Role and challenges of the use of UAV-aided WSN monitoring system in large-scale sectors

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***Abstract*— With the latest technological developments in UAVs and the ever-increasing evolution of commercialization, new UAV technologies have emerged for wireless sensor networks for data collection. The integration of UAVs in smart ground WSNs proved an effective and stable solution in many advanced applications for information collection, control, analysis, and decision-making. In this area, a wireless network of unnamed aerial-vehicle - wireless sensor network still faces many open technical challenges, despite the success of numerous applications and studies. These include pre-defined UAV paths, medium access control (MAC), UAV performance, and unexpected feature. The objectives of this research are to review and investigate the WSN system with UAV assistance focusing on the wide range of monitoring applications and the open problems for the operation of the system.**

Keywords*— *UAV, WSN, UAV routing, Access control, flight path, communication.

I. Introduction

The preferences to use collaborative UAV-WSN systems to monitor, investigate and monitor large areas of interest are becoming increasingly strong. This type of system will combine ground (WSN), air (UAV), and internet information. For monitoring application in the large-scale areas [1] to improve, accessibility, mobility, and response time in the case of an emergency. Thus the benefits of these collaborative systems have been emphasized.

Several studies, such as [2, 3] for WSN and [4] for UAV, are also available that analyze characteristics, applications, and challenges.

Comparison between WSN transmitting schedules and UAV flight patterns is also pertinent in the terms of collaborative aspects of the large-scale monitoring systems [5, 6].

Alongside this especially in a developing, there are a huge number of important and recent approaches, mostly in the form of research papers on WSN or UAV implementation and research projects and commercial products.

Sensor networks in both indoor and outdoor environments and in different types of use in the fields which have long been used for data collection [7]. Gradually the sensor networks were promoted with the elements of data processing for the requirements of on-board information, provided major technical developments [8-10]. The processing capacities and data transmission have been studied in many papers in the last few years and have mainly related to accessibility and production cost, reliability and scalability, networking protocols, and some physical limitations such as autonomy, communication range, and energy consumption.

On the other hand, unmanned aircraft were rapidly developing, allowing fast access to the large areas otherwise inaccessible with a basic focus on military applications and disaster management [11]. This type of system was known as drones, UAVs, aerial robots, and aerial platforms under various names in the literature.

Although there is no shortage of individual use for either WSN or UAV architectures, researchers have shown interest in the convergence of this technology in recent years. During the monitoring period, collaborative, hybrid, UAV-WSN systems were built [12, 13] based on existing developing monitoring and data collection criteria in broad geographical spaces [12-14].

However, an artificial intelligence aspect for collecting and transmitting data and processing as well as mission control is required for effective operation in a wide range of collaborative systems in the UAV–WSN [15]. Although there is a commercial availability of UAVs with different propulsion systems, only those with generally small electric propulsion, with reduced maintenance and operating costs will be included in this paper.

This article will describe and highlight the WSN mechanism that is supported by UAV to conduct relevant monitoring and evaluation system in some large areas such as agriculture and disaster management with a focus on the open issues for the operation of the system.

The remaining paper has the following structure. Section 2 explains Aircraft tracking system implementations in wide fields as well as main issues raised in both agriculture and disaster management. Section 3 addresses the UAV-WSN monitoring system's open technical challenges. The discussion and findings are highlighted in Section 4.

II. Applications of UAV-WSN monitoring system in large areas

In recent years, environmental data collection and monitoring in large areas has grown quickly [16]. Increased monitoring coverage and increased overall processing of data were powered by the introduction of wireless sensor networks (WSN) in unmanned area vehicles (UAVs) [17-19]. Two large industries will be discussed in this portion.

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A. *Monitoring in the modern Agriculture sector*

The expanding worldwide food needs include developing a high-performing, high-productivity, and sustainable agriculture system that involves collaboration in agricultural crop management between unmanned aerial vehicles (Unmanned Air Vehicles (UAV)) and Federated Wireless Sensor Networks (WSNs).

The studies in [20-23] describe applications relevant to UAVs-WSN systems in agriculture. The solar and air parameters modify the product yield and quality in a special type of precision agriculture. For this purpose, the solution for monitoring parameters such as temperature and humidity, and frost based on a collaborative system mini UAV (quadrotor type)–WSN is proposed in [20].

The UAV is used as a relay for communicating between sensors and a base station. In [21] provides a real application for monitoring sensitive parameters, both in agro-meteorological and UAV platforms. The ground data are connected to the data from the UAV platform with 8 rotors provided with a professional thermal camera, to achieve accurate monitoring of the specific indicators.

The research was conducted over two years. In [22] proposed a fixed-wing UAV type for data collection on large areas, as a data mule from the WSN ground.

Moreover, a high-definition (HD) camera has been attached to the UAV to detect selected diseases. Experimentally, several insecticides, fertilizers, herbicides, etc. were applied to a small tank. The UAV and WSN are both very cost-effective and not robust to demonstrate only. Furthermore, Reference [23] designed and developed a low-cost agro-meteorological monitoring system in a vineyard. Using multi-spectral image analysis, UAV acquired the best positioning of the sensors.

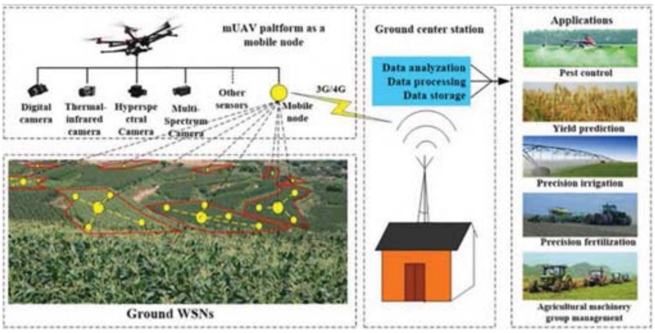

Fig. 1. UAV-WSN monitoring system in Agriculture sector

B. *Disaster Monitoring and management*

Unforeseeable events that cannot be avoided are natural disasters. However, some recovery procedures can be required to minimize their effects. Monitoring the effects of disasters, post-disaster is important to estimate, which in turn is used as the basis for determining recovery procedures [24]. Unmanned aerial vehicles (UAVs) are also a smart solution and can be used wherever possible for the deployment of the wireless sensor networks (WSNs), to monitor post-disaster.

Recently, the work of Liu et al. [25] at least in respect of the underlying networking environment it is one of the most related with the one presented above. Assist in covering the area provided by the UAV to reduce the number of hops, whereas assigning the WSN nodes the same role as the new study in their work. Their focus is on the scenario of post-disaster where the established infrastructure of communications is supposed to have collapsed.

However, UAVs cannot always supervise the disaster area because of their short flight time. Also, an optimum number of UAVs must be specified according to the environment and the nature of the mission is required to bring out the disaster management task and communication strategy between UAVs. As a result, more in-depth studies would be required to address distinguishing problems with reliable networking models for communication, self-learning mechanisms for monitoring, and the initial optimum placement of UAVs.

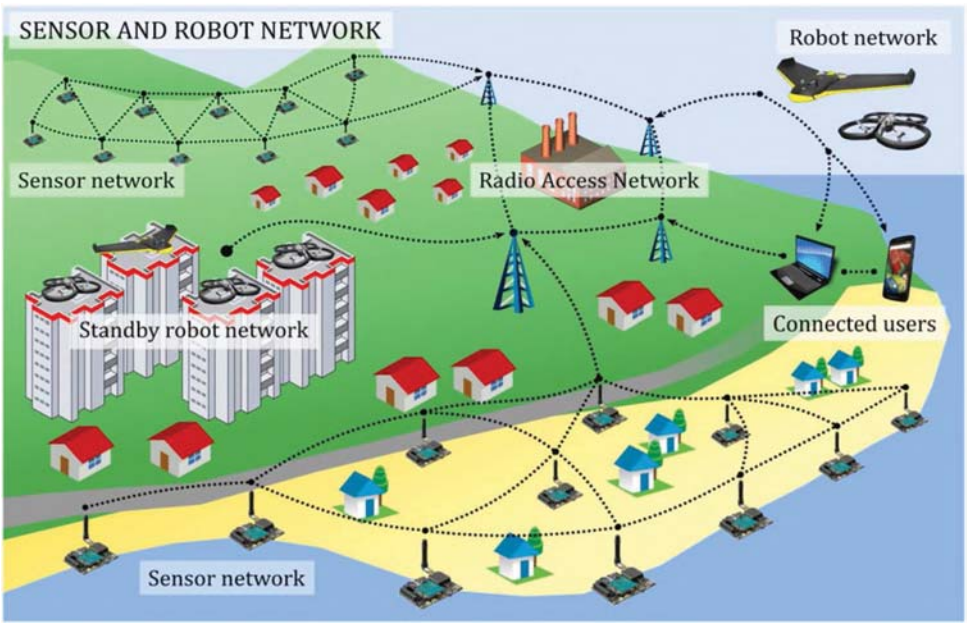

Fig. 2. UAV-WSN monitoring system in disaster management

III. Open Challenges of UAV–WSN Monitoring System

A. Communication and UAV routing

The difficult problem with UAV-based WSN systems is the detection of the appropriate routes since the UAV is distinguished by the battery constraints that limit their viability and efficiency in real-world applications (due to current manufacturing procedures). Features such as their size, shape, flight time, and the number of turns are usually related to energy consumption [26, 27], which often tackles difficult problems. Indeed, others have not been completely explored in the considered WSN environment, like the geometry of predefined UAV routes. One of the motivations for this work is the geometry shapes of the route that match the route of the UAV. Due to the geometry of the different route types, various metrics are investigated such as numbers of messages being exchanged, the average flight times of the drones, etc. A WSN along with the UAV as an information collector.

Various works deal with communication and routing issues between drones [26-30]. These works deal mainly with drones [31], where real site monitoring with a UAV network is represented using several UAVs at the same time. The underlying scenario in the work described in this study includes the ground to UAV communication [32, 33], rather than inter-UAV.

B. Medium access control (MAC)

Using UAVs with the WSNs, sensor data can be collected easily, with a reduced energy consumption prolonging the network's lifetime. Medium access control (MAC), as it focuses not only on system performance but also on battery-powered sensor nodes [34], is very important in UAV-aided WSNs (UWSNs). In most applications, it should be noted that the small sensor nodes are considered to be typically disposable, and their batteries cannot be replaced. Thus, a wide range of MAC protocols have been designed for UWSNs with different targets. Because of the fast mobility of the UAVs, the dynamic change of the network topology, and the operational and energy limitations of UWSNs, it is a big challenging task to establish an effective MAC protocol addressing these problems. Several MAC protocols are reported in UWSNs addressing advantages and problems with the use of UAVs in-ground sensor node data collection [35]. In [36] the nano MAC protocol indicated that the probability of disputes was halved when a collision occurred in [37], dynamic control system combinations were used to minimize overhead and increase energy savings. In [38] Z-MAC was developed using an energy-saving combination of CSMA and TDMA, which allows for improved utilization of spectrum and throughput. An improvement in overhead costs for Z-MAC was achieved in [39] by utilizing synchronization beacons and specifying an overhead reduction superframe structure. ER-MAC, a hybrid for wireless sensors of the TDMA and CSMA protocol is developed in [40]. Contentions faced by priority packet nodes in the Z-MAC were eliminated by two priority queues in ER-MAC. With the higher delivery, reduced latency, and lower energy consumption, ER-MAC outperforms z-MAC. Queue-MAC [41] addressed dynamic super-frames with TDMA variable slot.

C. Performance and architecture design of UAV

Many studies are based on WSN only, irrespective of UAV performance. Moreover, the position, terrain, and quality of the wireless communications in UAV-WSNs should not be considered in these approaches for the monitoring systems.

Implementation has been proposed for the central and distributed clustering of k-means algorithms in the network [42, 43]. It is a good way to cluster WSN, but the article just takes into consideration the distance.

Two approaches have proposed specific implementations to achieve a high-quality system overall and suggested a new UAV-WSN architecture [44, 45]. They focused on specific types of WSNs and do not take into consideration land networks and UAV systems.

The techniques in [46, 47] have still culminated in the energy savings of the whole system and various methods have still been taken to optimize UAV-WSN protocols for routing and MAC transport. In various studies, path planning and flight control were discovered from the view of UAV.

These studies have motivated UAV-WSN research and application [48, 49]. However, the methods we mentioned consider either the condition or the problem from a single perspective (WSN or UAV) and do not regard the land and air robotics as a whole system. This limits its use for many large-scale remote monitoring applications considerably.

In summary, most of these approaches cannot achieve all UAV-WSN Environmental Monitoring design objectives.

Finally, the UAV effort required the flight path recalculations due to changes in the topology of the network caused by cluster head changes. Most research in this area is focused on ideal assumptions that are not realistic and that more work needs to be done before data is collected in advance.

However, additional features will create unexpected problems which cannot be tackled by traditional methods designed for low-rate UAV–WSN systems, including inefficient data collection, high UAV–WSN energy consumption, environmental disruptions. Therefore, robust schemes must be developed to provide efficient user services while retaining a certain level of networking performance.

IV. Discussion

Compliance with robust environmental structures is important for large-scale implementations in which the UAVs beyond recognition. There is no robust sensor placement principle since it relies on the specific requirements of each environment. Moreover, the sensor groups must typically satisfy the need for sensory and communication coverage.

We believe that UAV-WSN systems will face open technological challenges in many ways. A description of these directions is mentioned in table 1.

TABLE I. Summary of Technical Open Challenges of UAV-WSN System

Technical challenges	Description of problem(s)	Suggested solution
UAV Communication	- Accurate location by preliminary flight of the ground sensors. - UAV inspected sensor states periodically. - Transfer commands to change the network sensor strategy and parameters.	Although several research works are relevant, more efforts are needed to study deeply the topologies of the aerial network and the integration in the communication networks.
UAV path and route Design	- Monitoring and special trajectory planning. - Data acquisition from WSNs through UAVs. - Internet Remote Control.	Develop an approach to routing, reduce packet losses, delivery delays, and UAV energy consumption.
Medium access control (MAC)	- establishment of WSNs as sensor clusters that can cover the monitored area both sensorially and communicationally. - The cluster heads of the WSNs are to be placed, named base stations, which will communicate data to UAVs.	- Develop security frameworks that take into consideration all the challenges mentioned above in this manuscript. - Ensure stable UAV connectivity to the central controller, so important information can be exchanged reliably.
Performance and architecture design of UAV	- Computing for edge and cloud. - Precision of UAV information with WSN information collected for measurement and parameter interpretation.	Development of new UAV technology mechanisms that address the distinguished challenges.
Unexpected issues	- The aggregation of inadequate data. - The disruptions in the environment.	- Development of new methods to reduce the effects of environmental disturbances and eliminate them.

Although the contributions of the separate UAVs and WSNs are well documented and important in the large monitoring phase, the integration of these components through an IoT system is also expected to significantly improve the monitoring, modeling, predicting, and decision-making solutions. However, some problems exist, and some have grown insignificant. The main ones are listed below:

Many technological problems such as bandwidth allocation, limited processing capabilities, intermittent UAV network connectivity, and energy consumption of UAVs and ground nodes can be described. To design a robust monitoring system, so many challenges require a detailed analysis.

Many challenges remain open such as optimal clustering of ground sensors, communication performance, energy-saving, and trajectory planning to achieve optimal ground sensor data collection.

In general, we consider the area of motion planning to have several avenues of evolution in the context of UAV–WSN applications and will grow significantly over the years to come.

V. Conclusion

The paper described an evaluation analysis for UAV–WSN collaborative monitoring system operation for large-scale areas. The survey explains how good it is to use the UAV-WSN system for large-scale monitoring and the open technical challenges, both to the Agriculture sector and the disaster management. Furthermore, during our study of these types of applications, several lessons are learned and can be described as follows:

- The most common method of monitoring in large areas is remote sensing using the UAV-WSN system.
- Since these types of applications are possible in the outdoor environment, it is necessary to take more consideration of the surrounding environments, such as bad weather, hazards, and complicated areas.
- Many technical challenges such as the allocated bandwidth, limited construction methods, intermittent UAV communication, and the energy consumption of UAVs and ground nodes can be established. To design a comprehensive monitoring scheme, all these need to be discussed in detail.

References

[1] A. C. Djedouboum, A. A. Abba Ari, A. M. Gueroui, A. Mohamadou, and Z. Aliouat, "Big data collection in large-scale wireless sensor networks," *Sensors,* vol. 18, p. 4474, 2018.

[2] P. Rawat, K. D. Singh, H. Chaouchi, and J. M. Bonnin, "Wireless sensor networks: a survey on recent developments and potential synergies," *The Journal of supercomputing,* vol. 68, pp. 1-48, 2014.

[3] H. Huang, A. V. Savkin, M. Ding, and C. Huang, "Mobile robots in wireless sensor networks: A survey on tasks," *Computer Networks,* vol. 148, pp. 1-19, 2019.

[4] H. Shakhatreh, A. H. Sawalmeh, A. Al-Fuqaha, Z. Dou, E. Almaita, I. Khalil, *et al.*, "Unmanned aerial vehicles (UAVs): A survey on civil applications and key research challenges," *Ieee Access,* vol. 7, pp. 48572-48634, 2019.

[5] S. Liu, Z. Wei, Z. Guo, X. Yuan, and Z. Feng, "Performance analysis of UAVs assisted data collection in wireless sensor network," in *2018 IEEE 87th Vehicular Technology Conference (VTC Spring)*, 2018, pp. 1-5.

[6] M. M. Hamdi, L. Audah, S. A. Rashid, and M. A. Al-Mashhadani, "Coarse WDM in Metropolitan Networks: Challenges, Standards, Applications, and Future Role," in *Journal of Physics: Conference Series*, 2020, p. 012062.

[7] B. Olivieri and M. Endler, "An algorithm for aerial data collection from wireless sensors networks by groups of UAVs," in *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2017, pp. 967-972.

[8] A. Dahane and N.-E. Berrached, *Mobile, wireless and sensor networks: a clustering algorithm for energy efficiency and safety*: CRC Press, 2019.

[9] M. M. Hamdi and J. M. Mohammed, "BER Vs Eb/N0 BPSK Modulation over Different Types of Channel," *Australian Journal of Basic and Applied Sciences,* vol. 12, 2018.

[10] S. F. Ahmed, Y. Raza, H. F. Mahdi, W. W. Muhamad, M. K. Joyo, A. Shah, *et al.*, "Review on sliding mode controller and its modified types for rehabilitation robots," in *2019 IEEE 6th International Conference on Engineering Technologies and Applied Sciences (ICETAS)*, 2019, pp. 1-8.

[11] K. P. Valavanis and J. George, "UAV Sense, Detect and Avoid: Introduction," *Handbook of Unmanned Aerial Vehicles, Springer Netherlands,* pp. 1813-1816, 2014.

[12] J. G. A. Barbedo, "A review on the use of unmanned aerial vehicles and imaging sensors for monitoring and assessing plant stresses," *Drones,* vol. 3, p. 40, 2019.

[13] M. Garraffa, M. Bekhti, L. Létocart, N. Achir, and K. Boussetta, "Drones path planning for WSN data gathering: A column generation heuristic approach," in *2018 IEEE Wireless Communications and Networking Conference (WCNC)*, 2018, pp. 1-6.

[14] M. S. Abood, I. K. Thajeel, E. M. Alsaedi, M. M. Hamdi, A. S. Mustafa, and S. A. Rashid, "Fuzzy Logic Controller to control the position of a mobile robot that follows a track on the floor," in *2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 2020, pp. 1-7.

[15] J. Grigulo and L. B. Becker, "Experimenting sensor nodes localization in wsn with uav acting as mobile agent," in *2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA)*, 2018, pp. 808-815.

[16] C. A. Trasviña-Moreno, R. Blasco, Á. Marco, R. Casas, and A. Trasviña-Castro, "Unmanned aerial vehicle based wireless sensor network for marine-coastal environment monitoring," *Sensors,* vol. 17, p. 460, 2017.

[17] P. Mathur, R. H. Nielsen, N. R. Prasad, and R. Prasad, "Data collection using miniature aerial vehicles in wireless sensor networks," *IET Wireless Sensor Systems,* vol. 6, pp. 17-25, 2016.

[18] M. M. Hamdi, L. Audah, S. A. Rashid, and M. A. Al-shareeda, "Techniques of Early Incident Detection and Traffic Monitoring Centre in VANETs: A Review," *Journal of Communications,* vol. 15, 2020.

[19] M. S. Abood, H. Wang, H. F. Mahdi, M. M. Hamdi, and A. S. Abdullah, "Review on secure data aggregation in Wireless Sensor Networks," in *IOP Conference Series: Materials Science and Engineering*, 2021, p. 012053.

[20] J. Valente, D. Sanz, A. Barrientos, J. d. Cerro, Á. Ribeiro, and C. Rossi, "An air-ground wireless sensor network for crop monitoring," *Sensors,* vol. 11, pp. 6088-6108, 2011.

[21] S. F. Di Gennaro, A. Matese, B. Gioli, P. Toscano, A. Zaldei, A. Palliotti, *et al.*, "Multisensor approach to assess vineyard thermal dynamics combining high-resolution unmanned aerial vehicle (UAV) remote sensing and wireless sensor network (WSN) proximal sensing," *Scientia Horticulturae,* vol. 221, pp. 83-87, 2017.

[22] J. Polo, G. Hornero, C. Duijneveld, A. García, and O. Casas, "Design of a low-cost Wireless Sensor Network with UAV mobile node for agricultural applications," *Computers and electronics in agriculture,* vol. 119, pp. 19-32, 2015.

[23] J. Honrado, D. B. Solpico, C. Favila, E. Tongson, G. L. Tangonan, and N. J. Libatique, "UAV imaging with low-cost multispectral imaging system for precision agriculture applications," in *2017 IEEE Global Humanitarian Technology Conference (GHTC)*, 2017, pp. 1-7.

[24] M. Erdelj, M. Król, and E. Natalizio, "Wireless sensor networks and multi-UAV systems for natural disaster management," *Computer Networks,* vol. 124, pp. 72-86, 2017.

[25] X. Liu, Z. Li, N. Zhao, W. Meng, G. Gui, Y. Chen, *et al.*, "Transceiver design and multihop D2D for UAV IoT coverage in disasters," *IEEE Internet of Things Journal,* vol. 6, pp. 1803-1815, 2018.

[26] Y. Zeng, R. Zhang, and T. J. Lim, "Wireless communications with unmanned aerial vehicles: Opportunities and challenges," *IEEE Communications Magazine,* vol. 54, pp. 36-42, 2016.

[27] M. Al-Mashhadani, "Flight path control for unmanned aerial vehicle," *Системный анализ и прикладная информатика,* 2014.

[28] A. Agárdi, L. Kovács, and T. Bányai, "Vehicle routing in drone-based package delivery services," in *Solutions for Sustainable Development: Proceedings of the 1st International Conference on Engineering Solutions for Sustainable Development (ICESSD 2019), October 3-4, 2019, Miskolc, Hungary*, 2019, p. 151.

[29] M. Kim and E. T. Matson, "A cost-optimization model in multi-agent system routing for drone delivery," in *International Conference on Practical Applications of Agents and Multi-Agent Systems*, 2017, pp. 40-51.

[30] X. Wang, S. Poikonen, and B. Golden, "The vehicle routing problem with drones: several worst-case results," *Optimization Letters,* vol. 11, pp. 679-697, 2017.

[31] E. Yanmaz, S. Yahyanejad, B. Rinner, H. Hellwagner, and C. Bettstetter, "Drone networks: Communications, coordination, and sensing," *Ad Hoc Networks,* vol. 68, pp. 1-15, 2018.

[32] D. Yang, Q. Wu, Y. Zeng, and R. Zhang, "Energy tradeoff in ground-to-UAV communication via trajectory design," *IEEE Transactions on Vehicular Technology,* vol. 67, pp. 6721-6726, 2018.

[33] C. Wang, F. Ma, J. Yan, D. De, and S. K. Das, "Efficient aerial data collection with UAV in large-scale wireless sensor networks," *International Journal of Distributed Sensor Networks,* vol. 11, p. 286080, 2015.

[34] A. Kumar, M. Zhao, K.-J. Wong, Y. L. Guan, and P. H. J. Chong, "A comprehensive study of iot and wsn mac protocols: Research issues, challenges and opportunities," *IEEE Access,* vol. 6, pp. 76228-76262, 2018.

[35] J. Kabara and M. Calle, "MAC protocols used by wireless sensor networks and a general method of performance evaluation," *International Journal of Distributed Sensor Networks,* vol. 8, p. 834784, 2012.

[36] A. F. Kacso and R. Wismuller, "Modeling and simulation of multihop routing protocols in wireless sensor networks," in *2009 Fifth International Conference on Wireless and Mobile Communications*, 2009, pp. 296-302.

[37] A. Roy and N. Sarma, "AEEMAC: Adaptive energy efficient MAC protocol for wireless sensor networks," in *2011 annual IEEE India conference*, 2011, pp. 1-6.

[38] I. Rhee, A. Warrier, M. Aia, J. Min, and M. L. Sichitiu, "Z-MAC: a hybrid MAC for wireless sensor networks," *IEEE/ACM transactions on networking,* vol. 16, pp. 511-524, 2008.

[39] H.-W. Cho, M.-H. Cho, J.-M. Chung, and W.-C. Jeong, "A centralized hybrid MAC protocol for wireless sensor networks," in *2007 3rd International Conference on Intelligent Sensors, Sensor Networks and Information*, 2007, pp. 455-460.

[40] L. Sitanayah, C. J. Sreenan, and K. N. Brown, "ER-MAC: A hybrid MAC protocol for emergency response wireless sensor networks," in *2010 Fourth International Conference on Sensor Technologies and Applications*, 2010, pp. 244-249.

[41] S. Zhuo, Y.-Q. Song, Z. Wang, and Z. Wang, "Queue-MAC: A queue-length aware hybrid CSMA/TDMA MAC protocol for providing dynamic adaptation to traffic and duty-cycle variation in wireless sensor networks," in *2012 9th IEEE International Workshop on Factory Communication Systems*, 2012, pp. 105-114.

[42] P. Sasikumar and S. Khara, "K-means clustering in wireless sensor networks," in *2012 Fourth international conference on computational intelligence and communication networks*, 2012, pp. 140-144.

[43] M. M. Hamdi, A. S. Mustafa, H. F. Mahd, M. S. Abood, C. Kumar, and M. A. Al-shareeda, "Performance Analysis of QoS in MANET based on IEEE 802.11 b," in *2020 IEEE International Conference for Innovation in Technology (INOCON)*, 2020, pp. 1-5.

[44] I. Jawhar, N. Mohamed, J. Al-Jaroodi, and S. Zhang, "Data communication in linear wireless sensor networks using unmanned aerial vehicles," in *2013 International Conference on Unmanned Aircraft Systems (ICUAS)*, 2013, pp. 492-499.

[45] M. Dong, K. Ota, M. Lin, Z. Tang, S. Du, and H. Zhu, "UAV-assisted data gathering in wireless sensor networks," *The Journal of Supercomputing,* vol. 70, pp. 1142-1155, 2014.

[46] R. Dutta, S. Gupta, and M. K. Das, "Low-energy adaptive unequal clustering protocol using fuzzy c-means in wireless sensor networks," *Wireless personal communications,* vol. 79, pp. 1187-1209, 2014.

[47] M. Nicolae, D. Popescu, and R. Dobrescu, "Uav-wsn communication algorithm with increased energy autonomy," in *2015 9th International Symposium on Advanced Topics in Electrical Engineering (ATEE)*, 2015, pp. 939-944.

[48] E. I. Grøtli and T. A. Johansen, "Path planning for UAVs under communication constraints using SPLAT! and MILP," *Journal of Intelligent & Robotic Systems,* vol. 65, pp. 265-282, 2012.

[49] A. Giorgetti, M. Lucchi, M. Chiani, and M. Z. Win, "Throughput per pass for data aggregation from a wireless sensor network via a UAV," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 47, pp. 2610-2626, 2011.