Resource-Efficient HAPS-RIS Enabled Beyond-Cell Communications

Safwan Alfattani, Member, IEEE, Animesh Yadav, Senior Member, IEEE, Halim Yanikomeroglu, Fellow, IEEE, and Abbas Yongaçoglu, Life Senior Member, IEEE

Abstract—In the future, urban regions will encounter a massive number of capacity-hungry devices. Relying solely on terrestrial networks for serving all UEs will be a cost-ineffective approach. Consequently, with the anticipated supply and demand mismatch, several UEs will be unsupported. To offer service to the left-out UEs, we employ an energy-efficient and cost-effective beyond-cell communications approach, which uses reconfigurable intelligent surfaces (RIS) on a high-altitude platform station (HAPS). Particularly, unsupported UEs will be connected to a dedicated control station (CS) through RIS-mounted HAPS. A novel resource-efficient optimization problem is formulated that maximizes the number of connected UEs, while minimizing the total power consumed by the CS and RIS. Since the resulting problem is a mixed-integer nonlinear program (MINLP), a low-complexity two-stage algorithm is developed. Numerical results demonstrate that the proposed algorithm outperforms the benchmark approach in terms of the percentage of connected UEs and the resource-efficiency (RE). Also, the results show that the number of connected UEs is more sensitive to transmit power at the CS than the HAPS size.

Index Terms—High-altitude platform station (HAPS), reconfigurable intelligent surfaces (RIS), non-terrestrial network (NTN), quality-of-service (QoS).

I. INTRODUCTION

FUTURE wireless networks are expected to face unprecedented demands for continuous and ubiquitous connectivity due to the increasing number of mobile users, the evolving deployment of Internet-of-Things (IoT) networks, and the growing number of novel use cases. Increasing base station (BS) density and using relays may be a straightforward solution to cope with this unforeseen situation, but it comes at the cost of high capital and operational expenditures. Alternatively, a green and an energy-efficient solution that utilizes reconfigurable intelligent surfaces (RIS) in terrestrial networks (TNs) has been introduced [1]. RIS constitutes a large number of low-cost and nearly passive elements, which can be configured to reflect the incident radio frequency (RF) signal to a desired direction [1], [2].

However, the deployment of RIS in terrestrial environments involves several challenges, such as placement inflexibility and channel impairments including excessive path loss and shadowing effects. Instead, in [3], we proposed the integration of RIS on aerial or stratospheric platforms and discussed its prospects for wireless systems and services. The main motivations behind this proposition include better channel links, wider coverage and dynamic placement. Moreover, since energy consumption is a critical issue in aerial platforms, equipping them with a massive number of active antennas would exaggerate the issue. Alternatively, mounting aerial platforms with RIS can provide an energy-efficient solution [4], [5], [6], [7], [8]. In addition, due to the favorable wireless channel conditions in non-terrestrial networks (NTN), reconfigurable intelligent surfaces (RIS) can support panoramic full-angle reflection serving wider areas with strong line-of-sight (LoS) links [4], [9]. Further, in [10], we showed that RIS-mounted high-altitude platform station (HAPS) has the potential to outperform RIS-aided terrestrial networks and other RIS-mounted aerial platforms (e.g., UAV). Indeed, although the path-loss from a terrestrial node to a UAV is significantly lower than that to a HAPS, the reflection gain offered by HAPS-RIS is much higher, due to the typical large size of HAPS.

To reap the benefits of RIS-mounted HAPS (HAPS-RIS), in [11], we proposed a novel beyond-cell communications approach. This approach offers service to stranded terrestrial user equipment devices (UEs), whose either channel conditions are below the required quality-of-service (QoS), or are located in a cell with fully loaded BS. In particular, stranded UEs get service from a dedicated ground control station (CS) through the HAPS-RIS. We showed that HAPS-RIS can work in tandem with legacy TNs to support unserved UEs. We also discussed the optimal power and RIS units allocation design schemes to maximize the system throughput and the worst UE rate.

Previous works on RIS-assisted communications consider serving all UEs by optimizing only the RIS phase shifts and the transmit power [1], [11]. However, due to practical limitations on system resources, including the transmit power of the CS and HAPS size (equivalently, the number of RIS units), it might be infeasible to serve all unsupported UEs by CS through HAPS-RIS, especially, for a large set of UEs. Accordingly, we formulated a novel optimization problem to maximize the resource-efficiency (RE) of the system.

- A novel resource-efficient optimization problem that maximizes the percentage of connected UEs while minimizing the usage of RIS units and transmit power is formulated.
- Since the resulting problem is a mixed-integer nonlinear program (MINLP) and hard to solve, a low complexity two-stage algorithm is proposed to solve it.
Through numerical results, we study the impact of HAPS size and QoS requirements of UEs on the percentage of connected UEs and demonstrate significant improvements in RE of the system.

The rest of this letter is organized as follows. In Section II, the system model is described. Section III presents the problem formulation. The proposed solution and the algorithm for solving the optimization problem are discussed in Section IV. Numerical results and discussion are presented in Section V. Finally, Section VI concludes this letter.

II. SYSTEM MODEL

We consider a typical urban region consists of \( K \) UEs, \( L \) terrestrial BSs,\(^1\) a single HAPS-RIS, and one CS,\(^2\) as depicted in Fig. 1. The UEs are assumed to suffer from severe shadowing and blockages, and NLoS paths, which are typical characteristics of propagation media in urban regions. Based on channel conditions between the BSs and the UEs, and the maximum serving capacity of the BSs, a set of \( K_1 \) UEs will be supported by direct links from the BSs (referred to as within-cell communications [11]). The set of remaining UEs \( K_2 \), which cannot form direct connection with the terrestrial BS will be served by the CS via HAPS-RIS (referred to as beyond-cell communications [11]). The CS is located somewhere in the HAPS coverage area.\(^3\) Note that \( K = K_1 \cup K_2 \). We assume that the CS serves the stranded UEs in set \( K_2 \) using orthogonal subcarriers, and hence, there will be no inter-UE interference. Further, both within-cell and beyond-cell communications occur in two orthogonal frequency bands, while keeping the subcarrier bandwidth \( B_{UE} \) same for both types of communications. As a result, the signals from within-cell UEs will not interfere with the signals from beyond-cell UEs and vice versa.

We assume that within-cell UEs are connected optimally with terrestrial BSs, and hence, our focus in this letter is on beyond-cell communications. Accordingly, the received signal at UE \( k \in K_2 \) on a given subcarrier can be expressed as

\[
y_k = \sqrt{P^{CS}_k} h_k \Phi_k \ x_k + w_k, \quad (1)
\]

where \( x_k \) and \( P^{CS}_k \) denote the transmitted signal and power of UE \( k \), respectively. \( w_k \) denotes the additive white Gaussian noise (AWGN) \( \sim \mathcal{C}\mathcal{N}(0, N_0 B_{UE}) \), where \( N_0 \) is the noise power spectral density. \( h_k \) denotes the effective channel gain from the CS to the HAPS-RIS and from the HAPS-RIS to UE \( k \), and is given by

\[
h_k = \sqrt{G^{CS} G^k (\Phi_k N_{PL}^{CS-HAPS-k})^{-1}}, \quad (2)
\]

where \( G^{CS} \) denotes the antenna gain of the control station, and \( G^k \) is the receiver antenna gain of UE \( k \). \( N_{PL}^{CS-HAPS-k} = N_{PL}^{CS-HAPS} P_{HAPS-k} \) denotes the effective path loss between the CS and UE \( k \) via HAPS-RIS. Since the amplitude and phase responses of RIS reflecting units are frequency-dependent \([13]\) and each UE uses different subcarrier, each UE is assigned with a distinct and dedicated set of RIS units tuned to its respective subcarrier. Accordingly, \( \Phi_k \) represents the reflection gain of the RIS corresponding to UE \( k \), and is expressed as

\[
\Phi_k = \sum_{i=1}^{N_k} \rho_i e^{-j(\phi_{i,k} - \theta_i - \theta_{i,k})}, \quad (3)
\]

where \( \rho_i \) denotes the reflection loss corresponding to RIS unit \( i \), \( \theta_i \) and \( \theta_{i,k} \) represent the corresponding phases between RIS unit \( i \) and both the control station and UE \( k \), respectively. \( \phi_{i,k} \) represents the adjusted phase shift of RIS unit \( i \) corresponding to user \( k \), and \( N_k \) represents the total number of RIS units allocated to UE \( k \).

Using (1), the signal-to-noise ratio (SNR) at UE \( k \) is written as

\[
\gamma_k = \frac{P^{CS}_k |h_k \Phi_k|^2}{N_0 B_{UE}} \quad (4)
\]

and the corresponding achievable rate can be expressed as

\[
R_k = B_{UE} \log_2(1 + \gamma_k). \quad (5)
\]

III. PROBLEM FORMULATION

Since the required power for the flight and control system of a HAPS4 is dependent on its type and size, for generalization, we focus on the power consumption due to communication payload. Using power efficiently at the HAPS-RIS for activating the RIS units, and at the CS for transmitting signals offer sustainable network and longer refueling intervals for HAPS. Also, in case of a large UE density or strict QoS requirement, it might be infeasible to serve all unserved UEs by the CS via HAPS-RIS. Therefore, we need to select as many UEs that can be supported by the CS, while using as minimum system resources (transmit power and RIS units) as possible. Accordingly, we define a novel performance metric known as resource efficiency as follows.

Definition 1: Resource efficiency (RE) of the beyond-cell communication system, \( \eta \), is defined as the ratio between the percentage of served UEs and the average power consumption in dBm by each supported UE, which includes

1BSs have down-tilted antennas dedicated to terrestrial UEs, and can’t generally communicate to HAPS.

2If the number of unsupported users increases, possible solutions may include increasing the CS transmit power or antenna gain or the number of CS in the HAPS coverage area.

3According to 3GPP standards [12], a CS (gateway) should be deployed to ensure minimum elevation angle of 5°, and the maximum Euclidean distance of 229 km between HAPS and CS.


the consumption towards signal transmission and RIS units configuration:

\[ \eta = \frac{1}{K} \left( K_1 + \sum_{k=1}^{K_2} u_k \right) \]

(6)

where \( u_k \) is the indicator variable, if \( u_k = 1 \), user \( k \) will get service by HAPS-RIS, otherwise not if \( u_k = 0 \). In the denominator, the terms \( \sum_{k=1}^{K_2} P_{k}^{\text{CS}} u_k \) and \( \sum_{k=1}^{K_2} P_{\text{RIS}} N_k u_k \) represent the total transmit power consumption at the CS and the total power consumed by the RIS units for all supported UEs, respectively. \( P_{\text{RIS}} \) denotes the consumed power by each RIS unit for phase shifting, which is dependent on the RIS configuration technology and its resolution. Finally, \( |\mathcal{U}| \) denotes the cardinality of the set, which constitutes the UEs supported by the CS via HAPS-RIS.

In the following, we formulate the resource-efficient UEs maximization problem. It can be expressed as

\[
\begin{align*}
\max_{u_k, \Phi_k, N_k, P_{k}^{\text{CS}}} & \quad \eta \\
\text{s. t.} & \quad L \leq L_{\text{max}}, \\
& \quad R_k \geq u_k R_{\text{th}}, \quad \forall k = 1, 2, \ldots, K_2, \\
& \quad \sum_{k=1}^{K_2} u_k N_k \leq N_{\text{max}}, \\
& \quad \phi_{i,k} \in \{0, \Delta\phi, 2\Delta\phi, \ldots, (2^b - 1)\Delta\phi\}, \quad \forall i = 1, 2, \ldots, N_k, \\
& \quad \sum_{k=1}^{K_2} u_k P_{k}^{\text{CS}} \leq P_{\text{CS}}^{\text{max}}, \\
& \quad N_k \in \{0, 1, \ldots, N_{k,\text{max}}\}, \quad \forall k = 1, 2, \ldots, K_2, \\
& \quad 0 \leq P_{k}^{\text{CS}} \leq u_k P_{k,\text{max}}^{\text{CS}}, \quad \forall k = 1, 2, \ldots, K_2, \\
& \quad u_k \in \{0, 1\},
\end{align*}
\]

\( P_{\text{CS}}^{\text{max}} \) denotes the maximum available transmit power at the CS, \( N_{k,\text{max}} \) and \( P_{k,\text{max}}^{\text{CS}} \) denote the maximum number of RIS units and the amount of power allocated to UE \( k \), respectively. Constraint (7b) limits the number of BSs in the area. Constraint (7c) guarantees that each selected UE satisfies the minimum rate requirement of \( R_{\text{th}} \). Constraint (7d) ensures the total number of RIS units allocated to the supported UEs does not exceed the maximum number of available RIS units, \( N_{\text{max}} \), which is limited by the HAPS size. Constraint (7e) determines the discrete range of the adjustable phase shifts values for each RIS unit, where \( \Delta\phi_{i,k} = 2\pi/2^b \) with \( b \) as the number of bits used to uniformly quantize the phase shifts of each RIS element. Constraint (7f) guarantees that the total allocated power by the CS to the selected UEs is less than the maximum available power. Finally, constraints (7g) and (7h) ensure fair allocation of both RIS units and CS power, respectively, to each UE.

IV. PROPOSED SOLUTION

Since problem (7) is an MINLP, it is hard to solve jointly with the involved variables in an optimal manner with lower complexity. Therefore, we decouple the problem into two subproblems and develop a low-complexity algorithm to solve it suboptimally. The main step of the proposed algorithm involves solving (7) in two stages.

In the first subproblem, we maximize the numerator of (7a) by maximizing the number of UEs, which can establish direct connection with TNs (i.e., by setting \( L = L_{\text{max}} \)).\(^4\) and then finding the set of maximum feasible UEs \( \mathcal{K}_2 \), which can be supported by the CS via HAPS-RIS. To this end, we first sort the channel gains of all UEs. Secondly, under the assumptions of equal power allocation to each UE and perfect reflection of each RIS unit, we allocate the minimum required number of RIS units to each UE as follows:

\[
N_k = \left\lceil \frac{N_0 B_{\text{UE}} \left( \frac{R_{\text{th}}}{2^b \eta} \right)}{P_{k}^{\text{CS}} |h_k|^2} \right\rceil.
\]

(8)

The initial RIS units allocation starts with UEs with the best channel conditions until all RIS units are utilized. As a result, a set \( \mathcal{U} \) with the largest number of feasible UEs is determined.

In the second subproblem, the denominator of (7a) is minimized by optimally allocating the CS power and RIS units to each UE belongs to set \( \mathcal{U} \). This is accomplished by solving the following optimization problem:

\[
\begin{align*}
\min_{\Phi_k, N_k, P_{k}^{\text{CS}}} & \quad |\mathcal{U}| \sum_{k=1}^{K_2} P_{k}^{\text{CS}} + P_{\text{RIS}} N_k \\
\text{s. t.} & \quad R_k \geq R_{\text{th}}, \quad \forall k = 1, 2, \ldots, |\mathcal{U}|, \\
& \quad \sum_{k=1}^{K_2} N_k \leq N_{\text{max}}, \\
& \quad \phi_{i,k} \in \{0, \Delta\phi, 2\Delta\phi, \ldots, (2^b - 1)\Delta\phi\}, \quad \forall i = 1, 2, \ldots, N_k, \\
& \quad \sum_{k=1}^{K_2} P_{k}^{\text{CS}} \leq P_{\text{CS}}^{\text{max}}, \\
& \quad N_k \in \{0, 1, \ldots, N_{k,\text{max}}\}, \quad \forall k = 1, 2, \ldots, |\mathcal{U}|, \\
& \quad 0 \leq P_{k}^{\text{CS}} \leq P_{k,\text{max}}^{\text{CS}}, \quad \forall k = 1, 2, \ldots, |\mathcal{U}|.
\end{align*}
\]

\( (9a)-(9g) \)

Without loss of generality, problem (9) can be re-written as

\[
\begin{align*}
\min_{\Phi_k, N_k, P_{k}^{\text{CS}}} & \quad |\mathcal{U}| \sum_{k=1}^{K_2} P_{k}^{\text{CS}} + P_{\text{RIS}} N_k \\
\text{s. t.} & \quad \frac{1}{\gamma_k} \leq \frac{1}{\gamma_{\text{min}}}, \quad \forall k = 1, 2, \ldots, |\mathcal{U}|, \\
& \quad (9c)-(9g).
\end{align*}
\]

(10a)-(10c)

Due to the involvement of integer and discrete variables \( N_k \) and \( \phi_{i,k} \), respectively, problem (10) is a challenging problem and is difficult to solve optimally in polynomial time. To solve it efficiently, we relax \( N_k \) and \( \phi_{i,k} \) to be continuous variables. After this relaxation, the objective and the constraints of (10) become posynomials,\(^5\) which can be solved optimally using geometric programming (GP) technique [14]. At the solution of the relaxed problem, the final solution to (10) is obtained by approximation as \( N_k \approx \lceil N_k^{\text{opt}} \rceil \). The pseudo-code of the proposed two-stage algorithm is described in Algorithm 1. Note that in practice \( \phi_{i,k} \) should be selected from a set of

\(^4\)This value is dependent on the communication frequency, and the statistics of the users density and their rate demands. It is also determined by operator’s expenditure analysis.

\(^5\)A posynomial function is a special function refers to a sum of positive monomials[14].
Algorithm 1 Efficient Maximization of Connected UEs
1: Set $L = L_{\text{max}}$ and obtained set $\mathcal{K}_2$.
2: Input: $h_k$, $k \in \{1, 2, \ldots, K\}$.
3: Sort $K_2$ UEs in descending order based on their channel gains $K_{S2} \leftarrow K_2$.
4: for $k = 1, \ldots, K_{S2}$ do
5: while $\sum_{k=1}^{K_{S2}} N_k \leq N_{\text{max}}$ do
6: $P_{k}^{\text{CS}} = P_{\text{max}}^{\text{CS}} / K_{S2}$.
7: Obtain initial $N_k$ from (8).
8: end while
9: end for
10: Stage-1 Output: Selected UEs $\mathcal{U}$.
11: Solve optimally (10) for the set $\mathcal{U}$.
12: Stage-2 Output: $P_{k}^{\text{CSmax}}$ and $N_k^* (\forall k = 1, \ldots, |\mathcal{U}|)$.

V. NUMERICAL RESULTS AND DISCUSSION

In this section, we present and discuss the performance of the proposed algorithm. For the purpose of comparison, we employ a benchmark approach, which first allocates equal bandwidth to each BS and then selects the UEs with the highest channel gains to be served first with the minimum number of RIS units until the QoS requirement is satisfied.

In the simulation setup, we consider an urban area with a dimension of 10 km by 10 km, with $L_{\text{max}} = 4$ terrestrial BSs serving $K = 100$ uniformly distributed UEs with a minimum separation distance of 100 m among them. We assume that the terrestrial BSs are optimally placed in the considered region. The channel gains between all the UEs and the terrestrial BSs are obtained by adopting the 3GPP standards [17]. The carrier frequency is set to $f_{c} = 2$ GHz with shadowing standard deviation $\sigma = 8$ dB. Unless stated otherwise, the minimum rate for a direct connection between a UE and a BS is $R_{\text{th}} = 2$ Mb/s.

Resource-efficiency performance of connected UEs for different $R_{\text{min}}$.

A. Resource-Efficiency Maximization

Fig. 2 plots the normalized RE obtained using Algorithm 1 (on the left-hand side y-axis) and the percentage of connected UEs (on the right-hand side y-axis) versus different values of minimum rate requirement $R_{\text{min}}$. It also compares the performance of Algorithm 1 with the benchmark approach. The maximum number of RIS units mounted on HAPS is set to $N_{\text{max}} = 220,000$ units. It can be observed that as the QoS (represented by $R_{\text{min}}$) increases, the percentage of connected UEs and the RE drops. However, this performance degradation is more significant in terms of the percentage of connected UEs than the RE. Furthermore, we observed that the RE obtained using Algorithm 1 significantly outperforms the one obtained using the benchmark approach. This is due to the fact that Algorithm 1 optimizes allocation of both power and RIS units to UEs.

B. Percentage of Connected UEs

Figs. 3 and 4 plot and compare the percentage of connected UEs obtained through Algorithm 1, the benchmark approach, and within-cell communication approach for different values of the number of RIS units $N_{\text{max}}$ available at the HAPS, and maximum power $P_{k}^{\text{CSmax}}$ available at the CS, respectively.

In Fig. 3, to study the impact of $N_{\text{max}}$, we consider only the second term (i.e., $P_{\text{RIS}}N_k$) of the objective function in (10a). The selected range of $N_{\text{max}}$ is set between 10,000 and 220,000 units. This range corresponds to a total RIS area between 9 m² and 198 m² at carrier frequency of 2 GHz.6 In Fig. 4, only the first term of (10a) (i.e., $P_{k}^{\text{CS}}$) is considered to study the

6This represents a limited area on a typical HAPS surface, as the length of an airship is between 100-200 m, whereas aerodynamic HAPS have wingspans between 35 m and 80 m. The size of each RIS unit is $(0.2\lambda)^2$ [19].
Moreover, the proposed approach is 1-3\% higher than the benchmark and 35 dBm, and the maximum transmit power of CS is set to vary between 30 dBm and 35 dBm, and \( N_{\text{max}} \) is set to 150,000 units. It can be observed from the figures that the percentage of connected UEs increases with the maximum power of the CS \( P_{\text{CS}}^{\text{max}} \), and the maximum number of RIS units \( N_{\text{max}} \) (or the size of HAPS). These behaviors are intuitive as making more system resources \( (P_{\text{CS}}^{\text{max}} \text{ and } N_{\text{max}}) \) available allows more number of stranded users to be served by the CS via HAPS-RIS.

Figs. 3 and 4 also show that the performance of the proposed approach is 1-3\% higher than the benchmark approach. Moreover, \( P_{\text{CS}}^{\text{max}} \) has more significant impact than \( N_{\text{max}} \) on the percentage of connected UEs. By increasing \( P_{\text{CS}}^{\text{max}} \) by 2 dB, the percentage of connected UEs increases about 4\%, whereas doubling of the RIS size is needed to achieve the same increase in the percentage of connected UEs. Furthermore, it can be observed from the figures that 76\% UEs are served through \textit{within-cell} communication approach, and the CS supports the remaining UEs via HAPS-RIS. Hence, \textit{beyond-cell} communications via HAPS-RIS is able to complement TNs.

VI. CONCLUSION

In this letter, we investigated the resources optimization of \textit{beyond-cell} communications that use HAPS-RIS technology to complement TNs by supporting unserved UEs. In particular, given the limitations of the CS power and HAPS-RIS size, it might not be feasible to support all unserved UEs. Therefore, we formulated a novel resource-efficient optimization problem that simultaneously maximizes the percentage of connected UEs using minimal CS power and RIS units. The results show the capability of the \textit{beyond-cell} communications approach to support a larger number of UEs. Further, the results show the superiority of the proposed solutions over the benchmark approach and demonstrate the impact of the HAPS size and the QoS requirement on the percentage of connected UEs and the efficiency of the system.

REFERENCES

[1] C. Huang, A. Zappone, G. C. Alexandropoulos, M. Debbah, and C. Yuen, “Reconfigurable intelligent surfaces for energy efficiency in wireless communication,” IEEE Trans. Wireless Commun., vol. 18, no. 8, pp. 4157–4170, Aug. 2019.
[2] M. Di Renzo et al., “Smart radio environments empowered by reconfigurable intelligent surfaces: How it works, state of research, and the road ahead,” IEEE J. Sel. Areas Commun., vol. 38, no. 11, pp. 2450–2525, Nov. 2020.
[3] S. Alfantani et al., “Aerial platforms with reconfigurable smart surfaces for 5G and beyond,” IEEE Commun. Mag., vol. 59, no. 1, pp. 96–102, Jan. 2021.
[4] J. Ye, J. Qiao, A. Kammoun, and M.-S. Alouini, “Non-terrestrial communications assisted by reconfigurable intelligent surfaces,” Proc. IEEE, vol. 110, no. 9, pp. 1423–1465, Sep. 2022.
[5] B. Shang, E. S. Bentley, and L. Liu, “UAV swarm-enabled aerial reconfigurable intelligent surface: Modeling, analysis, and optimization,” IEEE Trans. Commun., early access, May 18, 2022, doi: 10.1109/TCOMM.2022.3173369.
[6] M. Li, X. Tao, N. Li, and H. Wu, “Energy-efficient covert communication with the aid of aerial reconfigurable intelligent surface,” IEEE Commun. Lett., vol. 26, no. 9, pp. 2101–2105, Sep. 2022.
[7] H.-B. Jeon, S.-H. Park, J. Park, K. Huang, and C.-B. Chue, “An energy-efficient aerial backhaul system with reconfigurable intelligent surface,” IEEE Trans. Wireless Commun., vol. 21, no. 8, pp. 6478–6494, Aug. 2022.
[8] P. S. Aung, Y. M. Park, Y. K. Tun, Z. Han, and C. S. Hong, “Energy-efficient communication networks via multiple aerial reconfigurable intelligent surfaces: DRL and optimization approach,” Jul. 2022, arXiv:2207.03149.
[9] H. Lu, Y. Zeng, S. Jin, and R. Zhang, “Aerial intelligent reflecting surface: Joint placement and passive beamforming design with 3D beam flattening,” IEEE Trans. Wireless Commun., vol. 20, no. 7, pp. 4128–4143, Jul. 2021.
[10] S. Alfantani, W. Jaafar, Y. Hmaiche, H. Yanikomeroglu, and A. Yongacoglu, “Link budget analysis for reconfigurable smart surfaces in aerial platforms,” IEEE Open J. Commun. Soc., vol. 2, pp. 1980–1995, 2020.
[11] S. Alfantani, A. Yadav, H. Yanikomeroglu, and A. Yongacoglu, “Beyond-cell communications via HAPS-RIS,” in Proc. IEEE Global Commun. Conf. Workshops (GLOBECOM Workshops), Rio De Janeiro, Brazil, Dec. 2022, pp. 1–6.
[12] “Technical specification group radio access network; Study on new radio (NR) to support non-terrestrial networks,” 3GPP, Sophia Antipolis, France, Rep. TR 38.811 V15.4.0, Sep. 2020.
[13] E. Björnson, H. Wyhersch, B. Matthiesen, P. Popovski, L. Sanguinetti, and E. de Carvalho, “Reconfigurable intelligent surfaces: A signal processing perspective with wireless applications,” IEEE Signal Process. Mag., vol. 39, no. 2, pp. 135–158, Mar. 2022.
[14] S. Boyd, S.-J. Kim, L. Vandenberghe, and A. Hassibi, “A tutorial on geometric programming,” Optim. Eng., vol. 8, no. 1, pp. 67–127, Apr. 2007.
[15] M. Rivera, M. Chemini, W. Jaafar, S. Alfantani, and H. Yanikomeroglu, “Optimization of quantized phase shifts for reconfigurable smart surfaces assisted communications,” in Proc. IEEE 19th Annu. Consum. Commun. Network. Conf. (CCNC), 2022, pp. 901–904.
[16] O. M. Rosabal, O. L. A. Lépiz, D. E. Pérez, M. Shehab, H. Hillesheim, and H. Alves, “Minimization of the worst case average energy consumption in UAV-aided IoT networks,” IEEE Internet Things J., vol. 9, no. 17, pp. 15827–15838, Sep. 2022.
[17] “Study on channel model for frequencies from 0.5 to 100 GHz,” 3GPP, Sophia Antipolis, France, Rep. TR 38.901 V17.0.0, Mar. 2022.
[18] Reference Standard Atmospheres, Rec. ITU-R P.835-6 P Series, ITU, Geneva, Switzerland, Dec. 2017.
[19] G. K. Kurt et al., “A vision and framework for the high altitude platform station (HAPS) networks of the future,” IEEE Commun. Surveys Tuts., vol. 23, no. 2, pp. 729–779, 2nd Quart., 2021.