I.J. Wireless and Microwave Technologies, **2023, 4, 28-34**
Published Online on August 8, 2023 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijwmt.2023.04.04

RIS-assisted Coverage Maximization Using Multi-UAVs in LTE Networks

Ademola Adesokan*
American University of Beirut/Department of Computer Science, Beirut, 1107-2020, Lebanon
E-mail: aaa277@mail.aub.edu
ORCID iD: https://orcid.org/0000-0003-3803-5906
*Corresponding Author

Assaad El Halabi
American University of Beirut/Department of Computer Science, Beirut, 1107-2020, Lebanon
E-mail: ahe34@mail.aub.edu

Faten Houjaij
American University of Beirut/Department of Computer Science, Beirut, 1107-2020, Lebanon
E-mail: fkh10@mail.aub.edu

Received: 26 October, 2022; Revised: 18 December, 2022; Accepted: 03 March, 2023; Published: 08 August, 2023

Abstract: In this paper, in order to improve the coverage and the Quality of Service of end-users on the edge of a cellular network, the use of unmanned aerial vehicles (UAVs) is employed to give them direct line of sight. In addition to that, to improve the performance of the said UAVs, reconfigurable intelligent surfaces (RIS) are introduced to the model, in such a way that will enhance the connection of the UAVs with the base station. An RIS will receive a signal from the base station, modulate it and then the RIS will act as the transmitter, sending the signal towards the UAV. By simulating our proposed approach using MATLAB, we have demonstrated that utilizing RIS-assisted communication maximizes coverage between the Base Station and the UAV, outperforming the simulation results of coverage as a function of height without the use of RIS. The significance of this work lies in its ability to enhance the signal quality and coverage at cell edges by leveraging UAVs as intermediate relays. These UAVs serve the purpose of connecting users with weak or no links, effectively bridging the gap. In our simulation results, we employed RIS to strengthen the backhaul link quality between the UAVs and base stations. While our work successfully addresses the challenges of connectivity and coverage, it is important to note that we have not specifically focused on the cost aspect of these factors.

Index Terms: UAV, RIS, Base Station, Relay, Coverage Probability, SINR

1. Introduction

Coverage maximization and Quality of Service (QoS) improvement have been important research topics in computer networks. One among many primary goals of communication is to have good connectivity and performance by acquiring guaranteed signal strength between the communicating parties. Though many researchers have produced work towards enabling the signal from uplink communication, other researchers have proposed many novelties on the downlink communication. This brought about the consideration to combine the uplink and downlink communication to achieve the required signal strength for the communication purpose. In order to achieve this communication goal, there are ways in which all the devices in these networks are set up and distributed, which is vital in achieving good coverage. Because of this, weak or no coverage may be caused by the way these devices communicate due to poor distribution and setup, which will lead to degradable QoS. Mobile Relay Nodes (MRNs) are applicable in a situation like this to help in improving QoS. They have been used extensively to offer coverage and enhance performance because of their mobility advantage and ability to communicate between the base station to the cell edge users. Apart from the setups and distribution of these devices, circumstances for disasters and accidents such as landslides, mountain collapses, and road accidents, among many others, are inevitable when used in MRNs. Unmanned Aerial Vehicles (UAVs) can serve as leverage to achieve this remarkable feat to mitigate the disaster and accidental menace in LTE networks because they are flying relay nodes that could move in substantial distances to cover more users and strengthen the communication between the base station and the ground users.

UAVs, often called drones, are rapidly being employed in various disciplines and environments. The use of UAVs in a variety of different applications is being carried out in research to achieve communication objectives while acceptance is at an increasing rate for usage. One of those is extending network coverage and it is widely used to enhance and supplement other user equipment and enable different services. Because of their capacity to fly higher and lower, they can readily penetrate difficult-to-access places, they can have a clear Line-of-Sight (LoS) and avoid obstacles that can block signals. As much as UAVs will be use to enhance the LoS between the base station and the ground users. There is a great need to strengthen the signal received by the UAV from the base station. Therefore, the RIS was employed to improve the signal strength at the uplink from the base station to the UAVs.

This study aims to tackle the challenges faced by MRNs in enhancing network density, coverage, and performance, specifically addressing the issues of unreachable regions at the cell edge and disconnection during unforeseeable incidents. Our approach utilizes RIS-assisted communication, which has shown superior coverage between the Base Station and the UAV compared to simulations without RIS.

1.1. Paper's Organization

After the brief introduction, the remainder of this paper has the following structure. Section 2 describes the problem using a short MRNs scenario where ground users encounter weak or no network signals. Section 3 includes a survey of the literature by other researchers who have done comparable work utilizing UAV and RIS to enhance QoS. Section 4 outlines the paper's objectives to increase coverage for users at the cell's edge and enhance signal strength while employing RIS and UAV for uplink and downlink communication, respectively. Section 5 contains the paper's research contributions. Section 6 included methodology and simulations of the BS-RIS-UAV using the SimRIS simulator to reflect the signals and BS-UAV-Users using MATLAB. Section 7 has concluding observations.

2. Problem Definition

There is no gainsaying that MRNs have gained a lot of research interest to improve network density, coverage, and performance. Mobile relays provide the advantages of lower cost and adaptability to shifting network connection demands, which is a phenomenal advantage over stationary relays, especially when utilizing public vehicle availability [1]. Nonetheless, it faces several limiting factors, of which, one of them is that some regions around the cell edge are out of reach for MRNs (no roads pass through or nearby), which users around the edge or outside the cell might experience bad or no link to the base station even when the cell is MRN-assisted as shown in figure 1. Furthermore, when there is occurrence of unforeseeable incidents like accidents that brings down the connection, there is a high tendency that disconnection is bound to take place while the devices that produced these signals will be down which leaves the users within its coverage with no network connection.

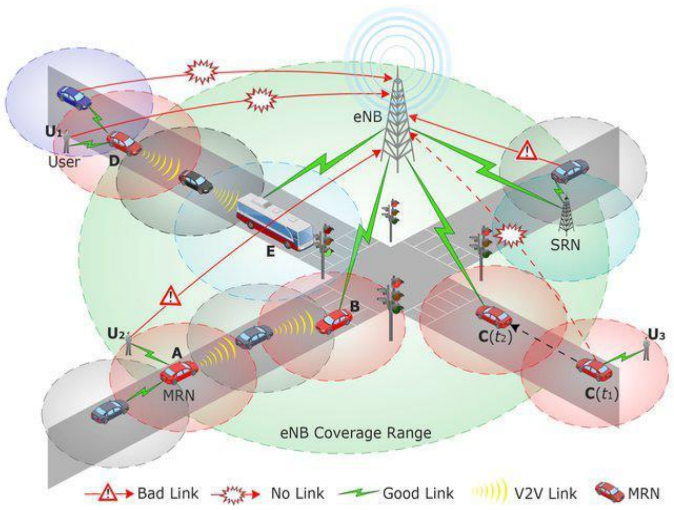

Fig. 1. Mobile-relay-assisted LTE-A sub-networking scenario [8].

3. Literature Review

The literature encloses a large body of work addressing the usage of UAVs and RIS usage, and feasibility of improving coverage and QoS. UAVs have been used in an efficient manner to serve as relays between base stations and ground users. Furthermore, in order to reduce obstacles such as signal blocking and shadowing and enhance communication links, there is a high probability of having a direct Line of Sight (LoS) from air-to-ground channels for the ground users and UAVs [2].

[3] presents two methods namely heuristic method and approximation algorithm for determining the UAV position to maximize the overall system throughput, and they also consider a related problem of keeping all users within the transmission range. To improve the signal strength when the distance between UAVs and base stations becomes large, employing reconfigurable intelligent surface solves this problem. RIS are 2d surfaces that are divided into tunable unit cells that have great capabilities in manipulating Electromagnetic waves. The idea behind this is that RIS can control the propagation of EM waves by changing the electric and magnetic properties of the cells in such a way as to customize the propagation of the waves without having to increase the power needed at either the transmitter or the receiver ends. By manipulating the reflection coefficient of unit cells in the RIS, it is possible to control the reflection of incoming signals and how they're reflected onto the receiver. RISs are a prospective improvement capable of improving and expanding the number of ground users, consequently raising the rate of communication [4-7].

Another intriguing network usage of RIS is for UAV, the RIS helps to improve the downlink communication of ground users and UAV by improving the QoS, hence aiding UAV trajectory and system performance optimization [6]. According to [8], the authors explained why servicing users in Long Term Evolution (LTE) cellular networks located at cell edges is a challenging task. The authors also elaborate how such users can experience a deterioration in signal quality (e.g., low power) and, consequently, a significantly reduced data throughput where no good link can be established even when MRNs were used because of limitations experienced by MRNs (limited MRN coverage, predetermined MRN paths which leads to poor QoS around edges). However, there has been an improvement to enable ground users to have more coverage using UAVs. Authors in [10] discussed the measurements of UAVs as flying relays, the quality of the backhaul link, quantified using signal strength and interference levels at the aerial flying node as performance factors. They also indicate the optimal heights for the best QoS and to achieve high capacity backhaul links. [11] proposed a multi-UAV coverage deployment model based on energy-efficient communication in UAV networks. In addition to this, there have been suggestions for the deployment of RIS on the wall of buildings in cellular base stations, which are primarily directed coherently to the reflected radio waves towards some UAVs in order to reduce the interference effects and boost their received signal strengths [12]. Authors in [13] also highlighted the several benefits of RIS for different applications. The authors of [14] used RIS to solve the complete restriction of users that are not able to have direct contact and communication with base station by making a possible connection to have clear sight. RISs have been investigated to work for power transfer systems. The phase shift matrix of the RIS is used to improve signal strength received in the charging zone in terms of energy received for the receiver; consequently, it helps to meet the criteria of energy harvesting [15].

4. Objectives

The main aim of this research paper is to enhance the coverage and QoS for end-users located at the cell edge of cellular networks. To achieve this, we propose the utilization of UAVs as relay nodes for users who have either poor or no direct link with the base stations, as illustrated in Figure 2. By employing UAVs as relays, we can bridge the connectivity gap and ensure seamless communication for these users. Furthermore, we intend to leverage the use of RIS technology to enhance the backhaul link between the UAVs and base stations. This integration of RIS aims to optimize signal strength and improve overall network performance.

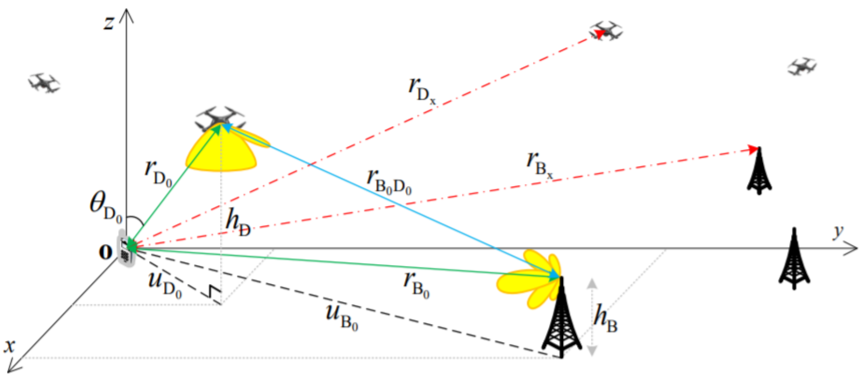

Fig. 2. BS-UAV-User.

5. Research Contributions

This paper proposes the use of RIS-assisted UAV relays to increase coverage and connectivity, and therefore assist in improving Quality of Service (QoS) to end users at the cellular network cell edge via:

- Improving cell edge's signal quality and coverage.
- UAVs serving as intermediate relays bridging disconnected users with bad or no links [9].
- RIS utilization to strengthen backhaul link quality between UAVs and base stations as shown in Figure 3

6. Methodology and Simulation Results

6.1. RIS Simulation

We used SimRIS, which is an open-source simulator to simulate RIS-communication [16] between the UAV and BS. The simulator takes the cartesian coordinates for the transmitter, receiver, and RIS, and generates matrices that

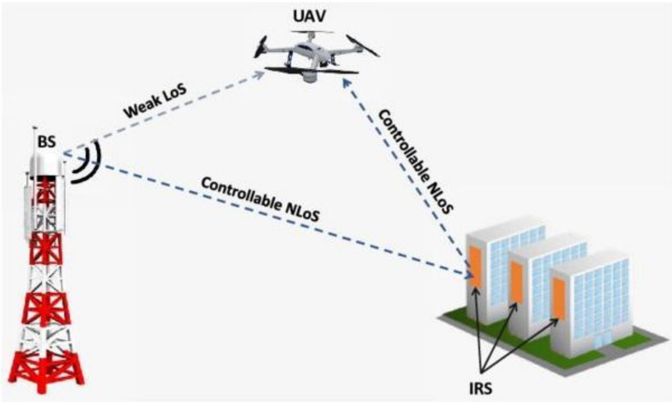

Fig. 3. BS-RIS-UAV.

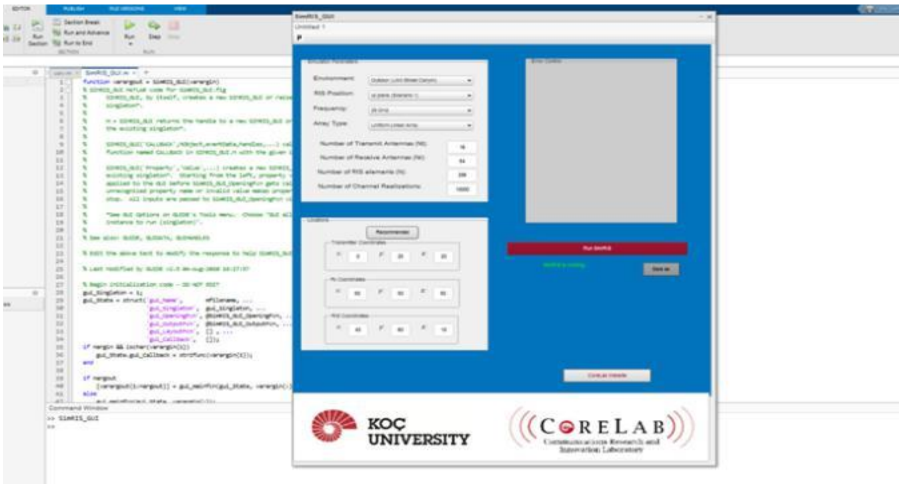

Fig. 4. RIS Simulation using SimRIS [16]

represent the channel coefficients between Transmitter-RIS, RIS-Receiver, and Transmitter-Receiver. In addition to that, the simulator allows us to manipulate other variable parameters, such as the size of the RIS (number of components), and the number of antennas at either end for the MIMO system. For our purposes, the transmitter will be our base station, and the receiver will be the UAV which will later act as a mobile relay. The main purpose is to study the achievable rate possible from such a RIS-assisted system in comparison to one without RIS. From the generated component matrices (G, H, D), with ϕ being RIS-dependent, the channel matrix can be calculated:

$$C = G\phi H + D \quad (1)$$

and from that, we can calculate the achievable rate of the system. We know that RIS and the transmitter are fixed components, which helps remove some layers of complexity from the work. Using the SimRIS Simulator, the wireless channels of the RIS-assisted system can be generated for different frequencies, number of RIS components, number of transmitting/receive antennas, and transmitter/receiver locations. This paves the way for us to generate another simulation for the second part of the system, which will use the incoming signal from the RIS and, using the UAV as a relay, transmit the signal to our main targets, users that are on the edge of the cell of the base station.

6.2. RIS-assisted UAV Simulations

The base station starts by sending a signal to the UAV through an RIS-assisted G2A (ground-to-air) link. After phase modulation by the RIS a modulated signal is obtained, the RIS modulates the information bits and the reflection phase. Which maximizes the SNR of the received signal at the UAV. After the UAV receives the transmitted, modulated signal from the RIS, it then sends it to the user, and vice-versa back. This shows the RIS-UAV-User simulation. The power of the signal received is calculated as follows

$$P_U = \sqrt{\frac{P_R}{L_{TU}} (\sum_{i=0}^{N} \beta_i)} e^{wm} + n \quad (2)$$

where PR is the power at the RIS, LT U is the path loss which is a function of the the distance between the RIS and the UAV and the height of the UAV, βi is a random variable that follows the Nakagami distribution, wm is a binary modulation phase defined by the RIS, and n is an additive white Gaussian noise, a uniform, normally distributed noise that is added to whatever noise is intrinsic to the system [17].

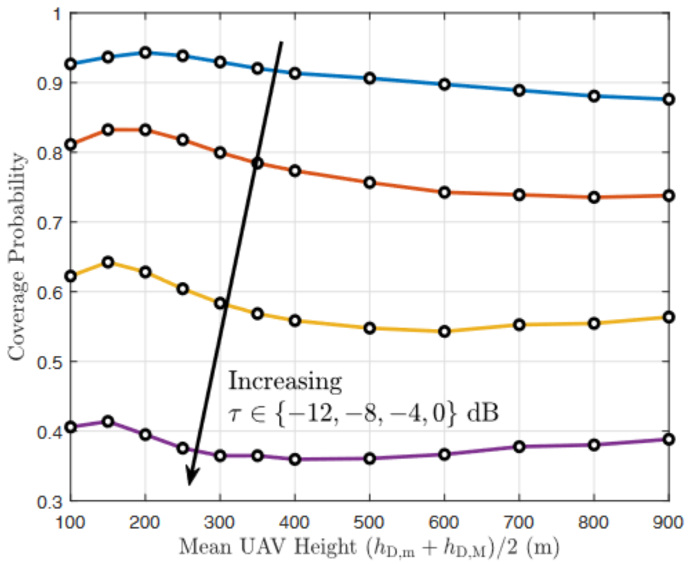

Fig. 5. Coverage probability as a function of UAV height without RIS [18]

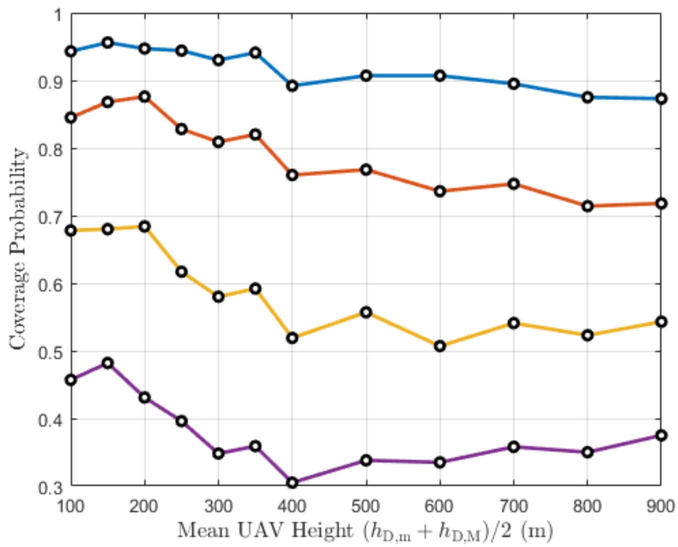

Fig. 6. Coverage probability as a function of UAV height with RIS

We then study the performance of this system by calculating the coverage probability, the probability that a user will receive a readable signal, with a signal-to-noise ratio above a certain threshold. To do that, we have used MATLAB for the simulation as used by the authors of [18] to simulate the BS and UAV without the RIS, but in our system, we included the RIS to improve the received signal at the UAV level.

Figure 5 represents the simulation results of coverage probability as a function of the height of the UAV as generated by [18] from a UAV system without the assistance of RIS, while figure 6 shows our generated results for the same parameters, but taking into consideration the impact of RIS to reflect the signal from BS to UAV.

The main parameter used to be able to generate these results was the horizontal distance between the RIS and the UAV. The ones that we took into consideration were large distances, meaning the UAV was closer to the user than it was to the RIS. And as we can see from figure 6 that the RIS-assisted system shows an improvement to the coverage probability, which indicates that the proposed system outperform the system in figure 5, for cases where the UAV is close to the user.

7. Conclusion

Our proposed work contributes to the field by addressing the challenges in network density, coverage, and performance posed by MRNs, particularly focusing on issues such as unreachable regions at the cell edge and disconnection during unforeseeable incidents. By incorporating RIS-assisted communication, the study demonstrates enhanced coverage between the Base Station and UAV, surpassing simulations without RIS (which is prone to network disconnection or low signals) and providing a promising solution to strengthen signal strength in uplink communication.

Our RIS-assisted UAV communication system incorporates a Nakagami distribution to model the RIS-assisted G2A link. Through a comprehensive analysis of coverage probability and SINR, we have observed that RISs have a substantial impact on increasing the coverage probability and improving SINR. This enhancement in QoS is particularly beneficial for users located near the cell edge. Notably, the optimal system performance is achieved when the UAV is positioned in close proximity to the intended destination.

References

[1] Sarieddine, K., Charaf, M., Ayad, M. and Artail, H., 2020. A framework for mobile relay node selection for serving outdoor cell edge users. *Computer Networks,* 178(1389-1286), p.107359.

[2] J. A. Merwaday and I. Guvenc, ”UAV assisted heterogeneous networks for public safety communications”, *Proc. IEEE Wireless Commun. Netw. Conf. Workshops (WCNCW),* pp. 329-334, 2015.

[3] Rahman, S.u., Cho, YZ. UAV positioning for throughput maximization. *J Wireless Com Network 2018,* 31 (2018). https://doi.org/10.1186/s13638-018-1038-0

[4] Liaskos, C.; Nie, S.; Tsioliaridou, A.; Pitsillides, A.; Ioannidis, S.; Akyildiz, I. A New Wireless Communication Paradigm through Software-Controlled Metasurfaces. *IEEE Commun. Mag*. 2018, 56, 162–169.

[5] Basar, E.; Di Renzo, M.; De Rosny, J.; Debbah, M.; Alouini, M.S.; Zhang, R. Wireless Communications Through Reconfigurable Intelligent Surfaces. *IEEE Access* 2019, 7, 116753–116773.

[6] Guo, X.; Chen, Y.; Wang, Y. Learning-based Robust and Secure Transmission for Reconfigurable Intelligent Surface Aided Millimeter Wave UAV Communications. *IEEE Wirel. Commun. Lett*. 2021, 10, 1795–1799.

[7] Wu, Q.; Zhang, R. Towards Smart and Reconfigurable Environment: Intelligent Reflecting Surface Aided Wireless Network. *IEEE Commun. Mag*. 2020, 58, 106–112.

[8] M. Khabbaz, and H. Artail, “Deadline-constrained connection request scheduling in mobile relay-assisted LTE networks” *IEEE Trans. Veh. Technol.,* 68 :7, 2019

[9] M. Khabbaz, et. al., “Modeling and performance analysis of UAV-assisted vehicular networks*” IEEE Trans. Veh. Technol.,* 68 :9, 2019.

[10] M. C. Batistatos, G. V. Tsoulos, D. A. Zarbouti, G. E. Athanasiadou and S. K. Goudos, ”LTE measurements for flying relays”, *Proc. 7th Int. Conf. Modern Circuits Syst. Technol. (MOCAST),* pp. 1-4, May 2018.

[11] L. Ruan et al., ”Energy-efficient multi-UAV coverage deployment in UAV networks: A game-theoretic framework,” in *China Communications,* vol. 15, no. 10, pp. 194-209, Oct. 2018, doi: 10.1109/CC.2018.8485481

[12] Z. Wei, Y. Cai, Z. Sun, D. W. Kwan Ng and J. Yuan, ”Sum-Rate Maximization for IRS-Assisted UAV OFDMA Communication Systems,” *GLOBECOM 2020 - 2020 IEEE Global Communications Conference, 2020,* pp. 1-7, doi: 10.1109/GLOBECOM42002.2020.9322325. ´

[13] D. Perez ´-Adan, ´O. Fresnedo, J. P. Gonzalez ´-Coma, and L. Castedo, “Intelligent Reflective Surfaces for Wireless Networks: An Overview of Applications, Approached Issues, and Open Problems” *Electronics,* vol. 10, no. 19, p. 2345, Sep. 2021.

[14] Guo, H.; Liang, Y.C.; Chen, J.; Larsson, E.G. Weighted Sum-Rate Maximization for Reconfigurable Intelligent Surface Aided Wireless Networks. IEEE Trans. *Wirel. Commun.* 2020, 19, 3064–3076.

[15] Yan, W.; Yuan, X.; He, Z.Q.; Kuai, X. Passive Beamforming and Information Transfer Design for Reconfigurable Intelligent Surfaces Aided Multiuser MIMO Systems. *IEEE J. Sel. Areas Commun.* 2020, 38, 1793–1808

[16] E. Basar and I. Yildirim, “Reconfigurable Intelligent Surfaces for Future Wireless Networks: A Channel Modeling Perspective”, in *IEEE Wireless Communications,* vol. 28, no. 3, pp. 108-114, June 2021

[17] Liang Yang, Fanxu Meng, Jiayi Zhang, Mazen Hasna, Marco Di Renzo. On the Performance of RIS-Assisted Dual-Hop UAV Communication Systems. *IEEE Transactions on Vehicular Technology, Institute of Electrical and Electronics Engineers*, 2020, 10.1109/TVT.2020.3004598. hal-03020385

[18] Banagar, Morteza and Dhillon, Harpreet, 3D Two-Hop Cellular Networks with Wireless Backhauled UAVs: Modeling and Fundamentals, 5, 2021, *arXiv:2105.07055*

Authors' Profiles

Ademola Adesokan is a second-year master's student in Computer Science Department at the American University of Beirut. He received a bachelor's degree in computer science from Federal University Dutsin-ma. His current research interest is in using machine learning models and information retrieval to solve health related issues, claim verification and disaster management problems. He is interested in travels, sports, and social development.

Assaad El Halabi holds a bachelor's degree from the American University of Beirut and is currently pursuing his master's degree at the same institution. Additionally, he works as a Software Engineer at Oreyeon and is a recipient of the MEPI scholarship.

Faten Houjaij holds both a bachelor's and master's degree from the American University of Beirut. In addition to her academic achievements, she has worked as a teaching assistant and co-founded Moubarmijah.

How to cite this paper: Ademola Adesokan, Assaad El Halabi, Faten Houjaij, "RIS-assisted Coverage Maximization Using Multi-UAVs in LTE Networks", International Journal of Wireless and Microwave Technologies(IJWMT), Vol.13, No.4, pp. 28-34, 2023. DOI:10.5815/ijwmt.2023.04.04