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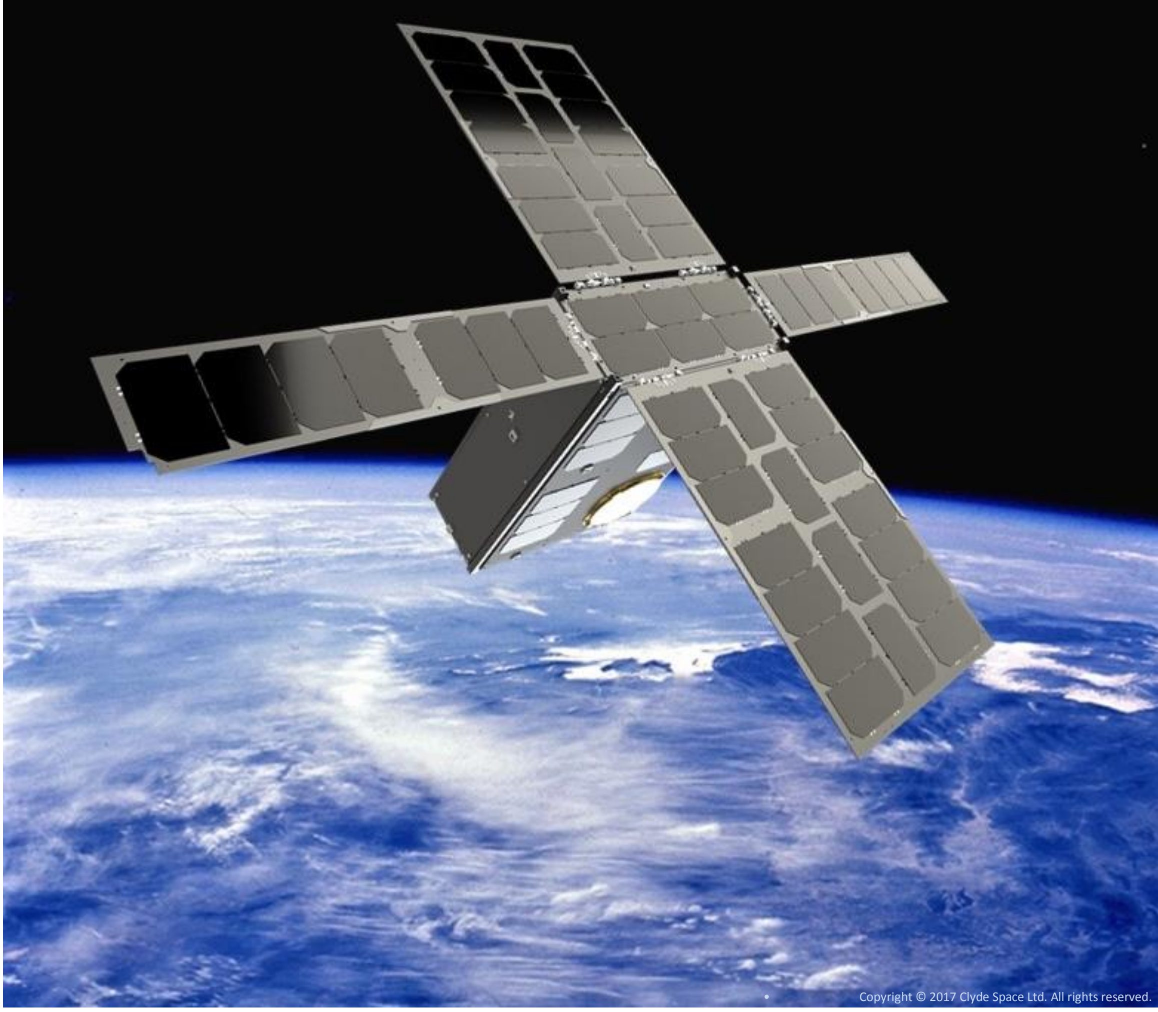

Nanosatellite Telecommunications: A Market Study for IoT/M2M applications

A Pathfinder study funded under the National Space Technology Programme (NSTP)

MARKET SIZING & REQUIREMENTS REPORT

LE London Economics

August 2017

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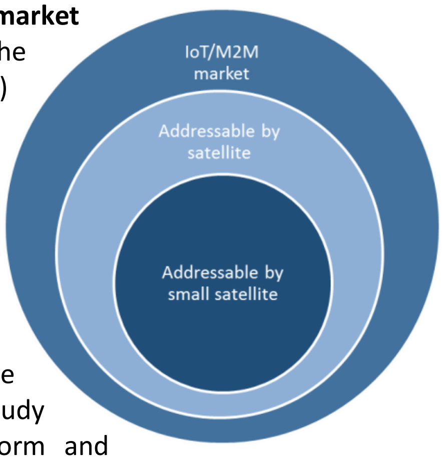
1 Introduction

The **Internet of Things (IoT)** refers to the networked connection of physical objects ('things') through the use of sensors, actuators, and other devices, that are capable of sensing or acting on their environment, and able to communicate with each other. The data amassed from these devices can be analysed to reveal insights and prompt real-time actions, thereby supporting the optimisation of products, services, and operations. These 'smart' objects can include simple objects with embedded sensors, household appliances, industrial machines, vehicles, and wearable objects. **Machine-to-machine (M2M)** is a related concept and refers to the transmission of data between devices or a relatively closed network that can be considered part of the IoT.

The development of M2M and IoT applications relies on **connectivity**. This can be achieved through a variety of different platforms, but the emergence of M2M and IoT applications to enable the monitoring and control of remote assets has created a specific demand for low-cost satellite communications to provide global connectivity. In particular, it is believed that constellations of nanosatellites can support high revisit rates and can therefore be used to achieve global coverage at lower cost than traditional larger satellite platforms or ground networks.

However, this is an **emerging domain**. To date, detailed information on the market for small satellite-addressable IoT/M2M applications and the specific requirements of users has been limited. This study attempts to **address this gap**.

The first half of this report attempts to provide this **market information**. As demonstrated in the diagram opposite, the specific IoT/M2M market that is addressable by small (nano) satellites – i.e. satellites within the <180kg[1] (1-10kg) mass range – represents a very specific niche within the total IoT/M2M market. It has therefore been necessary to adopt the following multi-step process to identify this specific niche: i) analysis of the overall IoT/M2M market; ii) investigation of the niche for satellite connectivity for IoT/M2M applications; iii) to the extent possible, given limited market data at this level, identification of the opportunity for small satellites in IoT/M2M. In this way, this study addresses the lack of market information to better inform and accelerate future UK investment in R&D for IoT/M2M applications.



The second half of this report goes one step further, using a combination of secondary and primary research to outline the **emerging requirements of these IoT/M2M applications**.

To this end, this study is arranged as follows:

- **Chapter 2** provides an overview of the IoT/M2M market, covering the ecosystem of technologies that make up the market, the IoT/M2M value chain, and estimates of the overall IoT/M2M market size;

[1] Following the NASA definition, as set out here: https://www.nasa.gov/content/what-are-smallsats-and-cubesats

- **Chapter 3** details the different wireless communication technologies that provide the connectivity that underpin IoT/M2M applications, and evaluates their strengths and weaknesses against key application (user) requirements;
- **Chapter 4** identifies the specific niche for satellite-addressable applications using the analysis presented in Chapter 3, and provides an overview of the main vertical segments and applications that are addressable by satellite;
- **Chapter 5** estimates the market for applications addressable by satellite overall, by key vertical segments, frequencies, and regions;
- **Chapter 6** categorises applications into specific use cases with common user requirements and identifies the high-level user requirements for each of these use cases, as well as providing the results of a high-level survey of IoT/M2M devices;
- **Chapter 7** identifies some of the key technical considerations of a small satellite system – such as frequency and constellation size – that aims to address the IoT/M2M market; and
- **Chapter 8** concludes on the value proposition for small satellites in IoT/M2M.

2 IoT/M2M market overview

This chapter presents an overview of the overall IoT/M2M market, value-chain and technology ecosystem in order to place satellite communications in context. At the simplest level, satellite communications represent one specific technology option within one layer of the IoT ecosystem. Satellites therefore serve a small fraction of the total IoT/M2M market, but their position as a network technology means that they underpin the functionality of many IoT/M2M applications.

2.1 Size of IoT/M2M market

Estimates of the IoT/M2M market size vary widely and depend on the definitions used.

Most optimistically, Intel[2] estimates that 15 billion connected devices were in use globally in 2015, rising to 200 billion in 2020 (equivalent to 26 connected devices per person). At the more conservative end, Machina Research estimate the market growing from **6 billion IoT connections in 2015** to **27 billion in 2025**, implying a Compound Annual Growth Rate (CAGR) of 16%[3]. In revenue terms, this equates to **$3 trillion in 2025**, compared to **$0.75 billion in 2015**.

Of this, 43% of all revenues will come from end users in the form of devices, connectivity, and application purchases. The remaining 57% will come from upstream and downstream IoT-related sources such as application development, systems integration, hosting, and data monetisation.

2.2 IoT/M2M ecosystem

As explained above, IoT/M2M is characterised by the interconnection of devices that can sense and act-on their environment. To enable this, IoT/M2M devices are equipped with embedded sensors, actuators, processors and transceivers.

[2] Please see infographic: http://www.intel.com/content/dam/www/public/us/en/images/iot/guide-to-iot-infographic.png
[3] Please see press release https://machinaresearch.com/news/press-release-global-internet-of-things-market-to-grow-to-27-billion-devices-generating-usd3-trillion-revenue-in-2025/

Sensors provide inputs about the current state of the device (internal status and external environment – e.g. accelerometers, light sensors, GNSS receivers), while an **actuator** can effect a change in the environment (e.g. motion-inducing actuators). The **storage and processing** of this data can be done on the edge of the network (e.g. in the device itself) or in a remote server. However, the capabilities in the first case are often constrained by the device's size, limited battery capacity and computational capability. For this reason, one of the key challenges in IoT/M2M is ensuring the right kind of data at the desired level of accuracy[4]. Another challenge is **communicating** this data between IoT devices. Since IoT devices are often installed at geographically dispersed locations, this communication is usually wireless. The specific needs of different applications and the constraints of their associated devices limits the suitability of different communication networks.

In this way, the IoT/M2M ecosystem can be reduced to three primary levels:

- **Perception level**: is the level which has sensors for sending and gathering information about the device and the environment.
- **Network level:** is responsible for connecting other devices and servers. Its features are also used for transmitting and processing sensor data.
- **Application level:** is responsible for delivering application specific services to end users.

The sensors, actuators, and the communication networks that characterise these levels form the core of components of IoT. However, the need for more ubiquitous and complex IoT/M2M systems means that a number of heterogeneous devices need to be interoperable and connected to each other in an efficient way. **Middleware platforms** (e.g. Software Defined Radios as detailed in Box 1 below) can therefore have an important role to play as a bridge between devices, applications, and the various networks that connect them.

Box 1 Software Defined Radios

Software Defined Radios (SDR) refers to a wireless communication system where components that have been typically implemented in hardware (e.g. amplifiers, modulators, filters) are instead implemented by software. In this way, significant amounts of signal processing are handed over to a general purpose processor rather than a special-purpose hardware. This offers two significant advantages over traditional radios:

- **Flexibility:** SDRs can be programmed to easily switch channels, change modulation, and thereby act as an effective bridge between heterogeneous devices, applications, and the networks that connect them. This results in a reduction in the number of analogue components and makes high-level integration of different devices much easier.
- **Adaptation:** SDRs can be programmed to support emerging standards and can be easily reconfigured and upgraded over-the-air without the need for any changes to hardware. This is useful for devices that are located in remote and hard-to-reach locations.

Source: based on a variety of sources including: i) Maheshwarappa, M. (2016). Software Defined Radio (SDR) Architecture for Concurrent Multi-Satellite Communications. Available at: http://epubs.surrey.ac.uk/813388/1/PhD%20Thesis_Mamatha_Maheshwarappa_Corrections%20-%20Final.pdf ii) Sadiku, M., Akujuobi, C. (2004). Software-defined radio: A brief overview. Available at: https://www.researchgate.net/publication/3227747_Software-defined_radio_A_brief_overview

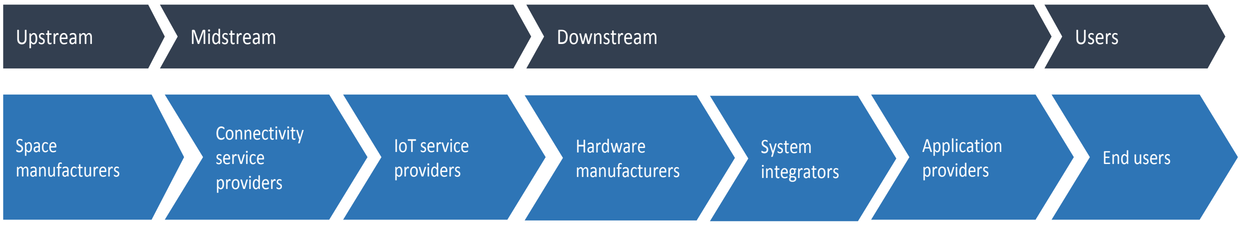
[4] Sethi, P., Sarangi, S., (2017). *Internet of Things: Architectures, Protocols, and Applications*; Journal of Electrical and Computer Engineering, Volume 2017. Available at: https://www.hindawi.com/journals/jece/2017/9324035/

The development of these middleware platforms also highlights an important factor: most **IoT/M2M applications are fundamentally agnostic about the kind of network technology they use**. The specific network technologies that end up serving different applications is simply determined by those technologies that are: i) the best fit for their specific application needs in a specific use case, and ii) occur at a price point that maintains the commercial viability of the application, given the availability and capabilities of competing network technologies. The commercial viability of small satellites for IoT/M2M applications is no exception.

2.3 Value chain

The IoT/M2M market refers to the market of devices (i.e. hardware including sensors and actuators), connectivity/network services, and managed services that are generated by the interconnection of things (data analytics, value-added applications etc.). This is best understood by considering the value chain for IoT/M2M (see Figure 1), which can be classified into seven broad segments.

Figure 1 Stylised IoT/M2M value chain



- **Space manufacturers** provide for the manufacturing, launch and operation of satellites, subsystems and ground infrastructure that produce satellite communication signals.
- **Connectivity service providers** provide electronic communication services, which consists wholly or mainly in the transmission of signals on electronic communication networks.
- **IoT service providers** provide an IoT service, which comprises the provision of an IoT platform and/or other IoT related IT-services or solutions.
- **Hardware manufacturers** manufacture components and modules which can be integrated into IoT/M2M devices by system integrators.
- **Systems integrators** manufacture devices for IoT/M2M applications. They may also purchase IoT services and incorporate it in their own products (e.g. connected devices) and/or services (e.g. electricity provider that provides smart meter services).
- **Application providers** provide value-added software and services that support IoT/M2M applications.
- **End-user** is the customer who purchases a connected device or utilises a service (e.g. car owner, electricity customer etc.). End users can include private individuals (e.g. car owner) or companies (car fleet operator).

The focus of this study is on the market for small satellites for IoT/M2M applications – represented by the space manufacturing segment. Nevertheless, as the value chain demonstrates, developments in this segment will respond to developments in other segments further downstream. For example, the connectivity/network services used by any one application in the downstream depend on the precise requirements of that application. The extent to which the connectivity/network service can meet this requirement in turn depend on the technical capabilities of the platform that provides the service (e.g. satellite). This platform is itself a product of the space manufacturing segment of the IoT/M2M value chain.

Thus, as the connectivity requirements of different applications gradually increase in complexity – given the need for more complex analytics and ubiquitous positioning of high value assets – the market is likely to move from purely communications service provision towards higher margin satellite-based based cloud computing and software provision[5]. This will push satellite IoT/M2M operators further down the value chain, and provide customers with end-to-end solutions as operators acquire new capabilities for service provision further downstream.

3 Wireless communication technologies

A range of technologies currently support the wireless connectivity of IoT and M2M devices, depending on the nature of the application and user preference. This section provides an overview of these technologies and assesses the strengths and weaknesses of each technology. In doing so, it presents a framework for identifying the specific niche for satellite communications within the IoT/M2M market.

3.1 Overview of wireless communication technologies

Wireless technologies can be classified into two broad categories – i) short range networks for localised connectivity, and ii) wide area networks to connect wireless devices over large areas. These two broad types of connectivity technologies can be sub-divided further as follows:

Short range networks

- Local Area Networks (LAN), e.g. Wi-Fi.
- Personal Area Networks (PAN) e.g. Bluetooth (incl. BLTE), ZigBee, Near Field Communication (NFC).

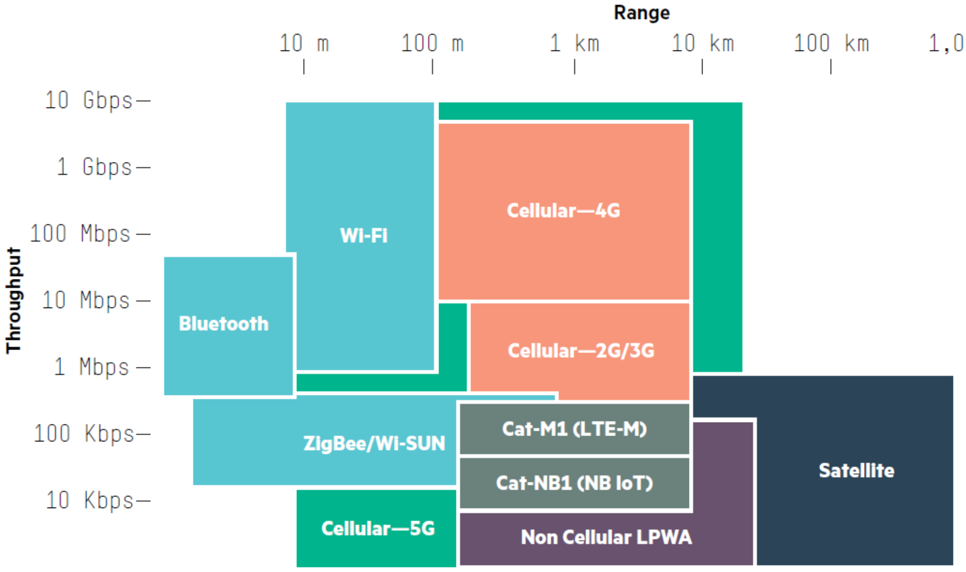
Wide area networks

- Cellular networks, e.g. 2G (GPRS), 3G (HSPA) and 4G (LTE) cellular networks which are deployed on frequencies under exclusive licence.
- Low Power Wide Area (LPWA) networks, e.g. LoRa, Sigfox, Ingenu.
- **Satellite networks.**

Each of these technologies are characterised by different characteristics that mean they can meet the connectivity requirements – as detailed in Figure 2 below – of some applications and not others.

[5] Please see following blog: http://www.nsr.com/news-resources/the-bottom-line/land-transport-drives-satellite-m2miot/

Figure 2 Range and throughput characteristics of wireless access technologies



Source: Hewlett Packard Enterprise (2016). Low Power Wide Area (LPRA) networks play an important role in connecting a range of devices, Business white paper. Available at: https://h20195.www2.hpe.com/V2/getpdf.aspx/4AA6-5354ENW.pdf?ver=3.2

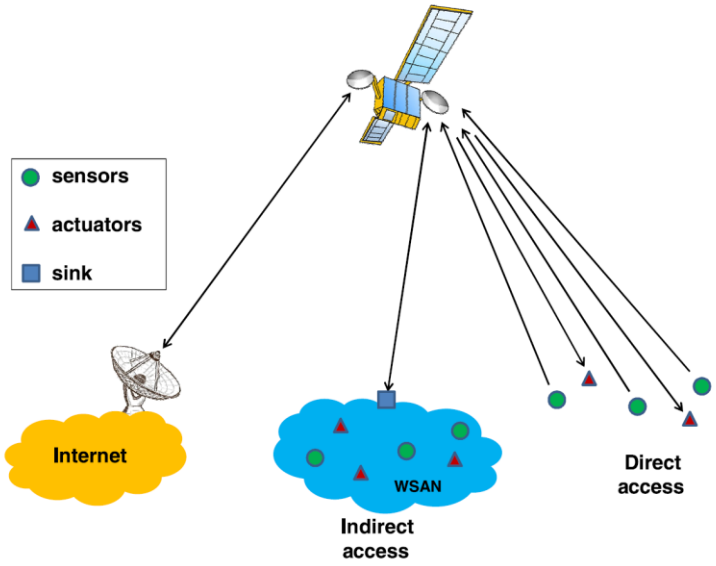
For this reason, the current **IoT/M2M connectivity landscape is characterised by a number of different technologies that occupy specific application niches**, depending on the specific connectivity, environmental, and cost needs of those applications.

On the device side, for example, there is always a **trade-off between power consumption and performance**. Battery-powered devices have very strict constraints on power consumption, so their connectivity needs can only be met by low power network technologies. This places a hard limit on the level of data exchange between battery-powered devices.

Within this context, **cellular** operators provide tailored services for communications across a range of vertical IoT segments across the globe. The older 2G networks offer sufficient performance for most applications, but the adoption of 3G and 4G is growing as the requirements for data increases (and indeed 5G in the near future). The relatively high cost and power inefficiency of cellular connectivity has nevertheless opened up space for **LPWA** networks for applications that require ultra-low data volumes and power consumption. **Satellites**, however, are the only networking technology capable of providing truly ubiquitous coverage anywhere on earth, including at sea and in remote and underpopulated areas that lack terrestrial infrastructure. However, the cost and data capacity of satellites often limits their use to applications that can tolerate the transmission of short messages at relatively high latency. For other more localised applications, where transmission of data is done over relatively short distances, **LAN** and **PAN** can offer sufficient connectivity.

Given these different characteristics, these technologies are often combined to support connectivity for applications with more challenging connectivity needs e.g. a short range technology may be used for sensing or gathering data, or for connecting a large number of devices concentrated over a relatively local but remote area, and a wide area technology may be used to exchange information with a central server or processor. An example of this is presented in Figure 3 below. In this case, satellites are used to provide the main network connectivity for a localised area which in turn relies on localised network (PAN or LAN) to distribute this connectivity between devices within this area.

Figure 3 Example of a satellite system communicating with sensors and actuators



Source: De Sanctis et al. (2016). Satellite Communications Supporting Internet of Remote Things, IEEE Internet of Things Journal, February 2016.

These communication technologies, their developments, and their relative strengths and weaknesses are explored in more detail below.

3.2 Types of wireless communication technologies[6]

3.2.1 Short range wireless communication technologies

For connectivity over short distances or within defined localised areas there are a number of low power technologies, particularly for M2M applications. These include Local Area Networks (LAN), such as Wi-Fi, and Personal Area Networks (PAN), such as Bluetooth and ZigBee.

Bluetooth

Bluetooth is a 2.5 GHz personal area network used for short-range wireless communication across the globe. Device-to-device file transfers, wireless speakers, and wireless headsets are often enabled by Bluetooth and it is expected to be a key technology for connecting wearable technologies.

Bluetooth Low Energy (BLE) is a version of Bluetooth designed for lower-powered devices that require less data. To conserve power, BLE remains in sleep mode until a connection is initiated. This makes it ideal for wearable fitness trackers and health monitors.

ZigBee

ZigBee is a 2.4 GHz mesh-based LAN that targets applications that require relatively infrequent data exchanges at low-data rates over a restricted area and within a 100m range such as in a building. It

[6] For details, please see: https://www.rs-online.com/designspark/eleven-internet-of-things-iot-protocols-you-need-to-know-about & https://www.link-labs.com/blog/complete-list-iot-network-protocols

was originally designed for building automation and control e.g. wireless thermostats and lighting systems often use ZigBee.

Wi-Fi

Wi-Fi is a LAN that provides internet access within a limited range. Devices exchange data via the internet using 2.4 GHz and 5 GHz radio waves. Bandwidth and speed of data transfer is high (up to hundreds of megabits per second), which supports video and audio streaming. However, Wi-Fi may be too power-consuming for many IoT applications.

3.2.2 Wide area wireless communication technologies[7]

Wide Area networks (WAN) are often used when other wireless networks are not a suitable fit. Bluetooth, BLE (and to a lesser extent, Wi-Fi and ZigBee) are often not suited for long-range performance.

Cellular

Cellular is a WAN that uses radio-waves to send and receive signals over long-ranges. Today, several generations of cellular technology support IoT services. **2G** and **3G** networks provide almost complete coverage of all densely populated parts of the world's landmass – 95% of the global population live in an area covered by a cellular network and 84% are covered by 3G or above based on 2016 estimates[8], and represent the dominant platform with a share of almost 90%[9]. While 2G is sufficient for most applications with largely narrow band data requirements, the long-term viability of the 2G network is uncertain as many cellular network operators are discontinuing connectivity. 3G is faster than 2G, and remains the most common network for cellular M2M connectivity. The fourth generation cellular network, **4G**, was launched in 2012 and uses the Long Tern Evolution (LTE) technology. This supports large and fast data transfer (300 Mbps compared to the 7mbs of 3G), but this requires higher processing power, and therefore comes at the cost of higher power consumption and costlier devices. The development of 4G as the new standard for M2M applications is therefore dependent on developments that improve device cost and battery life. The fifth generation of cellular network, **5G,** is expected to launch in 2020 and will ensure improvements in a number of areas, including: greater throughput, lower latency, increased reliability, higher connectivity density, and higher mobile range[10].

While **cellular's near-ubiquitous network coverage, particularly in the world's densest population centres, has made it the dominant IoT network platform**, it is not suitable for applications that are particularly price sensitive (cellular is associated with a recurring cost and expensive chipsets), have strict limits on battery capacity, or located in remote or sparsely populated areas that lack terrestrial infrastructure (33% of the world's rural population still do not have 3G or 4G network coverage[11]).

[7] For details, please see: AT&T (2016). *What you need to know about IoT wide area networks.* Available here: https://www.business.att.com/content/whitepaper/what_need_know_iot_networks.pdf
[8] ITU (2016). *ICT Facts and Figures 2016*. Available at: https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2016.pdf
[9] Berg Insight (2016). *The Global M2M/IoT Communications Market*. Protected by paywall.
[10] Emnify (unknown). *Globalized M2M/IoT Connectivity.*
[11] ITU (2016). *ICT Facts and Figures 2016*. Available at: https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2016.pdf

LPWA

Low Power Wide Area (LPWA) networks are a type of telecommunications network designed to allow long range communications at low-bit rates by utilising the unlicensed ISM-band frequencies. They are particularly suited for applications that require low hardware costs, long battery life and ubiquitous coverage (particularly where indoor penetration is important)[12].

Two of the main providers of LPWAN are **LoRa** (long range radio) and **Sigfox**.

LoRa is a LPWAN technology intended for wireless, low-cost, battery-operated devices in regional, national, or global networks, particularly those that must operate in harsh or isolated environments (e.g. underground). Communication is bi-directional and occurs between end-devices via a gateway. This means that a Wi-Fi or cellular connected is required to enable communication from the gateway to the server.

Sigfox uses the industrial, scientific and medical radio (ISM) band frequencies to support extremely low-energy devices that require low throughput and penetration through solid objectives (e.g. underground or in rough terrain). For this reason, they are particularly suited for devices in remote deployments that cannot be easily accessed for battery maintenance. However, their capacity to support only limited transmission (wireless throughput of up to 100bps) means that they are limited to those applications that do not require large amounts of data and/or frequent communication[13].

Satellite

Satellite communication technologies have a long history of use for telemetry and M2M applications. They are the only networking platform capable of providing truly **ubiquitous coverage anywhere on the planet**, including at sea and in remote unpopulated areas. Moreover, satellite-based systems are **safer**, **harder to disrupt** and **easier to deploy** than other terrestrial systems[14]. While satellite solutions vary from low throughput, low data rate, to higher bandwidth, real-time applications, they represent a **high cost** and **high latency** network option. This limits their use to remote applications that can tolerate the transmission of short data messages with high latency.

3.3 Wireless communication requirements of IoT/M2M

The choice of wireless communication technology depends on the connectivity requirements of the IoT/M2M application. These requirements concern three primary areas, as described in Table 1:

- **Range –** the extent to which an application favours short range or wide area technology;
- **Bandwidth –** the extent to which an application requires the transmission of a large amount of data at a high frequency and rate (wide band) or not (narrow band);
- **Quality of Service (QoS) –** the extent to which an application is mission-critical, and therefore in need of a connection with a high degree of security and reliability.

[12] Berg Insight (2016). *The Global M2M/IoT Communications Market.* Requires paid-for subscription
[13] Emnify (unknown). *Globalized M2M/IoT Connectivity.*
[14] Cocco, G., Ibars, I., (2012). *On the feasibility of Satellite M2M Systems.* Conference Paper, September 2012. Available at: https://www.researchgate.net/publication/257948749_On_the_Feasibility_of_Satellite_M2M_Systems

In addition, there are a number of other requirements that also have a bearing on the choice of communications technology, including the **power consumption**, **cost**, **lifecycle**, and device **size** needs of different applications.

Table 1 Connectivity requirements of IoT/M2M applications

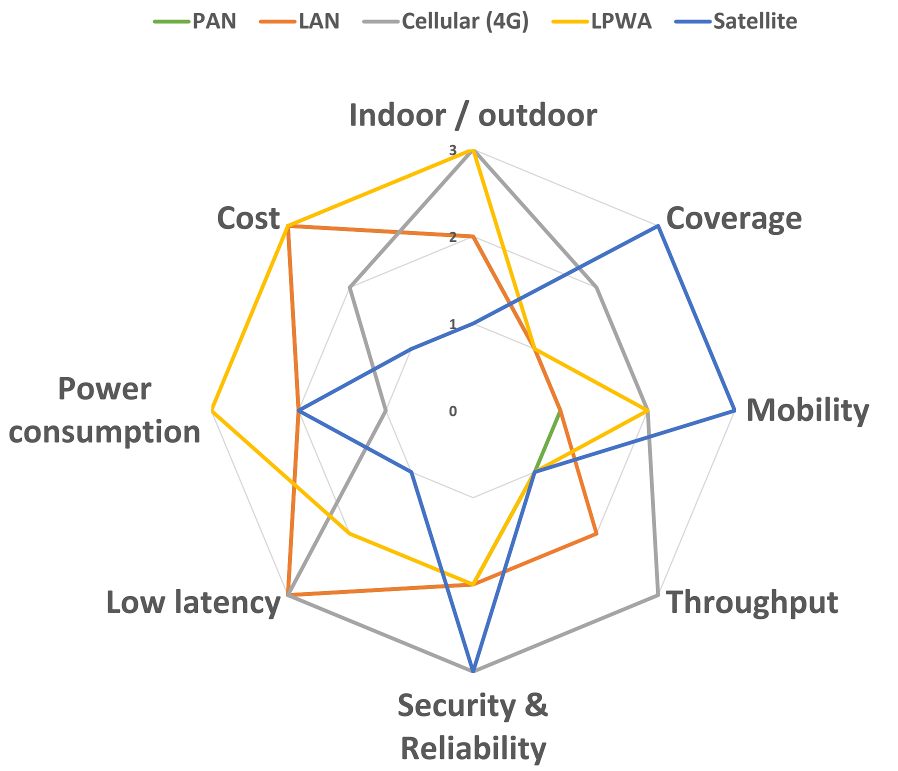
Category	Characteristic	Description of characteristic
Range	**Indoor / outdoor**	The extent to which the application requires coverage in all locations
	Density	The extent to which the applications needs to support a high concentration of devices
	Coverage	The need for wide-area or local-area coverage
	Mobility	The extent to which the applications needs to support devices that are continuously moving
Bandwidth	**Throughput**	The required rate at which data needs to be exchanged over the network
	Data cycle	The proportion of time application devices will be transmitting data
	Bi-directional communication	The extent to which the application needs to both transmit and receive data (i.e. support two communication)
Quality of Service	**Security**	The extent to which transmitted data needs to be authenticated, authorised or encrypted
	Reliability	The extent to which the application requires minimal error and false transmission of data, including low propagation / attenuation
	Low latency	The extent to which the application requires immediate receipt of a transmitted message within the IoT network
Power	**Power consumption**	Describes the required power efficiency of the device. Where devices have a fixed power source (battery), this characteristic also determines the replacement time (lifetime) of the device
Other	**Cost**	The required installation cost of transmitters and receivers, and the network subscription cost for the application to be commercially viable
	Lifecycle	The extent to which the device needs to be replaced because of physical damage, obsolescence, and limited battery life
	Size	The required size of the IoT devices that are associated with the application

Source: London Economics, building on content from Aegis Systems & Machina Research (2014). M2M application characteristics and their implications for spectrum

An analysis of the extent to which the main wireless communication technologies meet these requirements is presented in Figure 4 below. A RAG rating (red = low | amber = medium | green = high) summarises the overall strengths and weaknesses of these technologies in the table on the left hand side. These results are then mapped onto the radar diagram on the right hand side, where 1 indicates areas of weakness (red = low) and 3 indicates areas of strength (green = high).

Figure 4 Characteristics of wireless communication technologies

Connectivity characteristic	Wireless communication technology				
	PAN	LAN	Cellular (4G)	LPWA	Satellite
Indoor / outdoor[15]	Medium	Medium	High	High	Low
Coverage[16]	Low	Low	Medium	Low	High
Mobility	Low	Low	Medium	Medium	High
Throughput[17]	Low	Medium	High	Low	Low
Security & Reliability	Medium	Medium	High	Medium	High
Low latency[18]	High	High	High	Medium	Low
Power consumption	Medium	Medium	Low	High	Medium
Cost	High	High	Medium	High	Low



Note: Key connectivity characteristics of wireless communication technologies are summarised in the table, with a RAG rating (red = low | amber = medium | green = high) summarising the overall strengths and weaknesses of these technologies. These results are mapped onto the radar diagram, with 1 indicating areas of weakness (red = low) and 3 indicating areas of relative strength (green = high).

Source: London Economics analysis

[15] Low = No indoor penetration; High = Indoor penetration
[16] Low = Only local area coverage (metres); High = Global / regional coverage (1000s km)
[17] Low = < 1Mbps; High = > 1 GBps
[18] Low = > 200ms; High = <10ms

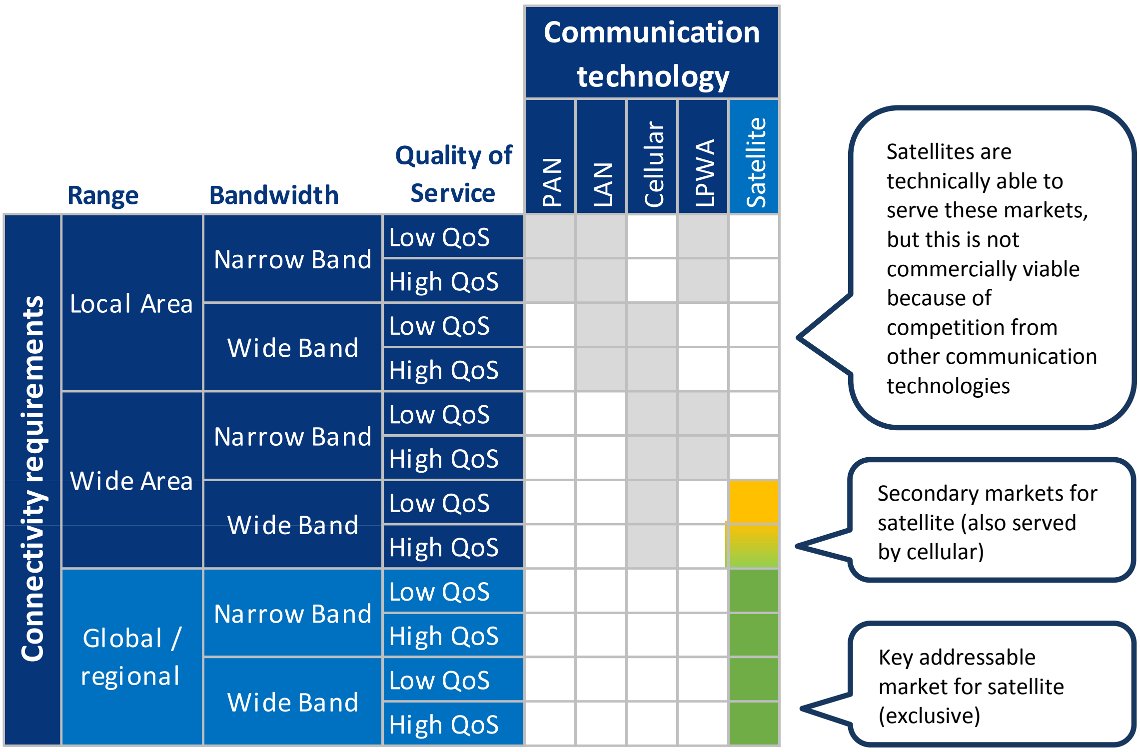
4 IoT/M2M market addressable by satellite

4.1 Identifying IoT/M2M applications that can benefit from satellite

The analysis presented in Figure 4 above makes it possible to identify the groups of applications that are best served by each of these communication technologies, and to ultimately identify the market for satellite-addressable IoT/M2M.

To segment the IoT/M2M market into logical application groups for this purpose, the three primary groups of requirements – range, bandwidth, and quality of service – can be used to segment the IoT/M2M market into 12 application groups. The analysis presented in Figure 4 can then be used to identify the suitability of different wireless communication technologies for each of these groups. An attempt to do this is presented in Table 2 below.

Table 2 Matrix of IoT/M2M application groups and communication technologies



Source: London Economics analysis which builds on application groupings from Aegis Systems & Machina Research (2014). M2M application characteristics and their implications for spectrum. Available at: [***https://www.ofcom.org.uk/__data/assets/pdf_file/0040/68989/m2m_finalreportapril2014.pdf***](https://www.ofcom.org.uk/__data/assets/pdf_file/0040/68989/m2m_finalreportapril2014.pdf)

This matrix demonstrates that satellite technologies can meet the needs of a very specific niche of applications, which my exhibit one or more of the following characteristics:

- IoT/M2M devices that are in **remote areas** (underserved by terrestrial networks) or are **dispersed** over a wide geographical area (e.g. regional or global);
- IoT/M2M devices that are **mobile** (regularly/continuously moving between geographical locations) and therefore in need of a single platform solution;

- A need for **redundancy** at critical sites;
- **Group-based communications** to ensure connectivity across many devices;
- Connected via other network technologies but require **backhaul via satellite**; and
- Require a high degree of **security and reliability**.

While applications with these characteristics represent the core addressable **use cases for satellite** communications, the actual market is further limited by:

- High **cost** (even though telecommunication services via small satellites are expected to be more cost-competitive than high throughput GEO satellite telecommunications);
- Medium/High **power consumption**;
- Low **data rates** (up to a few Kbps) of existing satellite communication technologies[19]; and
- High **latency** (1-2s) of existing satellite communication technologies (GEO)[20].

The current market for satellite-addressable IoT/M2M is therefore limited to **low-bandwidth** and **latent-tolerant** applications with one or more of the characteristics mentioned above.

4.2 Key vertical markets and example applications

There are a number of different applications which use satellite communications – either on their own or in combination with other wireless communication technologies – to enable the connectivity of IoT/M2M devices. Key satellite-addressable segments and their applications are summarised in the table below[21]. A case study on the applicability of satellite communication platforms for environmental monitoring is also provided in Box 2.

Table 3 Key vertical markets and example applications for satellite-addressable IoT/M2M

Vertical segment	Applicability of satellite	Specific applications
Land transport	The **mobility** of land transport applications means that there will always be a strong value proposition for reliable satellite M2M communications in this market. This will reflect a divergence in data requirements for land transport applications between very basic solutions to advanced telematics solutions.	Fuel management
		Dispatch optimisation
		Emergency response
		Location tracking
		Telematics and analytics
		Cargo logistics
		In-vehicle entertainment
		Safety requirements
Maritime	Gaps in cellular connectivity is a challenge for customers, driving maritime operators to satellite solutions for both broadband and M2M usage. This is particularly the case given stringent safety and security requirements.	Inspection and maintenance
		Communication and navigation
		Safety
		Cargo shipping
		Accident or incident
		Weather and meteorological data
		Material performance
		Inventory
		Ship security alert systems
		Long range identification and tracking

[19] De Sanctis et al. (2016). *Satellite Communications Supporting Internet of Remote Things.* IEEE Internet of Things Journal, February 2016
[20] De Sanctis et al. (2016*). Satellite Communications Supporting Internet of Remote Things.* IEEE Internet of Things Journal, February 2016
[21] Application groups are based on: Northern Sky Research (2016). *M2M and IOT via Satellite, 7th Edition*. November 2016.

		Fuel management
Aeronautical	Satellite communications is the only communication platform that is available everywhere and therefore in a position to service the **mobility** needs of aeronautical applications. Satellites are also sufficient for the **narrowband** needs of these applications, at least in the short term.	Aircraft health monitoring Real time flight navigation Weather data Predictive aircraft management Route optimisation Meter reading Passenger notifications Flight engine telemetry Maintenance schedule optimisation Analytics
Oil & Gas	A number of oil & gas applications occur in **remote** areas (offshore rigs) and across borders (pipeline monitoring, tanker logistics), which can only be served by satellite communications.	Pipeline monitoring Safety, security, and crew welfare Automation, especially on offshore rigs Meter reading Real time tracking for tankers and logistics, including for regulatory monitoring
Military	The need for **security** and **criticality** means that satellite face limited competition for military M2M. This is also compounded by the lack of reliable cellular coverage where units are operating and the need for connectivity that is independent of country or geography. Bandwidth requirements will remain **narrowband** for most land based applications, but will increase for unmanned aircraft solutions which will use more telematics.	Asset tracking Guided parachutes Biological and chemical sensing Maritime and aircraft safety systems and telematics Geofencing notifications Troop tracking and notifications Munitions transportation and tracking Fixed security systems at stockpile locations Diagnostic monitoring Emergency assistance
Civil government	With the exception of rural areas, satellite security communications for civil government will be a backup for terrestrial video surveillance. However, the future will see a greater focus on connectivity of **mobile** units (e.g. vessel and vehicle tracking) which will need to handle greater amounts of telematics data.	Scientific research Environmental meter reading and climate change analysis Aid agencies Border patrols Police agencies First responders (emergency services) Coast guard Forestry services Logistics departments
Connected car	The number of devices in this area will be extremely limited in the short to medium term, with most accounted for by trials and testing by auto manufacturers. With the exception of entertainment and hotspot connectivity, demand will be primarily for **narrowband** connectivity.	Vehicle diagnostics (consumer vehicles) Safety and security (consumer vehicles) Maintenance (consumer vehicles) Internet connectivity (consumer vehicles) Entertainment (consumer vehicles)
Consumer IoT	The target market for consumer IoT devices is outdoor enthusiasts, hikers, emergency backup and private vessel users. These uses cases are expected to be in regions where there is no terrestrial network coverage. Bandwidth requirements are expected to remain small.	Location tracking
IoT backhaul	The vast increase in the number of terrestrially connected IoT devices will justify	LPWA backhaul

	the emergence of **satellite backhaul**. Given the low bandwidth capacity of LPWA, the amount of data to be backhauled via satellite will be extremely small.	
Security and surveillance	Most use cases in this area concern the protection of **high value assets** at rest. For these use cases, continuous and robust coverage is a necessity, so satellite connectivity is often used as a **backup** to cellular connections.	CCTV cameras
		Motion detection
		Authentication systems
		Door/gate locking and unlocking
		Alarm management
		Anti-theft systems
Other IoT/M2M	These applications, while variable in specific communication requirements, share a common need for **connectivity in remote** (e.g. rural, offshore) and/or **underpopulated** areas that are underserved by cellular networks. Satellites therefore represent the only viable communication network for these use cases.	**Agriculture**, including animal tracking, fishery management, environment monitoring, yield forecasting, equipment monitoring
		Mining, including asset monitoring, exploration optimisation, meter readings, panic alerts
		Construction, including meter readings, employee tracking, health and safety, logistics, theft prevention
		Green energy, including security, diagnostic tracking, usage tracking, control, flow monitoring
		Utilities, including least-cost routing, substation control, monitoring systems, video monitoring, electrical generation

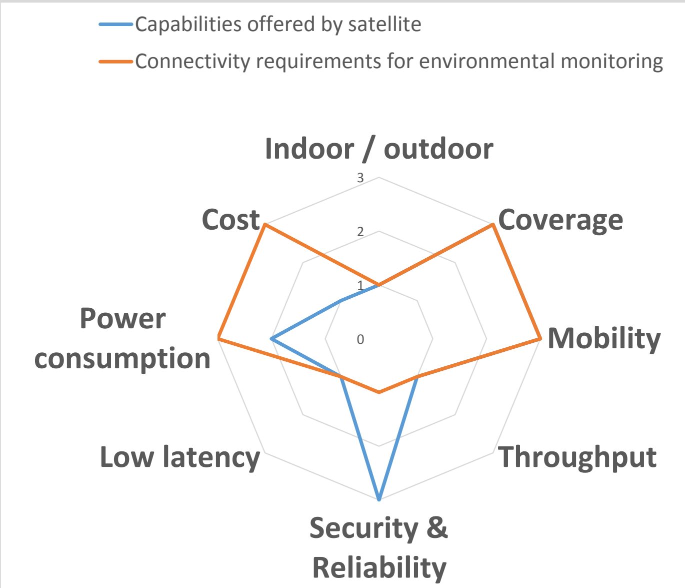
Source: Application groups sourced from Northern Sky Research (2016). M2M and IOT via Satellite, 7th Edition. November 2016.

Box 2 Case study: Environmental monitoring applications

Satellite platforms are becoming increasingly used for environmental monitoring. This is because of their capacity to provide regional or global coverage in isolated areas that are the site of destructive environmental phenomena such as landslides, avalanches, forest fires, volcanic, eruptions, floods, and earthquakes.

The successful monitoring of these events require **fast detection** and the need for a rapid intervention from emergency and environmental services. In this context, there is a need for a communication platform that can: support a large number of nodes, is **low cost**, can be **easily deployed**, is **low maintenance**, and has a long battery duration**. Wide area coverage** and **mobility** may also be important, particularly for wildlife monitoring, and requirements are sufficiently met by **narrowband** and relatively high-latency communication platforms.

As shown in the radar diagram below, the key range, bandwidth and quality of service requirements for environmental monitoring applications are sufficiently met by satellite communication platforms. However, satellites represent a relatively high-cost, high-power solution for this area. Even so, the energy self-sufficiency of many environmental monitoring applications (e.g. those utilising solar panels), and the absence of competitor networks that can operate in remote locations means that satellite communications remains the most viable solution for environmental monitoring in the short to medium term. Nevertheless, a lower-cost, lower power satellite solution would offer significant value for users in this area.



Source: Based on a variety of sources, including: London Economics analysis and De Sanctis et al. (2016). Satellite Communications Supporting Internet of Remote Things. IEEE Internet of Things Journal, February 2016.

5 Quantifying the market addressable by satellite

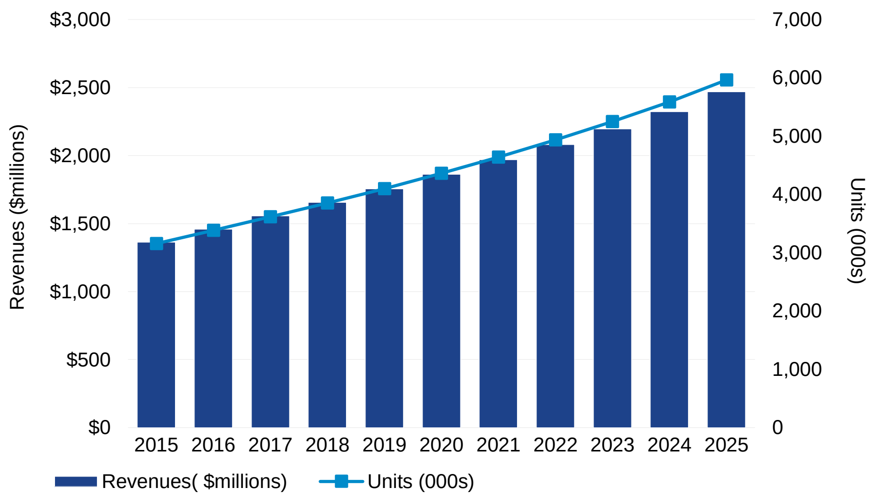
5.1 Addressable market overview

The emergent nature of the small satellite market (both supply-side and demand-side) and poor market data makes **estimation of the current IoT/M2M market that is accounted for by small satellites is difficult.** However, data does exist on the IoT/M2M market that is captured by manufacturers of IoT/M2M terminals and retails revenues within the satellite for IoT/M2M domain more generally[22].

Machina Research estimates that **satellites currently serve just 5% of all IoT/M2M applications** (and only 1% of all applications exclusively), with the vast majority of all other applications served by cellular networks[23].

Nevertheless, the unique value proposition for satellites – as the only platform that can offer truly global coverage – will hold for foreseeable future. Indeed, Northern Sky Research (NSR) project a total of **5.97 million in-use devices that use satellite by 2025**, compared to 3.16 million in-use devices in 2015, or a compound annual growth rate (CAGR) of 6.6%. However, declining Average Revenue per Unit (APRU) across all market segments mean that revenue growth is comparatively slower at a CAGR of 6.1%[24]. This means that the **global IoT/M2M market will reach $2.47 billion in 2025**, from $1.35 billion in 2015, as shown in Figure 5 below.

Figure 5 Global IoT/M2M via satellite market, 2015-2025



Source: Northern Sky Research (2016). M2M and IOT via Satellite, 7th Edition, November 2016.

This growth nevertheless varies significantly between market segments and applications.

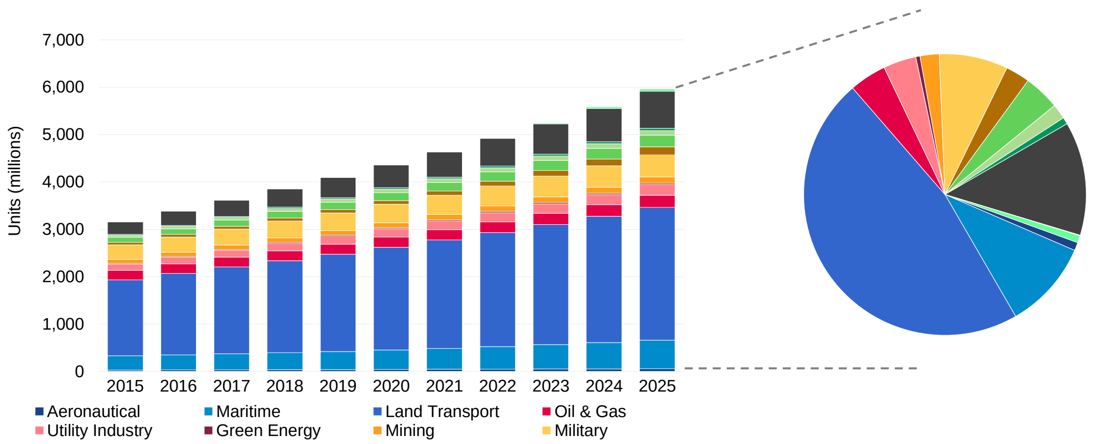
[22] This sections draws on analysis provided by: Northern Sky Research (2016). *M2M and IOT via Satellite, 7th Edition*. November 2016.
[23] Please see following press release: https://machinaresearch.com/news/press-release-global-internet-of-things-market-to-grow-to-27-billion-devices-generating-usd3-trillion-revenue-in-2025/
[24] Northern Sky Research (2016). *M2M and IOT via Satellite, 7th Edition.* November 2016.

5.2 Addressable market by vertical segment

As shown in Figure 6 below, **land transport is, and will remain, the dominant vertical segment** for satellite-addressable IoT/M2M by some distance, maintaining a 47-51% share of all units (2.8 million by 2025) throughout the 2015-2025 forecasting period.

Rapid growth in the heavily price-sensitive consumer market will see **Consumer IoT becoming the second largest vertical segment** in terms of units, with 13.1% of the market (or 779,300 units) by 2025. This is followed by the **maritime** (10.2%) and **military** (7.9%) segments, with the latter seeing its relative share decline given relatively slow 4.5% CAGR over the analysis period.

Figure 6 Global IoT/M2M via satellite units by vertical market segment, 2015-2025



Source: Northern Sky Research (2016). M2M and IOT via Satellite, 7th Edition, November 2016.

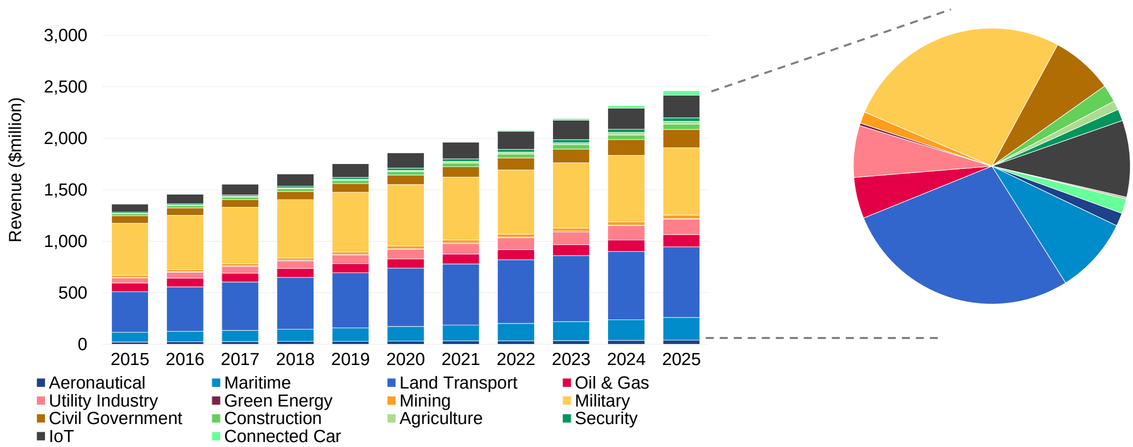
Land transport maintains a dominant 28-30% share of total market revenues ($685.9 million by 2025) throughout the 2015-2025 forecasting period (see Figure 7 below). APRU for the land transport segment is expected to increase in the medium-term, despite significant competition from cellular and LPWA networks in the longer term, as the market diverges between very low bandwidth requirements for most applications (e.g. for asset management and logistics applications) and higher bandwidth requirements for more advanced telematics solutions. Nevertheless, average bandwidth requirements for the whole segment are expected to increase slowly over time.

The **military** segment, driven largely by troop and munition tracking systems, is forecast to see a significant decline from 37% of total revenues in 2015 to 26% by 2025 ($653.1 million by 2025) as militaries push for more capacity at lower cost. Even so, this segment will continue to have the highest APRUs of any segment, given very niche use requirements. The critical nature of the military segment will also limit competition from terrestrial providers. Bandwidth requirements for most land based applications will also remain narrowband.

Maritime and the **consumer IoT** segment are expected to make up the other dominant segments by 2025, with forecast revenues of $220.9 million and $221.9 million, respectively. Within the maritime segment, merchant maritime and cargo applications will remain the largest driver of M2M units, although fishing and private vessels will see increasing growth, albeit from a smaller base. Narrowband solutions are sufficient for most M2M applications in this segment, especially given safety requirements.

On the other hand, the extractive segments (oil and gas, and mining) are forecast to lose market share given difficult market conditions that will be characterised by depressed commodity prices in the longer-term.

Figure 7 Global IoT/M2M via satellite revenues by vertical market segment, 2015-2025



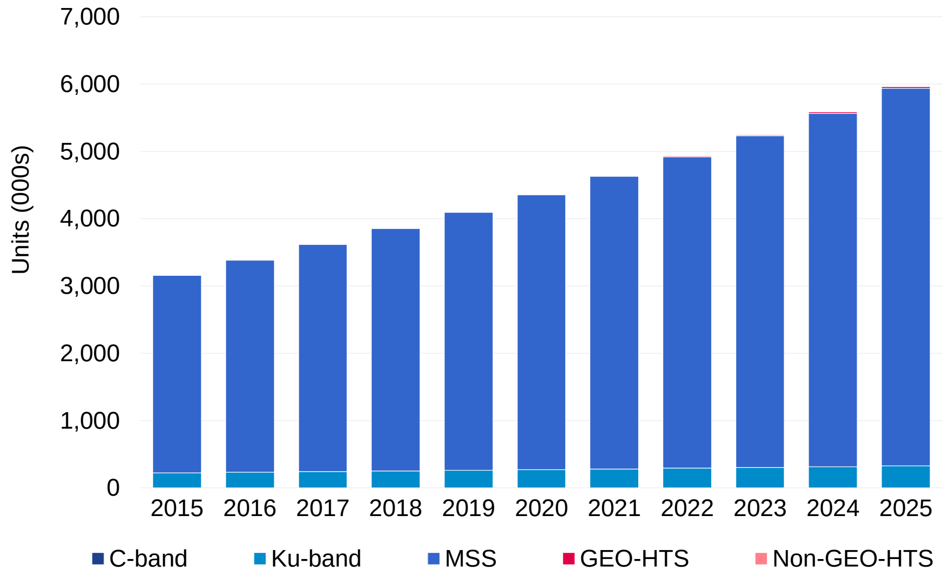
Source: Northern Sky Research (2016). M2M and IOT via Satellite, 7th Edition, November 2016.

5.3 Addressable market by frequency

IoT/M2M applications that are addressable by satellite are primarily narrowband. For this reason, **Mobile Satellite-Service** (largely L-band) dominate, with a **93%** share of all units (i.e. 2.93 million devices worth $1.21 billion in 2015). This is helped by fact that **L-band** solutions are the only frequency currently permitted by most aviation and maritime safety authorities. Units serviced by the higher-capacity **Ku-band comes a distant second** with just 7% (i.e. 220,600 devices worth $152.1 million in 2015), supporting niche video and security applications and backhaul.

Higher throughput satellites (HTS – GEO and non-GEO) are not active or currently needed to meet the needs of today's IoT/M2M applications, however requirements for higher bandwidth in some applications within the land transport, security and surveillance, and utilities segments mean that HTS will obtain an extremely niche (<1%), but growing share of the market over the next decade.

Figure 8 Global IoT/M2M via satellite units by frequency, 2015-2025



Source: Northern Sky Research (2016). M2M and IOT via Satellite, 7th Edition. November 2016.

5.4 Addressable market by region

North America dominates the satellite-addressable IoT/M2M market, with a 52% share of global revenues in 2015. The market will remain centred on the US in 2025, but revenues are expected to shift to more developing regions over this ten year forecasting period, particularly to Asia (from 9% to 13%) and MEA (from 11% to 12%), as the US share declines to 47%. This will be driven by a combination of increasing competition from cellular in the US and faster growth opportunities in these developing regions, notably in cargo shipping. Europe’s regional share of revenues will also decline over this period (from 12% to 11%), as cellular and LPWA are expected to act as increasing competitive constraints.

6 User requirements research

This chapter identifies the **emerging** user requirements of IoT/M2M applications that are addressable by satellite (by **use case**) and presents the results of a **high-level survey of satellite-enabled IoT/M2M devices** of some of the leading manufacturers to identify patterns in their technical capabilities.

This research has been informed by a combination of desk-based research, interviews with attendees at the IoT World Europe 2017 conference, and a number of interviews with experts that covered a cross-section of industry, government agencies, regulators, and researchers.

Caveats: The **emergent nature** of the IoT/M2M applications market as a whole, and particularly with respect to satellite-enabled connectivity, is reflected in the **uncertainty** of some the user requirements parameters. In these cases, a range or threshold is given. In all cases, an indication is given, based on the **collected best information and current knowledge in the field**.

6.1 Defining satellite use cases

The limited scope of this study mean that it is not possible to detail the specific user requirements of each of the 90 applications identified in the market analysis phase of this study (see Table 3). The scarcity of existing technical analysis at the application level makes this very difficult in any case. However, there are sufficient similarities between some applications that mean that an analysis of user requirements can be conducted at a more aggregate level. For example, it is possible to categorise all applications that can be addressed by satellite (as outlined in Chapter Figure 4) into **11 primary use cases** that share similar functional characteristics as far as communication needs are concerned. This is a more constructive level of analysis than one conducted at the level of vertical market segments, given the high variation in application-level requirements within vertical market segments. These **use cases** are summarised in Table 4 below. For simplicity, each application has been assigned exclusively to just one use case.

Caveats: Analysis of user requirements at the level of use cases – representing a grouping of applications by common functional characteristics – has been conducted because of the large variation in user requirements within use cases. However, it is recognised that many existing service providers access the market at the vertical segment level (i.e. developing a service offering, expertise, and a reputation that spans a segment), even if the service requirements differ substantially between applications within this segment. For this reason, future research in this area could attempt to define the market size and specific requirements of users at the more disaggregated 'use case within segment' level – the research conducted for this report confirms that this information is currently lacking.

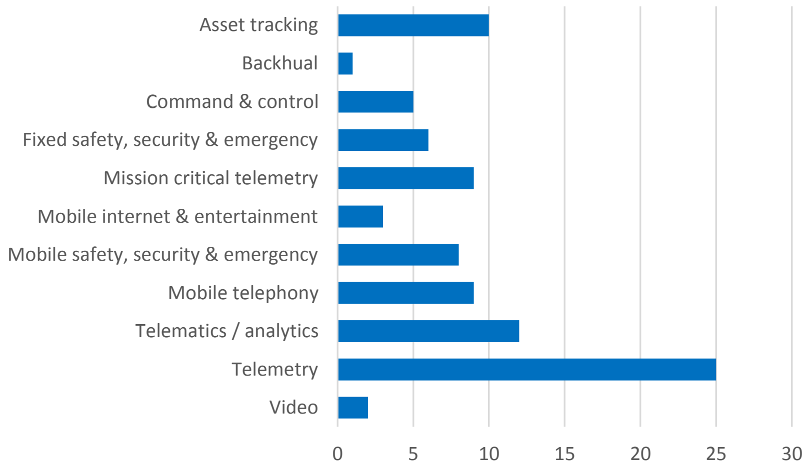
Table 4 Definition of satellite use cases

Use cases	Definition
Asset tracking	Applications that use telecommunications to monitor the location data of objects
Backhaul	An application that provides the intermediate link between the core telecommunications network and small subnetworks that can distribute data at the periphery
Command & control	Applications that use telecommunications to relay actionable commands between devices
Mobile safety, security & emergency	Mobile applications that use telecommunications for the purpose of safety, security and emergencies.
Fixed safety, security & emergency	Fixed applications that use telecommunications for the purpose of safety, security and emergencies.
Mission critical telemetry	Mission critical applications that use telecommunications to monitor the activity of devices, the environment or other objects
Mobile internet & entertainment	Applications that use telecommunications for the purpose of mobile internet access and/or entertainment
Mobile telephony	Applications that use telecommunications to relay telephony and internet data
Telematics / analytics	Applications that use telecommunications to monitor and then optimise the performance of devices
Telemetry	Non-mission critical applications that use telecommunications to monitor the activity of devices, the environment or other objects
Video	Applications that use telecommunications to transmit video data

Data on the IoT/M2M market that is addressable by satellite is available at the level of vertical market segment (as presented in 5.2). However, the limitations of the market data – specifically the absence of data at the more disaggregated application level – means that is not possible to identify the significance of these use cases in terms of device sales or revenues.

Nevertheless, the relative significance of these use cases – in terms of the number of applications – is shown in Figure 9 below. With 25 applications, **Telemetry accounts for the largest number of applications**, with a share of 28%. **Telematics / analytics** is the second largest user case in terms of applications (13%), with **Asset Tracking** (11%) in third.

Figure 9 Number of global IoT/M2M applications for each satellite use case



Source: London Economics analysis

6.2 User requirements by use case

6.2.1 Use case 1: Asset tracking

Satellite IoT/M2M connectivity can be used to monitor the location of high-value assets such as vehicles, fleets, and heavy machinery through a single point of contact. Examples of applications within the **asset tracking use case – widely considered one of the strongest and most commercially viable of all satellite use cases**[25] – are summarised in Table 5 on the right hand side.

These applications rely on the connectivity of GNSS-enabled devices (e.g. GPS) attached to these assets. The need for asset tracking is usually motivated by a need to monitor the location of a **large number of high-value assets** distributed over a **large area** and in **remote locations**. The majority of tracking needs are met by the

Table 5 Asset tracking

Vertical segment	Applications
Land transport	Cargo logistics
Maritime	Inventory
	Long-range identification and tracking
Military	Asset tracking
	Munitions transportation and tracking
Consumer IoT	Location tracking
Agriculture	Animal tracking
	Equipment monitoring
Mining	Asset monitoring
Construction	Logistics

Source: Applications sourced from NSR (2016).

[25] As identified by multiple stakeholders during the study consultations.

periodic transmission of **low bit rate** location data to a central server. These applications are therefore **tolerant of relatively high latency,** although this will depend on the value and criticality of the asset. However, since these assets are often **mobile** (e.g. container cargo and animal trackers), these devices must have **very low power consumption**.

For these reasons, asset tracking applications have the following network user requirements:

- A network that can support the location tracking of mobile assets;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- Relatively high network signal availability to minimise any significant gap in the coverage of the (high-value) asset's location;
- A network that can transmit periodic location data as energy efficiently as possible;
- Varying tolerance for latency (low and high), which will vary depending on the criticality of the asset;
- A need for no more than narrowband transmission, and
- A high need for a secure and reliable transmission of location data.

In quantitative terms, these user requirements are as follows:

<table>
<tr><th>Bandwidth</th><th>Latency</th><th>Availability</th><th>Mobility</th><th>Security & resilience</th><th>Power</th><th>Classification</th></tr>
<tr><td colspan="6">This section contains additional sensitive information that has been redacted for public dissemination.</td><td>Low bandwidth, moderate latency / Low bandwidth, high latency</td></tr>
</table>

6.2.2 Use case 2: Backhaul

Table 6 Backhaul

Vertical segment	Applications
IoT backhaul	LPWA backhaul

Source: Applications sourced from NSR (2016).

In order to deliver on its promise, the IoT/M2M ecosystem will need to support the deployment of a large number of connected devices in difficult to reach and underpopulated areas that are underserved by terrestrial networks.

The large number of devices in these remote environments require on-demand backhaul that avoids the need for costly terrestrial infrastructure. Given the large number of devices, cumulative bandwidth demand will be high.

For these reasons, backhaul applications have the following network user requirements:

- A network that can support communication with both mobile and stationary devices;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- A network with relatively high availability;
- Low tolerance for latency;
- A need for wide bandwidth to support the large number of connections, and
- A high need for a secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						High bandwidth, ultra-low latency

6.2.3 Use case 3: Command & control

As well as supporting monitoring, two-way IoT/M2M connectivity can be used to send communications that trigger actions in devices via an actuator. This type of communication is prevalent in automated or remote systems where, in the latter case, command actions can only be initiated at a distance.

Table 7 Command & control

Vertical segment	Applications
Oil & Gas	Automation, especially on offshore rigs
Security and surveillance	Door/gate locking and unlocking
	Alarm management
Green energy	Control
Utilities	Substation control

Source: Applications sourced from NSR (2016).

These type of applications rely on being able to send **secure** and **robust two-way communications** between a **large numbers of devices.** Geographically, these devices are often spread over a **large area**, often in **very remote** areas. These devices are normally attached to **fixed systems** and, given their remoteness and volume, are heavily **power constrained**. Despite the large number of potentially connected devices, the small bit rate of messages means that **cumulative bandwidth is likely to be relatively small.** Since command and control communications support applications that are characterised by automation and remote security, **low latency is also critical.**

For these reasons, command & control applications have the following network user requirements:

- A network that can support communication with stationary devices;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- A network with relatively high availability;
- Moderate tolerance for latency;
- A need for wide band transmission, and
- A critical need for a secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						High bandwidth, ultra-low latency

6.2.4 Use case 4: Mobile safety, security & emergency

A number of civil emergency (e.g. first responders), military, and commercial applications (specifically transport) rely on the reliable connectivity of **mobile** safety, security or emergency focused-devices. In most cases, these are statutory requirements.

As a result, **high availability**, **secure and reliable** connectivity, and **low latency** are of paramount importance. All of the devices within this use case are **mobile**.

Table 8 Mobile safety, security and emergency

Vertical segment	Applications
Land transport	Emergency response
	Safety requirements
Maritime	Safety
	Accident or incident
	Ship security alert systems
Military	Emergency assistance
Civil government	First responders (emergency services)
Connected car	Safety and security (consumer vehicles)

Source: Applications sourced from NSR (2016).

For these reasons, mobile safety, security and emergency applications have the following network user requirements:

- A network that can support communication with highly mobile devices;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- A network with very high availability;
- Low tolerance for latency;
- A need for no more than narrow band transmission, and
- A critical need for a secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						Low bandwidth, low latency

6.2.5 Use case 5: Fixed safety, security & emergency

As with the use case 4, there are a number of applications that have a specific need to support the connectivity of safety, security & emergency devices, often to support the safety and security of employees or fixed assets. Unlike use case 4, however, the applications considered within this group concern the connectivity of **fixed** devices.

Given the similarity, this use case shares many similar characteristics to use case 4. This includes a need for **high availability**, **secure and reliable** connectivity, and **low latency**. However, the fixed nature of these devices mean

Table 9 Fixed safety, security & emergency

Vertical segment	Applications
Security and surveillance	Authentication systems
	Anti-theft systems
Mining	Panic alerts
Construction	Health and safety
	Theft prevention
Green energy	Security

Source: Applications sourced from NSR (2016).

that they are more likely to have access to an external power source and therefore face a lower constraint on their power consumption.

For these reasons, fixed safety, security & emergency applications have the following network user requirements:

- A network that can support communication with fixed devices;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- A network with relatively high availability;
- Moderate tolerance for latency;
- A need for no more than narrow band transmission, and
- A critical need for secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						Low bandwidth, moderate latency

6.2.6 Use case 6: Mission critical telemetry

The power of connected devices lies in their capacity to support the (near) real-time monitoring of devices, their performance and the environmental conditions that they operate in. Telemetry describes the automatic measurement and wireless transmission of this monitoring data from remote sources.

For **mission critical** applications where the monitoring of this information is crucial for safety of life, for example, it must be possible to transmit telemetry information at all times (i.e. a need for **high availability**), with **very high levels of security and reliability**, sometimes in **real-time**. This latter requirements means that transmission must occur with **very low latency**. This requirement also means that the frequency of transmission may be high, although the bit rate of individual monitoring messages may be very small. **Cumulative bandwidth needs are therefore likely to be quite low.**

Table 10 Mission critical telemetry

Vertical segment	Applications
Aeronautical	Aircraft health monitoring
	Real time flight navigation
	Flight engine telemetry
Military	Biological and chemical sensing
	Geofencing notifications
	Troop tracking and notifications
	Fixed security systems at stockpile locations
	Diagnostic monitoring
Security and surveillance	Motion detection

Source: Applications sourced from NSR (2016).

For these reasons, mission critical telemetry applications have the following network user requirements:

- A network that can support communication with fixed and mobile devices;
- A network that provides regional or global coverage;

- A network that can support a very large number of connections;
- A network with very high availability;
- Very low tolerance for latency;
- A need for no more than narrow band transmission, and
- A critical need for very secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						Low bandwidth, ultra-low latency

6.2.7 Use case 7: Mobile internet & entertainment

IoT/M2M can vastly improve the entertainment experience of vehicle passengers by providing connectivity to the internet and to other in-vehicle entertainment systems.

Table 11 Mobile internet & entertainment

Vertical segment	Applications
Land transport	In-vehicle entertainment
Connected car	Internet connectivity (consumer vehicles)
	Entertainment (consumer vehicles)

Source: Applications sourced from NSR (2016).

A smooth in-vehicle entertainment experience requires a **high availability**, **high reliability**, **high bandwidth** and **low latency** network connection. Since the consumer vehicle market is mass market, the **number of potential connections is very large**. The security and resilience of the link also needs to be high, since the in-vehicle entertainment device is likely to be connected with the vehicle's other connected devices that may serve a more critical function. The need for resilience against external threats is therefore high.

Thus, mobile internet & entertainment applications have the following network user requirements:

- A network that can support communication with extremely mobile devices;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- A network with high availability;
- Very low tolerance for latency;
- A need for wide band transmission, and
- A critical need for very secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						High bandwidth, ultra-low latency

6.2.8 Use case 8: Mobile telephony

This use case captures all those civil, military, and commercial applications that use mobile telephony for voice communications between mobile devices. The electronic transmission of voice communications in this way – mobile telephony – has been an important part of the communications landscape since the development of mobile devices for mass market and professional applications.

Table 12 Mobile telephony

Vertical segment	Applications
Maritime	Communication and navigation
Oil & Gas	Safety, security, and crew welfare
Military	Guided parachutes
Civil government	Scientific research
	Aid agencies
	Border patrols
	Police agencies
	Coast guard
	Forestry services

Source: Applications sourced from NSR (2016).

The transmission of voice messages in real time implies the need for **high bandwidth** and **low latency**. The **criticality** of applications in this use case also means that communications must be **highly secure**, **reliable** and possible in the vast majority of instances (i.e. **very high network availability**). The large number of mobile telephony devices for these critical applications also implies the need for a large number of connections.

For these reasons, mobile telephony applications have the following network user requirements:

- A network that can support communication with extremely mobile devices;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- A network with high availability;
- Very low tolerance for latency;
- A need for wide band transmission, and
- A high need for very secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						High bandwidth, ultra-low latency

6.2.9 Use case 9: Telematics / analytics

As discussed previously, telemetry involves the remote recording and transmission of monitoring data. Telematics goes one step further and utilises information processing to make decisions or determine actions in response to this monitoring data in an automated way.

Applications within this use case therefore require communications that is **two-way** and able to support **low bandwidth** at **low latency,** though precise latency needs will depend on the criticality of the application. Beyond this, the requirements – e.g. for security & reliability, power, and mobility – vary quite significantly between applications within this use case. Thus, in order to service this use case, the most stringent of the most demanding applications needs to be met.

Table 13 Telematics / analytics

Vertical segment	Applications
Land transport	Fuel management
	Dispatch optimisation
	Telematics and analytics
Maritime	Fuel management
Aeronautical	Predictive aircraft management
	Route optimisation
	Maintenance schedule optimisation
	Analytics
Military	Maritime and aircraft safety systems and telematics
Mining	Exploration optimisation
Utilities	Least cost routing
	Electrical generation

Source: Applications sourced from NSR (2016).

For these reasons, telematics / analytics applications have the following network user requirements:

- A network that can support communication with both mobile and stationary devices;
- A network that provides regional or global coverage;
- A network that can support a large number of connections;
- A network with high availability;
- Varying (high and low) tolerance for latency, depending on criticality;
- A need for narrow band transmission, and
- A high need for very secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						Low bandwidth, moderate latency / Low bandwidth, high latency

6.2.10 Use case 10: Telemetry

As with the use case 6, there are a number of applications that have a need to support the automatic measurement and wireless transmission of monitoring data from remote sources.

This use case deals with **non-mission critical** applications where the monitoring of this information can support the improved efficiency and effectiveness of the applications in this use case. As such, this use case has a comparatively **less stringent requirement for security & reliability, and latency**. Nevertheless, monitoring information will need to be transmitted fairly frequently, although the bit rate of individual monitoring messages may be very small. **Cumulative bandwidth needs are therefore likely to be quite low.**

For these reasons, mission critical telemetry applications have the following network user requirements:

- A network that can support communication with fixed and mobile devices;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- A network with high availability;
- High tolerance for latency;
- A need for no more than narrow band transmission, and
- A moderate need for secure and reliable transmission of data.

Table 14 Telemetry

Vertical segment	Applications
Land transport	Location tracking
Maritime	Inspection and maintenance
	Cargo shipping
	Weather and meteorological data
	Material performance
Aeronautical	Weather data
	Meter reading
	Passenger notification
Oil & Gas	Pipeline monitoring
	Meter reading
	Real time tracking for tankers and logistics, incl. regulatory monitoring
Civil government	Environmental meter reading and climate change analysis
	Logistics departments
Connected car	Vehicles diagnostics (consumer vehicles)
	Maintenance (consumer vehicles)
Agriculture	Fishery management
	Environment monitoring
	Yield forecasting
Mining	Meter reading
Construction	Meter reading
	Employee tracking
Green energy	Diagnostic tracking
	Usage tracking
	Flow monitoring
Utilities	Monitoring systems

Source: Applications sourced from NSR (2016).

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						Low bandwidth, high latency

6.2.11 Use case 11: Video

This use case captures all those civil, military, consumer and commercial applications that transmit video messages between devices.

Table 15 Video

Vertical segment	Applications
Security and surveillance	CCTV cameras
Utilities	Video monitoring

Source: Applications sourced from NSR (2016).

The size of video messages which are continuously transmitted mean that applications in this use case require **wide bandwidth**. Since these video transmissions are usually used to support security and surveillance operations, these transmissions must occur in real or near time (**low latency**), with **high security & reliability**, and in the vast majority of instances (i.e. **very high availability**). Since video monitoring, in vast majority of instances, takes place around fixed installations, they are usually **powered by an external power supply** and therefore do not face the same power restrictions as most other IoT/M2M applications.

- A network that can support communication with fixed devices;
- A network that provides regional or global coverage;
- A network that can support a very large number of connections;
- A network with very high availability;
- Low tolerance for latency;
- A need for wide band transmission, and
- A high need for secure and reliable transmission of data.

In quantitative terms, these user requirements are as follows:

Bandwidth	Latency	Availability	Mobility	Security & resilience	Power	Classification
This section contains additional sensitive information that has been redacted for public dissemination.						High bandwidth, ultra-low latency

6.3 Summary of user requirements by use case

<table>
<tr><th>User group</th><th>Bandwidth</th><th>Low latency</th><th>Availability</th><th>Mobility</th><th>Security & resilience</th><th>Power</th><th>Classification</th></tr>
<tr><td>Mobile internet & entertainment</td><td rowspan="13" colspan="6">This section contains additional sensitive information that has been redacted for public dissemination.</td><td rowspan="5">High bandwidth, ultra-low latency</td></tr>
<tr><td>Backhaul</td></tr>
<tr><td>Video</td></tr>
<tr><td>Command & control</td></tr>
<tr><td>Mobile telephony</td></tr>
<tr><td>Mission critical telemetry</td><td>Low bandwidth, ultra-low latency</td></tr>
<tr><td>Mobile safety, security & emergency</td><td>Low bandwidth, low latency</td></tr>
<tr><td>Telematics / analytics (critical)</td><td rowspan="3">Low bandwidth, moderate latency</td></tr>
<tr><td>Fixed safety, security & emergency</td></tr>
<tr><td>Asset tracking (critical)</td></tr>
<tr><td>Telematics / analytics (non-critical)</td><td rowspan="3">Low bandwidth, high latency</td></tr>
<tr><td>Telemetry</td></tr>
<tr><td>Asset tracking (non-critical)</td></tr>
</table>

Source: London Economics analysis

6.4 IoT/M2M device survey

The requirements of different applications – in terms of latency, throughput, mobility, power constrains etc. – are enabled by the capabilities of IoT/M2M devices which receive and transmit satellite communication signals. Given limitations on the detail of the specific requirements of individual applications, a review of the **capabilities** offered by different satellite-enabled IoT/M2M devices can serve as a useful proxy for application requirements.

For this reason, a survey of **23 satellite-enabled IoT/M2M devices** was conducted which covered the major device manufacturers, such as Orbcomm, Globalstar, Iridium, and Thuraya. While available technical information was very patchy across manufacturers and devices (and should therefore be treated with caution), and the use cases of these devices heavily biased towards asset tracking, this survey provided some useful findings:

- **Frequency:** 11 out of the 12 devices with information on frequency operate within the **L-band**. More specifically, within the **1518.0–1626.5 MHz range** (with Rx at the bottom-end of this range and Tx towards the top of this range).
- **Data transmission:** of the 23 devices surveyed, only 8 provided details on the device's type data transmission. Half of this (4) declared both **duplex and multiplex capability**, while the remaining half (4) declared **only simplex capability**. Those devices which declared duplex capability (4) used the **time-division duplexing** (TDD) channel access scheme. All devices which declared multiplex capability (4) used both the **time-division multiple access** (TDMA) and **frequency-division multiple access** (FMA) channel access scheme.
- **Latency and throughput:** of the 23 devices surveys, latency information was provided for 11 of these. Using this information, it was possible to derive throughput, which ranged from **6.4 bps to 50 bps** for packet sizes of between **9b and 1Kb**.
- **Required power input:** of the 23 devices survey, power input information was provided for 17 of these. Required power input varied **between 3.2v and 55v**, though most devices had power input requirements which were concentrated within the **middle** of this range.

Details of these findings at the device-level are provided in **Annex 1.**

7 Key design considerations

7.1 Constellation size and integration with GEO and terrestrial

At LEO altitudes, the choice of constellation size will represent a trade-off between:

- The need to ensure **continuous and low-latency provision** on the one hand, particularly for the most mission-critical and latency-intolerant applications, and
- A **low-cost service** on the other, to ensure capture of the most cost-sensitive applications with relatively tolerant requirements.

For example, at LEO altitudes, the number of satellites that are required to ensure global continuous coverage and therefore lower latency as a result of higher satellite visibility[26] is large, even with a

[26] CEPT Electronic Communications Committee (2017). *Report on M2M via satellite.* 87th Meeting, Luxembourg, 30th January – 3rd February 2017. Working Group Frequency Management. Available at: https://cept.org/ecc/groups/ecc/wg-fm/client/meeting-documents/

constellation designed to work at low elevation angles. For example, the Iridium constellation – which operates at an orbit of 780km and a service coverage defined at 8˚of ground elevation angles – still requires 66 satellites to ensure continuous coverage[27].

The costs associated with the manufacture, launch and operation of such a large number of satellites may make it impossible to deliver a competitively priced service for some of the more price-sensitive use cases. A reduction in the number of satellites would make it possible to reduce service costs, but it would mean that global continuous coverage and therefore adequate service provision for the most demanding use cases would be lost. With discontinuous coverage, this low cost development option should also include a downlink to ensure that that IoT/M2M device information is only transmitted when the satellite is visible to the device (see 7.3 below). A case study of such a low-cost LEO constellation with discontinuous coverage is presented in Box 3 below.

Box 3 Case study: Satellite M2M system for low-end devices

The authors propose a single LEO satellite constellation to provide discontinuous coverage for delay-tolerant applications in order to reduce capital expenditure and minimise the cost of the service. The advantages of this approach are its favourable link budget and shadowing diversity, as well as its capacity to scale as traffic volume increases. To minimise propagation loss, the modelled system aims to deliver signals at low frequency (L or S band). In this way, the authors show that the system is able to support the following parameters:

- **Datagram (packet size):** 10-100 bytes
- **Data rate:** 10-100 Kbps
- **Transmission power:** 20 dBm

Source: Cocco, G., Ibars, C., (2012). On the Feasibility of Satellite M2M Systems. Available at: https://www.researchgate.net/publication/257948749_On_the_Feasibility_of_Satellite_M2M_Systems

An **integrated LEO-GEO constellation for IoT/M2M could represent a potential solution**, combining the lower latency and flexibility/scalability of LEO small satellites with the high-capacity and wide-coverage of existing GEO constellations. By utilising existing satellite infrastructure, this solution could ensure continuous and demand-responsive low-latency provision at a reduced capital expenditure and higher resilience.

However, the viability of this integrated system would depend on the extent to which it could guarantee the end-to-end delivery of data packets at a required latency, data rate, and quality of service for a large and diverse range of applications. This would require a system that could: i) optimise the routing of data packets across the different components of the networks (e.g. so that an application is routing via LEO when it requires low latency, and GEO when it wishes to transmit a large volume of data at any time), and ii) in a way that minimises the cost of service for each application. In technical terms, **the integrated system requires dynamic routing** to allocate the system's latency, data, and coverage to applications depending on user demand and priority (determined on the basis of variable subscription charges, for example).

Dynamic routing would nevertheless raise the cost and complexity of user device terminals, given the need to receive potentially multiple-frequencies transmitted by the integrated satellite

[27] CEPT Electronic Communications Committee (2017). *Report on M2M via satellite.* 87th Meeting, Luxembourg, 30th January – 3rd February 2017. Working Group Frequency Management. Available at: https://cept.org/ecc/groups/ecc/wg-fm/client/meeting-documents/

constellation, and could introduce additional complexity to the satellite payloads. By lowering the competitiveness of satellite technologies to both user device manufacturers and service users, these **cost increases could offset the advantages of satellite** for some of the more price-sensitive applications, particularly in the mass market. Software Defined Radios (as detailed in Box 1) could therefore play an important role in supporting the inoperability and dynamic routing of the constellation in a more cost-effective manner[28]. Even so, the implications of any satellite system design on the user device costs, and the capital and operating costs of the system should be explored in more detail as part of any follow-up to this study.

The integrated system and dynamic routing concept could also extend to a satellite-terrestrial concept, with 5G providing the system's high-capacity terrestrial backbone in the future[29,30]. By providing scalability through multi-cast, and instantaneous connectivity, the addition of satellites to 5G could support four distinct use cases: trunking and head-end feed; backhauling and tower feed; communications on the move, and hybrid multi-play[31]. In addition, small LEO satellites could be used to extend coverage and capacity as demand requires, particularly as a 'stop-gap' option in regions ahead of terrestrial roll-out, and provide resilience[32].

At this stage, there is insufficient market information (i.e. about market size and price points) at the use case level to draw any conclusions about the commercial viability of any of these development options. Along with technical viability, this should be explored further in any follow-on work.

7.2 Frequency

The choice of frequency band for satellite communications depends on a number of different factors. The factors reflect: the data and latency requirements of applications; the cost of user devices; the capacity of the constellation; and any constraints imposed by the regulation of spectrum, given the scarcity of unassigned frequency bands. The choice of frequency band will therefore be a compromise between these factors[33].

Figure 10 below provides an overview of the different frequency bands and their relative strengths and weaknesses.

Historically, most small satellites (particularly CubeSats) operated in the UHF bands (running approximately 9.6 Kbps) and have – given the limited amount of UHF spectrum available[34] – been growing into the S band and X band, and now the Ka band – something that was previously prohibitive for most satellites, given the greater technological difficulty associated with placing a higher frequency band payload on a small satellite.

[28] Miao, Y., Cheng, Z., Li, W., Ma, H., Liu, X., Chui, Z., (2017). *Software Defined Integrated Satellite-Terrestrial Network: A Survey.* Available here: https://www.researchgate.net/publication/315859422_Software_Defined_Integrated_Satellite-Terrestrial_Network_A_Survey

[29] Please see: *ESA (2016). 5G Integrated satellite terrestrial M2M/IoT networks.* 5G PPP 1st 5G Architecture Workshop. Available here: https://5g-ppp.eu/wp-content/uploads/2016/03/5G_ESA_M2M-presentation-Apr2016_ffsc.pdf

[30] Sigfox (2017). *Is satellite a relevant complement for terrestrial massive IoT?* Available here: http://www.ictspring.com/wp-content/uploads/2017/05/15h40-Christophe-Fourtet-Sigfox.pdf

[31] CEPT Electronic Communications Committee (2017). *What satellite solutions can bring to 5G.* Cascais, Portugal, 16th-20th January. Available at: https://cept.org/Documents/ecc-pt1/34246/ecc-pt1-17-037_what-satellite-solutions-can-bring-to-5g

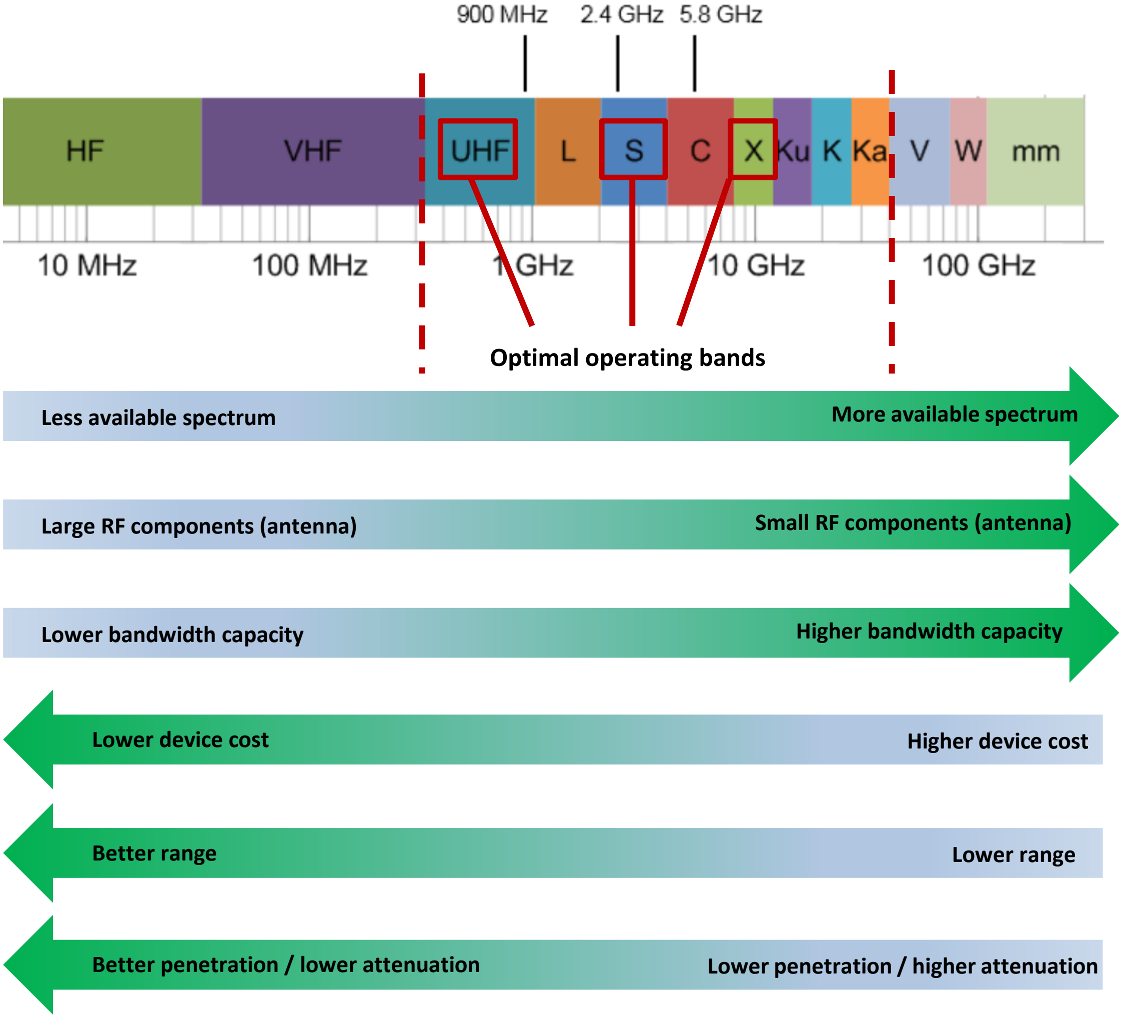
[32] Evans, B., Onireti, O., Spathopoulos, T., Imran, M., (2015*). The role of satellites in 5G.* 23rd European Signal Processing Conference. Available here: https://www.eurasip.org/Proceedings/Eusipco/Eusipco2015/papers/1570100777.pdf

[33] Dixon, J., Politis, C., Wijting, C., (2008). *Considerations in the Choice of Suitable Spectrum for Mobile Communications.* Available at: http://www.wwrf.ch/files/wwrf/content/files/publications/outlook/Outlook2.pdf

[34] Elstak, J., Speretta, S., Bonnema, A., Rotteveel, J. (2012) *Nanosatellite communication system trends.* Available at: https://www.researchgate.net/publication/280494093_Nanosatellite_communication_system_trends

The higher frequency bands promise: i) more throughout – up to several hundred Mbps or even Gbps in the future given continued R&D; ii) more spectrum; iii) smaller device terminals, and potentially iv) greater resilience to interference[35]. However, this requires **more expensive device components which could destroy the viability of satellite** for some of the most price-sensitive applications. For this reason, choosing a satellite frequency that is adjacent to the frequency bands of terrestrial applications – such as LPWAN – may be particularly attractive, as detailed in 7.2.1 below.

Figure 10 Overview of frequency bands and suitability for satellite addressable IoT/M2M



Note: Example of common ISM bands within the IEEE frequency band chart.

Source: LE analysis and annotation based on stakeholder interviews and Dixon, J., Politis, C., Wijting, C., (2008). Considerations in the Choice of Suitable Spectrum for Mobile Communications. Available at: http://www.wwrf.ch/files/wwrf/content/files/publications/outlook/Outlook2.pdf
Frequency diagram sourced from Southwest Antennas, Inc. (2016). Modern Co-Site RF Interference Issues and Mitigation Techniques. Based on "Frequency Band Comparison" by Treinkvist. Please see: https://southwestantennas.com/sites/default/files/white-paper/Whitepaper_Modern-Co-Site-Interference-Mitigation-Techniques_Southwest-Antennas.pdf

[35] Leong, S.C., Sun, R., Yip, P.H. (2015). *Ka band satellite constellations design analysis and optimisation.* DSTA Horizons. Available at: https://www.dsta.gov.sg/docs/default-source/dsta-about/ka-band-satellite-communications-design-analysis-and-optimisation.pdf?sfvrsn=2

7.2.1 Interoperability between satellite and terrestrial

As discussed in 4.1, one of the most important value propositions for small satellites is its potential to provide **ubiquitous coverage** for IoT/M2M devices. This is particularly important for devices that operate in remote areas or are dispersed over a wide geographical area. However, this ubiquitous coverage may not be accessible to all relevant IoT/M2M applications – characterised as they are by relatively low price points – because of the **potentially high cost of dedicated satellite device terminals** for end users. Even in the long-run, these dedicated terminals are not expected to achieve mass-market economies of scale because of the relatively small volume of these devices.

For this reason, the **combination of ubiquitous and affordable coverage may only be achieved by ensuring the interoperability** of the same IoT/M2M device through either satellite or terrestrial networks[36]. In this instance, the existing low-cost terminal for terrestrial connectivity is also sufficient for satellite connectivity. This interoperability in turn **relies on the satellite for IoT/M2M utilising the same or adjacent frequencies as terrestrial infrastructure**. Satellite communications for IoT/M2M represent a particular complement to Low Power Wide Area (LPWAN) networks, given their low power and low data requirements. This would suggest a need for a satellite service that can operate within the 862-870 MHz (UHF) frequency band. Analysis by the CEPT[37] suggests that this particular frequency band is feasible from both a technical (need for non-interference) and regulatory (availability of spectrum allocation) perspective. However, interference may occur if both satellite and terrestrial networks operate in the same frequency in some geographies. The satellite must therefore be able to coordinate with terrestrial networks in these situations.

Operation at this particular frequency band has implications for a number of other satellite parameters, including:

- **Antennas:** By operating at UHF frequencies, the LEO satellites can use existing UHF antenna technologies – e.g. crossed-dipole/canted turnstile antennas and Software Defined Radios – that are already designed for small/CubeSat applications. The low operating frequency means less path loss between the low-gain antennas on the satellite and the IoT/M2M devices. For example, Karim et al. (2014)[38] show that a low data rate of 2Kbps can be achieved with low-gain turnstile antennas with nearly 6 dB margin down to the 20˚ elevation angle.
- **Power:** To achieve 2Kbps with above characteristics, Karim et al. (2014) also show that this would require a transmission power of 1.4 W.
- **Channel access schemes:** The heterogeneity of potential IoT/M2M devices that will use the satellite network means that data traffic will be extremely variable. There is therefore a need to choose a multiple access scheme that can efficiently use satellite resource according to the data traffic and type of access that is required. When energy efficiency is very important, time-division multiple access (TDMA) is a suitable multiple access scheme. However, for other applications – particularly those with a large number of nodes and intermittent data transmission – other channel access schemes may be more useful[39].

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[36] CEPT Electronic Communications Committee (2017). Report on M2M via satellite. 87th Meeting, Luxembourg, 30th January – 3rd February 2017. Working Group Frequency Management. Available at: https://cept.org/ecc/groups/ecc/wg-fm/client/meeting-documents/

[37] CEPT Electronic Communications Committee (2017). Report on M2M via satellite. 87th Meeting, Luxembourg, 30th January – 3rd February 2017. Working Group Frequency Management. Available at: https://cept.org/ecc/groups/ecc/wg-fm/client/meeting-documents/

[38] Karim, S., Rogers, A., Birrane, J., (2013). *Bridging the Information Divide: Offering Global Access to Digital Content with a Disruptive CubeSat Constellation.* 28th Annual AIAA/USU Conference on Small Satellites.

[39] Cianca, E., Bisio, I., Araniti, G., Prasad. R., (2015). *Satellite Communications Supporting Internet of Remote Things.*

- **Routing and switching:** To ensure seamless interoperability with terrestrial networks – particularly within an integrated LEO-GEO or satellite-terrestrial network as detailed in 7.1 – satellites will need to support full duplex and have routing and switching capabilities[40].

7.3 Need for downlink

A space-to-Earth downlink from the satellite may be required to collect information from IoT/M2M devices so that the devices are aware of the satellite's presence. This is potentially a critical requirement for IoT/M2M for at least three reasons[41]:

- Downlink information can be used to synchronise and coordinate devices, which can help to optimise the capacity of the satellite network, particularly for a low-cost constellation that provides discontinuous coverage;
- Specific use cases (e.g. command & control) require it. A downlink therefore increases the potential addressable market for satellite, and
- Information about the satellite's location can be used to ensure that devices are not needlessly transmitting data and therefore using power. This can extend the battery life of IoT/M2M devices.

7.4 Dynamic bandwidth allocation

Some of the most stringent applications, particularly those with high security and reliability requirements, require a minimum level of signal quality of service (QoS) in all conditions. Rain, for example, can attenuate satellite signals, weakening the performance of the entire system.

To compensate for the resulting increase in signal-to-noise ratio (SNR) and the loss of spectral efficiency, satellites can implement an ACM mechanism. This ACM can be used to maintain QoS in these variable conditions by modifying the Modulation and Coding Scheme (MCS), based on feedback from the IoT/M2M devices[42]. The increase in signal robustness, however, may require more power and higher bandwidth, thereby lowering the capacity of the entire system as more redundancy is required. Bandwidth allocation therefore represents a compromise between robustness and other satellite and signal parameters, such as capacity and battery life[43].

8 The value proposition for small satellites

As detailed in 3.3 and 4.1, connecting IoT/M2M devices via satellites faces several challenges. These are driven largely by the high cost (of user device modules) and high power consumption (and by corollary, the capacity and lifetime) characteristics of existing satellite telecommunication

[40] SatellitePro (2017). *March 2017 Issue*. Available at: https://issuu.com/satelliteprome/docs/satellite_pro_march_2017/16

[41] CEPT Electronic Communications Committee (2017). *Report on M2M via satellite.* 87th Meeting, Luxembourg, 30th January – 3rd February 2017. Working Group Frequency Management. Available at: https://cept.org/ecc/groups/ecc/wg-fm/client/meeting-documents/

[42] Niephaus, C., Kretschmer, M., Ghinea, G. (2016). *QoS Provisioning in Converged Satellite and Terrestrial Networks: A Survey of the State-of-the-Art.* IEEE Communications Surveys & Tutorials, Vol 18, Issue 4.

[43] Cianca, E., Bisio, I., Araniti, G., Prasad. R., (2015). *Satellite Communications Supporting Internet of Remote Things.*

platforms. Scalability is also an issue as existing platforms are not designed to support hundreds of millions of direct connections[44].

For these reasons, existing satellite platforms for IoT/M2M connectivity is not suitable for the vast bulk of applications that require:

- Very low-end device costs;
- Very low latency;
- Low power consumption; and/or
- Low maintenance costs.

Small and nanosatellites can play an important role in overcoming some of these challenges. This is because **small and nanosatellites are small, lightweight (<180kg) and relatively low cost** when compared to larger more traditional systems[45]. **CubeSats** represent a subset of small satellites of between 1-10kgs (nanosatellites) that build on these strengths by leveraging standard form factor and commercial off-the-shelf (COTS) technology. Being in Low Earth Orbit (LEO), a sufficient constellation of small satellites can also reduce the battery loss, latency and attenuated signal problems that are often associated with satellites in Geosynchronous Orbit (GEO), given that they are in a lower-radius orbit and face lower propagation delays and shadow path loss[46].

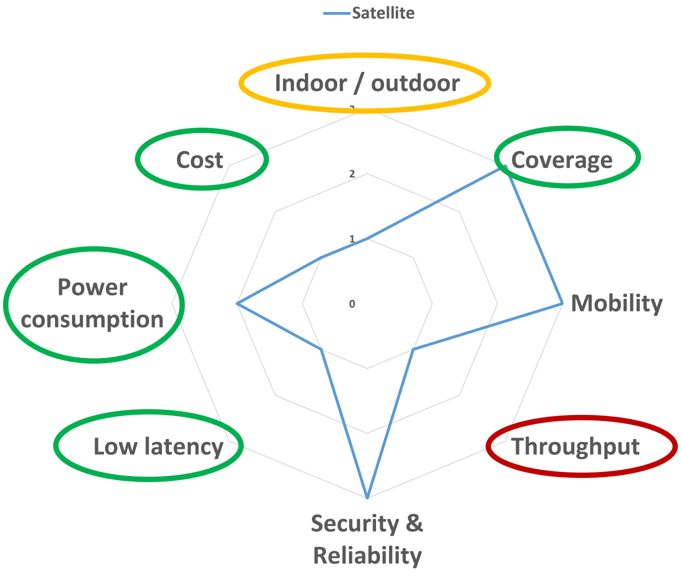
By addressing cost and power needs, existing small satellite technologies – and CubeSats in particular – could extend the capabilities of satellites, and therefore their potential addressable market IoT/M2M, as demonstrated in Figure 11 below.

Similarly, a large enough constellation of small LEO satellites can take advantage of LEO satellites' closer proximity to the Earth's surface and offset the increased latency that may be incurred by their potentially discontinuous coverage[47]. This of course assumes that these advantages are not in turn offset by the high user costs that would be needed to support such a large constellation. While this development represents a potential improvement on existing satellite capabilities, terrestrial technologies will always offer latency that is fundamentally better than satellites. Similarly, improvements to increased indoor penetration require R&D that can deliver this at the lowest possible increase in power consumption. For these reasons, **the competitiveness of small satellites for IoT/M2M may depend on its integration with existing satellite and/or terrestrial infrastructure as part of a single end-to-end solution**, as discussed in 7.1.

Beyond this, **the fundamental business case for small satellites for the IoT/M2M market depends on the extent to which a satellite service offer can minimise user devices costs** (e.g. through the appropriate choice of radio frequency, as detailed in 7.2.1).

44 IoT UK. (2017). *Satellite Technologies for IoT Applications*, March 2017.
45 For details, please see: https://www.nasa.gov/content/what-are-smallsats-and-cubesats
46 Cocco, G., Ibars, I., (2012). *On the feasibility of Satellite M2M Systems;* Conference Paper, September 2012. Available at: https://www.researchgate.net/publication/257948749_On_the_Feasibility_of_Satellite_M2M_Systems
47 Please see: http://www.intelsat.com/news/blog/leo-constellations-what-you-need-to-know/

Figure 11 Potential capability improvements offered by small satellite



Legend

- Requirements that can be partially addressed by small satellites now
- Requirements that can be partially addressed with further development of small satellites
- Requirements that cannot be addressed with small satellites

Source: London Economics analysis

Index of Tables, Figures and Boxes

Tables

Figures

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ANNEXES

Annex 1 User device survey

Manufacturer	Device	Use case	Dimensions	Weight	Duplex	Multiplex	Frequency (transmit & receive)	Protocol	Required power input	Latency
Globalstar	SmartOne C	Asset tracking	6.9 x 8.2 x 2.5 mm	102g	-	-	-	-	5v, 8-22v	-
Adaptive technologies	GT-IRDM-9603	Mobile telephony		-	-	-	1616 - 1626.5 MHz	-	6-55v	-
Iridium	9522b	Telemetry; asset tracking	16.2 x 5.5 x 2.8 mm	420g	TDD	TDMA / FDMA	1616 - 1626.5 MHz	-	4-32v	-
Iridium	9523	Mobile telephony	70.44 x 36.94 x 14.66 mm	32g	TDD	TDMA / FDMA	1616 - 1626.5 MHz	-	27v	-
Iridium	9602N transceiver	Asset tracking	41 x 45 x 13 mm	30g	TDD	TDMA / FDMA	1616 - 1626.5 MHz	-	-	-
Iridium	9602	Asset tracking	41 x 45 x 13 mm	-	-	-	-	-	5v	<20s per 340b
Iridium	9603	Asset tracking	31.5 x 29.6 x 8.1	-	-	-	-	-	5v	<20s per 340b
Iridium	Core 9523	-	70.44 x 36.04 x 8.9 mm	-	-	-	-	-	3.2v	<45s per 1kb
Iridium	9522B	-	162 x 81 x 28 mm	-	-	-	-	-	4-32v dc	<45s per 1kb
Iridium	Edge	Asset tracking	130 x 80 x 30 mm	-	-	-	-	-	9-32v	<20sper 340b
Numerex	SX1	Asset tracking	184 x 83 x 25 mm	369g	-	-	1622.35 - 1618.75 MHz	Simplex	-	1.4s per 9b
	Flex 2	Asset tracking	99 x 83 x 51 mm	397g	-	-	1622.35 - 1618.75 MHz	Simplex	-	1.4s per 9b
Orbcomm	GT 700	Asset tracking; Mobile safety, security & emergency	127 x 71 x 21 mm	212g	-	-	-	Simplex	-	-
Orbcomm	IDP 600	Asset tracking	126 x 126 x 10.1 mm	-	-	-	Rx: 1525.0 - 1559.9 MHz & Tx: 1626.5 - 1660.5 MHz	-	12v	<15s per 100b

Orbcomm	IDP 800	Asset tracking	432 x 147 x 25 mm	1300g	-	-	Rx: 1525.0 - 1559.9 MHz & Tx: 1626.5 - 1660.5 MHz	-	9-32v	<15s per 100b
Orbcomm	OG2	-	40 x 70 x 10.5 mm	-	-	-	-	-	2.8-15v dc	-
Orbcomm	OGi	-	40 x 70 x 10.5 mm	-	-	-	-	-	5-15v dc	-
RigNet	IsatData Pro	Asset tracking; telemetry; Mobile safety, security & emergency	126 x 126 x 47 mm	460g	-	-	Rx: 1525.0 - 1559.9 MHz & Tx: 1626.5 - 1660.5 MHz	-	9-48v dc	<15s per 100b
Satixfy	Sx-3000 ASIC	-	220 mm diameter	1200g	-	-	Ku or Ka band	-	-	-
SkyBitz	Cargo sensor	Asset tracking	127 x 152.4 x 63.5 mm	454g	-	-	-	-	3.6v	-
SkyBitz	GLS9602 Modem	Asset tracking	41 x 45 x 13 mm	3g	TDD	TDMA / FDMA	1616 - 1626.5 MHz	-	-	-
Globalstar	SmartOne LP	Asset tracking	8.3 x 16.5 x 2.5 mm	385g	-	-	-	Simplex	48v	-
Thuraya / ViaSat	FT2225	Mission critical telemetry	178 x 130 x 42 mm	<900g	-	-	Rx: 1518.0 - 1559.0 MHz & Tx: 1626.5 - 1675.0 MHz	-	10-32v dc	<2s per 100b

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