Final report

Dedicating 28GHz spectrum band to satellite services

An economic cost-benefit analysis for Africa

Network Strategies Report Number 41024.
5 May 2022

www.strategies.nzl.com

NETWORK STRATEGIES

Executive summary

The 28GHz spectrum band (27.5-29.5GHz) is widely used by satellite operators to provide global fixed and mobile satellite broadband services. With the advent of IMT-2020 5G radio technologies, mobile operators are seeking spectrum to meet new technical requirements (including niche applications in mmWave). While the 26GHz band has been globally identified for 5G IMT by the ITU (WRC-19), the 28GHz band has been preserved for satellite services on a global basis by the ITU (WRC-15, WRC-19). Deviating from the globally agreed spectrum allocations by wholly or partially repurposing the 28GHz band for 5G may present adverse impacts (technical and economic), as countries seek to expand ubiquitous broadband access across land, sea and air with investments in Ultra High Throughput Satellites (HTS).

Economic benefits of 5G in mmWave are likely to be representative of the use cases that require localised high-capacity coverage. Few, if any, benefits of 5G mmWave are expected in underserved or unserved areas. This has significant implications for governments seeking to encourage economic growth in some targeted areas or to reduce the digital divide between communities. For Africa this issue is crucial as about 55% of its total 1.37 billion inhabitants live outside densely populated areas. This study examines the socio-economic case for maintaining the 28GHz spectrum band for satellite services only.

Satellite is the most cost-effective option to address many universal coverage issues

Satellite provides links for mobile and broadband services, and access and satellite-powered connectivity for broadband services in underserved / unserved areas where populations do not have access to the same level of broadband available in urban areas.

Satellite is an affordable option for unserved and underserved communities

Our scenario analysis of a hypothetical African operator found that satellite is more cost-effective than 5G for providing access and backhaul in underserved / unserved areas, with:

- satellite-powered links instead of terrestrial microwave for mobile and broadband services
- access and backhaul for broadband services.

As these underserved / unserved areas are population clusters with lower density (around 50 inhabitants per square kilometre) located more than 70km from the closest urban centre or traffic aggregation node, the scenarios are relevant for most unserved and underserved communities in Africa.

A large proportion of the African mobile broadband coverage gap can only be addressed by satellite

The African continent has a large coverage gap of about 300 million people, representing about 22% of the total population. Countries with significant unserved populations include Nigeria, the Democratic Republic of Congo (DRC), Sudan, Tanzania, Niger, Ethiopia and Mozambique. These countries have large populations beyond urban areas with many communities located in difficult topography where it is economically unviable to lay terrestrial infrastructure. Assuming a gradual mobile coverage increase over a ten-year period into these unserved communities, we estimate that the demand will exceed 500Gbit/s by 2026 and exceed 4Tbit/s by 2031.

Satellite is the only option for enabling high-speed broadband applications for key global transportation sectors in urban and beyond urban areas

There is an increasing demand for high-speed connectivity for aviation and maritime. Implementation of data-centric applications is becoming a necessity in these sectors, as the industries seek to reduce costs through improved efficiency, increase revenues, comply with environmental targets and improve safety. The importance of FSS ESIM (Earth Stations in Motion) is a notable example where uninterrupted, ubiquitous and 'always-on' broadband is powering aircraft (gate-to-gate) and vessels (pier-to-pier) with seamless connectivity across the busiest airports and ports.

For example, our estimate of the potential direct benefits that could be achieved by shipping companies through high-speed broadband enabled applications on vessels, using a sample of 24 major global shipping companies, is between USD7.4 billion and USD11.6 billion for 2021-2025. Assuming cruise passengers return to pre-COVID-19 levels by 2022 and cruise ship operators ensure that their vessels have the capability for delivering broadband access, potential broadband-enabled revenues could reach USD2 billion by 2024. Global revenues for aviation satellite communications were USD527 million in 2019.

Satellite offers a future-proof solution for connectivity beyond urban areas

Terrestrial microwave links used beyond urban areas typically use frequencies in the range of 5-42GHz as these can support distances between 5-60km. However, these frequencies do not have sufficient capacity to meet the expected throughput of 5G cell sites and consumer data growth. As such, many communities in the African region will be left behind with limited network performance due to the terrestrial microwave bottleneck.

Satellite use case for 28GHz spectrum has high economic value

When re-planning spectrum bands international best practice is to examine alternative uses to identify which use maximises the value of that spectrum. The 28GHz spectrum band is currently assigned to satellite services, providing connectivity to ESIM applications and users without, or with insufficient, access to terrestrial services, particularly high-speed broadband services. These users could be in urban and beyond urban areas, on ships or in the air, and without satellite services utilising 28GHz the options for high-speed broadband are limited. Assessing the economic value of 28GHz for 5G must take into account the loss of value associated with removal of the arrangements for satellite services. This loss in value may have implications for national policy objectives as well as efforts to improve global trade. It therefore follows that the similar 26GHz band would have a higher value for 5G services than 28GHz, as it will cause no disruption to current and planned Ka-band satellite services which provide the highest capacity and performance in comparison to lower satellite bands (i.e. L-band, C-band and Ku-band).

Satellite plays a critical role in exploiting the potential of 5G

- Providing supplementary capacity to terrestrial networks to offload traffic in peak traffic times
- Carrying multicast traffic and caching of content on edge servers
- Providing satellite broadband connectivity to moving platforms such as vessels, trains and airplanes and temporary disaster recovery networks.

Dedicating 28GHz spectrum band to satellite services

Final report

Contents

Executive summary i

1 Introduction 1

2 Satellite: extending connectivity to the unserved and underserved 3
2.1 Demand for satellite broadband: current status 3
2.2 Connectivity for moving platforms across urban areas and beyond 11
2.3 Solutions to terrestrial network bottlenecks 14
2.4 Provision of multicast and edge caching 20

3 Beyond the reach of 5G mmWave access 23
3.1 5G mmWave: winners and losers 23
3.2 Connectivity in the sky 27
3.3 Connectivity on the seas 32

4 Assessment of cost-effectiveness of satellite 39
4.1 Model overview 39
4.2 Model results 41
4.3 Results summary 42

5 Concluding remarks 43

Annex A: Model approach, inputs and assumptions A1

NETWORK STRATEGIES

1 Introduction

The 28GHz spectrum band (27.5-29.5GHz) is widely used by satellite operators to provide global fixed and mobile satellite broadband services. There are already over 120 Ka-band satellite systems in service, with many more currently under development.

With the advent of IMT-2020 5G radio technologies policy-makers and regulators are facing considerable pressure from terrestrial mobile operators to refarm and repurpose spectrum to meet new technical requirements (including mmWave). To meet these requirements the 26GHz band has been a key focus of mobile operators. Despite an international commitment at WRC-15 to the critical role of satellite in the 28GHz band, it appears that in some cases the 28GHz band is under consideration for either partially or wholly repurposing for 5G.

This study examines the costs and benefits of maintaining the 28GHz spectrum band for satellite services only. While there are many studies on 5G mmWave there is little available on the economic benefits of the allocation of 28GHz spectrum for satellite.

Our assessment considers three issues:

- the use of satellite as a 5G enabler (Section 2)
- comparative demand for satellite versus 5G mmWave (Section 3)
- the cost-effectiveness of satellite (Section 4).

Our conclusions are presented in Section 5.

2 Satellite: extending connectivity to the unserved and underserved

Use cases of satellite connectivity within a 5G context include:

- offering a cost-effective solution for addressing many universal coverage issues
- introducing an affordable option for underserved and unserved communities
- addressing a large proportion of the African mobile broadband coverage gap
- providing supplementary capacity to terrestrial networks to offload traffic in peak traffic times
- carrying multicast traffic and caching of content on edge servers
- providing satellite broadband connectivity to moving platforms such as vessels, trains and airplanes and temporary disaster recovery networks.

5G infrastructure is envisioned to be an ecosystem of networks that serves applications with differing requirements and using multiple complementary technologies. As such, many regional and international organisations, including 3GPP and the European Commission, recognise the importance of an integrated satellite and terrestrial infrastructure in the 5G ecosystem.[1] The satellite industry can play a critical role in providing universal coverage and supplementing terrestrial capacity.

2.1 Demand for satellite broadband: current status

Satellite backhaul continues to play an important role for mobile operators, especially in emerging markets with challenging geographies and poor terrestrial infrastructure. As at September 2018, GSMA reports that 1.9% of global backhaul connections are satellite based. While the proportion of satellite backhaul links is predicted to fall to 1.4% by 2025, the total number of satellite backhaul links is expected to increase, however, with a lower rate than

1 3GPP (2016), *Technical Specification Group Services and System Aspects; Feasibility Study on New Services and Markets Technology Enablers*, technical report, 3GPP TR 22.891, 3GPP, 2016.

that of fixed microwave and fibre links.[2] In Sub-Saharan Africa (SSA) and the Middle East and North Africa (MENA) satellite backhaul will constitute about 3% of backhaul links in SSA and MENA by 2025 (Exhibit 2.1). This corresponds to a total of 70,000-80,000 satellite backhaul links in the region.

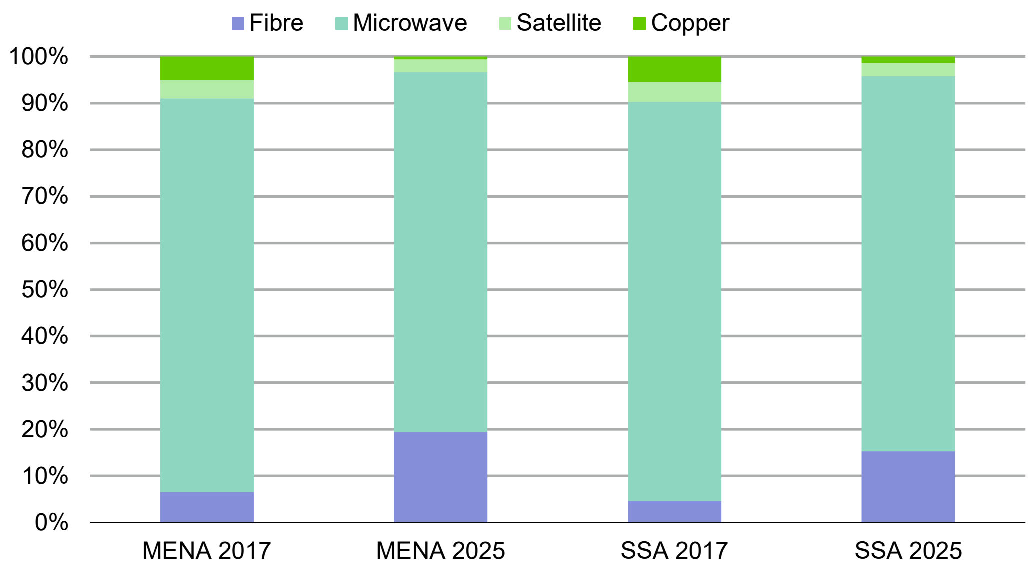


Exhibit 2.1: *Mobile backhaul by technology in Sub-Saharan Africa and the Middle East and North Africa [Source: GSMA]*

More than half (55%) of the 1.37 billion Africans live beyond urban areas.[3] Mobile operators face many topographical challenges such as connecting communities in isolated mountain villages, dense equatorial forests or remote desert areas. In many of these cases, laying terrestrial backhaul infrastructure is extremely impracticable considering the small user populations.

2 GSMA (2018), *Mobile backhaul options: Spectrum analysis and recommendations.* GSMA, September 2018.

3 World Bank (2020), *Data.* Available at https://data.worldbank.org/country.

EGYPT: REACHING REMOTE COMMUNITIES

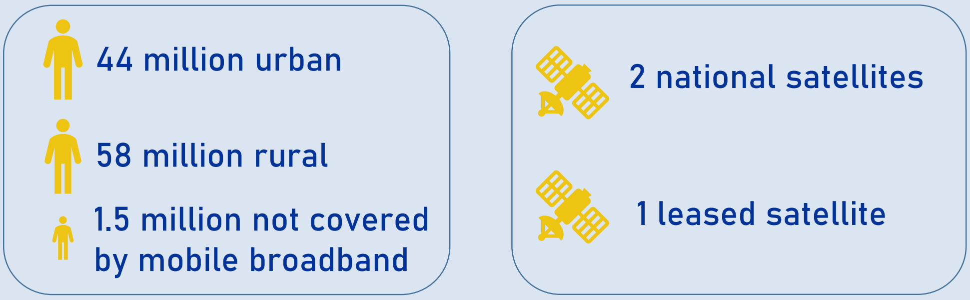


Exhibit 2.2: *Egypt: satellite use and demand [Source: Network Strategies]*

Topography and demographics

Egypt has a population of about 102 million, including a population outside urban areas of 58 million. About 95% of the 102 km^2 land area is desert. While most of the population live along the Nile, the country has many remote communities in the Western Sahara and Sinai Peninsula. About 1.5 million citizens have no access to mobile broadband.[4] Egypt has also a flourishing oil and gas industry that is located in isolated desert areas or offshore where terrestrial communications infrastructure is virtually non-existent.

4 GSMA (2020), *Mobile Connectivity Index*. Available at https://www.mobileconnectivityindex.com/.

Satellite services

Egypt introduced its first satellite company, Nilesat, in 1996. The company currently leases capacity from Eutelsat 8 West B (named Nilesat 104B) and owns one GEO satellite, Nilesat 201, which provides TV and radio broadcasting and high-speed data transmission. Nilesat 201 carries 24 Ku band (12-18GHz) and 4 Ka band (26.5-40GHz) transponders, with a footprint targeting more than 250 million people in the MENA region and Sub-Saharan Africa.

Egyptian telecommunications operators were largely reliant on leasing capacity from international satellite operators. In 2019, the country established the National Company for Telecommunications Service (NCTS). One of the main objectives of the company is to extend telecommunications services using satellite communications. In November 2019, the company launched the Egyptian satellite TIBA-1 which will operate in the Ka band. The new GEO HTS satellite will be mainly dedicated to data transmission to provide Internet services to remote areas and serve as a backup for terrestrial infrastructure. NCTS also plans to provide broadband services to the modern trains of Egyptian railways and the shipping industry.

Spectrum arrangements for 5G and satellite

The National Telecommunications Regulatory Authority of Egypt reserves frequencies in the UHF, X, Ku, K and Ka bands for satellite services.[5] No millimetre wave spectrum has been licensed to 5G as of September 2021. Recent mobile spectrum allocations in 2020-2022 were awarded in the 2.6GHz band. The award is technology neutral. As such, the band is being considered by Egyptian mobile operators for initial 5G deployment.

Connectivity for unserved and underserved sites: satellites vs terrestrial microwave

The backhaul technology of choice in non-urban areas is either long range terrestrial microwave (using 6-13GHz bands) or satellite links. Satellite equipment and traffic costs have been decreasing over time. The capital investment of satellite backhaul is typically a fraction of the cost of a terrestrial microwave link (Exhibit 2.3).

	Terrestrial Microwave (6-13GHz)	*GEO High Throughput Satellites*
Typical capacity (Mbit/s)	270-1,000	100–300
Range (km)	18-35	unlimited
Spectrum fee	Yes	no
Capital cost (USD)[6]	25,000–30,000	4,000
Maintenance costs (USD/year)	2,500–3,000	1,000
Traffic cost (USD/Mbit/s/month)	None	50-200[7]

***Exhibit 2.3**: Terrestrial microwave vs satellite links costs [Source: Network Strategies]*

Contrary to the historic perception that the capacity cost of satellite will lead to a higher total cost of ownership (TCO) than terrestrial microwave over time, satellite-based backhaul can have a lower cost under many scenarios. The business case for satellite links depends on many factors, including the number of subscribers, data consumption and cost of the alternative technology. For example, if connecting an unserved/underserved site requires more than one microwave hop, terrestrial microwave is often economically unviable, unless it is justified by the need for high capacity.

One main advantage of satellite links is that capacity can be assigned on demand where it can be pooled across many small cell sites, helping the mobile operator to reduce and manage the cost. The introduction of HTS and increase in supply within this decade is expected to bring satellite capacity costs below USD4 per Mbit/s per month by 2030, making satellite links more affordable over time and offsetting the cost of increasing data usage.[8]

5 National Telecommunications Regulation Authority (2021), *National Frequency Allocation Table*, June 2021. Available at https://www.tra.gov.eg/wp-content/uploads/2021/06/EGY-NTRA-June21-NFAT-1.pdf.

6 This includes the cost of a terrestrial microwave hop for the microwave option or, in the case of satellite, the cost of a ground satellite terminal.

7 Cost varies depending on the business model, length of contract and total capacity leased.

8 APSCC (2020). *Are Very High-Throughput Satellite Systems New Game-Changers?* Asia-Pacific Satellite Communication Council, December 2020. Available at https://apscc.or.kr/2020-3/#Future.

KENYA: SATELLITE IS THE KEY TECHNOLOGY FOR DELIVERING BROADBAND

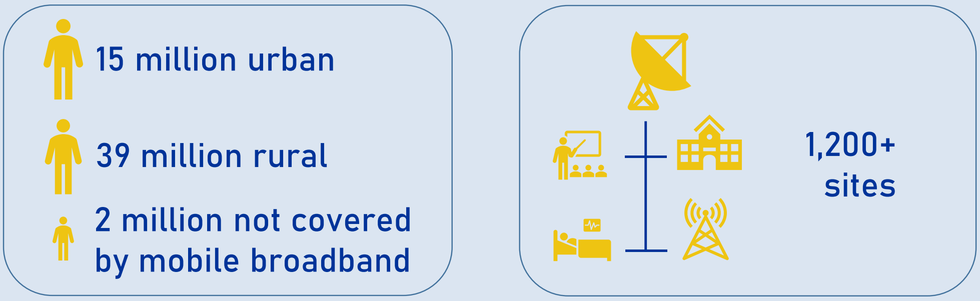


Exhibit 2.1: *Kenya: satellite use and demand [Source: Network Strategies]*

Topography and demographics:

Kenya has a land area of 580,000 km^2. The country has a diverse landscape, including very large mountainous regions, hilly terrain, and large forested areas. Kenya has one of the largest populations outside urban areas in Africa, encompassing about 39 million people.

Satellite services

Kenya has no state-owned communications satellites. However the country's telecommunications operators lease substantial capacity from international satellite operators to provide international connectivity, direct broadband Internet and mobile backhaul links. Despite having access to submarine cables, international satellite connectivity capacity has increased consistently over recent years, increasing from 0.27Gbit/s in 2015 to 5.58Gbit/s in 2019, while satellite data subscriptions doubled over the same period, reaching 1,243 links.[9] The country's national broadband plan identifies satellite as a key technology to deliver broadband to areas where terrestrials systems are not feasible.

Spectrum arrangements for 5G and satellite

In October 2021, the Communications Authority of Kenya released a consultation document on its roadmap and strategy for 5G mobile communications in Kenya. The authority identified 2.3, 2.5 and 3.5GHz as high priority bands and 26GHz as medium priority band for 5G deployment. The 28GHz band was not identified as a potential band for 5G and is still reserved for fixed satellite services and terrestrial point-to-point microwave links.[10]

The coverage gap: the untapped potential

From 2015 to 2020, mobile broadband population coverage has increased by about 30% in Africa. However, the coverage gap is still large and includes about 300 million people, representing about 22% of the continent's population. Most of the unserved population lives in just a few countries, including Nigeria, the Democratic Republic of Congo (DRC), Sudan, Tanzania, Niger, Ethiopia and Mozambique. These countries have large populations outside urban areas with many communities located in difficult topography where it is economically unviable to lay terrestrial infrastructure (Exhibit 2.4). It is important to note that, even in countries with high mobile broadband coverage, there are sizable unserved populations. For example, the unserved population in Egypt and Morocco is about 1.5 million and 380,000, respectively.

9 Communications Authority of Kenya (2019). *Annual Report 2018-2019,* December 2020. Available at https://www.ca.go.ke/wp-content/uploads/2020/12/Annual-Report-for-Financial-Year-2018-2019.pdf.

10 Communications Authority of Kenya (2021). *Public Consultation on The Roadmap For 5th Generation (5g) Mobile Communications in Kenya,* October 2021. https://www.ca.go.ke/wp-content/uploads/2021/10/Public-Consultation-Paper-on-5G-Roadmap.pdf.

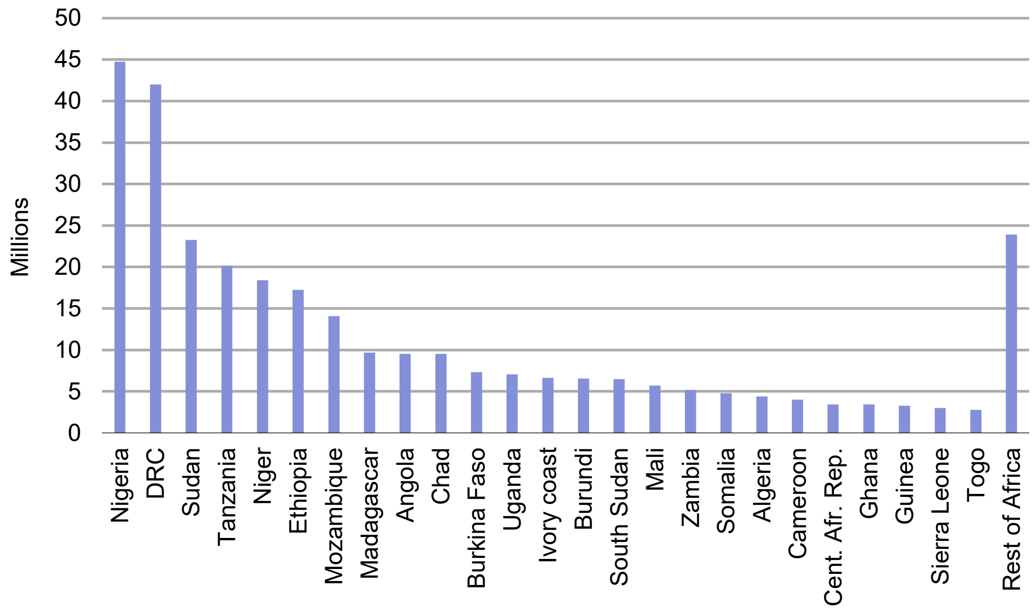


Exhibit 2.4: *Population not covered by either 3G or 4G in Africa region [Source: ITU]*

Extending the coverage to unserved communities depends on national policy and the economies of deployment. As a large proportion of this gap could only be served with satellites, it is worthwhile to estimate the expected demand of these communities. Assuming a gradual mobile coverage increase over a ten-year period into these unserved communities, we estimate that the demand will exceed 500Gbit/s by 2026 and exceed 4Tbit/s by 2031 (Exhibit 2.5).[11] To put this into perspective in terms of potential satellite capacity supply, the total global GEO satellite capacity that is expected to be deployed through 2024 is 30Tbit/s.[12]

11 This is the combined traffic growth resulting from increasing demand per subscriber and population growth. The forecast is based on the assumption that a user uses 1GB a month in the first year and traffic increases at the same rate as in urban areas.

12 Satellite Industry Association (2021), *State of Satellite Industry Report*, June 2021.

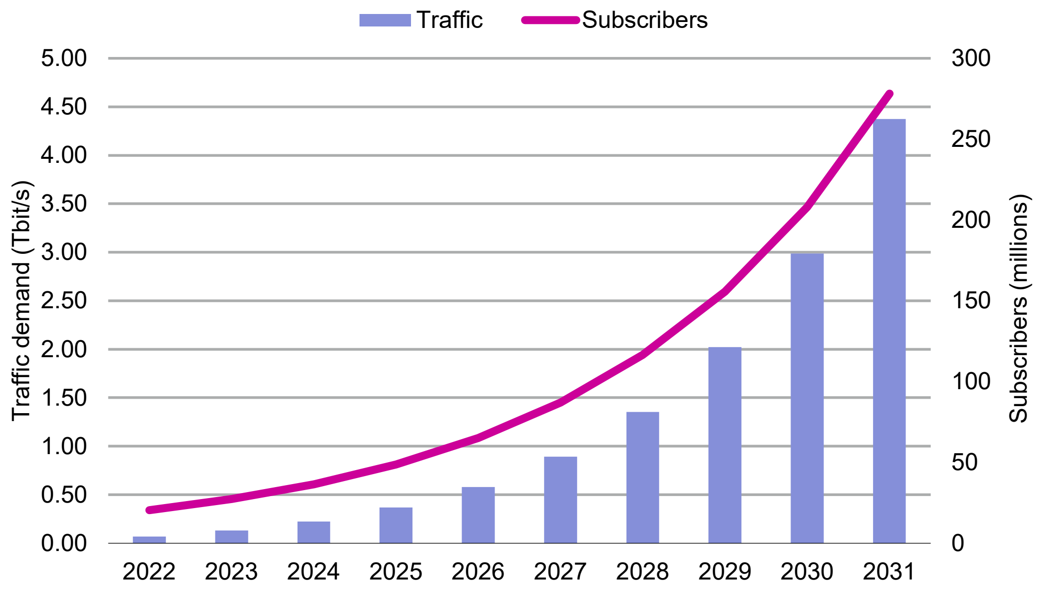


Exhibit 2.5: *Potential traffic demand of unserved communities in Africa [Source: Network Strategies]*

2.2 Connectivity for moving platforms across urban areas and beyond

Moving platforms such as airplanes and vessels in busy airports and ports represent cases where only satellite connectivity is possible, at least most of the time. For terrestrial transport, satellite can play a supplemental, but critical role for some cases. In this context, satellites can provide stand-alone links to moving platforms or provide connectivity directly to connected devices. Use cases that are envisioned for satellite services include (Exhibit 2.6):[13]

- multicast of traffic to update entertainment content onboard of airplanes (gate-to-gate)
- flight management data (gate-to-gate)
- broadband access for aircraft passengers (gate-to-gate)
- enterprise data transfer for maritime transport (pier-to-pier)

13 Liolis et al. (2018), 'Use cases and scenarios of 5G integrated satellite-terrestrial networks for enhanced mobile broadband: The SaT5G approach', *International Journal of Satellite Communications and Networking*, Vol. 37, pp.91–112.

- connecting self-driving vehicles in areas beyond urban centres lacking reliable mobile coverage
- emergency 5G networks for public safety and disaster recovery
- government uses.

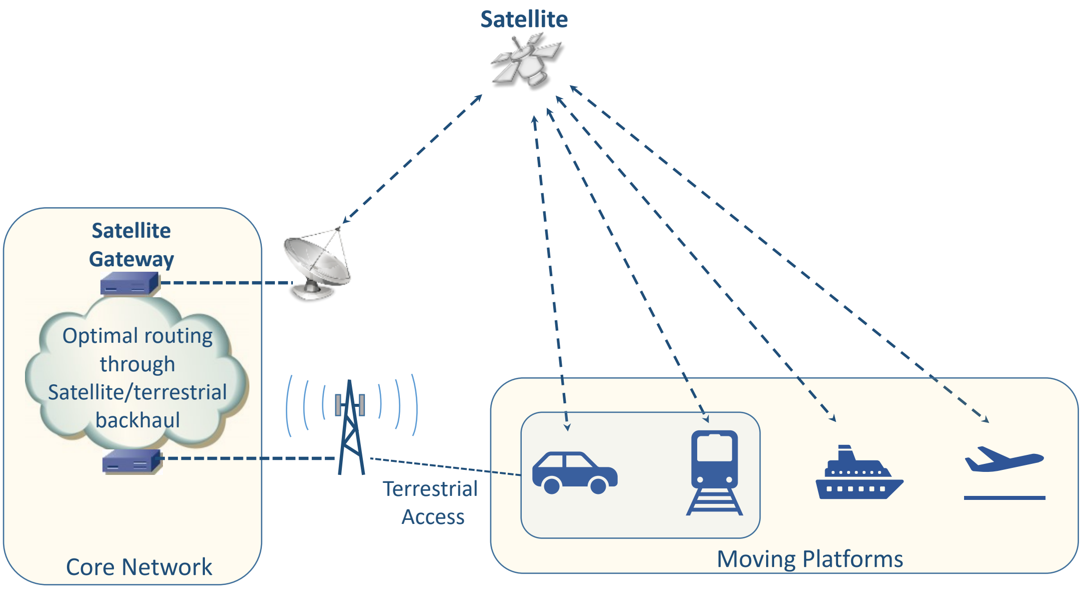


Exhibit 2.6: *Backhaul and broadband access for moving platforms [Source: Network Strategies]*

Satellite broadband connectivity to ships, aircraft and offshore oil and gas facilities is quite common and growing in demand. However, instead of merely connecting Wi-Fi hotspots, concepts are being developed for small 5G cells on moving platforms, as this will provide ubiquitous mobile coverage and seamless user experience.[14]

Moving communications platforms, that can be deployed quickly in case of emergencies, are also essential for public safety and disaster recovery. Mission critical communications are typically narrowband proprietary systems which do not allow traffic-intensive applications such as video and data transmission. However, 4G and 5G are specified to handle mission critical communications with far more capabilities. Integrating satellites with the terrestrial infrastructure adds resilience and robustness as the ‘always-on’ infrastructure is mostly

14 Völk et al. (2019), ‘Satellite Integration into 5G: Accent on First Over-The-Air Tests of an Edge Node Concept with Integrated Satellite Backhaul’, *Future Internet*, Vol. 11, pp.1–17.

located in space. In an event of disaster, emergency networks using satellite connectivity can be rolled out from scratch in a timely manner. 5G mobile base stations on moving platforms using satellite and with so-called Core-Edge Split (CES) have already been demonstrated.[15] The CES concept allows for communications to work within the cell, and between neighbouring cells, even when satellite coverage is temporarily unavailable. This distributed and flexible architecture with integrated satellite-terrestrial networks is likely to be a critical part of the future of Public Protection and Disaster Relief (PPDR) networks.

ViaSat-3 and ViaSat- 4: GLOBAL FSS and ESIM services

Commencing in 2023, the ViaSat-3 UHTS network will deliver broadband globally with end-user speeds of up to 1Gbit/s and throughputs of over 1Tbit/s per satellite. The ViaSat-4 design is expected to increase this throughput five to seven-fold.

Ground infrastructure is under construction in Africa which will support the network across the entire African continent. Viasat's innovative gateway technology is reducing the size of gateway earth stations and increasing capacity. The Viasat UHTS network will provide ubiquitous fast-broadband services across urban and non-urban areas, as well as direct fast broadband to fixed premises and offering a cost-effective solution through Viasat's Community Wi-Fi (VCI).

Using ESIM services, the Viasat network will facilitate uninterrupted fast-broadband onboard aircraft and ships (gate-to-gate and pier-to-pier), as well as supporting ground transport infrastructure.

15 Völk, F., Schwarz, R. T., Lorenz, M., and Knopp, A. (2020), 'Emergency 5G Communication on-the-Move: Concept and field trial of mobile satellite backhaul for public protection and disaster relief', *International Journal of Satellite Communications and Networking*, Vol. 39, pp.417–430.

2.3 Solutions to terrestrial network bottlenecks

The vast majority of population not covered by 3G/4G networks (unserved population) in Africa live outside urban areas (Exhibit 2.7). In some African countries, such Equatorial Guinea, virtually the entire population living outside urban areas is unserved, in addition to a proportion of the urban population. In addition to the unserved African rural population, it is important to note that a large proportion of the served population outside urban areas (450 million people) may also become underserved in the near or mid-term due to bottlenecks in the terrestrial network.

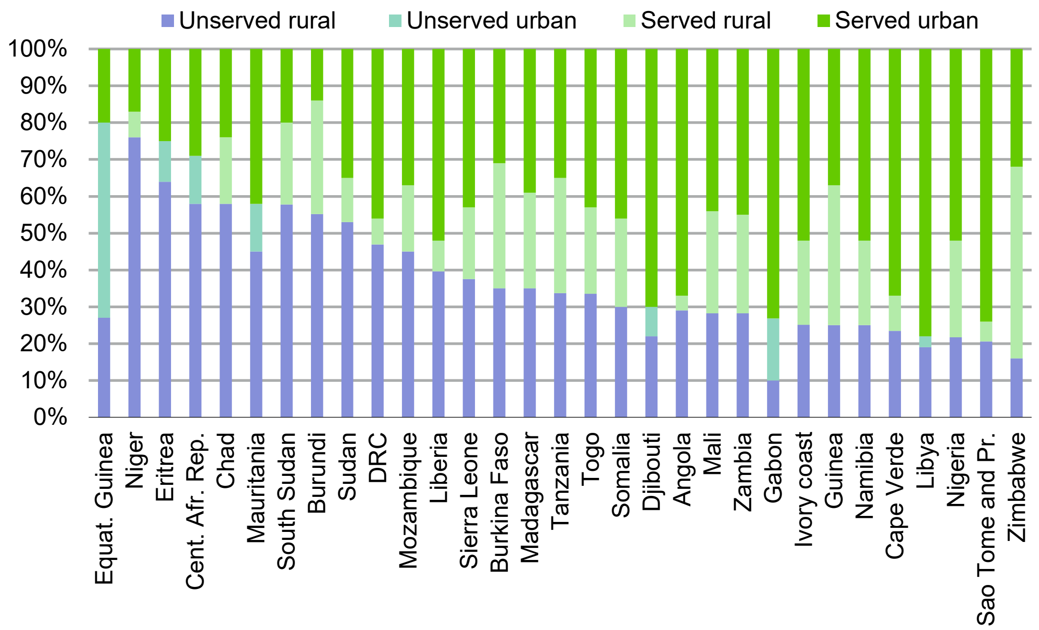


Exhibit 2.7: *The proportion of rural and urban populations not covered with 3G/4G (unserved) and rural and urban population covered by 3G/4G (served) in a select number of African countries [Source: ITU]*

Mobile backhaul beyond urban areas is typically deployed using terrestrial microwave links. Capacity advancements in terrestrial microwave links have been mainly achieved by using higher frequency bands in the millimetre wave range (Exhibit 2.8). While higher frequencies in the V- and E-bands can provide capacities in excess of 1Gbit/s, they are unsuitable for unserved and underserved areas due to the limited range of 1-2km and increased atmospheric absorption. Microwave links beyond urban areas typically use frequencies in the range of 5-

42GHz as these can support distances between 5-60km. However, these frequencies do not have sufficient capacity to meet the expected throughput of 5G cell sites and consumer data growth.[16] As such, communities beyond urban areas in Africa will be left behind with limited network performance due to the backhaul bottleneck.

Microwave frequency bands	*Typical capacity (Mbit/s)*	*Range (km)*
Sub-5GHz licensed	27	60
Sub-5GHz unlicensed	270	60
6GHz	270	35
13-25GHz	378	9-18
26-56GHz	540	1-9
56-71GHz (V-band)	810	1-2
71-86GHz (E-band)	5,400	1-2

Exhibit 2.8: *Typical terrestrial microwave capacities and range [Source: GSMA, Network Strategies]*[17]

Mobile data traffic is expected to grow by 35% annually in Sub-Saharan Africa and by 43% in North Africa over 2022-2027.[18] As the demand for mobile data grows, many cell sites beyond urban areas may become underserved compared to urban sites using high-capacity links (fibre and microwave). We estimate that there are around 366,000 cell sites serving populations beyond urban areas in Africa. Using GSMA forecasts of the types of backhaul links developed for Sub-Saharan and North Africa and the number of cell sites in each country[19,20] we estimate that about 57,000 sites and 148 million subscribers will be underserved by 2026 and about 226,000 sites and 362 million will be underserved by 2031 (Exhibit 2.9).[21]

16 A 5G cell site operating using a 40MHz channel at 3.5GHz can have a throughput in excess of 1Gbit/s. Using a 100MHz channel increases the throughput to more than 3Gbit/s.

17 GSMA (2021), *Wireless Backhaul Evolution: Delivering next-generation connectivity*. GSMA, February 2021.

18 Ericsson (2021), *Ericsson Mobility Report*. Ericsson, November 2021.

19 GSMA (2021), *Wireless Backhaul Evolution: Delivering next-generation connectivity*. February 2021.

20 The number of cell sites in each African country was estimated using data from different sources, including www.opencellid.org, towerco reports and telecommunications news websites.

21 The forecast is based on a conservative annual data traffic growth of 21%.

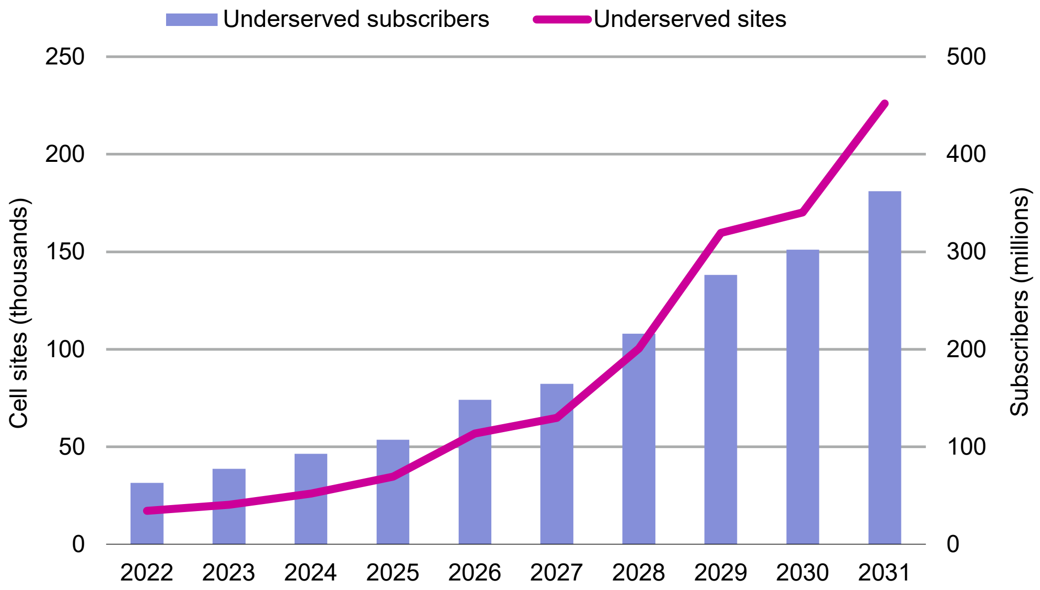


Exhibit 2.9: *Forecast for the number of cell sites and subscribers underserved by terrestrial microwave in Africa [Source: Network Strategies]*

The capacity gap between the forecast busy hour traffic of cell sites beyond urban and existing terrestrial microwave backhaul capacity is depicted in Exhibit 2.10. The ability of terrestrial technologies to cover this gap by upgrading existing infrastructure is likely to be limited by cost and topography. As such, this gap represents a sizable market for satellite services to offload traffic from terrestrial microwave links during peak traffic time and enable populations beyond urban areas to experience the full potential of 5G services, without the need for expensive capital investments.

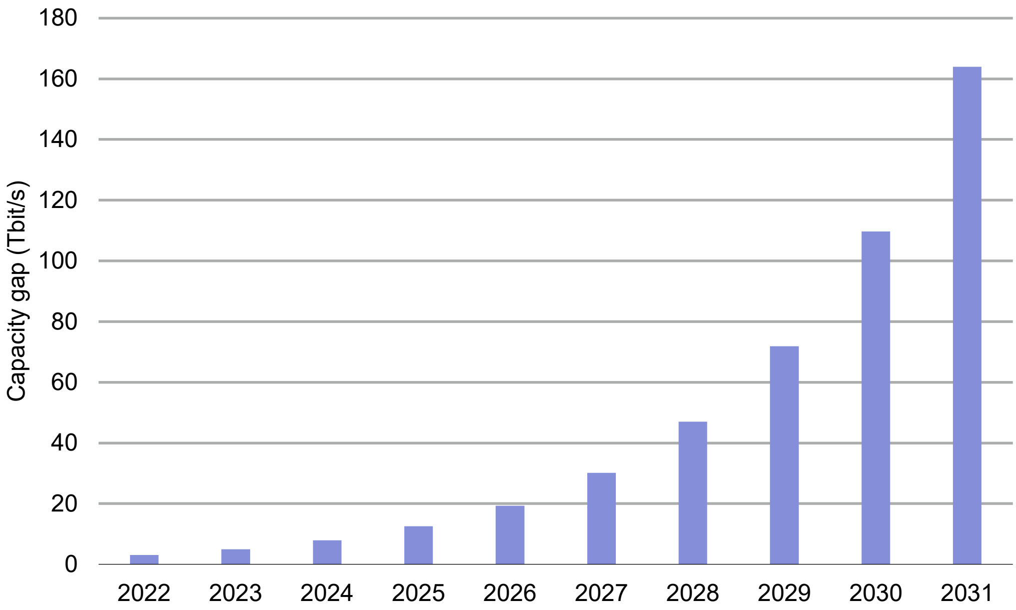


Exhibit 2.10: *Forecast for the gap between busy hour demand of rural cell sites and capacity of existing terrestrial microwave backhaul in Africa [Source: Network Strategies]*

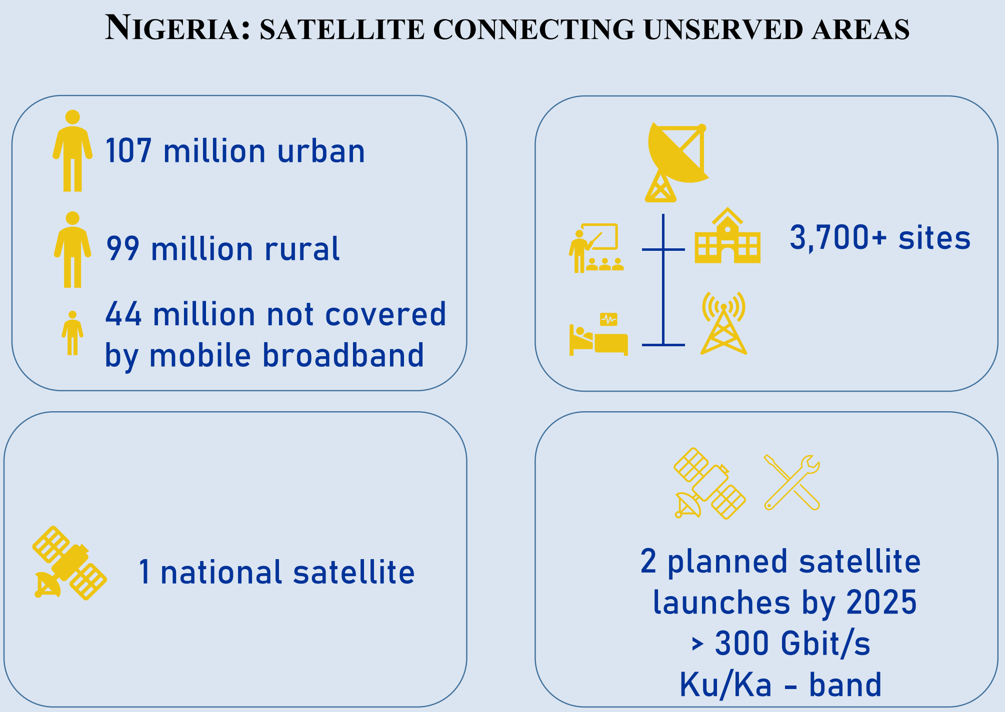


Exhibit 2.11: *Nigeria: satellite use and demand [Source: Network Strategies]*

Topography and demographics:

Nigeria encompasses a land area of 924,000 km^2. The country has a diverse landscape with varying population densities, including tropical forests and arid desert areas in the far north where the population density is as low as 40 persons per km^2. About 40% of the land is rain-fed farming area. Nigeria has the largest population dwelling outside urban areas in Africa, consisting of 99 million citizens.

Satellite services

Nigeria has one domestic communications satellite, NigComSat-1R. The satellite carries 28 transponders, including eight transponders in the Ka-band (26.5-40GHz). NigComSat-1R was launched in 2011 with an expected lifetime of 15 years. The satellite is operated by the state-owned Nigerian Communications Satellite Limited (NIGCOMSAT). In 2021, NIGCOMSAT announced plans to launch two communications satellites, NigComSat-2 by 2023 and NigComSat-3 by 2025. NigComSat-2 is planned to have a capacity of 300Gbit/s using Ku- and Ka-band transponders.

One of the priority initiatives of the Nigerian National Broadband Plan (2020-2025) is to leverage satellite capacity of NIGCOMSAT to connect unserved communities outside urban areas, with the intention to cover all unserved clusters by 2025. This will include providing satellite backhaul to 700 mobile cell sites and providing Internet access to over 3,000 sites including schools, hospitals, and local government buildings. [22]

Satellite backhaul is a key tool in extending mobile services in rural Nigeria. In late 2021, satellite operator YahClick and Global Communications Extension Services Limited signed a strategic partnership to provide satellite backhaul for hundreds of mobile cell sites, owned by 9mobile, in rural Nigeria. MTN, Africa's and Nigeria's largest mobile operator, embarked on a plan in 2019 to build new 5,000 in rural and remote areas across all MTN operations in Africa. Communities with a population density less than 500 persons per km^2 are being connected using satellite backhaul.

Spectrum arrangements for 5G and satellite

In February 2022, Nigeria's federal government released the 3.5GHz spectrum for the deployment of 5G in the country. Two lots of 3.5GHz spectrum had already been awarded to mobile operators earlier in 2021. 5G trials preceding spectrum allocations were conducted in the 3.5GHz and 26GHz bands. In 2021, the Nigerian Communications Commission (NCC) signed a memorandum of understanding with NIGCOMSAT to reserve the 3.9-4.2GHz band for satellite communications while leaving the 3.5-3.9GHz for 5G usage. The NCC has not allocated spectrum for 5G use in the mmWave band. However, it halted new licensing in the 26GHz, 38GHz and 42GHz bands as these are identified as potential bands for future 5G use.[23]

2.4 Provision of multicast and edge caching

Broadcast and multicast traffic typically use extensive network resources as it travels through many network routes to reach geographically scattered users. Most of this traffic is video traffic, which currently accounts for two-thirds of mobile data traffic and is expected to increase to 77% of traffic by 2026.[24] Meeting quality requirements of video streaming can also be challenging for congested terrestrial networks. Satellites are perfectly suited to address broadcast/multicast traffic, as well as to optimise the content delivery costs, due to their ability to cover large areas in a cost-effective manner. In these scenarios, a 5G core network can offload some of this traffic to satellites to bypass a congested terrestrial network and optimise resources (Exhibit 2.11). This can include:[25]

- offloading of broadcast/multicast traffic such as live video events
- pre-fetching and caching of content at edge servers where this content is on high demand
- delivery of software updates over the air to edge network nodes
- backhauling of aggregate IoT traffic from multiple sites.

22 Nigerian Communications Commission (2020), *Nigerian National Broadband plan 2020-2025,* March 2020. Available at https://www.ncc.gov.ng/documents/880-nigerian-national-broadband-plan-2020-2025/file.

23 Nigerian Communications Commission (2021), *Nigerian National Broadband plan 2020-2025,* October 2021. Available at https://www.ncc.gov.ng/accessible/documents/1019-national-policy-on-5g-networks-for-nigeria-s-digital-economy/file.

24 Ericsson (2021), *Ericsson Mobility Report*. June 2021.

25 Evans et al. (2020). 'An integrated satellite-terrestrial 5G network and its use to demonstrate 5G use cases', *International Journal of Satellite Communications and Networking*, Vol. 37, pp.358–379.

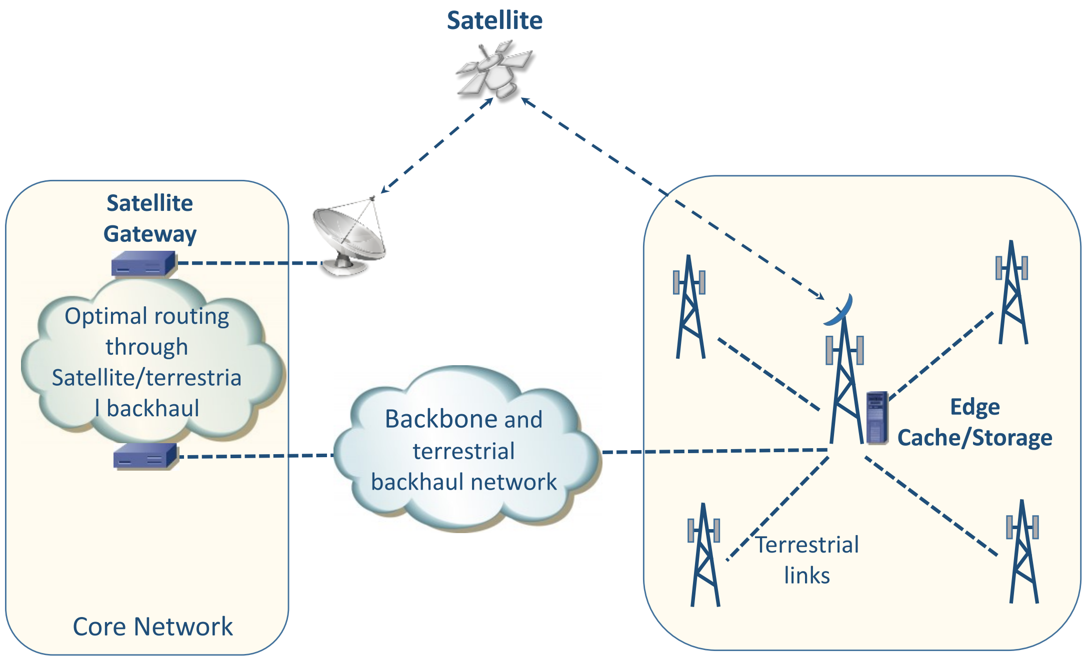


Exhibit 2.11: *Multicast/broadcast traffic to edge network nodes [Source: Network Strategies]*

3 Beyond the reach of 5G mmWave access

Much of the estimated socio-economic benefit of mmWave is generated within urban population centres. The more limited reach of the mmWave bands results in increased costs of deployment in less densely populated areas, serving fewer people, which translates to a reluctance by operators to prioritise mmWave rollout in many areas.

Beyond the reach of terrestrial networks, there is an increasing demand for high-speed connectivity for aviation and maritime. Implementation of data-centric applications is becoming a necessity in these sectors, as the industries seek to reduce costs through improved efficiency, increase revenues, comply with environmental targets and improve safety.

3.1 5G mmWave: winners and losers

As noted by the Australian mobile network operator, Optus:

> While much is unknown about the possible future service made possible through mmWave application, what we can say at this early stage is that mmWave spectrum is unlikely to be used to supply wide area mobile networks; its propagation characteristics simply make this uneconomic. Rather, mmWave will be targeted to specific users and ultra-high bandwidth applications, most likely in the enterprise market.[26]

The GSMA estimated the socio-economic benefit of mmWave, identifying the use cases likely to be the chief beneficiaries of mmWave as requiring "a large amount of data throughput in a small coverage area or face scarcity of spectrum in lower frequency bands"[27]. This clearly excludes many regions, that have population densities much lower than in urban

---

26 Optus (2020), *Spectrum allocation limits – 26GHz band*, submission in response to ACCC discussion paper, March 2020, paragraph 4. Available at https://www.accc.gov.au/system/files/Optus_31.pdf.

27 GSMA (2018), *Study on socio-economic benefits of 5G services provided in mmWave bands*, December 2018. Available at https://www.gsma.com/spectrum/wp-content/uploads/2019/10/mmWave-5G-benefits.pdf.

or suburban areas. These locations may have large coverage areas and often more than sufficient spectrum capacity to meet demand.

A second GSMA study[28] examined the economics of 5G mmWave for three notional geographic areas, based on sample locations from urban China, suburban Europe and rural United States (Exhibit 3.1). While the analysis demonstrated that mmWave delivered advantages for cost-effective 5G deployments, it is clear that the scenarios examined would have traffic densities considerably greater than could be achieved in many areas.

Scenario	*Population*	*Area (sq km)*	*Population density (persons per sq km)*
Urban China	2,300,000	112	20,300
Suburban Europe	25,000	5.6	5,000
Rural United States	19,000	17	1,100

Exhibit 3.1: *Characteristics of sample areas in GSMA study [Source: GSMA]*

A 2021 study of 5G 26GHz in Europe found that while the economic benefit of mmWave was significant, the use cases generating those benefits were characterised in interviews with mobile network operators as having multiple targeted locations within a wider network footprint that require "localised high-capacity coverage, and/or to cover specific industrial locations and corporate campuses"[29]. The use cases examined in the study included:

- **industrial**: ports, airports, smart factories
- **fixed wireless access:** macro site upgrades in areas with no fibre to the home (FTTH) but with minimum population density of 300 persons per square kilometre
- **high density urban / suburban locations** – shopping centres, city centres, transport hubs and stadiums.

28 GSMA (2021), *The economics of 5G mmWave*, January 2021.

29 Analysys Mason (2021), *Status, costs and benefits of 5G 26GHz deployments in Europe*, final report for Qualcomm and Ericsson, 14 May 2021. Available at ttps://www.analysysmason.com/contentassets/3716b071d2f647c9a9e57e56900b4f66/analysys-mason---status-costs-and-benefits-of-5g-26ghz-deployments-in-europe.pdf.

In other words, few if any benefits are expected beyond urban areas. This has significant implications for governments seeking to encourage economic growth beyond urban areas or to reduce the digital divide affecting unserved and underserved populations. A significant portion of the population in many African countries (Exhibit 3.2) is yet to benefit from the same broadband access available in urban areas.

In the United States 5G deployment to date has focused on mmWave bands, including 28GHz. However there has been an increasing awareness that this focus will worsen the digital divide. As noted by Jessica Rosenworcel, Commissioner of the Federal Communication Commission:

> … we have made a series of choices that have put us behind when it comes to freeing key airwaves we need for 5G. That's because to date the United States has aggressively focused its early efforts to support 5G wireless service by bringing only high-band spectrum to market. We have yet to auction a single megahertz of mid-band spectrum.
>
> … our focus on millimeter wave spectrum is threatening to create 5G haves and have-nots in the United States. That's because while these airwaves have substantial capacity, their signals do not travel far. As a result, commercializing them is costly—especially in rural areas. The sheer volume of antenna facilities required to make this service viable will limit deployment to the most populated urban areas. This will deepen the digital divide that already plagues too many rural communities nationwide.[30]

30 Jessica Rosenworcel (2020), *Statement of Jessica Rosenworcel, Commissioner, Federal Communications Commission before the Committee on Commerce, Science, and Transportation, United States Senate "Industries of the Future"*, 15 January 2020. Available at https://www.commerce.senate.gov/2020/1/industries-of-the-future.

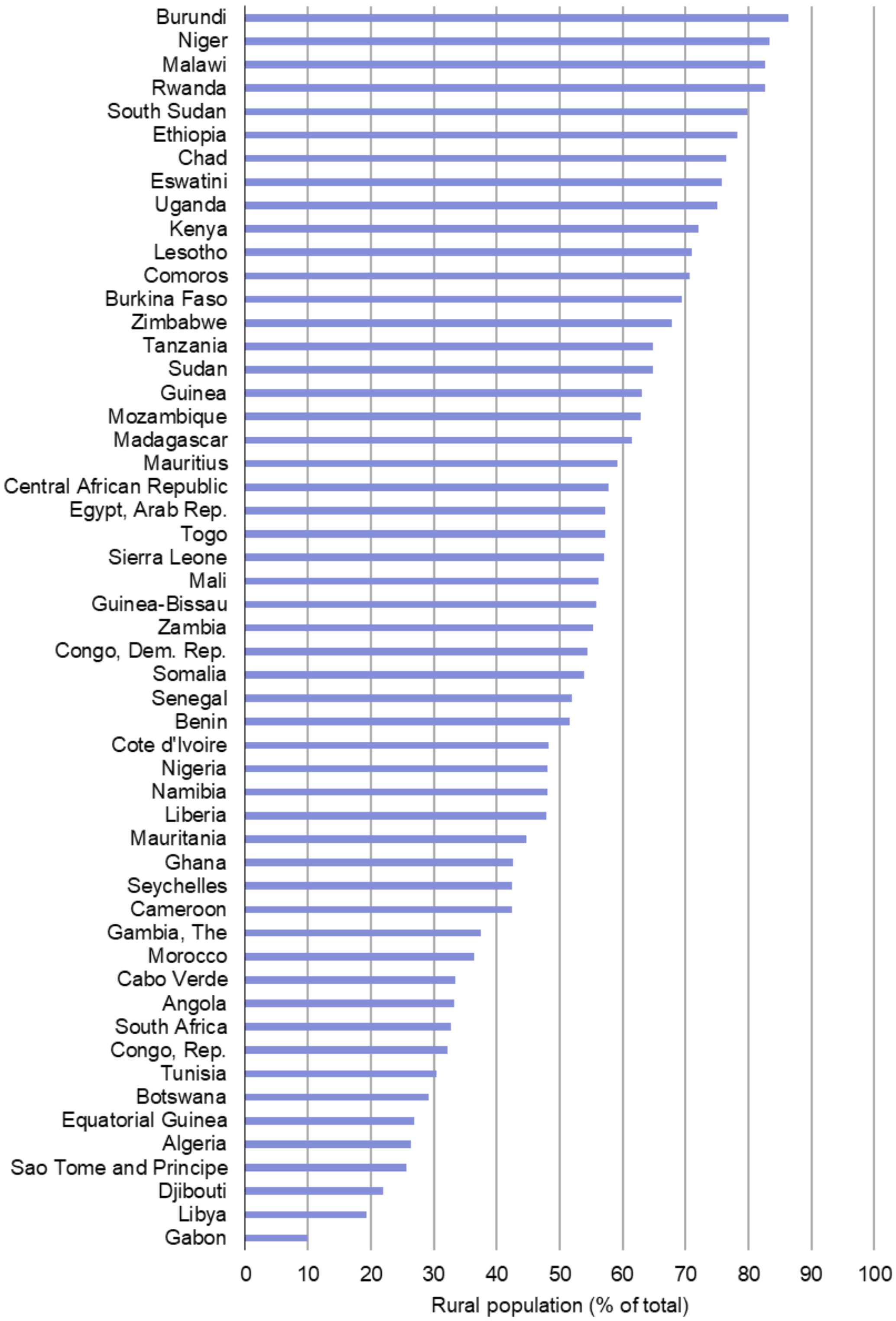


Exhibit 3.2: *Rural population as percentage of total population, 2020 [Source: World Bank]*

MOBILE MMWAVE 5G BROADBAND: LIMITATIONS AND HIDDEN COSTS

Millimetre waves (mmWaves) have a limited reach, which is typically in the range of 100-300 metres for indoors and potentially up to 1,000m for outdoor subscribers.[31] mmWaves also suffer from heavy blockage due to walls and foliage. While mmWave 5G FWA links can be engineered to achieve larger distance in rural areas, this is associated with additional costs including customer side equipment, skilled installation at the customer site, and higher masts at the cell site. This restricts mmWave 5G to niche market segments where the population density justifies the capital investment.

Integrating mmWave 5G capabilities in handsets also entails additional cost. For example, the iPhone SE, released in March 2022, does not include mmWave 5G support. According to Apple, adding mmWave to the iPhone would increase the handset cost by USD60-120, which would mean that it would not qualify as an entry level device, even in the United States.[32] This may affect the demand for mobile mmWave 5G broadband, particularly in emerging economies where the affordability of handsets is key for service adoption.

3.2 Connectivity in the sky

Global revenues for aviation satellite communications were USD527 million in 2019. Although restrictions on travel and health concerns due to the COVID-19 pandemic have

31 M. Sheikh et al (2021). *Measurement Based Study of Commercial 5G Frequencies in Urban Macro Cellular Environment*, 17th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), IEEE, 11-13 October 2021.

32 Fierce Wireless (2022). *Apple's new iPhone SE offers 5G, sans mmWave*. Fierce Wireless, 10 March 2022. Available at: https://www.fiercewireless.com/wireless/apples-new-iphone-se-offers-5g-sans-mmwave.

caused a major contraction in the airline industry worldwide, industry analysts are predicting compound annual growth of 3.3% to 2030.[33]

The International Civil Aviation Organization identified three data domains which categorise the type of information addressed by connectivity solutions.

Aircraft Control Domain (ACD)

ACD comprises mission-critical data that supports the safe operation of the aircraft, encompassing communications, navigation and surveillance data, flight information and alerting, and airline operations communication. The nature of this data requires real-time communication, under any conditions.

A 2017 study focussing on oceanic regions[34] found that satellite-enabled air traffic control applications delivered benefits of USD1.1 billion over the period 2001-16, comprising:

- direct benefit to airlines – USD420 million
- reduced carbon dioxide emissions – USD110 million
- indirect benefits for passengers – USD570 million.

A further USD1.9 billion in benefits were generated from satellite-enabled airline operations control over the same period. Note also that the annual benefits rose over time, as the number of 'connected aircraft' increased and aircraft separation reduced.

Airline information services domain (AISD)

AISD encompasses data for the operation of the aircraft, but not essential for the control of the aircraft, including applications for the

[33] Frost & Sullivan (2021), *Global aviation satcom growth opportunities*, 28 July 2021. Available at https://store.frost.com/global-aviation-satcom-growth-opportunities.html.

[34] Helios (2017), *The benefits of satcom to airlines*, report for Inmarsat. Available at https://www.inmarsat.com/content/dam/inmarsat/corporate/documents/aviation/insights/2017/Helios%20Study%20-%20Airline%20Benefits%20of%20Satcom%20-%20A%20Report%20for%20Inmarsat.pdf.coredownload.inline.pdf.

cabin or flight crew. Although the data may be commercially or operationally important, it is not mission-critical.

For a single Boeing 787 flight, it is estimated that 500GB of data is collected.[35] By 2026 a latest generation aircraft is projected to generate 5-8TB of data per flight[36].

Legacy systems may be paper-based, or may be stored onboard in a digital format for later download once the aircraft is on the ground. Once on the ground connectivity may be problematic – due to lack of mobile coverage or airport mobile 'black spots' – or the data volumes that can be transmitted are constrained due to bandwidth limitations of the local networks.

Based on existing connected aircraft numbers, the operational benefits of connected aircraft, enabled through satellite communications with the Internet of Things, is estimated to yield annual savings of USD5.5-7.5 billion. By 2035, these savings are projected to increase to USD11.1-14.9 billion.[37]

Passenger information and entertainment services domain (PIESD)

The focus of the PIESD domain is to increase passenger value by providing an enhanced passenger experience through entertainment and personalised services, driving brand loyalty and repeat purchase decisions.

It encompasses ancillary revenue generators, such as e-commerce, digital advertising, Wi-Fi access and premium-priced in-flight entertainment. This component can deliver significant revenue

35 Brendan Viggers (2015), *Using big data to schedule unplanned maintenance… streamlining the A&D support chain*. Available at https://www.aircraftit.com/articles/using-big-data-to-schedule-unplanned-maintenance-streamlining-the-ad-support-chain/.

36 Oliver Wyman (2017), *Aviation's data science revolution*, June 2017. Available at https://www.oliverwyman.com/our-expertise/insights/2017/jun/aviation-s-data-science-revolution.html.

37 LSE (2018), *Sky high economics – Chapter Two: evaluating the economic benefits of connected airline operations*, report for Inmarsat, June 2018. Available at https://www.lse.ac.uk/business/consulting/reports/sky-high-economics-chapter-two.

streams – as an example, ancillary revenue for Wizz Air, a low-cost European carrier, comprised 56% of total revenue in FY21 (increased from 45% in FY20, due to a decline in ticket sales).[38]

Airlines will be seeking to rebuilding businesses devastated by the COVID-19 pandemic, while also addressing passenger concerns over safety from infection. Differentiation strategies and quality experiences will be critical for value creation.

In a November 2020 survey, 39% of respondents stated that the availability of in-flight Wi-Fi was more important than it was before COVID-19.[39]

The opportunities from broadband-enabled ancillary revenue are considerable, as estimated by an LSE study,[40] with the total market projected to grow from USD3.8 billion in 2018 to USD131 billion by 2035. Over that period the airline share of the revenue is estimated to increase from USD0.9 billion to USD30 billion (Exhibit 3.3).

38 Wizz Air Holdings (2021), *Annual report and accounts 2021*. Available at https://wizzair.com/static/docs/default-source/downloadable-documents/corporate-website-transfer-documents/annual-reports/wizz-air-holdings-plc-annual-report-and-accounts-2021_c86fdf69.pdf.

39 Inmarsat (2020), *Passenger confidence tracker*, November 2020.

40 LSE (2017), *Sky high economics – Chapter One: quantifying the commercial opportunities of passenger connectivity for the global airline industry*, report for Inmarsat, September 2017. Available at https://www.lse.ac.uk/business/consulting/reports/sky-high-economics.

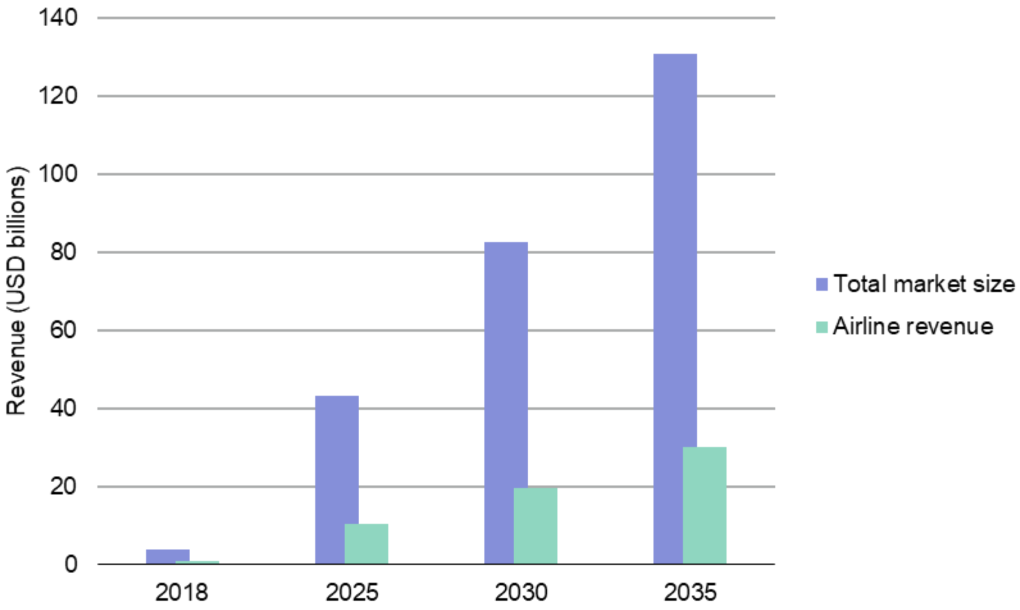


Exhibit 3.3: *Projections for broadband-enabled ancillary revenue and airline share, 2018 to 2035 [Source: LSE]*

The largest revenue category is broadband access, which accounts for just over half (53%) of the projected USD83 billion of broadband-enabled ancillary revenue in 2030 (Exhibit 3.4).

It is estimated that by the end of 2019, around 9,200 aircraft were equipped to provide in-flight connectivity, across 110 airlines, with this number expected to increase to between 15,000 and 18,000 aircraft by 2029.[41]

41 Euroconsult (2020), *COVID-19 shakes up in-flight connectivity industry*, 8 September 2020. Available at https://www.euroconsult-ec.com/press-release/covid-19-shakes-up-in-flight-connectivity-industry/.

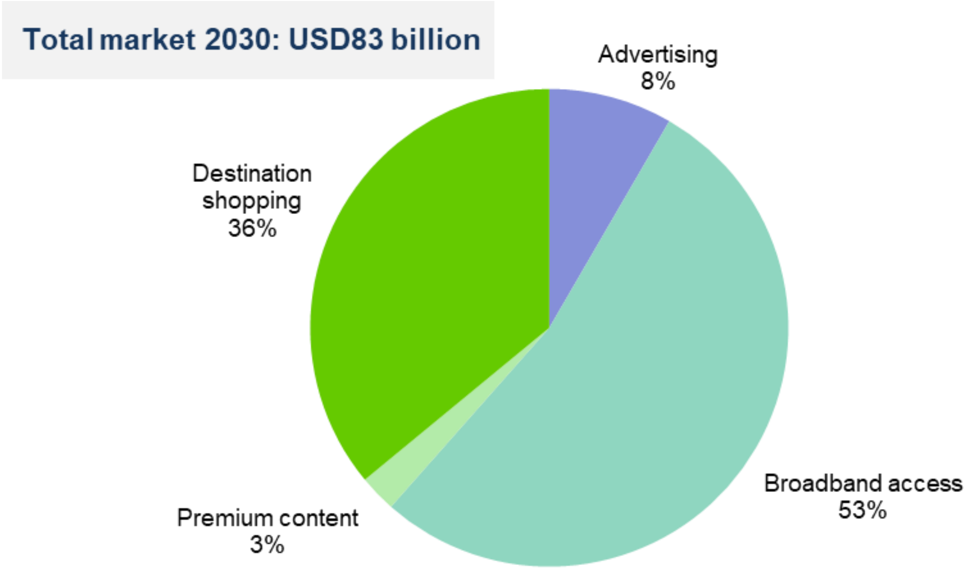


Exhibit 3.4: *Projected total market revenue by category, 2030 [Source: LSE]*

3.3 Connectivity on the seas

Satellite communications is becoming increasingly important for the maritime sector. Demand is continuing to shift away from legacy low-bandwidth mobile satellite services (MSS), delivered over L-band (1.5-2.5GHz) and C-band, as applications and expectations drive requirements for higher data-rates in Ku-band and in the band with widest bandwidth/ largest capacity available: the Ka-band.

After a slowdown in 2020 due to the effect of COVID-19, annual maritime satellite revenues are expected to reach USD2.5 billion by 2030 (Exhibit 3.5).[42]

42 Euroconsult (2021), *Impact of Global Pandemic on Maritime Connectivity Market Reflects Stark Contrast between Sectors*, press release, 27 April 2021. Available at https://www.euroconsult-ec.com/press-release/impact-of-global-pandemic-on-maritime-connectivity-market-reflects-stark-contrast-between-sectors/.

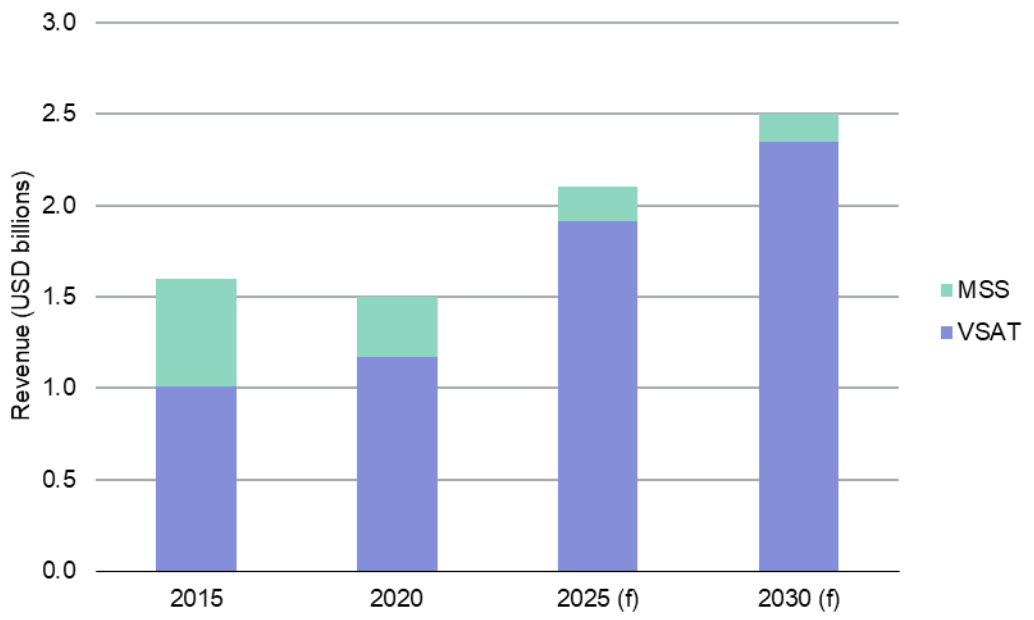


Exhibit 3.5: *Projected annual maritime satellite communications revenue, 2015 to 2030 (USD billion) [Source: Euroconsult]*

Bandwidth drivers for the maritime sector include:

Operational applications

According to the OECD, 'digitalisation increases the scale, scope and speed of trade'.[43] Operational applications address the need for greater efficiencies and improved safety procedures to reduce collisions and accidents due to human error. Such applications enable optimal route planning, improved fuel efficiency and remote monitoring of vessels.

Crew and passenger communications

Expectations of passengers on cruise ships and leisure vessels for always-on connectivity are driving demand for high speed broadband.

Crew welfare and retention are key concerns for shipping companies, becoming more important due to longer periods at sea and

43 OECD (nd), *The impact of digitalisation on trade*. Available at https://www.oecd.org/trade/topics/digital-trade/.

quarantines as a result of COVID-19 restrictions. High-speed broadband also facilitates e-learning, addressing the need for continued training and up-skilling of crew.

Smart ships

As shipping companies seek to increase efficiency and reduce costs, smart ship applications are being developed. Artificial intelligence is being harnessed for automation in navigation and control technology, with benefits including improved safety through collision avoidance systems, optimal route planning and optimised vessel operations (addressing preventative maintenance, energy efficiency, emissions reduction and fuel consumption).

For example, real-time monitoring of performance can predict potential equipment failure, alerting crew in advance to replace or maintain equipment. This reduces the need for emergency replacements and minimises the time that the vessel is out of action due to equipment failure and unscheduled maintenance.

Significant investment is financing the development of autonomous and semi-autonomous vessels – for example, in Europe (MUNIN and YARA Birkeland), the United Kingdom (Mayflower), China, Korea and Japan – and several trials have been conducted.

Reliable high-speed bandwidth under all operating conditions will be essential for the data-centric systems to support smart ships and their applications.

In 2020 UNCTAD identified six priority areas for policy action, to respond to the COVID-19 pandemic and what it referred to as “the persistent challenges facing the maritime transport and trade of developing countries”:

- support trade so it can effectively sustain growth and development
- help reshape globalisation for sustainability and resilience
- promote greater technology uptake and digitalisation
- harness data for monitoring and policy responses

- enable agile and resilient maritime transport systems
- maintain the momentum on sustainability, climate-change adaptation and resilience building.

Merchant trade

Over 80% of global merchandise trade by volume is carried by sea[44]. Although the number of vessels has increased slightly in recent times (Exhibit 3.6), over the past 20 years vessel sizes have increased markedly as shipping companies seek to optimise costs through economies of scale. For ships built in the last four years, oil tankers are nine times larger, container ships four times larger, general cargo ships are three times larger and bulk carriers twice as large as ships built 20 years ago.[45]

A 2019 OECD study explored the effect of digitalisation on multi-factor productivity (MFP). Adopting high-speed broadband resulted in MFP for the average firm increasing by 1.4%, with large firms achieving an increase of 1.9%.[46] BCG noted that dynamic pricing enabled through advanced analytics for container vessels resulted in profitability increases of between 3-5%.[47]

We have used these results to scope the potential benefits that could be achieved by shipping companies through high-speed broadband enabled applications on vessels. For a sample of

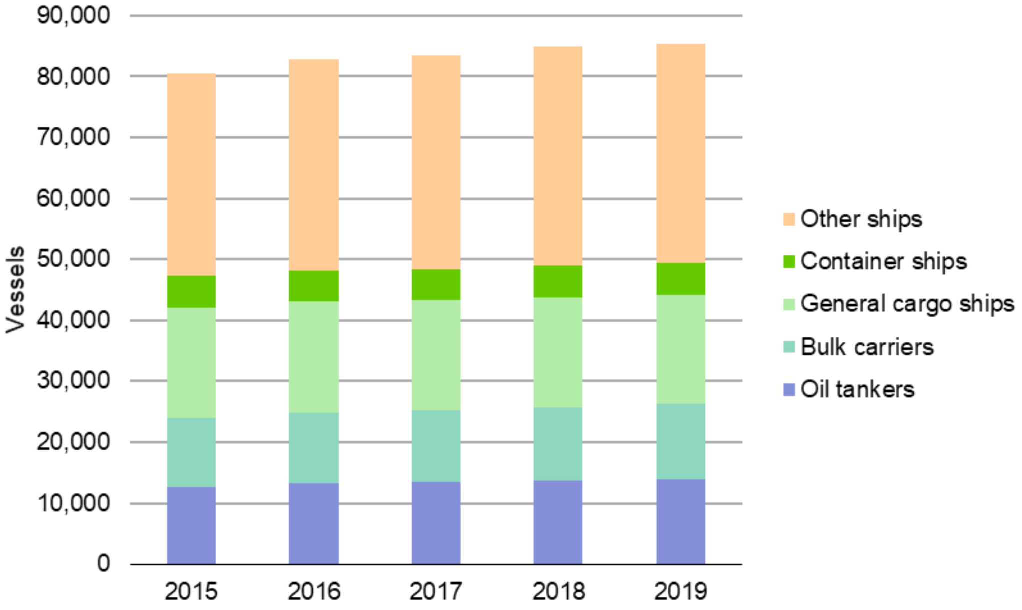
44 UNCTAD (2020), *Review of maritime transport 2020*, Available at https://unctad.org/topic/transport-and-trade-logistics/review-of-maritime-transport.

45 *Ibid*.

46 Peter Gal, Giuseppe Nicoletti, Theodore Renault, Stéphane Sorbe and Christina Timiliotis (2019), *Digitalisation and productivity: In search of the holy grail – Firm-level empirical evidence from EU countries*, OECD Working Papers No 1533, 9 February 2019. Available at https://dx.doi.org/10.1787/5080f4b6-en.

47 BCG (2018), *The Digital Imperative in Container Shipping*, 2 February 2018. Available at https://www.bcg.com/publications/2018/digital-imperative-container-shipping.

24 major publicly-listed global shipping companies[48], over the period 2021-25 the potential direct benefits would be between USD7.4 billion and USD11.6 billion.



Note: Data includes merchant vessels over 100 gross tonnage.

Exhibit 3.6: *World merchant fleet, 2015 to 2019 [Source: Equasis]*

Passenger vessels

High-speed satellite communications would provide cruise ships with similar operational benefits as for merchant vessels. Cruise ships also need to supply Wi-Fi access to their passengers, who typically expect high-speed broadband, with quality of service comparable to what they experience at home.

48 The sample included CMA CGM Group, COSCO, DHT Holdings, Euronav NV, Evergreen Line, Frontline Ltd, Hapag-Lloyd, HMM, International Seaways, Maersk, Mitsui, Navios Maritime Holdings, Nordic American Tankers, NYK Line, Orient Overseas Container Line, Overseas Shipholding Group, Scorpio Tankers Inc, SFL Corp Ltd, Star Bulk, Teekay Corp, Tsakos Energy Navigation, Wan Hai Lines, Yan Ming Marine Transport and ZIM.

Opportunities for revenue generation may be wider than simply providing passengers with Wi-Fi access. As is the case of aviation, potential revenue streams could also include e-commerce, premium content and advertising. Assuming cruise passengers return to pre-COVID-19 levels by 2022 and cruise ship operators ensure that their vessels have the capability for delivering broadband access, potential broadband-enabled revenues could reach USD2 billion by 2024 (Exhibit 3.7). This would also generate additional revenue for suppliers.

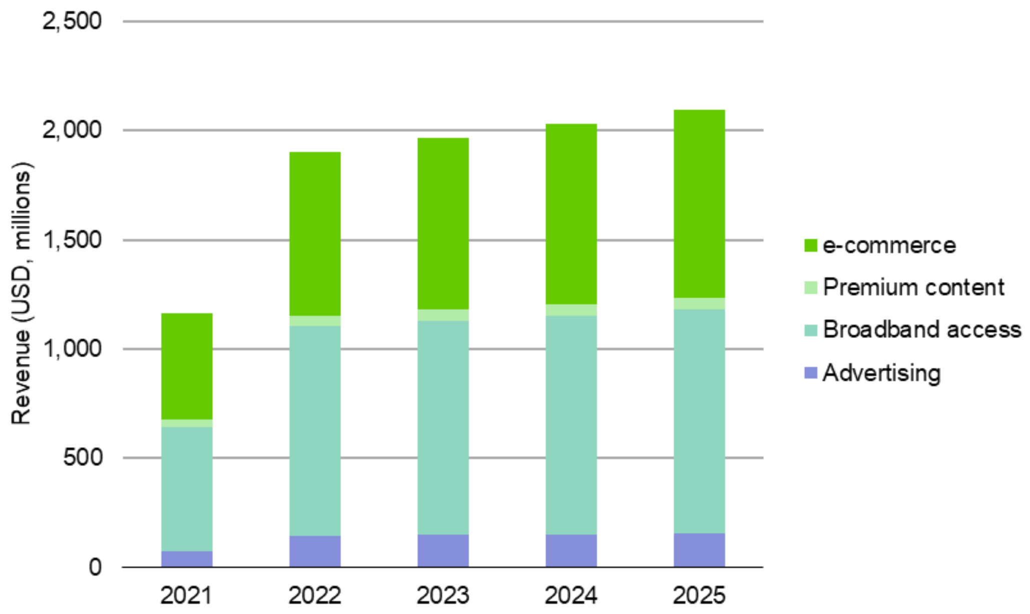


Exhibit 3.7: *Projected broadband-enabled cruise passenger revenue, 2021 to 2025 (USD, millions) [Source: Network Strategies]*

Some ferry operators provide Wi-Fi access to passengers. This market segment, however, lags that of cruise liners, although safety concerns – given a number of accidents over recent years – are likely to provide impetus for improved communications that would be resilient under all conditions.

4 Assessment of cost-effectiveness of satellite

One of the objectives of this study is to identify the point at which satellite becomes more cost-effective than terrestrial technologies (5G access and microwave backhaul) for a notional service. To undertake this analysis we developed a high-level reference model to assess the benefits of providing 5G service with satellite against that without satellite, using spectrum in the 28GHz band.

4.1 Model overview

The reference model calculates the cost incurred by a hypothetical operator in an African country when providing access and backhaul supply in underserved / unserved areas using satellite and 5G technologies.

Underserved / unserved areas are defined as population clusters with lower density (around 50 inhabitants per square kilometre) which are located more than 70km from the closest urban centre or traffic aggregation node.

The model calculates the Total Cost of Ownership (TCO) over the period from 2022 to 2027, for four scenarios (Exhibit 4.1):

- **Scenario 1: 5G** – in which the operator deploys a full 5G Radio Access Network (RAN) and connects the cell site via terrestrial microwave
- **Scenario 2: 5G RAN plus satellite** – same RAN network as in scenario 1 but using satellite connectivity instead of terrestrial microwave
- **Scenario 3**: **Wi-Fi plus satellite broadband connectivity** – deployment of Wi-Fi hotspots to provide broadband access via satellite connectivity
- **Scenario 4: Satellite** – in which the operator deploys a standalone satellite network to provide broadband connectivity.

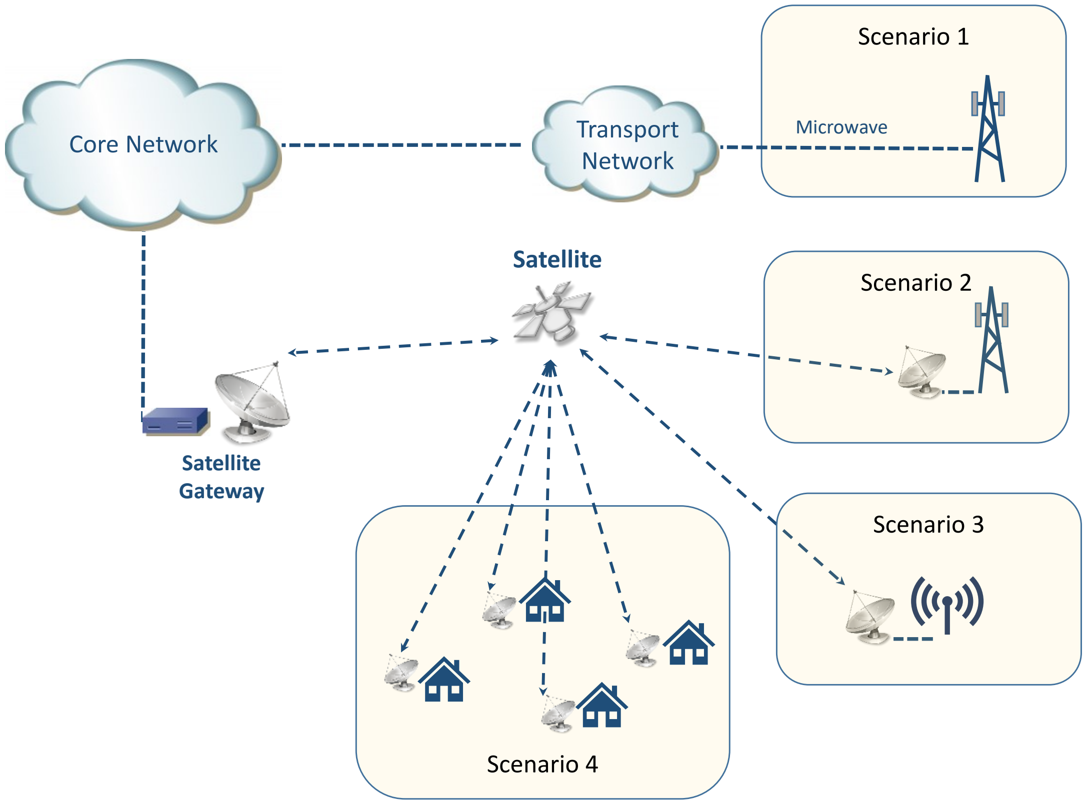


Exhibit 4.1: *Model scenarios [Source: Network Strategies]*

For scenarios with 5G technology the model assumes a 5G RAN operating in mmWave bands, namely 28GHz spectrum in scenario 1. This assumption is used to analyse the cost-benefit resulting from TCO when using the 28GHz band for either terrestrial or satellite broadband applications. Other scenarios where a 5G macrocell could use other 5G frequency ranges are out of scope, because the TCO of those macrocells would be subject to similar assumptions in terms of terrestrial microwave connectivity requirements in unserved/ underserved areas.

In each scenario the model calculates the cost of providing mobile and broadband services in an area equal to the coverage range of a single 5G radio site using mmWave bands.

4.2 Model results

From the analysis of the model results we conclude that satellite is the most cost-effective option for providing:

- Satellite-powered links instead of terrestrial microwave for mobile and broadband services
- Access and backhaul for broadband services.

The cost of satellite services is dependent on the amount of spectrum available. The model assumes that the satellite operator will have full access to the 28GHz band. Any reduction of the amount of 28GHz spectrum allocated for providing satellite services will result in a higher cost of satellite capacity due to reduced economies of scale, which in turn will diminish the economic benefits of using satellite in cases where other technologies are less cost effective.

The lowest cost alternative is scenario 3, followed by scenario 4. Both scenarios are more cost effective than the other two scenarios which include access over 5G technologies (Exhibit 4.2).

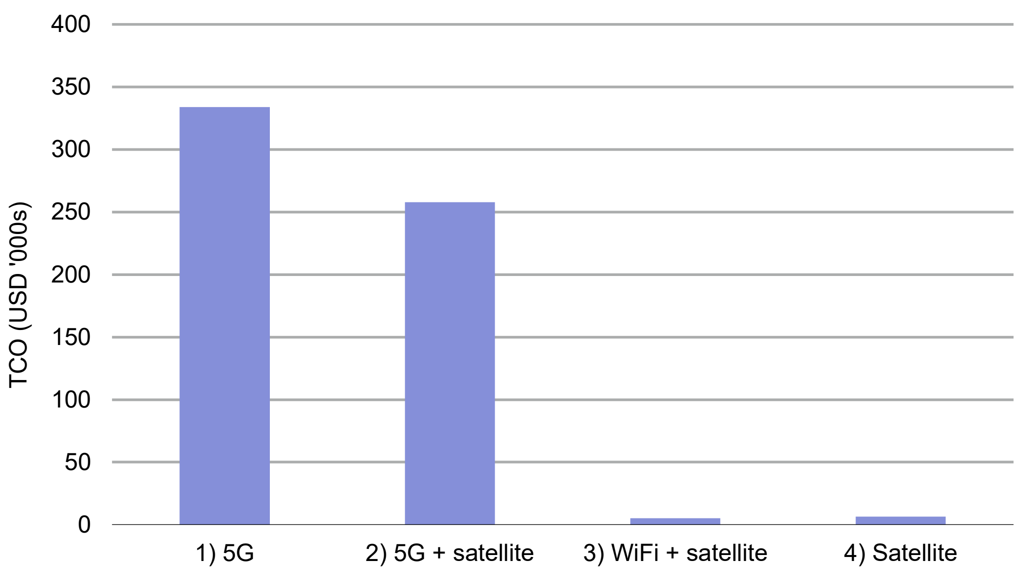


Exhibit 4.2: *Model results [Source: Network Strategies]*

A single Wi-Fi hotspot can serve several subscribers reducing the number of VSATs required in comparison to scenario 4 where one VSAT per subscriber is assumed. The lower capex required for scenario 3 makes this the most cost-effective solution.

Note that the additional revenues generated by mobile services can offset the additional costs of the other scenarios which include 5G access. Therefore, as the most cost-effective alternative of the two suitable for providing mobile services, scenario 2 may be preferable to scenarios 3 and 4 when considering if any additional revenues are viable.

4.3 Results summary

Model results for each scenario are summarised in Exhibit 4.3.

Scenario	*TCO (USD '000s)*
1) 5G	333.8
2) 5G + satellite	257.7
3) WiFi + satellite	5.2
4) Satellite	6.5

Exhibit 4.3: *Model results [Source: Network Strategies]*

5 Concluding remarks

In most countries the 28GHz spectrum band is currently assigned to satellite services, providing connectivity to users without access to terrestrial services, particularly high-speed broadband services. These users could be in unserved or underserved areas, on ships or in the air, and without satellite services utilising 28GHz the options for high-speed broadband are limited. The European Commission has fully protected the 28GHz band for satellite services, along with China, and Australia, while many more continue to do so. Globally, over 120 countries may be identified as having authorised the use of 28GHz for FSS and ESIM in accordance with their national licensing regimes and consistent with the current ITU global allocation for the frequency range corresponding to the band known commercially as the Ka satellite band.

In many developing countries fibre backhaul is not ubiquitous and in such circumstances satellite is necessary to provide connectivity services. In some countries, even if there is interest in investing in 5G mmWave, terrestrial fibre is unlikely to be available for backhaul and therefore satellite services will be required. If the 26GHz band is assigned to 5G while also retaining 28GHz for satellite, then satellite backhaul remains a viable option for terrestrial mobile operators to reach subscribers where fibre or microwave backhaul is not feasible.

When re-planning spectrum bands many regulators examine alternative uses to identify which use maximises the value of that spectrum.

Assessing the economic value of 28GHz for 5G must take into account the loss of value associated with removal of the arrangements for satellite services. This loss in value may have implications for national policy objectives as well as efforts to improve global trade and the aviation and maritime industries.

It therefore follows that the similar 26GHz band would have a higher value for 5G services, as unlike 28GHz assigning 26GHz to 5G will cause no disruption to existing and emerging High-Throughput Satellite services including ESIM for which there are few, if any, alternatives.

Annex A: Model approach, inputs and assumptions

Our analysis of the relative benefits of providing access and backhaul supply in underserved / unserved areas using satellite and 5G technologies is based on a reference model of a hypothetical operator.

The model is based on inputs and assumptions which include:

- definition of underserved / unserved areas based on population density
- technical assumptions such as coverage area, spectrum efficiency and spectrum bandwidth for the hypothetical operator
- unit cost information for network resources such as base stations, microwave links and satellite earth stations
- demand assumptions covering the number of subscribers and usage profiles/parameters.

The following overview of the model (Exhibit A.1) illustrates the key inputs, assumptions and outputs.

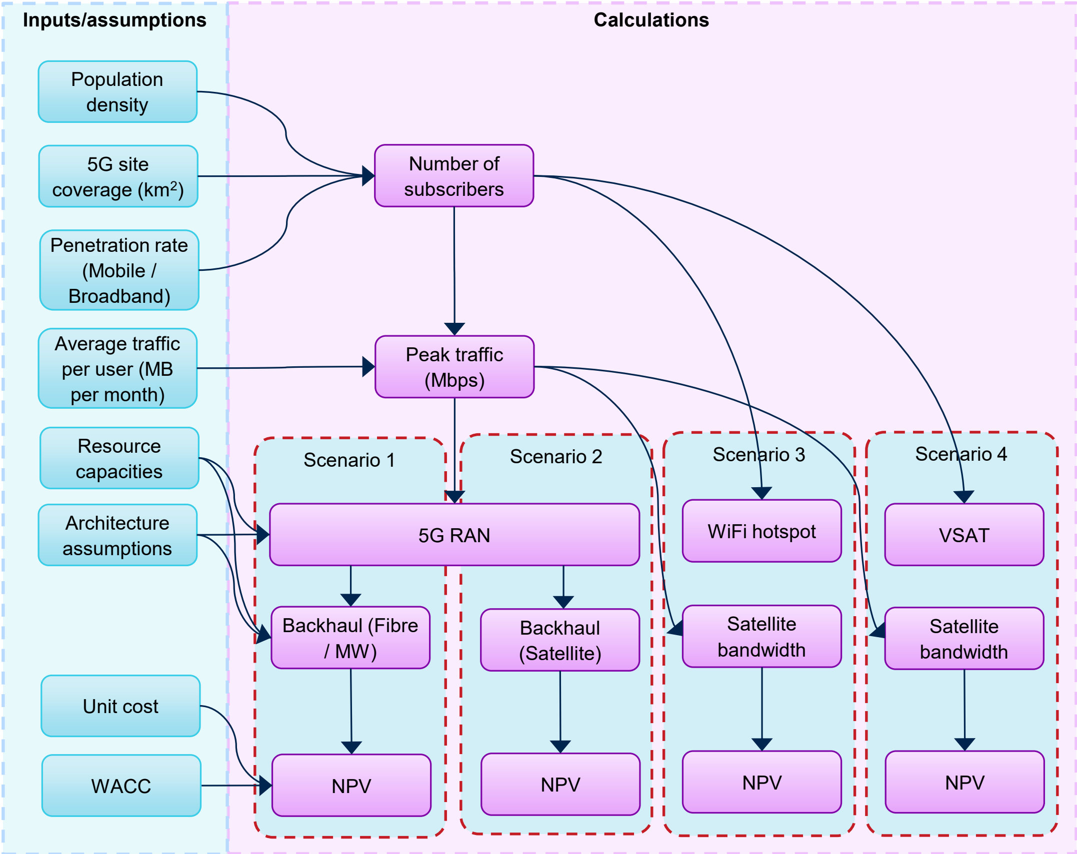


Exhibit A.1: *Cost model map [Source: Network Strategies]*

The model calculates the cost of providing mobile and broadband services in an area equal to the coverage range of a single 5G radio site using 28GHz spectrum. Population density and penetration rates (mobile and broadband subscribers per 100 inhabitants) are then used to calculate the number of subscribers in the coverage area.

Average traffic per subscribers (MB per month) and traffic assumptions (proportion of daily traffic in busy hour) are used to calculate the peak traffic (Mbit/s).

Using capacity and architecture assumptions the model then calculates the amount of resources needed to serve the estimated demand. This includes:

- number of 5G sites and base stations for scenarios 1 and 2
- satellite bandwidth for scenario 2

- Wi-Fi hotspots, VSATs and satellite bandwidth for scenario 3
- VSATs and satellite bandwidth for scenario 4.

Forecasts of mobile and broadband demand are used to calculate the resources needed for scenarios 1 and 2. In the case of scenarios 3 and 4, only broadband demand is considered as the solutions deployed do not support mobile services.

The main inputs and assumptions used in the model are summarised below.

Item	*Capex (USD)*	*Annual opex (USD)*
5G microcell (site and equipment)	99 811	22 761
Microwave (70km range using two hops link)	60 600	10 600
Satellite station	4 000	600
Wi-Fi hotspot and VSAT	1 400	194
VSAT	950	100
Satellite bandwidth ($ per Mbit/s)	-	720

Exhibit A.2: *Model assumptions – cost inputs [Source: Network Strategies]*

Item	*Value*
5G	
Spectral efficiency (b/s/Hz)	3.1 (2022) / 6.73 (2026)
28GHz (TDD) lot size (MHz)	400
Sectors per base station	3
Coverage of macrocell (km^2)	3.15
Wi-Fi	
Subscribers per hotspot[49]	8
Satellite	
Spectral efficiency (b/s/Hz)	2 (Download) / 1.5 (Upload)
28GHz lot size (MHz)	500

Exhibit A.3: *Model assumptions – resource capacities [Source: Network Strategies]*

49 While the Wi-Fi standard has a theoretical limit of 255 connected devices, in practice channel limitations result in performance being degraded with more than eight simultaneous user sessions per access port.

Item	*Value*
Subscriptions per 100 inhabitants	
Mobile	100
Broadband	0.8
Usage by subscription (MB per month)	
Mobile	4,900 (2022) / 14,000 (2027)
Broadband	26,478 (2022) / 70,107 (2027)
Population density (persons per km^2)	50

Exhibit A.4: *Model assumptions – demand inputs [Source: Network Strategies]*

The cost input values and resource capacities have been obtained from public sources and our in-house databases. When required, inputs and assumptions were adjusted to reflect the local conditions of the country modelled.

Demand information used in the model is specific for the country modelled and was sourced from the national telecommunications regulator and a local operator, and complemented with publicly available information.[50]

50 Ericsson Mobility Reports, available at https://www.ericsson.com/en/mobility-report?gclid=Cj0KCQjw5auGBhDEARIsAFyNm9GT-foEcP_0i9nGrVfatmE6nz8pYdhN7YwlMD4K7eDypylMTJNh6ycaAtnsEALw_wcB&gclsrc=aw.ds.