Satellite 5G: IoT Use Case for Rural Areas Applications

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***Abstract*—One of the key drivers for next-generation mobile communications, 5G, is the support of the Internet of Things (IoT) with billions of objects being connected to the Internet with low latency. The 5G technology will support the realization of smart cities, smart environments, and big data applications. Within the 5G framework, the terrestrial services can be augmented with the recent development of High Throughput Satellite (HTS) systems and mega-Low Earth Orbit (LEO) satellite constellations. In this paper, we investigate the integration of 5G technology and IoT by means of an aerial component composed of drones and satellites for a rural scenario. The prospected system can provide enhanced services, e.g., fire alarm detection, smart agriculture, animal tracking, and plant disease control. A use case of an agriculture application consisting of a number of areas whose sensor data are collected via drones is described. The proposed architecture consists of the drones connected to a satellite system to provide the necessary network control and connectivity. Subsequently, the satellite segment is connected to the terrestrial network and then to the cloud. In this study, we refer to a rural area scenario where drones are used to detect fire alarms collecting sensors data on the field, aggregating them, and then delivering messages via satellite to a control center. An analytical model has been developed to characterize the distribution of the time to detect and deliver an alarm. This study depends on many parameters; in particular, we have investigated the impact of the area size served by a drone, the maximum sensors range, and the sensor duty cycle.**

***Keywords*–5G; Satellite Networks; UAVs.**

I. INTRODUCTION

Recent studies estimate that about 4 billion people still lack Internet access [1]. The cost of a pure terrestrial coverage will quickly become unbearable with the increasing capacity needs for rural, remote, and urban areas. Moreover, terrestrial networks cannot guarantee the access to the Internet to passengers on aircrafts or high-speed trains, as well as users on vehicles on highways or in the countryside. Under these challenging operational conditions, the terrestrial infrastructure has to be complemented by the satellite segment as envisaged by 5G communication systems. Satellites will also support machine-type communications, paving the way to new applications, ranging from smart agriculture, environmental protection, transportation, animal tracking, etc. The new 5G system will be an umbrella system, enabling different Radio Access Networks (RANs) to operate together, including terrestrial base stations [now called g-Node Bs (gNBs)], aerial platforms of different types, including drones and satellites [2].

It is commonly assumed that 5G systems must address several challenges, including higher capacity, higher data rate, lower end-to-end latency, massive device connectivity, reduced cost and consistent Quality of Experience (QoE) provisioning [3]. ITU-R M.2083 Recommendation classifies three different 5G scenarios, as Enhanced Mobile BroadBand (eMBB), massive Machine-Type Communications (mMTC), and Ultra-Reliable Low-Latency Communications (URLLC) [4]. The satellite systems can support these scenarios as follows:

1) **eMBB**: Users in under-served areas, passengers on board vessels or aircrafts, disaster relief 5G services, emergency communications, media, and entertainment content broadcasts, passengers on board public transport vehicles, etc. These applications can be supported by satellite systems at different altitudes, such as Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and GEostationary Orbit (GEO).
2) **mMTC**: Global continuity of service for telematic applications based on a group of sensors/actuators. This scenario is more suitable for lower orbit satellites, like LEO constellations.
3) **URLLC**: Satellite systems (referring here mainly to LEO cases) can support URLLC-like services that require high reliability and high availability but that do not need extremely-low latency because of the large propagation delays.

This paper deals with, on the one hand, the system characteristics of the aerial component of future 5G systems and, on the other hand, with a use case of the mMTC type for rural areas monitoring, fire alarm, pollution detection, etc. This paper has been developed within the framework of the 5G satellite working group of the 5G IEEE Roadmap initiative [5].

After this introduction, this paper is organized as follows: Section II provides a survey on the state of the art of multi-layer architectures explaining the originality of this work; Section III deals with the aerial component (i.e., drones and satellites) of 5G systems; a system architecture is described in Section IV; sensor technologies are detailed in Section V; our case study dealing with the monitoring of rural areas by means of sensors connected via drones and satellites is provided in Section VI; finally, Section VII draws concluding remarks.

II. STATE OF THE ART

In view of future 5G systems, a multi-layer architecture is envisaged where low altitude drones, Unmanned Aerial Vehicles (UAVs) and High Altitude Platforms (HAPs) can be jointly used to provide a focused coverage or coverage extension to 5G systems with the support of a satellite component with LEO and/or GEO satellites. Layers typically correspond to the

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different altitude levels, where a higher altitude implies a wider coverage and a larger 'responsibility' in network management functions and routing support. The scenario of a multi-layer network with drones cooperating with satellites is a relatively new system concept that has received increasing interests recently. Li et al. [6] provide a very general overview on the use of UAVs and their role in an integrated network where there is also the possibility of UAV-to-satellite communications. Shi et al. [7] envisage a multi-layer architecture including a terrestrial part and the aerial component made of both drones and a network of LEO satellites. The interest of this study is on how to interconnect the layers optimally. This study is quite general and does not address the sensor scenario for rural areas and the need of providing services with low latency where there is not a terrestrial infrastructure to interconnect to the Internet.

Huo et al. [8] study a multi-layer aerial component with interesting details for the design of the UAV segment, but there is no consideration of the services, the design of the aerial component, and the impact of the latency experienced by alarm notifications. Finally, standardization bodies [like the European Telecommunications Standards Institute (ETSI), the Third Generation Partnership Project (3GPP), and the International Telecommunication Union - Radiocommunication Sector (ITU-R)] are also interested in the aerial segment with drones, HAPs, and satellites cooperating with the terrestrial 5G segment, as shown in [9] where scenarios and architectures are addressed.

The original contribution of this work is to build on the basis of the above architectures a feasibility study for a scenario where the data provided by sensors are collected by drones and sent via satellite in remote areas with no terrestrial Internet connectivity. A modellization effort has been pursued to characterize the service provided via drones.

III. THE AERIAL COMPONENT OF 5G SYSTEMS

We provide below an introduction to the different technologies and related networks for the aerial component of 5G systems.

A. Satellites

A High Throughput Satellite (HTS) has many times the throughput of a traditional Fixed Satellite System (FSS) for the same amount of allocated frequency in orbit. These satellites take advantage of high frequency reuse and multiple spot-beams to increase the throughput. A typical HTS satellite can have a capacity of hundreds of Gbit/s. New HTSs typically provide download speeds of more than 10 Mbit/s per user.

The different beams of an HTS satellite reuse the bandwidth according to a typical 4-color reuse pattern (two frequency slots and two polarizations). The satellite capacity can be increased if the different antenna beams of the satellite can use the same frequency band (i.e., full frequency reuse). This approach causes significant interference on a beam because of adjacent beams. A possible solution to reduce the inter-beam interference is adopting a precoding scheme (at the gateway, forward path) where the different transmitted signals on the distinct beams are multiplied by suitable coefficients aimed to orthogonalize them. To do so, an accurate channel estimation is needed so that it is possible to compute the coefficients of the precoding matrix used at the sender to compensate for the interference [10].

HTS platforms have been designed to serve the consumer broadband broadcast market; however, some of them are also offering services to government and enterprise markets, as well as to terrestrial cellular network operators experiencing a growing demand for broadband backhaul to rural cell sites. For instance, **ViaSat-2** [11] is a commercial-communication GEO HTS with a throughput of 300 Gbit/s. This satellite will provide satellite Internet to North America, parts of South America, including Mexico and the Caribbean, and to air and maritime routes across the Atlantic Ocean.

The propagation delay from a GEO satellite to the earth is about 256 ms and that from a MEO or LEO with an altitude lower than 10,000 km is in the range 10 - 70 ms, which is comparatively shorter, but still not negligible. This is why researchers have been more interested in MEO and LEO satellites in recent years. These non-GEO systems have global or quasi-global coverage, but many satellites (i.e., a constellation) are needed to cover all the earth. We consider here mega-LEO satellite constellations that are being developed with services foreseen by 2020. The proposed systems aim to provide access to the Internet with a quality comparable to that of terrestrial systems. The satellite segment comprises many satellites and several terrestrial GateWays (GWs) that are interconnected to the Internet. A dedicated terrestrial network is also used to interconnect the GWs. In some cases, there are inter-satellite links to allow the direct exchange of data among neighbor satellites and to perform routing in the sky. The frequencies currently adopted are in Ku and Ka bands. Satellite systems will also exploit higher frequency bands, such as Q/V/W.

We can consider the following examples of mega-LEO satellite constellations:

LeoSat [12] foresees a constellation (2022) of 78-108 high-throughput Ka-band satellites in LEO polar circular orbits at an altitude of approximately 1,400 km. These satellites form a high-throughput mesh network interconnected through laser inter-satellite links. A ground-based Virtual Private Network (VPN) interconnects the GWs with a public data network. One terminal can use a bandwidth of up to 500 MHz on both uplink and downlink.

Moreover, the **OneWeb** [13] system consists of a constellation of 720 LEO satellites in near-polar circular orbits at an altitude of 1,200 km. OneWeb will provide the users with high speed up to 50 Mbit/s and low latency lower than 50 ms and plans to interoperate with terrestrial mobile operators. It is expected that approximately 50 or more GW earth station sites will be deployed over the time.

The SpaceX satellite system, called **Starlink** [14], consists of two sub-constellations of satellites. A first LEO constellation is composed of 4,425 satellites and operates in Ku and Ka bands at altitudes around 1,110 km to provide a wide range of broadband communication services for residential, commercial, institutional, governmental, and professional users worldwide. The second component of Starlink will be based on another LEO constellation operating in the V band, comprising 7,518 satellites at altitudes around 340 km.

B. UAVs

UAVs are considered here as autonomous communicating nodes. UAVs can be classified into two categories: fixed-wing versus rotary wing. For example, Fixed-Wing UAVs (FW-UAVs) usually have high speed and heavy payload, but they

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must maintain a continuous forward motion to remain aloft, thus are not suitable for stationary applications like close inspection. To minimize the Doppler shift and the associated system design challenges, FW-UAVs need to cruise at the slowest possible speed. In contrast, Rotary-Wing UAVs (RW-UAVs), such as quadcopters, though having limited mobility and payload, can move in any direction as well as to stay stationary in the air. Thus, the choice of UAVs critically depends on the applications. UAVs must use dedicated wireless links (mmWaves, free-space optical channels, sub-6 GHz technologies such as LTE) to connect to the core network.

UAVs can also be categorized, based on their altitudes as HAPs and Low Altitude Platform (LAPs) [15] as follows:

1) **HAPs** can be balloons, which are quasi-stationary and operate in the stratosphere at an altitude of approximately 20 km above the earth's surface. HAP-based communications have several advantages over the LAP ones, such as wider coverage and longer endurance. Thus, HAPs are in general preferred for providing reliable wireless coverage for a large geographic area; on the other hand, HAPs are costly.
2) **LAPs** can fly at altitudes of tens of meters up to a few km and can quickly move. LAPs have several important advantages. First, on-demand UAVs are more cost-effective and can be much more swiftly deployed by means of LAPs that are especially suitable for unexpected or limited-duration missions. LAPs can establish short-range Line-of-Sight (LoS) communication links in most scenarios. LAPs can be used for data collection from ground sensors for monitoring purposes.

A balloon-UAV (HAP category) may be the most suitable aircraft for carrying a heavy 5G base station and hovering over the sky for the longest duration. Considering the significant height and coverage it can achieve, an energy-effective balloon-UAV can serve as a 5G terrestrial macrocell base station (gNB). UAV-assisted 5G communications have numerous use cases, including terrestrial base station offloading, swift service recovery after natural disasters, emergency response, rescue and search, and information dissemination.

From an industry perspective, an example of a recent project employing HAPs for wireless connectivity is the Google's Loon project [16]. Moreover, the Facebook's Internet-delivery project via drones has been stopped recently. Finally, Qualcomm and AT&T are planning to deploy UAVs for enabling wide-scale wireless communications in 5G systems.

IV. SYSTEM ARCHITECTURE

While Software-Defined Networking (SDN) aims to separate the control plane from the data plane, Network Functions Virtualization (NFV) allows the abstraction of the physical network in terms of a logical network, thus implementing network functions in software. The 5G physical infrastructure consists of the aerial component (the satellite RAN belongs to it), a Terrestrial RAN, and the interconnecting transport network. The logical level (network virtualization) consists of logical nodes such as logical GWs for the Satellite RAN and logical gNBs for the Terrestrial RAN. A controller supports the control plane of physical nodes and an NFV manager coordinates the virtualized functions. Virtualizing some functions of the satellite GWs would improve the flexibility and the reconfigurability in the provision of satellite services. Several virtualization alternatives are possible depending on the distinction between the functions that would remain located in the satellite GW and those that would be moved to the centralized and/or virtualized infrastructure. For transparent satellites, the GW can support the gNB, the Radio Network Controller (RNC), and the virtualized Evolved Packet Core (vEPC) interface. For regenerative satellites, the satellite always involves the gNB while the GW always provides the vEPC interface. The RNC can be either located in the satellite or in the GW [17].

In the NFV context, the adoption of network slicing could facilitate the definition of networks customized for certain traffic types and services. For example, there can be different requirements on functionality (e.g., priority, charging, security, and mobility), differences in performance requirements (e.g., latency, mobility, availability, reliability, and data rates), or distinctions in terms of the users to be served (e.g., public safety users, corporate customers, etc.).

Figure 1 below shows the aerial RAN of an integrated mMTC scenario with interconnections among the different elements as follows: we have interconnections between sensors and UAVs, among UAVs, and between UAVs and the satellite. In this system, we consider that UAVs fly periodically over a certain rural area to be monitored, collect the data provided by sensors spread in the area, and send these data via satellite. An alternative to this approach, not considered in this paper, would be that sensors transmit data to local sinks in fixed positions on the field that act as GWs to the network.

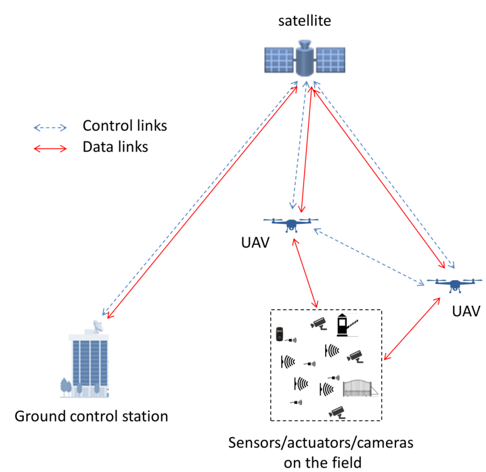

Figure 1. Network architecture for mMTC, aerial RAN.

V. SENSOR TECHNOLOGIES

ZigBee [18] is the most popular industry wireless mesh networking standard for connecting sensors, instrumentation and control systems. ZigBee is the classical Internet of Things (IoT) technology. ZigBee is an open, global, packet-based protocol designed to provide an easy-to-use architecture for secure, reliable, low-power wireless networks. ZigBee is a low data rate wireless system based on the IEEE 802.15.4 standard. IEEE 802.15.4 specifies a total of 27 half-duplex channels across the three frequency bands (868 MHz, 915 MHz, and 2.4 GHz). Channel data rate ranges from 20 kbit/s to 250 kbit/s. The transmission range depending on the frequency band can be from 200 m to 1 km. For instance, the free-space transmission range is around 300 m at 900 MHz (assuming transmission power P_t = +5 dBm, antenna gains $G_t = G_r$ = 1.2 dBi, and received power level of $P_r = -105$ dBm). Analogously, the maximum transmission range at 2400 MHz is 64 m with similar numerical assumptions as those used for 900 MHz, except for P_t = 0 dBm.

To save the batteries, each node can alternate between awake and sleeping phases. In the awake phase, nodes are active and can communicate messages to neighbors. In the sleeping phase, nodes turn their radios off until the next scheduled wake-up time. The duration of sleeping and active cycles are application-dependent and are set the same for all the nodes. A common duty cycle value is of 10% with wake up time of 10 s.

LoRa (the acronym of Long Range) [19] is a wireless technology specifically designed for long-range, low-power Machine-to-Machine (M2M) and IoT applications. The LoRa range is 5 km for urban and 20 km for rural areas. LoRa is based on the IEEE 802.15.4g standard and operates in the Industrial, Scientific and Medical (ISM) frequency band at 868/915 MHz. A spread spectrum modulation is adopted. LoRa bit-rates depend on the spreading factor; the maximum bit-rate is 50 kbit/s. There is a payload size of 243 bytes for each message. Each LoRa GW can manage up to millions of nodes. The LoRa software is open and its use is free for those who comply with protocol specifications.

Sigfox is a French global network operator that builds wireless networks to connect low-power objects such as electricity meters and smartwatches, which need to send small amounts of data. With Sigfox, a device can transmit up to 140 messages per day. The maximum range is 10 km for urban and 40 km for rural areas. Hence, long distances can be achieved while being very robust against the noise. Messages have a payload size of 12 bytes. Sigfox operates in the ISM band and uses a ultra narrow-band modulation; the maximum bit-rate is from 100 to 600 bit/s, depending on the region.

NB-IoT is a narrow-band technology standardized by the 3rd Generation Partnership Project (3GPP) starting with Release 13. For instance, an LTE operator can deploy NB-IoT inside an LTE carrier. NB-IoT numerology is inherited from LTE. In both downlink and uplink, the channel is divided into 12 subcarriers of 15 kHz. The time domain is divided into time slots, each lasting 0.5 ms and consisting of 7 symbols. Time slots are grouped as follows: two time slots form one subframe (1 ms), 10 subframes form one frame (10 ms). To further improve the coverage, a second numerology with 48 subcarriers of 3.75 kHz is introduced. This numerology is used for the preamble transmission of the random access procedure and optionally for uplink transmissions. In this case, the time slot lasts 2 ms and, for the sake of compatibility, one frame is composed of 5 time slots. The maximum payload size for each message is 1600 bytes. One uplink single-tone (subcarrier) data transmission at 15 kHz provides a physical layer data rate of approximately 20 bit/s when configured with the highest repetition factor (i.e., 128) and the most robust modulation and coding scheme. On the other hand, downlink data transmission achieves a physical layer data rate of 35 bit/s when configured with repetition factor 512 and the most robust modulation and coding scheme. The max data rate is limited to 200 kbit/s for downlink and 20 kbit/s for uplink. NB-IoT can allow a nominal maximum range of 35 km.

Table 1 in the next page provides a comparison among the different sensors technologies.

We can differentiate the sensor-based applications according to the type of data that must be gathered from the field. In particular, we can consider two categories as Event Detection (ED) and Spatial Process Estimation (SPE).

- In the first case, sensors are used to detect an event, for example, a fire in a forest or an earthquake. Every remote device has to measure a quantity, compare with a given threshold and send the binary alarm information. The density of nodes must ensure that the event is promptly detected with a suitable probability of success, while maintaining a low probability of false alarm. In case of a concentrator of alarms (i.e., a local sink collecting data from multiple sensors), the sensors, together with the concentrator, could cooperatively carry out the task of alarm detection.
- In the second case, the sensors aim at estimating a given physical phenomenon (e.g., the atmospheric pressure in a wide area). The main problem is to obtain an estimation of the entire behavior of the spatial process based on the samples taken by sensors placed at random positions. The measurements will be then processed in a distributed way by the nodes or centrally at the supervisor. The estimation error is strictly related to nodes density and the spatial variability of the process.

VI. CASE STUDY: ENVIRONMENTAL MONITORING OF LARGE AREAS FOR AGRICULTURE

Every year in Tuscany, a region of Italy, the emergencies for forest fires are repeated regularly, with an almost constant risk during the year and an increase in summer, destroying hundreds of hectares of forest. In Tuscany, more than 800 fire events occur every year with an increasing trend. It is impossible to carry out a direct control by operators in the field given its vastness and the need for continuous monitoring during the day. An automatic radio system is therefore needed to collect a variety of data from the territory to be sent via the Internet to a remote control unit. In the fight against forest fires, the rapid and careful delimitation of the perimeter of the burned areas is fundamental. Therefore, the use of low-cost distributed IoT radio sensors makes it possible to monitor and promptly detect fires, which have to be controlled and resolved in a short time. This technological approach can also be used in other contexts, such as monitoring of landslides, levels of air pollutants in wooded areas, hydrogeological risk, smart agriculture, etc.

The issue is that the sensors must be placed in remote areas where there is no Internet access for several kilometers so that there are problems to convey the data on the field to a remote control center. It is, therefore, necessary to make available a *backhaul interconnection* that can provide adequate capacity even in remote areas. The most suitable sensor technologies today such as LoRa, Sigfox, and NB-IoT do not allow to cover such remote areas. LoRa has a range of up to 20 km with bit rates up to 50 kbit/s. Sigfox has a range of 40 km with bit

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TABLE I. COMPARISON OF DIFFERENT WIRELESS SENSOR NETWORK TECHNOLOGIES.

IoT/M2M Technology	**Local Range/ Uplink and Downlink Bit-rate**	**Licensed/ Unlicensed Frequency Band**	**GW: Availability (Y/N)**	**GW: Supported Interconnection options (wireless, cable, satellite, etc.) with covered ranges**	**GW: Traffic capacity (Uplink and Downlink)**
LoRa	5 km (urban), 15 km (suburban), 20 km (rural). Data rates up to 50 kbit/s.	Unlicensed spectrum	GW needed	Support Ethernet, 3G, wireless, wired and satellite backhaul	Around 150000 to 1500000 packets per day depending on payload size, symbol rate, coding rate …
Sigfox	40 km in rural areas and 10 km for urban areas. Data rates up to 600 bit/s	Cellular-like, unlicensed spectrum, ISM	GW needed	Support of Ethernet, 3G, wireless, wired and satellite backhaul	Sigfox GW capacity is three times bigger than LoRa GW capacity
ZigBee (IEEE 802.15.4)	Indoor 10 m; Outdoor 100 m (LoS). Data rate up to 250 kbit/s	Unlicensed spectrum	GW needed	Support of Ethernet, 3G, wireless, wired and satellite backhaul	-
Narrow Band-IoT	Up to 35 km. Data rate up to 200 kbit/s for downlink and 20 kbit/s for uplink	Licensed frequency bands	An LTE cellular system (4G) is used to interconnect with base stations	-	-

rates up to 600 bit/s. NB-IoT has a range of 35 km with an uplink bit-rate up to 20 kbit/s. Therefore, these sensor solutions based on terrestrial infrastructures are not suitable for covering large and remote areas and for supporting high capacity for the transmission (if needed) of images or real-time videos. Therefore, the interest of this paper is to show the possibility to collect sensors data by means of drones with interconnection to the Internet via satellite.

A. Agriculture Monitoring Model

In this section, an application for agricultural monitoring is described that is suitable for large rural areas. The idea is to provide the farmer with periodic and precise monitoring of physical parameters (e.g., temperature, air pressure, humidity, plant illness conditions, etc.) for the real-time control of the plant area as well as for fire alarm. On the basis of the monitoring information, it is possible to increase the quality and amount of production, cut costs, and reduce the pollution caused by weed-killers.

Our system is divided into large areas of $D \times D$ size, each of them being controlled by a drone. In each area, there are many sensors to collect data from the field. A Point Poisson Process is the model typically adopted to characterize the distribution of the sensors on the field for a certain area. This means that the sensors are uniformly distributed in the area considered. The data collected by a drone from multiple sensors can also be aggregated before sending to the satellite.

The sensors can designed with an extremely low duty cycle that is also related to theirs density. During the active mode, each sensor collects measurements and transmits these data to the system via drones that are connected to the Internet via a satellite link [18]. The sensor-to-root data traffic (multipoint-to-point) is predominant. Each drone of the FW-UAV type acts as a mobile GW that has to manage different traffic classes with a scheduler able to share the satellite link capacity taking the Quality of Service (QoS) requirements of the different classes into account.

As shown in Figure 2, we consider that each drone operates over a certain area, collecting sensor data at each pass to be delivered via satellite to a control center. Each drone will use a satellite link not only for flight control but also for sensor data delivery. There can be different types of sensors in the field, such as micro-weather stations, infra-red temperature sensors, sensors to monitor plant diseases, hygrometers, etc. We can consider that the link between drones and satellite has to manage multiple traffic classes, including flight control, remote sensors data, video and/or photo traffic. The sensors traffic can be modeled in a simple way [20][21]. For instance, a sensor for alarms could have an ON-OFF duty cycle, sending an alarm in the ON phase only when a certain measurement threshold is overcome. Otherwise, we could have sensors reporting temperature measurements at regular intervals, from a few seconds to hours depending on the application. Each sensor could send a small measurement packet of max 120 bytes.

B. Delay and Area Size Analysis

We have to design the drone fleet to be able to deliver alarms within a certain predetermined maximum delay. Let d denote the maximum range for the transmission between sensors and drones. Let H denote the drone altitude. Let v_d denote the drone speed assumed to be constant. We consider that a drone can receive the signal from a square area of side W (drone visibility area) that can be characterized as follows:

$$W = 2\sqrt{d^2 - H^2}. \tag{1}$$

For the sake of simplicity, we assume that D/W has an integer value equal to N: $D/W = N$. Of course, $D \geq W$.

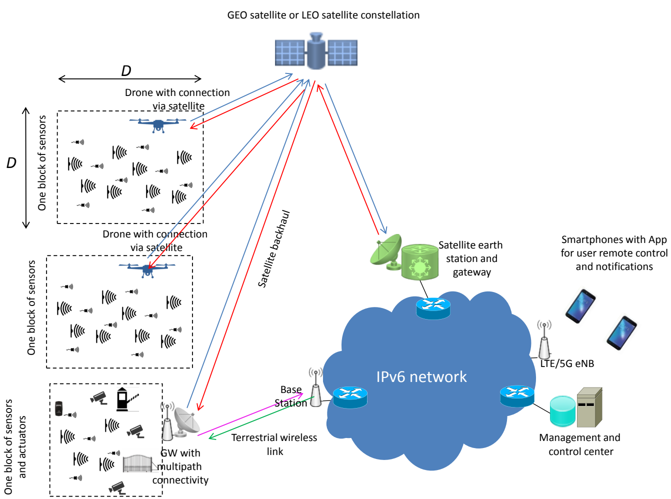

Figure 2. 5G integrated network scenario belonging to the mMTC case that is well suited to represent our sensor-based service.

For the communication between sensors and drones the link budget of the uplink is more critical than that of the downlink. Then, the maximum range d refers to the transmissions from sensors to drones (the transmission power is the one of sensors and the receiver sensitivity refers to the drone). The link budget can be expressed in terms of Allowed Propagation Loss (APL) as:

$$APL = P_t + G_a - S - M, \tag{2}$$

where P_t is the transmission power in dBm of the sensor, G_a denotes the antenna gain in dBi of the receiver (we consider sensors with omnidirectional antennas), S is the sensitivity in dBm of the receiver on the drone, and M represents a margin due to shadowing and interference in dB. Possible values for our scenario are: P_t = 15 dBm, $S = -137$ dBm, $M \approx 10$ dB, G_a = 0 dBi so that the APL becomes equal to 153 dB [22]. The APL term can be converted in terms of distance d (range) using a path loss formula as follows:

$$APL\,(d) = 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + APL\,(d_0) \quad [dB], \tag{3}$$

being γ the path loss exponent and d_0 a reference distance (equal to 1 km). According to [23], the following settings can be adopted for frequencies around 868 MHz (ISM): $\gamma = 2.65$ and $APL\,(d_0)$ = 132.25 dB so that d can be up to 6 km; however, this distance value can be further reduced for lower P_t values and considering noise figures and additional losses in the link budget.

The drone visibility interval t_d can be determined as:

$$t_d v_d = W \rightarrow t_d = \frac{W}{v_d}. \tag{4}$$

The drone can reveal an alarm if it receives the signal during its pass over an active sensor. Each sensor node has an ON/OFF activity to increase the lifetime of its batteries: a sensor can send an alarm only if the alarm conditions are fulfilled during its ON phase. Let T_{ON} (T_{OFF}) denote the mean ON (OFF) phase duration. The drone alarm detection probability due to a sensor P_d can be expressed as follows assuming that $t_d < T_{OFF}$:

$$P_d = \frac{T_{ON} + t_d}{T_{ON} + T_{OFF}}. \tag{5}$$

Let us consider that n independent sensor nodes are present in the alarm area. This parameter n can be related to the density of sensors in the area. Then, the total drone alarm detection probability $P_{d,tot}$ can be expressed as:

$$P_{d,tot} = 1 - (1 - P_d)^n. \tag{6}$$

A drone travels a certain distance P to cover its $D \times D$ service area. The drone cycle time is P/v_d. Since the alarm can occur at any point along this distance, the time that the drone takes to reach the alarm area t_a can be expressed as:

$$t_a = u\frac{P}{v_d}, \tag{7}$$

where u denotes a random variable with uniform distribution between 0 and 1.

Because of the ON-OFF cycle of the sensors, there could be the need for multiple passes over the alarm area to detect the event. The number of passes to detect the alarm is according to a random variable $X \in [1, 2, \ldots)$ with geometric distribution and parameter $P_{d,tot}$. The first pass needs a time t_a, while the following ones occur after a time P/v_d. Then, the total time to detect the alarm T_{alarm} is a random variable that can be expressed as follows:

$$T_{alarm} = u\frac{P}{v_d} + (X-1)\,\frac{P}{v_d} + t_{sat} = (u + X - 1)\,\frac{P}{v_d} + t_{sat}, \tag{8}$$

where t_{sat} denotes the propagation time from the drones via satellite to the terrestrial control station.

The expected alarm notification delay is:

$$E\left[T_{alarm}\right] = \left(\frac{1}{P_{d,tot}} - \frac{1}{2}\right)\frac{P}{v_d} + t_{sat}. \tag{9}$$

We consider that there is a relation between the controlled area size D and the length P of the path of the drone covering that area. The relation between D and P depends on the path selected. We consider the situation depicted in Figure 3.

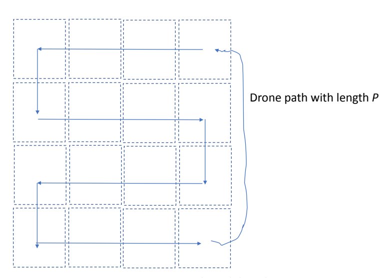

Figure 3. Path of a drone in covering a certain area of size $D \times D$, formed of $N \times N$ squares with side W.

The relation between D and W can be obtained as follows, where we distinguish the sum of horizontal segments and

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vertical segments to form the path shown in Figure 3:

$$P = W(N-1)N + 2W(N-1) =$$
$$= W(N-1)(N+2) = \quad (10)$$
$$= \frac{D^2}{W} + D - 2W.$$

By substituting all the previous formulas, we obtain the following expression of the mean delay to detect an alarm:

$$E[T_{alarm}] = \left(\frac{1}{P_{d,tot}} - \frac{1}{2}\right)\frac{\frac{D^2}{W} + D - 2W}{v_d} + t_{sat}. \quad (11)$$

The system can be designed to guarantee that the alarm is detected in the 95% of cases within a time limit $T_{max\ delay}$ that is imposed as a design parameter.

$$Prob\{T_{alarm} < T_{max\ delay}\} = 0.95. \quad (12)$$

Since T_{alarm} in (8) depends on two random variables, $u \in (0,1)$ and $X \in \{1,2,3,...\}$, we can use the following approximation:

$$T_{alarm} \approx X\frac{P}{v_d} + t_{sat}, \quad (13)$$

so that the 95-th percentile of T_{alarm} can be expressed by means of the percentile of the geometric distribution of X as:

$$T_{max\ delay} \approx \frac{\ln(1-0.95)}{\ln(1-P_{d,tot})}\frac{P}{v_d} + t_{sat}. \quad (14)$$

Hence, given the $T_{max\ delay}$ value (requirement) the system can be designed by selecting the most suitable D, d, v_d, n, H, T_{ON}, and T_{OFF} values.

C. Performance Results

Figure 4 shows the behavior of the mean notification delay $E[T_{alarm}]$ as a function of both sensor range d and number N of service areas per D side for $n = 2$ and 4 alarmed sensors/area. The numerical settings are: v_d = 160 km/h, H = 150 m, T_{ON} = 60 s, T_{OFF} = 600 s, t_{sat} = 250 ms. We can see that the mean notification delay increases with both the sensor range d and the number of service areas N per side.

Figure 5 shows the level curves for constant $T_{max\ delay}$ values depending on the number of sensors n and the duty cycle $[P_{ON} = T_{ON}/(T_{ON} + T_{OFF})]$. We can see that if we need to reduce P_{ON} to increase the battery life, there is the need of a smaller d and then a smaller service area for a drone to keep the same 95-th percentile of the alarm delay.

We can conclude that there is the need of a multi-parameter optimization to select the many system parameters to optimize system costs under requirements in terms of $T_{max\ delay}$.

VII. CONCLUSIONS

Many HTS and mega-LEO satellite constellations will deliver Terabits of capacity across the world by 2020-2025. These systems will provide the Satellite RAN of the whole 5G system conceived to be an umbrella system, enabling different technologies to operate together, including UAVs and satellites. In this paper, our major emphasis is on the mMTC scenario for rural areas where sensors on the field are used to monitor fire and pollution events. We have considered a future 5G scenario where drones are used in the territory to collect sensor data

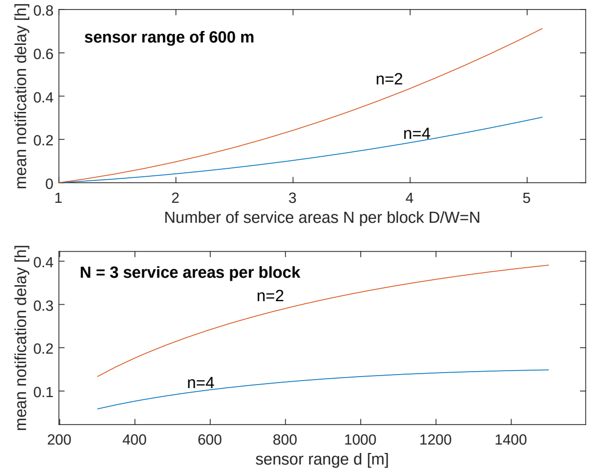

Figure 4. Impact of sensor range d and number N of service areas per block on the mean delay $E[T_{alarm}]$ in hours.

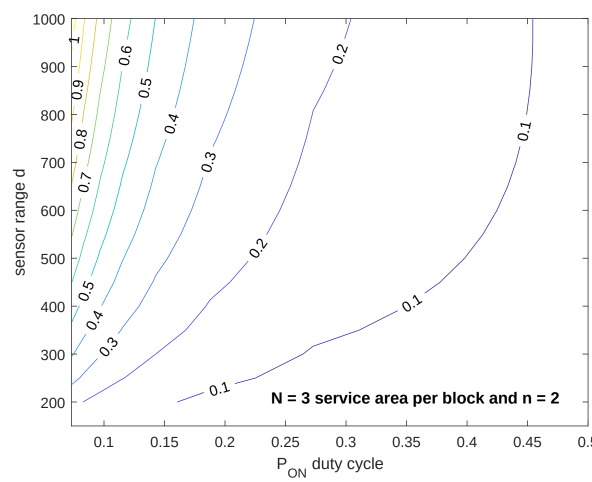

Figure 5. Impact of sensor range d and the duty cycle P_{ON} on the 95-th percentile of the delay, $T_{max\ delay}$ in hours.

that are delivered via a satellite link to a control center. An analytical model has been developed to characterize the time needed to detect an alarm in terms of mean value and 95-th percentile. The model developed in this study can be suitable for a further study to optimize the fleet of drones required to cover the entire rural area under consideration.

REFERENCES

[1] Report on “World Internet Users Statistics and 2018 World Population Stats”, available at the following URL [retrieved: March, 2019]: https://www.internetworldstats.com/stats.htm

[2] G. Giambene, S. Kota, and P. Pillai, “Satellite - 5G Integration: A Network Perspective”, *IEEE Network*, pp. 25-31, No. 5, September/October 2018.

[3] A. Gupta and R. K. Jha, “A Survey of 5G Network: Architecture and Emerging Technologies”, *IEEE Access*, Vol. 3, pp. 1206-1232, 2015.

[4] 3GPP, “3rd Generation Partnership Project; Technical Specification

Group Radio Access Network; Study on New Radio (NR) to support non-terrestrial networks", TR 38.811V0.2.1 (2017-11) - Release 15.

[5] IEEE 5G and Beyond Technology Roadmap White Paper, available at the following URL [retrieved: February, 2019] : https://futurenetworks.ieee.org/images/files/pdf/ieee-5g-roadmap-white-paper.pdf

[6] B. Li, Z. Fei, and Y. Zhang, "UAV Communications for 5G and Beyond: Recent Advances and Future Trends," *IEEE Internet of Things Journal*, early view available since December 2018.

[7] Y. Shi, J. Liu, Z. Md. Fadlullah, and N. Kato, "Cross-layer Data Delivery in Satellite-Aerial-Terrestrial Communication", *IEEE Wireless Communications Magazine*, Vol. 25, No. 3, pp. 138-143, 2018.

[8] Y. Huo, X. Dong, T. Lu, W. Xu, and M. Yuen, "Distributed and Multi-layer UAV Network for the Next-generation Wireless Communication", Available on arXiv:1805.01534 [eess.SP], 2018.

[9] ETSI, "Integration of Satellite and/or HAPS (High Altitude Platform Station) Systems into 5G and Related Architecture Options", SCN TC-SES DTR/SES-00405 ETSI TR 103 611, December 2018.

[10] A. Guidotti and A. Vanelli-Coralli, "Clustering Strategies for Multicast Precoding in Multi-Beam Satellite Systems", available on arXiv:1804.03891v1 [cs.IT] 11 Apr 2018.

[11] ViaSat-2 system Web site with URL [retrieved: March, 2019]: https://www.viasat.com/viasat-2-service-infographic

[12] LeoSat system Web site with URL [retrieved: March, 2019]: http://leosat.com/technology/

[13] OneWeb system Web site with URL [retrieved: March, 2019]: https://www.oneweb.world/

[14] J. Foust, "SpaceX's Space-Internet Woes", IEEE Spectrum, Vol. 56, No. 1, pp. 50-51, 2019

[15] M. Mozaffari, W. Saad, M. Bennis, Y.-H. Nam, and M. Debbah, "A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems", available on arXiv:1803.00680v1, March 2018.

[16] K. Kamnani and C. Suratkar, "A Review Paper on Google Loon Technique", *International Journal of Research In Science & Engineering*, Vol. 1, No. 1, pp. 167-171, 2015.

[17] 5GCHAMPION EU Project Web site with URL [retrieved: February, 2019]: http://www.5g-champion.eu/

[18] C. Buratti, A. Conti, D. Dardari, and R. Verdone, "An Overview on Wireless Sensor Networks Technology and Evolution", *Sensors (Basel)*, Vol. 9, No. 9, pp. 6869-6896, 2009.

[19] A. Lavric and V. Popa, "Internet of Things and LoRa Low-Power Wide-Area Networks: A Survey", International Symposium on Signals, Circuits and Systems (ISSCS) 2017, July 13-14, 2017, Iasi, Romania.

[20] 3GPP, "Study on RAN Improvement for Machine-Type-Communications", TR 37.868 V11.0.0, September 2012.

[21] A. Sivanathan *et al.*, "Characterizing and Classifying IoT Traffic in Smart Cities and Campuses," *IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, Atlanta, GA, pp. 559-564, 2017.

[22] G. A. Akpakwu, B. J. Silva, G. P. Hancke, and A. M. Abu-Mahfouz, "A Survey on 5G Networks for the Internet of Things: Communication Technologies and Challenges," *IEEE Access*, Vol. 6, pp. 3619-3647, 2018.

[23] H. Linka, M. Rademacher, O. G. Aliuy, and K. Jonas, "Path Loss Models for Low-Power Wide-Area Networks: Experimental Results using LoRa", ITG Fachtagung Mobilkommunikation, May 16, 2018.

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