UAV-enabled healthcare architecture: Issues and challenges

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Abstract

Unmanned Aerial Vehicles (UAVs) have great potential to revolutionize the future of automotive, energy, and healthcare sectors by working as wireless relays to improve connectivity with ground networks. They are able to collect and process real-time information by connecting existing network infrastructures including Internet of Medical Things (e.g., Body Area Networks (BANs)) and Internet of Vehicles with clouds or remote servers. In this article, we advocate and promote the notion of employing UAVs as data collectors. To demonstrate practicality of the idea, we propose a UAV-based architecture to communicate with BANs in a reliable and power-efficient manner. The proposed architecture adopts the concept of wakeup-radio based communication between a UAV and multiple BANs. We analyze the performance of the proposed protocol in terms of throughput and delay by allocating different priorities to the hubs or gateways. The proposed architecture may be useful in remote or disaster areas, where BANs have poor or no access to conventional wireless communication infrastructure, and may even assist vehicular networks by monitoring driver 19s physiological conditions through BANs. We further highlight open research issues and challenges that are important for developing efficient protocols for UAV-based data collection in smart healthcare systems.

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ABSTRACT

Unmanned Aerial Vehicles (UAVs) have great potential to revolutionize the future of automotive, energy, and healthcare sectors by working as wireless relays to improve connectivity with ground networks. They are able to collect and process real-time information by connecting existing network infrastructures including Internet of Medical Things (e.g., Body Area Networks (BANs)) and Internet of Vehicles with clouds or remote servers. In this article, we advocate and promote the notion of employing UAVs as data collectors. To demonstrate practicality of the idea, we propose a UAV-based architecture to communicate with BANs in a reliable and power-efficient manner. The proposed architecture adopts the concept of wakeup-radio based communication between a UAV and multiple BANs. We analyze the performance of the proposed protocol in terms of throughput and delay by allocating different priorities to the hubs or gateways. The proposed architecture may be useful in remote or disaster areas, where BANs have poor or no access to conventional wireless communication infrastructure, and may even assist vehicular networks by monitoring driver's physiological conditions through BANs. We further highlight open research issues and challenges that are important for developing efficient protocols for UAV-based data collection in smart healthcare systems.

1. Introduction

Internet of Things (IoT) is becoming increasingly important for cost-effective, unobtrusive, and ambulatory health solutions [1,2]. IoT is expected to transform the future of smart healthcare systems by allowing wireless connectivity of a large number of medical devices having short communication range. Such future smart healthcare systems may seamlessly integrate several technologies, such as wearable computing, micro and nano technologies, integrated circuits, and pervasive computing to enable remote health monitoring of patients suffering from chronic health conditions. These systems may also communicate with Internet of Vehicles (IoV) to monitor health status such as epileptic seizure, heart failure, and panic attacks, of the drivers to prevent life-critical accidents [3–5].

One of the examples of smart healthcare systems is Body Area Networks (BANs) that consist of tiny, intelligent, and low-power sensor devices capable of detecting and reporting abnormal health conditions [6–9]. These devices include wearable sensors, which are deployed on the human body or embedded in shirts, and implantable devices, which are implanted under the human skin. For example, the wearable device such as an electrocardiogram may continuously monitor heart rate of patients and detect the occurrence of any irregular heart beat, thus decreasing the chances of myocardial infarction. The wearable device may also be embedded in smart clothing to measure body vital signs for real-time health monitoring [10]. The implantable device such as an infusion pump may inject insulin to patients suffering from diabetes. In BANs, both wearable and implantable devices send collected information to a central device called a hub or a gateway, which is then forwarded to a remote server or a cloud for further analysis. The hub usually utilizes existing wireless communication infrastructure such as WiFi or 4G to deliver the collected information. However, in rural or disaster areas, the lack of adequate infrastructure may prevent efficient and real-time data delivery, thus affecting the health status of alarming patients.

Unmanned Aerial Vehicles (UAVs) have enormous capabilities to revolutionize the future of data communication in numerous

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ways, such as connecting vehicles in IoV infrastructure or providing data delivery services to BANs. UAVs also known as aerial vehicles or drones are pilotless aircrafts assisted by ground-based controllers. Earlier, UAVs were primarily used for military applications, however, their use is drastically increasing for other numerous applications including surveillance, industrial monitoring, agriculture, product delivery, etc.

There has already been a number of studies using UAVs as mobile data collectors for Wireless Sensor Networks (WSNs) [11–19], however, no attention has been given to employ UAVs for BANs. Since BANs are usually carried by chronic patients, they require quick and reliable access in life-critical situations, especially during the occurrence of disasters such as accidents or natural catastrophes that may destroy existing communication infrastructure. The UAVs may be sent to scan disaster areas for human casualties with their health status and report the collected information to remote servers. They can be used to communicate with BANs in rural areas having poor communication infrastructure. In the context of edge computing [20] the UAVs may also be used as data collectors to provide emergency services to patients.

The objective of our study is to investigate the potentials and merits of employing UAVs to cope with the limitations of existing BANs. We propose a UAV-empowered architecture that employs drones to collect data from BANs in a reliable and power-efficient manner. In the proposed architecture, the UAV organizes the hubs into a star topology network and uses a wakeup-radio technique for resource allocation. Control and data channels are used for wakeup-radio and data transmission, respectively. We analyze the performance in terms of normalized throughput and delay for different traffic arrival rates and priority classes. These two performance metrics are important to analyze reporting patients' data (e.g., routine and life-critical) to the UAV on time. We further present several issues and challenges that will open new research directions for future work. To the best of our knowledge, this is a first attempt to study the deployment of UAVs for data communication in BAN-assisted healthcare systems.

The rest of the article is divided into four sections. Section two presents the related work on the use of UAVs as mobile data collectors. Section three and four present the proposed architecture and performance results, respectively. Section five highlights open research issues and challenges. The final section concludes our work.

2. Related work

The concept of using UAVs as mobile data collectors for WSNs have already been addressed in the existing literature. We categorize them into the following two subsections.

2.1. UAV-enabled MAC protocols

In [11], the authors proposed a Medium Access Control (MAC) protocol for UAV-based data gathering that utilizes a stochastic priority scheme to achieve high throughput and efficiency. Another MAC protocol proposed in [12] considered multiple UAVs that communicate as a mobile ad-hoc network by employing a directional antenna. It is concluded that the proposed protocol extends the communication range due to the use of directional antenna in terms of end-to-end delay and throughput. As UAVs may communicate with low-power WSNs, the authors of [13] introduced an energy-efficient data collection protocol that optimizes the nodes wakeup schedule and UAVs trajectory to extend network lifetime. A delay-tolerant MAC protocol is proposed in [14], which utilizes returning paths of UAVs to achieve high channel access efficiency. The authors of [15] proposed a radio-frequency based wakeup method for aerial ground WSNs. It is shown that the proposed method saves enormous amount of energy compared to a conventional duty cycling technique and is suitable for geospatial field monitoring. In [16] , the authors investigated the performance of IEEE 802.11n at several frequency bands in a UAV-based wireless network by connecting two devices on the ground. It is concluded that the performance of IEEE 802.11n is better at 2.4 GHz band compared to that of 5 GHz band in terms of link quality and signal strength. In [17] , the authors proposed a dynamic programming algorithm that considers bandwidth and energy allocations to increase and adjust the transmitting rate in each time slot allocated to the nodes. Simulation results show effectiveness of the proposed algorithm over a benchmark algorithm called equal resource allocation algorithm. The authors of [18] introduced different priority levels for nodes in the UAV's coverage area using IEEE 802.11 MAC protocol. The proposed approach reduces data packet collision and decreases packet loss from the nodes present in the rear side of the UAV. The authors further introduced a routing algorithm to increase network lifetime. It is concluded that the proposed approaches are able to decrease distances between source and destination to achieve better channel quality and low energy consumption.

2.2. Data gathering frameworks and algorithms

In [19], the authors presented a UAV-based framework useful for emergency and delay-tolerant traffic. The proposed framework provided several UAV-based routing protocols using round-robin and demand-driven algorithms. A novel framework for UAV-based data gathering is presented in [21] where the authors determined the jointly optimal UAVs' locations, the effective movement of UAVs, and the optimal trajectories. The performance results concluded that the mobile UAVs decrease the total transmit power of the devices compared to that of a pre-deployed stationary stations. The authors of [22] used different graphical process models that assist in standardizing the entire data gathering process for repeated flights. The authors presented a case study of a water body shoreline to validate the proposed process in terms of selecting appropriate data and analysis. The authors of [23] studied effects of UAV mobility patterns on data collection. Using OMNET++ simulator, it is concluded that the circular mobility pattern is highly efficient in terms of time and coverage efficiencies compared to that of the tractor mobility pattern. The authors further proposed a new metric that may be used to formulate the tradeoff between maximum number of covered nodes with minimum amount of time required by the sink. In [24], the authors proposed a UAV-based framework to decrease energy consumption by monitoring the infrastructure using Linear Sensor Networks(LSNs). The proposed UAV-based LSNs saves enough energy due to: (1) significant decrease in the transmission ranges between sensor and relay nodes, and (2) the use of one-hop communication between relay nodes and the UAV. Furthermore, it is concluded that the proposed framework achieves good performance in terms of end-to-end delay and the buffer size of relay nodes.

In [25], the authors proposed a framework comprising of five components for aerial data collection. The proposed work introduced a fast path algorithm that enhances path planning speed and spatial continuity of data collection. The authors suggested that minimal data is collected by a UAV staying on the midair of the head node using single-hop communication, this however results in data loss for farther nodes. The authors of [26] proposed a cloud-based algorithm used for data gathering from emerging events. Using extensive simulations, the authors concluded that the proposed algorithm is able to reduce the flying time, delay, and energy consumption during data collection. Other important concepts on UAV-based communication are present in [27–30].

Since BANs are attached to a human body [6–9], their characteristics are different than that of WSNs in terms of data rate,

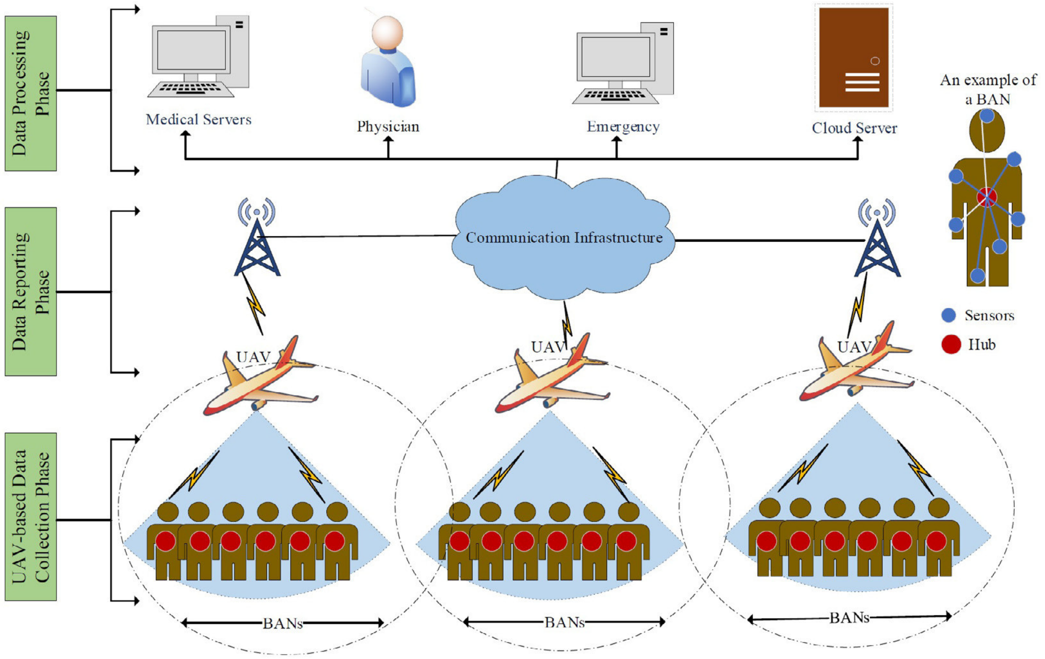

Fig. 1. A UAV-based smart healthcare architecture for BANs.

Beacon	Random Access Period employing a CSMA/CA protocol	Optional Contention Access Period	Beacon

Fig. 2. A superframe structure on the data channel.

scalability, life-critical traffic, nodes organization, and quality of service requirements, etc. The above-mentioned work focuses on UAV-based communication for WSNs and is not directly applicable to BANs. We propose the concept of a wakeup-radio based communication that allows UAVs to gather data from multiple BANs.

3. UAV-based smart healthcare architecture

The UAV-based smart healthcare architecture is comprised of the following three phases as given in Fig. 1.

1- Data Collection Phase: In this phase, the UAV collects patients' information from multiple BANs. These information are usually available at the hubs.

2- Data Reporting Phase: In this phase, the UAV sends the collected information to medical servers, physicians, and cloud servers.

3- Data Processing Phase: In this phase, the servers process the patients information for taking various health decisions, such as real-time diagnosis and prescription.

Since the communication protocols used in BANs usually follow the IEEE 802.15.6 standard that utilizes beacon broadcasting for synchronization, it is difficult to develop a beacon-based synchronization method to synchronize the UAV's schedules with BANs. One of the main reasons is that periodic beacons broadcasting require all hubs to stay active regardless of their intention to send data. Furthermore, the beacons may not be received when the hubs are in sleep mode, thus increasing data transmission delay. We proposed a wakeup-radio based communication technique that allows the UAV to collect data from multiple BANs efficiently. The proposed technique is comprised of the following two stages:

3.1. *Wakeup-radio stage*

The concept of wakeup-radio has already been adapted for WSNs in order to overcome the shortcomings of synchronous and duty cycling mechanisms. As the wakeup-radios are more effective for low-power and delay-sensitive applications, it may allow the UAV to communicate with the hubs in a reliable way. The UAV and the hub can be equipped with active and passive wakeup-radio circuits, respectively. The active wakeup-radio gains power from the UAV's battery, while the passive wakeup-radio circuit has no power source, and therefore gains its power from the wakeup-radio signal. The wakeup-radio is comprised of two methods: (1) Out-of-band wakeup-radio, where two channels are used for data communication, i.e., a control channel which is used for sending wakeup-radio packets, and a data channel which is used for data transmission, (2) In-band wakeup-radio, where a single channel is used for sending wakeup-radio signals as well as data. In our proposed approach, we adapt an out-of-band wakeup-radio where a UAV sends a wakeup-radio signal on a separate control channel to the hubs whenever required. The hubs, which are controlling their respective BANs, receive the signal and therefore triggers the main channel for sending data to the UAV.

3.2. *Data gathering stage*

Similar to IEEE 802.15.6 standard, the data channel is bounded by superframe structures as given in Fig. 2. Each superframe is comprised of a beacon, a Random Access Period (RAP), and an optional Contention Free Period (CFP). The beacons are used to carry control information such as packet size and superframe boundaries. The RAP is used by the hubs to send data to the UAV by employing a priority-based Carrier Sensor Multiple Access with Collision Avoidance (CSMA/CA) protocol. The optional CFP period consists of variable time slots that are reserved for multimedia traffic.

The priority-based CSMA/CA adapted in this work has three priority levels. The priority levels differentiate hubs having life-critical data; this is important in disaster areas where numerous hubs may have life-critical data and may require quick access to the

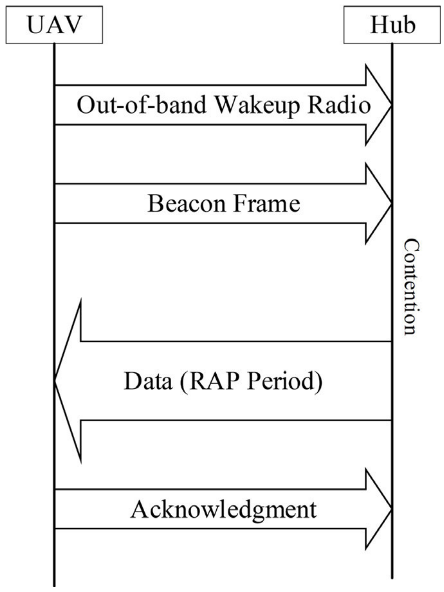

Fig. 3. Data flow model for uplink communication.

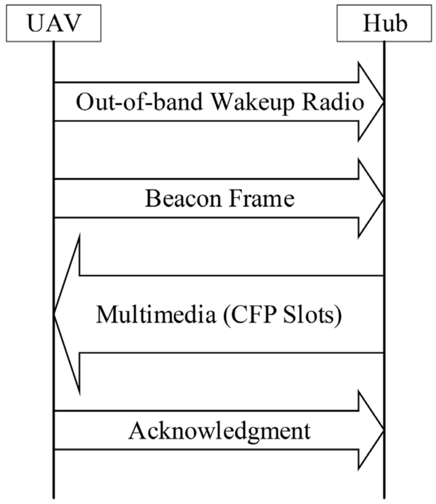

Fig. 4. Data flow model for uplink multimedia communication.

channel. After receiving the wakeup-radio signal and the beacon frame, all hubs set their backoff counters to a random integer over the interval $(1, CW)$ where CW is the contention window and is selected from minimum and maximum contention bound in the range (CW_{min}, CW_{max}). The hub decrements the backoff counter for each idle slot and transmits data to the UAV when the backoff counter is zero. Similar to the IEEE 802.15.6 standard, the value of contention window is doubled for even number of failures. The hub having high priority will have small contention window, thus sending its data before the low priority hub.

Fig. 3 depicts a data flow diagram for uplink communication, where the UAV first sends a wakeup-radio signal to the hub. Once the hub is active, the UAV sends a beacon frame to define boundaries of RAP and CAP periods. The hub sends data to the UAV using the above-mentioned priority-based CSMA/CA protocol. Once the data is received, the UAV sends back an acknowledgment frame. Fig. 4 demonstrates a data flow diagram for uplink multimedia communication such as gastrointestinal videos. The hubs send the multimedia data in the CFP slots after receiving the request in the beacon frame. A data flow diagram for downlink communication

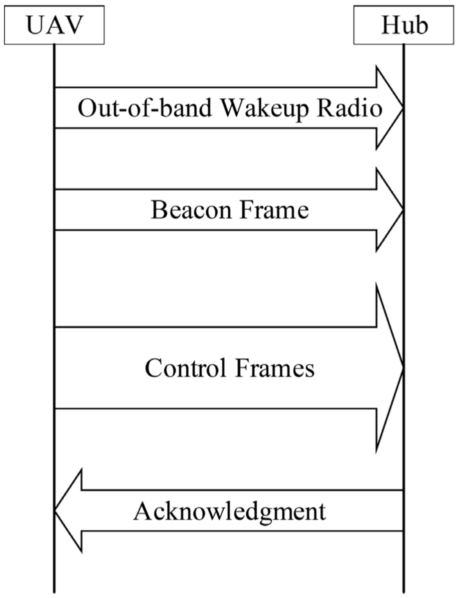

Fig. 5. Data flow model for downlink communication.

is given in Fig. 5. The UAV may send downlink control information such as configuration and synchronization frame in the beacon. The flow chart of the proposed protocol is given in Fig. 6.

4. Performance analysis and results

We consider a fixed number of hubs in each priority class. The hubs are connected to the UAV in a star topology network. We use MATLAB simulations to obtain throughput and delay results of the proposed protocol for three priority classes, i.e., priority class 0 to 2. We consider RAP period for the performance results; the CFP is not considered in our analysis. We further consider that the hubs in different priority classes coexist in the same network. The physical layer parameters are not considered in our analysis as we are more interested to analyze the performance at the MAC layer only. The values of CW are taken according to the IEEE 802.15.6 standard for three priority classes (priority class 0 to 2). The throughput is calculated as the ratio of the average transmission time of payload to the total transmission time, and is given by

$$T = \frac{T_{E[X]}}{[E[B] + T_W + T_D + T_{TO} + T_{ACK} + \psi] + \frac{1}{\lambda} + \alpha\frac{T_B}{2}} \tag{1}$$

where the average backoff period of the hubs is calculated by modeling the backoff process as a geometric random variable [31]. We consider that the average backoff is triggered by collision on the channel; the backoff may also be triggered due to error on the channel, however it is not considered in our results. The value $T_{E[X]}$ represents time to transmit the average payload size $E[X]$. The values T_W and T_{ACK} represent the average duration to transmit wakeup radio and acknowledgment packets, respectively. The value T_D represents the data transmission time and is obtained as $T_D = \frac{E[X]}{R}$ where R is the data rate. The values T_{TO} and ψ represent the average turn around and propagation delay, respectively. The value λ represents the packet arrival rate. It is important to consider the average waiting period during which the hubs wait for the beacon. The value $\frac{T_B}{2}$ represents the average beacon inter-arrival time, and α represents the probability that the channel is busy due to ongoing traffic on the channel. The value of α is obtained through multiple simulation runs.

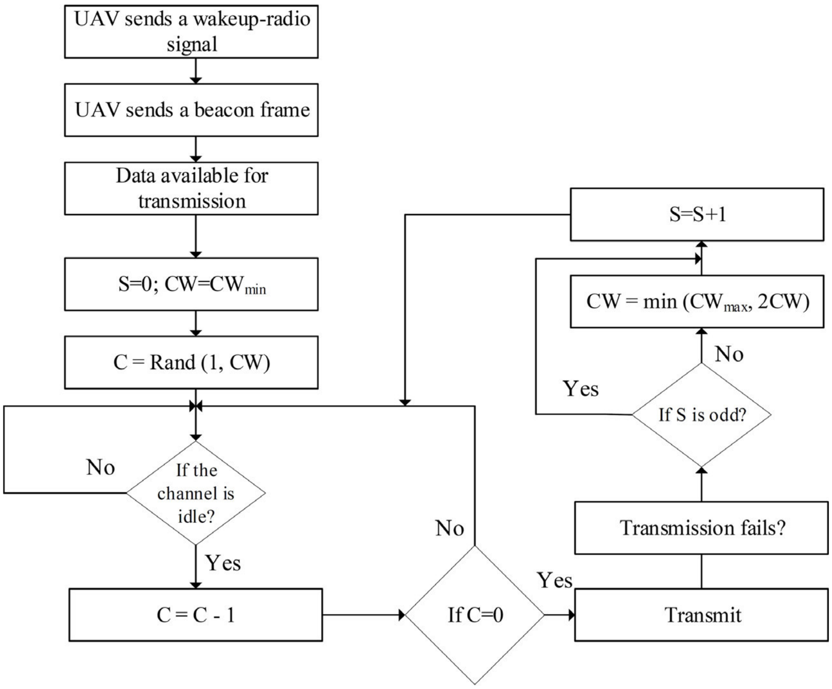

Fig. 6. Flow chart of the proposed protocol. S: backoff stage, C: backoff counter.

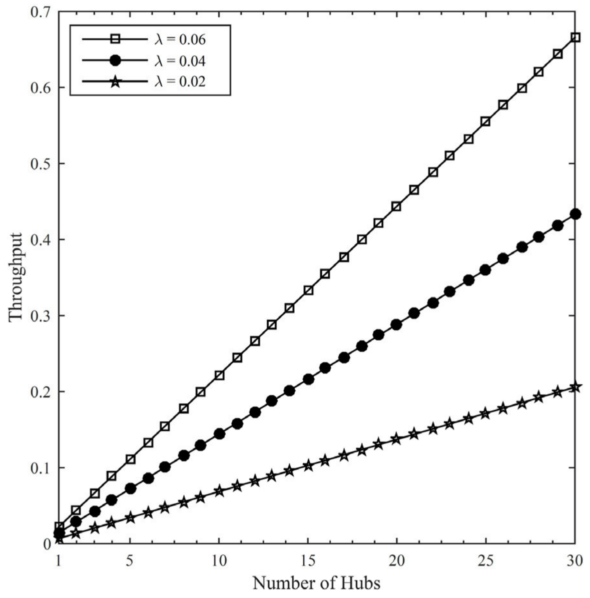

Fig. 7. Normalized throughput vs. number of hubs for different values of λ.

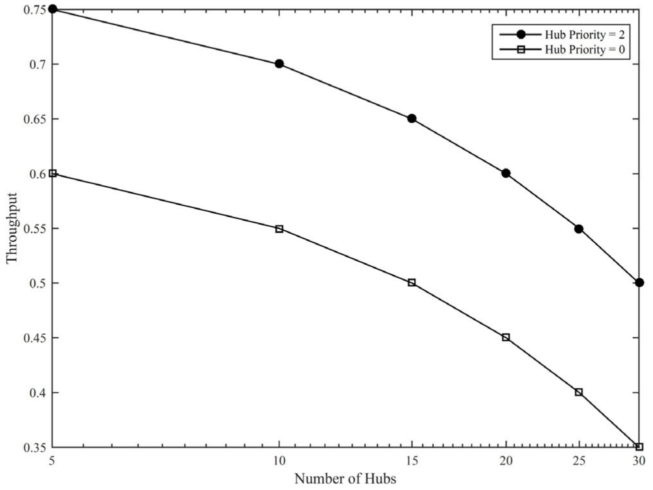

Fig. 8. Normalized throughput vs. number of hubs for different priority classes.

Similarly, the total average delay can be obtained as

$$E[D] = E[B] + \alpha \frac{T_B}{2} + T_D \tag{2}$$

To obtain the performance results, we assume that the size of T_W and T_{ACK} are 10 bytes and 20 bytes, respectively. The values of T_D (including MAC and physical layer headers) and R are 80 bytes and 450 kbps. The values of T_{TO} and ψ are 0.5 ms and 1 µs, respectively. The values of (CW_{min}, CW_{max}) are taken as $(16, 64)$ for priority class 0, $(16, 32)$ for priority class 1, and $(8, 32)$ for priority class 3.

Fig. 7 shows the normalized throughput as a function of number of hubs. For an arrival rate of λ, the normalized throughput increases over the number of hubs in the same priority class. For a high value of λ, the normalized throughput is greater than that of a lower λ, however this trend may be changed when the throughput reaches a saturation point where heavy contention starts decreasing the normalized throughput. For twenty number of hubs, the normalized throughput is 0.44 and 0.28 for $\lambda = 0.06$ and $\lambda = 0.04$, respectively. The throughput is expected to reach the saturation point when the value of λ is too high. This is shown in Fig. 8 where the normalized throughput decreases as a function of number of hubs when the value of λ is taken as 0.8. This figure further explains that high priority hubs (in priority class 2) achieve higher throughput in the presence of low priority hubs (in priority class 0); this is obvious as high priority hubs have smaller contention windows and backoff periods than that of low priority hubs. For fifteen number of hubs, high and low priority hubs are able to deliver 67% and 50% of data to the UAV, respectively.

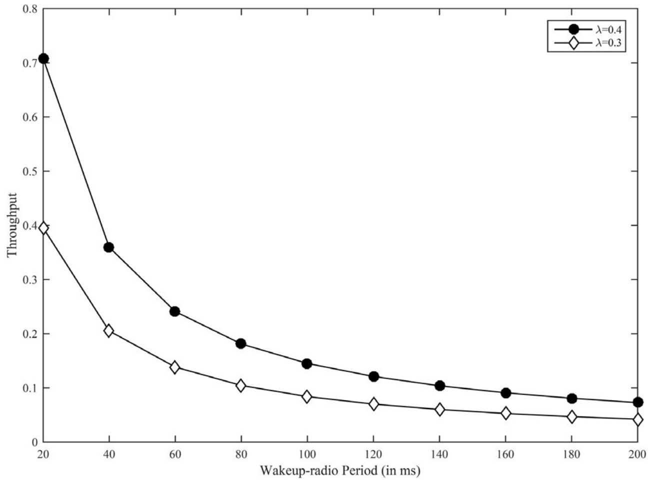

Fig. 9. Normalized throughput vs. wakeup-radio period for different priority classes.

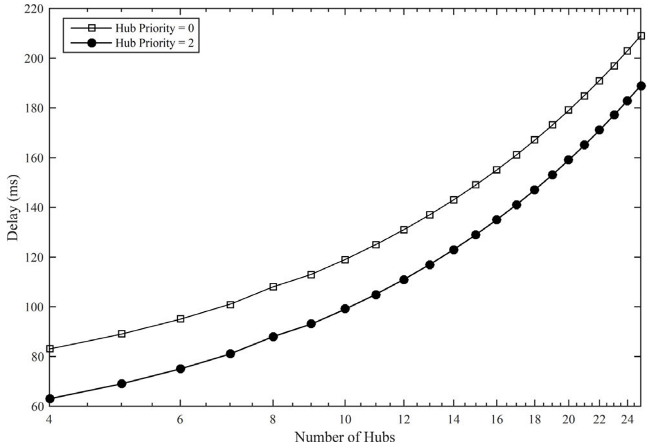

Fig. 10. Delay vs. number of hubs for different priority classes.

The results of Fig. 7 consider a fixed duration between wakeup-radio packets. The effects of wakeup-radio period on the normalized throughput is given in Fig. 9. It is observed that as we increase the duration of the wakeup-radio period, the throughput eventually decreases. It is obvious as larger wakeup-radio periods allow the hubs to wait for a longer period of time in order to receive resource allocation information. Furthermore, larger wakeup-radio periods also increase the average queuing delay that negatively affects the throughput.

Fig. 10 shows the average delay as a function of number of hubs for different priority classes. It is observed that high priority hubs experience lower delay due to smaller contention windows compared to that of low priority hubs. For ten number of hubs in the priority class 2 and 0, the average delay to send data to the UAV is 120 ms and 90 ms, respectively.

5. Open research issues and challenges

The above sections presented a wakeup-radio based communication technique that allows UAVs to gather data from multiple BANs. However, there are several open research issues and challenges that may be addressed in order to enhance UAV-based data collection in smart healthcare systems. The following subsections present open research issues and challenges in the context of utilizing UAVs as mobile data collectors in smart healthcare systems.

5.1. *Routing layer*

Routing protocols are important for enabling different UAVs to deliver BAN data by selecting an optimal and shortest path. As mentioned in [27], path planning is one of the major problems of UAVs. It requires alternative solutions, especially in disaster areas, to calculate an optimal movement trajectory for UAVs. Position based routing may be adapted by the UAVs. However, it usually fails to discover an optimal path due to UAVs mobility, and hence require further study in this direction. Proactive routing may also be adapted by the UAVs. The problem is that it updates routing tables frequently even when the UAVs have no data to send, thus increasing extra energy consumption. Reactive routing, on the other hand, is more suitable for UAVs because it does not require periodic flooding and is responsive to link failure. However, the latency to discover new routing paths is high. Existing work on routing for UAVs is not competent, most of them do not consider the issues of network load balancing and high speed mobility of UAVs. Further research study is required to address the aforementioned issues and develop reliable routing protocols that effectively enhance quality of the network. Other protocols such as cluster and geo-cast routing may also be studied to improve network performance.

5.2. *MAC layer*

As mentioned in section two, there are many MAC protocols proposed for UAV-based communication for WSNs, however none of them is accepted as a standard protocol. One of the main reasons is that these protocols target a specific application with no support for scalability, low-power communication, high throughput, synchronization, etc. The CSMA/CA protocol provides high throughput with no synchronization overhead, however it requires alternative mechanisms to avoid collisions between multiple hubs in disaster areas where multiple BANs are required to send their data on urgent basis. Time Division Multiple Access (TDMA), on the other hand, avoids collisions and idle listening problems and is suitable for low-power communication. Since TDMA protocols require frequent synchronization, they require reliable methods to avoid clock drifting between high-speed UAVs and multiple BANs. Other protocols such as polling, frequency division multiple access, code division multiple access, preamble sampling may be investigated to achieve the desired quality of service.

5.3. *Localization*

Localization protocols are important to monitor and track UAVs during delivery of health data. Furthermore, they may also track location of patients who require immediate medical assistance. Global Position System (GPS) is used to localize UAVs with consistent accuracy, however it experiences communication issues due to bad weather conditions resulting in poor signal reception and accuracy. As UAVs are required to communicate with BANs in natural disaster areas or in bad weather conditions, further study is required to develop localization protocols in this direction. The protocols may be based on relative, absolute, or landmark-based localization that improve tracking accuracy of UAVs in diverse environments.

5.4. *UAV coverage*

UAVs usually follow different types of trajectories and may hover or fly all the time. This affects the coverage area that the UAV may sense and monitor for data collection. In case the UAV is static, the problem is more similar to WSN coverage problem [32,33], however when the UAV is dynamic, multiple UAVs may be required to cover a particular area for data collection. Research efforts are required to address the coverage issues in the context of smart healthcare systems with focus on maximizing coverage in disaster areas.

5.5. *UAV handoffs*

Depending on the application requirements and the coverage area, UAVs are required to maintain their speeds and may eventually go out of service [28]. In such scenarios, the network is required to reconfigure itself by seamlessly handing over the ongoing communication session to other UAVs. This concept is common in cellular networks where ongoing calls are transferred to another network when the mobile station goes out of service [34]. Research on handoff procedures for UAV-based communication is required to support heterogeneous applications requiring diverse coverage of an area. One of the solutions would be to investigate the conventional soft or hard handover techniques for UAV-based communication. Unlike hard handoff where the communication session is broken before it is handed over to another network, soft handoff techniques may be suitable in this direction because the communication session is not broken and is maintained during the handoff process.

In addition to the above research directions, the integration of IoT with Artificial Intelligence (AI) is expected to play a significant role in providing high quality healthcare services to the end users. By following [35], research efforts are required to explore AI-enabled techniques that can be used to recognize emotion of users to improve interaction with the UAV-assisted healthcare intelligent systems.

6. Conclusion

In this article, we introduced a UAV-based smart healthcare architecture that allows the UAV to utilize a wakeup-radio protocol to collect data from multiple BANs. The proposed protocol gathers data by employing the priority-based CSMA/CA protocol. Our preliminary results show that the wakeup-radio protocol achieves acceptable throughput and delay for different values of λ and priority classes. We further identified open research issues and challenges concerning routing layer, MAC layer, localization, coverage, and handoff procedures. We believe that this article will open new ways of research and development in the area of UAV-based data gathering in smart healthcare systems.

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Competing interests

The authors declare that they have no competing interests.

Author's contributions

S.U is the lead author and proposed the entire study including analytical approximations. KI.K and F. A. helped in correcting and revising the analytical model. KH.K helped in the proposed architecture by correcting the data flow models. M.I helped in highlighting open research issues and challenges. P.K and E.T. helped in the analysis of the final results and have also revised the whole manuscript for correctness and consistency. All authors read and approved the manuscript.

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