# Improving the Energy Efficiency of a LoRaWAN by a UAV-based Gateway

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***Abstract*—The Internet of Things (IoT) devices and applications are spreading all over around us to become the cardiovascular infrastructure for the data of the cyber-physical systems of the future. The implementation of a reliable collection of telemetry data within various application domains, including medicine, safety, and security, industry, smart cities, or environmental monitoring, to name just a few, is among the major challenges still to be solved. Importantly, many of the use cases imply a huge geographic area span or operation in remote areas with limited infrastructure availability and poor reachability. To address these scenarios in this paper, we propose a combination of the two technologies  the Low Power Wide Area Network (LPWAN) and the Unmanned Aerial Vehicles (UAVs). Specifically, we study the energy utility and the communication performance of introducing a UAV-based GW into an LPWAN based on the LoRaWAN technology. The results of our simulations show that a UAV-based GW enables to reduce the mean energy consumption for communication in the network by up to 59%. Depending on the UAV speed, the communication performance in terms of the packet delivery ratio can either increase or decrease by several percentage points.**

***Index Terms*—LPWAN, UAV, gateway, LoRaWAN, low power, energy efficiency, wide area network, wireless, communication.**

## I. Introduction

In the modern world, fast and resource-efficient collection of large amounts of data is of extreme importance. This challenge is today faced by virtually every application domain. This fact stimulates the design of solutions for wireless data collection (i.e., the telemetry), facilitates the development of novel concepts and applications, and drives new devices to the market. The concept of the Internet of Things (IoT) [1], [2], which refers to the interconnection of a variety of physical objects through information and communication technologies, attempts to harmonize and provide a common basis for the versatile solutions.

The poll of the IoT-grade wireless communication solutions available today is excessively diverse. Some of them have been developed for short distances - few centimeters to dozens of meters. Zigbee, Bluetooth, infrared, near field communication and ultrawideband are prime examples of these technologies. However, the current primary trend for massive machine type communication (MMTC) is to go for long-range communication while keeping the consumption low. These communication technologies are known as the Low Power Wide Area Networks (LPWAN). Among these are the LoRa Wide Area Network (LoRaWAN) and Sigfox, operating in the not-licensed spectrum, or NB-IoT operating in the licensed spectrum [3]. The LPWAN technologies have been in active deployment through the past few years and many regions are already covered by one or even several networks. Still, there are many use cases, especially in the context of smart agriculture, infrastructure or wildlife monitoring, for which the infrastructure is either not in place or is populated sparsely. Importantly, the sensors in these areas often feature poor reachability resulting in the high cost of their service (e.g., the replacement of their batteries) or replacement.

To address this challenge in this paper we propose using the unmanned aerial vehicle (UAV) within a LoRaWAN-based LPWAN to collect the periodic data reports from the sensor devices. By means of in-depth simulations, we investigate the effect of the different configuration parameters, such as the UAV trajectory or speed, on the most crucial application performance metrics  the data delivery probability and sensors' energy consumption. These results constitute the main contributions of this paper.

## II. Related Works

A brief overview of the different LPWAN technologies is provided by the authors in [3]. The study highlights the strengths and weaknesses of each technology, including that of the LoRa Wide Area Network (LoRaWAN). Today, this technology became one of the most widespread LPWAN solutions operating in the license-exempt frequency bands. In more details this technology is discussed in [4], where the authors investigate the scalability of LoRaWAN and reliability of the data transfer (with respect to packet delivery ratio - PDR) for the typical use case scenarios. These results are detailed further in [5]- [8] by accounting the non-ideal orthogonality of the signals with different spreading factors (SFs) and other relevant issues. The energy aspects of LoRaWAN communication have been studied in [9].

Meanwhile, recently, the studies in which the authors suggest UAVs be used for improving the performance or enabling new functionalities within LoRaWAN have started to appear. Specifically, in [10], the UAVs are used to charge the LoRaWAN devices, and in [11]- [13], the UAVs are used to collect the data from LoRa and LoRaWAN sensors. In [11], the authors investigate how a drone-based gateway (GW) can improve the reliability of LoRaWAN communication in urban scenarios. In [12], the authors assess how much can a drone increase the coverage of the network. The author of [13] investigates how to use the groups of UAV-based LoRaWAN GWs to improve the data delivery reliability. Nonetheless, to the best of our knowledge, none of the current studies focuses on the LoRaWAN end device energy consumption and lifetime improvements enabled by the UAV GWs. Another issue, which has barely been investigated is the effect of the drone mobility parameters (e.g., the trajectory and speed) on the energy and data transfer performance of the LoRaWAN. In this paper, we address this omission and investigate these tradeoffs.

## III. Technical Background

### A. LoRaWAN Technology

The physical layer of the LoRaWAN technology is primarily based on the use of LoRa proper chirp-spread-spectrum modulation technique, patented by Semtech, which is defined by the three key parameters:

- Bandwidth (BW). In the EU bands typically the BW of 125 kHz is set.
- Coding Rate (CR). The coding rate of the forward error correction (FEC). It can take values from 4/5 to 4/8, but for LoRaWAN the rate of 4/5, enabling detecting errors but not correcting them, is used for data payload.
- Spreading Factor (SF). The LoRa SF is directly related to the duration of the chirp and typically ranges from seven to twelve. As the spreading factor increases the symbol rate, given by $RS = BW/2^{SF}$, decreases, thereby trading the data rate for range increase [6]. The SF typically takes the values from 7 (minimum range but fastest transmission) to 12 (maximum distance and slowest transmission). The signals with different SFs are not perfectly orthogonal and require to have a power margin of -7 to -25 dB, depending on the combination of target and interfering SF, to be received correctly [14].

The LoRa Alliance defines the medium access (MAC) and network layers in a separate specification [19]. The specification defines three different LoRaWAN device classes, named A, B, and C. The support of class A functionality is obligatory for each LoRaWAN device. These devices can transmit their data in uplink at any moment of time implementing ALOHA-like channel access while respecting the duty cycle restrictions imposed by the frequency regulation authorities. The frequency channel is selected by a device randomly from the poll of the channels listened by the network. To enable downlink communication, a device opens up to two receive windows following an uplink transmission. In addition to these, the devices of class B support periodic receive windows, and devices of class C stay in receive all the time they do not transmit.

The LoRaWAN network, schematically depicted in Fig. 1, is composed of a single network server (NS), optionally a join server (JS) handling the connection and roaming, the optional application servers (AS), one or several GWs, and end devices (EDs). All data sent by the end devices in uplink go through the GW to the NS, and, optionally, further to the respective ASs. The downlink traffic goes vice versa.

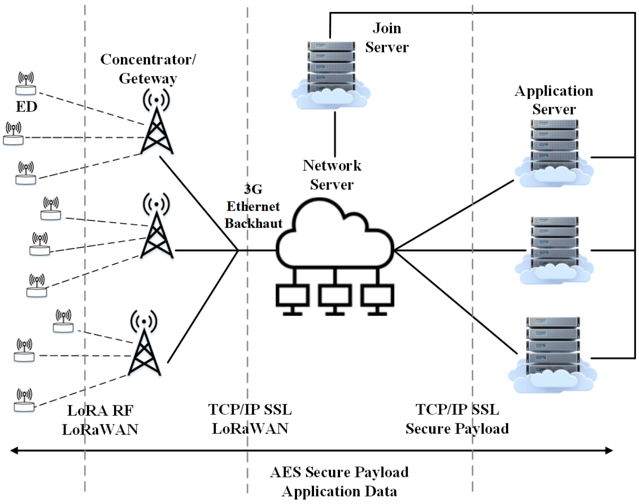


Fig. 1. Structure of a typical LoRaWAN network.

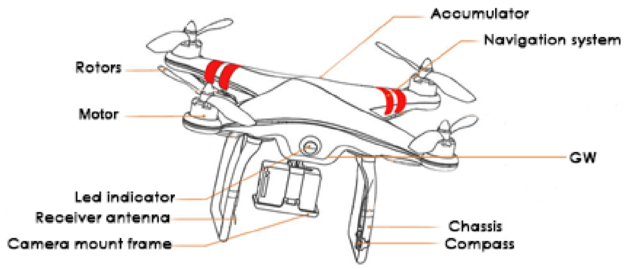


Fig. 2. Structure of the considered multi-rotor UAV.

Among other notable LoRaWAN features can be listed the Adaptive Data Rate (ADR) [16] mechanism. This mechanism enables the adaptation of the SF and the transmit power to the channel conditions experienced by each particular ED.

### B. UAV Technology

The UAV refers to an aircraft, which operates without a pilot on board completely autonomously or under the control of a remote operator from the ground. Previously used mostly for military purposes, these days the UAVs are getting extensively used in various civilian applications. Depending on the design, the UAVs can be classified into several groups:

- Fixed-wing UAV. These UAVs are equipped with a fixed-wing [17], the surface of which creates the lifting force. Due to the rigid wing, the drone has glider characteristics and is more resistant to piloting errors or technical malfunctions. Fixed-wing UAVs can also carry more load over long distances with less energy. These UAVs are great for longer missions but cannot hang over one place.

- Rotary wing UAV. These UAVs operate with the lifting force created by a rotor [18]. The main advantage of this type of UAV is the possibility of vertical take-off and landing, allowing to use them in small spaces. The ability to hover and maneuver allows these UAVs to perform high-precision missions. The downsides are more complex maintenance, higher consumption, and lower weight load.
- Multi-rotor UAV. These UAVs are equipped with several (typically 3, 4, 6, 8, 12 or 16) rotors [19]. Being similar to ordinary rotary-winged drones, these UAVs are easier to manage and more stable. This enables to use them for the missions that require exceptional accuracy (e.g., filming).

The main elements of a multi-rotor UAV, considered in this study, are depicted in Fig. 2.

### C. Legal regulations on UAV use

Addressing the massive use of the UAVs and the several UAV misuse accidents, in recent years a set of legal regulations have been introduced in different countries. Below we summarize some of them.

**Austria.** Obligatory pilot license and insurance for drones with the kinetic energy of above 79 Joules (e.g., 250 g at 30 m height) or flying above 30 m height [20]. Flights over crowds and near airports prohibited. Flights with commercial purpose require permission.

**Finland.** Maximum flight height of 150 m [21]. Electronic notification before the flight [22]. Designated recommended hobby flight areas [23]. The drone must be marked with the owner's contact information. Flights over crowds and near airports prohibited.

**Russia.** Obligatory registration of UAVs weighing more than 250 g [24]. Flights of such drones need to be notified in advance. Particular areas are closed for UAV flights.

**UK.** The Civil Aviation Administration (CAA) [25] allows to fly the drones weighing below 20 kg without registration and licensing under the following conditions:

- The UAV should be used within the "line of sight," i.e., within 500 meters (1.640 ft) horizontally or 400 feet (122 m) vertically;
- UAV equipped with a photo-video camera must be located at a distance of at least 50 m (164 ft) from a person, car, building or any structure;
- Private UAVs should not be used in the area where a large group of people is located, such as a sporting event or concert (no closer than 150 m);
- For commercial purposes, operators must have CAA drone clearance.

**USA.** The Federal Aviation Administration (FAA) requires UAVs to be registered. Pilot license is required for all commercial flights. The UAV must be kept in the line of sight. Flights over crowds, near airports and not in class G aerospace are prohibited. Drone's weight should not exceed 55 lbs (25 kg) [26].

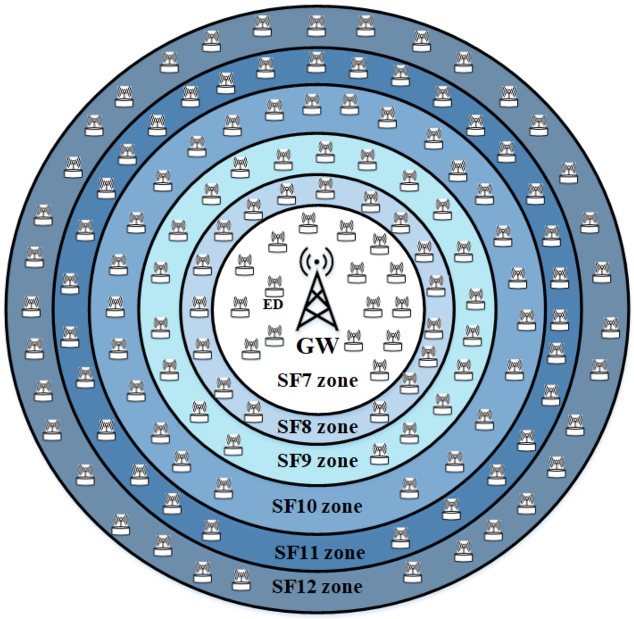


Fig. 3. Baseline scenario

**Algeria, Barbados, Brunei, Cote d'Ivoire, Cuba, Iran, Iraq, Kuwait, Kyrgyzstan, Madagascar, Morocco, Nicaragua, Saudi Arabia, Senegal, Syria.** Flying UAVs is prohibited [27].

## IV. System Models and Experiment Setup

In our study, we consider a LoRaWAN deployed in a suburban area. Without the loss of generality, we consider a network with a single GW with only one single 125 kHz-wide frequency channel with a carrier of 868.1 MHz. Note that real LoRaWAN features more than one channel, but in this work, for the illustrative purposes, we consider only a single channel. The obtained results can be scaled up to account for this. To facilitate the comparison with the state-of-the-art results, we have aligned our simulation set up with that in [6]. Specifically, we imply that class A EDs are uniformly distributed around the GW within 6.1 km range. The transmit power of the EDs is fixed at 14 dBm. Once per day, unless stated otherwise, each ED sends an uplink packet with 8-byte application data payload. No acknowledgments or retransmissions are used. Under these implications, we investigate two scenarios illustrated in Fig. 3 and Fig. 4.

- The baseline scenario. The scenario is similar to the one probably in [6] and implies all communication to go through the GW. The SF is allocated based on the distance from the ED to the GW.
- Proposed scenario. Represents a baseline scenario into which we integrate the second LoRaWAN GW deployed on a UAV. We consider that the UAV moves along a constant circular orbit centered at the GW with a constant speed following a pre-determined schedule known to the EDs. Alternatively, if a schedule is not known, the UAV and EDs may be equipped with wake-up radios to enable

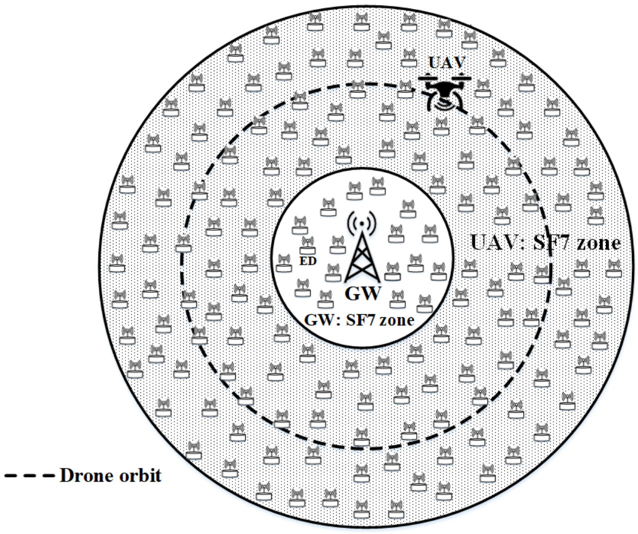


Fig. 4. Proposed scenario

TABLE I
PARAMETERS OF THE SIMULATIONS

| **Common parameters and configurations:** | | | | |
|---|---|---|---|---|
| ***Description*** | ***Value*** | | | ***Reference*** |
| Channel BW | 125 kHz | | | [6] |
| Carrier frequency | 868.1 MHz | | | |
| Number of channels | 1 | | | |
| Traffic model | 8-byte packet once a day unless stated otherwise | | | [6] |
| Speed of UAV | [5 km/h ... 80 km/h] | | | n/a |
| Uplink transmit power | 14 dBm | | | |
| Propagation loss model | LogDistancePropagationLoss | | | [6] |
| Radius of the test area | 6.1 km | | | [6] |
| **Parameters for different actors:** | | | | |
| ***Description*** | ***Values*** | | | ***Reference*** |
| | ***GW*** | ***UAV*** | ***ED*** | |
| Number | 1 | 1 | 250 | n/a |
| Antenna gain | 6 dBi | 6 dBi | 2.15 dBi | [30] |
| Sensitivity | [-124 to -137] dBm for SF7 ...SF12 | 124 dBm for SF7 | n/a | [5] |
| Position | Center of test area | Circular orbit | Random within test area | n/a |

EDs to detect the approaching UAV. Depending on its position, an ED sends its data either to the primary GW or the UAV, whichever is closest, using the minimum SF possible.

We also imply that, if served by the UAV, the ED delays its transmission and waits for the UAV to come close to the ED for the latter to use the minimum SF possible. Knowing the UAV trajectory and speed, the ED estimates the duration of the time window during which its transmission can reach the UAV, and randomly selects the transmission start time. Depending on the availability of the infrastructure, the UAV either aggregates the data and delivers them to the NS opportunistically, or forwards them over a backbone radio interface - e.g., the LTE.

For our simulations, we use the specially-developed MATLAB scripts to estimate the delivery ratio of the packets and the energy consumption of the EDs and the UAV. The energy consumption models implemented in the script are based on [28]. The voltage of the devices is assumed to be 3.6 V [29]. While modeling the data delivery, we account for both the inter- and the intra-SF interferences using the models proposed in [5], [6]. The main parameters of our models are summarized in Table I. 10 000 simulation rounds with different ED spatial distributions were run for each parameter set, and the results were statistically processed.

First of all, we analyzed the radio channel budget and compared it against the sensitivity levels typical for the state-of-the-art LoRaWAN receivers. The results reveal that a single drone, which flies the orbit with a radius of approximately 4 km, enables all EDs to operate using SF7. To get an insight into the benefits this brings to the EDs, we estimated their energy consumption and compared it against the baseline scenario. The results are illustrated in Figs. 5 and 6, which reveal the energy improvement of the proposed UAV-based scenario for communication only and overall consumption. One can see that the proposed approach reduces the mean consumption of the EDs for communication by over 50%. However, given the very low (once a day) report period, the consumption of EDs during the sleep phase in between the transmission plays the major role in the total ED's consumption and thus the resulting lifetime improvement is only in the order of few percents. Note, that with the decrease of the report period to five minutes, the overall lifetime improves by up to 59%, as shown in Fig. 7.

The charts also reveal the effect of the two other parameters the drone's orbit radius and the drone's speed. With the increase of the drone's orbit from 4 to 6 km, the energy benefit decreases. This happens due to the increase of the number of EDs served by the main GW (see Fig. 9), which have to operate using the SFs higher than SF7. No effect of the drone's speed on the ED consumption has been observed. Nonetheless, as can be seen from Fig. 8, the speed of the UAV strongly affects the number of the UAV required when the reporting period of the EDs reduces. To give an example, up to 92 UAVs may be needed to serve a network with EDs reporting every 5 minutes.

Finally, Fig. 10 provides an insight into how the introduction of the UAV affects communication performance with respect to the PDR. As one can see, a slow-moving drone increases the chance of packet delivery. For a single-drone case, with the increase of the drone's speed, the PDR decreases. The reason for this behavior is the decrease of the transmit window duration for EDs, which happens along with the increase of the drone's speed, thus increasing the probability of packet collisions between the neighboring EDs.

## V. CONCLUSIONS

In this paper, we first proposed the concept and then studied the utility of introducing a UAV-based GW into a remotely located single-gateway LoRaWAN network. Our results provide

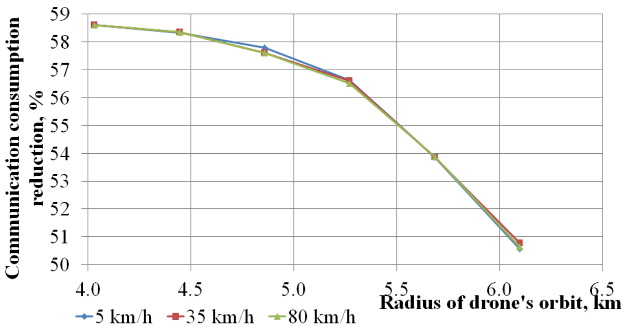


Fig. 5. Effect of drone‘s orbit radius and speed on the communication consumption reduction

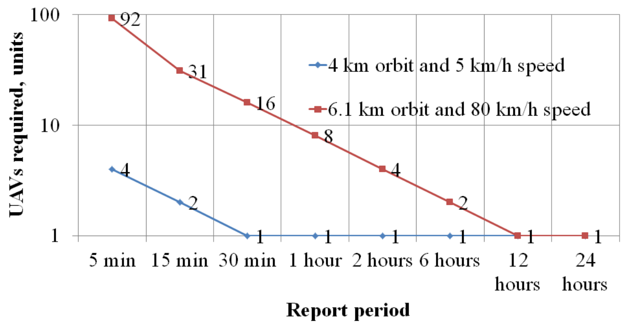


Fig. 8. Effect of ED’s report period on the number of UAV-based GWs required

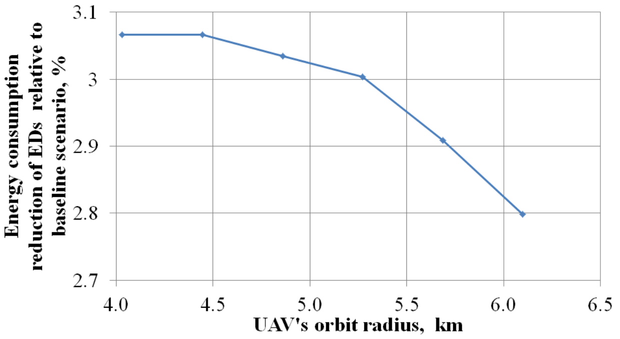


Fig. 6. Effect of UAV’s orbit radius on the lifetime improvement of EDs relative to the baseline scenario

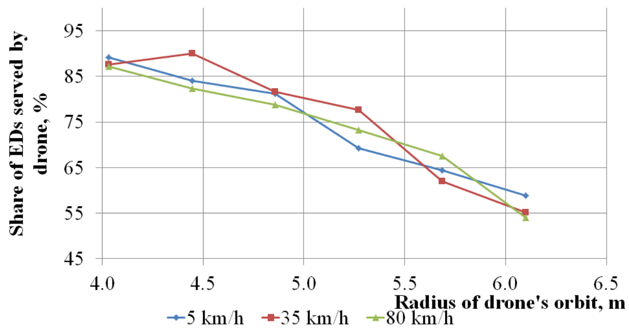


Fig. 9. Effect of drone’s orbit radius and speed on the share of EDs served by UAV and main GW

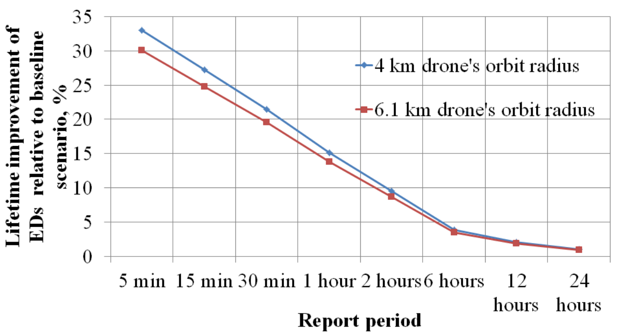


Fig. 7. Effect of ED’s report period on the lifetime improvement of ED relative to the baseline scenario

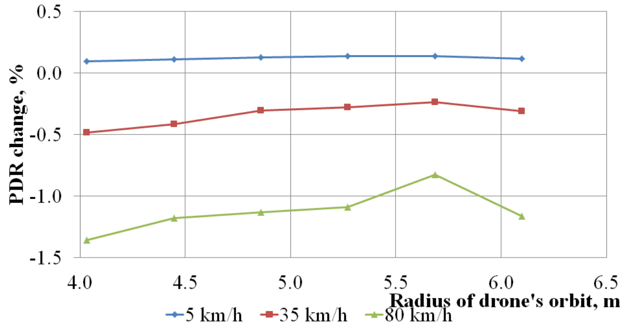


Fig. 10. Effect of drone’s orbit radius and speed on the PDR change relative to baseline scenario

an insight into the tradeoffs related to the operation of such a system and the potentially reachable benefits. Specifically, we demonstrated that the use of a drone-based GW in addition to the main GW in a LoRaWAN enables substantial energy savings, which can exceed 58% for the frequently-reporting EDs. These saving are obtained by enabling the EDs to use low SF, given that the EDs know the UAV schedule and can delay their data transfers. Meanwhile, our results demonstrate that the energy benefits, the probability of packet delivery, and the number of the UAVs needed, all depend on the speed of the UAV and the radius of its orbit. Given this, the optimization of these parameters by means of analytical methods is an interesting task for future works.

Other potential directions of the future studies are the development and investigation of more detailed models (e.g., for radio signal propagation or drone’s mobility) and the real-life experiments based on the proposed concept.

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