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SCMA Spectral and Energy Efficiency With QoS

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ABSTRACT Sparse code multiple access (SCMA) is one of the promising candidates for new radio access interface. The new generation communication system is expected to support massive user access with high capacity. However, there are numerous problems and barriers to achieve optimal performance, e.g., the multiuser interference and high power consumption. In this paper, we present optimization methods to enhance the spectral and energy efficiency for SCMA with individual rate requirements. The proposed method has shown a better network mapping matrix based on power allocation and codebook assignment. Moreover, the proposed method is compared with orthogonal frequency division multiple access (OFDMA) and code division multiple access (CDMA) in terms of spectral efficiency (SE) and energy efficiency (EE) respectively. Simulation results show that SCMA performs better than OFDMA and CDMA both in SE and EE.

INDEX TERMS Dual method, energy efficiency, SCMA, spectral efficiency, QoS.

I. INTRODUCTION

In the history of mobile communication network development [1], multiple access technique has evolved from frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA) to orthogonal frequency division multiple access (OFDMA), where a fundamental cornerstone is the orthogonality of resource block (RB). However, in the next generation of mobile communication system, the demand for massive connection, low latency, high spectral efficiency and energy efficiency has become a vital necessity. Indeed, this scenario may make a turning point from orthogonality to non-orthogonality [2], [3]. The author in [4] discussed the energy efficiency in CDMA networks for M-QAM (Quadrature Amplitude Modulation) modulation using a game-theoretic framework, taking into consideration of the constellation size that maximizes the EE while satisfying the (QoS) constraint. Correspondingly, Kastrinogiannis *et al.* [5] debated the effect of efficient power allocation in uplink CDMA system using Nash equilibrium theory, to optimize the framework and the tradeoffs between users overall throughput performance while fulfilling the QoS requirements. Besides, Gunturi and Paganini [6] presented a non-cooperative game theory for power control problem in CDMA wireless networks, for both the single cell and multicell case together with a base station assignment and hand-off scheme for the multi-cell scenario respectively. Similarly, [7] addressed the problem of efficient utility based power control with convex pricing in uplink CDMA network, taking into consideration of satisfying QoS prerequisites. An efficient power allocation obtained via using a game theoretical framework with convex pricing of users transmission power, results in analytically a Pareto efficiency.

Sparse code multiple access (SCMA) as a potential non-orthogonal multiple access technique is the key technology of the 5th generation mobile communication systems (5G). It allows multiple users share the same RB and offers 300% overloading number of user access links [8]. Fig. 1 shows the evolution from OFDMA to SCMA.

SCMA first introduced in [8], is developed from the low density signature (LDS). In SCMA the user codeword is mapped directly into the layer vector, while in LDS, the user codeword is repeated in layer vector element. Therefore SCMA has shapping gain compared with LDS. SCMA has sparsity in spreading sequences, which allows to use a near optimal message passing algorithm (MPA) to decode. A systematic approach to optimize the SCMA codebooks has been

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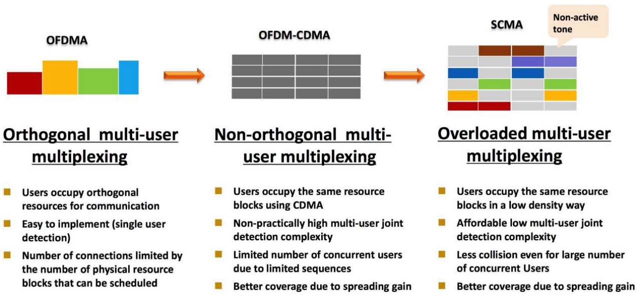

Orthogonal multi-user multiplexing

- Users occupy orthogonal resources for communication
- Easy to implement (single user detection)
- Number of connections limited by the number of physical resource blocks that can be scheduled

Non-orthogonal multi-user multiplexing

- Users occupy the same resource blocks using CDMA
- Non-practically high multi-user joint detection complexity
- Limited number of concurrent users due to limited sequences
- Better coverage due to spreading gain

Overloaded multi-user multiplexing

- Users occupy the same resource blocks in a low density way
- Affordable low multi-user joint detection complexity
- Less collision even for large number of concurrent Users
- Better coverage due to spreading gain

FIGURE 1. **From OFDMA to SCMA.**

proposed in [9] based on the design principles of lattice constellations. Futhermore, a resource allocation scheme for SCMA has been proposed in [10].

Reference [11] evaluated the SCMA average spectral efficiency (SE) with adaptive codebooks based on star-QAM signaling constellations, while [12] tested the spectral efficiency improvement for three 5G key performance indices. Reference [13] compared the spectral-efficiency in SCMA system with three operational scenarios to evaluate their SE performance. Besides, [14] presented 5G radio access technologies for very large number of links, which was achieved by SCMA based on optimized sequence design. In addition to analysis and optimization of spectral efficiency studies, SCMA is also compared with the existing techniques [15] for the practical performances. It is shown that SCMA outperforms OFDMA in terms of throughput and coverage in practical scenarios. The SCMA area spectral efficiency for cellular network is analyzed via stochastic geometry in [16] and [17], which shows that SCMA is a competitive technique for 5G massive access. Reference [18] discussed resource allocation and spectrum efficiency for 5G technology, highlighting the optimal selection of subcarrier assignment for each user.

On the other hand, the SCMA energy efficiency (EE) is also extensively investigated in literatures such as [19], [20] and [21]. An attempt was taken in [22] which maximizes the SCMA rate and energy efficiency for the wireless powered communication networks. Similarly, [23] analyzes the energy efficiency for non-orthognal multple access network by providing an analytic framework, which is also used to derive and simulate the SCMA energy efficiency in the uplink scheme. Through simulation and prototype measurement, [24] investigated a method to solve the EE maximization problem with sum rate requirements. Since EE maximization problem is a non-convex fractional programming problem [25], we use symbol transformation and utilize Dinkelbach method to transfer the non-convex problem to a convex problem and derive the global maximum by using an iterative method.

In this paper, we will investigate the spectral efficiency and energy efficiency of SCMA with an individual rate requirement, which have not been studies before. Since it is diffcult to derive the analytic solution of the SE and EE optimization problem, we developed iterative methods to solve the SE and EE optimization problem. Since EE maximization is a non-convex problem, the Dinkelbach method is used to transfer the non-convex problem to a convex problem and then solved by iterative method. Simulations show that the SCMA outperforms CDMA and OFDMA both in the terms of SE and EE with QoS.

II. RELATED WORKS

In [23], the EE of uplink SCMA network was analyzed and a comparison was made between the performance of average block error rate (BLER) and EE for the SCMA scheme and LTE-A. The obtained simulation results demonstrate that the SCMA scheme is capable of aggregating more users in the uplink network to support the massive connectivity requirements for 5G systems with reasonable energy consumption. In addition to considering equal transmit power of nonzero elements for all users, a fixed factor graph matrix is also used in this reference for problem analysis. The codebook assignment and optimal power allocation for downlink SCMA is investigated in [26]. The obtained simulation results reveal that the SCMA network significantly outperforms the OFDMA network in term of EE. Moreover, in [27], resource allocation for EE maximization of layered multicast in downlink SCMA network, by separating codebook assignment and power allocation was considered.

Reference [22] investigated the rate and energy maximization problem in SCMA networks with simultaneous wireless information and power transfer. In [24] cooperative co-evolutionary particle swarm optimization (CCPSO) was applied to solve the EE maximization problem for uplink SCMA network. In [28] the Lagrange dual decomposition method and Dinkelbach theory to solve the non-convex optimization problem to maximize the EE for SCMA downlink systems is employed, based on which a three-level power allocation to improve the sum capacity for SCMA downlink system is proposed in [29]. The authors in [30] proposed a computationally efficient algorithm to maximize the global energy efficiency (GEE) with subject to both maximum power and minimum transmission rate constraints in the multi-carrier wireless interference network. Finally, it is converted into a non-convex fractional problem and was tackled through an interplay of fractional programming based on Dinkelbach algorithm, fixed-point learning and the generalized game theory. In [31] the EE problem was approximately decomposed into some independent convex sub-problems by applying the fractional programming theory and using the coordinate descent method, and the closed-form solutions of each sub-problem are derived. Reference [24] evaluates EE of the network using the power allocation matrix without considering different path-loss. On the other hand, solving the resource allocation problem using separate subcarrier assignment and power allocation [32] is useful in analyzing downlink SCMA EE, especially in reducing the computational cost [26]. Moreover, [28] employs the water-filling algorithm to solve the non-convex power allocation optimization problem to evaluate the performance of downlink SCMA in term of EE with fixed factor graph. Briefly, we need to develop optimal resource allocation algorithms for uplink SCMA scheme by incorporating the factor graph matrix optimization to increase energy efficiency that meets 5G network requirements. The aim of this paper is to maximize the EE for an uplink SCMA system where the path-losses between each user and the base station (BS) are not necessarily equal. The EE optimization problem involving subcarrier assignment and power allocation is a non-convex mixed-integer non-linear program (MINLP) problem [33]. To reduce the computational cost, we separate subcarrier assignment and power allocation. A fast subcarrier assignment algorithm with power equally distributed is proposed to determine an energy efficient optimal and of low-complexity factor graph matrix. For specified factor graph matrix, a power allocation algorithm is proposed for EE maximization, which is decomposed into convex sub-problems by applying the fractional programming theory based on Dinkelbach method.

III. SYSTEM MODEL

Consider a scenario of single-cell uplink in SCMA networks with K users, N subcarriers and M codebooks, where the base station (BS) and users are equipped with a single antenna. The sets of users and subcarriers are respectively denoted by $K=\{1, 2, \ldots, K\}$ and $N=\{1, 2, \ldots, N\}$. SCMA codebook and subcarriers are the basic resource units [8], [15], similar as OFDMA [32], [34]. Consider overloading access, the user K is greater than the subcarrier N, and K/N is called overloading rate. Each user has a codebook and each codeword of size N in the codebook has sparsity. Let d be the non-zero element in a codeword. Then $d \ll N$.

The SCMA system network diagram with 6 users and 4 subcarriers is shown in Fig. 2. Each user k has a codebook with 4 dimensional codewords, where each dimension of the codeword uses one subcarrier. All 6 transmitted codewords $(xk1, xk2, xk3, xk4)$ are combined into the sequence $(s1, s2, s3, s4)$. Because of the sparsity of SCMA codeword, the receiver can use message passing algorithm (MPA) to detect multi-user. For MPA receiver, codewords allocated to different layers can be regarded as orthogonal resources, so the interference only occurs among users using the same layer.

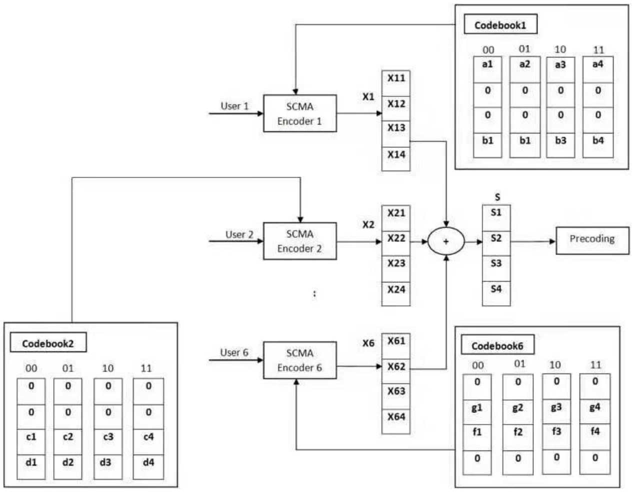

FIGURE 2. SCMA system network block diagram.

The SCMA uplink system, with minimum rate requirement of all users, aims to maximize the total system rate, and establishes an optimal mathematical model for the power allocation and SCMA layer allocation problem. Based on the advocacy of green communication, it is desirable to minimize the transmission power of the system under certain communication guarantees. Therefore, the power allocation scheme is needed. The important content of the research needs to manage the power resources reasonably and effectively according to the specific optimization objectives.

Set up M codebook labels. Set an SCMA codebook and its associated subcarriers can be regarded as a layer of SCMA resources. So there are N SCMA layer resources on each time-frequency resource. Therefore, different users obtain multiple access by sharing time-frequency resources on SCMA layer. The codebook size is defined by the length of the codeword and the number of non-zero elements. Assume that the number of SCMA layers in a time-frequency resource block is m, and the number of subcarriers is n. Indicator variable c_{nm} represents the mapping between the SCMA layer m and the subcarrier n. So if layer m occupies subcarrier n, then $c_{nm} = 1$, otherwise 0.

Define $S = \{s_{k,m}\}$ as SCMA layer distribution matrix, where $s_{k,m} = 1$ when layer m is assigned to user k, otherwise $s_{k,m} = 0$. Define $P = \{p_{k,m}\}$ as power allocation matrix. Then, the total power can be written as

$$P^{tot} = \sum_{k=1}^{K} \sum_{m=1}^{M} s_{k,m} p_{k,m}. \tag{1}$$

The power ratio factor assigned to user k using subcarrier n on SCMA layer m is defined as $\alpha_{n,m}$, where $0 < \alpha_{n,m} < 1$ and $\sum_{n=1}^{N} \alpha_{n,m} = 1$. Then the SNR [35], [36] of user k over layer m is

$$SNR_{k,m} = \frac{\sum_{n=1}^{N} \alpha_{n,m} p_{k,m} h_{k,n}}{\sigma_k^2}, \tag{2}$$

where $h_{k,n}$ is the channel state information from user k to base station on subcarrier n, σ_k^2 represents the noise power to user k with white additive Gaussian noise. Therefore, the achievable rate of user k is

$$R_k = \sum_{m=1}^{M} s_{k,m} \log_2(1 + SNR_{k,m}). \tag{3}$$

IV. SCMA SPECTRAL EFFICIENCY WITH QoS

In order to maximize the network rate, we take into consideration the constraints of QoS (Quality of Service). Let w_k denote the weight factor, R_k^{req} be the minimum data rate requirement of user k, and $P^{\max}$ be the maximum transmission power of system. The optimization model can be established as follows.

$$\begin{aligned}
&\max_{P,S} \sum_{k=1}^{K} w_k R_k, \\
&s.t.\ C_1 : R_k \geq R_k^{req},\ \forall k, \\
&\quad\ C_2 : P^{tot} \leq P^{\max}, \\
&\quad\ C_3 : \sum_{k=1}^{K} s_{k,m} \leq 1,\ \forall m, \\
&\quad\ C_4 : s_{k,m} \in \{0, 1\},\ \forall k, m, \\
&\quad\ C_5 : p_{k,m} \geq 0,\ \forall k, m.
\end{aligned} \tag{4}$$

The physical meaning of the optimization problem (4) is to jointly consider SCMA layer allocation and power allocation, by maximizing the network capacity. The constraint C_1 guarantees that the data rate of each user is lower-bounded for fairness. The constraint C_2 requires that the total transmission power is below the maximum transmission power. The constraint C_3 and C_4 jointly ensure that each SCMA layer is allocated to one user at most. Constraint C_5 is made to ensure that the layer allocated by the user is powered. Note that problem (4) is a mixed integer optimization problem.

We use the Lagrange dual decomposition method to solve the optimization problem (4). Let $X = \{x_{k,m} | x_{k,m} = p_{k,m}s_{k,m}\}$. Its partial Lagrange function is

$$\begin{aligned}
&L\left(X, S, \lambda, \mu\right) \\
&= \sum_{k=1}^{K} \left[w_k R_k + \lambda_k (R_k - R_k^{req}) \right] + \mu (P^{\max} - P^{tot}),
\end{aligned} \tag{5}$$

where $\lambda = \{\lambda_1, \lambda_2, \ldots, \lambda_k\}$ and μ are Lagrange multipliers. Then its dual problem is

$$\min_{\lambda,\mu} \max_{X,S} L(X, S, \lambda, \mu),\ \forall \lambda, \mu \geq 0. \tag{6}$$

The optimal $\left\{p_{k,m}\right\}$ can be obtained by finding the partial derivative of (6) and making it equal to zero, i.e.,

$$\frac{\partial L}{\partial p_{k,m}} = 0. \tag{7}$$

Then the optimal power can be calculated as follows.

$$\hat{p}_{k,m} = \left[\frac{w_k + \lambda_k}{\mu \ln 2} - \frac{\sigma_k^2}{\sum_{n=1}^{N} \alpha_{n,m} h_{k,n}} \right]^+, \tag{8}$$

where $[x]^+ = \max(0, x)$, means that its takes x if $x > 0$ the value is x and 0 otherwise. Using the derived optimal power $\hat{p}_{k,m}$ and variable relaxing method, consider the partial derivative of L with respect to $s_{k,m}$.

$$\frac{\partial L}{\partial s_{k,m}} = H_{k,m}, \tag{9}$$

where

$$\begin{aligned}
H_{k,m} &= (w_k + \lambda_k) \log_2 \left(1 + \frac{\sum_{n=1}^{N} \alpha_{n,m} \hat{p}_{k,m} h_{k,n}}{\sigma_k^2} \right) \\
&\quad - \frac{w_k + \lambda_k}{\ln 2} \times \frac{\sum_{n=1}^{N} \alpha_{n,m} \hat{p}_{k,m}}{h_{k,n}} \sigma_k^2 \\
&\quad + \sum_{n=1}^{N} \alpha_{n,m} \hat{p}_{k,m} h_{k,n} - \mu \hat{p}_{k,m}.
\end{aligned} \tag{10}$$

Then m will be assigned to the user $k^\bullet$ with the maximum $H_{k,m}$, i,e.,

$$\hat{s}_{k^\bullet,m} = 1|_{k^\bullet = \arg\max_k H_{k,m}},\ \forall m. \tag{11}$$

Subsequently, the Lagrangian multipliers λ and μ can be updated by the following formulas.

$$\begin{aligned}
\lambda_k(l+1) &= [\lambda_k(l+1) - \beta(R_k(l) - R_k^{req})]^+, \\
\mu(l+1) &= [\mu(l+1) - \beta(P^{\max} - P^{tot}(l))]^+,
\end{aligned} \tag{12}$$

where β is the iteration step size. Through iterations of (8), (11) and (12), the optimal solution of (5) can be obtained, where one of the metric for the convergence of the iteration is such that $\max_k H_{k,m}$ close to 0. This is summarized in Algorithm 1.

Algorithm 1 SCMA Spectrum Efficiency

```
Initialization the multipliers $\lambda_k(0)$ and $\mu(0)$, tolerance $\epsilon$;
Step 1: Update $\hat{p}_{k,m}$ by (8),
Step 2: Update $\hat{s}_{k,m}$ by (10) and (11),
If max $H_{k,m} > \epsilon$
Then $l = l + 1$, goto Step 1,
End If
Output $\hat{p}_{k,m}$, $\hat{s}_{k,m}$.
```

V. SCMA ENERGY EFFICIENCY WITH QoS

In this section, to maximize the energy efficiency of the system, the objective function is established. Based on the quasi-convex optimization theory, the objective function is analyzed, and a joint power and SCMA layer assignment algorithm is proposed, which improves the network energy efficiency while satisfying all individual users' QoS requirements. The total power consumption of the SCMA system is

$$P = \varepsilon_0 P^{tot} + P_0, \tag{13}$$

where the coefficient ε_0 is the power amplifier factor, and P_0 is the circuit power. According to (1), (2) and (3), the system energy efficiency (EE) is defined by

$$\eta_{EE} = \frac{R}{P} = \frac{\sum_{k=1}^{K} R_k}{\varepsilon_0 \sum_{k=1}^{K} \sum_{m=1}^{M} s_{k,m} p_{k,m} + P_0}. \tag{14}$$

Based on the system model, the energy efficiency of power-constrained single cell multi-user networks is planned by joint power allocation and codebook allocation, and formulated as follows.

$$\begin{aligned}
&\max_{P,S} \frac{\sum_{k=1}^{K} R_k}{\varepsilon_0 \sum_{k=1}^{K} \sum_{m=1}^{M} s_{k,m} p_{k,m} + P_0}, \\
&s.t.\ C_1 : R_k \geq R_k^{req},\ \forall k, \\
&\quad\ C_2 : P^{tot} \leq P^{max},
\end{aligned}$$

$$\begin{aligned} &C_3 : \sum_{k=1}^{K} s_{k,m} \leq 1, \forall m, \\ &C_4 : s_{k,m} \in \{0, 1\}, \ \forall k, m, \\ &C_5 : p_{k,m} \geq 0, \ \forall k, m. \end{aligned} \tag{15}$$

In the optimization problem (15), the constraint C_1 guarantees that individual user's rate meets its minimum rate requirement satisfying the QoS, C_2 requires that the total transmission power is not greater than its maximum transmission power, C_3 and C_4 ensures that each user can allocate up to one layer of SCMA resources, and lastly C_5 ensures the power allocated by users to SCMA layer is non-negative.

The optimization problem (15) is a fractional programming problem with combinatorial properties and belongs to non-convex optimization problem, and it is hard to directly solve this problem. In order to facilitate operation, define $X = \{x_{k,m} | x_{k,m} = s_{k,m} p_{k,m}\}$. Therefore, the problem (15) can be rewritten as follows.

$$\begin{aligned} &\max_{X,S} \frac{\sum_{k=1}^{K} \sum_{m=1}^{M} s_{k,m} \log_2(1 + SNR_{k,m})}{\varepsilon_0 \sum_{k=1}^{K} \sum_{m=1}^{M} x_{k,m} + P_0}, \\ &s.t. \ C_1 : \sum_{m=1}^{M} s_{k,m} \log_2 \left(1 + \frac{\sum_{n=1}^{N} \alpha_{n,m} x_{k,m} h_{k,n}}{\sigma_k^2 s_{k,m}} \right) \geq R_k^{req}, \\ &\quad C_2 : \sum_{k=1}^{K} \sum_{m=1}^{M} x_{k,m} \leq P^{max}, \\ &\quad C_3 : \sum_{k=1}^{K} s_{k,m} \leq 1, \ \forall m, \\ &\quad C_4 : 0 \leq x_{k,m} \leq 1, \ \forall k, m, \\ &\quad C_5 : x_{k,m} \geq 0, \ \forall k, m. \end{aligned} \tag{16}$$

At this stage, the optimization problem (16) is still a non-convex optimization problem, which needs further transformation. Assuming that the objective function of the optimization problem (16) is q, and write

$$\begin{aligned} F(q, s_{k,m}, x_{k,m}) \triangleq &\sum_{k=1}^{K} \sum_{m=1}^{M} s_{k,m} \log_2 \left(1 + SNR_{k,m}\right) \\ &- q \left(\varepsilon_0 \sum_{k=1}^{K} \sum_{m=1}^{M} x_{k,m} + P_0 \right). \end{aligned} \tag{17}$$

If $F(q, s_{k,m}, x_{k,m}) = 0$, the optimal solution $(\hat{s}_{k,m})$ and $(\hat{x}_{k,m})$ of the optimization problem (16) in term of q is obtained, and q is the optimal EE. Therefore, the original optimization problem can be further transformed into

$$\begin{aligned} &\max_{X,S} F(q, s_{k,m}, x_{k,m}), \\ &s.t. \ C_1, C_2, C_3, C_4, C5\text{in } 16. \end{aligned} \tag{18}$$

At this stage, the optimization problem (18) is a convex optimization problem, and Lagrange function is

$$\begin{aligned} L(X, S, \lambda, \mu) &= \sum_{k=1}^{K} R_k - q \left(\varepsilon_0 \sum_{k=1}^{K} \sum_{m=1}^{M} x_{k,m} + P_0 \right) \\ &\quad + \sum_{k=1}^{K} \lambda_k (R_k - R_k^{req}) + \mu (P^{\max} - P^{tot}), \\ &= \sum_{k=1}^{K} R_k (1 + \lambda_k) - \sum_{k=1}^{K} \lambda_k R_k^{req} \\ &\quad - q\varepsilon_0 \sum_{k=1}^{K} \sum_{m=1}^{M} x_{k,m} - \mu P^{tot} - q P_0 + \mu P^{\max}, \end{aligned} \tag{19}$$

where $\lambda = \{\lambda_1, \lambda_2, \ldots, \lambda_K\}$ and μ are Lagrange multipliers. Its dual problems is

$$\min_{\lambda,\mu} \max_{X,S} L(X, S, \lambda, \mu), \ \lambda, \mu \geq 0. \tag{20}$$

The optimal $x_{k,m}$ can be obtained by finding the partial derivative of (19) and making it equal to 0, i.e.,

$$\frac{\partial L(X, S, \lambda, \mu)}{\partial x_{k,m}} = 0. \tag{21}$$

This lead to

$$x_{k,m} = \frac{(1 + \lambda_k) s_{k,m}}{(\mu + q\varepsilon_0) \ln_2} - \frac{\sigma_k^2 s_{k,m}}{\sum_{n=1}^{N} \alpha_{n,m} h_{k,n}}. \tag{22}$$

Hence the optimal power can be written as

$$\hat{p}_{k,m} = \frac{x_{k,m}}{s_{k,m}} = \left[\frac{(1+\lambda_k)}{(\mu+q\varepsilon_0) \ln 2} - \frac{\sigma_k^2}{\sum_{n=1}^{N} \alpha_{n,m} h_{k,n}} \right]^+. \tag{23}$$

The partial derivative L with respect to $s_{k,m}$ is as follows.

$$\frac{\partial L(X, S, \lambda, \mu)}{\partial s_{k,m}} = H_{k,m}, \tag{24}$$

where

$$\begin{aligned} H_{k,m} = &(1 + \lambda_k) \log_2 \left(1 + \frac{\sum_{n=1}^{N} \alpha_{n,m} \hat{p}_{k,m} h_{k,n}}{\sigma_k^2} \right) \\ &- \frac{1 + \lambda_k}{(\mu + q\varepsilon_0) \ln 2} \\ &\times \frac{\sum_{n=1}^{N} \alpha_{n,m} \hat{p}_{k,m} h_{k,n}}{\sigma_k^2 + \sum_{n=1}^{N} \alpha_{n,m} \hat{p}_{k,m} h_{k,n}} - \mu \hat{p}_{k,m}. \end{aligned} \tag{25}$$

The codebook layer m should be allocated to have the maximum $H_{k,m}$:

$$\hat{s}_{k^\bullet,m} = 1|_{k^\bullet = \arg\max k H_{k,m}}, \ \forall m. \tag{26}$$

According to the sub-gradient algorithm, the Lagrangian multipliers λ_k and μ can be updated as follows.

$$\begin{aligned} \lambda_k(l + 1) &= [\lambda_k(l + 1) - \beta(R_k(l) - R_k^{req})]^+, \\ \mu(l + 1) &= [\mu(l + 1) - \beta(P^{\max} - P^{tot}(l))]^+, \end{aligned} \tag{27}$$

where β is the iteration step. Through iterations of (23), (26) and (27), the optimal solution of (19) can be obtained, where the metrics for the convergence of the iteration are such that $\max_{X,S} F(q, s_{k,m}, x_{k,m})$ and $\max_k H_{k,m}$ close to 0. This is summarized in Algorithm 2.

TABLE 1. Simulation parameters.

Parameter	Value
Number of subcarriers	4
Number of codebooks	6
Circuit power consumption	1w
R	500m
h	30m
Subcarrier bandwidth	156kHz
SCMA layer	12
Noise power	-112dBm
Iteration times	100
Weight factor	1
P_0	1w
R_k^{req}	120Kbps
P^{max}	100w
Power amplifier factor	1/0.37

```
Algorithm 2 SCMA Energy Efficiency
Initialization: The multipliers $\lambda_k(0)$ and $\mu(0)$, the energy efficiency $q$, tolerance $\epsilon > 0$;
Step 1: Update the power allocation $\hat{p}_{k,m}$ by (23);
Step 2: Update the assignment index $\hat{s}_{k,m}$ by (25) and (26);
Step 3: Update $q$, update $\lambda_k$ and $\mu$ by (27);
If max $F(q, p_{k,m}, x_{k,m}) > \epsilon$,
Then $l = l + 1$; goto Step 1,
End If
Output the maximum EE $q$, $s_{k,m}$ and $p_{k,m}$.
```

VI. SIMULATION RESULTS

In this simulation section, the Algorithm 1 and the Algorithm 2 are simulated and compared. The simulation parameters are given in the Table 1. The following Fig. 3 and Fig. 4 respectively show a comparison of the spectral performance and energy efficiency for SCMA, CDMA, and OFDMA. It is found that SCMA perfoms better than CDMA and OFDMA both in SE and EE.

Fig. 3 shows that SCMA spectral efficiency outperforms both OFDMA and CDMA. Meanwhile, OFDMA had a better spectral efficiency performance comparing to CDMA at roughly 50 BSs, where CDMA spectral efficiency remains stable; hence, OFDMA supports higher modulation and coding leading to a better spectral efficiency, enhancement of reachability and provides a significant improvement in spectral usage comparing to CDMA technology performance.

Fig. 4 illustrates a significant decrease of OFDMA energy efficiency when the number of users increases due to the high level consumption of the power; while SCMA proves a better energy efficiency achievement.

We evaluate the performance of the proposed SCMA layer allocation and power allocation scheme. In the SCMA system, suppose that the radius of the macro base station is R = 500 meters [37], the height of the base station is h = 30 meters, the carrier frequency is $f_c = 2\text{x}10^9$Hz, all users are evenly distributed around the base station, and the circuit power P_0=1w [38]. The detailed parameters of the simulation are shown in the following table.

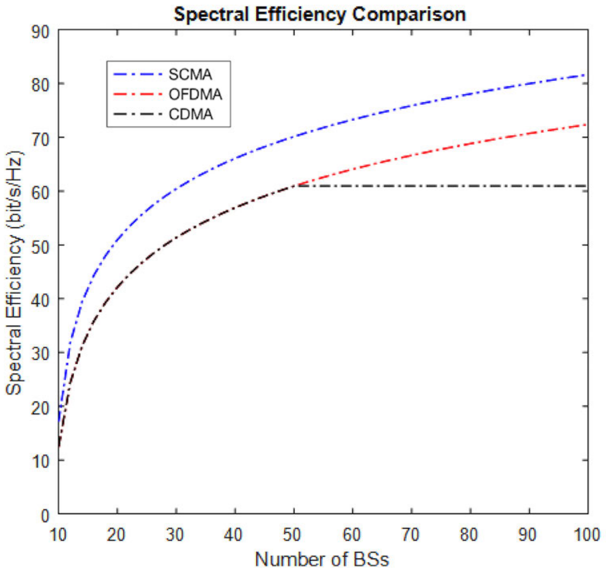

FIGURE 3. The SE performance for SCMA, OFDMA and CDMA.

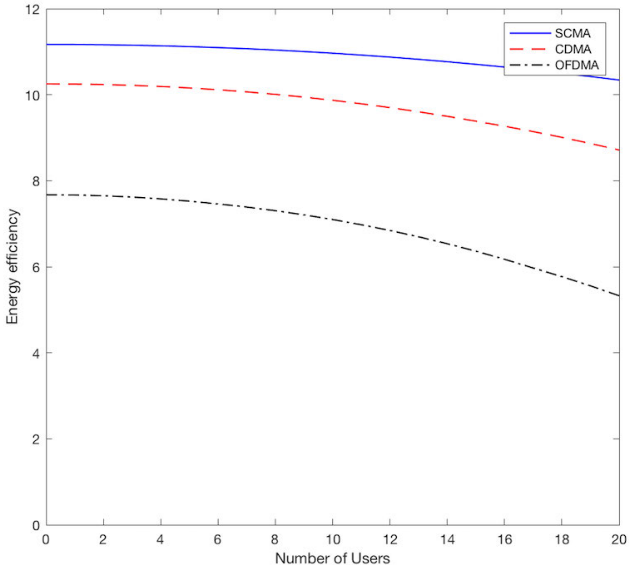

FIGURE 4. The EE performance for SCMA, OFDMA and CDMA.

According to the above system assumptions and simulation parameter settings, the simulation results are shown in Fig. 5.

Fig. 5 shows a schematic diagram of the convergence characteristics of the proposed algorithm, where the maximum transmission power of the base station is set to P = 100w, with 120Kbps in order to meet the minimum rate of user satisfying the QoS requirements. The schematic diagram illustrates the convergence of the SCMA layer and power allocation algorithm based on energy efficiency maximization when M = 12. It can be seen from the figure that there is an obvious jitter in the initial stage of the iteration. For stable convergence, it basically meets engineering realization.

TABLE 2. Simulation parameters.

Parameter	Value
Number of subcarriers	4
Number of codebooks	6
Base station maximum transmission power	100 w
Circuit power consumption	1 w
Subcarrier bandwidth	156 kHz
SCMA system layer number	6, 12, 24, 36
Noise power spectral density	-112 dBm
Standard deviation of fading channel	8 dB
Power amplifier factor	1/0.37

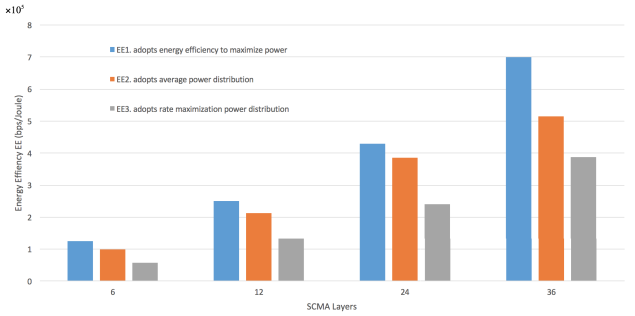

FIGURE 5. The system energy efficiency performance comparison.

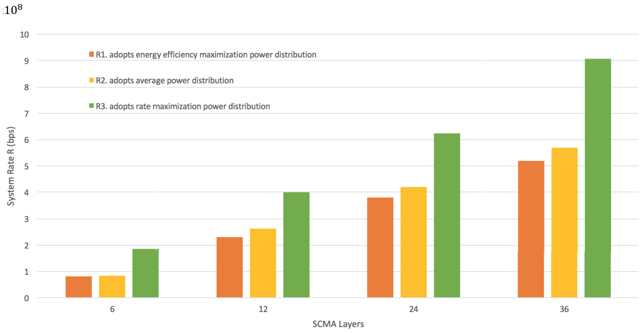

FIGURE 6. Total system rate performance comparison.

Fig. 5 demonstrates the system rate versus the number of SCMA layers, and the system energy efficiency is showing an increasing trend. Based on the energy efficiency maximization power allocation SCMA layer resource algorithm, the system energy efficiency has a large tendency to increase in the same SCMA layer. In the case of maximum energy efficiency, the energy efficiency under the SCMA layer resource algorithm based on maximum energy efficiency power allocation is the largest, followed by the average system energy efficiency under the power allocation SCMA layer resource algorithm. Therefore, in the SCMA system, under the same overload degree, the maximum energy efficiency can be adopted. Subsequesntly, the algorithm is optimized to improve the energy efficiency limit of the SCMA system.

Fig. 6 demonstrates that when the number of SCMA layers increases, the total system rate shows an increasing trend. Compared with the use of energy efficiency maximization power allocation SCMA layer, resource algorithm and the average power allocation algorithm uses the rate maximization power allocation SCMA layer resource algorithm to increase the system rate. In the case of the same number of SCMA layers, the total system rate under the SCMA layer resource algorithm with maximum rate and power allocation is the largest, followed by the SCMA layer resource algorithm with system rate and energy efficiency maximization power allocation under the average power allocation SCMA layer resource algorithm. Therefore, in the SCMA system, under the same degree of overload, the SCMA system can be improved by increasing the number of SCMA layers and adopting the algorithm for maximizing the rate and power allocation, the proposed algorithm has a significant improvement in total system rate.

VII. CONCLUSION

This paper maximizes the spectral efficiency and the energy efficiency for SCMA network with the individual user's rate requirements. The formulated optimization problem is fractional programming non-convex problem. Using symbol transformation and Dinkelbach method, the original problem is transformed into convex problems, and solved by Lagrange dual decomposition method. The proposed algorithms are simulated to compare with CDMA and OFDMA. It is found that the SCMA performs better than CDMA and OFDMA both in SE and EE, since the proposed method has shown a better network mapping matrix based on power allocation and codebook assignment.

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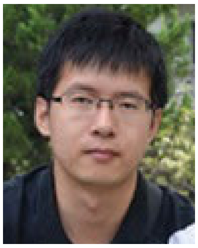

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