be noted that, in this case, we rotate a same angle for the entire codebook of one user. However, it can be different for codewords in different columns, and the analysis of this is left as a future study.

IV. Simulation Results

In this section, we compare the performances of SCMA, LDS and IrLDS in terms of block error rate (BLER). Both LDS and IrLDS are with phase rotations. Moreover, SCMA with different phase rotation scenarios are simulated to evaluate

$$I(\mathbf{x}_1:\mathbf{y}) = H(\mathbf{y}) - H(\mathbf{y}|\mathbf{x}_1)$$
$$= \log_2(N_1) - \frac{1}{\prod_{i=1}^{6} N_i}\sum_{\mathbf{x}} E\left[\log_2\left(\frac{\sum_{\mathbf{x}} \exp((-|\Delta_{135}+z_1|^2 - |\Delta_{236}+z_2|^2 - |\Delta_{146}+z_3|^2 - |\Delta_{245}+z_4|^2)/\sigma^2)}{\sum_{\mathbf{x}/\mathbf{x}_1} \exp((-|\Delta_{35}+z_1|^2 - |\Delta_{236}+z_2|^2 - |\Delta_{46}+z_3|^2 - |\Delta_{245}+z_4|^2)/\sigma^2)}\right)\right] \quad (15)$$

$$I(\mathbf{x}_2:\mathbf{y}|\mathbf{x}_1) = H(\mathbf{y}|\mathbf{x}_1) - H(\mathbf{y}|\mathbf{x}_1,\mathbf{x}_2)$$
$$= \log_2(N_2) - \frac{1}{\prod_{i=2}^{6} N_i}\sum_{\mathbf{x}/\mathbf{x}_1} E\left[\log_2\left(\frac{\sum_{\mathbf{x}/\mathbf{x}_1} \exp((-|\Delta_{35}+z_1|^2 - |\Delta_{236}+z_2|^2 - |\Delta_{46}+z_3|^2 - |\Delta_{245}+z_4|^2)/\sigma^2)}{\sum_{\mathbf{x}/\mathbf{x}_1,\mathbf{x}_2} \exp((-|\Delta_{35}+z_1|^2 - |\Delta_{36}+z_2|^2 - |\Delta_{46}+z_3|^2 - |\Delta_{45}+z_4|^2)/\sigma^2)}\right)\right] \quad (16)$$

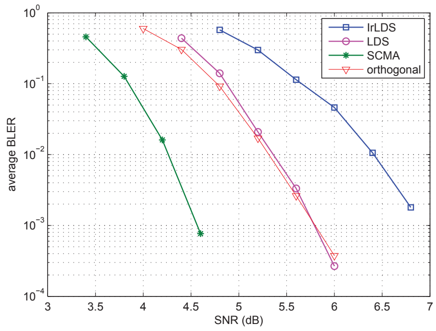

Fig. 7. BLER of SCMA, LDS and IrLDS in AWGN channels.

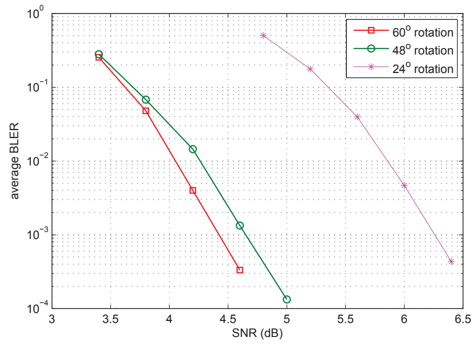

Fig. 8. BLER of SCMA with different phase rotations in AWGN channels.

the phase impact. The simulation parameters are set for fair comparisons, which are listed in Table.II.

TABLE II. MAIN SIMULATION PARAMETERS

Parameters	Non-orthogonal	Orthogonal
Channel Type	1T1R, AWGN	1T1R, AWGN
Modulation order	4	4
Coding rate	1/2 Turbo	3/4 Turbo
UE number	6	4
Overload	150	100
RB number	6	6

According to Fig. 7, SCMA achieves the lowest BLER among the three non-orthogonal schemes and the orthogonal case over AWGN channels, while IrLDS performs the worst, which coincides with our theoretical CC capacity calculations shown in Fig. 5 and Fig. 6. The orthogonal scheme is shown to be worse than SCMA but outperform LDS and IrLDS. Finally, the BLER curves of SCMA systems with different rotated angles over AWGN channels are presented in Fig. 8. Obviously, under this circumstances, the larger separation the constellations keep, the better performance they can achieve.

V. CONCLUSIONS

This work compared the performance of a series of non-orthogonal multiple access techniques via both theoretical analysis and link level simulations. First of all, the CC capacities of the proposed system model have been derived, and the complete SCMA is shown to outperform the simplified version LDS/IrLDS via numerical calculations. Our CC capacity model and theoretical results are also useful for the search of the optimal phase rotation between different SCMA codebooks for different data layers. Future work may also consider different phase rotations for different codewords in the same codebook. Finally, link level simulations for AWGN channel have also been provided which align with the theoretical findings and support the conclusion that the complete SCMA scheme with the design of multi-dimensional modulation on top of the sparse spreading outperforms its simplified version with low density spreading only, no matter the spreading is regular (LDS) or irregular (IrLDS).

REFERENCES

[1] *5G: An Technology Vision*, Huawei, 2015. [Online]. Available: http://www.huawei.com/5gwhitepaper/

[2] K. Au, L. Zhang, H. Nikopour, E. Yi, A. Bayesteh, U. Vilaipornsawai, J. Ma, and P. Zhu, "Uplink contention based scma for 5g radio access," in *Globecom Workshops (GC Wkshps), 2014*, Dec. 2014, pp. 900–905.

[3] R. Hoshyar, R. Razavi, and M. Al-Imari, "Lds-ofdm an efficient multiple access technique," in *Vehicular Technology Conference (VTC 2010-Spring), 2010 IEEE 71st*, May 2010, pp. 1–5.

[4] Y. Wu, S. Zhang, and Y. Chen, "Iterative multiuser receiver in sparse code multiple access systems," in *The IEEE International Conference on Communications (ICC) 2015*, Jun. 2015 (accepted).

[5] J. Harshan and B. Rajan, "On two-user gaussian multiple access channels with finite input constellations," *Information Theory, IEEE Transactions on*, vol. 57, no. 3, pp. 1299–1327, March 2011.

[6] H. Nikopour and H. Baligh, "Sparse code multiple access," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2013 IEEE 24th International Symposium on*, Sep. 2013, pp. 332–336.

[7] M. Taherzadeh, H. Nikopour, A. Bayesteh, and H. Baligh, "Scma codebook design," in *Vehicular Technology Conference (VTC Fall), 2014 IEEE 80th*, Sep. 2014, pp. 1–5.