An assessment of IoT via satellite: Technologies, Services and Possibilities

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Abstract

The number of proposed satellite constellations for communication purposes has been steadily increasing in the past years. Currently, more than 18 constellations have been proposed and are in different stages of development, from early design to having already launched in-orbit-demonstration (IOD) satellites. The common feature among these different proposals is that all of them aim to provide connectivity to IoT sensor systems in areas outside coverage from terrestrial mobile networks.

Despite the generalized use of IoT for several purposes, IoT via satellite systems typically target a few special use-cases, leaving other relevant applications and services behind. In this work, we study and discuss how such systems can be integrated and augment a broader range of terrestrial IoT and mobile systems. This includes an analysis of the technical properties of the constellations, their service philosophies, and how they are aligned with existing communication networks. Relevant cellular and non-cellular terrestrial technologies are considered, including LoRA, SigFox and 5G alternatives such as NB-IoT.

The impact of mega constellations will also be taken into account, identifying existing technology and service gaps. These gaps in satellite-IoT systems and in mega constellations may result in an inadequate augmentation of terrestrial networks and fail to fulfill user requirements. Relevant end-user services are investigated, spanning from asset tracking, simple environmental and industrial sensors to more advanced sensor networks in remote areas. The different user requirements are compared and matched against available and upcoming IoT solutions.

From this, different strategies for integration of IoT via satellite with terrestrial systems are proposed and evaluated.

1 Introduction

Communication is crucial in our daily lives, and our dependence on being online is only growing. It is important for our personal life and well-being, as well as for our work, our research and our administration of resources. In urban and well-developed parts of the world, communication services are plentiful, but one should not venture far outside a city before coverage gaps are encountered. The situation in developing parts of the world is even more challenging.

Satellites can be fundamental for enabling the United Nations Sustainable Development Goals [1], in particular when considering innovative, responsible and sustainable development in remote/unconnected regions of the world. Challenges to future satellite solutions encompass a careful allocation of specific radio frequencies for various applications, as well as detailed technical provisions and regulatory procedures. This includes with mobile networks, namely with the fifth generation cellular technology (5G) ecosystem. Strategic integration avoids competing for frequencies and instead helps to relieve congestion and overloaded networks, while also increasing connectivity when and where typical terrestrial networks (TNs) are not available. With this in mind, ongoing on 3rd Generation Partnership Project (3GPP) specifications include studies and requirements for 5G satellite access and for the broadening the 5G technology to non-terrestrial networks (NTNs) (e.g. satellites and unmanned aerial systems) [2, 3, 4, 5].

5G promises to revolutionise terrestrial communications by enabling three defined main use-cases: enhanced Mobile Broadband (eMBB) access for high data-rate applications; massive Machine Type Communications (mMTC) for a large number of devices with sporadic communication needs such as Internet of Things (IoT) applications; Ultra-Reliable Low-Latency Communications (URLLC) for mission critical applications. However, such scenarios will likely only be available in urban areas, mostly ignoring rural or underdeveloped areas due to their lower revenue potential. In these neglected areas small and light satellite terminals could provide reliable radio links, or gateway ground-stations could be used as a backhaul for affordable terrestrial solutions. Deploying an ultra-secure and highly reliable optical backbone in space is already envisaged, supported by lasers to interconnect satellites and up to 1.5 times faster than fiber backbones (LeoSat) [6].

Satellites can effectively provide coverage in remote areas, support highly mobile users (e.g. aircraft and ships, including first responders) and are suited for different applications, from IoT to search and rescue operations. Compared with terrestrial solutions, satellite connectivity is becoming increasingly more cost effective when considering remote areas or developing areas. The integration of satellite and terrestrial solutions is the most sustainable approach due to the complementarity between the two solutions, simultaneously fostering economic growth, social inclusion and meeting consumer demand.

The importance of integrating terrestrial and non-terrestrial networks has been the subject of several research works, focusing on subjects such as vehicular networks (air, space and ground) [7] or IoT and maritime IoT [8, 9, 10, 11], and building on the main features and development from both networks (4G/5G) [12, 13, 14, 15, 16]. The value of this integration is also acknowledged by the European Space Agency (ESA) through several research projects [17, 18] such as SATINET [19], SATis5 [20] and M2MSAT [21]. Larger research projects funded by the European Union's Horizon 2020 research and innovation programme such as SANSA [22], VITAL [23] and SAT5G [24] have also addressed the integration of terrestrial and satellite networks. Similarly, 3GPP, the 5G Public Private Partnership (5G PPP) and the International Telecommunication Union (ITU) have been following these developments and contributing not only to the awareness but also to the specification of integrated terrestrial and non-terrestrial networks for improved communications around the world [2, 3, 4, 5, 6, 25].

In this paper we analyse how satellites can support IoT, augment terrestrial networks and bring connectivity to areas where it is sparse or non-existent. Section 2 provides an overview of ongoing or proposed satellite networks, their characteristics, features and how they may support IoT around the globe. This is followed by an analysis of how cellular 5G networks can be augmented by such satellite initiatives into an integrated ecosystem, in Section 3. Section 4 reviews possible services and use cases considering different possibilities for system and network architectures. Finally, Section 5 provides avenues for further discussion and some concluding thoughts.

2 Satellite IoT

Communication links to remote sensor systems have been available through machine-to-machine (M2M) communication over satellite for many years, before IoT was coined as a term. The Argos tracking system [26] and Iridium dial-up or Short Burst Data (SBD) [27] are good examples of this. Depending on definition, we may also include these in the IoT family, since their systems provide access and information about sensors in remote locations. IoT is here defined as such [28]:

> *The internet of things, or IoT, is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.*

In addition to the existing systems, there are several initiatives that offer support for IoT-devices through a satellite component. In this section we focus on satellite systems independent from popular terrestrial communication solutions, and initiatives related to 5G are discussed separately in Section 3.

A selection of efforts and developments on satellite communications suitable for IoT-like applications are summarized in Table 1. The table shows the main features for each of the systems, namely: System **T**ype); **S**tatus; **F**requency; **C**ontinuous coverage amd **A**rctic coverage. The System Types are divided into:

- **A** – Asset Tracking, corresponding to tracking the location of objects as animals, vessels or freight
- **B** – Narrowband IoT, corresponding to systems for generic two-way communication
- **C** – Message-based IoT, corresponding to systems using one or two-way short messages
- **D** – Broadband, corresponding to systems capable of high-bandwidth generic two-way communication

Some systems may fall into more than one category. Regarding the *status of a system*, it may be considered as **O**perational, in **T**esting or currently being **P**lanned. The considered *frequency* bands include **V**HF, **U**HF, **S**-band and **K**a/Ku. Not all systems provide *continuous coverage* and this is shown in the table as **Y**es or No ('**-**'). Similarly, *Arctic coverage* is not always provided and this will be noted with **Y**es, No ('**-**') or partially ('/'). '**?**' denotes missing or unknown information.

The table includes both generic services like Automatic Identification System (AIS) [31] and Automatic Dependent Surveillance – Broadcast (ADS-B) [32] which are offered by several actors, or specialized proprietary networks. Some of the systems are proposed to cover a broad aspect of communication services, and it can be assumed they will be linked to 5G in the end. For example, the mega-constellations by StarLink and Oneweb for access and backhaul, whereas Telesat is expected to only be used for backhaul.

The different communication systems offer a variety of services. Many revolve around communication systems for *asset tracking*, while others focus on the support of *two-way communication.* Asset tracking means that the only information propagating through the system is the position and other simple properties of an asset. Examples of this are GlobalStar [33], Argos [26], AIS for tracking of ships and ADS-B for tracking of airplanes. These are mostly one-way communication, where the end-users have little control over when the message should be sent, or the delivery time. Systems supporting two-way communication to small devices, such as Iridium dialup or SDB [27], Kepler Kipp[39], VDES [41], and Astrocast [42] can be used for a wide range of applications.

Some systems provide direct access to the user equipment, like Iridium and Myriota [52], others provide relay/gateway nodes to which smaller sensor nodes (i.e. the UE) can connect to. Figures 2 and 3 show the concept with and without the relay node. Similar approaches are expected by proposed satellite systems that announce basing their services on LoRa, such as Lacuna Space [53] and Fleet [48]. However this is still an unknown detail for other systems. Several satellite initiatives have launched test satellites during the last 12 months, like Kepler [39], Lacuna [53], Astrocast[42] and Helios Wire [44]. Apart from Kepler's Ka-band service in operation, little is known about their status, both regarding technical results and the financial soundness of these companies.

3 5G Satellite and IoT

Satellite access should allow the delivery of 5G services where terrestrial networks do not, and complement them where they do. 5G Satellite (5GSat) access has the potential of serving remote areas, or areas prevented from service either due to economic reasons (low revenue *vs.* profitability) or to disasters that lead to outages or damaged terrestrial network infrastructures. Service continuity for verticals like maritime communication, public safety, should also be supported by 5GSat networks.

Even though 5G considers eMBB, mMTC and URLLC as its main usage scenarios for terrestrial cellular networks, their implementation in satellite networks may face some challenges. While eMBB and mMTC are interesting scenarios for 5GSat, ultra-low latency (e.g. $< 1\,ms$ over the air) cannot be achieved with satellite links [4]. Examples of eMBB supported by 5GSat include providing broadband connectivity (to moving/static cells/relay nodes and the core network), secondary backup connectivity, an anchor point between two networks, multicast/broadcast, among other applications where medium to large antennas and continuous power-supply are typically available. Contrastingly, mMTC supported by 5GSat should provide connectivity to small/handheld, battery-operated IoT devices, where continuity of service is desired, or instead provide connectivity to a relay-node acting as a base station a connecting to other IoT devices. In addition, due to the wide service coverage capabilities and reduced vulnerability of space systems (e.g. physical attacks and natural disasters), 5GSat mMTC can be used to broadcast/multicast resources to a large scale of devices (e.g. Firmware/Software Over The Air Upgrades).

Similar to past 4G Satellite initiatives [14], 5GSat can provide service in un-served areas that cannot be covered by TNs (e.g. isolated/remote areas, aircrafts, vessels) and in underserved areas (e.g. sub-urban or rural areas) where the performances of TNs is limited terrestrial. However, critical infrastructures such as energy grids and transport (e.g. railway, maritime, aeronautical) increasingly rely on M2M/IoT devices, where service availability must be ensured. If prop-

Table 1: Overview of IoT-like satellite communication systems and initiatives

System	**Feature** T	S	F	C	A	**Status**
OrbComm [29]	A	O	V	–	–	Short, random messages, no Arctic coverage Own set of satellites. Evolved from type A to also C L-band through Inmarsat
ARGOS [26]	A	O	U	–	Y	Short, random messages. Receivers on National Oceanic and Atmospheric Administration (NOAA) satellites. New generation closer to type C
Iridium SBD [30]	C	O	L	Y	Y	Short messages only.
AIS [31]	A	O	V	–	Y	Tracking vessels (and installations) only
ADS-B [32]	A	T	V	–	/	Tracking airplanes only
Iridium [30]	B	O	L	Y	Y	Low-rate two-way, modem type communications Iridium NeXT use large terminals, can be local gateways
Globalstar [33]	B	O	L	Y	/	Tracking services. Limited Arctic coverage
Inmarsat [34]	B	O	L	Y	–	No Arctic service
Gonets [35]	B	P	U	Y	Y	Low rate system.
Thuraya [36]	B	O	L	–	–	No Arctic coverage
StarLink [37]	D	T	K	Y	/	First deployment in 53 deg orbit. Next phase includes 81 deg, so no Arctic coverage the first period
OneWeb [38]	D	T	K	Y	Y	No Inter Satellite Links (ISL), more Earth stations. Indications of development for mobile equipment.
Kepler's Kipp [39]	D	T	K	–	Y	High-datarate service operational, IoT-service planned
Telesat [40]	D	P	K	C	Y	Backhaul, not for single terminals
VDES [41]	B	T	V	–	Y	Shared system, limited capacity, low rate, two way
OQ Technology	C	P	?	?	?	Low rate system
Astrocast [42]	C	T	L	–	Y	Two-way communication, very small messages
AISTECH [43]	A	P	?	?	?	Asset tracking
Helios Wire [44]	C	T	S	–	–	Asset tracking, low-rate IoT + blockchain. Status of testing unknown.
Sky and Space Global [45]	C	T	S	–	–	Voice + short messages. No polar coverage.
Hiber Global [46]	C	T	?	–	Y	Low rate
Aerial Maritime [47]	A	T	V	–	-	Asset tracking (AIS & ADS-B) between 37 deg N/S
Fleet [48]	B	T	U	–	Y	LoRaWAN [49] gateways. One terminal can cover 15 km
Spire [50]						AIS & ADS-B.
Swarm technologies [51]	C	T	U	–	Y	Small sensors
Myriota [52]	B	P	?	?	?	IoT module/modem/egde computing device. No extra gateway needed for users
Lacuna Space [53]	B	T	?	?	?	Based on LoRaWAN

[T] System type: A: Asset tracking; B: Narrowband IoT; C: Message based IoT; D: Broadband
[S] Status: O: Operational; T: Testing; P: Planned
[F] Frequency: V: VHF; U: UHF; S: S-band; K: Ka/Ku-band
[C] Continuous coverage: Y: Yes; '–': No
[A] Arctic coverage: Y: Yes; '–': No; '/': Partially

erly integrated with cellular 5G, 5GSat has the potential of reinforcing the required service reliability in a cost effective manner and including all the features provided by 5G (e.g. confidentiality, integrity, roaming, QoS, billing, among others).

3.1 Cellular 5G and 5GSat Integration

From an architectural point of view, connecting to a terrestrial network via Satellite access could be transparent, using a bent-pipe satellite payload for connecting to a ground station coupled with a Public Land Mobile Network (PLMN) or core network. However, this view is too simplistic and would result in the loss of features and mechanisms provided and used by 5G. For example, due to longer propagation delays in satellite systems, timers used by protocols and mechanisms such as Hybrid Automatic Repeat Request (HARQ) would have to be extended in order to maintain functionality.

In order to include satellite links between 5G's New Radio (NR) access network and the Next Generation Core (NGC) the 3GPP system must to be enhanced not only to handle the latencies introduced by the satellite backhaul, but also to support service continuity between land-based 5G access and satellite-based access networks [2]. This implies not only providing services using satellite access but also ensuring handover (HO) and roaming support. Such services may be directly accessed by the UE, through a relay UE or through a Next Generation Node B (gNB) backhauled by a satellite link.

Compared to previous approaches to the Integration of terrestrial and non-terrestrial networks, the use of new non-geosynchronous orbit (NGSO) constellations and the softwarisation of 5G into Virtualised Network Functions (VNFs) creates both challenges and opportunities. For example, while NGSO systems are enablers for massive IoT access at a lower cost and with smaller energy requirements, the mobility of the infrastructure's transmission equipment, such gNBs and Remote Radio Heads (RRHs) may lead to Inter Carrier Interference (ICI) and increased HO signalling [4]. On the other hand, VNF allows the delocalization of network functions, which could be used to improve the overall QoS scenarios where, for example, in areas where user density is expected to increase (e.g. Access and Mobility/Session Management Functions (AMF/SMF) delocalization to improve/enhance local communications). This requires further investigation of services, their requirements, of configuration/maintenance and of regulatory frameworks between satellite and terrestrial networks, addressing service continuity, ubiquity and the scalability of these networks.

Important aspects in 5GSat include roaming between terrestrial and non-terrestrial networks, guaranteeing satellite trans-border service continuity as well as optimal routing over satellite for enabling a global 5G satellite overlay [2]. This would build on, for example, constellations of LEO satellites providing access to UEs, where each spacecraft is equipped with a gNB and Inter-Satellite links for connecting to other spacecrafts. In addition, 5GSat access should also be aligned with 5G's orchestration mechanisms, not only for edge delivery, content offload and multi-access edge computing (MEC) VNF software, but also for including satellite resources as Physical Network Functions (PNFs) in the 5G ecosystem.

Overall, 5GSat should enable indirect connection through a 5G satellite access network, which could be used for example to enable communication in Offshore Wind Farms. The possible satellite access approaches can be defined as: 1) UE direct access to 5G satellite, 2) UE relayed access to 5G satellite RAN and 3) gNB supported by a satellite backhaul.

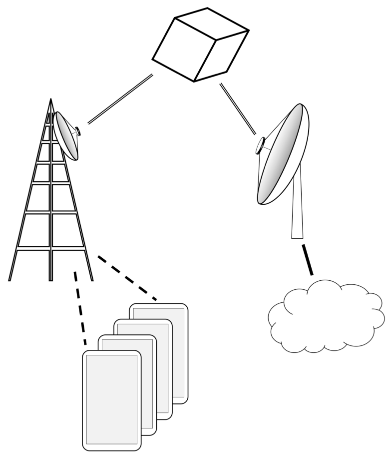

Figure 1: Traditional backhaul architecture

Direct access can be provided by a 5G-enabled satellite that connects directly to the Core Network or through an overlay of satellites. Alternatively, direct access may also result from a bent-pipe satellite (transparent, with no on-board processing capabilities) used to connect to a 5G Satellite RAN. Relayed access occurs when a UE connects, using the 5G NR interface, to a relay UE which in turn has capabilities to connect to the satellite network. This connection again results either from a satellite directly providing

a 5GSat RAN or using a bent-pipe approach. These approaches are further discussed in Section 4.
A more traditional approach considers access through cell towers (gNBs) supported by a satellite backhaul, where UE's shall operate normally as with 100% terrestrial networks. This solution is particularly interesting for expanding a 5G mobile platform (e.g. a train with installed gNBs) or for recovering access after disaster scenarios. In this case NR-capable deployed towers would have their interfaces to the 5G Core directly transported over the satellite link, as seen in Figure 1.

3.2 Challenges and Possible Solutions

Typical cellular networks, and 5G, were not designed to handle large coverage areas such as those given by satellite nodes, particularly geosynchronous orbit (GSO) satellites. This raises questions regarding connection management, node accessibility (paging) and overall mobility. Different PLMNs may be overlapped by a single satellite, cell selection mechanisms are open, roaming, authentication and billing/charging must also be taken into account.

3.2.1 Mobility Issues

In order to ensure service continuity handover (HO) signalling must be extended, supporting HO triggering whenever a UE leaves or enters cellular coverage. This HO can happen between terrestrial and non-terrestrial networks, based on different handover triggering policies. For example, a UE may leave a 5GSat network as soon as enough cellular coverage is available but only only chose to leave a cellular network when the signal is too poor.
The HO process should be lossless and consider measurement report from both access technologies (terrestrial and non-terrestrial), while also supporting different possible NTN architectures (e.g. using regenerative or bent-pipe payloads). For this purpose, common mobility management techniques such as defining Tracking Areas (TAs) and Registration Areas (RAs) must be used by both TNs and NTNs. Regarding the definition of TAs, fixed beam spots of a GSO satellite can be associated to a specific TA, as defined by the Satellite Operator. With NGSO satellites a different approach must be used, with Earth-fixed TAs (based on latitude and longitude coordinates), which remain independent from moving beams spots.
A mobility aspect to be considered specifically NGSO satellites is the mobility of satellite gNBs, even when the UE is stationary. This will require the UE to perform a cell re-selection between the disappearing serving cell and a new one, possibly emerging in quick succession above the horizon. However, it is not clear how eventual coverage gaps between satellites can be handled, for example with delay-tolerant networking techniques [54].
Grouping the satellites of a constellation in a single TA, or groups of TAs, of which a Tracking Area Identity (TAI) List can be composed by the Access and Mobility Management Function (AMF) to send to the UE, is an already existing solution. However, the drawback is that by using the same TA the UE does not need perform Mobility Registration Updates and, therefore, the network will be unaware of the UE's location, which will require it to page over large areas. If each non-geostationary gNB is assigned a different TAI then the network awareness of UE location is improved and so is the paging procedure, at the expense of additional Mobility Registration Update signalling. Currently, a new paging procedure with minimum update signalling is being proposed by 3GPP as an alternative [55], where the AMF provides the UE with a list of Registration Areas that should follow each other, in a pre-defined order, as expected in NGSO satellite constellations.

3.2.2 Access Issues

Radio Access in 5G (NR), was not designed for NTNs and therefore issues may arise when considering Satellite links. These issues arise from the specificity of propagation channels, with different multipath delay and Doppler spectrum models, from the chosen frequency plan and channel bandwidth, from power limited link budgets, among other aspects.
The Physical Layer of NR needs to be adapted (e.g. reference signals, preamble sequences, slot aggregation, Physical Resource Blocks, HARQ, among others), as well as MAC and network layers, in order to support the pairing between UL/DL bands for Satellite communications (e.g. S and Ka bands). In particular, appropriate modulation and coding schemes for low Peak to Average Power Ratio (PAPR) should be considered in order to guarantee power savings in the UL [4], which is particularly relevant when considering direct access of IoT devices in remote locations.
The possible range of maximum one-way delay values found in satellite access (from $30\,ms$ to $280\,ms$ depending on altitude) raises questions on the impact on the 5G system, including in the Non-Access Stratum (NAS), where Session Management and Mobility Management procedures are handled. This delay affects the link between the UE and gNB, as well as the link between the gNB and the Core Network. Architectural assumptions to minimise the impact on

the 5G NAS must be made and certain satellite requirements may also be needed for minimising this impact.

Latency may also have an impact on 5GSat's Quality of Service (QoS) and thus adding a new *Radio Access Technology (RAT) type* identifier for satellite access has been proposed. This allows the AMF to determine the RAT Type so that the Session Management Function (SMF) is able to impose restrictions on which QoS profiles can be used for Packet/Protocol Data Unit (PDU) sessions going via the selected RAT. Similar QoS concerns need to be considered in 5GSat not only for direct UE-satellite access but also when using a satellite-based backhaul, where for example ultra-low latency (e.g. packet delay $\leq 5\,ms$) cannot by supported by GSO satellites.

4 Services and Possibilities

Novel satellite communication systems currently being planned will fill many of the existing communication gaps, if deployed. The impact of filling these gaps spans from cutting Internet-connection costs for regular households to bringing connectivity to new areas of the globe. For example, a study from BroadbandNow, released earlier in 2019, predicts that households in the US may save up to $30 billion USD due to the entry of one or more alternative suppliers of broadband. The cost for households with only one provider is 15% higher than for households that have access to two providers [56]. Conversely, in several remote areas without Internet connectivity – both on land, at sea, and in less-populated areas as the Arctic and Antarctica – service coverage would be the main added value.

4.1 Network Architecture Possibilities

Generically, network architectures supported by satellite systems use satellite link as a backhaul between the core network, or the Internet, and gateway nodes compatible with this link. In cellular networks these nodes correspond base stations (e.g. gNB) for other nodes to connect. This allows for nodes constrained by power or size, among other limitations, to use different radio technologies and remain connected (e.g. LoRaWAN). As discussed in Section 3, and illustrated by Figure 1, such backhaul architecture can be used to enhance 5G coverage. However, there are alternatives to this solution, which requires pre-existing gNBs or the deployment of new ones (e.g. in remote locations or disaster areas).

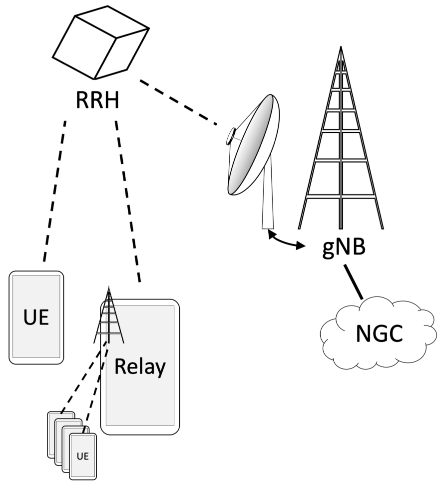

Figure 2: Transparent architecture

Figures 2 and 3 show the foreseen architecture alternatives for satellites as part of 5G networks. The figures follow 5G nomenclature as defined by 3GPP, seeking to provide an integration between terrestrial and non-terrestrial networks, but similar concepts can be valid for different systems as well. In addition, while the figures depict only one satellite node, the space segment could correspond to a network or constellation of satellites with or without inter-satellite-links.

Figure 2 illustrates a *bent-pipe* satellite architecture, or transparent architecture, and can be seen as a generic communication link between a user terminal and a terrestrial 5G base-station (gNB). With a transparent payload, the satellite is seen as Remote Radio Head (RRH), which is simpler from the space segment point-of-view, however it requires an NR-based interface between the gNB and the RRH. This NR interface requires additional care since it will be used in conditions different than those for what it was designed (e.g. longer delays or Doppler shifts). In this approach, the gNB is connected to the satellite link via a ground station and the UEs can either directly connect using the satellite link (Direct Access) or via a Relay Node (RN). The RN may either be seen as 5G-compatible node that provides a standard 5G interface, or as a gateway for non-5G nodes/sensors.

Using an RN, in both transparent and regenerative architectures, may reduce some of the differences between the two payload options. In particular, an RN can terminate procedures and air interfaces (up to Layer 3) and it may also allow for the use of standard satellite communication links, or an adapted more suitable NR link for the backhaul (between RN and a [Donor]gNB), while keeping a standard NR interface with the UEs. This would limit the impact of typical satellite channel impairment to this link only and allow for simpler and more energy-efficient 5G communication with the UEs.

Figure 3 shows a *regenerative* satellite architecture where the satellite acts a 5G base station (gNB). A regenerative payload typically increases satellite complexity but it also allows for lower delays since PHY/MAC procedures (e.g. error correction) can be locally terminated at the onboard gNB. In addition, a regenerative payload allows using standardised satellite-communication technologies for connecting the satellite with the terrestrial gateway/NGC. Optionally, to simplify the payload, a satellite may only implement a gNB's lower-layers, known as a gNB Distributed Unit (gNB-DU, up to layer 3), and connect to the corresponding gNB Centralised Unit (gNB-CU), typically hosted by the gateway.

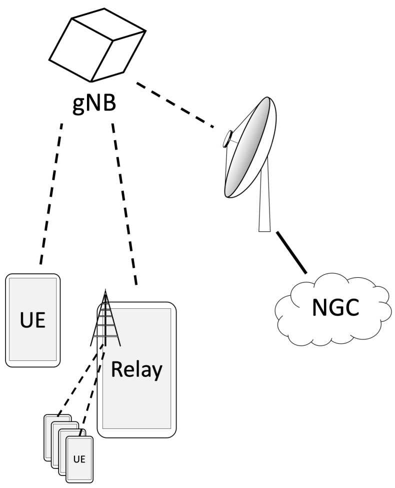

Figure 3: Regenerative architecture

4.2 Satellite System Architecture

An important focus from 5GSat is the ability to support mobility and handovers in order to maintain continuous a link between the UE and the 5G core. On the other hand, most of the existing or foreseen IoT Satellite systems typically provide a *store-and-forward* type of services, or possible intermittent two-way communication. Each of these approaches has its benefits and drawbacks, which means that different use-cases may fit better or worse.

There are generally two ways of ensuring a continuous link between the user and the core network. One method is to make use of many ground stations around the world, so that satellites are able to directly relay traffic between a UE and the network core. This method is used for example by OneWeb [57]. The second method is to make use of inter-satellite links (ISL) such that traffic is routed through various satellites until a ground station is reachable. Iridium and Starlink are examples of such approach, requiring a lower number of ground stations. However, satellites supporting ISLs demands a larger and more capable platform with higher power and maneuvering/pointing capabilities. This leads to a complex system design, both for the satellite bus and operations [57].

As an alternative to ISLs between similar satellites in one system or constellation, it is also possible to consider a backhaul network provided by satellites in a different orbit. These can be larger and more complex satellites in orbital planes that will be visible for a longer period, such as GEO or HEO. Ultimately, different communication possibilities, and satellites with varied size, cost and complexity, can be combined to address different purposes.

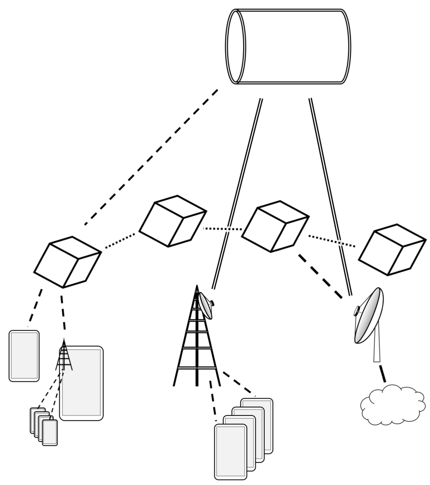

Figure 4: Layered satellite architecture

Figure 4 illustrates different satellite overlay possibilities, ISL and backhaul, which can be combined for creating alternative routing paths. This may contribute not only to add robustness to the overlay network but also to explore different access options for UEs. As shown in the figure, in addition to UEs directly connecting to NGSO satellites (e.g. LEO), terrestrial gateways (static or mobile) may also support them by connecting directly to a GSO satellite backhaul.

Satellites in GEO orbit may be suited for providing backhaul connectivity since they are perceived as being stationary and support powerful links, due to their increased size and capabilities. Elliptical orbits as Highly Elliptical Orbits (HEO) or eccentric Medium Earth Orbit (eMEO) can also be used, as they provide coverage over a larger area with only a few satellites. For example, the Arctic area can be continuously covered by only two or three HEO (for example, Molyna or Tundra orbits [58]) or eMEO satellites. However, the use of GEO satellites may impose a higher latency than LEO/ISL, depending on the desired destination. A typical HEO system will inflict a propagation latency similar to, or larger than, GEO satellites. eMEO-satellites, for example in a 4-hour orbit, will cause a delay on the order of 30 to 40 ms one way, compared to over 100 ms with GEO.

4.3 Services and Use Cases

Table 2 shows combinations of use cases that include a satellite component. The different architectures that we consider are 5G backhaul, 5G/IoT direct access to UE and 5G/IoT relayed access to UE. As earlier specified, IoT satellite corresponds to satellite solutions proposed before 5G. On the other hand, while also support IoT, 5G satellite focuses on the integration between terrestrial and non-terrestrial networks.

Table 2: Use cases and architectures

	5G backhaul	5G access	5G relay	IoT access	IoT relay
Two-way comms.	Y	Y	Y	/	/
Continuous coverage	Y	Y	Y	–	–
Powerful UE	–	Y	Y	Y	Y
Low-energy UE	–	/	Y	/	Y
Constrained UE	–	/	Y	Y	Y
Tracking of small animals	–	–	–	Y	–
Sparse deployments	–	/	–	Y	–
Emergency deployments	Y	/	Y	–	–

In Table 2 a cell marked with '**Y**' means that the architectural component in the respective column can support the use case and requirement in the corresponding row. A cell marked with '/' indicates partial support, whereas a cell marked with '–' indicates a poor fit.

Different scenarios and UE properties are listed in the table, such as *two-way communications* (two-way comms.), *continuous coverage*, *Powerful UEs* like semi-mobile terminals on vehicles or larger sensor systems, *low-energy UEs* which can be small sensors deployed around a farm or a facility, *constrained UEs* which can be terminals with limited antenna sizes, *tracking of small animals* which implies low-energy and constrained UEs, *sparse deployments* composed of UEs for tracking assets or monitoring the environment, and deployments of *emergency* base-stations.

The table indicates that non-5G and 5G systems can offer complementary services, suitable for different needs. It is assumed that small, low-power, low-rate and sparse sensor deployments will benefit most from tailored or optimized non-5G solutions. In these cases, the communication links can be tailored to optimize the energy consumption. However, integrated 5G systems may also offer similar suitable solutions by using the same radio technologies and more streamlined approaches. This can be seen, for example, in the specifications of 4/5G Narrowband IoT (NB-IoT) which does not include handover support and uses narrower carriers.

5 Conclusions

The potential of satellite solutions for supporting communications around the world is not new. However, there has been a significant increase of lower-cost solutions compared to the traditional large-scale, high-cost GEO satellites. In this paper we compare 27 new or developing satellite solutions with different capabilities and explore their potential in supporting IoT.

While integrating satellite solutions as a backhaul for terrestrial networks has already been explored in the past, this has mostly served high-throughput applications and not focused on the direct support of UEs. Currently, the integration of terrestrial and non-terrestrial networks is a building block for 5G and its ambitions of global coverage.

Regarding the integration of terrestrial and non-terrestrial networks aspects that need to be researched include the handover support in in NGSO, which should be quick handovers and scalable. This concerns the management of tracking and registration areas, information needed at the AMF, as well as techniques for handling paging the UEs. From the communication link perspective, increased propagation delays from NTNs require the adaptation of MAC/RLC protocols and procedures. However, 5G's support of multiple radio access technologies and definition of different slices/QoS bearers, among other functionalities, may help with adoption of this technology in distinct use cases.

Despite the potential of a 5G solution for providing IoT around the world, with unified and standardized approach for UEs and other network components, several approaches are possible. Different architectures and technologies may be more suitable for distinct use-cases and their requirements. For example, an integrated 5G satellite solution has the potential for providing a suitable answer in disaster scenarios such as floods, avalanches or other natural disasters. Deploying emergency base stations, or simply using 5GSat as an alternative backhaul link for damaged terrestrial connections, could mitigate serious communication issues. On the other hand, due to the fast-paced evolution of the IoT and the wide range of applications, smaller and more agile satellite systems, may provide more adequate solutions and push new technology without going through long and slow standardization and roll-out phases. However, non-5G systems may become more dependent on individual companies and their strategic plans, which leads to a higher risk of a system becoming discontinued.

The choice between a standalone satellite-IoT and a 5GSat solution significantly depends on the use case being considered and on how these technologies may evolve. We consider different network architectures and use cases, based on currently available or proposed satellite systems, and conclude that use cases characterized by extremely limited resources and/or physical constraints will benefit from tailored satellite solutions, despite the integration of terrestrial and non-terrestrial networks proposed by 5G.

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