Data Power Optimization Algorithm for Downlink Multi-ARS Small Cell Communication Systems

Bui Anh Duc[1], Tran Manh Hoang[2], Nguyen Thu Phuong[1], Xuan Nam Tran[1], Pham Thanh Hiep[1]

[1] Advanced Wireless Communications Group, Le Quy Don Technical University, Hanoi, Vietnam.
[2] Telecommunication University, Nha Trang, Khanh Hoa, Viet Nam.

Correspondence: Pham Thanh Hiep, thanhhiep@lqdtu.edu.vn
Communication: received 6 Dec 2023, revised 16 Dec 2023, accepted 21 Jan 2024
DOI: 10.32913/mic-ict-research.v2024.n1.1248

***Abstract*: In this paper, we investigate a novel downlink Small Cell (SC) system based on the Cell Free (CF) model, with the deployment of Unmanned Aerial Vehicles (UAVs) as Aerial Relay Stations (ARSs) simultaneously serving users in a specific area. The new SC model concept is expressed in the user-centric idea that the user will choose only one ARS with the best conditions for communication, and the concept of “cell" or “cell boundary" will no longer exist. The Time Division Duplex (TDD) mechanism is used for system-wide communication protocol, and the Minimum Mean Squared Error (MMSE) technique is applied for downlink channel estimation. We establish the downlink user throughput expression and then propose a Bisection optimization algorithm to control power for downlink data transmission to improve system quality and save energy. We evaluate the downlink multi-ARS SC communication system with and without power optimization in different aspects, such as altering the number of users, the number of ARSs, the number of antennas, and the transmission channel estimation interval. The results also reveal that the system quality is significantly improved when applying the downlink power factor optimization problem.**

Keywords: *Small Cell, Multi-ARS, power optimization, bisection algorithm.*

I. Introduction

In recent years, the rapid proliferation of wireless devices has posed numerous challenges for the telecommunications industry. Therefore, the next generation must focus on solving more practical problems such as high speed in gigabits per second, low latency, high throughput, and high spectrum efficiency within a specific coverage area or application scenario. The infrastructure of the present day is easily capable of supporting advanced techniques and scenarios. Potential candidates include Small Cell (SC) systems that feature well-connected nodes and high-capacity backhaul links, as well as Unmanned Aerial Vehicles (UAVs) communications that function as aerial relay stations (ARSs) with flexible deployment [1, 2]. The challenge of integrating ARS communication and SC systems is inherently innovative and holds significant potential for reciprocal advancements in the communications technology industry.

To begin with, it is evident that ARSs communication is an exceptional field that has been the subject of numerous studies examining various aspects. Due to its advantageous characteristics, including rapid response time, high mobility, cost-effectiveness, flexible deployment, favorable channel conditions, and precise controllability, ARS-enabled wireless mobile communication finds extensive utility not only in everyday situations but also in military and rescue operations [3]. The authors also investigated various application scenarios for ARS communication, including single UAV relaying networks, multi-user UAV relaying networks, multi-hop UAV relaying networks, and the Internet of UAVs. In addition, the Amplify-and-Forward (AF) or Decode and-Forward (DF) relaying scheme, Time Division Multiple Access (TDMA), Orthogonal Frequency Division Multiple Access (OFDMA) protocols, and the problem of optimizing capacity and ARS trajectory in the ARS communication network are also introduced in detail [4].

Moreover, a conventional SC system is predicated on an extremely dense deployment of Base Stations (BSs), which are considerably smaller in size than a typical microcell. SC models are, in essence, BSs intended to serve a restricted coverage area that is approximately one hundred times smaller in size than conventional macro-BSs. By focusing their transmission at low power and a coverage radius of 50–150 meters, SC models enhance energy efficiency and minimize transmission loss through the reduction of the distance between users and BSs [2]. As a result, the deployment of SC models has attracted the interest of mobile operators seeking to improve system quality in various homes or geographical areas.

The combination of ARS communication and SC models for user cluster coverage through beamforming and mm-wave techniques has also been extensively investigated. The results show that the system quality depends on the height of the ARS, the number of ARS, and the size of the user cluster [5]. To decrease the power consumption of SC systems, researchers developed a power optimization strategy. This framework utilizes a novel control algorithm that can autonomously deactivate the BSs of the redundant SC model in response to network traffic requirements [6, 7].

1. Motivation

With the above-mentioned basic survey of SC and ARS communication systems, as well as the current state and high demands of the telecommunications industry and future directions. As a result, there are some compelling reasons to combine the SC system and ARS communication.

Firstly, conventional SC systems provide benefits such as high-speed processing, monitoring, and flexible deployment with picocells, femtocells, and microcells. However, the nature of the conventional SC model still exists in the concept of cells with a small scope. In practice, more cells lead to more complex signal processing, increased inter-cell interference, and affect the radio connection. Therefore, a novel approach is required to enhance and develop the conventional SC model to guarantee the concept of "Cell" is removed.

Secondly, the survey reveals that limited studies have been conducted on the issue of integrating ARS communication and SC models. In particular, a completely new SC model is developed when considering no cells. Furthermore, when SC is combined with ARS communication, a combined model with outstanding characteristics such as high LoS probability, flexible deployment, and simple signal processing is created. These issues demonstrate that this combined model is entirely feasible for real-world scenarios such as rescue missions, military operations, and connecting IoT devices at common civilian events.

Finally, the simple power optimization problem is always prioritized to be applied in accordance with the models of the cellular networks to reduce the influence of interference and improve system quality. In particular, in the context of the emergence of ARS communication, it will save energy and prolong the life of the wireless network.

2. Contribution

Based on the aforementioned research motivations, we develop a new downlink SC structure-assisted ARS based on the Cell Free (CF) multi-ARS system model. Simultaneously, a simple Bisection optimization algorithm is proposed to address the problem of controlling data transmission power in order to improve system quality, deploy a flexible system, and save energy. The detailed structure of our research is shown in the following important contributions:

- We develop the downlink SC communication model on the CF system, so there is no concept of cell or cell boundary with all ARS deployed and serving the same users in a specific area [8]. The SC model is established according to the user-centric idea, in which each user chooses only one ARS with the best channel conditions for communication.
- We design the channel model according to advanced LTE standards provided by the International Telecommunication Union (ITU) and the 3rd Generation Partnership Project (3GPP) to support airborne vehicles. The Time Division Duplex (TDD) protocol is applied to the network-wide communication protocol. In addition, the Minimum Mean Squared Error (MMSE) channel estimation is applied to downlink channel estimation.
- We establish the expression for the downlink throughput per user. Next, we deploy the bisection algorithm to solve the linear problem under the power control factor constraint, thereby optimizing the power for the downlink communication system from the ARSs to the users.
- We evaluate the system quality by comparing the user throughput without and with data power coefficient optimization in different aspects, such as changing the number of users, number of ARSs, and channel estimated interval in the downlink.

The subsequent sections are organized as follows: Section II discusses the downlink multi-ARS SC system. Section III addresses signal processing, including downlink channel estimation, downlink data transmission, and power optimization. Section IV displays numerical findings, and Section V outlines our concluding observations. Table I is structured for convenient reference to the mathematical symbol notations.

II. Downlink Multi-ARS Small Cell System

1. Channel model

We investigate the model of a novel multi-ARS SC structure applied in various real-world scenarios as de-

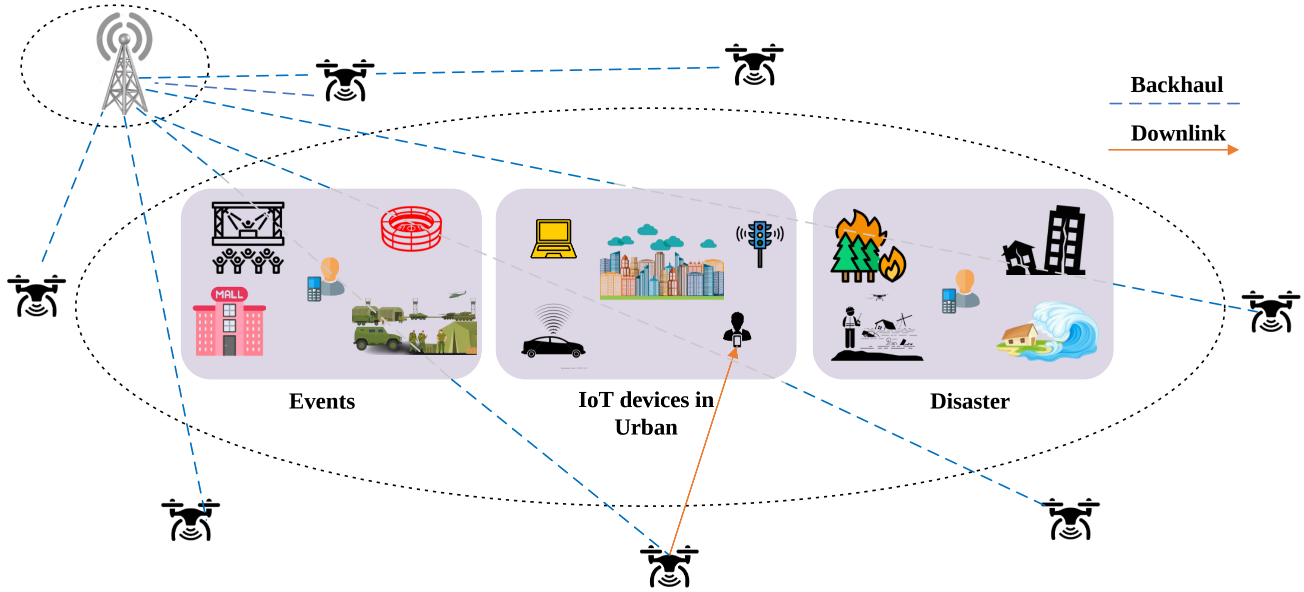


Figure 1. The downlink multi-ARS Small Cell system.

TABLE I
MATHEMATICAL SYMBOLS EMPLOYED IN THIS ARTICLE

Notation	Description
$(.)^*$	Conjugate
$(.)^H$	Conjugate-Transpose
$\mathbb{E}\{\cdot\}$	Expectation operator
$(.)^{-1}$	Inverse
$(.)^T$	Transpose
$\|.\|$	The Euclidean norm
$\mathbf{I}_N$	The $N \times N$ identity matrix
$\mathbb{C}^{m \times n}$	A vector or matrix with size of $m \times n$
τ_k^{d}	Downlink data power control coefficient
$\alpha_{\mathrm{p}}^{\mathrm{d}}$	Downlink channel estimation interval
K	Number of Users
N	Number of antennas at ARS
S	Number of ARSs

scribed in Figure 1. We first design a multi-ARS CF communication model with S ARS and K ground users [8]. ARSs are configured with N antennas, while users are equipped with a single antenna. Moreover, ARSs and users are randomly distributed in a specific area. We examine under the conditions of the multi-ARS CF model, meaning that all ARSs serve users at the same frequency and time resource. The ARSs connect to the ground base station (GBS) through a perfect backhaul channel.

In this paper, we illustrate the channel from sth ARS to kth user as follows:

$$\mathbf{g}_{sk} = \sqrt{\beta_{sk}}\mathbf{h}_{sk}, \tag{1}$$

where the small-scale fading is denoted by $\mathbf{h}_{sk}$ and is considered under the assumption that it follows an independent and identically distributed distribution (i.i.d.) $\mathcal{CN}(0, \mathbf{I}_N)$ random variable (RV) vectors. Moreover, the large-scale fading is illustrated below.

$$\beta_{sk} = 10^{\frac{\mathrm{PL}_{sk}}{10}}, \tag{2}$$

$\mathrm{PL}_{\mathrm{lk}}$ is the path loss provided by the advanced LTE standard of the ITU for the Urban Micro (UMi) [9, Table B-2] communication scenarios.

$$\mathrm{PL}_{sk} = \tag{3}$$
$$\begin{cases} \mathrm{PL}_{\mathrm{LoS}} = \max\{\mathrm{PL}', 30.9+ \\ (22.25 - 0.5\log_{10}(h_{ARS}))\log_{10}(d_{3\mathrm{D}}) + 20\log_{10}(f_c)\} \\ \mathrm{PL}_{\mathrm{NLoS}} = \max\{\mathrm{PL}_{\mathrm{LoS}}, 32.4+ \\ (43.2 - 7.6\log_{10}(h_{ARS}))\log_{10}(d_{3\mathrm{D}}) + 20\log_{10}(f_c)\}, \end{cases}$$

where PL', $\mathrm{PL}_{\mathrm{NLoS}}$, and $\mathrm{PL}_{\mathrm{LoS}}$ represent free space, Non-Line-of-Sight (NLoS), and Line-of-Sight (LoS) path loss, respectively.

2. Multi-ARS Small Cell model

The deployment of the SC model brings numerous significant benefits and has become one of the crucial solutions for the next generation of networks, as mentioned in Section I.1. We propose a multi-ARS SC downlink model to be established under the assumption that each user is served by a single ARS. It means that for each user, the ARS with the best signal contribution will be selected, and the ARS selection problem is based on the best large-scale fading coefficient. The mathematical model is specified as follows:

$$s_k \triangleq \underset{s\in\{\in ARSs\}}{\arg\max} \quad \beta_{sk}. \tag{4}$$

We take into consideration the requirement that the time interval be sufficiently short to avoid handover between ARSs [10]. The problem of handovers can be addressed in future research. Furthermore, unlike the CF model, the SC model does not have the constraint of the harden channel condition. This means that in the CF system, the channel gain is nearly equal to its mean value [11]. However, in the SC model, the channels are single fading Rayleigh channels. Therefore, both users and ARS must perform channel estimation. In this study, we investigate a communication system employing the TDD protocol [12] as shown in Figure 2, and focus on examining downlink channel estimation and downlink data transmission.

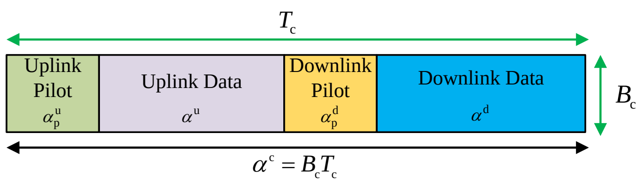


Figure 2. Time-division duplex (TDD) protocol.

III. Signal Processing

1. Downlink channel estimation

We define $\alpha_{\mathrm{p}}^{\mathrm{d}}$ as the period of time for downlink channel training and $\sqrt{\alpha_{\mathrm{p}}^{\mathrm{d}}}\boldsymbol{\phi}_k \in \mathbb{C}^{\alpha_{\mathrm{p}}^{\mathrm{d}}\times 1}$, $\|\boldsymbol{\phi}_k\|^2 = 1$ is the pilot sequence sent from the s_kth ARS, with $\rho_{\mathrm{p}}^{\mathrm{d}}$ denotes the transmit power per the pilot symbol.

Subsequently, the received pilot signal at kth user show as follows:

$$\mathbf{y}_{\mathrm{p}} = \sqrt{\alpha_{\mathrm{p}}^{\mathrm{d}}\rho_{\mathrm{p}}^{\mathrm{d}}}\mathbf{g}_{s_k k}\boldsymbol{\phi}_k^H + w_p, \tag{5}$$

where w_p is additive noise at user. Next, the projecting of $\mathbf{y}_{\mathrm{p}}$ to $\boldsymbol{\phi}_k$, the MMSE estimation for $\mathbf{g}_{s_k k}$ is

$$\begin{aligned}\hat{\mathbf{g}}_{s_k k} &= \mathbb{E}\left\{\mathbf{g}_{s_k k}\breve{\mathbf{y}}_{\mathrm{p}}^H\right\}\left(\mathbb{E}\left\{\breve{\mathbf{y}}_{\mathrm{p}}\breve{\mathbf{y}}_{\mathrm{p}}^H\right\}\right)^{-1}\breve{\mathbf{y}}_{\mathrm{p}} \\ &= c_{s_k k}\breve{\mathbf{y}}_{\mathrm{p}}\end{aligned} \tag{6}$$

where $\breve{\mathbf{y}}_{\mathrm{p}} \triangleq \mathbf{y}_{\mathrm{p}}\boldsymbol{\phi}_k$, and

$$c_{s_k k} \triangleq \frac{N\sqrt{\alpha_{\mathrm{p}}^{\mathrm{d}}\rho_{\mathrm{p}}^{\mathrm{d}}}\beta_{s_k k}}{N^2\alpha_{\mathrm{p}}^{\mathrm{d}}\rho_{\mathrm{p}}^{\mathrm{d}}\sum_{k'=1}^{K}\beta_{s_{k'}k}\left|\boldsymbol{\phi}_k^H\boldsymbol{\phi}_{k'}\right|^2 + 1}. \tag{7}$$

According to [13], the channel estimation from s_kth ARS to kth user is represented as follows:

$$\hat{\mathbf{g}}_{s_k k} = \mathbf{g}_{s_k k} - \boldsymbol{\varepsilon}_{s_k k}, \tag{8}$$

where $\varepsilon_{s_k k}$ is error of channel estimation and is independent of $\hat{\mathbf{g}}_{s_k k}$. Moreover, we have $\hat{\mathbf{g}}_{s_k k} \sim \mathcal{CN}(0, \mu_{s_k k})$, and $\varepsilon_{s_k k} \sim \mathcal{CN}(0, \beta_{s_k k} - \mu_{s_k k})$ [13] with $\mu_{s_k k}$ is mean-square of the estimated channel vector $\hat{\mathbf{g}}_{s_k k}$, can be computed as

$$\begin{aligned}\mu_{s_k k} &\triangleq \mathbb{E}\left\{\left|\hat{\mathbf{g}}_{s_k k}\right|^2\right\} = N\sqrt{\alpha_{\mathrm{p}}^{\mathrm{d}}\rho_{\mathrm{p}}^{\mathrm{d}}}\beta_{s_k k}c_{s_k k} \\ &= \frac{N^2\alpha_{\mathrm{p}}^{\mathrm{d}}\rho_{\mathrm{p}}^{\mathrm{d}}\beta_{s_k k}^2}{N^2\alpha_{\mathrm{p}}^{\mathrm{d}}\rho_{\mathrm{p}}^{\mathrm{d}}\sum_{k'=1}^{K}\beta_{s_{k'}k}\left|\boldsymbol{\phi}_k^H\boldsymbol{\phi}_{k'}\right|^2 + 1}.\end{aligned} \tag{9}$$

2. Downlink data transmission

K users rely on the pilot sequence received from ARSs to select the best ARS for data transmission. Denote $\sqrt{\tau_k^{\mathrm{d}}}q_k$, where $\mathbb{E}\left\{|q_k|^2\right\} = 1$ is the symbol sent from the s_kth ARS to the kth user with the power control factor of τ_k^{d}. The signal at kth user is described below:

$$\begin{aligned}\mathbf{y}_k &= \sum_{n=1}^{N}\sqrt{\rho^{\mathrm{d}}}\sum_{k'=1}^{K}\mathbf{g}_{s_{k'}k}\sqrt{\tau_{k'}^{\mathrm{d}}}q_{k'} + w_k \\ &= \sum_{n=1}^{N}\sqrt{\rho^{\mathrm{d}}}\hat{\mathbf{g}}_{s_k k}\sqrt{\tau_k^{\mathrm{d}}}q_k + \sum_{n=1}^{N}\sqrt{\rho^{\mathrm{d}}}\boldsymbol{\varepsilon}_{s_k k}\sqrt{\tau_k^{\mathrm{d}}}q_k \\ &+ \sum_{N=1}^{N}\sqrt{\rho^{\mathrm{d}}}\sum_{k'\neq k}^{K}\mathbf{g}_{s_{k'}k}\sqrt{\tau_{k'}^{\mathrm{d}}}q_{k'} + w_k,\end{aligned} \tag{10}$$

where ρ^{d} represent the normalized downlink transmit SNR, and $w_k \sim \mathcal{CN}(0,1)$ is additive Gaussian noise. By considering the last three components of Eq. (10) as noise components, we obtain the Eq. (11) for the downlink data transmission rate of kth user, as shown on the next page.

It can be observed that in Eq. (11), $\left|\hat{\mathbf{g}}_{s_k k}\right|^2$ follows an exponential distribution with mean $\mu_{s_k k}$. Therefore, the expression for the achievable rate of kth user in Eq. (11) can be transformed by using the exponential integral function Ei(.)[14, Eq. (8.211.1)] as follow:

$$R_k^{\mathrm{d}} = -\left(\log_2 e\right)e^{1/\bar{\mu}_{s_k k}}\ \mathrm{Ei}\left(-\frac{1}{\bar{\mu}_{s_k k}}\right), \tag{12}$$

where

$$\bar{\mu}_{s_k k} \triangleq \frac{\rho^{\mathrm{d}}\tau_k^{\mathrm{d}}\mu_{s_k k}}{\rho^{\mathrm{d}}\tau_k^{\mathrm{d}}\left(\beta_{s_k k} - \mu_{s_k k}\right) + N\rho^{\mathrm{d}}\sum_{k'\neq k}^{K}\tau_{k'}^{\mathrm{d}}\beta_{s_{k'}k} + 1}. \tag{13}$$

3. Power optimization

The power control problem brings numerous benefits aimed at enhancing system quality, managing interference,

$$R_k^{\mathrm{d}} = \mathbb{E}\left\{\log_2\left(1 + \frac{\rho^{\mathrm{d}}\tau_k^{\mathrm{d}}\left|\hat{\mathbf{g}}_{s_k k}\right|^2}{\rho^{\mathrm{d}}\tau_k^{\mathrm{d}}\left(\beta_{s_k k} - \mu_{s_k k}\right) + N\rho^{\mathrm{d}}\sum_{k'\neq k}^{K}\tau_{k'}^{\mathrm{d}}\beta_{s_{k'} k} + 1}\right)\right\}. \tag{11}$$

ensuring service quality synchronization, and conserving energy for the entire system. Some power optimization methods contribute to the very high overall throughput of the system. However, within them, there are some users with very good throughput, but there are also some users with very poor throughput. Therefore, this issue leads to unfairness, or, in other words, uneven service quality for users.

The max-min power optimization problem is intended to achieve a certain fairness among users. Fairness can be attained by increasing the data transmission power of users with low throughput. In our proposed model, power optimization is addressed through a max-min problem using the Bisection algorithm, where both the objective functions and constraints are semi-linear and linear. The mathematical model is specifically described as follows:

$$(\mathbf{P1})\ \max_{\tau_k^{\mathrm{d}}}\ \min_{k=1,\dots,K} R_k^{\mathrm{d}} \tag{14a}$$

$$\text{subject to } 0 \le \tau_k^{\mathrm{d}} \le 1,\ k = 1,\dots,K. \tag{14b}$$

Because R_k^{d} is the monotonically increasing function of $\bar{\mu}_{s_k k}$. Hence, (P1) problem is reformulated as follows:

$$(\mathbf{P2})\ \max_{\tau_k^{\mathrm{d}}}\ \min_{k=1,\dots,K} \bar{\mu}_{s_k k} \tag{15a}$$

$$\text{subject to } 0 \le \tau_k^{\mathrm{d}} \le 1,\ k = 1,\dots,K. \tag{15b}$$

To address the optimization problem, the objective functions and constraints must be linear or quasi-linear functions. (P2) is a maximization problem of $\min_{k=1,\dots,K}\bar{\mu}_{s_k k}$ with regard to τ_k^{d}. It is observed that in P2, (15b) is a linear function, whereas (15a) does not guarantee linear. By introducing the slack variable ξ, we transform (15a) expression with ξ as the upper bound of $\min_{k=1,\dots,K}\bar{\mu}_{s_k k}$ [15, Chapter 5, 6]. Thus, (P2) has an additional constraint is $\xi \le \bar{\mu}_{s_k k}$.

Specifically, P2 is reformulated as follows:

$$(\mathbf{P3})\ \max_{\tau_k^{\mathrm{d}},\xi} \xi \tag{16a}$$

$$\text{subject to } \xi \le \bar{\mu}_{s_k k},\ k = 1,\dots,K \tag{16b}$$

$$0 \le \tau_k^{\mathrm{d}} \le 1,\ k = 1,\dots,K. \tag{16c}$$

The (P3) problem is a linear problem with respect to ξ that can be successfully solved via the Bisection method as follows:

Algorithm 1 Bisection Algorithm

1: **Initialization**: Select the initial values of ξ_{min} and ξ_{max} define a range of relevant values of the objective function in (P3). Denote a tolerance value $\epsilon = 10^{-2}$
2: **Set:** $\xi := \frac{\xi_{min}+\xi_{max}}{2}$. Solve the(P3) quasi-linear problem
3: **If** (P3) problem is feasible, set $\xi_{min} := \xi$, else set $\xi_{max} := \xi$
4: **Stop** if $\xi_{max} - \xi_{min} \le \epsilon$ Otherwise, return to Step 2.

Remark 1: In optimization problems, it is often challenging to find an exact absolute solution, as in problems with explicit formulas. Specifically, in the bisection algorithm, the exact solution is a point within the search interval. Therefore, as the search intervals become smaller, the search solution gets closer to reaching the optimal point. The accuracy of the solution in the optimization problem depends on the tolerance value. The smaller the tolerance value, the approximate solution gets closer to the optimal solution. Typically, the tolerance value is set between 10^{-2} to 10^{-5}.

IV. Numerical results and discussions

We evaluate the system performance of multi-ARS based on the SC model using the Cumulative Distribution Function (CDF) of user throughput both without and with optimized downlink data power. Additionally, we also experiment with the system quality when varying parameters such as the number of ARS, the number of antennas, the time allocated for downlink channel estimation, and the large number of users.

1. Parameters and Setup

We exame with throughput per user, taking into account estimated channel interval. The throughput expression is expressed as follows:

$$T_k^{\mathrm{d}} = B\frac{1-\alpha_{\mathrm{p}}^{\mathrm{d}}/\alpha^{\mathrm{c}}}{2}R_k^{\mathrm{d}}. \tag{17}$$

Without data power optimization, the ARSs transmit at full power, i.e., $\tau_k^{\mathrm{d}} = 1$

With data power optimization, the ARSs implement transmission with the optimized power control coefficients (τ_k^{d}) as described in Section III.3.

TABLE II
PARAMETERS OF THE SYSTEM USED FOR SIMULATION.

Parameter	Value
Carrier frequency	1.9 GHz
Bandwidth (B)	20MHz
Coherence bandwidth (B_c)	200 KHz
Coherence time (T_c)	1 ms
ARS height	$22.5m \leq h_{ARS} \leq 300m$
ρ_p^d, ρ^d	100, 200 mW
Coherence interval α^c	200 samples
The distributed area (S)	1 km^2

2. Results and Discussions

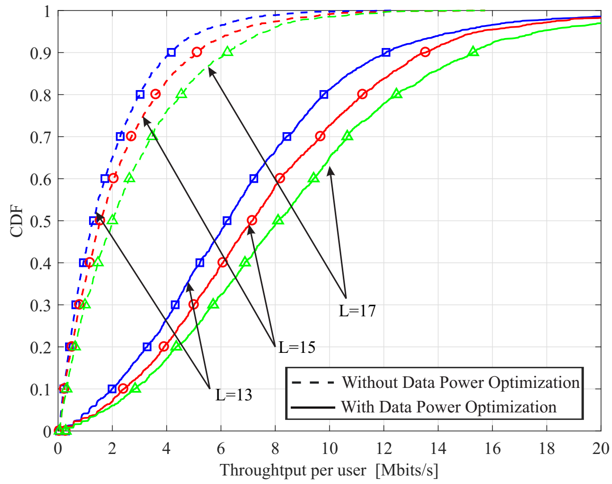


Figure 3. CDFs of the per-user throughput without and with data transmission power optimization, $L = 13, 15, 17$, $K = 10$, $N = 1$, and $\alpha_p^d = 10$.

Figure 3 illustrates CDF of user throughput as the number of deployed ARSs varies. On the one hand, it can be observed that the power optimization problem significantly improves throughput efficiency. For example, with a total of deployed ARSs ($L = 13$), the 90%-likely user throughput without power optimization is only around $0.1 Mbits/s$, whereas with power optimization, it is $2 Mbits/s$. The reason for this is that when the transmit power is optimized, the ARSs transmit with just enough power to manage interference or noise at the receiver, thereby improving user throughput.

On the other hand, as the total number of deployed ARSs increases sequentially with $L = 13, 15, 17$, user throughput also improves. As the L value increases, the probability of selecting an ARS with the best channel condition, corresponding to the SC model, also increases. This ensures an improvement in user service quality.

In Figure 4, we examine user throughput as the number

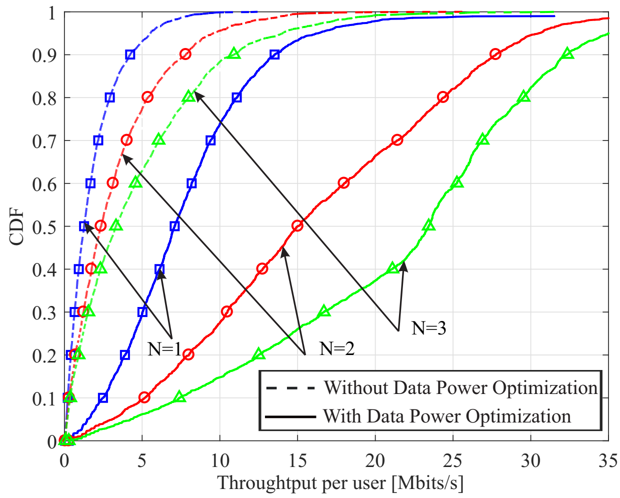


Figure 4. CDFs of the per-user throughput without and with data transmission power optimization, $L = 15$, $K = 10$, $N = 1, 2, 3$, $\alpha_p^d = 10$.

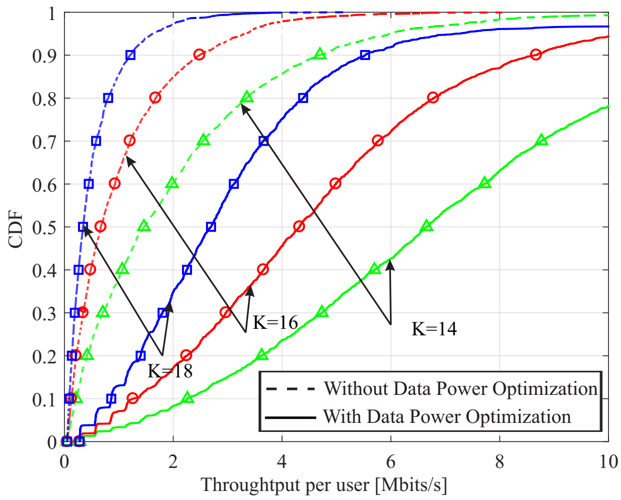


Figure 5. CDFs of the per-user throughput without and with data transmission power optimization, $L = 15$, N-$ARS = 15$, $K = 14, 16, 18$, $N = 1$, and $\alpha_p^d = 10$.

of antennas on ARS varies. User throughput increases significantly as the number of antennas per ARS increases ($N = 1, 2, 3$). In practice, it can be observed that as the number of antennas increases, the diversity gain also increases, leading to improved user service capabilities.

Figure 5 shows the CDF of user throughput as the number of users varies. In this simulation result, we investigate the system performance under real-world conditions with a varying number of users both larger and smaller than the deployed number of ARSs. The results indicate that with a high number of users, the user connections to ARSs require more competition, especially for users at a distance,

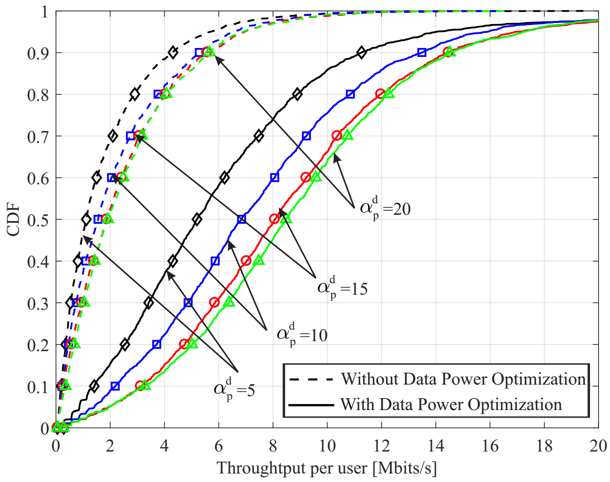


Figure 6. CDFs of the per-user throughput without and with data transmission power optimization, $L = 15$, $K = 10$, $N = 1$, $\alpha_p^d = 5, 10, 15, 20$.

leading to reduced user throughput. However, even with a high number of users, the power optimization problem still yields significant effectiveness.

In Figure 6, we investigate user throughput as the length of the downlink channel training pilot sequence varies, or, in other words, the time allocated for downlink channel training. It can be observed that as the time allocated for channel estimation increases ($\alpha_p^d = 5, 10, 15, 20$), user throughput improves.

However, with $\alpha_p^d = 20$, user throughput slightly increases and tends to saturate. The reason for this is that as the α_p^d value increases, indicating an increase in the time allocated for channel estimation, the quality of channel estimation improves. However, if the α_p^d value continues to increase, it will impact the data transmission time. Therefore, as the α_p^d value increases, user throughput tends to saturate and decrease.

V. Conclusion

This study has investigated a multi-ARS downlink system based on the SC model. By deploying ARSs to jointly serve ground users in a specific area, similar to the CF model. Then, the selection of an ARS with the best channel condition to serve users is referred to as the SC model. In addition, a power control algorithm is proposed to enhance the system quality. The system quality is evaluated based on various parameters such as the total number of deployed ARSs, the number of users, the number of antennas, and the length of the pilot sequence. The results also reveal that user throughput improves when applying the power control problem. However, at present, we are examining the connection between ARS and GBS as an ideal backhaul channel. In future work, we will study other optimization algorithms and apply deep reinforcement learning to the multi-ARS SC model to improve system performance, reduce complexity and signal processing time.

Acknowledgement

This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 102.02-2021.56.

References

[1] D. C. Nguyen, M. Ding, P. N. Pathirana, A. Seneviratne, J. Li, D. Niyato, O. Dobre, and H. V. Poor, "6G Internet of Things: A comprehensive survey," *IEEE Int. J.*, vol. 9, no. 1, pp. 359–383, Aug. 2022.

[2] J. Tanveer, A. Haider, R. Ali, and A. Kim, "An overview of reinforcement learning algorithms for handover management in 5G ultra-dense small cell networks," *Applied Sciences*, vol. 12, no. 1, p. 426, 2022.

[3] B. Alzahrani, O. S. Oubbati, A. Barnawi, M. Atiquzzaman, and D. Alghazzawi, "UAV assistance paradigm: State-of-the-art in applications and challenges," *Journal of Network and Computer Applications*, vol. 166, p. 102706, 2020.

[4] B. Li, S. Zhao, R. Miao, and R. Zhang, "A survey on unmanned aerial vehicle relaying networks," *IET Communications*, vol. 15, no. 10, pp. 1262–1272, 2021.

[5] M. A. Ouamri, D. Singh, M. A. Muthanna, A. Bounceur, and X. Li, "Performance analysis of UAV multiple antenna-assisted small cell network with clustered users," *Wireless Networks*, vol. 29, no. 4, pp. 1859–1872, 2023.

[6] Q. Alsafasfeh, O. A. Saraereh, A. Ali, L. Al-Tarawneh, I. Khan, and A. Silva, "Efficient power control framework for small-cell heterogeneous networks," *Sensors*, vol. 20, no. 5, p. 1467, 2020.

[7] N. Parvaresh and B. Kantarci, "A continuous actor–critic deep Q-learning-enabled deployment of UAV base stations: Toward 6G small cells in the skies of smart cities," *IEEE Open Journal of the Communications Society*, vol. 4, pp. 700–712, 2023.

[8] B. A. Duc, T. M. Hoang, N. T. Phuong, X. N. Tran, and P. T. Hiep, "Optimizing power for data transmissions in uplink cell-free multi-ABSs communication systems," in *2022 Int. Conf. Advanced. Technol. Commun. (ATC)*. IEEE, Nov. 2022, pp. 23–28.

[9] 3GPP, "Technical specification group radio access network; study on enhanced LTE support for aerial vehicles," *TR 36.777, Dec 2017*.

[10] Z. Liu and L. Dai, "A comparative study of downlink MIMO cellular networks with co-located and distributed base-station antennas," *IEEE Transactions on Wireless Communications*, vol. 13, no. 11, pp. 6259–6274, 2014.

[11] S. Elhoushy, M. Ibrahim, and W. Hamouda, "Cell-free massive MIMO: A survey," *IEEE Commun. Surveys & Tutorials.*, vol. 24, no. 1, pp. 492–523, Oct. 2022.

[12] T. L. Marzetta and H. Yang, *Fundamentals of massive MIMO*. Cambridge University Press, 2016.

[13] S. M. Kay, *Fundamentals of statistical signal processing: estimation theory*. Prentice-Hall, Inc., 1993.

[14] D. Zwillinger and A. Jeffrey, *Table of integrals, series, and products*. Elsevier, 2007.

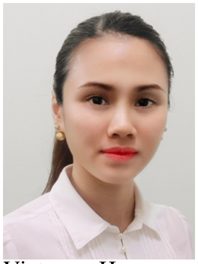
[15] E. K. Chong, W.-S. Lu, and S. H. Żak, *An introduction to optimization*. John Wiley & Sons, 2023.

Bui Anh Duc received a B.S. degree in Communication Command at Telecommunications University, Ministry of Defense, Vietnam, in 2011, and an MS degree from Le Quy Don Technical University, Vietnam in 2017. He is currently pursuing a Ph.D degree at Le Quy Don Technical University, Hanoi, Vietnam. His research interests include unmanned aerial vehicle communications, MIMO and Cell Free Massive MIMO systems, and signal processing for wireless cooperative communications.

E-mail: buiducsqtt@lqdtu.edu.vn

Tran Manh Hoang received the B.S. degree in communication command from Telecommunications University, Ministry of Defense, Nha Trang, Vietnam, in 2002, the B.Eng. degree in electrical engineering from Le Quy Don Technical University, Ha Noi, Vietnam, in 2006 the M.Eng. degree in electronics engineering from Posts and Telecommunications Institute of Technology, Ho Chi Minh City, Vietnam, in 2013 and the Ph.D degree from Le Quy Don Technical University, Hanoi, Vietnam, in 2018. He is currently working as a Lecturer with Telecommunications University Khanh Hoa, Vietnam. His research interests include energy harvesting, UAV, short packet communication, non-orthogonal multiple access, and MIMO, RIS, signal processing for wireless cooperative communications.

E-mail: tranmanhhoang@tcu.edu.vn

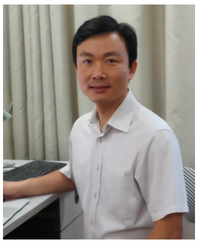


Nguyen Thu Phuong received the B.S, M.S and PhD degrees from Le Quy Don Technical University, Vietnam in 2008, 2012 and 2016, respectively. She is now a lecturer at Faculty of Radio-Electronics Engineering, and a significant member of the Advanced Wireless Communication Group, Le Quy Don Technical University, Hanoi, Vietnam. Her research interests are in the area of emerging technologies for future wireless communications: Energy harvesting, Non-orthogonal multiple access (NOMA), space-time processing, space-time coding, spatial modulation and index modulation, and massive MIMO systems.

E-mail: phuong.nt@mta.edu.vn

Xuan Nam Tran received his Master of Engineering (ME) in Telecommunications Engineering from University of Technology Sydney, Australia in 1998, and Doctor of Engineering in Electronic Engineering from The University of Electro-Communications, Japan in 2003. He is currently a full professor and head of a strong research group on advanced wireless communications, Le Quy Don Technical University. Prof. Tran is the founding chair and currently the chapter chair of the Vietnam Chapter of IEEE Communications Society. He is a member of IEEE, IEICE and the Radio-Electronics Association of Vietnam (REV). His research interests are in the area of emerging technologies for future wireless communications: Energy harvesting, Non-orthogonal multiple access (NOMA), space-time processing, space-time coding, spatial modulation and index modulation, and massive MIMO systems, signal processing for wireless cooperative communications.

E-mail: namtx@mta.edu.vn



Pham Thanh Hiep received a B.E. degree in Communications Engineering from National Defence Academy, Japan, in 2005; received the M.E. and Ph.D. degrees in Physics, Electrical, and Computer Engineering from Yokohama National University, Japan, in 2009 and 2012, respectively. Now, he is a lecturer at Le Quy Don Technical University, Ha Noi, Viet Nam. His research interests lie in the area of wireless communication technologies and signal processing.

E-mail: thanhhiep@lqdtu.edu.vn