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IoT Network for Satellite Communication Applications and Challenges

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Abstract—The Internet of Things (IoT) is expected to bring new technology for several existing and new applications for improving several services for the Society.It can provide both accuracy and sustainability in the emerging services and applications. It has been spreading in the recent past few years, and it covers a wider range of possible application scenarios, such as smart city, smart factory, and smart agriculture, among many others. In this framework, massive connectivity represents one of the key issues. IoT has several advantages and it can provide different levels of coverage in different geographical locations and contexts. In the recent years, world has witnessed the ubiquitous applications of Internet of things (IoT) for many different scenarios. There are several applications in which the wide coverage, low power and reliability of the communication have very high priorities. There are several critical applications where the results are essential and the mission has to be successful at any cost. Such applications are well known as mission critical applications. These applications are really critical and deal with very serious situations. IoT is one of the main use cases which are growing, leading to a massive amount of data that need to be exchanged throughout the Internet. Satellite communication networks are essential in remote and isolated environments and can support fully connected environments by offloading the terrestrial infrastructure concerning delay–tolerant traffic flows. However, satellite network resources are limited and expensive, so they need to be carefully used in order to avoid waste and satisfy the required user performance. Our paper presents a survey on current solutions for the deployment of IoT services in remote/rural areas by exploiting satellites.We present the applications where these satellite based IoT networks can play important roles. This article analyses the performance of a satellite architecture in the IoT framework.

I. Introduction

Internet of things (IoT) is pervasive extension of the Internet in different domains. In fact, the dimension of the Internet can be expanded in many ways using IoTs. The impact of IoT on many aspects of life, being they industry, logistic or everyday use, is growing quickly. New promising use cases are constantly added, supported by new and smarter technologies. Mission critical applications are very important as they deal with very serious circumstances and their failure may result in big losses of lives and properties. In mission critical military applications, protection of borders and defense of territories are associated. The Internet of Things (IoT) is one of these recently-emerging use cases, which will involve an even higher number of connected devices aimed at collecting and sending data with different purposes and over different application scenarios, such as smart city, smart factory, and smart agriculture. A massive growth and spread of devices, such as sensors and actuators, has been envisioned for 2021 and beyond, with a consequent big mass of data that need to be collected, processed, and, in some cases, displayed to users remotely connected to the Internet. Satellite-based approaches, such as the space–air– ground integrated networks , are considered as viable solutions thanks to their ubiquitous coverage and broad- cast/multicast capabilities. Considering the IoT context and the associated connectivity requirements, satellite access can play a significant role in enabling IoT services. Satellite communications (SatCom) networks are partic- ularly suitable to offer connectivity to a high number of devices located in wide areas, complementing terrestrial infrastructure thanks to the large coverage. In the perspective of expanding the benefits brought by IoT to include geographical areas where it is not usually viable, for technical and/or economic reasons, to provide ubiq- uitous coverage, telecommunication providers and enterprises are looking for integrated IoT-based global coverage solutions. Indeed, IoT operation can become critical in remote areas with low/no cellular connectivity for many different industries such as transportation (maritime, road, rail, air), fleet management, logistics, solar, oil and gas extraction, offshore monitoring, utilities smart metering, farming, environment monitoring, mining, and many others. With this perspective, *satellite-based technologies* that can be integrated with existing IoT terrestrial networks seem to be the way to go. Satellites are there- fore conquering the special and important role of including in this ecosystem remote geographical areas where terrestrial networks are unavailable or out of reach, such as on remote land (think at the case of areas such as, e.g., forests) as well as offshore (e.g., in the oceans).

II. Satellite based IoT networks

At present, regardless of all the technologies available, all existing mission critical distributed applications face performance and reliability problems. These applications may go through any of the software or hardware failure, which causes losses in time, data, money and human lives. Failure of the system can put business in fail or can put unfavorable affect on business and society.Normally, satellites and IoT do not seem to be natural partners in the communication world. However, due to the compulsions of some specific situations they meet each other in several instances. Therefore there are several reasons the IoT should be combined with the satellites to meet these special demands. Here in this section we present the major reasons for their conjugation. In Fig. 1 we show a satellite based IoT network. The coverage area of the satellite has been shown as an oval within which lies the IoT network. The IoT trans-receivers are the triangular towers and the red dots are the sensor nodes. Both the IoT and the satellite links are wireless. Existing terrestrial long-range IoT wireless solutions and standards are considered the most appropriate at driving satellite IoT market expansion for their scalability, reduced costs, greater supplier diversity and easier integration for the customers. All state-of-the-art long-range IoT wireless solutions share common features that can be summarized as a radio access network (RAN) based on a *star topology* each IoT node, hereafter referred to as machine-type device (MTD), is connected directly over- the-air (with a single hop) to an IoT gateway providing connectivity towards an application server, reachable through the Internet.

III. Satellites for IoT

Satellite constellations in geostationary earth orbits (GEO) provide terabytes of capacity and mainly are used for direct to home broadcast and Internet over satellites. GEO satellite constellations are not suitable for mission critical applications due to their high latency. Due to path loss between earth and satellite and slotted nature of the geostationary orbit, terminal antennas in such systems must have large gains to close the link and higher directivity to avoid interference with adjacent satellites and systems. LEO satellite constellations when compared to GEO have advantage of low propagation delay, global coverage and small propagation loss which are the basic needs of a mission critical application. Due to lower orbit altitude (generally lower than 2000 km) the round trip time for LEO constellation is around 100 ms while that of GEO satellite constellation is 600 ms [16]. Similar to LEO some highly elliptical orbit (HEO) satellite constellations operate closer to earth compared to GEO satellites and offer the advantage of lower path loss and hence are less costlier, lighter and have low latency. Hence these are well suited for mission critical applications. However, LEO and HEO constellations have a drawback that there location keeps on changing with respect to a point on earth hence they give rise to a highly time variant communication channel and therefore need steerable antennas.

IV. IoT Technologies

The IoT refers to the data exchange between a large amount of devices and sensors connected wirelessly without human interference. It can be used in various fields such as smart metering, smart buildings, and environmental monitoring. The number of IoT connected devices installed worldwide has increased exponentially from 15.41 billion in 2015 to 23.14 billion in 2018, and it is expected to reach 75.44 billion in 2025.IoT wireless technologies can be divided into two categories: short and long range. Table1 contains a summary of short-range solutions and of long-range brand-defined approaches available on the market and also identified as commercial solutions.IoT devices transmit their data to a brand-defined gateway through a technology acting at the data link and physical layers where IoT application data are directly encapsulated. All involved protocols are strictly brand defined. Each gateway is a protocol converter encapsulating the private IoT application into an Internet protocol stack to be conveyed to the IoT cloud where a brand-defined server will apply an application layer conversion from the IoT application to an Internet application protocol (such as HTTP) suitable for end users.

V. Role of satellites in IoT applications

Satellites can have two main alternative roles in a typical satellite/terrestrial integrated network for IoT applications: direct-access (fronthaul) or backhaul.In the first case, sensors are directly linked to the satel- lites, which are the first hop of the communication path between IoT devices and users. Third Generation Partner- ship Project defined six different reference scenarios [24] changing the altitude of the considered satellites (GEO and non-GEO), the complexity of the carried satellite payload (transparent or regenerative), and the flexibility of the gen- erated beams (steerable or moving beams) for direct-to- satellite access (front haul). The most promising approaches are mainly considering low earth orbit (LEO) and very low earth orbit satellites, even if intrinsic challenges have still to be overcome, such as the heterogeneity of the IoT solutions and the high energy consumption of IoT devices. Some ongoing activities are investigating these issues to assess the feasibility of direct-to-satellite access, such as and In the second case, satellites can be adopted as backhaul to the Internet or to a dedicated service center. Sensors' data are collected within an edge cloud in the terrestrial access network and then made available through a satellite data network backhaul by using IP-based protocols. High throughput satellites and very high throughput satellites GEO platforms operating at Ka or higher frequency bands are the main options. They can considerably reduce the com- munication costs providing large amounts of bandwidths, making satellites a viable solution to enhance the overall network capability. applications demand dependable, low latency and high- throughput connections. These requirements can be fulfilled by using high throughput satellites (HTS). HTS utilize technologies such as concentrated spot beams, higher frequency bands and frequency reuse to increase the speed and capacity of GEO/LEO/HEO satellite constellations. Additional aspects specific to mission critical application such as low SNR, time variant channel and link budget needs to be considered while tailoring the communication standard. An integrated or hybrid LEO- GEO constellation can be a potential solution for many applications. Hybrid systems may provide benefits of both such as, lower latency, flexibility, and scalability of LEO satellites. Likewise high-capacity and wide coverage of existing GEO constellations can be achieved. However such system will require an optimized routing system which routes to LEO when it requires low latency and GEO when there is a need to transmit a large volume of data at any time. For such system to be success dynamic routing must be in place.

VI. Satellite IoT Enablers in 5G Systems

Satellites are expected to cover a relevant role in IoT sup- port in 5G systems. Indeed, while terrestrial communications will probably cover the majority of application scenarios, satellite will most likely play a role in the framework of mMTC, for their wide area coverage and relatively short ser- vice deployment time. Tab. V, which contains data from [46], summarizes the key satellite mMTC-UE requirements in two distinct time frames: 2018 (i.e., today) and 2023, when 5G is expected to be deployed worldwide. The table clearly outlines two major specific requirements of IoT application scenarios:

i) the sparseness of data communication and relaxed latency constraints, and ii) the mean time between maintenance operations. The latter represents an extremely long time, that is measured in years, which is expected to further increase as we look into the future scenarios.

VII. Industrial focus

After the presentation of the technological enablers, let us now survey the most interesting industrial players in the satellite IoT arena. We will categorize these initiatives by technological enabler, following the presentation order of such enablers we adopted in the previous sections and keep- ing in mind that, at the time of writing, the standardization of 5G is still ongoing thus no initiatives can be ascribed under the 5G umbrella. Therefore, we will describe indepen- dent initiatives leveraging LEO satellites (see Section III-E) and LPWANs (see Section IV-B), distinguishing between LoRa-based initiatives and NB-IoT-based initiatives.

VIII. Open challenges and future directions

In the previous sections, we identified the technological enablers of the satellite IoT paradigm provided by LPWANs and 5G, as well as the most prominent initiatives which are leveraging them to support a broader adoption of IoT services, thus creating new business opportunities and mod- els. Those represent the current state of the art in terms of standardization and ongoing initiatives. Nevertheless, research is looking more in the future, towards technologies capa- ble of providing further advances and revolutionary solutions.

IX. Conclusions

In this article, we discussed the main utilities of the satellite based IoT systems for mission critical tasks. We have gone through the basic requirements of a typical satellite based IoT system, its coverage limitations and the power needs. SIoTs are essential for several mission critical applications due to their superior performances. These systems overcome several natural difficulties of the traditional systems. For the long term sustainability, SIoTs have to be energy and bandwidth efficient. Thus resource efficient versions such as the NBIoT are preferred over other forms for the long term. Current market demand and commercial perspectives of SIoT based businesses are bright. Several companies have planned to use SIoT in businesses. Several startups companies are also showing great interest in the SIoT based services. The huge amount of raw IoT data could stress the limited and expensive SatCom resources, which have to be carefully managed. Equipping the edge of the network with local pro- cessing MEC functionalities, such as data compression and aggregation, allow improving end-to-end performance and QoS in communications when satellite links are exploited. This article has analyzed a SatCom-based MEC network architecture where a GEO satellite acts as a backhaul node between an IoT sensor network and the Internet. A dis- tributed MQTT framework is defined where local instances of MQTT brokers and data aggregation and compression techniques are deployed as Virtual Functions at the edge of the network. Performance evaluation is carried out through an ad hoc designed testbed comparing the obtained perfor- mance with three different network configurations in terms of the amount of data that need to traverse the satellite link and data delivery time. The employment of MEC functionalities allows obtaining a significant reduction of the satellite link bandwidth utilization and of the achievable data delivery time in most of the considered cases. The use of data aggregation techniques leads to a higher delivery time in some cases, which can affect delay-tolerant data, so implying a careful design.

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