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Abstract	The Internet of Things (IoT) is expected to bring new opportunities for improving several services for the Society. In this framework, massive connectivity over large geographical regions represents one of the key issues. In such scenarios, the usage of satellites might represent a viable solution for providing wide area coverage and connectivity in a flexible and affordable manner. This chapter will focus on current solutions for the deployment of Internet of Remote Things (IoRT) services and how it will lead to the Internet of Space Things (IoST). Open issues, new challenges, and innovative technologies will be focused, carefully considering the issues that current IoT standardization framework will impose to the practical implementation of future satellite-based IoRT systems.

Keywords (separated by "-")	6G - Non-terrestrial networks - Internet of Things - Internet of space things - Low-Earth orbit

Chapter 12
The Internet-of-Things, the Internet of Remote Things, and the Path Towards the Internet of Space Things

Fabrizio Granelli, Claudio Sacchi, Marco Centenaro, and Cristina Costa

12.1 Introduction

The Internet of Things represents an extension of the Internet technologies and IP-based networking solutions towards integrating real objects (Things) in the real world, and somehow enable the Internet and its Cyberspace to integrate with the Real World where we are living. The opportunities unleashed by such integration are expected to revolutionize several aspects of Society, from industry to cities, from health to mobility and transportation.

Nevertheless, most of the attention is currently focused on Earth, while few visionaries are "looking at the sky". Indeed, the Space might represent an additional dimension to the development of the concept of Internet of Things, by leading the way to better Internet of Things integration on Earth (the so called Internet of Remote Things) and finally to the Internet of Space Things!

This chapter focuses on the existing enabling technologies and challenges to make the Internet of Space Things a reality. The authors already analyzed such scenario in the groundbreaking contribution published in [**?**]. This chapter presents an extension and update of some of the material presented in the paper, with specific

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focus on Internet of Things, Internet of Remote Things and Internet of Space Things and the related communication and networking requirements.

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Existing long-range wireless technologies that might be used to implement the Internet of Things mainly derive from two different strands: mobile cellular networks and low-power wide area network (LPWAN) emergent technologies. As for mobile networks, which are currently managed by nation-wide mobile network operators (MNOs), various radio access technologies (RATs) are available, spanning from the second-generation (2G) General Packet Radio Service (GPRS), the third-generation Universal Mobile Telecommunications Service (UMTS), and the fourth-generation (4G) Long-Term Evolution (LTE) standard. Despite mobile networks were historically designed to satisfy human-originated traffic and human-centered applications, in recent years the standardization efforts of Third Generation Partnership Project (3GPP) progressively introduced support for IoT traffic, through the massive machine-type communication (mMTC) profile. Such profile is expected to support latency/reliability-tolerant IoT traffic with a very high number of service requests per base station (BS), but it was demonstrated to still present several challenges. On the other side, LPWAN technologies are emerging for their clear advantages in terms of low power operation and capability to explicitly support IoT requirements by design.

This chapter is organized as follows: the next Section provides an overview of the recent developments of 3GPP Mobile Network standards to support IoT, while the following one addresses LPWAN and LoRA in particular. Section IV introduces the possibility of exploiting LEO-based solutions for the Internet of Remote Things, and finally Section V concludes the paper identifying open challenges that research and industry should address in order to advance towards the Internet of Space Things.

12.2 3GPP Non-Terrestrial Networks for the IoT

Two major requirements of IoT application scenarios are usually considered:

- the sparseness of data communication and relaxed latency constraints;
- the mean time between maintenance operations.

Both requirements can be intrinsically satisfied by the mobile network technology standardized by the Third Generation Partnership Project (3GPP), because of the long-range coverage and the extended lifespan on the network infrastructure, respectively. However, while terrestrial communications will probably cover the majority of application scenarios, satellite will most likely play a role in the framework of massive IoT (MIoT), for their wide area coverage and relatively short service deployment time. For this reason, the satellites are expected to cover a relevant role for the IoT support in mobile systems.

As of today, mobile networks support IoT services either by means of existing technology generations like 2G (with EC-GSM-IoT) and 4G (with LTE Cat-M), or via LPWAN technology, that is, NB-IoT. However, all of these represent temporary solutions, bridging legacy technologies towards the newest one, i.e., the 5G [1]. In fact, a large body of research has been carried out about the new 5G air interface design, called NR, including the native support to MIoT [2].

In general, the integration of satellite connections in IP-native networks (including the mobile network technology) yield specific challenges, such as:

- compensation of long transmission delay. With the support of Performance Enhancement Proxies (PEP), TCP connections can be split in order to better adapt the congestion control strategy to the satellite link while maintaining the terrestrial section unmodified;
- overcome some of the limitations of HTTP/1 and HTTP/2. The direct use of unmodified mainstream protocols, such as HTTP/1, is challenging on constrained networks (e.g., high-latency, low-power, lossy). To overcome some of the limitations of HTTP/1, the Internet Engineering Task Force (IETF) has standardized HTTP/2. HTTP/2 runs over TCP, but the IETF is currently standardizing HTTP/2 support over QUIC, a new UDP-based, stream multiplexing, always-encrypted transport protocol focused on minimizing application latency. This transition could lead to the standardization of an HTTP/3 supported by QUIC, with the advantage that QUIC provides reliable data transfer and pluggable congestion control.

Specifically, the mobile networks need to transpose the general requirements above to assure connectivity to remote IoT-type user equipment (UE) via a so-called 3GPP non-terrestrial network (NTN), defined as a network, or segments of a network, using a spaceborne vehicle or an airborne vehicle for transmission. Two main differences can be identified between NTNs and the terrestrial ones, being:

- the long distance between IoT-type UE and the non-terrestrial RAN infrastructure, which introduces timing synchronization issues;
- the potential amount of devices to be supported in the IoT scenario.

The delay component is particularly relevant in the case of GEO satellites, which at an altitude of 36,000 km introduce a minimum one-way latency between IoT-type UEs and RAN of 238 ms. The usage of airborne vehicles as base stations, operating at an altitude of few tens of km, would help mitigating the latency and Doppler shift issues.

In this context, other than 5G, NB-IoT (and, in part, existing technology generations) are being evolved to implement satellite IoT solutions. However, the features of these two classes of technologies are extremely different. For 5G-native mobile networks, several brand-new features have been introduced, including:

- network slicing. It represents the biggest advancement at system level, enabling to isolate overlay networks capable of adapting to different use cases (including MIoT);
- O-RAN solutions, to better balance base station complexity and support interoperability between vendors;

- control plane optimization, to optimize signaling overhead in case of massive connections.

On the other hand, the typical NB-IoT architecture has been evolved towards supporting longer transmission ranges, with the following features:

- potential extension of NB-IoT modulations on the satellite link;
- flexibility at the physical layer seems to be moving in the direction of introducing SDR technologies, especially at the gateway level to promote interoperability.

12.2.1 Innovations of the Latest 3GPP Releases

The planning of 3GPP technology releases is reported in Fig. 12.1. The organization has been including significant contributions aimed at incorporating satellite components into the mobile network architecture [3, 4] since the beginning of 5G standardization, for a variety of use cases spanning from disaster communication to broadcasting and including Internet of Things. The study item phase on the so-called 3GPP non-terrestrial networks (NTNs) focused on integration of both satellites and airborne base stations into the terrestrial 5G network for extending network coverage, improve service continuity, and implement robust multicasting [5–7]. The subsequent work item phase has been taking care of developing work on the feature implementation details based on the agreed-upon concepts from the study item technical reports. In the following, we will present a bit more in detail the standardization work that was performed on NTNs across the latest (at the time of writing) 3GPP releases.

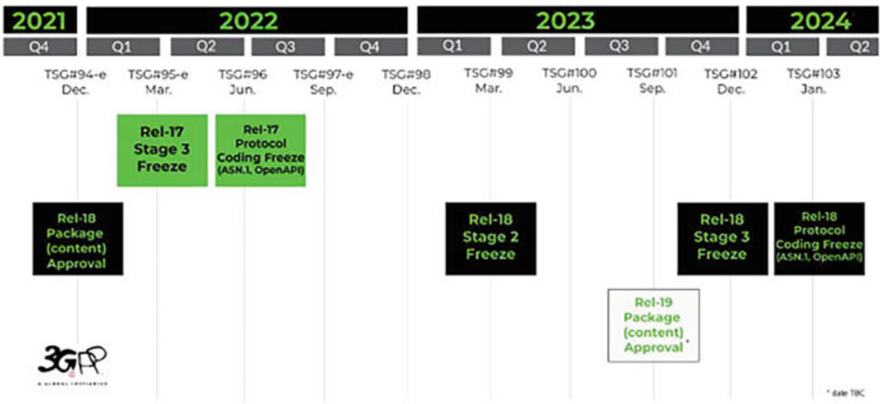

Fig. 12.1 3GPP release roadmap (courtesy of https://www.3gpp.org/specifications-technologies/releases)

12.2.1.1 Release 16

The 3GPP release 16 initiated the integration work of satellite components in the 5G architecture. However, such an integration was defined only in Stage 1. Since this was not consistent with the 3GPP methodology, where all aspects of a given Feature (Stages 1, 2, 3, charging, security, and so on) have to be completed within the same release, the rest of the work was moved to the following releases.

12.2.1.2 Release 17

Two distinct, though complementary, work directions were followed during the development of technical specifications during Release 17, one aiming at specifying the so-called NR-NTN integration (potentially including 5G-enabled MIoT) and IoT-NTN integration based mainly on NB-IoT. In both cases, three types of links between the UE and the base station are supported:

- Earth-fixed links, which are provisioned by beams continuously covering the same geographical areas all the time (e.g., the case of GEO satellites).
- Quasi-Earth-fixed links, which are provisioned by beams covering one geographic area for a limited period of time and a different geographic area during another period of time.
- Earth-moving links, which are provisioned by beam(s) whose coverage area slides over the Earth surface.

NR-NTN

Depending on how the satellite NG-RAN is exploited by the mobile network, two architectures are identified:

- Direct access with transparent satellite, where the satellite NG-RAN can be used as a new RAN 3GPP access—see Fig. 12.2.
- Satellite backhauling, where the NG-RAN is used as a backhaul between the 5GC and terrestrial NG-RAN, providing a transport for the N1/N2/N3 reference points—see Fig. 12.3.

While the latter option, thanks to the assumption of constant backhauling delay, minimizes the impact on the overall 3GPP network architecture, the former option

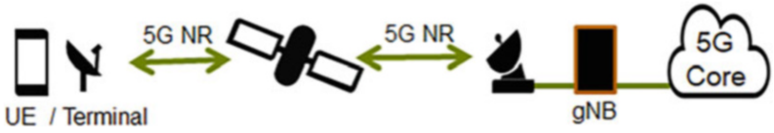

Fig. 12.2 Direct access with transparent satellite (courtesy of [8])

Fig. 12.3 Satellite backhauling (courtesy of [8])

requires substantial updates on the air interface. As a matter of fact, non-terrestrial radio access is provided by means of:

- an NTN payload, that is, a network node on-board a satellite or airborne vehicle;
- ~~2.~~ an NTN gateway interconnected by a feeder link.

As shown in Fig. 12.4, the UE accesses NTN services through the NTN payload via a service link. The NTN payload transparently forwards the radio protocol received from the UE to the NTN gateway and vice versa. Nevertheless, in order to allow connectivity to both NTN or terrestrial networks, the RF requirements of an NTN-capable UE requires the same RF performance as UE operating with terrestrial network. Timing, synchronization, and HARQ enhancements as well as mobility management enhancements were also introduced in the NR air interface to cope with the non-terrestrial communication. The considered operating bands are as shown in Table 12.1.

NTN for E-UTRAN access encompasses platforms that provide radio access through GEO, LEO or MEO satellites. The radio access works similarly to the NR-NTN one—see Fig. 12.5 Timing and synchronization, discontinuous coverage and assistance information, as well as mobility management enhancements were also introduced in the air interface to cope with the non-terrestrial communication.

12.2.1.3 Release 18

The 3GPP release currently under development continues to work on a further list of enhancements for both NR-NTN and IoT-NTN, including the definition of enablers for NR-based satellite access in bands above 10 GHz to serve fixed and moving platforms as well as building- mounted devices [10].

12.2.2 Innovation Projects

12.2.2.1 5G-EMERGE (2022)

In June 2022, the European Space Agency (ESA) launched a project called 5G-EMERGE which aims at developing a mixed satellite/terrestrial communication system based on open standards for the distribution of high-quality media content,

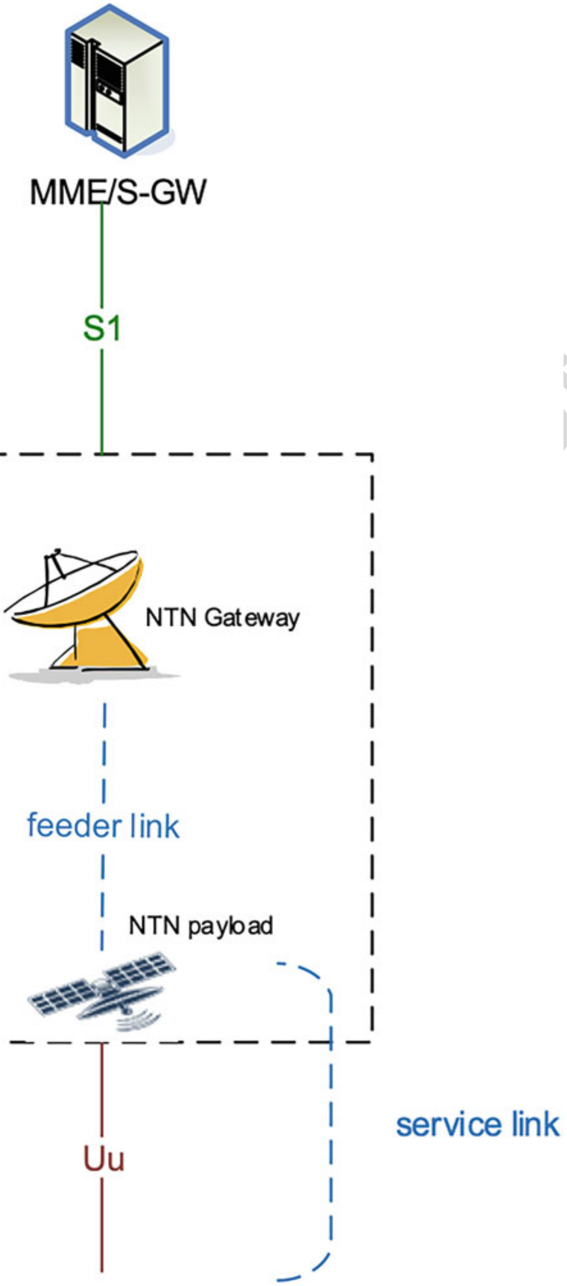

Fig. 12.4 NR-NTN radio access (courtesy of [9])

Table 12.1 Operating band for NR-NTN

Satellite operating band	Uplink (UL) operating band	Downlink (DL) operating band	Duplex mode
n256	1980 MHz–2010 MHz	2170 MHz–2200 MHz	FDD
n255	1626.5 MHz–1660.5 MHz	1525 MHz–1559 MHz	FDD

especially conceived for locations on Earth where the backhaul connectivity may be an issue [11].

The consortium is led by the European Broadcasting Union (EBU), and includes 20 companies from Italy, Luxembourg, the Netherlands, Norway, Sweden, and Switzerland, each of which covering specific components of the envisioned hybrid communication system. The consortium will join forces to create the distributed edge technology and service-delivery features leveraging on the structural advantages of satellite-base infrastructures combined with the flexibility of 5G and beyond-5G technologies to reach anyone, anywhere. At the network edges (that are, the places where end users reside like a neighborhood or even a single household), smart satellite gateways will be able to connect to a regular smartphone, a tablet or a TV set.

12.3 LPWAN for IoT

The typical approach to Satellite IoT is traditionally gateway based, where devices send data through the ground network to a gateway that acts as a collection hub and a node of communication towards the satellite. While this approach applies to many use cases, it still needs to be more effective for isolated and remote areas. In these cases, Direct-to-Satellite (DtS) approaches are more suitable. With this approach, devices are directly connected with Low Earth Orbit (LEO) Satellites which act as orbiting gateways. Indeed, since LEO satellites orbit at lower heights compared with geostationary satellites, MTDs on the earth's surface can establish links with the satellite at reduced power budgets and acceptable round trip time (RTT) delays, making DtS a feasible approach. As such, DtS-IoT does not require a ground infrastructure of connected gateway hubs. This architecture is especially interesting in scenarios where it is difficult or impossible to build a complete infrastructure, or the low density of MTDs makes inconvenient its deployment [12–14]. In these cases, the deployment can be quicker and more effective, and it is expected that there will be more such use cases in the future.

DtS-IoT is an attractive yet challenging approach since simplifying the architecture comes with a cost. In order to implement this approach, IoT devices need to be equipped with a robust Radio Frequency (RF) transceiver since data frames must reach the LEO satellites orbits at distances of up to 550 km at which the LEO satellites orbit [15]. However, the shorter distance between the MTD and

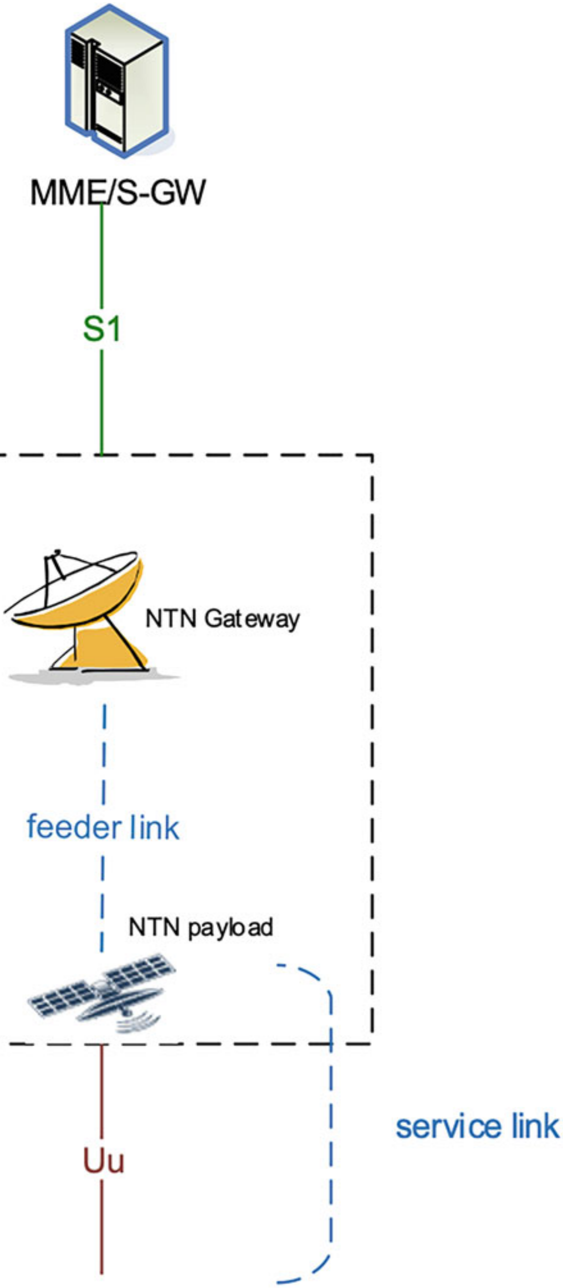

Fig. 12.5 NR-NTN radio access (courtesy of [9])

the LEO satellite (compared to geostationary ones) also creates a highly dynamic channel: indeed, considering an LEO satellite moving at more than 25,000 km/h, at a low orbit in the order of 500 km, this means that it remains visible in a serviced area for less than 10 min. This dynamic affects the service design since it is impossible to guarantee continuous coverage in time, as it happens for geostationary satellites. A possible approach is to adopt near-Earth constellations of LEO satellites, where the same region is covered by multiple LEO satellites during the day, thus achieving nearly continuous coverage. However, achieving acceptable coverage means growing the number of satellites in the order of hundreds. To reduce the number of satellites deployed, authors in [16] have proposed an optimal positioning of the orbiting gateways and properly dimensioning the delivery delay, thus allowing the adoption of sparse constellations of LEO satellites.

LoRaWAN is one of the low-power wide area networks (LPWAN) protocols currently used by the IoT community [17]. It has recently shown more potential to be adopted for the DtS-IoT deployment, together with Narrowband Internet of Things (NB-IoT) [18]. LoRaWAN [19] operates in the unlicensed spectrum. Its physical level relies on a combination of the Long-Range proprietary modulation (LoRa) derived from chirp spread spectrum (CSS) [20, 21] (patented by Semtech) and on frequency-shift keying (FSK) modulation. A Hamming channel code protects data packets. Working bandwidths are either 125 kHz, 250 kHz, or 500 kHz for uplink channels and 500 kHz for downlink channels. The medium access control (MAC) is derived from the classic ALOHA protocol and allows MTDs to transmit with quasi-orthogonal spreading sequences to mitigate the multiple access interference. LoRa has been designed to satisfy IoT main characteristics: low-power operations to support MTDs restricted resources, low data rate (as low as 250 bits/s with spreading factor SF12 in the 125 kHz channel), focus on uplink communication (even if it is possible to have communications in downlink) and kilometre-scale communication range.

When the number of MTDs increases and becomes dense regarding the area covered, the mandated duty cycle (which constrains the time on air that can be utilized per device) and the ALOHA-based medium access control (MAC) protocol used by LoRaWAN severely impacts the overall network capacity [22, 23]. Network densification is a likely future scenario for DtS-IoT due to its wide-area coverage, and scalability can become an issue. This requirement and the extremely long range that characterize direct satellite communications encouraged the proposal of LoRa physical layer variations. Recently, Semtech has proposed the long-range frequency hopping spread spectrum (LR-FHSS) [24]. It is a new PHY layer transmission that aims to increase the network capacity while maintaining the same radio link budget as LoRa. It has demonstrated considerable improvements in network scalability compared to traditional LoRa modulation.

12.4 Open Challenges Towards the Internet of Space Things

In this section, we focus on the analysis of the gaps that remain from the technological point of view, starting from the remarks provided in previous Sections, in order to fully unleash the potential of the Internet of Space Things.

The section is intended to identify open challenges and briefly introduce them, in order to suggest some potential areas for research and development in the area of the Internet of Things in general and the Internet of Space Things in particular. For clarity, those challenges are clustered around the layers of the TCP/IP protocol stack, starting from the physical layer up to the application layer and service support. More detailed discussion can be found in [**?**].

12.4.1 Independent LEO Satellites for IoRT/IoST

One of the enabling technologies for Internet of Remote Things is the use of independent LEO satellite constellations [25]. Such constellations are made of independent and small satellites that are typically cubic-shaped. The low deployment and launch costs of these satellites are expected to give new impulse to the initiatives concerning IoRT. Moreover, being LEO-based, small satellites offer reduced latencies and pathloss as compared to GEO solutions. Of course, such valuable advantages are paid in terms of reduced coverage and shorter lifetime. A usual classification of small satellite is made on the basis of the mass, distinguishing femto (less than 0.1 kg), pico (0.1–1 kg), nano (1–10 kg), micro (10–100 kg) and mini (100–1000 kg) satellites. CubeSats emerged among pico-satellites for their standardized modular architecture than can be expanded by integrating multiple basic cubic shapes of 10 × 10 × 10 cm [26].

The recent trends consider LEO satellites as the preferential solution for IoRT. Different design solutions have been proposed: RF-based and optical based, with or without Inter-Satellite-Link (ISL) [25]. Let's briefly discuss in the following pros and cons of the various solutions.

12.4.1.1 LEO Satellites of IoT with and Without ISL

Two main applications for RF LEO constellations for IoT have been discussed in [27], namely: delay tolerant and delay sensitive applications. LEO constellations without ISL are valuable and low-cost solutions for delay tolerant applications, as they avoid operation of inter-orbital switching whose complexity is not trivial. In such constellations, the orbit eccentricity plays a key role in determining the coverage. We can show, as example, in Fig. 12.6 the Rosette constellation with inclination orbit of 42°.

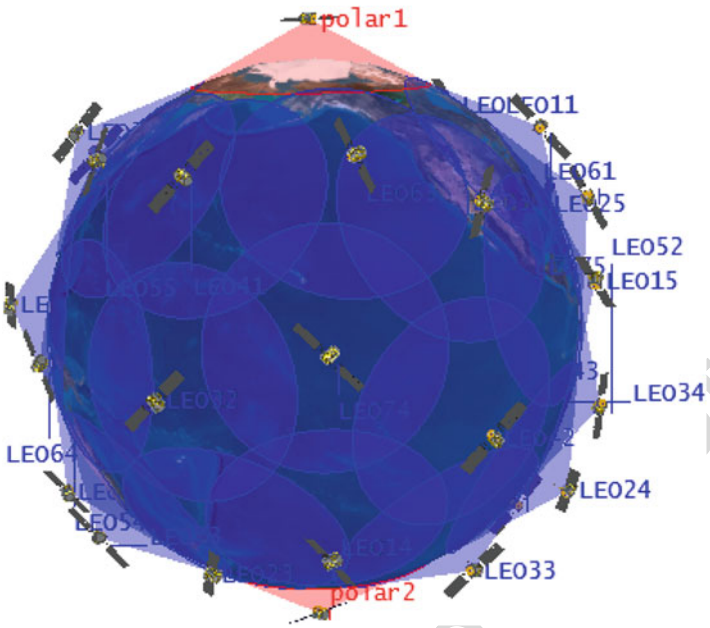

Fig. 12.6 Example of LEO constellation for IoT: Rosette constellation not using inter-satellite links (courtesy of [27]

The LEO solution using ISL can improve coverage and reduce latency at the price of an increasing payload complexity. ISL-based constellations favourably consider the use of polar orbital planes, as shown in Fig. 12.7. The constellation consists of 40 satellites in five orbital planes [25]. To reduce cost and complexity, the number of satellites and ISLs should be adequately minimized. In particular, ISLs between orbital planes are ignored.

Typical requirements for ISL links in IoT applications are in the 6000 km distance range, asking for a data-rate of 10 Gbps and more [25]. A practical solution coping with such such requirements is made by optical links based on laser communications, as shown in [28]. The use of laser communication terminals is very effective, as it combines very high data-rates and resilient performance thanks to interference and eavesdropping immunity. The configuration of [28] encompasses four ISL link terminals per satellite, providing connections to satellites placed in front, behind, at the left and at the right. The laser communications terminal of [28] has a mass of 15 kg and a power consumption of 80 W.

12.4.1.2 Commercial LEO Constellations for IoT

A considerable number of industrial initiatives in the field of satellite-based IoT are emerging in the last years [25]. In the framework of LEO satellites, the

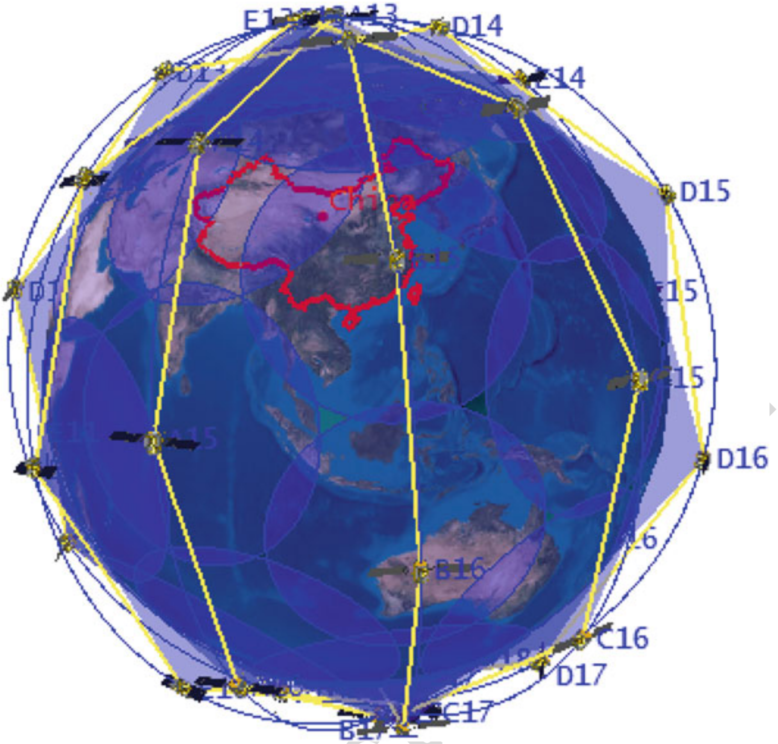

Fig. 12.7 Example of LEO constellation for IoT: Rosette constellation not using inter-satellite links (courtesy of [27])

industrial solutions proposed by many new Space startups, are based on low-cost small satellite technologies for being able to enter in the market [25]. Small satellites ~~cam~~ provide low-cost, low-power and low bit-rate connection services thus enabling direct-to-satellite architectures that allow to bypass local area IoT networks and ground IoT gateways. Let's review now some recent commercial satellites constellations for IoT applications.

- *Astrocat*, owned by a Swiss company, consists of 80 LEO satellites using a proprietary low-power L-band transceiver [29]. Astrocat offers to the customary suitable facilities like low-latency (less than 15 min), transmission optimized for direct-to-satellite IoT applications and support for bi-directional communications. L-band has been chosen due to low-cost RF hardware, smaller antennas and better propagation (no gaseous and rain attenuation).
- *Myriota* is a nanosatellite constellation provided by an Australian company [30]. The frequency range is in the UHF or VHF band. Low-cost and low-power direct-to-satellite connectivity is offered to IoT services with 4 satellite passes per day on average granted.

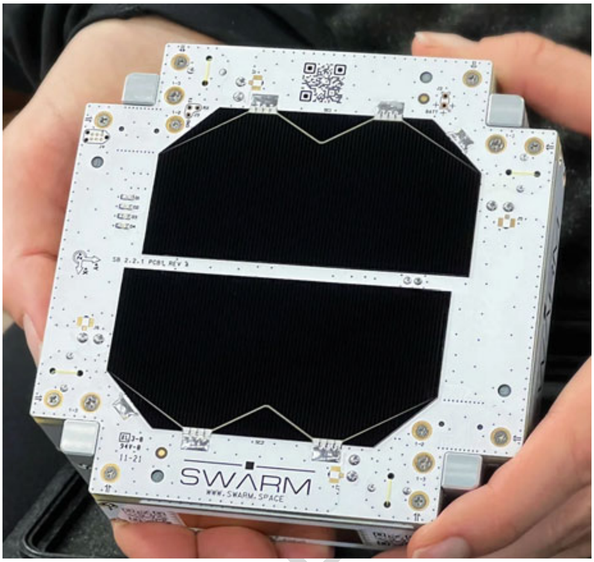

Fig. 12.8 Example of industrial small-satellite payload for IoT applications (courtesy of [33])

- *Kineis* is the commercial product of a French company. A proprietary chipset is used for the payload. The constellation of small satellites has been launched in orbit in 2021. Low-cost and low-rate services are offered to the customary under a meaningful catch-phrase: “IoT everywhere!” [31]
- *Kepler Communications* is a Canadian company developing 140 satellites to provide low-cost direct-to-satellite IoT connectivity. The constellation will become operative in 2023 [32]. Bi-directional communications will be offered to ensure data acknowledgement and firmware update.
- *Swarm Technologies* is a Silicon Valley startup that aims at supporting direct-to-satellite IoT connectivity [33] by means of small satellites of 11 × 11 × 2.8 cm (see Fig. 12.8). The satellites orbit are placed at 450–550 km altitude. The satellites are spread out like strings of pearls into a series of distributed sun-synchronous orbital planes. This configuration should allows the satellites to maintain reliable global coverage [33]. Swarm’s proprietary hardware can be integrated with third-party devices and supports a variety of communication protocols [25].

12.4.2 Physical Layer

Some physical layer solutions are gaining momentum and leading to new solutions. Those works are developing different approaches to improve spectrum utilization and agility in modern and future space communication systems. Such goals are typically addressed by the introduction of multiple RF interfaces or the integration of SDR technology. Indeed, as the physical layer is traditionally built on hardware for reliability and stable performance, current technology does not enable reconfiguration or updates in the modulation and coding schemes used on satellites or other space devices. Software Defined Radio platforms might revolutionize this vision by enabling over-the-air reconfiguration and providing space objects with longer lifetime and up-to-date technological solutions. Indeed, on the long term, both in terrestrial as well as in non-terrestrial communications a trend is emerging towards converge to a more uniform physical layer setup, consisting of a software-defined RF interface capable of providing multi-standard support and runtime reconfiguration.

12.4.3 Medium Access

The Medium Access Control functionality is typically tightly coupled with the physical layer and adapted to the application profile and requirements. Medium access control schemes are expected to maintain a certain level of heterogeneity both in the short as well as in the long term. This is mostly due to the plhetora of available transmission bands and related technologies existing in the literature.

In this framework, as mentioned in Sect. 12.2, relevant upgrades are expected in 5G and beyond mobile networks including in the short term IoT-oriented optimization of the control plane functionalities and Non-Terrestrial Networks integration, and in the long term most advanced mechanisms such as non-orthogonal multiple access schemes for 5G and non-pure-Aloha-based approaches for LoRa.

Indeed, the definition of low-complexity MAC strategies suitable for the Internet of Things still represent an open challenge by itself.

12.4.4 Network and Higher Layers

The network and higher layers of the protocol stack are evolving towards integration of virtualization and softwarization even in the case of terrestrial networks. Consequently, this is expected to gain momentum in non-terrestrial and satellite communications, too.

Nevertheless, network softwarization and virtualization will most likely impact in the network layer and above that. On one side, emerging solutions targeted to improve network performance in IoT scenarios (SCHC, performance enhancing proxies, network slicing) will become a reality in the short term, depending on the respective reference architectures.

In the long term, it is expected that the Internet of Remote/Space Things will incorporate novel management paradigms such as self-organization networks and SDN. Indeed, softwarization might represent a solution in the long term to reduce the amount of devices to be used and to increase their lifetime and re-usability

In this scenario, mobile networks represent a potential reference for the evolution of the Internet of Space Things. Indeed, the roadmap of 3GPP standard is clearly addressing an improved flexibility and extendability of the mobile network functionalities via extensive usage of SDN and NFV technologies, while maintaining the capability to support heterogeneous access technologies. A clear example of this potential is already available in the standard as the mMTC network slices, specifically designed for IoT applications. Merging such concept with the flexibility and programmability of the 5G Service Based Architecture will enable higher degrees of freedom and adaptability to the evolving needs of IoRT/IoST.

12.4.5 Edge Computing

Edge computing is expected to impact and be affected by remote IoT scenarios at different degrees and time scales.

In the short term, edge computing or multi-access edge computing solutions might be used to integrate different access technologies within existing terrestrial network standards, but mostly to enable deployment of processing capabilities within the satellite section of the networks. This would support the dynamic deployment of LoRA gateways, processors for multi-standard conversion and local processing of data. Solutions based on independent LEO as well as 5G might integrate edge computing to facilitate computation offloading or enabling deployment of functionalities at the edge of the network (like in the case of 5G and ETSI MEC).

In the long term, the possibility to host remote containerized solutions on space platforms will spread across all the scenarios, to enable better placements of key functionalities inside the network infrastructure itself as well as to optimize the allocation of task among network elements (e.g., BS splitting). This might lead to relevant changes in the perception of the satellite/space links, from non-terrestrial and “far from home” technologies to enabling technologies to build datacenters in the sky.

12.5 Conclusions

The IoT is gaining momentum due to the market expectations and the rapid development of novel solutions in the field of communications. This paper focuses on a path that drastically differs from several existing solutions on the market as well as in the literature and moves the attention to the Sky and how non-terrestrial communication solutions might support the Internet of Things while integrating also “Space Things”. Indeed, this area represents a big challenge, both for industry as well as for research, since short term goals and long-term visions are both required to steer the ongoing efforts towards interoperable and affordable solutions, capable of being deployed everywhere in the World. Open challenges are discussed, as well as hints and potential solutions that will affect the future of IoT and the Internet of Space Things.

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