Challenges and Opportunities in Integrated Space-Terrestrial Internet of Things

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Abstract—Large geographical regions and communities remain uncovered by terrestrial network connections. To enable access equality, near-Earth orbit satellites will play a defining role in providing Internet of Things (IoT) connectivity on a world-wide scale in a flexible and cost-effective manner. This paper presents the opportunities arising from global IoT solutions based on space assets, as well as the key research challenges to be addressed. In particular, we discuss existing space and terrestrial IoT technologies and protocols, and the requirements that they need to meet to successfully materialize satellite IoT services. We also propose a novel network architecture to be used by NB-IoT and LoRaWAN technologies for implementing future space-terrestrial integrated IoT networks.

Index Terms—Satellite Internet of Things, Satellite Constellations, LPWAN

I. INTRODUCTION

The recent spur in space projects [1] has revamped the interest in satellite communication. This is especially observed in the Internet of Things (IoT) community that constantly seeks to diversify the application scenarios [2], but also, from the telecommunication operators that want to expand the IoT network coverage to offer a promising omnipresent world-wide service.

The unique characteristics of satellites in the new space context (cheap deployment, quick procurement) enable architectural alternatives with degrees of scale and flexibility hitherto impossible [3]. Indeed, by adding IoT equipment in the payload of satellites, they can serve as passing-by Low-Earth Orbit (LEO) gateways to which end-devices in inaccessible areas can directly offload buffered data to. Moreover, inexpensive CubeSat satellites as well as classical Geosynchronous satellites (GEO) can serve as backbone relays for connecting IoT gateways placed in regions with limited accessibility. These are known as direct and indirect satellite IoT approaches [4]–[10], which are classified and discussed in detail in this article.

On the IoT technological side, thanks to their long range capabilities and reduced energy consumption, Low Power Wide Area Networks (LPWANs) such as LoRaWAN [11] and NB-IoT [12] are in the perfect spot to materialize future space-terrestrial IoT developments. Indeed, existing terrestrial IoT networks could enjoy an enhanced coverage for rural and out-of-reach areas, offering ubiquitous global connectivity services, and enabling a plethora of new applications opportunities. These will impact sectors such as assets tracking (in land, sea and air), environmental monitoring, energy (oil and gas), utilities smart metering, agriculture, and remote healthcare solutions [13].

However, transmission distance and orbital dynamics, combined with highly constrained devices on the ground makes satellite IoT a very challenging problem. Existing IoT medium access control schemes need to be revised and/or extended to scale up to potentially millions of devices simultaneously at sight from LEO satellites. The limited available energy and high latency provoked by the long space-terrestrial channel range complicates negotiation approaches based on extensive handshakes. Furthermore, crucial LPWAN core network functionalities will need to be identified and virtualized [14] so that they can be flexibly placed in space or ground elements as mandated by the time-evolving nature of satellite IoT network topology.

To cope with these issues, we argue that unprecedented solutions could arise from exploiting the predictable nature of orbital mechanics, leveraging the delay-tolerant nature of the IoT traffic, and learning from frequent revisits to service areas by
passing by satellites [15]. These leads to the core of this work which identifies the challenges and opportunities of integrating space technologies with terrestrial low-power long-range communication in a comprehensive satellite-IoT network architecture. The novelty of this article is the focus on the integrated space-terrestrial networks as a whole, leveraging the state-of-the art of space technology, protocols and procedures. To this end, we propose a suitable reference architecture and discuss the main challenges to be taken by the exiting technologies to realize a world-wide IoT connectivity. We specifically concentrate in the radio access and core network parts of main LPWAN technologies: LoRaWAN and NB-IoT.

II. Background

We start this paper by presenting the main characteristics of satellite and IoT technologies on which we base our contribution.

A. Satellite Orbits and Technology

Satellites can be deployed in different orbits with diverse characteristics. On the one hand, satellites in Geosynchronous Equatorial Orbit (GEO) exhibit an orbit with a rotation period equal to that of the Earth, appearing motionless to an observer on the ground. GEO satellites have an altitude of 35,786 km, what gives them a coverage of approximately 30% of the Earth’s surface (see Fig. 1). On the other hand, satellites in Low Earth Orbit (LEO) are deployed at lower altitudes, between 160 km and 1,000 km. However, they move at ~7 km/s, which results in overflights of <10 min over a given spot on the surface. Thus, constellations of several LEO satellites are needed to provide persistent coverage.

The difference in LEO and GEO imposes constraints also in launch and deployment costs: from just a few thousands of dollars per kilogram in LEO to 6 times more for the same mass in GEO [3]. Spacecrafts in GEO are also more adverse to risk than those in LEO, and the selection of flight-tested components is mandatory, which reduces the opportunities for innovation. As a result, LEO satellites are much more attractive as testbeds for new space technology such as satellite IoT.

Started as a nanosatellites standard for pedagogical purposes, CubeSat evolved beyond its academic expectations as it provided a common mechanical and electrical framework for the efficient and inexpensive development of nanosatellites by government agencies and companies. Specifically, a 1U (1 unit) CubeSat is characterized by a weight of ≈1 kilogram and a form factor of $10 \times 10 \times 10$ centimeters. Since its introduction, the cost of CubeSat plateforms has dropped dramatically, and are now included in LEOs, allowing the so-called new space actors (e.g., Lacuna Space, Fleet, Sateliot), to venture into the challenging satellite IoT domain. To further reduce costs and risks, while extending compatibility, existing IoT technologies are being leveraged.

B. LPWAN Technologies

Low Power Wide Area Networks (LPWANs) are IoT technologies designed to enable low-volume data transmission over tens of kilometers, while keeping very low energy consumption for the end-devices. This was achieved by combining new radio modulations with a simplified network architecture in which all the intelligence is moved towards a central server, allowing the development of cheap end-devices and gateways. As of 2021 more than
200 million devices are being served by the most representative LPWAN technologies: LoRa (combined with the LoRaWAN protocol that defines the network architecture and the communication protocols [11]), NB-IoT (developed by 3GPP) [12], and Sigfox. We briefly introduce below the main features of LoRaWAN and NB-IoT, and we leave aside other LPWAN technologies that do not have any current satellite deployments.

a) **Frequency bands and modulation:** NB-IoT operates over licensed bands, as it is designed to be deployed mainly alongside existing LTE services in three different modes: in-band, guard-band, or standalone (over a GSM band). Also, NB-IoT leverages SC-FDMA and OFDMA in the uplink and downlink channels respectively. The scheme operates over a 180 kHz bandwidth with reduced frequency and time synchronization requirement, as compared to LTE. BPSK and QPSK modulation schemes with single antenna are supported in NB-IoT. LoRaWAN on the other hand, runs over unregulated industrial, scientific and medical (ISM) bands, which means possible interference from neighboring devices and from other technologies. In Europe, for example, the used frequency for LoRaWAN is 868 MHz, which enforces very strict regulations on the transmission power and on the duty cycle (maximum ratio of time that a device can transmit per hour). More specifically, LoRaWAN can use a duty cycle of 1% for its uplink communication (from end-devices to gateway) and 1% to 10% for its downlink communication (from gateway to end devices). LoRaWAN leverages a proprietary chirp spread spectrum (CSS) modulation on channels bandwidths of 125 kHz, 250 kHz or 500 kHz.

b) **Radio access:** LoRaWAN uses an Aloha-based medium access protocol and defines three modes of operation: (i) class A, where end-devices spend their time in an idle state, waking up only when they have new data to transmit and consecutively wait for a possible downlink communication, (ii) class B that offers regularly-scheduled, fixed-time opportunities for downlink communication, and (iii) class C, where end-devices are always listening for downlink messages, unless they are transmitting an uplink.

NB-IoT, on the other hand, inherits a tighter access control from the base station, as in LTE. Thus, cell acquisition and synchronization are required on the device side, and the base station informs the end devices a scheduling of the radio resources via the so-called DCIs (Downlink Control Indicators). However, NB-IoT devices do leverage a random access channel (RACH) for initial uplink synchronization, also needed after a long state of inactivity. These includes so-called Power Saving Mode (PSM), and extended Discontinuous Reception (eDRx).

c) **Gateway association:** In NB-IoT, end-devices communicate directly with a single base station (i.e., they are associated and served by a single antenna). LoRaWAN uses a more flexible association approach, enabling the so-called multi-gateway feature. This implies that a single uplink packet transmission will be received by all the base stations in reach of that end-device. It is then up to the network server to combine or discard the received frames, and choose which is the best base station to send a downlink packet when needed (e.g., an acknowledgment).

d) **Core network:** On the core network side, NB-IoT is organized in more functions and elements than LoRaWAN. The reason is that NB-IoT is designed to co-exist with legacy 3GPP mobile networks architectures (i.e., 3G, LTE). For instance, NB-IoT discriminates between IP and non-IP traffic, which flow over control/management functions or traffic service elements respectively. This complexity is largely simplified in LoRaWAN where all core functionality is performed by a network server and a join server.

C. Satellites and IoT

In the space context, IoT has not been prominently addressed under such naming, however, application-specific low power and low data volume technologies already exist for several years. For example, Argos [7] is a device-to-satellite protocol designed in the 70s to transport small amount of environmental data and used today to provide telemetry and telecontrol to more than 22 thousands weather stations and buoys. Satellite Automatic Identification System (S-AIS) [9] and Satellite Automatic Dependent Surveillance–Broadcast (ADS-B) [10] are two other popular space protocols used to collect tracking data from vessels and aircraft worldwide.

Although a common interest, a truly global satellite IoT is more likely to be achieved if ground
IoT can be ported to the space domain, rather than replacing terrestrial IoT by the aforementioned space protocols. The reasons behind this strategy are three-fold: (i) satellite IoT could profit from mass production and derived lower costs already achieved by terrestrial IoT; (ii) satellite IoT would benefit from a larger ecosystem and community optimizing the attainable performance with scarce resources; and (iii) satellite IoT will seamlessly integrate with existing terrestrial deployments. In other words, the hypothesis behind this paper is that satellite IoT networks will coexist and inter-operate with the terrestrial ones, likely by adapting or configuring well-developed LPWAN protocols inspired by operation procedures from classical space networks. The resulting protocol ecosystem is illustrated in Fig. 2.

III. OPPORTUNITIES

A satellite-based global network for IoT would boost and enable access equality in regions where coverage is otherwise technically and/or economically not viable. The opportunities brought about by such a worldwide IoT service are many-fold.

The immediate benefit of satellite IoT is the massive and ubiquitous collection of data. This, in turn, will support more informed decisions, which could reduce operational costs via process automation both on an industrial and a domestic scale. In most cases this would be achieved by logistics enhanced by anywhere and anytime assets tracking, such as land, sea and air transport vehicles, fleets, objects and materials. Massive data collection will also unlock the monitoring of environmental parameters over geographical areas where terrestrial networks are not present, including inaccessible forests, large deserts, and oceans. In particular, the energy sector typically operates in remotes regions, where satellite IoT could bring unprecedented management. Besides traditional gas and oil extraction, renewable solar farms and offshore wind-parks could drastically boost their efficiency in generating but also in delivering energy from remote zones. Utilities smart metering, agriculture, and most importantly effective healthcare solutions already available in urbanized regions could be brought to faraway lands with otherwise isolated individuals. Indeed, the reduced cost of CubeSat nanosatellites in the new space context enables a more democratic access including developing countries.

Besides massive data collection, the global connectivity of assets has the potential of creating the largest networked ecosystem where unparalleled interaction could take place. The satellite IoT phenomena interestingly occurs in times where federated machine learning is starting to unblock the classical centralized training approaches [13]. Instead of fusing large amounts of data together (which suffers from privacy, security, industry confidentiality or bureaucratic problems), the discipline is switching to a new training paradigm in which data owners collaboratively train a model without exposing sensible data, while keeping quasi-optimal fitting performance. In this context, satellite IoT could contribute with the potential of collecting and safely sharing world-wide data to enable future intelligent applications such as driver-less cars, automated medical care, finance, insurance, among other sectors.

These opportunities come at the expense of successfully dealing with non-trivial technical challenges. To properly identify them, the following section depicts the proposed satellite IoT network architecture.

IV. THE FUTURE IOT NETWORK ARCHITECTURE

In the context of enabling access equity by bringing together satellite communication and IoT
technologies, we propose the network architecture depicted in Fig 3. We claim that the future IoT networks have to take advantage of all available technologies by deploying and mixing both terrestrial and satellite networks. The decision of which specific technology to be deployed in a given area should be taken by accounting for the specificity of that geographical area, the availability of electrical power, and the density of end-devices. In this respect, we identified two possible deployment scenarios that can benefit from the Satellite-IoT paradigm. It is important to not see these different deployments as individual, but as interconnected networks belonging to the same global network.

A. Indirect to Satellite IoT

Outside highly accessible, dense, urban areas, we find rural areas with a high concentration of end-devices that justifies the deployment of dedicated IoT gateways to serve them. However, the terrain and local conditions (i.e., lack of cellular coverage, impossibility to deploy fiber) might make it difficult to have an available infrastructure to transport data from the gateways to the core network. In this case, using satellites to serve as backhaul for these gateways on ground is a very appealing solution. GEO satellites are particularly interesting to this end, as their fixed high-gain antenna placement facilitates the commissioning of new gateways.

As end-devices do not reach the satellite directly (but via gateways) this type of deployment has been named indirect-to-satellite IoT communication. The protocols to be used can be based on a clearly separated ground and space domains. Specifically, standard IoT (e.g., LoRaWAN, NB-IoT) will continue to be used the same way between end-devices and the gateways, with some adjustments to account for the higher delay between the gateway and the network server, as a consequence of the satellite link (e.g., adapting the times for scheduling downlink communication in LoRaWAN). Space-specific protocols and technologies (e.g., CCSDS-based protocols) can then be implemented on the gateway-to-satellite link. The challenge will be in integrating them into an harmonic end-to-end satellite IoT architecture.

B. Direct to Satellite IoT

On the other hand, applications on less accessible regions (i.e., oceans, mountains, poles) might not justify or even hinder the deployment of IoT gateways. In such scenarios, IoT devices should rather directly access the satellite with an on-board gateway. As GEO links are not suitable due to the large range, LEO satellites emerge as the most appealing approach. Flying at less than 1000 km above Earth, the channel with LEO satellites can be set up to meet the margins required by LoRaWAN and NB-IoT protocols, even with low-cost antennas on the
IoT device (and without any other modification to the device).

The main challenge with direct-to-satellite IoT access is that LEO orbital periods are in the order of 90 minutes, which implies the duration of a typical satellite pass over a given point of the planet will be in the order of 10 to 3 minutes (for a perfectly zenithal pass and a pass over the horizon, respectively). During this period, the channel conditions will vary drastically from more than 2,000 km to the actual satellite altitude (at the zenith position as seen from the device perspective). The coverage region of a single LEO satellite will thus move at the same speed over the surface (approx. 7 km/s), implying that the set of served devices will change in time. In other words, DtS-IoT renders a high-speed flying IoT gateway with a highly varying channel over a predictable orbital trajectory.

In order to ensure continuous services, LEO satellites are deployed in constellations. As a result, as one satellite hides in the horizon, another is rising to serve a given device on the surface. In these cases, Inter-satellite links (ISL) allow LEO fleets to coordinate and relay user data with the ground station connected to the core network.

C. LoRaWAN and NB-IoT in the Space Context

Fig. 4 presents the 3GPP NB-IoT network architecture and LoRaWAN architecture elements in the context of indirect and direct to satellite IoT. The key aspect of these LPWAN architectures is that mobility is solely addressed on an end-device level, but in satellite IoT, gateways and even part of the core network location could be dynamic.

NB-IoT offers rich mobility features inherited from LTE technologies. In particular, 3GPP Release 14 introduces an optional Radio Resource Control (RRC) to resume data transfers once the IoT device moved between cells. This requires data transfer via the control plane and internal core network synchronization. Also, the standard supports mobility during idle mode, to address cases where the IoT device needs to be accessible even when moving to another base station.

LoRaWAN, on the other hand, enjoys a much simpler and limited mobility support. The multi-gateway approach means a seamless transition for the IoT end devices, unlike following the handoff processes required in NB-IoT (i.e., to let the network know that a device is now associated to another eNB). Nevertheless, simplicity in mobility in LoRaWAN comes at the expense of under-specification by the standard e.g., the algorithm to chose the gateway for sending a downlink is not specified. While in LoRaWAN class A a downlink is only possible after an uplink (which allows to identify the current best gateway), Class B and C devices might move since the last uplink without the server to notice a new gateway should be considered. However, the LoRaWAN specification states that a mobile end-device should periodically inform its location to update the downlink route. Furthermore, the standard indicates that ADR should not be enabled while devices are moving even within a single gateway coverage.

These mobility aspects have a profound implication when migrated to Satellite IoT, especially in...
LEO. Indeed, from the device on ground perspective, a LEO constellation of IoT gateways might render a mobility scenario not even considered for terrestrial IoT (i.e., satellite passes of a few minutes, multiple gateways present for a few seconds, etc.).

V. CHALLENGES

Based on the proposed architecture satellite IoT architecture, we present the open challenges that will need to be addressed to materialize them in the short term.

a) Cultural: One of the main challenge to be addressed in satellite IoT is cultural. Two communities from very different origins and application domain meet at the satellite IoT spot. On the one hand, a space community where trajectories and actions of a very expensive and dynamic system are known in advance, and tightly controlled by a centralized mission control. On the other hand, a thriving terrestrial IoT sector where costs from devices and gateways are negligible, and where control can be disregarded at the expense of achieving scalability. Both, however, share some common aspects, such as the great importance of the scarce energy resource.

b) Physical layer: Radio access is likely the main technological challenge in satellite IoT. On the physical layer side, there is room for demonstrating the performance of LoRaWAN and NB-IoT modulations in ground-space channel conditions (atmosphere, Doppler, etc.). Also, the proper antenna design for the gateway at the satellite requires attention, together with spectrum management on a global scale, whether licensed or not. To support IoT technologies that work in the ISM bands (e.g., LoRaWAN), the network server needs to be able to update the gateways so that the geographical area over which the LEO satellite is flying is synchronized with the frequency band supported by that region. All of the above could leverage existing know-how from the space community.

c) MAC protocols: On the MAC side, we need to be able to scale existing IoT protocols to handle hundreds of end devices that need to access the gateway in (the same) very short window (see Fig. [1]), so that they fit the short-lived coverage of LEO satellites. This challenge is boosted by the very long-range on the direct satellite-to-ground links with devices in Dts-IoT. The opportunity at hand, however, is to profit from the predictable LEO satellite trajectory to determine optimal transmission spots. Either the orbital path can be computed on constrained devices, or the satellite dynamics can be estimated by means of broadcasted position in beacons, or by Doppler shift measurements on the device side. Based on this information, traffic (and control messages) can be conveniently aggregated (both on device and gateway side) and scheduled at the optimal time to enhance the performance and reduce energy waste. Thus, new access control schemes can be derived from this combined prediction, aggregation and scheduling access approaches.

d) Core: The placement of network functions in satellite IoT is a related and open research topic. When mounted of a satellite, the gateway or the eNB might no longer enjoy a stable and low-latency connection with the network core. As a result, virtualization can be exploited to dynamically locate delay-sensitive functions at the edge of the network (i.e., the satellite), while keeping delay-tolerant aspects in the core at ground. For instance, ACK, HARQ, ADR, among other handshake-based features will need to be deployed and coordinated in orbit when no direct connection with the core is present. The resulting Network Function Virtualization (NFV) strategy will need to cope with unprecedented connectivity gaps mandated by the predictable orbital mechanics. Same with authentication, authorization, and accounting (AAA) functionalities, traditionally exclusively handled at the core network. Indeed, the scalability issue highlighted in the access part, is also applicable the distribution of core functionalities in a satellite IoT. On a related front, multi-gateway implications in the satellite IoT domain remains to be explored. For example, deciding which orbiting gateway should react with an ACK to a given message, or which should send a beacon or downlink user data on a given instant depends on coherent but likely asynchronous satellite IoT core procedures yet to be defined.

e) Mobility: While in terrestrial IoT networks existing LoRaWAN and NB-IoT standards already account (more or less) for a possible mobility of the end-devices, in satellite IoT networks we have an opposite mobility scenario: end-devices are mostly static, but gateways are mobile in orbit (with predictable trajectories). This opens two new challenges in IoT: (i) how do end-devices take into
account the mobility of gateways for sending their packets uplink? (ii) how do network servers handle the scheduling of downlinks while accounting for the orbital dynamics of the satellite? Moreover, periods of disconnections should be coped with in sparse constellations designs that allows for connectivity gaps that reduces the fleet size requirements, as presented in \[15\]. In this context, it remains unclear if the tighter mobility control imposed by cellular-based NB-IoT with respect to LoRaWAN can be beneficial or detrimental to future satellite IoT. In particular, further research is expected to understand the trade-off between energy cost and performance gain of NB-IoT and LoRaWAN mobility approaches.

f) Management: From a more general perspective, operations and network element management will rest at the core of successful satellite IoT systems. On the one hand, the access part of the system will need to be enabled by access schemes that consider drifting clocks on IoT devices. This can be achieved by MAC that either keep them synchronized, or that can operate without common time bases (i.e., LoRaWAN Class A vs. Class B). The trade-off among both approaches is an appealing research topic. On the other hand, the core portion of the network will need to coordinate and manage actions over asynchronous satellite-to-satellite and satellite-to-ground links. For instance, downlink data flows could be buffered in advance in LEO satellite’s memory, then scheduled to overcome otherwise high-latency device-to-server handshakes and to save collision in such dense DtS-IoT network. Indeed, gateway (satellite) mobility in DtS-IoT is to be managed by these same means. This overall synchronization challenge demands novel network operation concepts at the intersection of terrestrial IoT and space.

g) Standardization: To allow a seamless connectivity between ground and satellite IoT networks, the IoT stack provided by IETF should be used (UDP/CoAP/DTLS). Because of capacity limitations and delay constraints specific to the satellite context, this protocol stack should be extended, e.g., introducing a new convergence protocol for CoAP, and new multicast addresses for group communication (be it at the network or application layer). Also, the compression and fragmentation mechanisms provided by SCHC (RFC9011) should be adapted in this new context. For further standardization discussions including 3GPP group the reader is referred to \[2\].

h) Others: Other derived aspects are relevant in future satellite IoT research. Adequate performance metrics for satellite IoT will need to be derived to evaluate the hybrid IoT-space network. Benchmark scenarios are also envisioned to this new research domain. Methodological-wise, the discipline can enjoy multiple approaches, from the optimization field, protocol design, model verification, among others. Finally, security topics remains a relevant research topic in this context, as link intermittency in the core and access networks complicates key distribution and hinder stable encrypted data exchange.

VI. OUTLOOK

The opportunities emerging from a global IoT vision are unprecedented, as they can impact traditionally strong business sector as well as currently unserved remote communities. This paper has analyzed state-of-the-art space and terrestrial IoT technologies, in the attempt of detecting adaptation and integration needs to overcome the missing terrestrial infrastructure. Framed in a novel space IoT architecture, we were able to outline the main open research challenges laying on the path towards an IoT infrastructure with an ambitious goal of achieving a global service footprint. In particular, we believe that the key challenges emerges from adapting the existing IoT radio access and core infrastructure to cope with the specifics of orbital dynamics: extremely long communication ranges, and frequent but predictable connectivity gaps.

REFERENCES

[1] I. Leyva-Mayorga, B. Soret, M. Röper, D. Wübben, B. Matthiesen, A. Dekorsy, and P. Popovski, “LEO Small-Satellite Constellations for 5G and Beyond-5G Communications,” IEEE Access, vol. 8, pp. 184,955–184,964, 2020.

[2] M. Centenaro, C. E. Costa, F. Granelli, C. Sacchi, and L. Vangelista, “A survey on technologies, standards and open challenges in satellite IoT.” IEEE Communications Surveys & Tutorials, 2021.

[3] H. Jones, “The recent large reduction in space launch cost.” 48th International Conference on Environmental Systems, 2018.

[4] J. A. Fraire, S. Céspedes, and N. Accettura, “Direct-to-satellite IoT-A survey of the state of the art and future research perspectives,” in Int. Conf. on Ad-Hoc Networks and Wireless. Springer, 2019, pp. 241–258.

[5] M. R. Palattella and N. Accettura, “Enabling internet of everything everywhere: LPWAN with satellite backhaul,” in 2018 Global Information Infrastructure and Networking Symposium (GIS). IEEE, 2018, pp. 1–5.
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