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Non-Terrestrial Networks-enabled Internet of Things: UAV-centric architectures, applications, and open issues

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Abstract: Although Unmanned Aerial Vehicles (UAVs)-aided wireless sensor networks (WSNs) have gained many applications, it is not long that research works have been put to design effective algorithms and protocols. In this article, we address the UAV-enabled WSN (U-WSN), explore the performance and the capability of the UAV, define the UAV functionalities as a communication node, and describe the architectures and the relevant typical technologies that emerge from this new paradigm. Furthermore, this article also identifies the main factors which influence the U-WSN design and analyzes the open issues and challenges in U-WSN. These insights may serve as motivations and guidelines for future designs of UAV-enabled WSNs.

Keywords: Wireless sensor networks; unmanned aerial vehicles; network architecture; mobility; trajectory planning

1. Introduction

Non-Terrestrial Networks (NTN), including drones and nano-satellites, bring considerable solutions for collecting data in future internet of things. Indeed, wireless sensor networks (WSNs) have attracted exponential research growth due to their broad range of applications ranging from military [1,2], environmental [3,4] to agriculture [5,6]. The main function of a WSN is to collect as much data as possible and transmit it to the data center, where it is observed, analyzed and processed. Multi-hop is a widely accepted option to improve data collection in applications where sensors are statically deployed and battery-powered. However, it brings sensors that act as intermediate nodes to die faster than simple nodes because they consume a lot of energy to relay messages. As a result, mobile sinks are introduced into WSN to balance network energy consumption by moving between sensors. The mobility of the sink brings new issues including dynamic topology, synchronization, network lifetime, etc ([7–9]). In existing research, most of the network typologies utilize static or quasi-static (move on the ground at a low speed) nodes. However, it is hard to be implemented in harsh terrains, such as snowberg or forests, which are dangerous for humans. In such applications, Unmanned Aerial Vehicles (UAVs) are more widely accepted due to their great flexibility and no need to involve humans.

UAVs can be drones, quadcopters, gliders, and balloons. Due to different application requirements, they could be equipped with various sensors, e.g., cameras, super-sonic sensors, etc. UAV-enabled WSN (U-WSN) comprises an air platform and a ground platform. The air platform could be composed of several UAVs. UAVs should be well controlled to keep a safe flight distance and a proper distance with the ground control center to make them under control. The ground platform could be composed of many sensor nodes, base stations, and data center according to applications. In applications, e.g., UAVs are

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dispatched for aerial photography, no ground sensors needed to be deployed. Thus, the ground sensors are not mandatory in a U-WSN.

The design of U-WSN applications requires wireless networking techniques. Although many protocols and algorithms have been proposed for traditional WSN applications, they can no longer meet up with the unique features and application requirements of U-WSN. The main differences between WSN and U-WSN are outlined below:

- The topology of a U-WSN changes more frequently.
- The sensors are prone of being out of the range of the UAV if they have high relative velocities.
- The scale of the area of a U-WSN can be several orders of magnitude higher than the scale of a WSN.
- The UAVs are very limited in power compared to the ground sensor nodes and the base station.
- The UAVs need to be dispatched to maintain a safe flight and other issues.

Many researchers are currently engaged in developing schemes that fulfill these requirements. This paper presents a review of UAV-centric architectures, applications, and open issues. We aim better to understand the current research issues in this field. We also attempt to investigate design constraints and outline specific tools to meet the design objectives.

The main contributions of this paper are summarized as follows:

- analyze the performance and the capabilities of the UAV, based on which, we summarize the U-WSN applications.
- refine the UAV functionalities as a communication node in a U-WSN.
- compare and draw the network architecture and the standard technologies in U-WSN.
- evaluate the main factors which influence the U-WSN design.
- review and analyze the open issues and challenges in U-WSN.

The organization of this article is as follows: In Section 2, summarize the performance and capability of the UAV, and the relative applications of the U-WSN, and the functionalities of the UAV as a communication node. Section 3 analyzes the factors that influence the U-WSN design. Section 4 presents open issues and challenges in U-WSN. Section 5 gives a conclusive remarks of this work. Finally, Section 6 concludes this work.

2. Applications of U-WSN

Using UAVs is much more diverse in our daily life because of its significantly deployment possibilities. Applications of U-WSN may either be traditional ones such as military monitoring and reconnaissance, environmental disaster detecting and industrial control or completely new application types such as smart city.

There are extensive surveys that have been done on the applications of U-WSN. For example, authors in [10] give a review on the task using mobile robots. Shakhathreh et al., provide a survey on civilian applications [11]. These research mainly focus on the application fields when studying the application of the UAV. In this section, we will study U-WSN applications through the performance and the capabilities of the UAV.

2.1. UAV Categorization

UAV is known as an aircraft or a drone without human on board. Humans control the UAV in a variety of ways, such as ground control center, pre-programmed flight trajectory and more complex and autonomous systems. Due to its different performances, capabilities and restrictions, the UAV encompass a wide range of different platforms.

One of the detailed and widely used schemes has been proposed in [12], as shown in Table 1. In which, the UAVs are classified based on the mass, range, altitude, and endurance. Moreover, another scheme based on Mean Take off Weight (MTOW) and the ground impact risk has also been proposed [12], as illustrated in Table 2.

Table 1. UAV categorization for differentiation of existing systems.

Category	Mass (kg)	Range (km)	Flight alt. (m)	Endurance (h)
Micro	< 5	< 10	250	1
Mini-UAV	< 20/25/30/150 ¹	< 10	150/250/300	< 2
Tactical				
Close range (CR)	25–150	10–30	3,000	2–4
Short range (SR)	50–250	30–70	3,000	3–6
Medium range (MR)	150–500	70–200	5,000	6–10
MR endurance (MRE)	500–1,500	>500	8,000	10–18
Low altitude deep penetration (LADP)	250–2,500	>250	50–9,000	0.5–1
Low altitude long endurance (LALE)	15–25	>500	3,000	>24
Medium altitude long endurance (MALE)	1,000–1,500	>500	3,000	24–48
Strategic				
High altitude long endurance (HALE)	2,500–5,000	>2,000	20,000	24–48
Stratospheric (Strato)	>2,500	>2,000	>20,000	>48
Exo-stratospheric (EXO)	TBD	TBD	>30,500	TBD
Special task				
Unmanned combat AV (UCAV)	>1,000	1,500	12,000	2
Lethal (LET)	TBD	300	4,000	3–4
Decoys (DEC)	150–250	0–500	50–5,000	<4

¹ Varies with national legal restrictions.

Table 2. Classification of UAVs based on the MTOW and the ground impact risk.

Number	T_{GI}^1	MTOW	Name	Note
0	10^2	Less than 1 kg	Micro	Most countries do not regulate this category since these vehicles pose minimal threat to human life or property
1	10^3	Up to 1 kg	Mini	These two categories roughly correspond to R/C model aircraft
2	10^4	Up to 13.5 kg	Small	
3	10^5	Up to 242 kg	Light/ultralight	Airworthiness certification for this category may be based either on ultralights (FAR ² bpart 103), LSA ³ (Order 8130), or even normal aircraft (FAR Part 23)
4	10^6	Up to 4332 kg	Normal	Based on MTOW these vehicles correspond to normal aircraft (FAR Part 23)
5	10^7	Over 4332 kg	Large	These vehicles best correspond to the transport category (FAR Part 25)

¹ T_{GI} is the minimum time between ground impact accidents.

² Federal Aviation Regulations.

³ Light Sport Aircraft.

2.2. Applications of U-WSN

Hereafter, we summarize and group the applications of U-WSN as in Table 3. If we consider the area where the sensors are deployed, the applications can be classified as in Table 4.

In aforementioned applications, both UAV and WSN play different roles and have different functionalities. We will detailed the functionalities of UAV in the next sub-section.

2.3. Functionalities of UAV as a Communication Node

In WSN applications, one of the objective is to obtain meaningful information through sensors deployed in the region of interest. Traditionally, the data gathering issues were implemented in multi-hops in which the sensors that are closer to the base station will selected as the relay nodes for those sensors that deployed far away from the base station. As a result, these relay nodes consume energy much faster than other nodes. As the network connectivity depends on these relay nodes, this will result in a shorter network life-time. To address these issues, mobile vehicles were introduced.

Table 3. Classifications of the applications of U-WSN according to the performance and the capability of the UAV.

Category	Application fields	Applications
Industry Grade	Aerospace	e.g., UAVs are used for aircraft maintenance in airlines. In Jun. 2015 EasyJet began testing UAVs in the maintenance of their Airbus A320s. And in 2016, Airbus demonstrated that using UAVs for the visual inspection of an aircraft on Farnborough Airshow.
	Reconnaissance	e.g., product quality monitoring and Smart-Grid measurements [13].
	Environmental	e.g., agriculture application [5].
	Urban	e.g., traffic monitoring, urban surveillance and civilian security [14].
Consumer Grade	Others	e.g., military communication and surveillance [2].
	Recreational	e.g., filming and photographing recreational activity.
	Hobby	e.g., toys.
	Others	e.g., journalists using UAV for news gathering.

Table 4. Classifications of the applications of U-WSN according to the sensor deployment.

Category	Subcategory	Applications
Ground	On-ground	e.g., sensors are deployed on ground for environmental monitoring [8].
	Under-ground	e.g., the nodes are deployed underground for pipelines safety and monitoring [15]
Water	On-water	e.g., filming and photographing recreational activity.
	Under-water	e.g., use acoustic communications [16]
Hybrid	Combination of the above	e.g., sensors are floating on the surface of the sea to monitoring marine disasters [17].

Generally, it has limited conditions, such as limited velocity, and obstacles due to actual movement environment, when the mobile vehicles move on the ground. It would be a huge challenge if the traditional mobile vehicles are used in specific applications that are dangerous for human participation. Thus, UAV which has high extensive and flexible and do not need human on board, is a better choice in these similar applications. In this section, we will analyze and study the functionalities of UAV when it works as a communication node in WSN.

As previously described, UAV has been extensively applied in many areas. In this section, we analyze the existing applications and propose the main functionalities of the UAV in WSN.

2.3.1. Maintaining Connectivity and Relaying

Maintain connectivity is one of the key problem in wireless networks. The failures occurrence leads to the disconnect of the networks. The solution of such issues is to provide a reliable multi-hop path to maintain the connectivity through other kinds of nodes, such as mobile vehicles. However, it cannot maintain the wireless network connectivity all the time. That is because the mobility of the mobile sink, based on which a node is within the transmission range of the mobile sink at this moment may out of its range at next moment. And the motion trajectory of the mobile sink is also restricted by the network deployment. Thus, UAV, which trajectory could be predefined or randomly, is introduced to work as mobile sink.

Extensive investigations have been conducted on maintaining connectivity in the context of U-WSN. Research in [4] address the city-scale video monitoring in WSNs. Multiple UAVs ride buses in a noisy 3-D environment were considered. The UAVs could recharge through moving bus, thus, it could maintain the connectivity of the network. However,

their study addressed on static objective nodes. In our previous works, [18–20], we address the dynamic wireless networks in which both the mobility of collectors and nodes were considered. The simulation results in [19] present that the moving of UAV can maintaining the connectivity of the wireless network. The sensor nodes that are without the transmission range of the base station could have an opportunity to communicate with the UAV through create connection path to the connected neighbours.

However, our previous works fail to consider the case that the UAV and the sensor moving in opposite directions. In section 4.2, we not only study the mobility of the UAV and the sensor, but also consider the case where they move in different directions, and the relationship between them also considered.

In Table 5, we summarize and compare the use of UAV for maintaining connectivity in wireless networks.

Table 5. Summarising and comparison of the UAV functionalities in the existing U-WSN.

Ref.	Functionalities			N_{uav} ⁴	Performance Objective
	M.C. ¹	D.C. ²	Loc. ³		
[5]	Yes	Yes	No	Multiple	Optimization of the photogrammetry process.
[4]	Yes	Yes	No	Multiple	Maximization of data delivery.
[13]	Yes	Yes	Yes	Multiple	Smart view in smart grid.
[14]	Yes	Yes	Yes	Multiple	Civil security and disaster management.
[15]	Yes	Yes	Yes	Multiple	Monitoring and mapping optimization of the oil or gas pipelines.
[18]	Yes	Yes	No	1	Maximization of packet delivery ratio and network fairness.
[19]	Yes	Yes	No	1	Maximization of packet delivery ratio, system fairness and throughput.
[20]	Yes	Yes	No	1	Maximization of packet delivery ratio and network fairness.
[21]	Yes	Yes	Yes	Multiple	Practical deployment.
[22]	Yes	Yes	No	1	Optimization of the UAV flying path.
[23]	Yes	Yes	No	Multiple	Maximization of data delivery.
[24]	Yes	No	Yes	1	Optimization of localization
[25]	Yes	Yes	No	1	Minimization of system energy consumption.
[26]	Yes	Yes	No	Multiple	Maximization of data delivery.
[27]	Yes	Yes	No	Multiple	Optimization of the speeds of UAVs.
[28]	Yes	Yes	No	Multiple	Maximization of data delivery.
[29]	Yes	No	Yes	Multiple	Optimization of localization in three-dimension space.
[30]	Yes	No	Yes	1	Optimization of real-time localization.
[31]	Yes	Yes	Yes	Multiple	Maximization of data delivery.
[32]	Yes	Yes	Yes	Multiple	Energy efficiency maximization.
[33]	Yes	Yes	Yes	1	Maximization of data delivery.

¹ M.C. is the abbreviation of "Maintain Connectivity".

² D.C. is the abbreviation of "Data Collection".

³ Loc. is the abbreviation of "Localization".

⁴ N_{uav} is the number of UAVs.

2.3.2. Data collection

In traditional data collection protocols, sensors were usually assumed to be static and densely deployed. Sparse and mobility were not considered because they cannot maintain connectivity of the network. Thus, the nodes may not be connected through multi-hop paths. After the introduction of mobile nodes, how to collect data from the mobile nodes becomes a new challenge.

Data collection has been addressed extensively in the literature. In [34,35], the authors proposed an energy conservation scheme to extend the network lifetime, and the data collecting time is extended accordingly. In reference [25], the authors attempt to make full use of integrating small-scale UAV in a ground wireless network for information collecting

and environmental monitoring and surveillance. The cost-reducing and energy-saving were conducted through using small-scale UAVs.

In [26], the authors address the data gathering problem of how to efficiently utilize the battery power for the maximizing data collection performance in rechargeable WSN. The rechargeable sensor network can provide enough energy to maintain the system connectivity. In [27], the authors propose the optimal speed control of the UAV which could helps the system to collect data efficiently. Both of them are based on a single UAV. Authors in [28] address the data collection issue through multi-UAVs, in which both the packet received ratio and packets tracking ratio were evaluated. However, the fairness and collisions between UAVs are failure to considered in this work. And this is one of the main contributions that the authors in [23] have done. The authors concentrate on the problem of data gathering from scattered sensors through integrating several UAVs in the context of large scale sensor networks. A heuristic algorithm based on a column generation approach was proposed and the results perform well.

The main idea of these research is to extend the data collection time through extending the network life time. They pay little attention on the impact of the network topology on data collection. In U-WSN, the dynamic topology has a critical influence on the connectivity of the wireless network. It will directly affect whether a route is created between two nodes and the endurance of the connection.

However, most of existing works address the static network topology. The authors concentrated on the dynamic topology in [18–20], both the mobility of the UAV and sensors are considered. The authors fail to present all the relationships between the mobility and the data collection because of space limitations. In section 4.2, we address the impact of the dynamic topology on the connection. In Table 5, we give a summarisation and comparison of using UAV for data collection in the existing applications.

2.3.3. Localization

Location-based services in variety of applications, such as weather forecasting, traffic monitoring, smart home [36] and rescue application. Global Positioning System (GPS) [37] is a solution in such applications. GPS works well on localization when the applications are implemented outdoor. It is better for the GPS to be used far enough from buildings or obstacles otherwise GPS signals become unreliable. However, GPS has high power consumption, especially in large scale networks, and poor performance when applied indoors. Thus, a large number of works have been done to optimize the location-aware performance.

Various types of categories of existing localization methods have been introduced according to different standards, range-based and range-free, coarse-grained and fine-grained, cooperative and cooperative-free, networking centric positioning and self-positioning. Among these classifications, the Range-Based and Range-free algorithms are the typical one according to whether to use range information. Typical Range-Based algorithms like Time of Arrival (ToA), Time Difference of Arrival (TDoA) and Received Signal Strength (RSS). Range-free methods calculate the location information from the connectivity information.

There is a huge scope of application offline training for localization. Thus, it is critical for the localization mechanisms to implement the training step for taxonomic hierarchy in the infrastructure of internet of things. The localization algorithms are classified into two categories, self determining and training dependent methods, if we take into account the internet of things scenario.

Localization methods with mobile nodes are the best solutions regarding these issues. Vehicles moving in the interesting area and broadcasting 'beacons' messages, through which vehicles can self-localize via combining with appropriate methods. Nodes that have received the 'beacon' messages are within the transmission range of the mobile vehicles. Through combining with proposed technologies, the sensor nodes can give an estimation about their locations after enough 'beacons' messages are received. The vehicle-aided localization algorithms are classified into two categories, static vehicle-aided localization

and mobile vehicle-aided localization. In static vehicle-aided localization algorithms, e.g., in [38], the localization accuracy depends on many factors, the number of vehicles, the deployment and the trajectory of the vehicles, etc. It can be predicted that uniform deployment in high density will bring a high localization accuracy. However, it also leads to high hardware cost and energy consumption. The UAV, which moves at a high speed and has high flexibility, works as a mobile vehicle which is the best choice in such applications.

In the context of U-WSN, the authors in [29] address the issue of how to achieve three-dimensional localization using a UAV. In this work, sensors are deployed in the monitoring area without equipped a GPS while UAV is equipped with a GPS. UAV flies over the area and broadcasts 'beacon' messages which include the geographical information of the UAV. The nodes that received the 'beacon' messages are able to estimate their geographical positions through combing with appropriate technologies. However, it is not a real-time algorithm. Authors in [30] proposed a real-time localization algorithm using Extended Kalman Filter which is based on time difference of arrivals. The proposed algorithm works well on the estimation of sensors positions. In section 4.2, we focus on the dynamic topology wireless network and give a definition on the relationship between the UAV and the mobile nodes, based on which the nodes positions could be well estimated. In [39], the authors give a summary on mobility-assisted localization algorithms in wireless networks.

In Table 5, we summarize the use of UAV for localization in the existing applications. Thereafter, the functionalities of UAV as a communication node are detailed in Table 5.

3. Factors Influencing U-WSN Design

A U-WSN design is influenced by many factors, including architecture of U-WSN; relative motion between the UAV and the Sensors; fault tolerance; scalability; production costs; operating environment; hardware constraints; transmission media; and power consumption. These factors are addressed by many researchers as surveyed in this paper. However, none of these studies has a full integrated view of all factors that are driving the design of sensor networks and sensor nodes. These factors are important because they serve as a guideline to design a protocol or an algorithm for sensor networks. In addition, these influencing factors can be used to compare different schemes.

3.1. Architectures of U-WSN

In the architecture design, the main objective is to impose few requirements to the execution capabilities of the UAV. Basically, the UAV is able to move to a given location and activate their payload when required. Then, according to different applications, UAV is integrated in different architectures. The global picture of the main architectures in U-WSNs is shown in Fig. 1. The general architecture could be mapped to various specific scenarios. In the following, we introduce the links and the relevant technologies with their application fields in Fig. 2.

3.1.1. Sensor-Sensor Link (S-S)

The communication between sensors is the basic one included in other links. A low energy and data rate protocol can be used. The standard IEEE 802.15.4 [40], along with the corresponding upper layers which are compliant with the ZigBee [41] protocol stack, is typically used at this link layer. Generally, the data-rate is less than 1 *Mbps*.

3.1.2. UAV-Sensor Link (U-S)

In the link between UAV and sensor, the UAV usually acts as a mobile sink. The distance between the UAV and a sensor is ranging from several meters to hundred meters. In the case of close range, the U-S links could apply the technologies as in S-S link. The connection between UAV and sensors is able to use the IEEE 802.15.4 (ZigBee) and IEEE 802.11ah (WiFi) [42] protocols. These protocols have the medium range that could achieve several hundred meters.

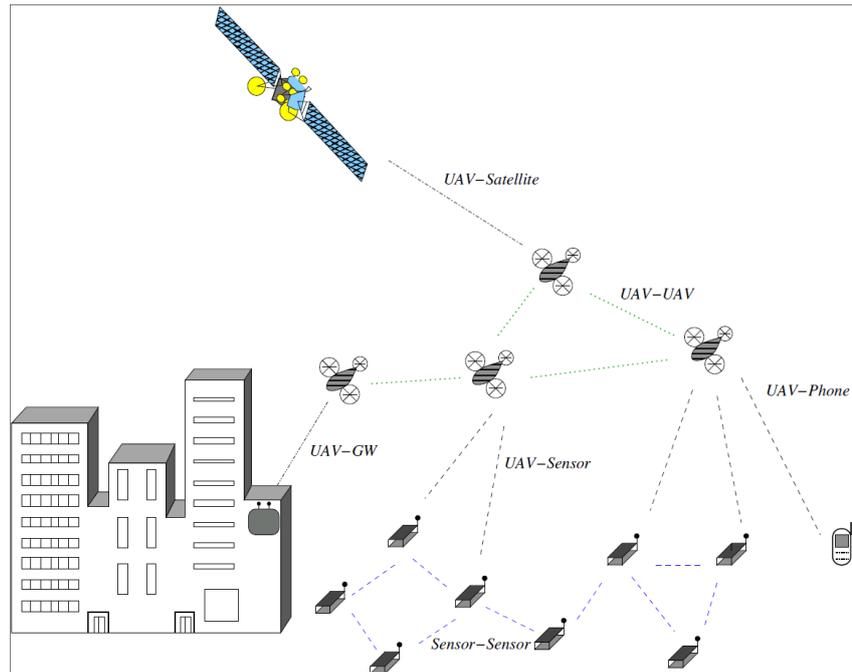


Figure 1. A general architecture of U-WSN.

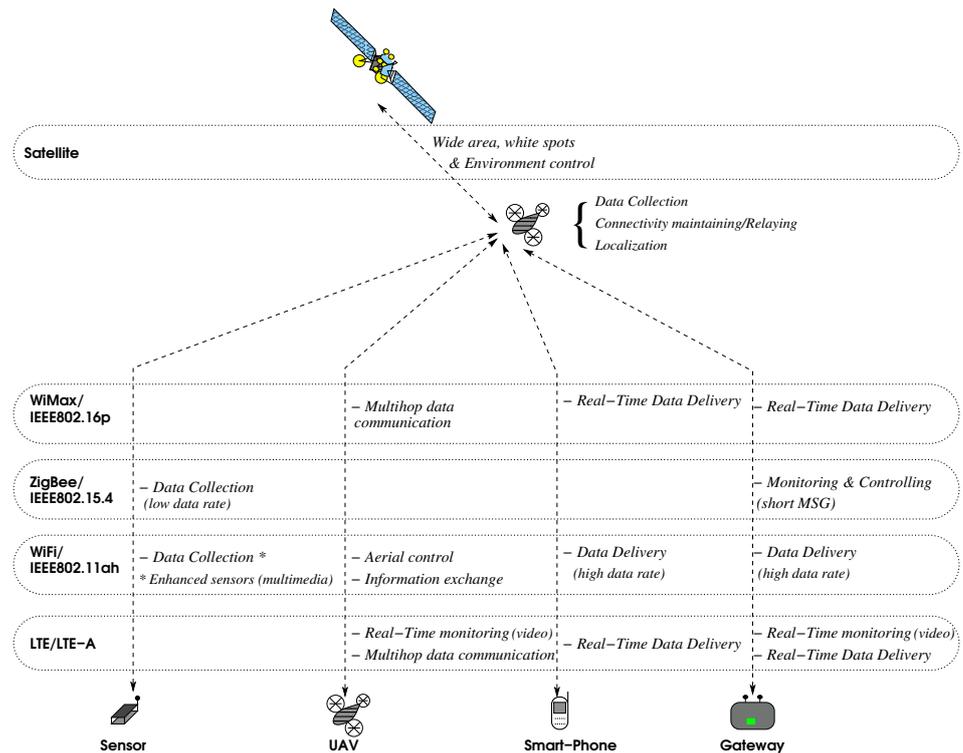


Figure 2. Links, technologies and applications of UAV-assisted WSNs.

3.1.3. UAV-Smart Phone Link (U-SP)

In some applications, the UAV is connected to smart-phone in order to collect data from the phone. The commutation range between them is medium. Thus, the U-SP link basically uses the medium range protocols such as IEEE 802.11ah (WiFi) and IEEE 802.16p (WiMAX), which are adapted for machine to machine communication. Adaptations of LTE-Advanced (LTE-A) are also experimented [43].

3.1.4. UAV-GateWay Link (U-GW) 253

Similarly to U-SP, the connection between UAV and gateway used to collect information. Thus, their communication range are at the same level. The U-GW link use medium range protocols such as IEEE 802.16p (WiMAX) for real-time data delivery and LTE/LTE-A for transmitting large data (e.g. video) in real-time monitoring. 254
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3.1.5. UAV-UAV Link (U-U) 258

In this category, the data transfer between UAVs, and the UAV create link with UAV. The protocols, e.g. IEEE 802.11, IEEE 802.16p (WiMAX), with medium range can be used to achieve the connectivity between the UAVs. In real-time applications, the U-U links can apply LTE/LTE-A. 259
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3.1.6. UAV-Satellite Link (U-SL) 263

In some applications, the UAV is connected to satellite. The communication range is long. To achieve the long distance connectivity, the Random Access (RA), hybrid schemes and Demand Assignment (DA) schemes are usually used. In Fig. 2, we give a summary and comparison of their technologies and applications. 264
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3.2. Scalability 268

The number of sensor nodes may be in the order of hundreds or thousands, or reach an extreme value of millions. The network topology is dynamic The new schemes must be able to work with this number of nodes and utilize the high density of the network. The density gives by the number of nodes within the transmission radius of each node in region A , and it can be calculated according to [44] as 269
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$$\rho(R) = \frac{N\pi R^2}{A} \quad (1)$$

where N is the number of sensors in region A , and R is the radio transmission range. In general, the density can be as high as 20 sensor nodes per m^3 [45]. The node density depends on the application. For the vehicle tracking application is around 10 sensor nodes per region [45]. A home may contain around two dozens of home appliances containing sensor nodes [46], but this number will grow if sensors are embedded into furniture and other miscellaneous items. For human motion tracking application is around 5 nodes per $5 \times 5 m^2$ [31]. For habitat monitoring application, the number of sensor nodes ranges from 25 to 100 per region [47]. 274
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3.3. Fault Tolerance 282

Some sensor nodes may fail or be blocked because of power exhaustion, the UAV's motion, or environmental interference. The failure of sensor nodes should not affect the overall task of the U-WSN. This is the reliability or fault tolerance issue. Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures [48,49]. The reliability $\gamma(t)$ or fault tolerance of a sensor node is modelled in [49] using the Poisson distribution to capture the probability of not having a failure within the time interval $(0, t)$: 283
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$$\gamma(t) = \exp(-\lambda_k \cdot t) \quad (2)$$

where λ_k and t are the failure rate of sensor S_k and the time period, respectively. Note that protocols and algorithms may be designed to address the level of fault tolerance required by the applications. If the studied environment has little interference, then the protocols can be more relaxed. For example, if sensor nodes are being deployed in a house to keep track of humidity and temperature levels, the fault tolerance requirement may be low since this kind of sensor networks is not easily damaged or interfered by environmental noise. On the other hand, if sensor nodes are being deployed in a battlefield for surveillance 290
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and detection, then the fault tolerance has to be high because the sensed data are critical and sensor nodes can be destroyed by hostile actions. As a result, the fault tolerance level depends on the application of the U-WSN, and the schemes must be developed with this in mind.

3.4. Power Consumption and Network Lifetime

The wireless nodes and the UAV are powered by battery which has limited power source. Both the lifetime of the sensors and the UAV show a strong dependence on the micro-electronic device lifetime. Therefore, power conservation and power management take on additional importance. It is for these reasons that researchers are currently focusing on the design of power-aware protocols and algorithms for sensor networks.

The main task of a sensor node in a sensor field is to detect information and forward them. And the main task of the UAV is to load sensors or devices. Hence, the power consumption of the sensors includes three phase: *UAV flying, sensing, communication, and data processing*. The main power consumption of the UAV is the movement consumption [31]. It cost a lot when it flying at an altitude [31]. And there is a big gap between the energy consumption during different UAVs [31]. The sensing unit and the data processing are the same as in traditional WSN [50]. For the communication unit, it was noticed that, in a U-WSN, the communication contains two phase, the communications between sensors on the ground and the communications between the on-ground sensors and the air sensors that deployed in the UAV. And the communications between the ground sensors is able to adopt the model as presented in [50]. In this section, we will focus on the air-ground communication.

3.4.1. Power Consumption during Air-ground Communication

The Signal-to-Interference-and-Noise Ratio (SINR) is used to measure the achievable throughput and link quality. Suppose that, the SINR is denoted by S_{inr} , then,

$$S_{inr} = \frac{P_r}{P_{s,r} + P_{n,r}}, \quad (3)$$

where $P_{s,r}$ is the interference power summing at the receiver, $P_{n,r}$ is the receiver noise power, P_r is the received power from the serving transmitter. For a particular application, in order to achieve the required throughput, the SINR is set at a given throughput (denoted by $S_{inr,0}$) through adjusting the transmitter power. The energy consumption involved in the process of delivering a message (from a ground node) towards an aerial collector over a session interval Δt , can be given as the following [51],

$$E_{S_i} = S_{inr,0} \cdot (\overline{P_{I,a}} + P_{n,p}) L_{S_i} \cdot \Delta t, \quad (4)$$

where $\overline{P_{I,a}}$ is the average aerial interference power, and $P_{n,p}$ is the platforms noise power. Then, the total energy consumption is obtained ¹,

$$E_{all} = \sum_{i=1}^N E_{S_i}. \quad (5)$$

3.4.2. Network Lifetime

Network lifetime is a key design consideration for battery-powered U-WSNs. There exist number of research focus on the lifetime maximization issues [52,53] or on the prediction of the remaining lifetime [54,55]. Other research focus on the energy-efficiency issues so as to extend the network lifetime [56–59], and the trajectory planning of the UAV is one of the most consideration among these schemes [32,60,61]. Although a number of studies have been done for network lifetime, U-WSN still face some issues, e.g., the collisions and

¹ Generally, the main focus is in the energy consumption of the sensor nodes, and, it assumes that the network is not constrained by the possible limitation in the aerial platforms energy. Accordingly, its energy consumption is not account.

re-transmissions during communications, which cannot fully avoided in applications that degrade the lifetime.

3.5. Security and Regulation

Security and regulation of the data collected from a U-WSN, either while stored inside the UAV or during their transmission from the UAV to a gateway, is a major unsolved concern. Furthermore, as thousands of businesses could receive clearance to fly drones in the near future, UAVs will face with various security issues such as loss of data, authentication, access control, and intrusion attacks. In U-WSNs, security solutions are required for data confidentiality, authentication and integrity at low cost.

Moreover, there are still many regulation issues to be resolved in the coming research. Indeed, there are many requirements from the governments to regulate where the drones fly and what is done with the torrents of data collected from aerial surveillance [62]. In fact, numerous civilian drone manufacturers claim that the main barrier in U.S. and Europe is not the technology, but the regulation. For instance, the U.S. FAA (Federal Aviation Authority) provide some basic regulations and restrictions of the airspace that will govern who can fly drones in the United States and under what conditions. A standard that is formulated by 2016 will permit unmanned aircraft systems (UAS) to interoperate with manned aircraft using an "electronic means" to see and avoid potential aerial disasters. Due to the UAV is flying in the same national airspace, it is crucial for the world to comply with a same safety regulations and restrictions.

4. Open Issues and Challenges

This section summarizes and discusses the open research issues and challenging future directions. L. Gupta et al. give a survey on important issues in U-WSN [63].

4.1. Synchronization Issues

The synchronization issue was a thorny subject in U-WSN, considering the limited communication time. In the past, many synchronization algorithms have been investigated to keep the synchrony of networked systems. The perfect time synchrony, Time-Diffusion Protocol (TDP) [64], was proposed by Su and Akyildiz. In the synchronization process, the TDP applies an iterative and weighted averaging mechanism built on the collected messages from the whole network. In reference [65], the authors through enhancing the TDP scheme to adapt to the particular applications (e.g., tracking and surveillance) that require global time synchronization and fault-tolerance. However, most of these research are based on traditional wireless networks. In the context of U-WSN, especially in dynamic topology, the beaconing mechanism is usually used for the network synchronization [18–20,66,67]. In [68], the authors give a survey on the synchronization in U-WSNs.

4.2. Relative Motion between the UAV and the Sensors

Both UAVs and targets are moving in U-WSN applications, such as animals monitoring. The topology of the network changes as the node and the UAV move. At this point, one node is within the range of the UAV, while at another time, it may be outside the transmission range. Thus, mobility directly affects the connectivity of the network. It has a significant impact on the data transmission performance of the network.

The duration that the mobile node is within the transmission range of the UAV has an essential impact on the performance of the network, which is defined as contact duration [18–20,31]. However, it only considers the case of mobile nodes and the same mobile direction as the UAV, the static case and opposite mobile direction with the UAV are not considered. In the following, we will give a complete definition.

4.2.1. Contact Duration between the UAV and the Sensor

In U-WSN with mobile sensors, the node has an opportunity to communicate with the UAV when they are within range of each other. The link duration is named as *contact*

duration [18–20,31]. As the "one UAV and one sensor" is the min-unit in U-WSN, we take this scenario where the UAV moves along a predefined path to maintain the network connectivity, for example, to calculate the *contact duration* (which is denoted as T_{cd} in this article).

According to the existing research, we refined the scenario into two categories: (a) both the UAV and the sensors move along a straight path, and (b) they move along a curved path. The other cases, e.g., the "trajectories" of the UAV and the sensors have some intersections, T_{cd} still need further study.

(a) Straight Path

When the trajectory of the UAV is a straight path, the scenario can be further refined as: sensor is static (Fig. 3), sensor and the UAV are move at the same direction (Fig. 4), and in the opposite direction (Fig. 5).

The relative movement distance between sensor and the UAV is denoted by d_r . UAV fly at a height h with constant velocity v . The range of the sensor is denoted by r . The original distance between UAV and node is d_x . Then, we will discuss the calculation of the contact duration time as follows:

- The node is static (Fig. 3). In this case, the relative velocity between the node and the UAV is v . The relative movement distance between them is $d_r = A_s B_s$, i.e.

$$d_r = 2(r^2 - h^2 - d^2)^{\frac{1}{2}}. \quad (6)$$

when the UAV is out of the range (Fig. 3(a)). In Fig. 3(b), when the UAV is within the range of the node, $d_r = D_s B_s$, i.e.

$$d_r = (r^2 - h^2 - d^2)^{\frac{1}{2}} + d_x. \quad (7)$$

The *contact duration* between the UAV and the static node, T_{cd} can be given by,

$$T_{cd} = \frac{d_r}{v}. \quad (8)$$

This is based on an assumption that the flying height of UAV is smaller than the range of the node ($h < r$) and the UAV is out of the range of the node in the beginning ($d_x > r$). The relative movement distance will be different if their topologies are changed (as illustrated in Fig. 4 and Fig. 5).

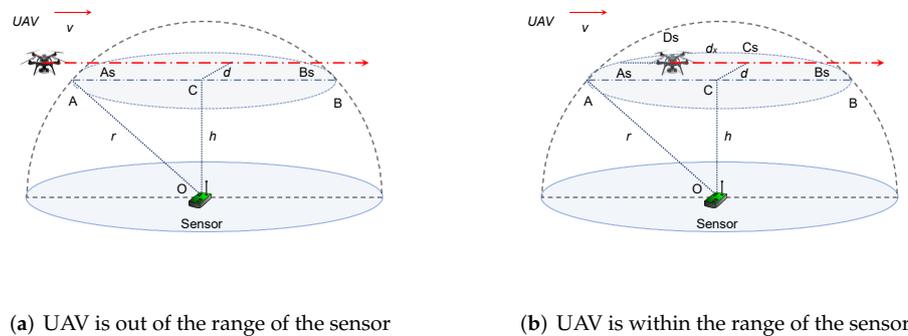


Figure 3. Simple scenario with one UAV and one Sensor (Static).

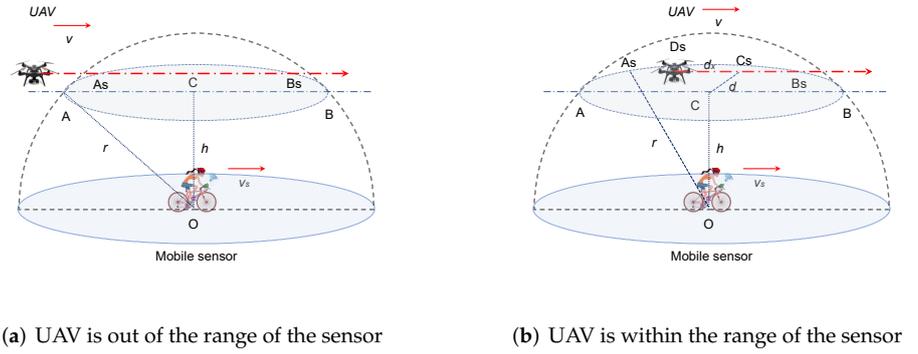


Figure 4. Simple scenario with one UAV and one Sensor (Same direction).

- The node and the UAV move at the same direction (Fig. 4). The sensor velocity is v_s . The contact duration time depends on the original deployment of the UAV if the sensor and the UAV have the same speeds ($v_s = v$). The relative velocity between the node and the UAV is 0. Let the moving time and distance of node are T and L respectively. The relative movement distance between the UAV and the sensor is $d_r = 0$ when the UAV is out of the range of the UAV ($d_x > r$ in Fig. 4(a)). $d_r = L$ when the UAV is within the range of the node ($d_x \leq r$ in Fig. 4(b)). When $v_s \neq v$, similarly to static case, the relative distance between them can be given by,

$$d_r = \begin{cases} 0 & v_s > v, d_x \geq r, \\ A_s B_s & v_s < v, d_x \geq r, \\ A_s D_s & v_s > v, d_x < r, \\ D_s B_s & v_s < v, d_x < r. \end{cases} \quad (9)$$

Then, according to equation (8) and Fig. 4(b), the T_{cd} between the UAV and the mobile sensor (moving at the same direction), can be given as in,

$$T_{cd} = \begin{cases} T & v_s = v, d_x \leq r, \\ 0 & v_s = v, d_x > r, \\ 0 & v_s > v, d_x \geq r, \\ \frac{2A_s C_s}{v - v_s} & v_s < v, d_x \geq r, \\ \frac{A_s C_s - d_x}{v_s - v} & v_s > v, d_x < r, \\ \frac{A_s C_s + d_x}{v - v_s} & v_s < v, d_x < r, \end{cases} \quad (10)$$

where $A_s C_s = (r^2 - h^2 - d^2)^{\frac{1}{2}}$.

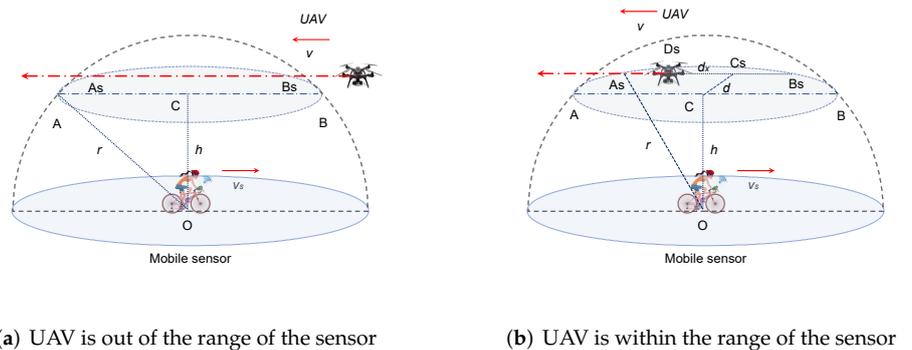


Figure 5. Simple scenario with one UAV and one Sensor (opposite direction).

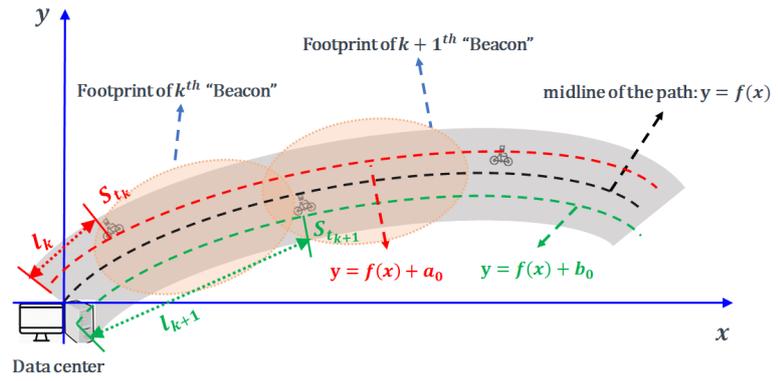


Figure 7. An illustration of the trajectory of S_i . In this figure, l_k is the curve length.

Let T_{cd,t_k} be the *remaining contact duration* of the node S and the UAV at t_k . It means that the S will out of the range of the UAV after T_{cd,t_k} , and it can be obtained through,

$$T_{cd,t_k} \doteq \frac{1}{v} \int_{x_{t_k}}^{x_{t_\lambda}} \sqrt{(1 + (y')^2)} dx, \quad (14)$$

with a boundary conditions $d_{t_\lambda}(U_{t_\lambda}, S_{t_\lambda}) = R$ where $t_\lambda = t_k + T_{cd,t_k}$ and R is the transmission range of the UAV. 437 438

4.2.2. Summary and Insight 439

Through reviewing the relative motion between the UAV and sensors, the contact duration between the sensor and the UAV is one of the key factor in the U-WSN applications. 440 441 The longer the contact duration, the higher opportunity for the communication between the sensor and the UAV. Conversely, the shorter the contact duration, the lower opportunity of the communication between them. Thus, the data transmission of the network can be better improved, if the contact duration is considered [18,33]. 442 443 444 445

Furthermore, the fairness of the network can be enhanced if the contact duration is considered when designing the routing protocols [48] or MAC protocols [20]. 446 447

4.3. Trajectory Planning of the UAV 448

As aforementioned, mobile vehicle based technologies are effective methods addressing localization issue because of its mobility and flexibility. Path planning is object to improve the localization accuracy with a best possible trajectory of the UAV. Proper path planning can guarantee good coverage of the whole sensing field as well as keeping the minimum path length. Study in [69] is an application to UAV path planning. An adaptive operator quantum-behaved pigeon-inspired optimization algorithm along with logistic mapping method were proposed in [69] for the application to UAV path planning. A comparison result presents that the performance of their proposed algorithm is better than parts of the existing algorithms in terms of convergence and accuracy. Indeed, according to different applications, many investigations with different objective functions and optimization methods have been done (we summarize them in Table 6). 449 450 451 452 453 454 455 456 457 458 459

Moreover, according to whether there is interaction between UAVs and nodes, path planning of U-WSN has two categories. First is static path planning in which the path is predefined and second is dynamic path planning in which the path can be changed. The existing algorithms are summarized and compared in Table 7. 460 461 462 463

Table 6. The objectives of path planning in U-WSN.

Objectives	Detail	Applications
$\max C(\mathbb{S})$	Maximization of the coverage of the whole sensing field. In some applications, it is better to make sure that all the nodes within the interesting area to be covered.	In [70], the authors formulate an area coverage reliability issue. Their proposed algorithm quantifies the network likelihood that the network can be in an operating state where the coverage condition is satisfied.
$\min P_{UAV}$	Minimization of the UAV flying path. The whole path length should be controlled to reduce the localization delay and the system energy consumption.	Authors in [22] proposed an effective path length reduction algorithm for UAV path planning which has a low computational complexity. The proposed algorithm not only used in control center but also in UAV controller.
$\min D_{UAV}$	Minimization of the UAV's travel duration. This objective helps the system to save energy consumption.	In [23], the authors address the path planning issue with the objective of the minimization of UAV's flying duration. Energy, fairness, collision and tracking between UAVs were considered.
$\max A(\mathbb{S})$	Maximization of the localization accuracy. This objective helps the sensors within the coverage be localized with high accuracy.	In [24], the authors address the path planning accuracy problem on U-WSN. They proposed a novel algorithm which considers the accuracy of positioning and the efficiency of flight.
$\min E_{wsn}$	Minimization of energy consumption. This is the main problem in almost all of the applications.	In [71], based on genetic algorithm, the authors proposed an energy efficient mechanism for autonomous UAV. In this algorithm, the authors considered the relief and obstacles.
$\max Q_{data}$	Maximization of the quality of data communication. The main objective in almost all of the application due to their research based on the collected data.	Authors in [72] proposed two data collection protocols (IDGP and DDGP) based on infrastructure through plan the mobile path.
$\max L_{network}$	Maximization of the network lifetime. The longer the network lifetime, the more collections of the network.	Authors in [32,60,61] proposed trajectory planning algorithms to extend the network lifetime.

\mathbb{S} is the sensor set.

4.3.1. Static path planning

In static case, the trajectory for mobile vehicles is determined in advance. Vehicle moves along the pre-determined trajectory strictly. The simplest case is that the vehicles move in Lines [73]. The vehicle moves in a predefined line and broadcasts gradient signals to localize the unknown node. The trajectory is a x-rays. Based on this, the algorithms can be SCAN, DOUBLE SCAN, and HILBERT [74]. In SCAN algorithm, the vehicle moves in one direction while it moves in both directions in DOUBLE SCAN method. In HILBERT SCAN scheme, the vehicle moves in the Hilbert pattern. They all have the same objective that is to maximize the network coverage, even in the corner. It can be noticed that some areas are visited frequently because of the linearity of the trajectory. Thus, curves were introduced. Circle and s-curve [75] are the critical methods to reduce localization col-linearity [75]². However, this types of scan leave the corner of the region. Thus, mobile anchor node centroid localization (MACL) algorithm [76] was introduced. In MACL, the mobile vehicle traverses the interesting area following a spiral trajectory and periodically

² In Statistics, the co-linearity refers to the fact that the explanatory variables in the linear regression model are distorted or difficult to estimate accurately due to the existence of precise correlation or high correlation between the explanatory variables. Thus, in the localization mechanism, the localization could be well estimated if the col-linearity could be reduced.

broadcasting beacon packets which contain its current position. More algorithms and their characteristics are summarized and compared in the Table 7. 478
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Table 7. Comparison of existing path planning algorithms based on mobility.

Algorithms	N_{mv} ¹	E_c ²	A_l ³	Advantages	Disadvantages
Static Path Planning					
Lines[73]	1	Low	High	The simplest path planning.	Shorter communication range.
SCAN, Double SCAN, Hilbert[74]	1	Medium	High	These algorithms are object to maximize the coverage.	They waste much of col-linearity.
Circle, S-curve [75]	1	Medium	Medium	No col-linearity	These algorithms leave the corner of the interest area.
MACL [76]	1	Medium	Low	In MACL, the vehicle moves along a spiral path and broadcasts 'beacon' (including the current location information) periodically.	The accuracy of the localization is about 50%.
PI [77]	1	Medium	High	Perpendicular Intersection (PI) is used to localize nodes. Vehicle moves in zigzag line with an angle within $(0, \frac{\pi}{3})$.	Energy consumption for turns are not considered.
LMAT [78]	1	Medium	Medium	In this algorithm, the vehicle moves along an equilateral triangle line to send 'beacons', through which, the sensors positions are well estimated even if the "beacon" are col-linear.	The authors fail to consider the energy consumption for turns.
S-type [79]	1	High	High	This algorithm achieves the shortest path through making the vehicle moves in 'S'. The interesting area is divided into small square (with each has a size of $\frac{R}{\sqrt{2}}$), based on which the col-linearity problem is solved.	Much energy consumed for turns and low vehicle utilization.
WCL [80]	4	High	High	In WCL algorithm, four mobile vehicles were used. They form a three-dimensional space and move in 3D-space, thereby, a 3D space network could be covered.	Due to 3D localization, this algorithm consume much energy. Beacon col-linear problem are fail to sloved.
Dynamic Path Planning					
MBAL [81]	1	Medium	Low	MBAL works better when the sensors are irregularly deployed.	This algorithm fail to consider the obstacle case.
BRF, BTG [82]	1	Medium	High	In the two algorithms, the network topology was regard as a connected indirectly graph. And they are able to localize all the sensors if they are densely deployed.	Both the two algorithms have high real-time requirements.
MBL(ndc) [83]	1	High	High	It is a dynamic trajectory planning algorithm.	The algorithm complexity is high when the network size is large.
MALS [84]	1	Medium	High	This algorithm is proposed based on clustering mechanism. And it is designed for non-uniform and irregular deployment scenarios.	Due to it is based on clustering, thus, high localization delay is brought.
DREAMS [85]	1	Medium	High	In DREAMS, the sensory field information are not required in advance.	It performs normal when the node failure is presence.
Virtual Ruler [86]	2	High	High	In virtual ruler, it can be measured in different values from different point of view. It is applicable for obstructed networks.	In this algorithm, all unknown nodes are required to deploy an ultrasound receiver or "beacon".

¹ N_{mv} is the number of mobile vehicles.

² E_c is the energy consumption. Here, we have three levels: "Low", "Medium" and "High" which are from the original references that the algorithms are defined.

³ A_l is the localization accuracy. A_l has three levels: Low: $A_l < 70\%$; Medium: $A_l \in [70\%, 90\%]$; High: $A_l \geq 90\%$.

4.3.2. Dynamic path planning 480

Static path planning algorithm works well when the unknown nodes are assumed to be uniformly deployed. However, it may not be a better solution when the nodes are deployed disarray. Due to the disarray deployment, it spends a lot of localization time and moves long path if the system use the static path planning algorithms. Some researchers concentrate on the work of dynamic case to fully utilize the distribution information and minimize the energy consumption and path length. In dynamic case, none of the mobile path is defined in advance. All of the trajectories are determined based on the real-time information. 481-488

A large number of investigations have been done on dynamic path planning. Due to the dynamic characteristics, one of the central issues is whether to consider obstacles. Thus, the existing dynamic path planning algorithms can be classified into two categories, with and without obstacle. 489-492

Authors in [81] proposed a movement mechanism, mobile beacon-assisted localization (MBAL). It is a low computational complexity algorithm among movement path planning algorithms. However, the obstacle case is not considered. In [82], the authors proposed two algorithms, Breadth-First (BRF) and Backtracking Greedy (BTG) algorithms, based on which all nodes could be localized. However, it requires very high real-time condition. We give a summarizing and comparison in Table 7. 493-498

4.3.3. Summary and Insight 499

Through reviewing the static and dynamic path planning of mobile vehicles (as presented in Table 7), we notice that few algorithms use extra hardware to plan the trajectory. Most of the existing algorithms use col-linearity principle [75] of mobile vehicles. A single mobile vehicle would be cheaper. However, it may bring more col-linearity or longer localization time issues. Multiple mobile vehicles could help to reduce the localization time, especially in 3-dimension scenarios. 500-505

Compared to the dynamic case, static path planning algorithms fail to fully utilize the real-time information that obtained. In practical applications, the environment where the sensors are deployed is full of uncertainties, and therefore, dynamic path planning performs better than pre-defined one because it can consider more real-time information. The main issues in dynamic path planning are adaptability and computational complexity. In the existing dynamic path planning algorithms, which applied in obstructed scenarios, it is assumed that the nodes are equipped with hardware (such as cameras, radar, infra-red, sonar, etc) for detecting obstacles. Based on these, the dynamic algorithms are recognized to fully use the real-time information and they are more accepted for areas with uncertainties. 506-514

5. Discussions 515

In this section, we introduce a working example to discuss the aforementioned factors and issues. 516-517

5.1. A Working Example 518

Without loss of generality, take the UAV trajectory as a curve. In the following, we take the scenario as presented in Fig. 6, which has one UAV and multiple sensors, as an example. As shown in Fig. 6, the data center is set at the original center point of the path, sensors are deployed in the front part of the predefined path and move along the path. The UAV takes-off from the data center and flies to the given height h , and then, flies along the path with a given speed v to collect data from sensors. 519-524

The main energy consumption of such scenario is the energy consumption of the battery [31]. Thus, the network lifetime depends on the UAV flying time. We set it as 300 seconds in the simulation. 525-527

We used periodic beacon mechanism to synchronize the network. The UAV sends a beacon message to its surrounding coverage to announce its coming. The sensors that received the beacon send a join message which contains the location and the speed to the 528-530

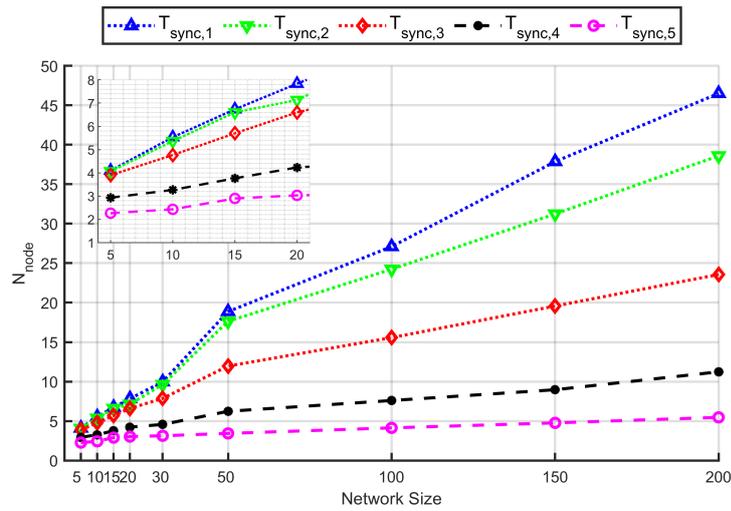


Figure 8. The number of sensors (N_{node}) that participate the communications. The $T_{sync,i}$ ($i = 1, 2, 3, 4, 5$) are the synchronization intervals.

UAV. After the reception of the join messages from the sensor nodes, the data collection phase starts. The interval between adjacent beacons is named as synchronization intervals, and denoted as T_{sync} .

Fig. 8 presents the scalability and the data collection performance of the network in different synchronization intervals and network size. It shows that the shorter the T_{sync} , the larger the N_{node} . This is because, the shorter T_{sync} brings larger number of nodes that are detected. Thus, the number of nodes that participate the communication increased. It is also able to enhance the fairness of the network when appropriate T_{sync} was selected. This is because the appropriate T_{sync} brings the communication opportunity of those nodes that will never be detected in other case.

5.2. Extension of the U-WSN use-case to NTN-Aided IoT

The current state of the art shows the need for 3D modeling and simulation of NTN, including moving in space connected objects. Problems studied in the case of UWSN could be extended to general non-terrestrial network use cases. Opportunistic routing under energetic constraints is challenging, particularly in autonomous crewless vehicles and nano-satellites. Even though recent works on energy harvesting show the opportunity to optimize the overall system either through flying ad-hoc networks deployment [87] and drones trajectory control [88] or by using efficient data collection [89] combined with fast wireless power transfer [90]. The system control could be via centralized, distributed, or multi-tier architectures. Designed for WiFi devices, crowd-based schemes [91] allow autonomous adaptive placement without exploiting the device's location. The applicability of those distributed schemes raises energy optimization needs when it is a matter of things with low-power. The self-organization of the NTN is particularly challenging, to efficiently collect and send data via the network on intermittent connection to infrastructure to the cloud. Autonomy and placement to maintain permanent connectivity [92] dictate revisiting communications from UAVs to the cloud, which are investigated in the context of 5G and beyond [93].

Furthermore, in addition to the issues mentioned in this paper, there are wide open challenges in U-WSN applications. For example, the charging challenges, collision avoidance and swarming, etc.

The UAV missions necessitate effective energy management for battery-powered UAVs. Reliable, continuous, and intelligent management can help UAVs achieve their missions and prevent loss and damage. The UAV's battery capacity is a crucial factor in

enabling sustainable missions. But as the battery capacity increases, its weight increases, which causes the UAV to consume more energy for a given task. The main directions in the literature to mitigate the limitations in UAV batteries are UAV battery management [94], wireless charging for UAVs [95], and solar powered UAVs [96].

UAVs can collide with obstacles by moving or stationary objects in indoor or outdoor environments. Therefore, during UAV flights, it is vital to avoid accidents with these obstacles. Thus, the development of UAV collision avoidance techniques has gained research interest.

5.3. Future Edge flying Servers

Edge computing is an optimization method that consists of processing data at the edge of the network, close to the data sources, i.e., near the sensors (at the border of the IoT perception layer). Basics of Mobile Edge computing are provided in [97]. Drones with more computing capacity than sensors can thus play the role of Mobile Edge Servers. Therefore, it would be possible to minimize the bandwidth requirements between the sensors and the data processing centers by undertaking the analyses as close as possible to the On-ground data sources. There are several advantages to placing computation at the drone level. Indeed, this makes possible the placement of functions to reduce the volumes of data to be transmitted, perform complex tasks in particular for reconfigurable sensor architectures, correlate data from heterogeneous sources, etc. Furthermore, UAV-enabled Edge computing in IoT helps to avoid the transmission of irrelevant data to data centers or the cloud, thus bringing fluidity and speed of analysis and decision-making.

UAV-enabled edge server approaches require mobilizing resources that may not be permanently available. Consequently, the same networking challenges highlighted above are raised: the intermittency of the links, the Air-Ground contact duration, and the energy consumption, but also computing ones such as responsiveness and prioritization of task execution. Several issues can be considered in UAV-enabled edge computing for IoT, particularly those of data and task offloading.

6. Conclusions

In this article, we provided the main basics and features of UAV-enabled wireless sensor networks. Compared to traditional WSN, UAV-enabled WSNs present different issues and challenges. Through detailed analysis of the existing U-WSN applications, we refined the performance and the capability of the UAV and its functionalities when used as a communication node. In addition, the architectures, standard technologies, open issues, and challenges that emerge from this new paradigm are also mined. These insights may serve as motivations and guidelines for future designs of U-WSN.

The high flexibility of the UAV and the high dynamic topology of the network create new problems that cannot be ignored, the *contact duration*. In the future, the remaining contact duration between the UAV and the sensor would be a key criterion when addressing the issues in U-WSN, especially in the context where the sensor nodes are mobile. Because of the relative movement of the UAV and the sensors, the factors that influence the U-WSN design show difference from WSN. The UAV trajectory planning has become a link that cannot be crossed in the design of a U-WSN.

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