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FURTHER UPDATES TO THE WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT APT NEW REPORT ON DEVELOPMENTS IN IOT APPLICATIONS USING SATELLITE TECHNOLOGIES

Introduction

In order to develop and facilitate IoT applications for a variety of industries in Asia Pacific region using satellites, AWG is working on a new Report on future satellite technologies, sharing efforts and information within Asia Pacific countries using current and future satellites in IOT applications. It is noted that this Report will provide valuable information for APT members.

Discussions

Modern IoT applications using satellite technologies allow industries to remotely monitor and more effectively manage both fixed and mobile activities. For example, satellite IoT can monitor the equipment status, operating parameters, environmental changes, energy consumption, and other metrics of fixed assets like electrical grids and machinery in manufacturing plants. They can also enable monitoring of mobile fleets of trucks, trains, planes, and ships, as well as personnel monitoring through wearables. These IoT applications help industries achieve cost savings, accelerated time-to-market, and improved safety.

Mainly there are two models, as shown in Figure 1, for provision of satellite-based connectivity for IoT and low-bit-rate applications:

(i) Hybrid model consisting of LPWAN and Satellite,

(ii) Direct to satellite connectivity.

Proposals

This proposal includes to add a summary diagram and clear indication of these two types of models to be used for Satellite IOT in the draft report as indicated in the attachment.

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WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT APT NEW REPORT ON DEVELOPMENTS IN IOT APPLICATIONS USING SATELLITE TECHNOLOGIES

1. Introduction

As 4G and 5G communication services are being deployed in Asia Pacific region, the usage of satellite communication services is an effective way of realizing IoT because satellite communication systems can bridge the regional information gap in the spread of terrestrial infrastructure. Moreover, applications using IoT technologies have also received attention in recent years in a variety of industries such as agriculture, medical care, disaster prevention, disaster response, and utilization of natural data. In particular, the improvement of production efficiency in some industries such as agriculture is expected by utilizing IoT technology that makes big data quickly accessible to users using satellites.

In order to develop and facilitate IoT applications for a variety of industries in Asia Pacific region using satellites, this Report describes the introduction of future satellite technologies, sharing efforts and information within Asia Pacific countries using current and future satellites. The discussions on satellite applications will provide valuable information for APT members.

2. Scope

[Comment: This report provides information to develop IoT applications using satellites technologies for a variety of industries in the Asia Pacific region.]

This report is intended to support the adoption of IoT applications using a wide range modern future satellite technologies to enhance efficiencies in the Asia Pacific region's industrial sectors.

[This report should not duplicate works by ITU-R WP-4B and other ITU-R working parties. For reference purposes, only links to these documents to be included in this report in Section 4.5 of this report.]

3. Vocabulary of terms

3GPP	:	3rd Generation Partnership Project
AESA	:	Aerodynamic Electronically Scanned Array
BSR	:	Buffer Status Report
CBB	:	Connection by Boeing
CRDSA	:	Contention Resolution Diversity Slotted Aloha
ESIM	:	Earth Stations in Motion
eMTC	:	enhanced Machine-Type Communication
GSO	:	Geostationary-Satellite Orbit
HAPS	:	High Altitude Platform Systems
HTS	:	High Throughput Satellites
IoT	:	Internet of Things
IMT	:	International Mobile Telecommunications
ITU	:	International Telecommunication Union

ITU-R	:	ITU Radiocommunication Sector
LPWAN	:	Low-Power Wide-Area Network
LTE	:	Long Term Evolution
MAC	:	Medium Access Control
MEC	:	Mobile edge computing
MPR	:	Multi Packets Reception
mMTC	:	Massive Machine Type Communication
M2M	:	Machine-to-Machine
NB-IoT	:	Narrowband Internet of Things
NBS-IoT	:	Narrowband Satellite Internet of Things
NFV	:	Network Functions Virtualisation
NGAT	:	Next Generation Access Technologies
NGSO	:	Non-Geostationary-Satellite Orbit
NR	:	New Radio
NTN	:	Non-Terrestrial Network
PID	:	Proportional-Integral-Derivative
RB	:	Resource Block
SDN	:	Software-defined Networking
UAV	:	Unmanned Aerial Vehicle
UE	:	User Equipment
URLLC	:	Ultra-Reliable and Low Latency Communications
VHF	:	Very High Frequency
WRC	:	World Radiocommunication Conference

4. Modern IoT Applications using Satellites

This section provides currently running applications and plans under consideration using satellites, which realize the improvement of production efficiency in some industries

[Editor's Note*: Other applications based on input documents may be considered]*

4.1 Overview of Modern IoT Applications Using Satellite Technologies

Industries operate more safely and efficiently using satellite IoT applications, which enable real-time data access and monitoring nearly everywhere. Satellite technologies currently support several sectors including the agriculture, energy and critical infrastructure, manufacturing, ground transportation, aviation and maritime, and weather and environmental monitoring sectors.

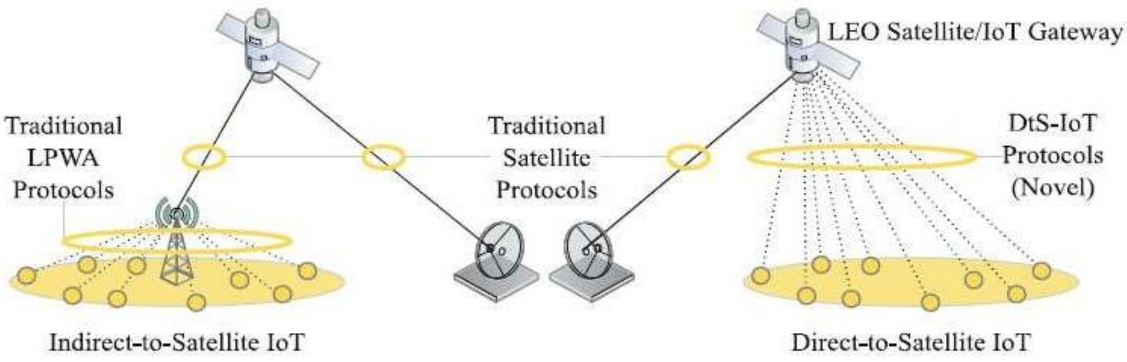
Modern IoT applications using satellite technologies allow industries to remotely monitor and more effectively manage both fixed and mobile activities. For example, satellite IoT can monitor the equipment status, operating parameters, environmental changes, energy consumption, and other metrics of fixed assets like electrical grids and machinery in manufacturing plants. They can also enable monitoring of mobile fleets of trucks, trains, planes, and ships, as well as personnel monitoring through wearables. These IoT applications help industries achieve cost savings, accelerated time-to-market, and improved safety.

Mainly there are two models for provision of satellite-based connectivity for IoT and low-bit-rate applications: as shown in Figure 1 below:

(i) Hybrid model consisting of LPWAN and Satellite,

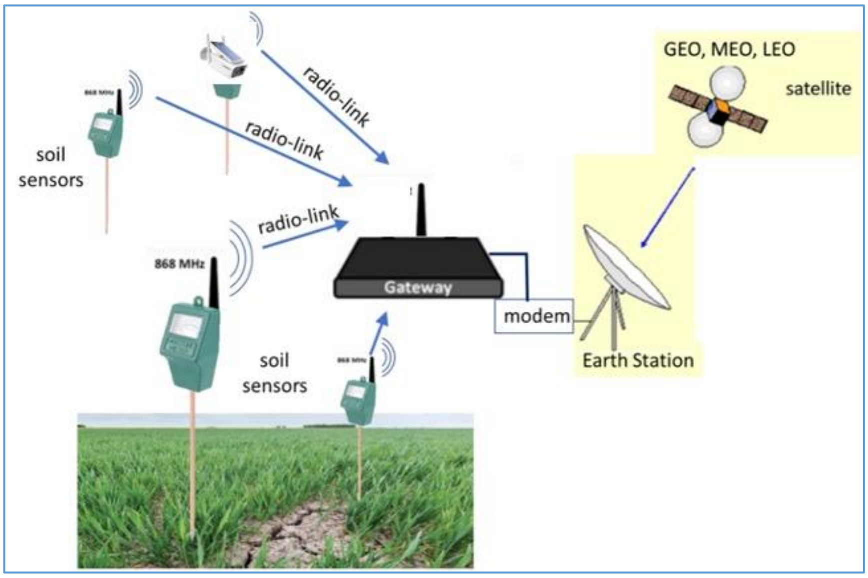
(ii) Direct to satellite connectivity.

Figure 1 - Models for provision of Satellite-based connectivity for IoT and low-bit-rate applications



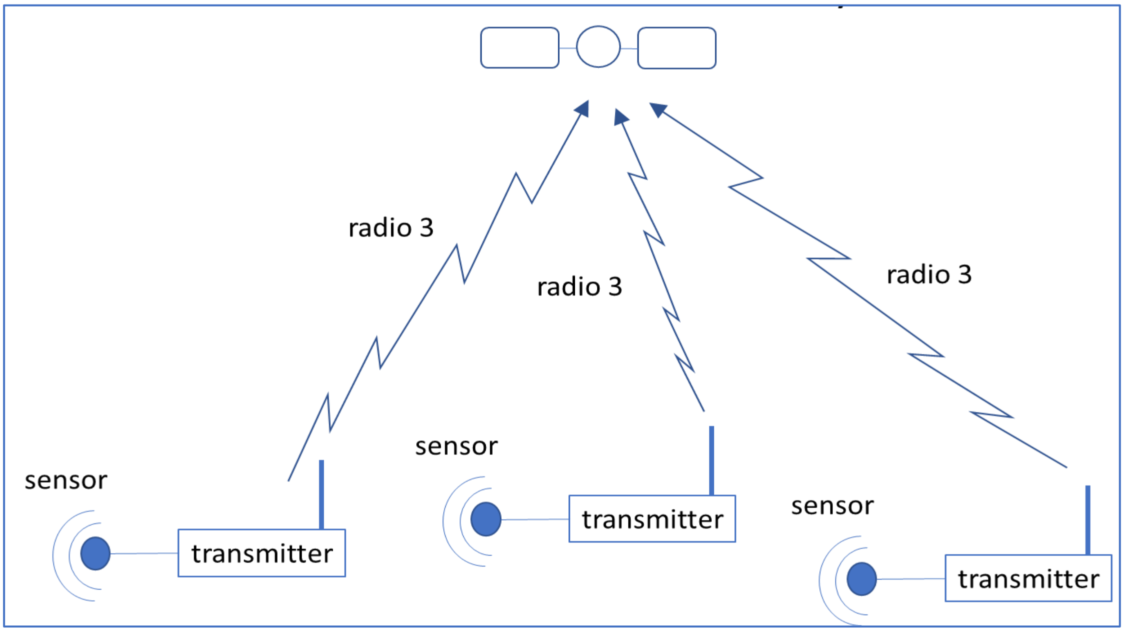
1. **Type 1 IOT system using Satellite network**
   The **Type 1** satellite networks are where the IoT devices communicate between a "sensor" and a "base-station", using a low frequency/low power radio signal, and then the base station is connected to a satellite Earth station of any type (GEO, MEO, LEO);

Figure 1:Type 1 IoT System using satellite network



2. **Type 2 IOT system using Satellite network**
   Those systems where the IOT device is directly connected to a satellite (or a constellation of satellites) via a satellite radio transmitter at the device itself.

Figure 2: Type 2 IoT System directly connected to the satellite(s)



Both types of IoT systems are being deployed presently, and depending on which one is used, a different satellite system and frequency band is required for the proper operations of the system. Cost of the satellite terminals and their capacity, and latency could be the deciding factor for the selection of the appropriate satellite solution as the IOT devices are expected to be dispersed geographically and in large numbers.

It may be noted that:

- Satellite systems employed in **Type-1** IoT systems allow the use of broadband satellite systems in all the orbits, i.e., LEO, MEO and GEO. This is most commonly used system today.
- Satellite systems employed in **Type-2** IoT systems are mostly using Low earth orbits about 1000 Km above the ground level. Some L-band GSO satellite systems also provide IoT service following this configuration.

The decision on which satellite systems are used is a financial (business model/cost model) one, and not a regulatory / legal one.

Further, various other models may be derived using combination or adaptation of these models to suit the specific requirements of the use case being catered for.

- Hybrid (LPWAN + Satellite) or Indirect Model

In such an architecture, each sensor and actuator in a network may communicate with the satellite through an intermediate sink node, i.e., Low Power Wide-Area Network (LPWAN) or LPWAN gateway. In LPWAN, a network server coordinates several gateways through a reliable backhaul and in turn gateways interact through wireless links with potentially billions of low-power devices.

In this model, the LPWAN gateway is equipped with traditional satellite terminal and a traditional LPWA Radio Interface to communicate with the sensor or actuator nodes in the area. These networks communicate with low-cost localized gateways to concentrate larger numbers of IoT devices in their vicinity, even thousands. But this limits the area of deployment as it is confined to the coverage of the LPWAN gateway node on ground.

The LPWAN technologies have been standardized by 3GPP[1]. The LPWAN technologies possess several characteristics that make them particularly attractive for applications requiring low mobility and low levels of data transfer (100s of bps to several 100s of kbps).
Their main characteristics are as below:
Low power consumption (to the range of nanoamp) that enable devices to last for 10 years on a single charge

- Optimized data transfer (supports small, intermittent blocks ofdata)
- Low unit device cos
- Simplified network topology and deployment
- Improved outdoor and indoor penetration coverage compared with existing wide-area technologies
- Secured connectivity and strong authentication
- Integrated into a unified/horizontal IoT/M2M platform, where operators have this in place
- Network scalability for capacity upgrade

Some LPWAN technologies suitable for IoT are LoRa, Sigfox, LTE-M or NB-IoT. These are specifically designed to share the properties of WPAN and cellular networks, i.e., low power and long range (more than 10 km). The NB-IoT technology operates on licensed spectrum, which is a subset of LTE Bands. On the other hand, LoRaWAN uses linearfrequency modulation in the unlicensed frequency ranges

Advancements in satellite technologies means that satellite technologies can deliver quality and affordable services to everyone and everywhere. Recent and upcoming HTS GSO systems with higher throughput and lower cost can provide economies of scale by serving the broader region, and NGSO systems which allow for very low latency for many real time IoT applications. These satellite technologies will complement GSO and current ground-based satellite services to fully support the Government's forward-looking vision of Digital India, ITU mission of removing the digital divide and providing broadband to all. In fact, despite the telecom revolution in India over the last decade, there is still a very significant portion of the Indian population living in remote and sparsely populated areas that lacks reliable and high-quality connectivity, which can be effectively addressed with the new satellite communication technologies.

[1] https://www.gsma.com/iot/wp-content/uploads/2016/10/3GPP-Low-Power-Wide-Area-Technologies-GSMA-White-Paper.pdf

In parallel, the direct to satellite model (**Type-2** IoT systems) is seeing new players that are deploying LEO constellations. They aim at addressing the specific needs of applications requiring ubiquitous connectivity from area not covered by terrestrial networks (such as: Earth's poles, oceans, deserts, rural areas, crop fields, earthquake monitoring, isolated industrial sites, etc.). This model also enables hybridization with terrestrial networks when the satellite connectivity is not the best option, for example in dense urban areas. In that case the end-user will integrate to its devices both satellite and LPWAN/NGAT connectivity that best fit its need. Again, we restate that the choice of a specific system architecture solution is that of finance (business/cost model) and the regulatory authorities should make it possible to allow all technologies to prosper and compete.

4.2 Modern Satellite Industrial IoT Use Cases

The subsections below identify several modern IoT applications using satellite technologies. This catalog is illustrative only and not intended to serve as an exhaustive list of use cases.

4.2.1 Agriculture

Satellite IoT can improve efficiencies in the agriculture sector through precision farming. Numerous environmental factors, large and small, affect agriculture operations. Satellite IoT enables the collection of extensive data on crops, livestock, and their environment. This includes data on light, humidity, temperature, soil moisture and nutrition, feed consumption, and more. Since most of the livestock are located in remote locations, satellite IoT have make it possible to track and monitor the farm animals automatically. The results inform farmers on how best to maximize their harvests in a sustainable manner.

For example, satellite IoT services are currently used to help fisheries gain highly specific data on the environment to optimize fish growth and minimize waste [1]. Satellite IoT capabilities enable fisheries to assess the water temperature, oxygen levels, and water currents in sea cages floating several miles offshore where there is no access to terrestrial service. This data is then used to determine the best time for feeding—one of the largest operational costs for fish farms—to minimize food waste.

Satellite IoT data also helps farmers to predict crop or livestock yields. To reduce unnecessary logistics and labor costs, supply chains can be adjusted to match the predicted harvest.

4.2.2 Energy, Critical Infrastructure and Mining

Satellite IoT has important applications for the energy and critical infrastructure sector, including power and water utilities, oil and gas, and mining. Situational awareness in these industries is essential. Satellite IoT provides continuous and real-time data necessary for informed decision making and improved safety.

Using satellite IoT, the energy and critical infrastructure sector can monitor expansive operations from a single location. This includes monitoring of power grids, pipelines, towers, tank measurements, equipment performance, and more that may extend throughout the region, as well as oil, gas, or mining activities in remote or offshore locations. Such monitoring minimizes the need for frequent and expensive visits to often dangerous sites to monitor activities.

Satellite IoT, for example, is currently used monitor active and reserve fuel tanks [2]. Many critical infrastructure sectors depend on fuel for ongoing operations or to support backup generators in the event of power outages, which can have a devastating effect on essential services. Fuel tanks and reserves must be monitored regularly for leaks to ensure adequate fuel stores. Rather than routinely dispatch workers to travel to and manually check fuel reserves, enterprises can use satellite IoT applications to monitor fuel levels in real time and issue a notification when fuel is low. This eliminates the risk of inaccurate fuel level readings from manual assessment. Enterprises further benefit from reduced costs as a result of improved efficiencies.

Satellite IoT applications also provide safety benefits. In the case of mining, IoT solutions can monitor air and water quality, acid mine drainage, and other effects from drilling and blast hole activities [3]. Additionally, IoT applications using current satellite technologies are used to enable real-time monitoring of the safety and performance of mine tailings dams [4]. Tailings dam failures in the Asia Pacific region can have tragic results including significant human and environmental losses. Energy and critical infrastructure enterprises can further monitor field teams and lone workers through wearables while they travel and work in the field [5]. An inactivity signal could alert emergency response that a worker has been injured or needs assistance.

4.2.3 Manufacturing

The manufacturing sector, particularly enterprises with operations based in rural areas, rely on IoT applications using satellite technologies to monitor machinery and systems. Applications support M2M diagnostics, providing real-time alerts and identifying maintenance needs. IoT sensors are also used to monitor conditions within facilities like heating, cooling, ventilation, and lighting. This reduces system maintenance costs in addition to reducing opportunity costs from system downtime. Enterprises further benefit from reduced energy consumption costs.

The sector can maximize supply chain efficiencies using IoT technology. For example, IoT monitoring enables predictive analysis to determine production volumes. This information can then be used to inform decision making down the supply chain, realizing efficiencies in packaging and distribution.

Large-scale manufacturing activities often require substantial space for physical operations. Satellite IoT services allow enterprises to base operations in rural areas where real estate costs may be lower without fear of being without connectivity.

4.2.4. Ground Transportation

From trucking to the railroad industry, satellite enabled IoT applications support many enterprises in the ground transportation sector [6]. IoT technologies allow for remote monitoring of fleets. Continuous fuel assessments and engine monitoring improve maintenance planning and provide for quick identification and response to unforeseen problems. Start and stop reports, idling notifications, and speed readings apprise enterprises of when to expect delivery or arrival. Weather and traffic sensors alert operators to conditions that may affect a shipping route in time to adjust the schedule or route selected. Improved efficiency and engine operations can reduce emissions and increase cost savings.

Satellite IoT applications can also be tailored to meet industry-specific needs. The rail industry can prevent derailments caused by root track problems by employing IoT sensors that measure track vibrations and other data points to identify deficiencies in the track or supporting mechanical components. The trucking industry uses data collected to evaluate driver performance and identify driver fatigue.

Satellite services provide IoT connectivity in parts of the region lacking terrestrial communications services. This is essential, as the ground transportation sector traverses throughout the Asia Pacific region and abroad.

4.2.5 Aviation and Maritime

The aviation and maritime sectors, which are critical for regional trade and transport, use satellite IoT applications to enhance both safety and efficiency [7] [8]. Large fleet operators can remotely track plane and ship operations in real time. Sensors monitor engine operations and conditions in the skies or sea. Such continuous monitoring allows operators to anticipate maintenance needs and environment trends and then respond quickly to irregularities. Gaining the insight on faults or problems before they become major results in fewer maintenance delays and improves overall operational and flight safety.

By maintaining systems and avoiding, where possible, harsh weather conditions, planes and ships run more efficiently. This reduces carbon emissions. It also reduces fuel costs, which comprise a significant portion of aviation and maritime operating expenses. Reducing fuel costs in turn enables these sectors to better compete with the ground transportation sector.

Opportunities exist to reduce regulatory compliance costs through IoT data gathering. Enterprises use satellite IoT applications to assess, record, and report fuel consumption or emissions, for example. They might also use IoT data gathering to demonstrate compliance with health and safety requirements for transport. Sensors can be used, for example, to monitor and record the temperature of cargo requiring climate-controlled transport.

4.2.6 Weather and Environmental Monitoring

Separate from Earth imaging services, satellite systems enable the collection of weather and environmental data through IoT. Sensors deployed throughout the region, even in the most remote areas, collect information on light, wind speed and direction, snow and rainfall, seismic conditions, temperature, biometric pressure, humidity, and other climate patterns. They also evaluate air quality.

Satellite IoT applications serve as a complement to terrestrial applications gathering data to support weather and environmental monitoring. The further reaching the IoT network, the more data available for experts to predict the cumulative effects of weather conditions. Satellite applications are necessary to collect data from remote areas, including at sea.

5. New IoT Applications using Future Satellite Technologies

This section provides examples of the new IoT applications using future or existing satellites

[Editor's Note: Other applications based on input documents may be considered]

5.1 Satellite 5G Technology

Future 5G networks will be a "network of networks" that use heterogeneous network technologies together to create a ubiquitous connectivity platform. Satellite technologies will be a key component of these future networks, as recognized by 3GPP in its ongoing standardization efforts related to 5G. Work is underway at 3GPP now on the including of NTN, including satellite, in future 5G systems [9]. Integration of satellite technologies in future 5G systems will be essential to support new and enhanced deployments of 5G applications like NB-IoT and mMTC, which can connect thousands of "things" simultaneously. Only by leveraging satellite technologies will NB-IoT and mMTC applications be able to be deployed on a global scale. Tests of satellite 5G NB-IoT services are already underway and will be contributed to the ongoing 3GPP standardization work [10].

5.2 Industry Automation and Remote Control

As described above, IoT applications using current technologies already improve efficiency and safety in fields like agriculture and transportation (among others) through remote monitoring that enables better decision making. In the future, advances in remote sensing capabilities will increase the amount of data collected, which can be leveraged to support automation and remote control capabilities. In the agriculture sector, for example, certain IoT transmissions could trigger automated operations such as irrigation, pesticide, or fertilizer application at optimal times and in precise amounts. In the medium to long-term, this even extends to robotics being used for field operations rather than people driving tractors. For the downstream supply chain, greater monitoring of the world's food supply in transit, whether on land, sea or air will help reduce food waste and losses, by maintaining optimum conditions (e.g. temperature and humidity) and optimising logistics routes [11].

While IoT automation will begin incrementally and in isolated use cases, the future is one of greater automation, being able to run these assets intelligently and safely with less human intervention (and human error). Autonomous trains do exist today, including in the Asia-Pacific Region [12]. The future is for more of this according to harmonised standards. However, ubiquitous coverage and high-capacity connectivity provided by satellite services could potentially support autonomous shipping by rail or sea globally, including far beyond the reach of current terrestrial networks [13].

5.3. IoT Applications using Satellite-NGAT Integration

5.3.1. Background of Satellite-NGAT Integration

Conventional satellite communication has its role in services that make use of the characteristics of wide area and multicast / broadcast, emergency communication in the event of disaster, or broadband services to mobility such as ships and aircrafts. In recent years, satellite communication system technologies have been progressed by the introduction of large-capacity satellites such as high-throughput satellites (HTS) using multi-beams, and mega-constellation consisting of many low-earth orbit satellites. With that, high-speed, large-capacity and flexible channel control, reduction of communications cost, and improvement of satellite services are expected.

For these situations, the integration of satellite communications into the Next Generation Access Technologies (NGAT) is being discussed in 3GPP [14] and ITU-R [15] on IMT-2020 requirements. Especially in Europe, joint projects between the public and private sectors are being actively carried out. The joint projects on the integration of NGAT and satellite in Europe aims to apply the following key NGAT technologies into satellites.

- SDN (Software Defined Network)
  SDN is the technology to implement network configuration, functions, performance, etc. by software.
- NFV (Network Function Virtualization)
  NFV is the technology that extends virtualization to network infrastructure.
- Network slicing
  Network slicing is the technology realized based on SDN / NFV in which the network is virtually divided (sliced) according to service requirements such as low latency, high reliability, and high security.
- Orchestration
  Orchestration is the integrated management, control and optimization of network services and resources, which reduces the time required for the process by allocating networks and resources quickly and flexibly.
- Edge computing
  Edge computing is the technology to locate server at the vicinity of the user. It realizes low latency, large data processing, offload of terminal load.

Applying these technologies are expected to have a significant effect on satellite-NGAT integration. An assessment of some key elements, implementation of concepts and/or challenges to be considered for the Asia Pacific region has been reported [16]. A working group on satellite-NGAT integration has been held in Japan to discuss use cases, key technologies, standardizations [17]. The following subsections describe the uses cases and related key technologies discussed in the working group.

5.3.2. Examples of use cases for Satellite-NGAT integration

In the NGAT and beyond era (2020-2040), Japan will be faced with the serious issues to be challenged as follows.

- Population declines after peaking in 2005, and will be about 111 million in 2040
- Super aging society (consumer market occupied 40% by elderly people)

It is important to consider the abovementioned domestic issue and other social situations. There are various fields of use cases, but the following three categories where satellite utilization is expected in the future are studied such as “smart city”, “mobility”, and “emergency response”. Table 5.3.1 shows the expected use cases for IoT applications for each category.

Table 5.3.1. Expected use cases for IoT applications

Category	Expected use cases
Smart city	- Various data communication services using satellite terminals and base stations installed on traffic lights - Provision of information for tourists by natural environment monitoring - Autonomous driving (effective in rural areas due to population decline) - Expansion of NGAT area - Telemedicine - Autonomous robot - Use of satellite link to local/private NGAT (e.g. construction site) - Large-scale agriculture
Mobility	- Monitoring data collection of various devices on ship - High-speed, large-capacity, low-cost aircraft communications - Land-sea seamless connection in logistics systems - Autonomous driving - Flying car
Emergency response	- Landslides / dam monitoring, etc. - Collecting and providing natural disaster prediction information using distributed sensors - Disaster situation observation by IoT (when ground system cannot be used)

1. Smart city:
   This category is studied on the premise that spot service area would be created where there is no ground network, such as in rural areas. End users (services) include use at events, screening meters, monitoring, agriculture, forestry and fisheries, smart grids, telemedicine, etc. Service providers include government agencies, local governments, and communications carriers.
2. Mobility:
   End users (services) include ship / airlines / cars, passengers, and logistics. The entities involved include service providers, ship companies / airlines, and equipment manufacturers.
3. Emergency response:
   Disaster rescue and surveillance can be considered as use cases, but surveillance is the main use case for IoT applications. The end users include local governments. The service provider is a telecommunications carrier.

5.3.3. Related technologies for Satellite-NGAT integration

The effectiveness brought to users by the integration of satellite into NGAT, and the technology required for realization are described as follows for each category of use cases.

- Smart city:
  Regarding the effectiveness to users, it is expected that the simultaneous accommodation number of users will be improved by simultaneous control and data collection. It would be more effective for IoT-like data collection than high-speed communications. It is also expected that the transmission efficiency will be improved by selecting necessary data at the mobile edge computing (MEC) on the terminal side. If one terrestrial-satellite connection can be made seamlessly with one NGAT protocol,

the switching time between terrestrial and satellite link will be reduced.

- Mobility:
  The effectiveness to users includes the improvement of efficiency for the operation management, internet connection, monitoring of ship / aircraft status, and container location information management for logistics. Since mobility are considered as users (terminals) and move globally, service continuity is indispensable, and network slicing is required to realize simultaneous large number accommodation, high speed, and large capacity.

- Emergency response:
  The effectiveness to users includes management of disaster victim detection and use of transmitting video information from the sky to the disaster response headquarters to check the situation in the disaster area. The content for monitoring is video, telephone call, data, data from an IoT sensing device, etc., and network slicing for each application can be set as a realization method. At that time, it is necessary to control the communications speed, delay, etc. in consideration of both the satellite and the terrestrial network. Backhaul system using UAV, HAPS, and satellite are considered as a network infrastructure.

5.4. Narrowband Satellite IoT (NBS-IoT)

5.4.1. Background

The technology standard of NB IoT has been developed by 3GPP along with the enhanced Machine Type Communications (eMTC) for Low Power Wide Area (LPWA) IoT service from Release-13 and beyond. Since 3GPP recommends the integration of eMTC and NB-IoT with the Long Term Evolution (LTE), these technologies can be supported through a simple software upgrade over existing LTE infrastructure. However, as LTE infrastructure would be mostly constrained in the urban area, the use of such NB IoT will have some difficulties in reaching to rural and the remotest areas. It is therefore considered important to propose an NBS-IoT system as an alternative and a complementarity to the NB IoT in such a remote area, i.e., as the way forward for the Coverage Extension of the NB IoT system service.

5.4.2. The nature of frequency spectrum for the use of NBS-IoT

With regards to the frequency spectrum suitable for NBS-IoT, in particular for the aggregate data rate less than 500 kbps, based on the frequency band characteristics, the spectrum can be divided into three categories: 100 MHz < F1 < 2 GHz, 2 GHz < F2 < 10 GHz and F3 > 10 GHz. The following Table depicts qualitative description of such categories of spectrum [21].

5.5.2. Summary of frequency band characteristics for the use of NBS-IoT system

Parameter	100 MHz < F < 2 GHz		2 GHz < F < 10 GHz		> 10 GHz	
	NGSO(LEO)	GSO	NGSO(LEO)	GSO	NGSO(LEO)	GSO
Link Distance	< 3000 KM	37000 KM	< 3000 KM	37000 KM	< 3000 KM	37000 KM
Mode of Link	LOS, NLOS	LOS	LOS, NLOS	LOS	LOS, NLOS	LOS
Fading Process	Lightly Rician	Very Lightly Rician	Rician,	Lightly Rician	Severely Rician	Rician
Uplink Power	Very Low	Low	Low	Medium	Medium	High
Spectral Efficiency	Low	Low	Medium	Medium	High	High
RFI Sources	Terrestrial, Other LEO/MEO/GEO	Terrestrial, Other LEO/MEO/GEO	Terrestrial, Other LEO/MEO/GEO	Terrestrial, Other LEO/MEO/GEO	Terrestrial, Other LEO/MEO/GEO	Terrestrial, Other LEO/MEO/GEO
Rain Attenuation	Very Less	Very Less	Less	Less	High/Very-High	High/Very-High
Differential Doppler Freq	Yes	No	Yes	No	Yes	No

From the table above one may observe that the spectrum F1 will be more suitable in conveying the NBS-IoT signals, both for GSO and NGSO satellites. This is due to fact that the lower frequency leads to less spectral efficiency. However, the less bandwidth requires less power to compensate the noise, a prevailing condition for Low Power Wide Area IoT service, hence for that of NBS-IoT too, equally.

5.4.3. Suitable MAC Protocol for NBS-IoT

The proliferation of NBS-IoT services will be pronounced in line with the increasing number of conceivable applications, ranging from agricultures, pipelines, plantations, environmental, volcanos, tsunamis, and general disasters. This will call the enhancement in the MAC protocols so as to achieve the betterment of throughput performance in the system. While for further 3GPP works regarding this subject, the great body of the literature reveals the so called MPR (Multi Packets Reception) technique [24] and CRDSA (Contention Resolution Diversity Slotted Aloha) method [22], as the way to the improvement of the obtainable throughput.

5.4.4. NBS-IoT through NGSO Satellites

The comparison of NGSO vs GSO for the NBS-IoT would be, among others : a) the trend of using nano/small satellites for NBS-IoT service is driven by the lesser costs of launching, b) although some 25 dB difference in free space loss prevails, however, it's also worth noting that for nano/small satellites in particular, a significant portion of that advantage is lost owing to the limited gain of their small antennas [23] [25], c) The significant difference is due to the intermittent nature of the NGSO links -- unless if a dense constellation will be in use --, which leads to inventing an important class of a *non-real-time and low data rate* market for the users of the NBS-IoT through NGSO.

5.5. IoT Applications for Aircraft and Ships

5.5.1. Introduction and Background

As discussed in Section 4.2.5, the enhancement of monitoring technologies and new requirements in the aviation and maritime sectors is leading to new possibilities for the use of IoT in those fields. Broadband communication to aircraft and ships using Earth Stations in Motion (ESIM) is considered as one technology to enable IoT applications.

Previously, when ships were at sea or aircraft cross the oceans, they were out of reach of terrestrial networks. Satellite Communications to ship have changed from analog communication in the 1980s to digital communication at present, and the communication speed has evolved from several kbps to over 10 Mbps. The airlines and ship operators are now fitting their fleets with ESIM services, to provide continuous broadband connectivity for passengers and crews. At the World Radiocommunication Conference (WRC) held in 2015, broadband satellite communication using Earth Stations in Motion (ESIM) which communicate with the space station in geostationary orbit, became possible in some fixed-satellite service (FSS) bands. In addition, the regulations for ESIM were expanded at WRC-19 to additional frequency bands, in total to cover 17.7-20.2 GHz and 27.5-30 GHz. WRC-23 is looking to include regulations for ESIMs operating with non-GSO FSS networks.

The demand for broadband services especially for aircraft is increasing due to the spread of smartphones and tablet PCs and the ability to provide broadband Internet connectivity for passengers. In the next 20 years, the number of aircraft expected to be equipped with broadband connectivity through ESIMs will increase from about 24,000 to about 41,000, and the number of new production aircraft is expected to be 35,000 [18].

ESIMs are typically deployed on aircraft and ships for a range of broadband applications and they provide potential connectivity for IoT devices onboard the ship/aircraft. In particular those which follow the “Type 2” configuration may use the broadband channel provided by the ESIM to transmit the sensor data from ship to ground or aircraft to ground. Forward link communication is also possible, using the ESIM capability to command the IoT devices.

5.5.2. Broadband service providers for aircraft

In the 2000s, in response to the demand for high-speed communication due to the spread of the Internet, WRC-03 approved the allocation of part of the Ku band frequency to the aeronautical mobile service, opening the way for the use of Ku band satellite communications in aircraft, and in 2004 Ku-band CBB (Connection By Boeing) launched the service for the first time in the world. After that, Panasonic Avionics launched an aircraft broadband communication service in the Ku band. Currently, in the Ku band, Panasonic Avionics, GOGO, and Global Eagle are developing services.

In the Ka band, Viasat started service in the United States in the 2010s. Viasat plans to launch three HTSs from 2019 onwards to cover the world. Inmarsat launched four HTS satellites covering the world by 2016 and launched the Ka-band service Inmarsat GX in 2017. Inmarsat provides an aircraft broadband service for business jets under the Jet Connex service name, and for passenger aircraft under the GX Aviation service name. SES also teamed up with Thales to announce the launch of an aircraft satellite communications service in the Ka band in 2016 and started services in North America from 2017. In the future, they plan to expand services by incorporating SES-17 and O3b mPower launched in 2017.

Table 5.4.1 summarizes the commencement years of Ka-band aircraft satellite communication services. In the mega-constellation plan to launch multiple satellites in low orbit, OneWeb, Space X, Telesat, etc. will be launched after 2020, and are expected to be used in the aircraft field.

Table 5.4.1. Commencement years of Ka-band aircraft satellite communication services

Service Name	Exede	JetWave/GX Aviation	FlytLive
Satellite operator	Viasat	Inmarsat	SES, Hughes
Service start year	2013	2017	2017

5.5.3. Antenna systems for on-board antenna

The most currently used satellite communication antennas for aircraft have a structure in which the antenna aperture is physically rotated. Therefore, it is necessary to secure a volume equivalent to the rotating sweep section in the radome. Therefore, the radome becomes large, and as a result, the aerodynamic resistance received by the aircraft tends to increase. The onboard antennas for aircraft and other IoT terminals need to be smaller in order to further expand IoT applications. Therefore, a thin and low aerodynamic electronically scanned array antenna (AESA) type satellite communication antenna is appearing on the market, in the Ku band and Ka-band. Figure 5.4.1 shows some types of the satellite communication antenna for onboard aircraft.

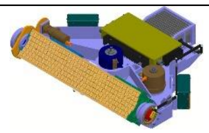
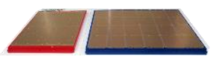
Planner antenna	**parabolic antenna**	**AESA**
		
Height 20 cm	Height 40 cm	Height 3 cm

Figure 5.4.1. Satellite communication antenna for onboard aircraft

5.6. Access Methods for IoT Applications

5.6.1. Background

Report APT/AWG/REP-89 "APT REPORT ON INTEGRATION OF SATELLITE TECHNOLOGY INTO THE NEXT GENERATION ACCESS TECHNOLOGIES ECOSYSTEM" provides information regarding study items in 3GPP TR 38.811[19], which describes the key impact areas for adapting the operation of the New Radio protocol to non-terrestrial (mainly to satellites) networks. After this report, the study of "Solution for NR to support non-terrestrial networks" started in 3GPP TR 38.821(Release 16) [19], intending for standardization in Release17. In 3GPP TR 38.821, technical studies and definition of related solutions are discussed.

5.6.2. Uplink Resource Allocation Method of LTE/5G NR-based Satellite-Ground Access Scheme Considering its Long Delay

As part of R&D activities in Japan, studies on uplink scheduling algorithm for long delay environments are being conducted [20]. The network architecture is assumed to provide bent-pipe links among airplanes, ships and ground stations equipped with LTE/5G station's capability (Fig. 5.5.1).

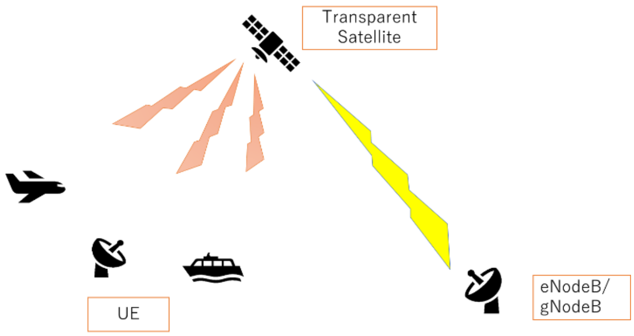


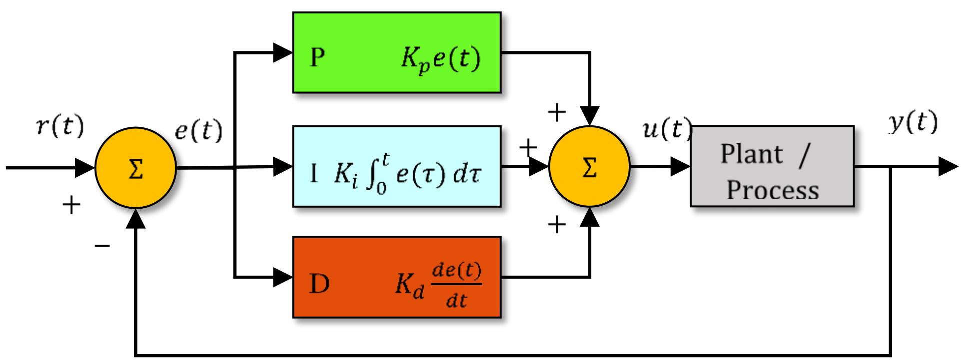
Figure 5.5.1. Network architecture with transparent satellite

5.6.2.1. Issues

Regarding the original LTE, to determine the resource block (RB) allocation for uplink, buffer status report (BSR) is the only information source to guess the current status of each UE's traffic demand. This mechanism has an assumption that the buffer status values always propagate immediately and the time lag between BSR and allocation is very small. However, in satellite communications, especially in the geostationary satellite bent pipe system, it takes 480 msec to propagate for the satellite communications. Since instantaneous control is performed based on delayed information, appropriate allocation is not performed, and excessive resource allocation and insufficient resource allocation are likely to occur.

5.6.2.2. Proposed Method

The UE reports the average amount of arrival data to its transmission buffer instead of the amount of current data in the transmission buffer. The eNodeB securely allocates resources to UEs by PID control method (Fig. 5.5.2). At the PID control, 'Resource Margin' is used as a control target. Here, the 'Resource Margin' means the difference between the amount of allocated resources and of the generated data.



$r(t)$ = Average of arrival traffic bytes
$e(t) = r(t) - y(t)$
$u(t)$ = Control result for resource allocation (bytes)
$y(t)$ = Resource bytes allocated.

Figure 5.5.2. Resource control by PID control

5.6.2.3. Performance Analysis via Network Simulations

As for the scheduling algorithms, Fixed, Proportional Fairness (PF) and Round Robin (RR) are chosen for the comparison of the proposed method. Fixed performs no resource coordination. Meanwhile, PF and RR are both typical scheduling algorithms. Table 5.5.1 shows the traffic model and TCP parameters. Fig. 5.5.3 is the simulation scenario and the network simulation setup. Broadband communication inside the airplane is assumed in this evaluation scenario.

Table 5.5.1. TCP traffic model (left), TCP parameters (right)

Parameter	Value
Traffic Size	3M bytes
Start Time	Uniform random value from 0 to 50 sec
Number of Occurrences	(a) 12 for each airplane (b) 8,17,14,6,20 for each airplane (c) 7,10,13,16,19 for each airplane (d) 5,9,13,17,21 for each airplane (e) 15 for each airplane
Number of Airplanes	5
Simulation Time	120 sec

Parameter	Value
TCP variant	HTCP
TCP send buffer size (byte)	100000
TCP receive buffer size (byte)	1000000
Initial congestion window	100
Max segment size (byte)	1000

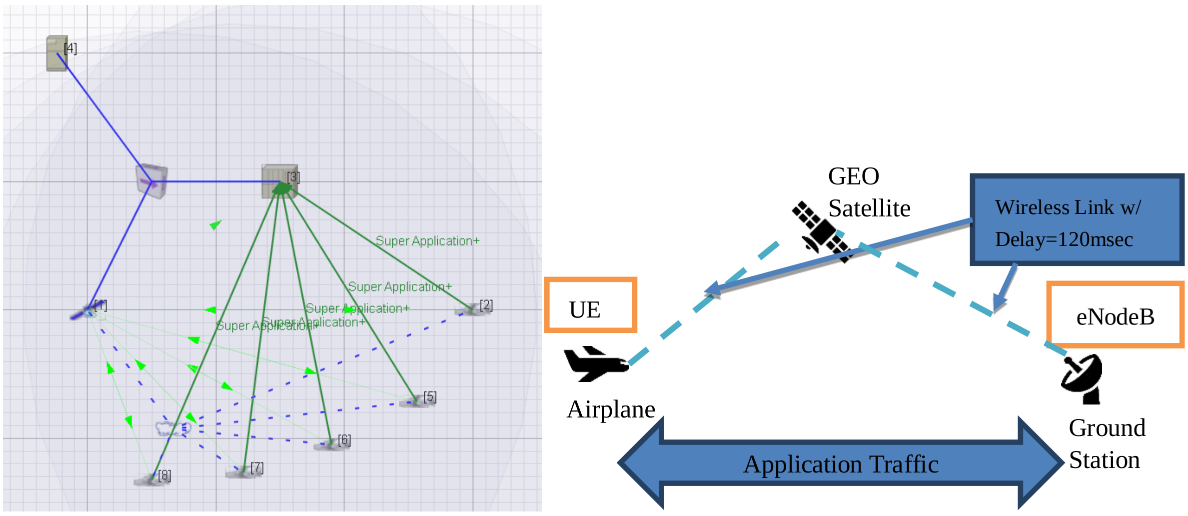


Figure 5.5.3. Simulation scenario on QualNet (left), Network simulation setup (right).

5.6.2.4. Simulation Results

The simulation results have shown that the proposed scheduler got the shortest delay compared to the traditional schedulers in all evaluation scenarios, assuming long delay environment (Table 5.5.2).

Table 5.5.2. Average traffic duration of 3Mbyte TCP application traffics for each radio resource scheduling method (sec) (std. deviation)

	(a)	(b)	(c)	(d)	(e)
FIXED	17.66 (2.56)	25.32 (9.49)	22.63 (7.67)	25.14 (10.19)	21.68 (4.69)
PF	20.94 (4.15)	28.28 (8.68)	25.42 (7.11)	27.16 (8.36)	26.47 (6.12)
RR	18.26 (2.18)	22.53 (6.06)	21.08 (4.82)	22.14 (5.95)	21.87 (4.38)
Sat-SLA	16.42 (1.64)	17.29 (3.06)	17.32 (2.70)	17.21 (2.38)	20.28 (5.08)

Fig. 5.5.4 clearly shows that the more application sessions, the longer the average session duration (delay). Among the scheduling algorithms, the proposed SLA method always shows the best results regardless of amount of traffic.

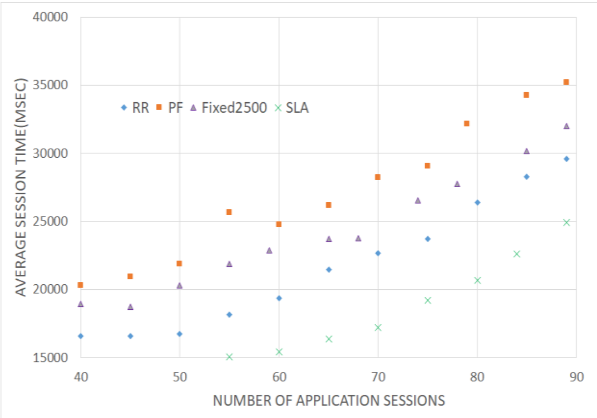


Figure 5.5.4. Number of Application Sessions vs. Session Duration(delay).

5.6.3. Slicing of satellite radio access network

To expand satellite IoT application, it is important to consider the recent years' increasing demand for 5G system including satellite communication to accommodate not only broadband applications but also traffic having various different requirements such as mMTC and URLLC. To meet this demand, it is necessary to realize more efficient control by utilizing network slice technology based on SDN and NFV, which is one of the features of 5G technology. Network slicing is targeting end-to-end QoS isolation, which includes slicing of Radio Access Network (RAN) control, such as retransmission control and the scheduling method as described in 5.5.2. Figure 5.5.5 shows an example of satellite RAN slicing architecture in which the entire base station function is virtually divided into slices.

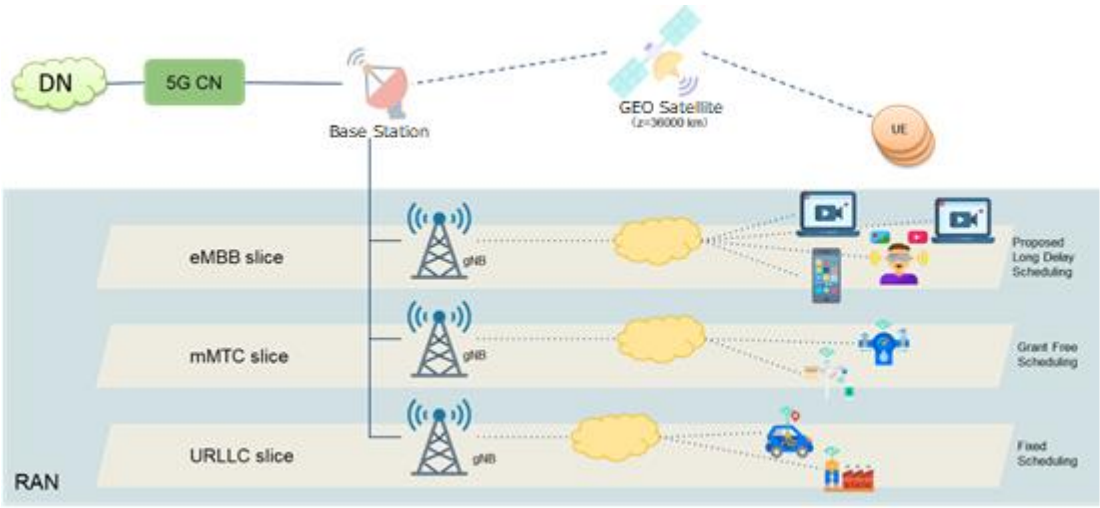


Figure 5.5.5. Example of satellite RAN slicing architecture

6. Conclusions

As exemplified in the existing and future use cases identified above, satellite technologies have an integral role in IoT connectivity. The Asia Pacific region can maximize the benefits of IoT capabilities by sharing information on and supporting deployment and adoption of satellite IoT services.

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