Mobile backhaul options

Spectrum analysis and recommendations

September 2018

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1 Executive Summary

Total mobile service provider revenue stood at more than US$1.05 trillion and supports nearly 800 mobile operators, as well as a highly competitive mobile device, infrastructure, and software developer ecosystem.

At the end of 2017, total mobile subscriptions worldwide reached 8.1 billion, with an annual growth rate of 5.4% year-on-year. A number of regional markets are saturated, but global subscriptions will continue to grow to reach 9.8 billion by 2025. 3G and 4G will represent 51% of total subscriptions, while 5G subscriptions are anticipated to surpass 849 million. Over the course of ABI Research's forecasts, mobile data traffic is anticipated to grow at a Compound Annual Growth Rate (CAGR) of 28.9% to surpass 1,307 exabytes on an annual basis in 2025. 4G and 5G subscribers may only represent 55% of total subscriptions in 2025, but they represent 91% of the total traffic generated in 2025.

Mobile operators have a challenging time backhauling the mobile voice and data traffic from varied environments, such as urban, suburban, rural, offices, residential homes, skyscrapers, public buildings, tunnels, etc. Table 1 outlines how mobile operators rely on a variety of backhaul approaches to transmit their traffic to and from macro and small cell base stations.

Table 1

Mobile Backhaul Technology Trade-Offs
Wireless vs Fixed vs Satellite

Segment	Microwave (7–40 GHz)	V-Band (60 GHz)	E-Band (70/80 GHz)	Fiber-optic	Copper (Bonded)	Satellite
Future-Proof Available Bandwidth	Medium	High	High	High	Very Low	Low
Deployment Cost	Low	Low	Low	Medium	Medium/High	High
Suitability for Heterogeneous Networks	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network	Indoor Access Network	Rural only
Support for Mesh/Ring Topology	Yes	Yes	Yes	Yes where available	Indoors	Yes
Interference Immunity	Medium	High	High	Very High	Very High	Medium
Range (Km)	5-30, ++	1~	~3	<80	<15	Unlimited
Time to Deploy	Weeks	Days	Days	Months	Months	Months
License Required	Yes	Light License/ Unlicensed	Licensed/ Light License	No	No	No

Note: Shading indicates preferred choice for 5G mobile backhaul.

Source: ABI Research

Mobile carriers are increasingly facing the reality of having to deploy a Heterogeneous Network (HetNet) architecture of macro and small cells that may rely on 3G, 4G, and 5G. Microwave and millimeter bands (V-band (60 GHz) and E-band (70/80 GHz)) are very suitable for HetNet backhaul because it allows for outdoor cell site and access network aggregation of traffic from several base stations, which can then be handed off to the mobile switching centers and finally the core network.

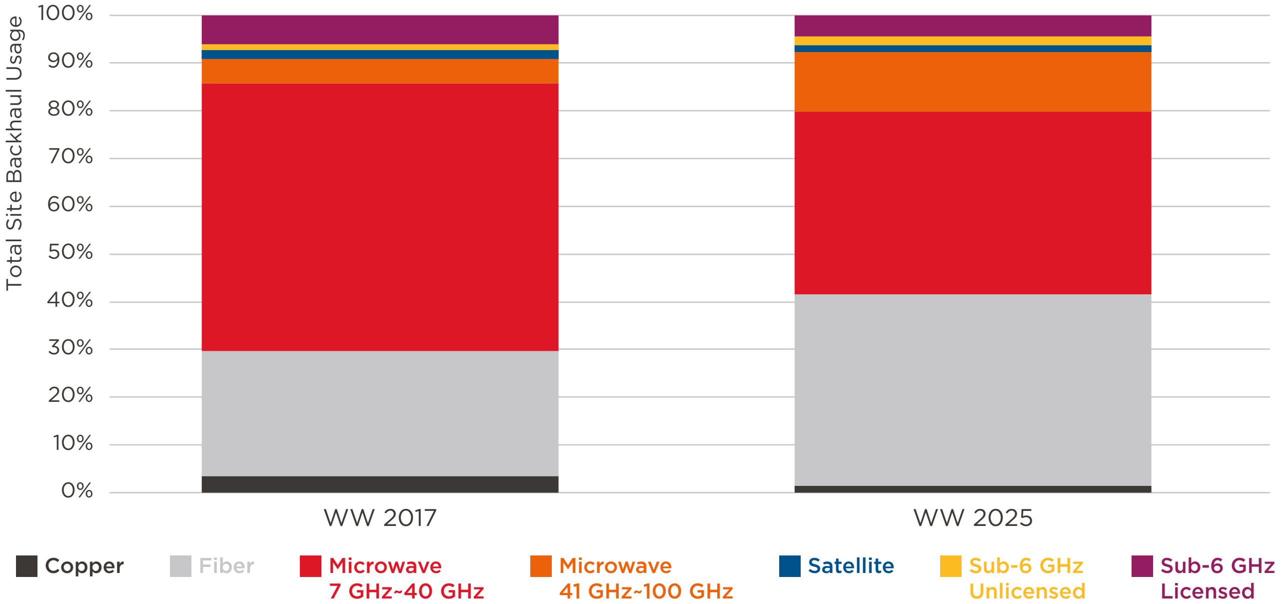
In 2017, the majority share of backhaul links (an aggregate of macrocells and small cells) deployed was in the traditional microwave 7 GHz to 40 GHz (56.1%) bands. The higher bandwidth requirements of LTE are driving a significant share of fiber (26.2%). Bonded copper xDSL connections (3.5%) are available in 2017, but the need for this technology is declining over the next 7 years. Satellite-based backhaul, which primarily plays a role in backhauling traffic in peripheral locations or rural environments where microwave may not exist, represents 1.9% of backhaul links worldwide.

On a worldwide basis, fiber-optic backhaul is expected to grow to 40.2% of macrocell sites by 2025, which just eclipses microwave in the 7 GHz to 40 GHz band with 38.2%. Microwave Line-of-Sight (LoS) in the 7 GHz to 40 GHz bands is still a long-term viable solution for macrocell sites. Microwave links in the 41 GHz to 100 GHz bands will double from 5.1% to 12.6%.

Chart 1

Total (Macrocell & Small Cell) Backhaul by Method

World Markets, Historical 2017 and Forecast 2025

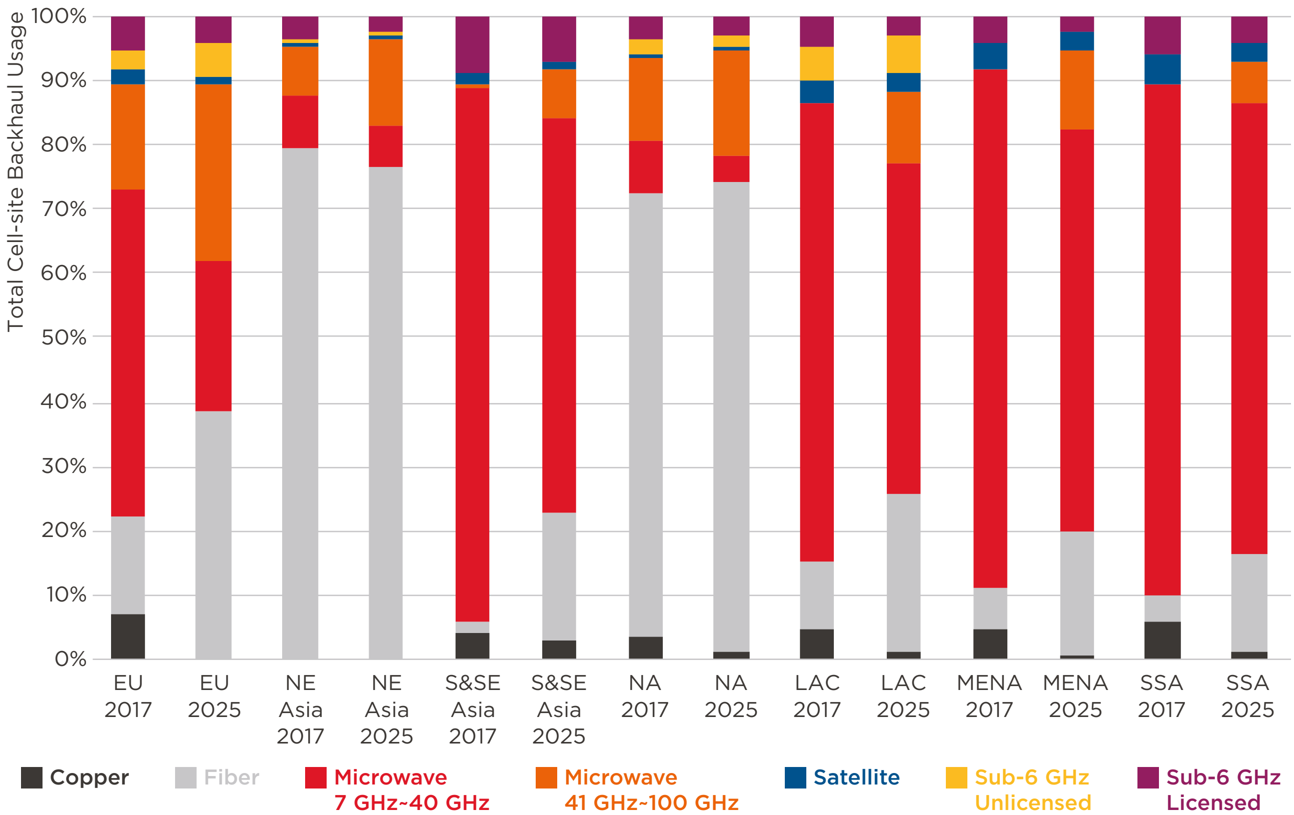


Source: ABI Research

Chart 2

Total (Macrocell & Small Cell) Backhaul by Method

By Region, Historical 2017 and Forecast 2025



Source: ABI Research

This report highlights the mobile cellular backhaul options available to the mobile service provider, the Strengths, Weaknesses, Opportunities, and Threats (SWOT) facing each solution, and Total Cost of Ownership (TCO) considerations, as well as a synthesis of policy and industry recommendations based on primary and secondary research.

2 Fixed versus wireless telco backhaul

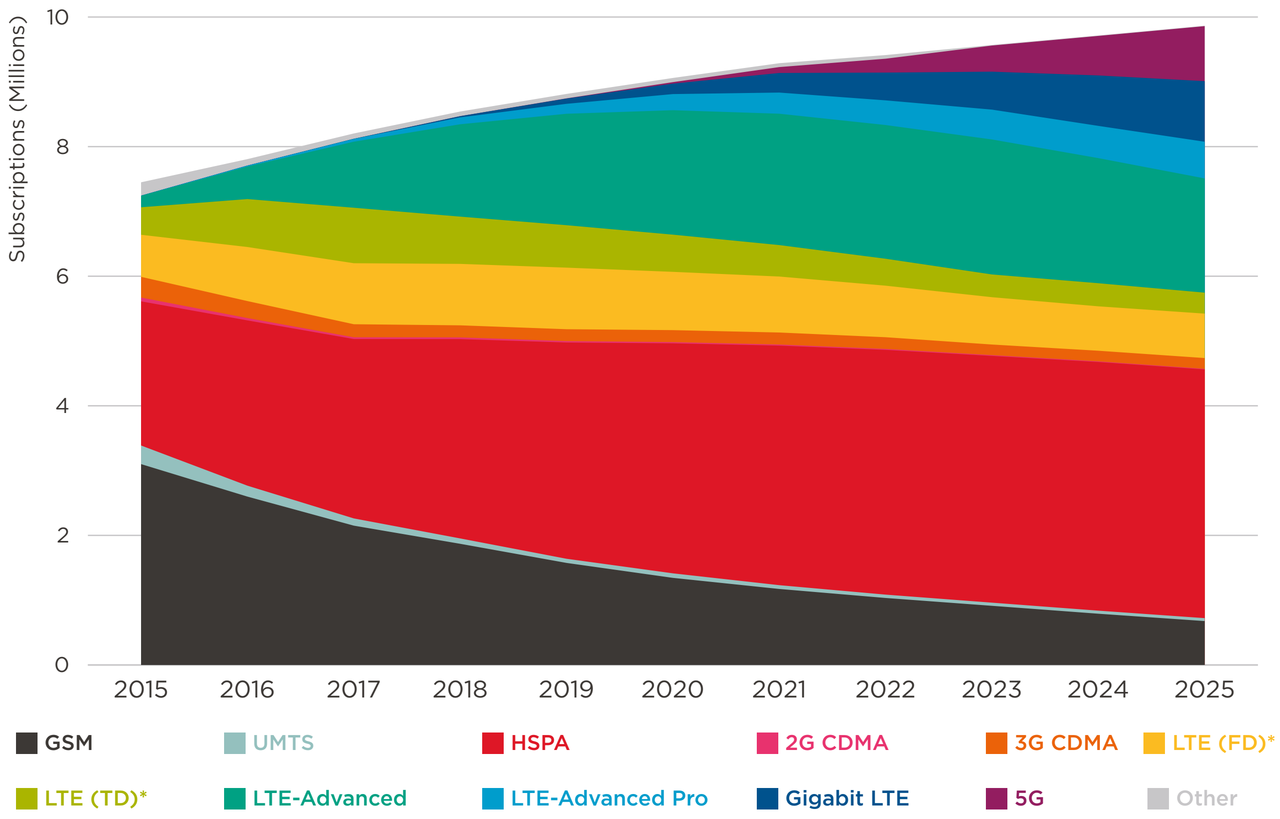
Wireless and fixed-line backhaul infrastructure is an essential component of the mobile telecommunications network. Voice traffic, text messages, instant messages, mobile data, and video traffic all need to be backhauled to and from the mobile cellular base stations to the core network. The success of 4G Long-Term Evolution (LTE) has placed even greater challenges on mobile operators as they strive for more network capacity, latency reduction, and the need to deliver an enhanced user experience. As of January 2018, the Global mobile Suppliers Association (GSA) reported there were more than 651 LTE operators in more than 202 countries. By 2020, the stakes will increase further as next-generation 5G networks are commercialized.

2.1 Growth in subscriptions

At the end of 2017, total mobile end-user subscriptions worldwide exceeded 8.1 billion, with an annual growth rate of 5.4% year-on-year. A number of regional markets are saturated, but global end-user subscriptions will continue to grow to 9.8 billion by 2025. The 2017 subscription count means that overall cellular penetration stood at 110%. At the end of 2017, 3G and 4G subscriptions totaled 5.94 billion, or 73.2%. LTE subscriptions have been growing at a rapid rate; at the end of 2017, there were 2.86 billion, which is 35.2% of the overall total, but by 2025, LTE will surpass 43.3%. By 2025, 5G subscriptions will start to hit critical mass by reaching 849 million. At present, most Machine-to- Machine (M2M)/Internet of Things (IOT) devices use short range unlicensed spectrum. However, cellular-based IOT devices, including LTE Enhanced Machine Type Communications (eMTC) and Narrowband IoT (NB-IoT) are expected to grow to 4.2 billion by 2025 from 376 million in 2017.

Chart 3

2G, 3G, 4G, and 5G Mobile End-User Subscriptions Excluding IoT
World Markets, Forecast: 2015 to 2025



Source: ABI Research

2.2 Upgrading LTE

While 5G is on the horizon, a number of technical innovations in LTE have been approved by the 3GPP. LTE-Advanced Pro, also known as 4.5G, is a notable upgrade that will benefit LTE telcos in emerging and developed markets. The technical features of LTE-Advanced Pro provide peak bandwidth enhancements, greater energy efficiency for IoT connections, more reliable emergency first responder services, and a better voice and video user experience. LTE-Advanced Pro's most notable feature is that it enables high data rates up to 1 Gbps, which is 8X to 10X higher than standard LTE. This high data rate is expected to be particularly invaluable for video traffic as mobile devices start to support 2K and 4K resolution. Other key features include:

- **Peak Bandwidth:** Larger than 450 Mbps, 256 QAM downlink/64 QAM uplink
- **Carrier Aggregation (CA):** Three Component Carriers (CC) CA and higher, up to 32 carriers, enabling Category 9 and above devices
- **Lower Latency:** Shorter transmission time interval and round-trip delay time (10 ms)
- **Advanced Antenna Features:** Three-Dimensional (3D)/full-dimension Multiple-Input Multiple-Output (MIMO), elevation beamforming
- **Utilization of 5 GHz Band:** LTE-Unlicensed, Licensed Assisted Access (LAA)/Enhanced LAA (eLAA), MulteFire
- **DigitalTV:** LTE Broadcast, single cell Point-to-Point (PMP) through superposition coding

2.3 The outlook for 5G

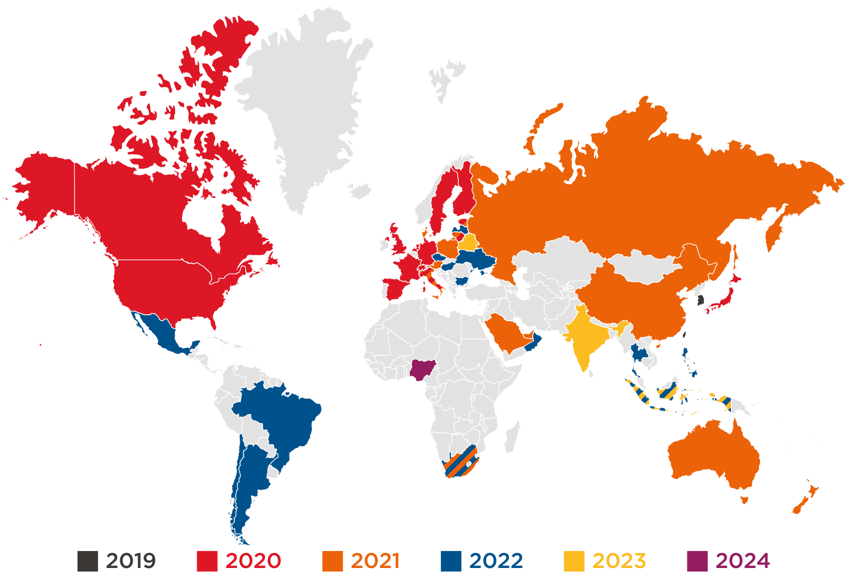
AT&T and Verizon Wireless are jostling to be the first to deploy commercial Fixed Wireless Access (FWA) 5G services by the end of 2018, but the first mainstream 5G mobile and fixed wireless services are expected to commence in 2020. South Korea, Japan, and the United States are likely to be the first countries to do so. 5G is intended to deliver an end-to-end digital transformation with the objective of minimizing Operating Expenditure (OPEX), delivering efficiencies, and driving revenue growth.

A prominent feature of 5G is network slicing. Network slicing treats related logical network functions from the Radio Access Network (RAN) to the core to serve the needs of a specific application, as an “instance” or a slice of the entire network. Examples of network slicing could be Wireless to the x (WTTx) ultra-broadband users, public safety 5G, Industrial IoT, or supporting autonomous driving (Vehicle-to-Infrastructure (V2X)).

In January 2018, the GSA reported that 113 operators in 56 countries had started 5G trials. Some of these trials have been small technical evaluations, while in other countries, they have been wide area pre-commercial demonstrations. Based on ABI Research’s own research, all of the top 50 countries will have one or more 5G networks up and running by 2024 (see Figure 1).

Figure 1

Anticipated Commercial Deployment of 5G Services
World Markets, Forecast: 2018 to 2024



Source: ABI Research

2.4 5G needs additional access spectrum

5G offers an unprecedented leap in bandwidth speeds compared to the previous generation. This is made possible by using high-band frequency spectrum, as well as key antenna technologies, such as massive MIMO. Bands in three spectrum ranges will be needed for 5G: Sub-1 GHz, 1-6 GHz, and above 6 GHz. Crucial 5G spectrum bands above 24 GHz will be agreed upon at the World Radiocommunication Conference in 2019 (WRC-19); this includes 26 GHz and 40 GHz, which already have significant international support for 5G access. Outside of the WRC process, the 28 GHz band is also supported for 5G access by important markets such as the United States, Japan, and Korea. For the initial enhanced mobile broadband use case, spectrum within the 3.3 GHz to 3.8 GHz range is emerging as an important harmonized 5G "mid-band."

The step change in performance expected from 5G networks is, in large part, based on using significantly more access spectrum. The key virtue of the bands above 24 GHz, such as 26 GHz and 28 GHz, is that significantly wider channel bandwidths should be available, leading to significantly faster data speeds and network capacity. As 5G will employ significantly more spectrum in the access portion of the networks, it will also require significantly higher bandwidth backhaul solutions. Section 5 discusses the key wireless backhaul bands and what migration may need to occur to accommodate future 5G access bands.

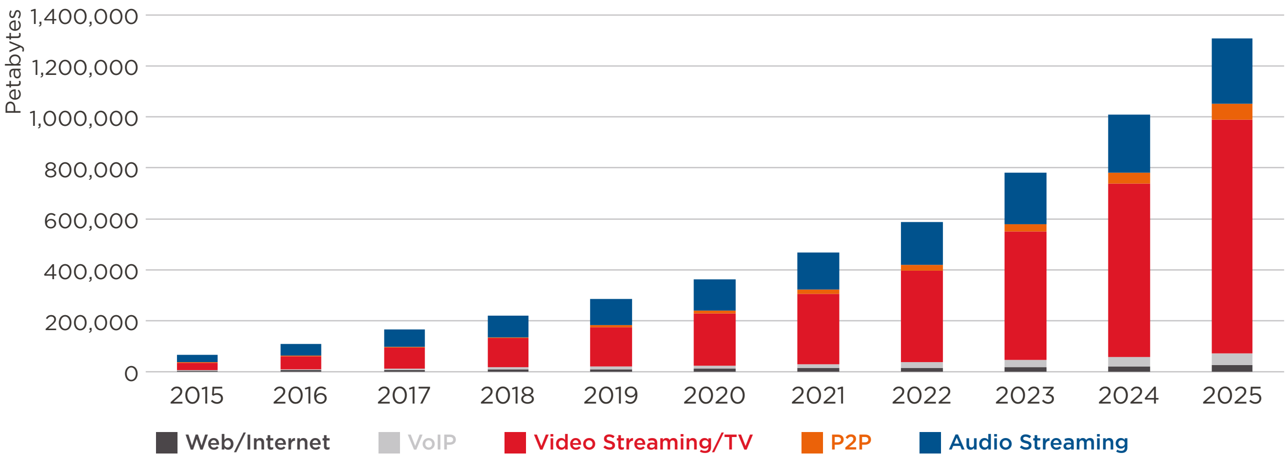
2.5 Mobile data traffic strains the network

All of these mobile data subscribers are continuing to make greater and greater demands on the operators' networks. Over the course of ABI Research's forecasts, mobile data traffic is anticipated to grow at a CAGR of 28.9% to surpass 1,307 exabytes on an annual basis in 2025. 4G and 5G subscribers may only represent 55% of total subscriptions in 2025, but they represent 91% of the total traffic generated in 2025.

Over the 8-year period, there is a crucial shift in the type of traffic that will take its toll on the mobile operator. In 2017, worldwide video streaming generated 81.6 exabytes in traffic or 49.3%. By 2025, video streaming expands to 70% of total mobile traffic worldwide. The global average amount of traffic generated per user per month is expected to grow from 1.71 gigabytes as of year-end 2017 to just under 11.3 gigabytes. In certain markets like Korea and Japan, mobile smartphone users were already generating 12 gigabytes in 2017.

Chart 4

Mobile Network Data Traffic by Traffic Type
World Markets, Forecast: 2015 to 2025



Source: ABI Research

M2M and the IoT may push up the number of non-human connections, but a large proportion of the data traffic generated will come from end users' smartphones and other mobile devices, such as tablets and laptops. There will be fairly dramatic cyclical shifts in data traffic usage throughout the day, as end users commute/travel during a 24-hour day. Additional cell sites, most likely small cell deployments, will need to be deployed to address these cyclical hotspots as end users commute from home to work and back again.

2.5.1 THE IMPORTANCE OF LATENCY

The exponential growth of mobile data traffic will be driven largely by the uptake of streaming TV and movie services, as well as video content in social media and instant messaging. A 4G base station based on a Common Public Radio Interface (CPRI) architecture requires bandwidth of 1 Gbps to 10 Gbps per sector, while a 5G base station with the upgraded Enhanced CPRI (eCPRI) architecture requires 10 Gbps to 25 Gbps. However, mobile service providers cannot ignore the latency requirements for 4G and 5G services. A 4G or 5G base station based on eCPRI architecture requires no more than 75 μs, but even in the most latency-tolerant scenario (S1/NG), latency of no more than 30 ms is needed. Many operators have either upgraded their networks to LTE-Advanced or are in the process of doing so. In the case of LTE-Advanced, new RAN optimization techniques impose critical performance requirements on the X2 interface (essentially the IP control and user plane for communications links), which results in a latency cap of no more than 10 ms from end to end. This means latencies across the backhaul network need to be <1 ms. In 5G, for mission-critical applications, latencies will need to be sub-1 ms.

Figure 2

4G and 5G Bandwidth and Latency Requirements

LTE	Bandwidth	Latency
CPRI	1–10 Gbps/sector	75 μs
S1/NG	1–2 Gbps/site	30/5 ms
5G NR	**Bandwidth**	**Latency**
eCPRI	10–25 Gbps	75 μs
F1	1–10 Gbps	5 ms
S1/NG	1–10 Gbps	30/5 ms

Note: Actual numbers will depend on site size, access spectrum and network type

Source: Ericsson (2017)

Only areas served with fiber-optic cable or microwave links will be able to support the latency tolerances required by some LTE and 5G applications. In areas served by satellite backhaul, mobile operators may be constrained to 2G, 3G, and non-latency-sensitive LTE services.

2.6 Technical capabilities of backhaul solutions

When it comes to backhaul solutions, mobile operators have several technical solutions at their disposal. Copper line, primarily as a bonded Digital Subscriber Line (DSL) solution, is still a backhaul option, but mobile operators are increasingly preferring fiber-optic where available, especially in city centers, but microwave is the mainstay solution for backhauling traffic. Satellite backhaul is deployed for a marginal percentage of backhaul links for the network fringe where existing backhaul infrastructure is not available or new deployments where the operator has not been able to secure long-term Point-to-Point (PTP) or PMP microwave link licenses.

2.6.1 FIBER-OPTIC BACKHAUL

Optical fiber may be used as the physical medium connecting cell sites to Mobile Switching Centers (MSCs) and then to an exchange or central office where it can be transferred to the landline network, long haul metro, and regional networks. As the cost of fiber-optic cable has steadily come down in price and more efficient deployment solutions, such as micro-trenching and fiber-optic insertion solutions, have come into play, fiber-optic has become an increasingly popular option for mobile service providers. The traffic generated by LTE has accelerated the demand for Fiber to the Tower (FTTT) and has required Mobile Network Operators (MNOs) to upgrade many aspects of their backhaul networks to fiber-based Carrier Ethernet.

Even though fiber has significant bandwidth, several techniques in use completely avoid any bandwidth constraints, essentially rendering the fiber assets future-proof. Wavelength Division Multiplexing (WDM) technology combines multiple optical signals by carrying each signal on a different wavelength or color of light. WDM can be divided into Coarse WDM (CDWM) or Dense WDM (DWDM). CWDM provides 8 channels using 8 wavelengths, while DWDM uses close channel spacing to deliver even more throughput per fiber. Modern systems can handle up to 160 signals, each with a bandwidth of 10 Gbps for a total theoretical capacity of 1.6 Tbps per fiber. As can be seen in Section 2.7, fiber- optic adoption is expected to grow from 25.3% of macrocell backhaul links in 2017 to 37.3% in 2025, but microwave is still the predominant backhaul solution due to its capacity capabilities and deployment flexibility.

While fiber-optic has tremendous operational capacity, its main limitation is the cost and logistics of deploying fiber-optic. Over the past 5 years, the cost of deploying fiber-optic cable has come down, in addition to the purchasing price of the fiber-optic cable. Nevertheless, it can take several months to provision each cell site with fiber-optic backhaul, Fiber may cost up to US$70,000 per km, depending on the location; 5 years ago, it was closer to US$100,000.

2.6.2 COPPER-LINE BACKHAUL

With 2G and even some 3G networks, copper-based backhaul was the primary backhaul technology. Given the amount of traffic being generated from LTE users, copper-based backhaul has become an infrequently used solution. At the heart of copper-based backhaul is the T1/E1 protocol, which supported 1.5 Mbps to 2 Mbps. Vendors such as Genesis Technical Systems have responded to the technical challenge by bonding two or more lines together. Having up to 12 bonded paired lines enables bonded copper backhaul to provide over 150 Mbps downlink capacity over 1.5 km, which was previously only capable of delivering 24 Mbps.

Nevertheless, copper lines do not scale easily to provide adequate bandwidth at a distance above a few hundred meters (m) to support 3G and LTE broadband usage. 5G traffic scenarios will prove particularly challenging for mobile service providers. In bonded configurations, monthly costs increase linearly with bandwidth requirements.

Another challenge with copper-based backhaul solutions is due to available DSL bandwidth being inversely proportional to distance, and the longer a DSL connection between the cell site and the aggregation point or digital subscriber line access multiplexer is, the lower the bandwidth of the connection is likely to be. Depending on the DSL variant in use, this generally limits the reach of DSL backhaul for LTE to around 500 m. DSL comes into its own in terms of mobile backhaul for indoor small cells, in-building HetNets, and public venue small cell networks.

A number of DSL technologies are available, including ADSL2+ and VDSL2 that can be used to provide near-term bandwidth relief for high-bandwidth applications like LTE. VDSL2 with vectoring has been shown to achieve data rates of 100 Mbps at distances of up to 400 m, and 40 Mbps can be supported with loops as long as 1,000m. Pair bonding is a well-established technique that can be used to either increase bandwidth or extend the reach of a given bandwidth, making it suitable for LTE backhaul over short distances.

Ethernet over copper is suitable for indoor applications, such as small cells where backhaul can use the existing in-building CAT5/DSL cable. Copper-based backhaul solutions face particular challenges in emerging markets where the value of copper on the scrap metal market has led to theft of copper cable. Even in developed markets, telcos are upgrading copper links with fiber-optic links to better serve mobile cell sites, as well as business and residential users.

2.6.3 SATELLITE BACKHAUL

Satellite backhaul is a niche backhaul solution for mobile telcos. It is deployed in fringe areas of the network, usually in rural scenarios in emerging markets. It is also used as an emergency backhaul communications link solution in developed and emerging markets. Furthermore, satellite backhaul may be deployed as a temporary measure as the telco waits for regulatory microwave licenses to be approved.

Satellite terminal vendors such as Gilat are positioning satellite as a fallback backhaul solution for rural sites where a small cell can be combined with a low-cost satellite modem/router. A recent example of backhaul with satellite technology involved Hughes Network Systems, using its high-throughput satellite modem and Lemko Corporation's Distributed Mobility Wireless Network. Over the years, satellite vendors have been able to improve bandwidth and latency by implementing data compression, byte-level caching, predictive cache loading, and data stream de-duplication. For example, Gilat offers a satellite backhaul transceiver that supports 150 Mbps on the downlink and 10 Mbps on the uplink.

From ABI Research's analysis of backhaul link usage, satellite backhaul constituted 1.9% of worldwide backhaul links in 2017. By 2025, the percentage ratio drops to 1.4 on a percentage basis. It should be noted the overall installed base of satellite backhaul links will increase over the forecast period. But fiber-optic, and in particular, microwave backhaul, are growing much faster. They are the preferred backhaul solutions for mobile telcos as they upgrade from 3G to 4G and 4G to 5G. Nevertheless, there are markets in Africa, South America, and the Middle East where satellite has a complementary role to play.

3GPP Evaluates Satellite Backhaul

Due to its complementary role, there is ongoing standardization work being done. The 3GPP has already evaluated the potential of satellites for 5G backhaul as part of Release 14. It is now proceeding with at least two studies to determine the technical aspects of integrating satellite networks into 5G network infrastructure deployments. One study aims to define deployment scenarios and related system parameters as well as to gain more information on channel models. The second phase of the study will handle evaluation and definition of RAN protocols and architecture. It is unclear what the precise definition of any satellite component to 5G will be at this stage. But it is clear the performance will be notably lower than terrestrial IMT-2020.

LEO Satellite Provider Startups

Latency is a challenging bottleneck for satellite backhaul systems, especially for 4G and 5G traffic. Geostationary satellite-link latency was seen to have a round-trip delay of around 500 ms to 600 ms, which can affect the response time of 4G, and even 3G data applications.

A number of startup satellite providers, such as OneWeb and Telesat, are attempting to address the bandwidth and, just as crucially, the space satellite-to-ground latency challenges. Their approach is to deploy satellites in Low Earth Orbit (LEO). Instead of 36,000 km from Earth, the satellites are 1,500 km away. While this reduces LoS latency to ~50 ms, the LEO satellite company may have to route traffic through additional LEO satellites to reach a satellite ground station. This is because LEO satellites are constantly moving overhead because they are not in geostationary orbit.

There are still large question marks concerning these LEO satellite systems. Many of these LEO satellite systems are still at the design stage, so their commercial deployment status is uncertain. While LEO satellite providers like OneWeb do have an explicit goal of targeting the backhaul needs of mobile telcos, it is far from certain if they can provide carrier-grade reliability to mobile telcos, given the non-stationary LEO coverage, complexity of their networks, and the need to hand-off traffic to terrestrial satellite gateways.

2.6.4 MICROWAVE BACKHAUL

Despite fiber being the first choice for mobile telcos for 4G and 5G backhaul, most operators heavily rely on microwave backhaul solutions in the 7 GHz to 40 GHz bands, as well as the higher microwave bands, such as V-band (60 GHz) and the E-band (70/80 GHz). Backhaul links using the V-band or the E-band are well suited to supporting 5G due to their 10 Gbps to 25 Gbps data throughput capabilities. The main drawback to fiber is its cost. Deploying fiber to a cell site involves trenching, boring, or ducting, and invariably requires permits.

Microwave, on the other hand, is a low-cost option for mobile backhaul, as is the higher frequency E- band; both can be deployed in a matter of days and support a range of up to several miles. Microwave and E-band technologies are developing rapidly with innovations that include ACM, high order QAM, XPIC, compression accelerators, and MIMO, all aimed at increasing bandwidth on the link:

- **Adaptive Coding and Modulation (ACM):** ACM helps manage the modulation, coding, and other signal and protocol parameters to the conditions on the microwave radio link.
- **High Order Quadrature Amplitude Modulation (QAM):** 64-QAM and 256-QAM are often used in digital cable television, but QAMs of 1024 are becoming common in microwave links.
- **Compression Accelerators:** Other capacity-boosting techniques are often employed that involve compression accelerators (both hardware and software) that are used to reduce the volume of traffic on the microwave link by compressing and de-duplicating the data payload.
- **Cross Polarization Interference Cancellation (XPIC):** XPIC can potentially double the capacity of a microwave link.
- **MIMO:** MIMO allows the use of multiple antennas at both the transmitter and receiver to improve communication performance.
- **Multi-Carrier Bonding:** Mobile operators are increasingly combining a low-band microwave link with a high band (typically E-band) to boost capacity, but also to have the assurance of a reliable link that is resistant to atmospheric attenuation (e.g., rain fade).

Due to adequate bandwidth, the possibilities of operating the microwave link in Non-LoS (NLoS), as well as in LoS, makes it suitable for mesh and ring topologies required in backhauling LTE outdoors. The drawback is that microwave requires that a license be obtained, unless the link is in the E-band, which is lightly licensed or even potentially unlicensed as in the case of the V-band. However, because of E-band's and V-band's high frequency, it is subject to atmospheric effects or rain fade, which can attenuate the signal and limit its range. This "limitation," however, is being turned to its own advantage. E-band is proving popular and practical as a solution for high bandwidth, short distance links, which are required for small cells.

Furthermore, E-band links are being combined with a lower frequency band with different properties that serve to get the best out of both bands. By combining a lower-frequency band that has robust propagation properties with a higher-frequency band that has greater capacity, it is possible to achieve high capacity over longer distances with enhanced availability. For example, in the northern latitude climate, the same hop length can be achieved at 70/80 GHz as for 18 to 28 GHz. For a more tropical climate, the same hop length can be achieved at 70/80 GHz as for 15 to 23 GHz.

2.6.5 PERFORMANCE AND TCO TRADE-OFFS

The comparative merits of the various backhaul solutions are complex and no one solution fits all scenarios. The trade-offs for 4G and especially 5G mobile backhaul technology are listed in Table 2.

Table 2

Mobile Backhaul Technology Trade-Offs in Relation to 5G
Wireless versus Fixed versus Satellite

Segment	Microwave (7–40 GHz)	V-Band (60 GHz)	E-Band (70/80 GHz)	Fiber-optic	Copper (Bonded)	Satellite
Future-Proof Available Bandwidth	Medium	High	High	High	Very Low	Low
Deployment Cost	Low	Low	Low	Medium	Medium/High	High
Suitability for Heterogeneous Networks	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network	Indoor Access Network	Rural only
Support for Mesh/ Ring Topology	Yes	Yes	Yes	Yes, where available	Indoors	Yes
Interference Immunity	Medium	High	High	Very High	Very High	Medium
Range (Km)	5-30, ++	1~	~3	<80	<15	Unlimited
Time to Deploy	Weeks	Days	Days	Months	Months	Months
License Required	Yes	Light License/ Unlicensed	Licensed/ Light License	No	No	No

Note: Shading indicates preferred choice for 5G mobile backhaul.

Source: ABI Research

The assessment is dependent on the location and the ground conditions facing the backhaul engineer. For wireless-based solutions, it is essential there is sufficiently available spectrum for future deployments to the backhaul architecture. Deployment cost can be a key criterion when the network operator is faced with deploying several hundred to potentially thousands of (small) cell sites in a year.

- While fiber-optic is considered to provide a versatile, high capacity backhaul link solution that scales well as operators move from 3G traffic, to 4G LTE (and its incremental upgrades LTE-Advanced and LTE-Advanced Pro), and then onto 5G, it is also a comparatively expensive option to deploy.
- Leased fiber-optic is approximately 4X the TCO of microwave PTP and even the higher frequency V-band (60 GHz) and E-band (70/80 GHz) millimeter links. Indeed, microwave deployed in a PMP configuration can be approximately half the cost of microwave PTP backhaul links.
- The cost of satellite terminal equipment located at the base station is in line with microwave equipment installed at the cell site but the operator also needs to factor in the "pay as you use" monthly usage fees. Recent new High-Throughput Satellites (HTSs) have helped to reduce the cost per megabyte. At present, HTS fees is in the range of US$1.5 to US$3 per GB transferred and there is reoccurring monthly fee of between US$500 to US$1,000 depending on the data speed required. The main challenge with satellite backhaul is its variable TCO aspect compared to flat-rate fiber or microwave links.
- Bonded copper is not really being deployed on newly commissioned sites. For the opportunity cost of having to dig a trench, operators are preferring to deploy fiber-optic cable. Copper line also runs the risk of being stolen in certain emerging markets. Copper is, therefore, being used or upgraded to bonded copper where there are existing trenches or poles.

Mobile carriers are increasingly facing the reality of having to deploy a *HetNet architecture* of macro and small cells that may rely on 3G, 4G, and 5G. Microwave and millimeter spectrum (V-band and E-band) is very suitable for HetNets because it allows for aggregation of traffic from several base stations at the periphery of the network, which can then be handed off to the mobile switching centers and onto the core network. The *X2 protocol* is an ultra-fast broadband-related protocol that allows 4G and 5G base stations to communicate directly with each other. This enables the operator to potentially use mesh topologies to offload traffic.

Other criteria that operators are also burdened with are *time to deploy* and *licensing*. While a cell site is usually operational for several years, if not decades, the network manager is often under pressure to get a cell site "operational" as quickly as possible. Having to wait several months for a fiber-optic or copper line connection to be provisioned to the cell site can be debilitating on network traffic in the short term.

The "blue" highlighted cells in Table 2 indicate attributes that particularly benefit 4G, and especially 5G backhaul. Clearly, fiber-optic does have its role to play in specific scenarios, and microwave links in the 6 GHz to 40 GHz bands have been a mainstay of wireless backhaul for macrocell sites; the V- band and E-band could play a more prominent role in the mobile operators' backhaul networks. Additional spectrum is being legislated and harmonized by a number of countries in the 92 to 114.25 GHz (W-band) and the 130–174.8 GHz (D-band) bands to further boost the available backhaul capacity.

2.7 Macrocell site backhaul deployments

While the macrocell microwave LTE backhaul market will not grow at the same rate as small cell microwave backhaul, it does show consistent growth. In 2017, the majority share of macrocell backhaul links deployed was in the traditional microwave 7 GHz to 40 GHz (56.9%). The higher bandwidth requirements of LTE are also driving a significant share of fiber (27.2%). Bonded copper xDSL connections (3.6%) were available in 2017, but the outlook over the next 7 years is likely to decline.

On a worldwide basis, fiber-optic use for backhauling grew to 39.6% of macrocell sites by 2025, which is a robust growth rate, but microwave 7 GHz to 40 GHz still captures 45.1% of all backhaul links. Microwave LoS in the 7 GHz to 40 GHz bands is still a long-term viable solution for macrocell sites.

Microwave links in the 41 GHz to 100 GHz bands will grow over time. For macrocell, backhaul links in this category will effectively double from 3.2% to 6.1%.

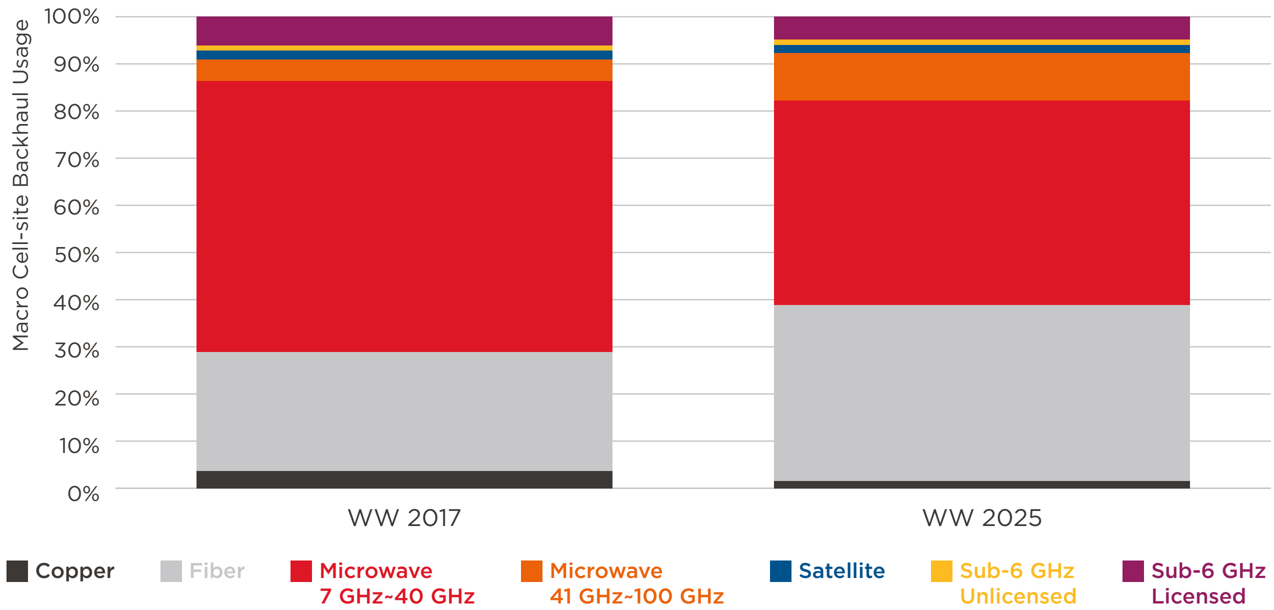
Transmission distances are contained to ~3 km, but being able to support data throughput of up to 25 Gbps to even 100 Gbps makes it suitable for macrocell sites in downtown locations with high levels of traffic.

There is some marginal (less than 1%) use of Wi-Fi for macrocell site backhaul (e.g., in some emerging markets like India and Latin America), but the unlicensed nature of Wi-Fi, combined with growing interference from neighboring public and private Wi-Fi access points, as well as poor transmission distances, severely limits deployments. Satellite will remain a niche solution, seeing some deployments in rural areas where microwave or other cabled technologies are hard to justify.

Comparing the backhaul links analysis ABI Research performed in 2013 *versus* the current analysis based on historical 2017 data, the forecast for fiber-optic deployment has been essentially in line with previous expectations, as well as for microwave: 7 GHz to 40 GHz. What is notable is the more rapid decline of copper-based backhaul links (3.6% share versus the previous 10%). Copper has not scaled capacity-wise as effectively as microwave, which is comparatively low cost to deploy, but has also experienced upgrades in modulation, size of channels, and interference mitigation. Mobile operators have not only upgraded their access networks to support LTE-Advanced, but also LTE-Advanced Pro, so operators have opted for more scalable backhaul capacity solutions. In the current forecast, satellite represented 2% of links in 2017, compared to a forecasted 0.1% in the previous report. Satellite backhaul is a niche solution, an "edge of network" solution, but it does have a complementary role to play in the mobile network, especially in developing markets. In these markets, low disposable income and universal coverage required by regulators can oblige operators to use satellite backhaul. In some developed markets, satellite backhaul has been deployed in emergency or natural disaster situations.

Chart 5

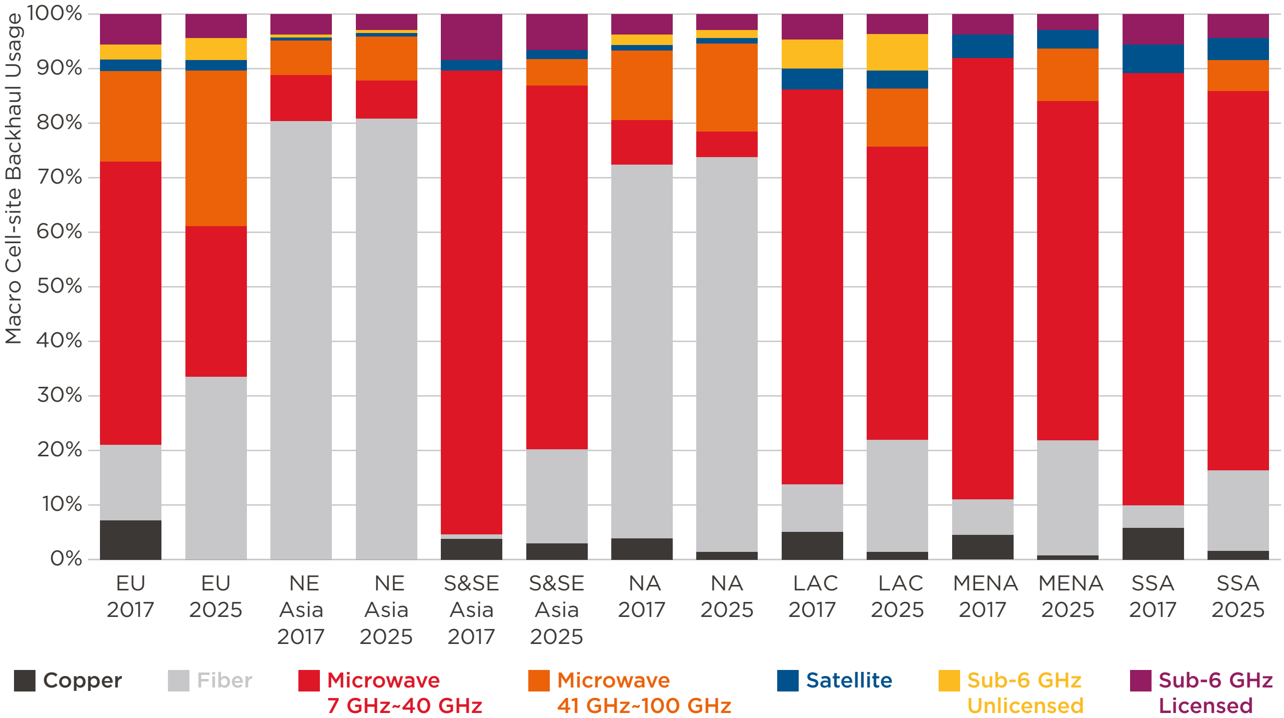
Macro Backhaul by Method
World Markets, 2017 and 2025



Source: ABI Research

Chart 6

Macro Backhaul by Method
Regional Markets, 2017 and 2025



Note: Detailed total worldwide, and by region, 2G, 3G, 4G and 5G segmentations for backhaul links by method of transmission can be found in Appendix 1 on page 66.

Source: ABI Research

2.8 Addressing small cell deployments

As LTE subscriber adoption and traffic builds, mobile operators have been increasingly reliant on small cell site deployments. In 5G, small cells providing 3.5 GHz and even higher 26 GHz or 28 GHz access coverage will be even more essential. Small cells promise a new "underlay" of outdoor and indoor, low-power microcells, picocells, and even femtocells that are deployed on public and private infrastructure within the urban environment. Sites being considered include:

- Pole tops (e.g., street lighting, traffic lights, telco poles, etc.)
- Busstops
- Building walls
- Building rooftops

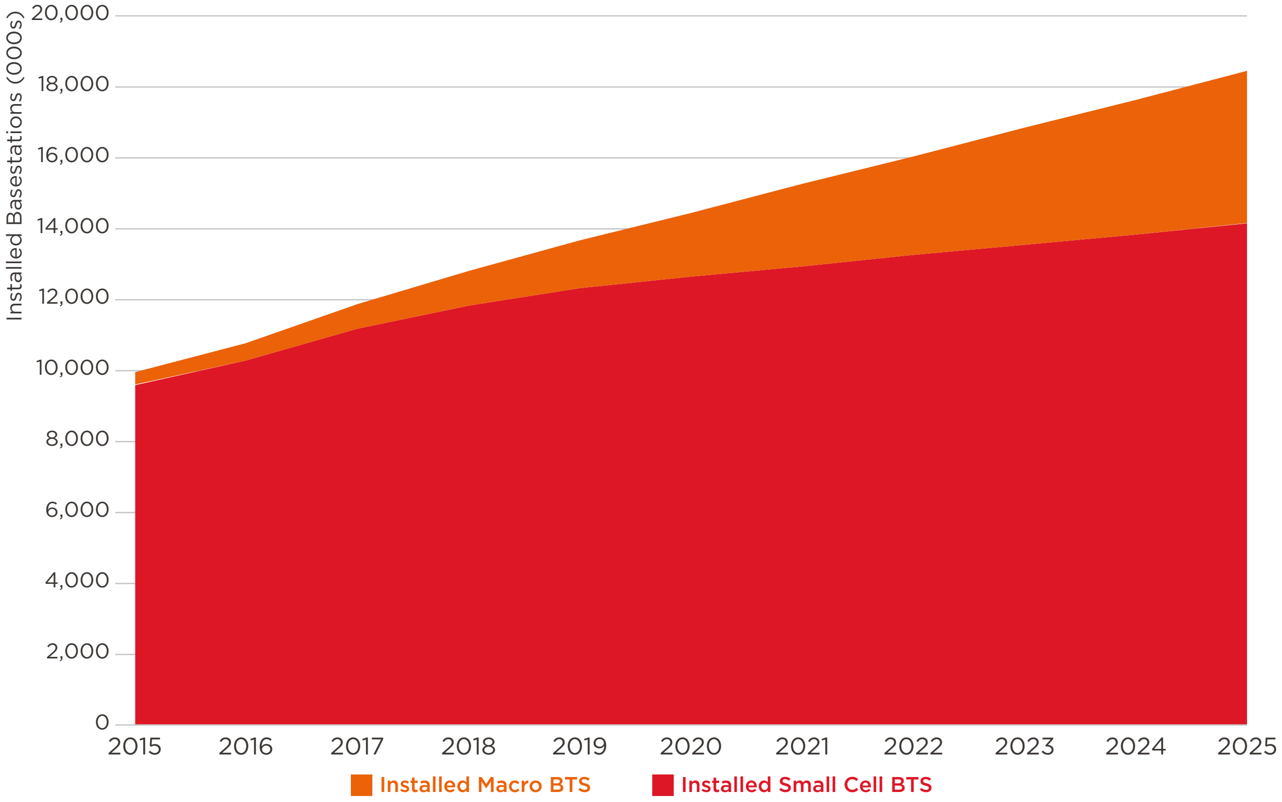
These new sites will need to be compact, simple to install, and energy efficient, and incorporate an organically scalable and tightly integrated backhaul solution. As a result, there will be many more sites—some vendor projections estimate that up to 10 small cells will be deployed for every macro site. Small cells hold out the promise of great gains for end users, but pose a massive challenge for operators—particularly in backhaul.

Small cell deployments, so far, have mainly been concentrated in Northeast Asia, Europe, and the United States. Throughout the forecast period, the installed base of macrocell sites grows from 11.1 million in 2017 to 14.1 million in 2025. In the same period of time, small cells are expected to grow from 0.71 million to 4.3 million (see Chart 7).

Chart 7

Installed Cell Sites by Cell Type

World Markets, Forecast: 2015 to 2025



Source: ABI Research

To address the backhaul needs of small cells, a combination of PTP and PMP solutions will be needed.

2.9 Small cell site backhaul deployments

To address the backhaul needs of small cells, fiber-optic can prove costly and logistically challenging to execute on a comprehensive scale where there is limited, pre-existing, installed fiber-optic cable. To date, a sizeable proportion of small cells deployed has been in urban cities with a high level of fiber-optic provisioning. For example, in Tokyo, Japan, and Seoul, South Korea, small cells are serviced by fiber-optic backhaul links in some locations. In the United States, Crown Castle has installed more than 50,000 small cells supported by fiber-optic cable.

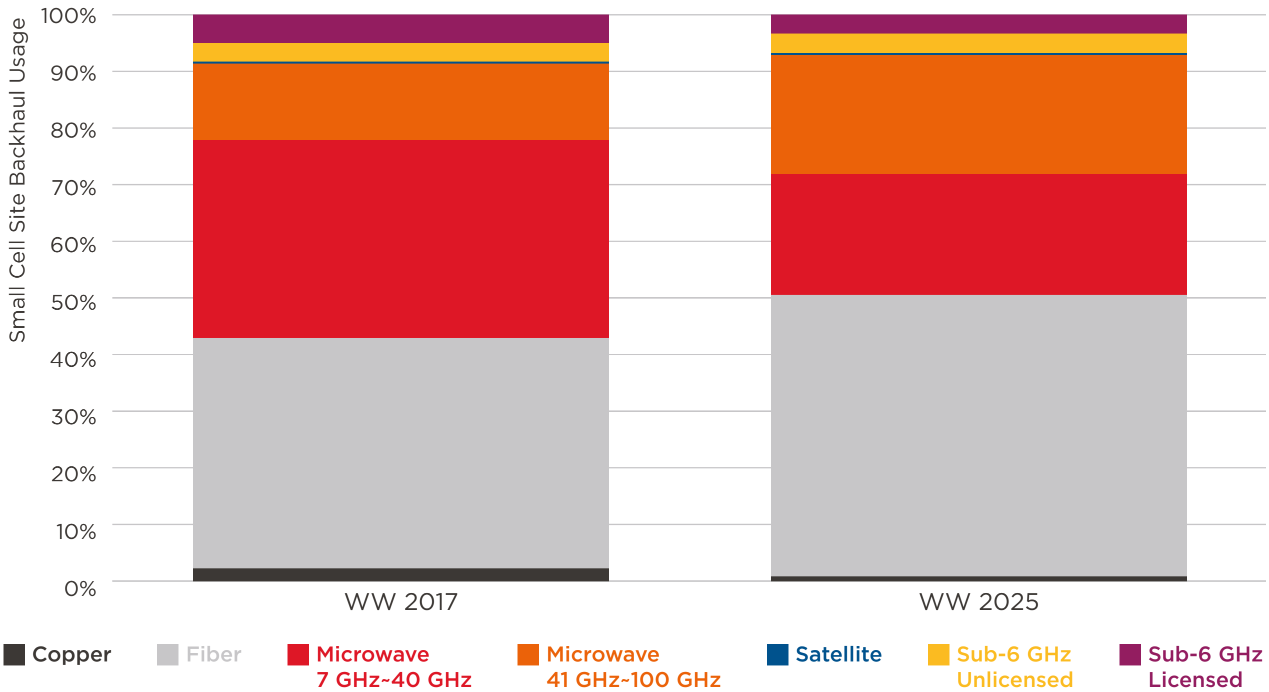
Fiber-optic is the predominant backhaul method for small cells with 43.2%, followed by microwave in the 7 GHz to 40 GHz range with 35.2%. By 2025, the percentage of small cells supported by fiber-optic will grow to 56.1%. Microwave links in the 41 GHz to 100 GHz range grow from 10.4% to 13.1%.

While licensed and unlicensed sub-6 GHz have NLoS properties, the increased prioritization of sub-6 GHz spectrum for access services is likely to constrain the adoption of backhaul links in the sub-6 GHz bands. The higher microwave bands, especially the E-band, the V-band, and the D-band, will encourage small cell vendors to offer solutions with those operating parameters. The higher bandwidth and data rates available in the 60 GHz band means that this technology will become a popular option as links are daisy-chained and aggregated for transport back to the network core (see Chart 8).

The small cell market has had a more challenging outlook. Small cells have been regularly commented on by vendors and mobile operators as a necessary feature of the RAN to be able to handle the future growth in traffic. However, operators have held back, preferring to squeeze additional capacity out of their existing networks. Nonetheless, 4G LTE traffic is now achieving significant levels, and with 5G going commercial in 2020, small cell deployments with fiber-optic provisioning have outpaced expectations. Fixed telco operations have been accelerating their rollouts of fiber-optic in urban areas, where the small cells tend to be. The outlook for microwave in the 7 GHz to 40 GHz range has remained in line with expectations; the same is true for microwave in the 40 GHz to 100 GHz range, as well as satellite.

Chart 8

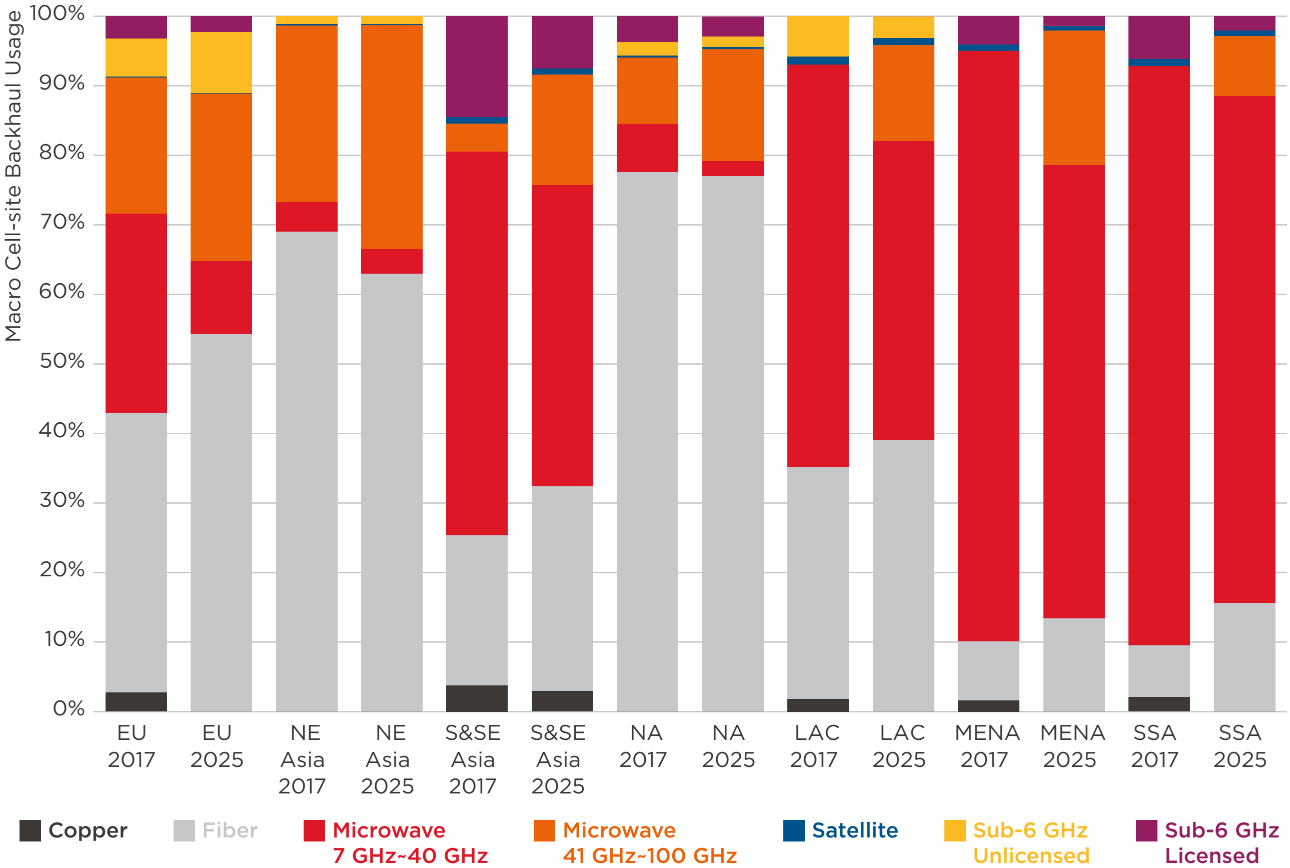
Small Cell Backhaul by Method
World Markets, 2017 and 2025



Source: ABI Research

Chart 9

Small Cell Backhaul by Method
Regional Markets, 2017 and 2025



Note: Detailed total worldwide, and by region, 2G, 3G, 4G and 5G segmentations for backhaul links by method of transmission can be found in Appendix 1 on page 66.

Source: ABI Research

2.10 Stakeholders analysis

The framework for this analysis is quite extensive. The mobile operators are the key stakeholders. Many operators have anywhere from several thousand to hundreds of thousands of cell sites to manage. And that is "before" the growth in small cell site deployments.

The deployment scenarios for those cell sites are complex and diverse. They can range from 50m lattice towers to angled rooftop deployments on public buildings/private multi-dwelling unit buildings, to streetlight outdoor small cells. NLoS transmission blockages, such as skyscrapers, large trees, and hillsides, pose additional challenges for operators.

Operators will need a wide range of fixed and wireless backhaul solutions from a larger number of manufacturers to cater to the various scenarios. While the ecosystem is heavily segmented, competition has led to a number of innovative solutions.

In the mainstream macrocell microwave market, the largest vendor is Ericsson, but other vendors have closed the gap. Notable vendors include Huawei, NEC, and Nokia, which acquired Alcatel-Lucent and its microwave portfolio. Aviat Networks and DragonWave-X also have comprehensive portfolios.

The small cell site deployment represents a potential line of disruption to the incumbents. Vendors such as Huawei, Tarana Wireless, Cambridge Broadband Networks, Cambridge Communication Systems, Siklu Communications, and VubIQ are providing robust small cell backhaul solutions. There are at least 30 vendors in the wireless backhaul ecosystem. The level of competition is intense and not every vendor will remain commercially viable in the long term. Over the past 5 years, the number of vendors has contracted by approximately 20%. A small percentage of operators will opt for multi- vendor (three or more) arrangements, but given that the vast majority of backhaul vendors have proprietary solutions, operators will not be able to use these backhaul solutions in a modular manner.

2.11 Potential regulatory considerations

Mobile operators have a challenging time backhauling the mobile voice and data traffic from varied urban, sub-urban, rural, office, residential home, high-rise buildings, public buildings, tunnels, etc. They need options. As can be seen in Chart 5 in Section 2.7, macrocell's fiber-optic's prevalence does grow from 25.3% to 37.3%, but there is still a heavy dependence on LoS microwave, LoS millimeter wave, and even 802.11ac Wi-Fi (primarily 5 GHz). This usage outlook reflects maturing technical solutions that will need the spectrum support from national regulators.

This pressure to support backhaul solutions and spectrum for the macrocell site market is also reinforced by the need to support the backhaul connectivity for small cell deployments that are expected to reach 4.3 million by 2025 on a worldwide basis. Spectrum and licensing considerations are investigated in the following sections.

3 Wireless backhaul equipment harmonization

The wireless backhaul network equipment market is characterized by a number of multinational vendors, such as Ericsson, Huawei, and NEC, as well as a number of specialized boutique vendors that solely target the backhaul market. The macro microwave cell site backhaul market was worth US$8 billion in 2017. The microwave/millimeter small cell backhaul market is starting to build traction, but by 2020, ABI Research calculates its value will be US$3 billion. It is, therefore, worth delineating the ecosystem, identifying the key players, and assessing what opportunities there are for harmonization and standardization.

3.1 Wireless backhaul equipment vendor ecosystem

Apart from the large end-to-end system suppliers, most vendors can be partitioned by wireless backhaul technology with some offering multiple technologies. For example, Aviat offers products for both microwave and E-band applications, DragonWave has a portfolio containing sub-6 GHz, microwave, and millimeter wave products, and Ceragon's portfolio offers sub-6 GHz and E-band radios.

For each of the technologies, there is a group of specialist or niche vendors represented. Examples include: in microwave, 41 GHz to 100 GHz bands technologies by BridgeWave; in the E-band (70/80 GHz), LightPointe, Loea, Siklu, and VubIQ; and Airspan, Cambium, Fastback Networks, Proxim, Radwin, and Tarana are companies that specialize in sub-6 GHz systems. The specialists in microwave small cell backhaul include Cambridge Broadband Systems Limited (CBNL), Cambridge Communication Systems (CCS), and Intracom.

Large vendors such as Nokia, Aviat, Ceragon, Cisco, DragonWave-X, Huawei, and NEC. offer complete end-to-end infrastructure portfolios that feature multi-technology small cell backhaul portfolios. These companies offer small cell backhaul technologies that cover all segments, either as a wholly-owned product or in partnership with the specialist vendors. Other specialists are Hughes Networks Systems and iDirect for satellite backhaul.

In the small cell wireless backhaul equipment market, the "most effective" backhaul technology for small cells is a hotly debated topic. There are multiple technologies available for small cell backhaul, and it is likely that a mix of technologies will be required, depending on the deployment scenario. These include NLoS schemes in either licensed or unlicensed bands, which are suitable for use in urban environments where LoS techniques are less effective than they are in suburban and rural settings.

Another technology, the recently released 60 GHz or V-band for unlicensed use, shows potential, because the attenuation effects of oxygen absorption work in favor of linking closely spaced small cells with short hops. Another emerging technology is the E-band (70/80 GHz) and the W-band (92 to 114.25 GHz), which with very wide channels make 10 Gbps to 25 Gbps data rates a real possibility in the backhaul, without the complexities of high-order modulation schemes.

Table 3

Wireless Mobile Backhaul Vendor Ecosystem Portfolio Comparison

Vendor	Sub-6 GHz Unlicensed	Sub-6 GHz Licensed	Microwave (7–40 GHz)	V-band (60 GHz)	E-band (70/80 GHz)	TV White Space	Satellite
Airspan		●					
Aviat Networks			●		●		●
BridgeWave Communications				●	●		
Cambridge Broadband Networks			●				
Cambridge Communication Systems			●				
Cambium Networks	●	●					
Carlson Wireless						●	
Ceragon	●	●			●		
Communication Components (formerly Blinq Networks)		●					
DragonWave-X	●	●	●	●	●		
E-band					●		
Ericsson	●		●	●	●		
Fastback Networks		●					
Huawei			●		●		
Hughes Network Systems							●
iDirect							●
Intracom			●				
LightPointe Wireless				●	●		
Loea Communications					●		
NEC			●	●	●		
Nokia Networks			●				
Proxim	●	●					
Ruckus Wireless	●						
Radwin	●	●					
Siklu Communications				●	●		
Sonus Networks (Taqua)		●					
Tarana Wireless		●					
VubIQ				●			

Source: ABI Research

3.2 Impact of fragmented spectrum bands

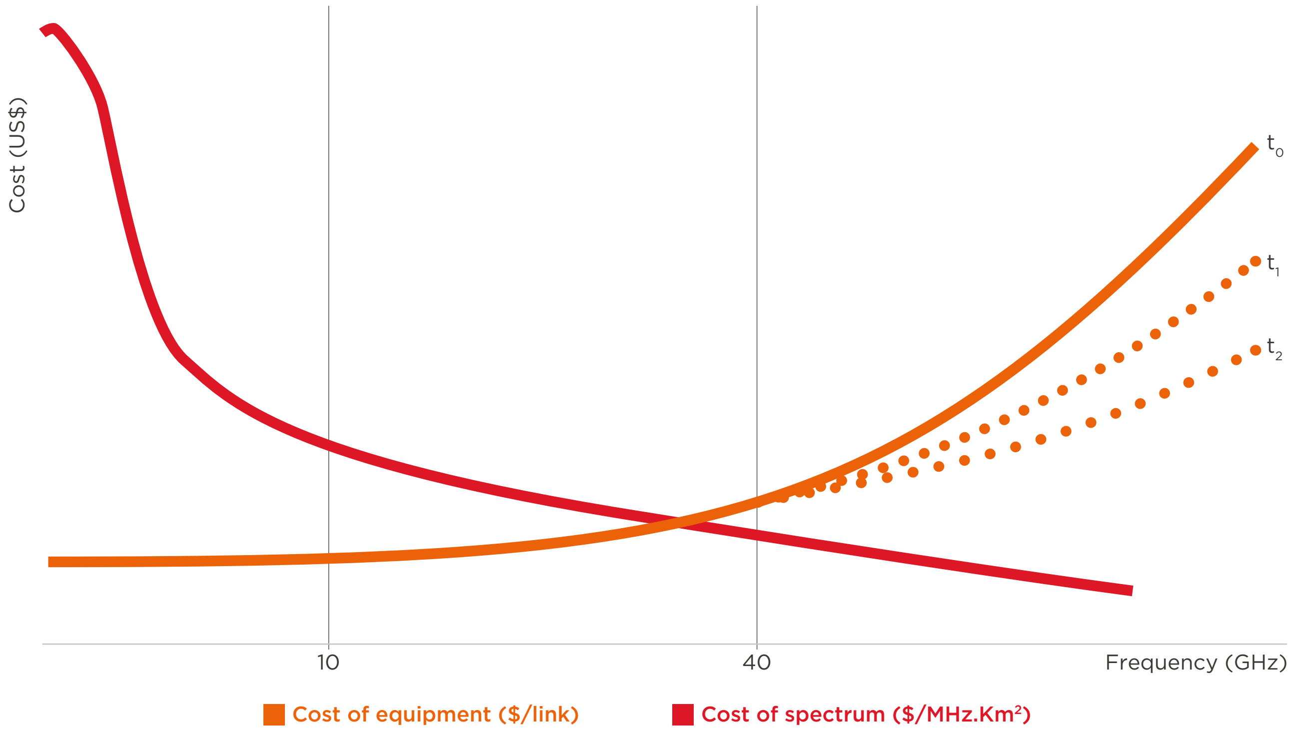
Depending on how one defines a contiguous block of mobile telco backhaul spectrum, there are at least 52 bands in use for wireless backhaul between the range of 1 GHz and 95 GHz. The true number is likely to be much higher.

Based on research interviews conducted with equipment vendors, the incremental costs of supporting different frequency ranges (e.g., migrating to 32 GHz from 28 GHz) is fairly marginal. It is the broader support for a spectrum category (such as the 60 GHz or the 70/80 GHz bands) that has proven to be the greater challenge. There are, in fact, two cost equations taking place as one moves up the frequency bands:

- The size and cost of the antenna drops as one moves up the frequency bands. The antenna size for E-band backhaul is well suited for the small cell form factor.
- The cost of producing the electronic components, especially for the baseband/transceiver, used to be high for spectrum bands over 40 GHz (see Figure 3). The rationale for this has largely been driven by economies of scale. However, over the past 5 years, regulators have increasingly made available spectrum above 40 GHz and this has galvanized the infrastructure vendors to scale up production. As can be seen from Chart 11 (Regional Backhaul Spectrum Allocation by Frequency Range), the majority of wireless backhaul deployments have been in the 10 GHz to 40 GHz bands. However, ABI Research has observed a substantial shift in the availability of spectrum in the 70 GHz to 90 GHz bands.

Figure 3

Cost of Spectrum versus Cost of Equipment over Time



Source: ABI Research, others including CBNL

The implementation of novel semiconductor engineering initiatives, such as silicon/germanium chips, has helped push down the cost of equipment curve.

3.3 Opportunities for standardizing wireless backhaul

There has been some discussion as to whether there are opportunities for standardizing or harmonizing the hardware for wireless backhaul. There are currently more than 30 wireless backhaul vendors addressing PTP, PMP, and LoS, as well as NLoS solutions. These solutions operate from the sub-6 GHz all the way up to the 90 GHz E-band and satellite backhaul.

The number of vendors in this sector does provide a key market indicator: the wireless backhaul market is starting to mature. Over the past 5 years, the number of vendors has contracted by approximately 25% and will continue to consolidate over the next 5 to 7 years. Many of the vendors are startup companies or at least boutique specialists. Only a handful of companies—Ericsson, Huawei, NEC, and Nokia—have infrastructure solution portfolios that extend beyond backhaul.

Many smaller vendors will, therefore, seek a merger with a larger parent company in order to secure additional financial resources, economies of scale from larger production facilities, or improved leverage for input cost negotiation with suppliers. The marketplace will inevitably consolidate.

ABI Research would advocate that is a healthy process for the wireless backhaul industry. The range of solutions witnessed is a function of the competitive pressure on the wireless backhaul marketplace. The current and perceived future profits from wireless backhaul solutions have served to attract startups and entrepreneurs, many of which have financial backing from venture capital firms.

3.3.1 DIGITAL AND SIGNAL PROCESSING INNOVATIONS

Due to the significant number of small cells that will be deployed over the next 7 years, backhaul must evolve to be compatible with the small cell value proposition and become an integral part of the small cell. The way some vendors are doing this is to innovate at the silicon level and bring advanced digital and signal processing techniques to bear on the problem, maximizing link performance and mitigating interference in complex PMP and NLoS topologies.

Vubiq has incorporated silicon-based Integrated Circuits (ICs) into a novel waveguide packaging solution that facilitates low-cost, high-volume production of these radios. Furthermore, the company has incorporated the radio into a standard WR-15-type waveguide to enable customers to directly outfit their own antennas. These silicon IC production tools are transforming the cost of manufacturing backhaul solutions. BridgeWave Communications, which supplies 4G millimeter wave backhaul solutions, also relies on silicon/germanium RF technology that enables high-power operation, while the high level of integration delivers a lower cost of coverage.

3.4 Hybrid wireless backhaul solution integration

Competition has slimmed down the ecosystem. There has been momentum to introduce a certain amount of standardization in the radio infrastructure architectures, such as the **Open Base Station Architecture Initiative (OBSAI)** and the **CPRI** that has reduced costs and improved interoperability.

The OBSAI standard has had considerable success in bringing down the cost of base station-related equipment, but has now been largely superseded by the CPRI standard. The OBSAI was a trade association created by LG Electronics, Hyundai, Nokia, Samsung, and ZTE in 2002 with the objective of creating an open market for cellular network base stations.

The OBSAI specifications defined a number of parameters:

- The internal modular structure of the wireless base station
- Provided a set of standard Base Transceiver Station (BTS) modules with specified form, fit, and function, so that a BTS vendor can acquire and integrate modules from multiple vendors in an Original Equipment Manufacturer (OEM) fashion
- Specify the internal digital interfaces between BTS modules to assure interoperability and compatibility
- Support for different access technologies, such as GSM/EDGE, CDMA2000, WCDMA, and LTE

The CPRI standard offers infrastructure vendors and mobile service providers a flexible interface between Radio Equipment Controllers (RECs) and Radio Equipment (RE). The CPRI allows the replacement of copper or coax cable connections between a radio transceiver and the base station, so that a connection can be made from a more remote or more convenient location (fronthauling). Usually, this uses a fiber-optic connection, but it can be microwave, as long as latency is kept to a minimum. The CPRI specification was initiated by Ericsson, Huawei, NEC, and Nokia.

Both solutions are based on the implementation of digital radio over fiber, whereby the radio signal is sampled and quantized, and, after encoding, transmitted toward the Baseband Unit (BBU). However, the two specifications differ in the way that information is transmitted. The CPRI is a serial line interface transmitting Constant Bit Rate (CBR) data over a dedicated channel, while the OBSAI uses a packet- based interface. Based on initial research, it looks like most global vendors have chosen CPRI for their products, as the standard is considered to be more efficient than OBSAI.

3.4.1 AUTOMATION AND ZERO TOUCH

As mobile operators prepare for 5G, their networks are becoming increasingly complex, with often thousands or even tens of thousands of network elements. Mobile service providers are, therefore, aspiring to achieve "zero touch" network management. Self-Optimizing Network (SON) procedures and tools are becoming essential features of radio network infrastructure, and this includes backhaul.

SON promises that wireless backhaul will become self-configuring, self-optimizing, and self-healing, much like the small cell RAN itself in 3GPP Rel. 8 and later. The self-configuration feature is intended to render the wireless backhaul link "plug-and-play." Self-optimization establishes the presence of neighboring backhaul radios and mitigates interference, while the self-healing feature adjusts the link's transmission parameters to compensate for a failed link or a new link addition.

It is unlikely that small cells can be made to be plug-and-play in terms of their backhaul interfacing on an individual cell site by cell site basis. It is more likely that "clusters of small cells" from a particular vendor are installed. The respective clusters of small cells and their backhaul links would need to be "aware" of the other vendor solutions on the network, and self-organizing processes would be needed to mitigate interference and allow the various components from different vendors to work seamlessly together.

3.5 Stakeholders analysis

Among the vendors offering some form of SON for wireless backhaul (for their own solutions) is Nokia, which worked with Coriant to develop a SON-based backhaul solution in 2015. Airspan is another vendor offering a form of SON embedded in its small cells, which it calls AirSON and makes use of electronically steerable MIMO antennas, removing the need for manual alignment during installation, coupled with a zero-touch provisioning feature that enables rapid single-person deployment.

Siklu also offers SON-based zero-touch plug-and-play installation on its 60 GHz Etherhaul-600 radios for small cell backhaul, and according to the company, the product can be installed by an unskilled technician and rendered operational in a matter of a few minutes.

3.6 Potential regulatory considerations

This section has largely focused on competition theory, chipset innovation, hardware standardization, and collective negotiation, but there are some regulatory coordination activities needed to support overall backhaul solution harmonization. ABI Research does advocate that coordination efforts are put in place to support some crucial wireless backhaul initiatives:

- More active promotion of the 70/80 GHz E-bands for wireless backhaul in the international regulatory community.
- More active promotion of the 60 GHz V-band for wireless backhaul in the international regulatory community.
- Promotion and support for spectrum needed for PMP backhaul applications, with the associated need for per block licensing in the 10 GHz, 32 GHz, and 60 GHz bands.
- The main microwave bands 10 GHz to 40 GHz are generally deemed to have sufficient spectrum, but more effort is needed to align similar microwave bands in more markets, particularly at the regional level. This would have the benefit of bringing down the cost of equipment.
- Potential bands that have secured a degree of regional support include the 6 GHz, 7 GHz, 8 GHz, 11 GHz, and 13 GHz bands, 18 GHz; 23 GHz and 24 GHz; 38 GHz and 40 GHz. As part of those efforts, channel sizes have also been increased (e.g. to 112 MHz and 224 MHz wide) to support greater capacity especially for 4.5G LTE and 5G.

4 LoS versus NLoS wireless backhaul

Historically, most wireless backhaul links have been LoS due to the high frequencies being used, as well as the narrow beam widths used. In the past 10 years, NLoS has become a viable solution that should prove particularly advantageous with clusters of small cells that mobile operators are expected to deploy over the next 5 to 10 years.

4.1 LoS versus NLoS comparison

When comparing small cell wireless backhaul to wired small cell backhaul, there is an added consideration and that is whether both ends of a link are "visible" to each other or not. LoS solutions tend to operate in the higher microwave and millimeter wave ranges. LoS systems also have higher gain antennas and narrow beam widths compared to NLoS systems.

NLoS links generally operate in the sub-6 GHz frequencies. Near-Line-of-Sight (nLoS) can operate up to around 10 GHz. These backhaul links make use of these signals' ability to penetrate or diffract around obstacles. Unlike LoS, these systems do not require alignment at set up. NLoS systems can potentially offer better coverage in dense urban environments, provided the links support the bandwidth, synchronization, and latency requirements of the RAN.

4.1.1 LoS advantages

A LoS wireless small cell backhaul solution, such as microwave, 60 GHz, and E-band, require, as the name implies, direct, unobstructed visibility between the transceivers at each end of the link. A highly directional beam transmits data between two transceivers and transports the data in a straight line with little or no fading or multipath radio interference. This is a highly efficient use of spectrum, as multiple microwave transceivers can function within a few feet of each other and reuse the frequency band for transmitting separate data streams.

Mainly used for high-bandwidth applications for outdoor small cell deployments, rather than indoor femtocells or picocells, LoS links can allow a single small cell with integrated backhaul, such as a lamppost femtocell, to communicate with the next point of aggregation. Microwave is best used as a highly directive beam, so spectrum is not much of an issue; two microwave transceivers can be used at very close range compared to NLoS technologies. This setup is useful in areas with a high concentration of cells.

4.1.2 LoS disadvantages

LoS applications are more effective in some situations than others. For example, a park where many trees could block LoS is an impractical location for small cells backhauled through LoS technology. Pole tilt and sway are also a concern for small cell backhaul, and this becomes increasingly important for frequencies above 18 GHz where the antenna beam width is narrower. This is a concern for operators wishing to deploy small cell backhaul on structures like utility, lighting, and traffic poles, which were not originally designed to resist sway to the extent required by microwave backhaul.

Another problem lies in the cost of the backhaul, which can be considerable, especially for scenarios in which 2,000 to 5,000 small cells could be deployed in a typical network, such as in metropolitan hot-zones. Each transceiver requires a PMP link, and if daisy chains are involved, the cost of the backhaul increases quickly when compared to NLoS. This becomes significant, as skilled technicians are usually required for antenna alignment for LoS technologies, and when large numbers of small cells are deployed, the costs become prohibitive. On the other hand, NLoS technologies are much more plug-and-play and can be set up in a short amount of time with lower labor costs.

4.1.3 NLoS advantages

Vendors with expertise in Orthogonal Frequency-Division Multiplexing (OFDM) technologies are offering OFDM-based products with proprietary optimizations for NLoS backhaul. NLoS backhaul can service the coverage area for small cell deployments by relaying information back to the central base station that provides coverage. NLoS backhaul needs only to be placed within range of the backhaul radio unit. NLoS systems using OFDM present a level of tolerance to multipath fading and other wireless channel impairments not possible with LoS systems.

Properly designed NLoS solutions can provide coverage for various types of small cell setups; however, the 100 Mbps capacity limit, higher latency, and latency variability of these solutions limit their ability to aggregate multiple sites. As a result, an upper limit exists as to how many small cells can be blanketed through this type of solution in order to ensure that each covered cell receives a certain Quality of Service (QoS) and has a minimum capacity per link.

The main advantage of NLoS technology is that a single NLoS base station can provide coverage for multiple small cells within the coverage area. NLoS systems also circumvent the need for an unobstructed path between the transceivers, making this technology extremely helpful for future planning and upgrades. NLoS solutions are easier to plan and more convenient to deploy than LoS solutions.

4.1.4 NLoS disadvantages

NLoS technology has an upper limit to the amount of data that each coverage area can backhaul. OFDM-based NLoS technologies are well suited to 3G networks. To illustrate, assume that an OFDM-based NLoS technology provides about 1 Gbps of backhaul data transfer. In the situation where LTE peak download rates are around 300 Mbps, roughly three small cells can connect at the peak to the NLoS backhaul without causing bottleneck issues. Since LTE small cells will initially require about 100 Mbps to 150 Mbps on average, about six to nine small cells can fit under this umbrella from the standpoint of bandwidth. This number is better than the initial three, but their peak rates may not be as high as designed capacity if the cells are packed under one NLoS backhaul coverage area.

NLoS backhaul solutions also limit spectrum; in certain areas, frequency planning would have to be coordinated to avoid producing too much interference. Additionally, if the solutions use unlicensed frequencies, they would need to be coordinated to avoid interference with other cell sites using the same spectrum bands. Given the current rate of growth for data usage, every bit of usable spectrum that could connect a mobile user to the internet should and will be used for this purpose. Mobile consumer and mobile user connectivity take up many of the best NLoS frequencies. Using these frequencies for backhaul could pose a problem.

4.2 Topological considerations

When it comes to deploying their wireless backhaul links, operators have traditionally deployed PTP solutions, which have been typically LoS, but PMP is increasingly becoming a serious contender.

4.2.1 POINT-TO-MULTI-POINT

In a PMP arrangement, a central hub transceiver links to multiple small cells. The hub typically uses multiple sector antennas so that links can be maintained with a number of small cell terminals surrounding the hub site, such that the hub transceiver bandwidth is shared with the small cell terminals. In a PMP deployment, a single access point on one side of the link is set up to cover a sector that spans 90° in one direction, thus blanketing an area that can contain multiple base stations. In this topology, for every “N” microwave links, only N+1 radios are required, representing a Capital Expenditure (CAPEX) saving over PTP networks and also an OPEX saving, because adding another base station only requires one radio to establish the link, with a consequent reduction in setup time.

PMP technology is deployed mostly in high-density urban areas. PMP microwave links require smaller antenna sizes compared to PTP systems and reduce spectrum rental fees, as the same frequency can be used for multiple links, which makes PMP links fast to deploy and cost efficient. Operators are increasingly considering deployment of PMP networks for backhaul in the heavy cellular traffic sites in their urban locations for its advantages of deployment in small cells.

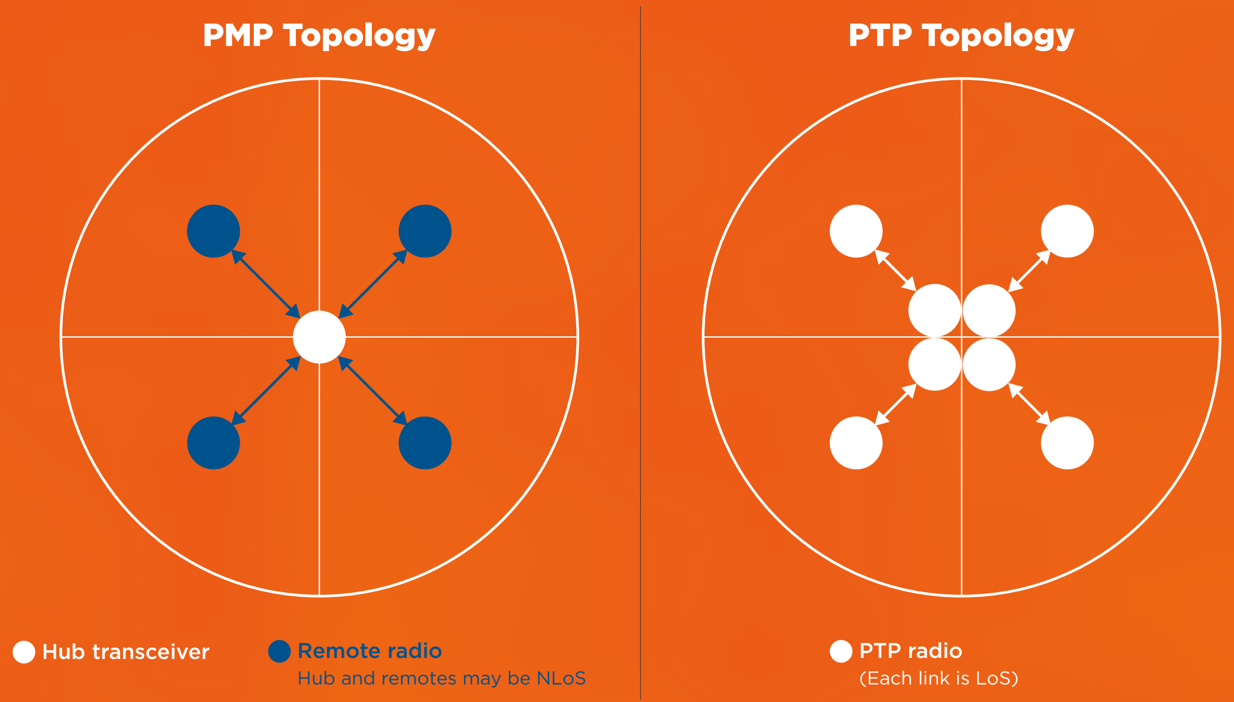
4.2.2 POINT-TO-POINT

In contrast, PTP topologies are typically LoS with highly directional antennas at each end of the link, and each small cell can access the full link bandwidth. PTP topologies require transceiver hardware at each side of the link. When compared to a PMP connection of “N” small cells in the backhaul access layer, a PTP array would result in double the number of transceivers for a functional small cell site (i.e., two N transceivers per link). PTP connections would be expensive for this setup, requiring two transceivers for each link, possibly increasing the cost of a backhaul link, but offering higher bandwidth to the small cell. Each link requires its own antenna at each end, so the Point of Presence (PoP) site can soon become overcrowded with many antennas. Figure 4 compares the PTP and PMP topologies and illustrates the differences in the number of radios required in each case.

Figure 4

PMP and PTP Backhaul Topologies Compared

Four-Cell Small Cell Network



Source: ABI Research

4.3 TCO backhaul considerations

Using these two arrangements as building blocks, combinations can be used to create more complex arrangements. In chain or tree arrangements, PTP links are interconnected in a daisy chain with traffic combined with each successive small cell as the link nears the aggregation PoP. The daisy-chain topology is used in PTP layouts to extend a branch and increase the distance from a base station to a PoP. Small cell architectures provide coverage in closely spaced locations, so a daisy chain could connect multiple small cells to an egress point.

Because a daisy chain requires multiple backhaul elements to connect a small cell, this would be economically viable only in certain use case scenarios. To keep costs down, small cells need to reduce backhaul costs as much as possible. If setting up an outdoor picocell requires a three-hop microwave daisy chain to provide backhaul, the backhaul equipment will probably be just as expensive or even more than the small cell itself. Daisy chains would be more useful to microcell base stations. The cost of anything smaller than a microcell base station would not justify the use of this setup. The capacity of this type of backhaul must be properly dimensioned to take into account the number of downstream cells, which must be supported, perhaps, as in the case of ring network arrangements, by providing redundant links to ensure resistance to link outages.

4.3.1 RING NETWORK

A ring topology, as the name suggests, is built from a chain of PTP links that circles back on itself. One of the disadvantages of a ring is that it takes many radio hops to reach a distant small cell, which adversely affects latency. Increasing the ring capacity for increased demand can be expensive because each node must receive similar upgrades. One way to increase ring capacity is to interconnect each node so the ring becomes a mesh network. Ring network configurations are proving to be an increasingly common deployment architecture for backhauling traffic across a country or across regions.

4.3.2 MESH NETWORK

In a mesh network, the close proximity of neighboring cells allows them to interconnect and create a tightly knit and resilient network, because there are many redundant links that provide multiple paths between the nodes.

Wi-Fi networks can be set up for mobile backhaul and operate in the 2.4 GHz or 5 GHz bands. While the 2.4 GHz band could be used for backhaul, the high degree of congestion and limited size of channels does not make the 2.4 GHz band a viable option for backhauling 4G and 5G traffic. Therefore, it is typically the 5 GHz band, using 802.11ac modulation schemes, that is being used for backhaul where licensed PTP or PMP licenses are not available.

Currently, Wi-Fi has a mesh protocol layer that can be set up for mesh networking. The mesh uses the Wi-Fi protocol standards, so it could be deployed only in Wi-Fi-designated frequencies (currently 2.4 GHz and 5 GHz). In addition, many outdoor Wi-Fi access points already support this, or could, through a slight modification or addition to the unit.

In-band mesh networks use the licensed frequencies of the 2G, 3G, or 4G/LTE RAN. The attitude toward in-band mesh is starting to shift. Until 3 years ago, many MNOs did not consider in-band backhaul very favorably because it was perceived to cannibalize expensive licensed spectrum, resulting in loss of capacity in dense urban and metropolitan areas. However, where the operator has sufficient spectrum, they are implementing the solution. Sprint, for example, uses in-band cellular links in the 2.3 GHz band to backhaul traffic from small cells in urban cities such as New York.

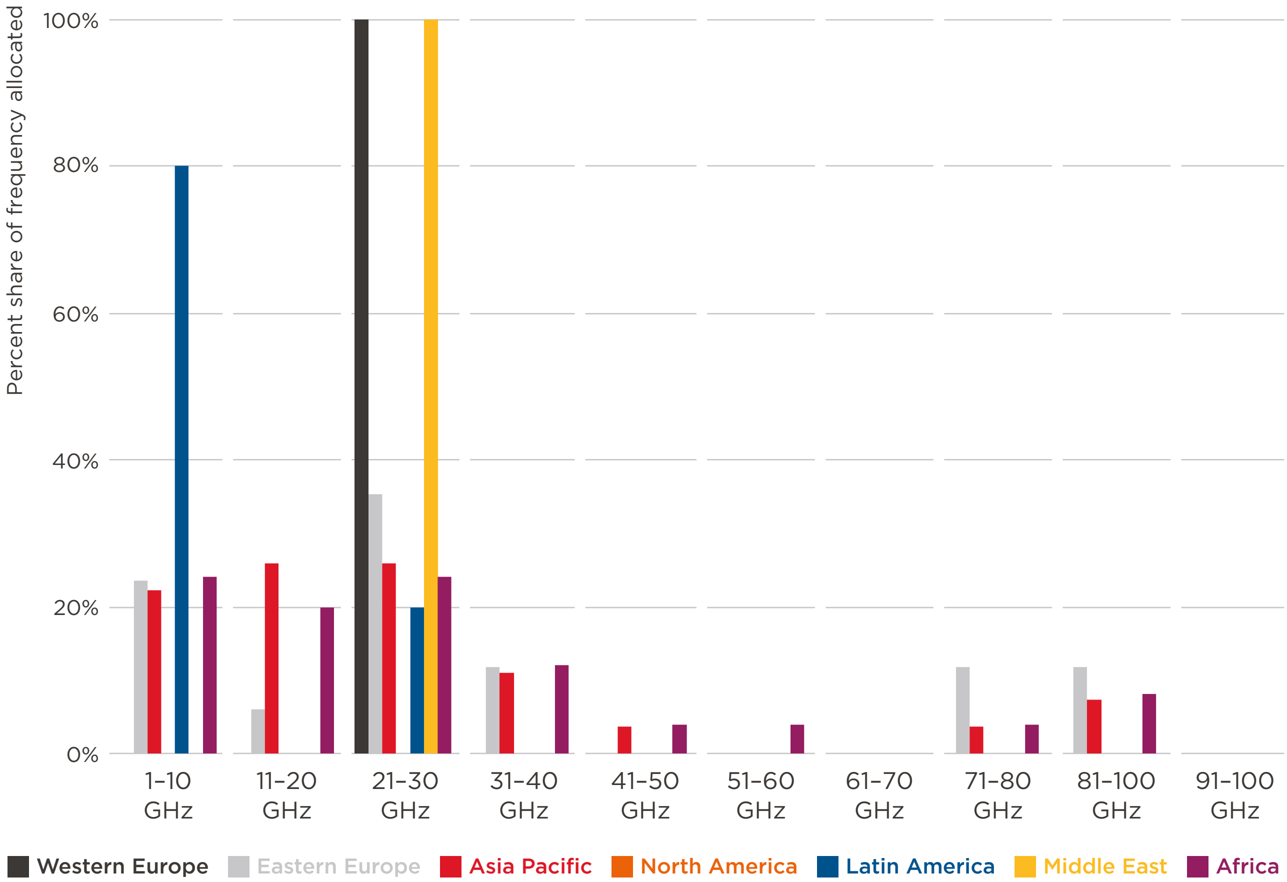
In situations where a small cell network is used for coverage and not capacity, such as on roads or freeways with very low population density (the only population density would be traffic) and very little in the way of infrastructure, in-band backhaul can be useful. In such situations, a handset in use in a vehicle travels out of range from one small cell and falls into coverage of the next small cell very rapidly. By reducing the cost of extra backhaul equipment and having an egress point to the core network after several hops, a small cell network would be less expensive than a macro network.

4.4 Regional PMP spectrum availability

Typically, PMP often needs to operate in environments where NLoS is the norm. PMP has been deployed in the sub-6 GHz band in North America and Europe. PMP backhaul has also been deployed in the 11 GHz (Asia-Pacific) and 25 GHz to 27 GHz bands (Western Europe and the Middle East). Eastern Europe has PMP spectrum allocated in multiple spectrum bands, from sub-10 GHz to 81 GHz to 90 GHz (see Chart 10).

Chart 10

Regional PMP Backhaul Spectrum Allocation by Frequency Range
World Markets, 2017



Source: ABI Research

There is considerable opportunity for PMP deployment. CBNL has live networks in at least 47 countries around the world; in emerging markets, as well as developed markets.

Table 4

PMP Markets by Region
2017

Western Europe	Eastern Europe	Asia Pacific	North America	Latin America	Middle East	Africa
United Kingdom	Russia	Malaysia	United States	Argentina	Saudi Arabia	Mali
Germany	Poland	Indonesia		Venezuela	Iraq	Kenya
Ireland	Czech Republic	Philippines		Peru	Lebanon	DR Congo
Belgium	Slovakia	Australia		Uruguay	Afghanistan	Nigeria
Netherlands	Ukraine			Mexico		Ghana
Italy	Hungary			Guadeloupe		South Africa
Sweden	Romania			Martinique		Cameroon
France				Ecuador		Rwanda
				Brazil		Zambia
						Tanzania
						Guinea
						Senegal
						Mauritania
						Morocco
						Botswana
						Somalia

These countries support 1 or more PMP bands in 10.5, 26, or 28 GHz

Source: ABI Research, CBNL

4.5 Stakeholders analysis

The PMP ecosystem is not as mature as the traditional PTP marketplace. Clearly, backhaul solutions have to be very robust, with minimal downtime—either due to hardware failure or due to transmission interference. Nevertheless, a number of PMP vendors have gained traction in the wider mobile operator backhaul marketplace. Key PMP players include Cambridge Broadband Networks, CCS, Airspan, Cambium Networks, Carlson Wireless, Intracom, Proxim, Radwin, and Ruckus Wireless.

The majority of the mobile backhaul links deployed are PTP links. All countries surveyed in this report use PTP backhaul links, but the number of countries that have reported the use of PMP backhaul links has steadily grown. Out of the 30 countries surveyed, at least 11 had PMP networks. Key markets include France, Germany, Italy, Poland. Australia, Japan, Saudi Arabia, and South Africa.

PMP technology operates at multiple frequencies. In Germany, frequency bands in the range 24.5 GHz to 26.5 GHz are partly allocated for PMP backhaul links.

4.6 Potential regulatory considerations

4.6.1 NLOS SUPPORT

For true NLoS wireless backhaul services, the spectrum bands have to be below 6 GHz. There are nLoS solutions that can be added to the operator's toolkit, but the long-term outlook for sub-6 GHz is that it will increasingly be used for the access side of the network as the sub-3 GHz, which has become substantially congested. For 5G, regulators around the world will be allocating spectrum in the 3.3 GHz to the 4.2 GHz for base station to end-user communication links.

4.6.2 PMP SUPPORT

At present, there is primarily support for PMP backhaul in the 10.5 GHz, 26 GHz, and 28 GHz bands. It is estimated that in the 26 GHz and 28 GHz bands, there is approximately 2 GHz available that does support high-capacity throughput and the propagation characteristics make the spectrum band effective for mid-distance backhaul (5 km to 10 km). However, there is considerable momentum and consensus to use the 26 GHz to 28 GHz band for 5G access, 24.25 GHz to 27.5 GHz (5G Pioneer Band, 26 GHz) in Europe and Asia, while North America prefers to set aside the 27.5 GHz to 28.35 GHz; and 37.6 GHz to 40.0 GHz bands for 5G. There is likely to be strong interest in the 26 GHz to 28 GHz band for FWA around the world, both in developed and emerging markets. In developed markets, the band will be used as an alternative for fiber-optic where the OPEX/CAPEX considerations rule it out. In emerging markets, it will be used as a primary broadband wireless solution for homes and businesses. PMP solutions are emerging in the 60 GHz V-bands and ABI Research anticipates deployments will grow over the next 5 to 10 years, especially for small cells.

5 Spectrum availability

Along with the variety in technical backhaul solutions, operators also have a number of spectrum bands in which they can establish PTP, and increasingly PMP, wireless links. Wireless backhaul spectrum exists in a number of spectrum allocations. Wireless backhaul takes place in the sub-6 GHz (licensed and unlicensed), microwave (6 GHz to 40 GHz), V-band (60 GHz), and E-band (70/80 GHz band), as well as the W-band (92 GHz to 114.25 GHz). Satellite is also an option for rural sites, but fees are usage based and, therefore, need to be monitored and controlled.

5.1 Data throughput

The data throughput is an essential consideration for mobile service providers, even for small cells that are often deployed in dense population centers. Small cells may have a small physical coverage area of often 0.5 km^2 to 4 km^2, and they could be handling large amounts of traffic from multiple customers. The data throughputs are also a function of the modulation and compression schemes implemented on the backhaul link, as well as how wide the channels are. Generally, the higher the frequency band, the greater the throughput. The 60 GHz V-band can handle 10+ Gbps, while the E-band can handle 10 Gbps to 25 Gbps (see Table 5).

Table 5

Performance Characteristics for Various Spectrum Bands

Sub-6 GHz, Microwave, and Satellite

Characteristics	Sub-6 GHz Unlicensed	Sub-6 GHz Licensed	Microwave (7–40 GHz)	V-band (60 GHz)	E-band (70/80 GHz)	Satellite
Carrier Frequency	2.4 GHz, 5 GHz	3.5 GHz to 6 GHz	6 to 56 GHz	56 to 64 GHz	70 to 80 GHz	4 to 6, 10 to 12, 20 to 30 GHz
Capacity	300 to 750 Mbps	250 to 500 Mbps	1 Gbps+	10 Gbps+	10–25 Gbps	150 Mbps DL /10 Mbps UL
Latency	~10 ms	5 ms/hop	<1 ms/hop	<200 μs max., 40 to 50 μs typ./hop	65 to 350 μs/ hop	300 ms
Range (km)	250 m max	<50	5-30++	<1	~3	Ubiquitous
Topology	NLoS	NLoS	LoS	LoS	LoS	Universal
Installation	PMP	PMP	PMP, PTP	PTP	PTP	PMP

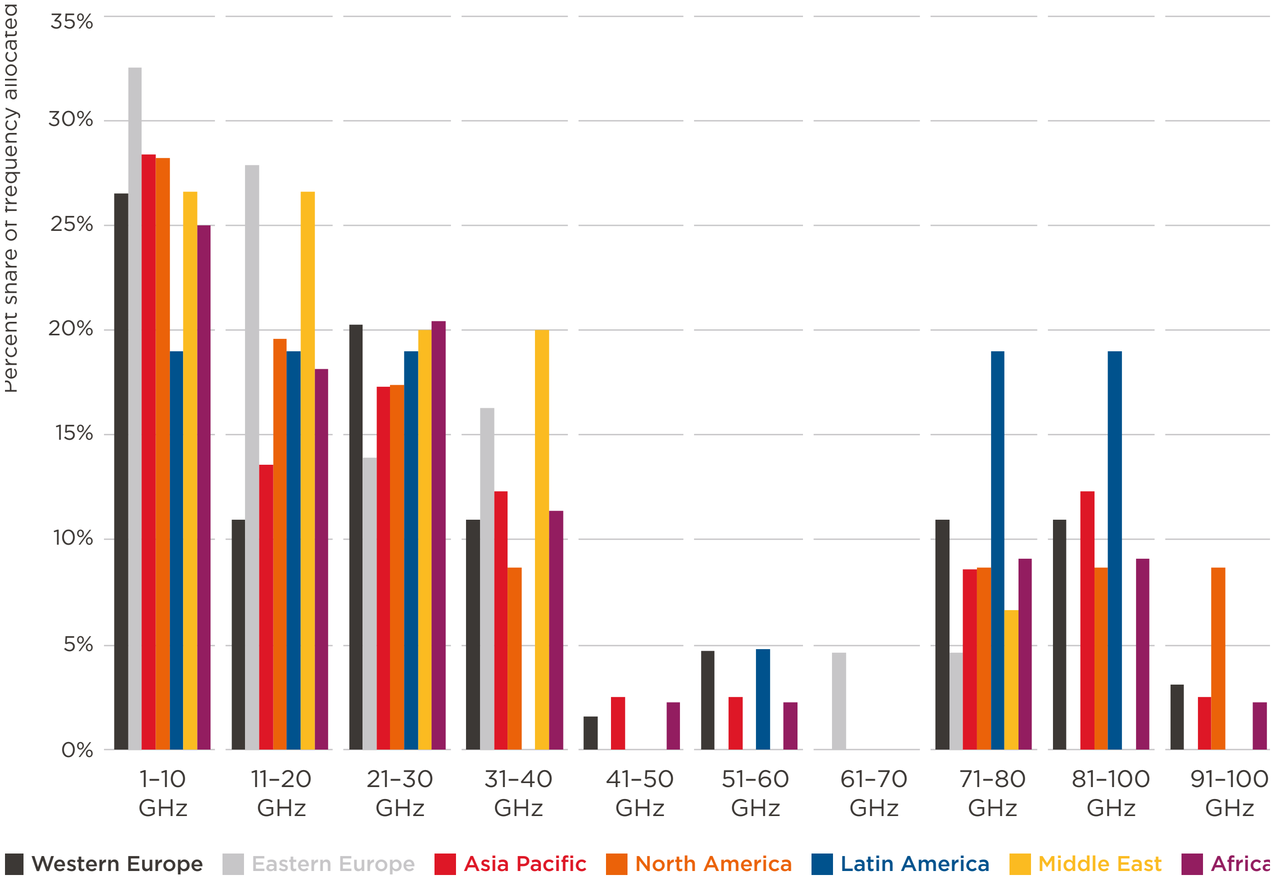
Source: ABI Research

ABI Research conducted a survey of 33 countries around the world to investigate which spectrum bands have been allocated for wireless backhaul, as well as the licensing procedures they use. A summary of the spectrum band usage can be found in Chart 11. Of the wireless backhaul spectrum links, 44.9% were in the 1 GHz to 10 GHz and 11 GHz to 20 GHz bands. Generally speaking, state regulators are now trying to reallocate backhaul spectrum to higher bands (21 GHz and above). This is partly because the 1 GHz to 10 GHz band is already heavily congested with backhaul links in a number of markets, and regulators intend to keep spectrum in the sub-6 GHz band for end-user access services.

In the case of the European Commission (EC), it established a Radio Spectrum Policy Group work program "... to identify and analyze strategic spectrum issues relative to wireless backhaul for mobile networks." Standard and regulatory bodies in other regions and countries will also need to give careful consideration to spectrum and licensing issues in relation to wireless backhaul.

Chart 11

Regional Backhaul Spectrum Allocation by Frequency Range
World Markets, 2017



Source: ABI Research

By and large, there is sufficient spectrum in the 21 GHz to 30 GHz and 31 GHz to 42 GHz bands for mobile operators. However, momentum is well under way in the 71 GHz to 80 GHz bands, as well as the 81 to 90 GHz as they are lightly licensed. These bands increased to 9.2% and 9.2%, respectively, of overall backhaul spectrum made available compared to just 4.7% and 3.2%, respectively, 4 years ago. Furthermore, due to the generous channel bandwidths, data throughput is in the 10+ Gbps to 25+ Gbps throughput range and has the potential to support up to 100 Gbps, which is more than adequate for small cell and even macrocell backhaul. Capacity can be further boosted by multi-carrier bonding between a low-frequency and a high-frequency microwave link.

It is noticeable that the V-band that spans from 57 GHz to 66 GHz, depending on the country, has shown mixed traction. While the majority of countries either have or are actively taking steps to make the V-band for unlicensed use, some countries have opted for light licensing and others have yet to release the spectrum.

The 0.6% activity in the chart correlates to light licensing activity. This is essentially the same as the 1.1% activity 4 years ago. It appears that mobile service providers have reservations about the 60 GHz band incurring oxygen and rain attenuation, and while that could help keep transmission ranges short, thereby allowing spectrum reuse, it is still a material concern. In some countries, the 59 GHz to 61 GHz band is used for NATO/military applications, while in other countries, administrations have reserved the band 61–61.5 GHz for Industrial, Scientific, and Medical (ISM) applications only.

Data for Chart 11 came from Table 6 on the next page. The full spectrum band allocations and their licensing conditions, as collected by the ABI Research survey are listed in Appendix 2: Backhaul Spectrum Allocation Summary. In the following sub-sections, ABI Research analyzes which wireless backhaul spectrum bands are used and how.

Table 6

Regional Backhaul Spectrum Allocation
World Markets

Region	Country / Frequency (GHz)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Africa	South Africa	●	●	●		●			●		●	●	●	●	●	●						●		●	●		●	●	
Africa	Nigeria			●	●	●			●		●				●	●		●						●		●			
Middle East	UAE			●			●																						
Middle East	Saudi Arabia			●				●				●		●		●			●					●			●		●
South America	Uruguay						●	●	●					●		●									●				●
South America	Brazil				●													●		●		●		●					
North America	United States			●		●	●				●	●																	
North America	Canada	●	●	●	●	●	●	●	●		●	●	●	●	●	●		●	●	●		●	●	●	●	●	●	●	●
Asia Pacific	Singapore			●		●																			●				
Asia Pacific	New Zealand	●			●	●	●		●		●	●												●	●				●
Asia Pacific	Malaysia			●							●				●	●								●	●				
Asia Pacific	Japan	●																●	●	●			●	●					
Asia Pacific	Indonesia			●	●				●																				
Asia Pacific	India			●			●	●						●		●			●			●							
Asia Pacific	Australia			●	●	●		●			●					●					●	●			●			●	
Eastern Europe	Poland						●	●	●			●		●		●			●					●					
Eastern Europe	Czech Republic			●	●	●	●	●			●	●		●		●			●					●			●	●	●
Eastern Europe	Croatia		●	●			●	●	●			●		●	●				●					●					
Western Europe	UK	●	●	●							●																		●
Western Europe	Italy			●	●		●																		●		●	●	
Western Europe	Germany	●		●	●	●	●	●					●	●	●	●		●		●			●	●	●		●	●	
Western Europe	France			●			●																				●		
Western Europe	Denmark							●			●								●										●

Region	Country / Frequency (GHz)	29	30	31	32	33	36	37	38	39	40	41	42	43	56	57	70	71	75	76	80	81	86	92	95
Africa	South Africa	●						●		●	●			●		●		●	●			●	●		
Africa	Nigeria	●		●		●												●		●		●	●	●	
Middle East	UAE																				●				
Middle East	Saudi Arabia			●	●				●																
South America	Uruguay																	●		●		●	●		
South America	Brazil															●		●		●		●	●		
North America	United States								●		●							●		●		●	●	●	●
North America	Canada								●		●							●		●		●	●	●	●
Asia Pacific	Singapore	●		●		●		●						●				●		●		●	●		
Asia Pacific	New Zealand																	●		●		●	●		
Asia Pacific	Malaysia			●		●									●					●		●	●	●	●
Asia Pacific	Japan																								
Asia Pacific	Indonesia				●	●									●					●		●	●		
Asia Pacific	India																								
Asia Pacific	Australia		●	●		●		●						●						●		●	●		
Eastern Europe	Poland				●		●		●								●		●						
Eastern Europe	Czech Republic			●	●				●								●				●				
Eastern Europe	Croatia								●																
Western Europe	UK				●						●					●		●	●	●		●	●		
Western Europe	Italy	●																							
Western Europe	Germany	●		●		●		●			●			●		●		●					●	●	●
Western Europe	France																	●		●		●	●		
Western Europe	Denmark								●							●		●				●	●		

Source: ABI Research

5.2 Sub-6 GHz

5.2.1 UNLICENSED

In the sub-6 GHz unlicensed category, there are small cell mobile backhaul solutions that operate in the 2.4 GHz or 5 GHz unlicensed bands. The 2.4 GHz band is highly congested when compared to the 5 GHz band, which has a shorter range and a large spectrum block. The close proximity of Wi-Fi access points, as an example, permits them to be interconnected in a Wi-Fi mesh to exchange data traffic with each other and a gateway point, replacing costly cable runs for backhaul and reducing total operator CAPEX. Wi-Fi, however, is not the only solution available for unlicensed operation in the sub-6 GHz bands, with several vendors implementing proprietary modulation schemes for interference mitigation and performance advantages.

While unlicensed spectrum is essentially "free" to the user, the spectrum comes with a drawback in that it is, by definition, regulated by rules (technical limitation) and subject to adjacent and co-channel interference. In some very limited situations, ISM bands have been used for wireless backhaul, which raises the possibility that backhaul may interfere with Wi-Fi access and vice versa. However, due to the limitation associated with the licensing regime, such an approach will remain extremely limited and is not the priority for future wireless backhauling deployment.

5.2.2 RE-ALLOCATION OF 3.3 TO 3.8 GHZ FOR 5G

Countries around the world will start to set aside spectrum in the 3.3 GHz to 3.8 GHz band for 5G services. As 5G services will start to commence in 2020, regulators, like Ofcom, have completed their auction process.

In some regions, such as the Mediterranean and Southeast Asia, spectrum in the 3.2 GHz to 4.4 GHz band is dedicated to satellite ground stations. Either alternative spectrum bands will need to be found or these satellite ground stations will need to be geo-fenced to prevent ~3.5 GHz cell sites causing interference.

5.2.3 4 GHZ TO 9 GHZ CASE EXAMPLES

Spectrum bands in the 4 GHz to 9 GHz band range are commonly used as backhaul links in many countries across different regions, except Japan, which has not allocated spectrum in the 4 GHz to 9 GHz range for wireless backhaul (see Table 7).

Spectrum in the 4 GHz to 9 GHz bands has traditionally been a good fit for wireless backhaul. Spectrum below 6 GHz can be effectively used for NLoS. However, the 4 GHz to 9 GHz bands also house unlicensed spectrum in the 5 GHz bands. The unlicensed 5 GHz band is being used by mobile carriers for backhaul, especially in emerging markets, such as Brazil, but the unlicensed ISM nature of the band has meant there are increasing numbers of Wi-Fi access points and client devices that are contributing to the "noise floor" of the band. As the growth of personal and commercial 802.11n access points and hotspots has grown, along with smartphones, tablets, and laptops, the reliability of the unlicensed 5 GHz band will reduce the reliability of the band for mobile operator backhaul links.

Regulators have been reporting that the 4 GHz to 9 GHz bands are becoming increasingly congested. A number of countries, such as Denmark, have reported that the 7 GHz band is one of the most crowded bands in the country. The bands will remain popular with telcos because of the NLoS or at least nLoS capabilities of the sub-6 GHz bands.

The anticipated assignment of spectrum for 5G access in the 3.5 GHz range, which varies and includes differently sized portions ranging from 3.3 GHz up to 3.8 GHz (and some countries are considering using up to 4.2 GHz) will likely have further ramifications on the spectrum around it in the long term. Spectrum in the 6 GHz to 10 GHz band has nLoS characteristics, which could make it attractive for future "access" application services or allocation to non-cellular applications (e.g., government or industrial) that have been affected by frequency re-allocations lower down in the sub-6 GHz bands.

The sub-10 GHz bands still have a role to play in serving sites/locations that are more remote and require longer hops and/or NLoS. More needs to be done to manage and coordinate spectrum use in the sub-9 GHz bands for NLoS PMP and also PTP backhaul links. It is not just developed markets like Germany and Singapore that have widely encouraged the use of PMP in the sub-7 GHz bands, but also South Africa, which is using the 4 GHz, 6 GHz, 7 GHz, and 8 GHz bands for small cell PMP backhaul.

Table 7

Backhaul Spectrum Summary, 3 GHz to 9 GHz Bands
Countries Surveyed by Region

Country	Backhaul Band (GHz)
Western Europe	
Denmark	7
France	3.5
	3.4–3.8
	6
Germany	**3.8–4.2**
	5.925–6.425
	6.425–7.125
	7.125–7.425
	7.425–7.725
Italy	3.4–4.2
	6
United Kingdom	—

Country	Backhaul Band (GHz)
Eastern Europe	
Croatia	3.8
	6
	7
	8
Czech Republic	3.6–3.8
	4
	6
	7
Poland	6
	7
	8
Hungary	5

Country	Backhaul Band (GHz)
Asia Pacific	
Australia	3.575–3.7
	4.8–4.9
	5.6
	7
India	3.4–3.5
	6
	7
Indonesia	3.3
	3.7–4.2
	4.2–6
Japan	—
Malaysia	3.9
	3.155–3.4
New Zealand	4.4–5
	5.925–6.42
	6.42–8.5
Singapore	3.4–3.6
	5.725–5.85
	5.875–5.925

Country	Backhaul Band (GHz)
North America	
Canada	3.7–4.2
	5.295–6.425
	6.425–6.930
	7.125–7.25
	7.25–7.3
	7.725–8.275
United States	3.7–4.2
	5.925–6.425
	6.425–6.7
	6.7–6.875

Country	Backhaul Band (GHz)
Latin America	
Mexico	3.4–3.7
	5.725–5.85
	7.11–7.725
Venezuela	3.4–3.6
	3.7
	4.2
	5.725–5.85
	5.9–6.4

Country	Backhaul Band (GHz)
Brazil	5.9–6.4
	6.4–7.1
	7.4–7.8
	7.7–8.3
	8.2–8.5
Uruguay	6
	7
	8

Country	Backhaul Band (GHz)
Middle East	
Saudi Arabia	3.4–3.8
	7
UAE	3.6
	6

Country	Backhaul Band (GHz)
Africa	
Nigeria	3.6–4.2
	4.4–5.03
	5.15–5.35
	5.47–8.75
South Africa	3.5
	5.725–8.496

Note: PTP, **PTP/PTMP**

Source: ABI Research

5.2.4 STAKEHOLDER ANALYSIS

In the sub-6 GHz band, there are seven vendors providing licensed and unlicensed solutions: Ericsson, Cambium Networks, Ceragon, DragonWave, Fastback Networks, Proxim, and Radwin.

For the sub-6 GHz bands, vendor support demonstrates a high level of competition, although many of them are specialized vendors that tend to specialize in carrier-grade Wi-Fi-related solutions. The size of the antennas/waveguides can take up a sizable footprint at the cell site.

The sub-6 GHz band does have other non-mobile cellular backhaul stakeholders. In Europe, as well as in Southeast Asia, a number of countries use the 4 GHz band for coordinating with receiving satellite earth stations, which may constrain use in certain locations. Both the lower and upper 6 GHz bands may have to be shared with satellite uplinks.

5.3 Microwave spectrum in the 10 GHz to 40 GHz range

Microwave is a mature technology used for many years to backhaul traditional macrocells, designed for carrier-grade LoS operation over long distances. This LoS technology is suitable for connecting rooftop microcells, rather than a dense cluster of outdoor picocells and femtocells. It is, however, a very well understood and commonly used backhaul technology, which renders it attractive as an option for small cell backhaul.

Equipment operating in these bands is now being designed to be compatible with small cell backhaul by reducing the power requirements, because small cell links are much shorter and require a compact form factor with an integrated antenna, which can lower costs. ABI Research believes microwave plays an important role in small cell backhaul now and in the future. Link capacity is a function of channel size and spectral efficiency, so it is the subject of considerable innovation and optimization by the vendor community.

5.3.1 10 GHz TO 18 GHz BAND CASE EXAMPLES

Spectrum bands within 10 GHz to 18 GHz are generally used for medium-haul systems. Spectrum bands below 20 GHz still have a role to play for users requiring longer links in both rural and suburban areas, as well as for applications where an increase in capacity is needed. This spectrum range is commonly used in a large number of countries as backhaul links. The exceptions are countries like New Zealand and Saudi Arabia (see Table 8).

Table 8

Backhaul Spectrum Summary, 10 GHz to 18 GHz Bands
Countries Surveyed by Region

Country	Backhaul Band (GHz)
Western Europe	
Denmark	10
	12
	15
	18
France	10.7–11.7
	12.75–13.25
	17.7
Germany	**12.75–13.25**
	14.5–15.35
	17.7
Italy	—
United Kingdom	10

Country	Backhaul Band (GHz)
Eastern Europe	
Croatia	11
	13
	14
	18
Czech Republic	10
	11
	13
	15
	18
Poland	11
	13
	15
	18
Hungary	10–12.5

Country	Backhaul Band (GHz)
Asia Pacific	
Australia	10.5
	15
India	13
	15
	18
Indonesia	10.7–11.7
	12.75–13.25
	14.4–15.35
	17.7
Japan	17.85–17.97
	18
Malaysia	**10–14**
	14.3–15.35
	15.7–16.6
New Zealand	10.5–10.68
	10.7–11.7
Singapore	**10.5–10.68**
	10.7–11.7
	12.2–12.7
	12.75–13.25
	14.4–15.35
	17.7

Country	Backhaul Band (GHz)
North America	
Canada	10.55–10.68
	10.7–11.2
	11.2–11.7
	12.7–13.25
	14.5–15.35
	14.975–15.35
	17.8–18.3
United States	10.55–10.6
	10.6–10.68
	10.7–11.7

Country	Backhaul Band (GHz)
Latin America	
Brazil	10.7-11.7
	14.5-15.4
	17.7
Uruguay	13
	15

Country	Backhaul Band (GHz)
Middle East	
Saudi Arabia	**11**
	13
	15
	18
UAE	—

Country	Backhaul Band (GHz)
Africa	
Nigeria	10-10.68
	10.7-14
	14.3-15.35
	18
South Africa	10.7–11.7
	12.75–13.25
	14.5–15.35

Note: PTP, **PTP/PTMP**

Source: ABI Research

Spectrum in the 10 GHz to 18 GHz range is used for a combination of PTP and PMP backhaul links. The 10 GHz to 12 GHz and the 15 GHz to 18 GHz bands are used for PMP in Germany, Saudi Arabia, Malaysia, and Singapore.

Congestion is occurring in a number of the 10 GHz to 18 GHz bands. The 12 GHz, 15 GHz, and 18 GHz bands are heavily congested in Denmark. Similarly, Germany and Italy reported heavy-duty use in the 12.75 GHz to 13.25 GHz, 14.5 GHz to 15.35 GHz, and 17.7 GHz to 19.7 GHz bands. Chart 11, Regional Backhaul Spectrum

Allocation by Frequency Range, shows the 11 GHz to 20 GHz bands had the third largest allocation of spectrum bands available for wireless backhaul (17.9% compared to 29.4% 4 years ago), while the 1 GHz to 10 GHz spectrum is the most popular with 27.4%. Mature microwave solutions and reasonably good propagation characteristics supporting PTP and PMP applications make it a popular spectrum category for wireless backhaul. There is, however, a need to relieve some of that congestion using very high microwave and even millimeter spectrum bands.

5.3.2 20 GHz TO 40 GHz BAND CASE EXAMPLES

In a number of regions, spectrum bands above 20 GHz are used as backhaul links because higher frequency bands allow higher bandwidth. As congestion has built up in the 1 GHz to 10 GHz and 11 GHz to 20 GHz bands, countries in developed markets have taken steps to make available the 20 GHz to 40 GHz bands. A number of countries in Western Europe have allocated substantial amounts of spectrum in the 20 GHz to 40 GHz bands for backhaul links. Countries in Asia-Pacific allocate more commonly in the spectrum range between 20 GHz and 30 GHz (see Table 9).

Table 9

Backhaul Spectrum Summary, 20 GHz to 40 GHz Bands

Countries Surveyed by Region

Country	Backhaul Band (GHz)
Western Europe	
Denmark	28
	38
France	19.7
	26
Germany	22–23.6
	24.5–26.5
	27.5–29.5
	31.8–33.4
	37–39.5
	40.5
Italy	24.5–26.5
	27.5–29.5
United Kingdom	28
	32
	40

Country	Backhaul Band (GHz)
Eastern Europe	
Croatia	23
	38
Czech Republic	23
	26
	28.2205–28.4445
	29.2285–29.4525
	31
	32
	38
Poland	23
	26
	32
	38

Country	Backhaul Band (GHz)
Asia Pacific	
Australia	20.2–21.2
	23
	24.25–27.5
	30–31
	31.8–33.4
	37
India	21
Indonesia	21.2–23.6
	32–33
Japan	22.21–22.5
	22.5–22.55
	22.55–22.6
	23–23.2
Malaysia	**24.45–31.3**
	31.5–31.8
	33.5
New Zealand	23–28
Singapore	**24.25–29.5**
	31.8–33.4
	37

Country	Backhaul Band (GHz)
North America	
Canada	9.3–19.7
	21.8–22.4
	23–23.6
	24.25–24.45
	25.05–25.25
	25.25–26.5
	27.5–28.35
	38.6–40
United States	38.6-40

Country	Backhaul Band (GHz)	Country	Backhaul Band (GHz)	Country	Backhaul Band (GHz)
Latin America		**Middle East**		**Africa**	
Brazil	21.8–23.6	Saudi Arabia	**23**	Nigeria	**25.25–29.5**
	37–39.5		**26**		**31–31.3**
Uruguay	24		**28**		**31.5–31.8**
	28		**32**		**33**
			38	South Africa	**21.2–23.6**
		UAE	40		**24.549–26.453**
					27–29.5
					37-39.5
					40.5-42.5

Note: PTP, **PTP/PTMP**

Source: ABI Research

PMP applications have gained significant footholds in the higher 20 GHz bands, especially in the 26 GHz to 29 GHz bands. In the United States, the 31 GHz to 32 GHz bands were also dedicated to Local Multipoint Distribution Service (LMDS), a digital Television (TV) broadcast service. The LMDS spectrum bands were then re-allocated for wireless backhaul for mobile cellular networks. PMP architectures can be found in Germany, Malaysia, Singapore, Saudi Arabia, Nigeria, Saudi Arabia, New Zealand, and South Africa.

The spectrum bands are LoS, but have the available spectrum to support PMP deployment scenarios. Multiple links can be set up with a single node. Propagation characteristics are lower than the 10 GHz to 18 GHz band, but still attractive for traditional microwave backhaul applications.

In different parts of the world, portions of spectrum in the 26 GHz to 28 GHz bands are very likely to be assigned to 5G access services. In Europe, the Radio Spectrum Policy Group (RSPG) has identified the 26 GHz band as the European pioneer millimeter wave band. Large parts of Asia and emerging markets are anticipated to also set aside the 26 GHz band for 5G. The United States' Federal Communications Commission (FCC), however, intends to offer the 28 GHz band for the same services, as do Japan and Korea. Existing backhaul links in the 26 GHz to 28 GHz bands are expected to migrate to the 32 GHz and higher bands, which will have wider channels that allow for greater capacity and data throughput.

The 38 GHz band, and bands around it, will be reviewed under the International Telecommunication Union's (ITU) World Radiotelecommunication Conference (WRC)-19 Agenda Item 1.13 for potential 5G access services. The European Radio Spectrum Policy Group (RSPG) has identified the 40.5 GHz to 43.5 GHz band as a potential band for 5G in Europe. It is, therefore, likely the 40.5 GHz to 43.5 GHz band, along with the lower 37 GHz to 40.5 GHz band, will have the opportunity to become globally harmonized ranges for 5G equipment.

5.3.3 STAKEHOLDER ANALYSIS

The 10 GHz to 40 GHz microwave range represents the core spectrum bands used for wireless backhaul, both in PTP and PMP configurations. LoS is invariably required because the signal does a poor job of penetrating physical structures. However, some vendors are experimenting with nLoS solutions where transmissions may be bounced off buildings. Eleven vendors are able to address backhaul solutions in the 10 GHz to 40 GHz band. These include Nokia, Aviat Networks, Cambridge Broadband Networks, CCS, DragonWave-X, Ericsson, Huawei, Intracom, NEC, Siklu Communication, and VubIQ Networks.

At present, the 10 GHz to 40 GHz band may be the most popular with operators for their current wireless backhaul needs. It also incurs very substantial competition, with Ericsson, NEC, Huawei, Nokia, and DragonWave-X controlling a significant proportion of the shipment volume.

5.4 Upper microwave wave bands (41 GHz to 100 GHz)

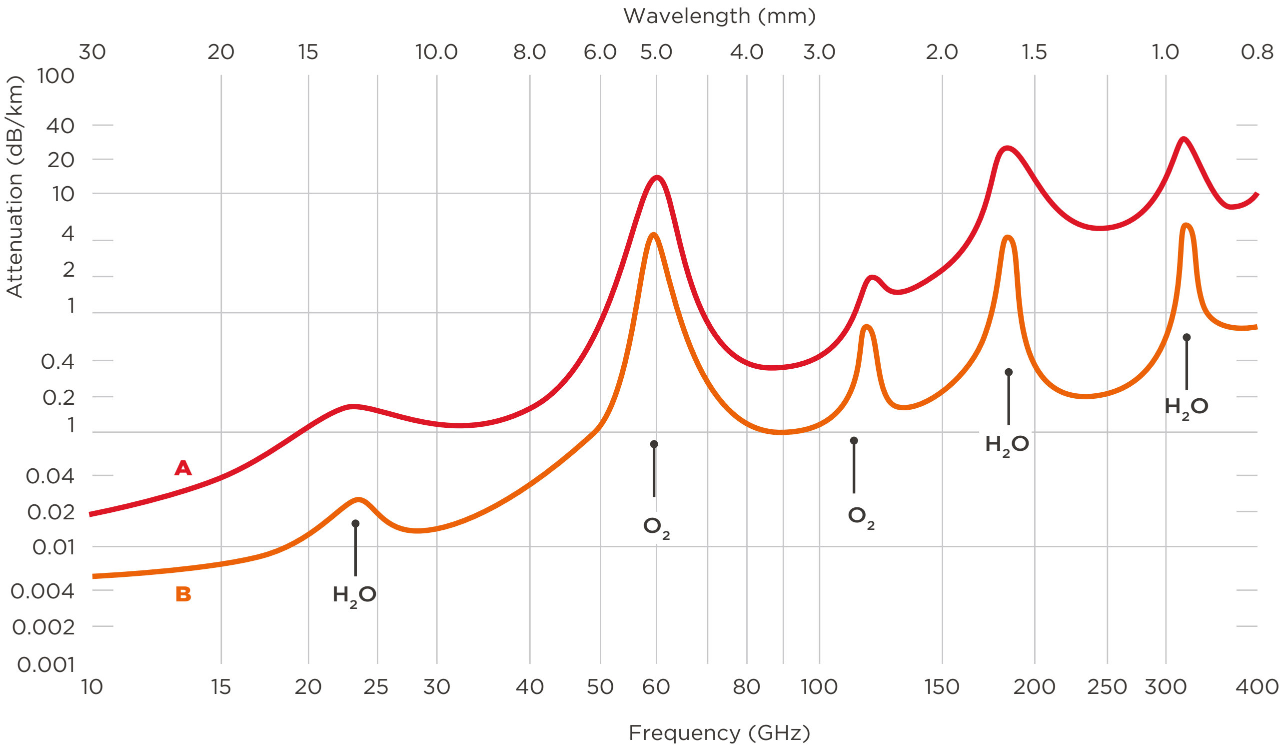
The microwave 41 GHz to 100 GHz spectrum include the unlicensed 60 GHz band, the licensed/lightly licensed 70/80 GHz E-band, and the W-band (92 GHz to 114.25 GHz). These frequencies are compelling for small cell backhaul because little congestion occurs in these bands, and they are very well suited to the short-range requirements of small cells, thanks to their high frequency.

5.4.1 DEPLOYMENT CONSIDERATIONS

Microwave wave backhaul in the 41 GHz to 100 GHz band uses a very narrow beam width, which reduces interference between links in close proximity. The high frequencies also translate into smaller, more compact antennas and help meet the zero footprint requirements of small cell backhaul. Also, the typical full duplex bandwidth capacity seen for 60 GHz bands is between 5 Gbps and 10 Gbps, while in the 70 GHz to 80 GHz E-band, it can reach up to 25 Gbps. The 70/80 GHz bands also have the advantage of longer transmission distances (~3 km versus <1 km) because its signal is not absorbed by oxygen atoms to same degree as the 60 GHz band (see Figure 5). Of course, a disadvantage for these higher microwave wave bands (41 GHz to 100 GHz) is that it requires LoS, which limits flexibility when planning small cell placement.

Figure 5

Oxygen and Rain Absorption versus Transmission



Source: U.S. Department of Transportation

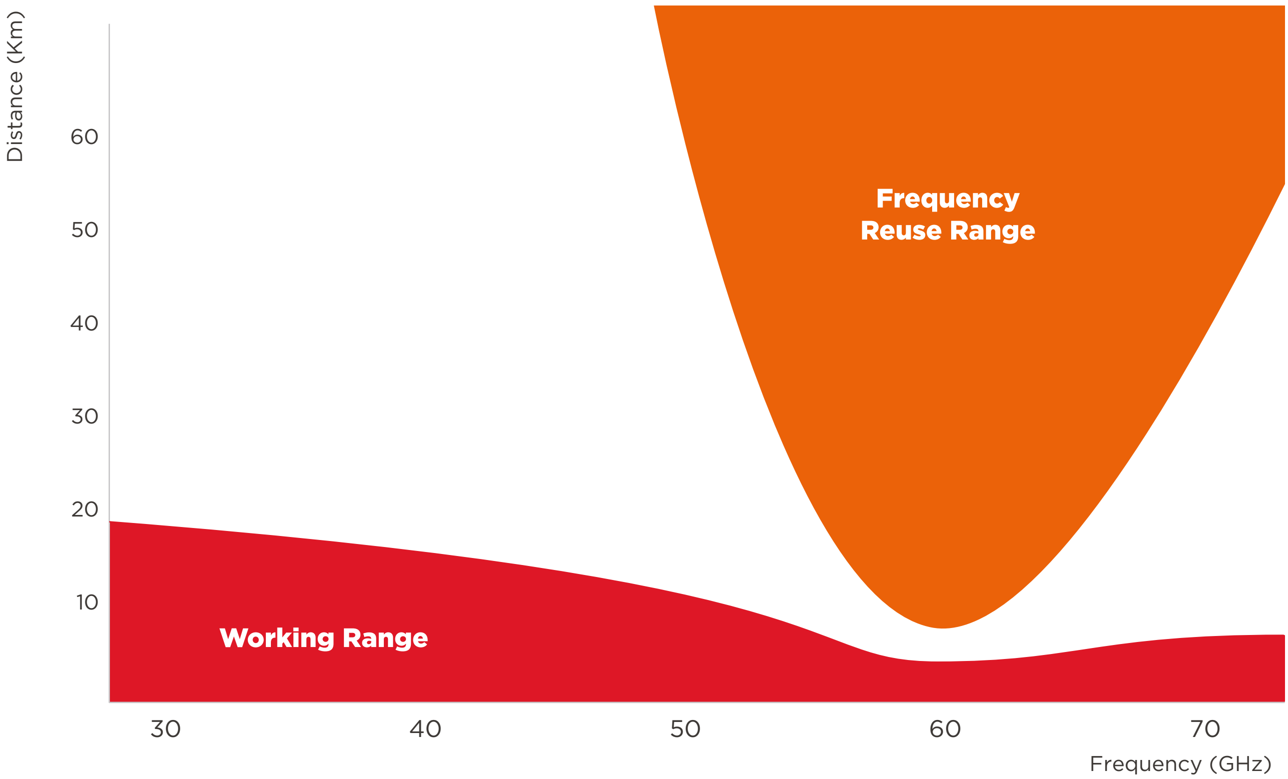
Small cell backhaul bandwidth today may require a minimum of 1 Gbps for 4G and 10 Gbps to 100 Gbps for 5G, and if the small cells are interconnected in a daisy chain, the backhaul band width may need to be double the above-mentioned data rates.

As MNOs densify their RANs, capacity requirements increase and transmission ranges decrease, making millimeter link an attractive proposition for small cell backhaul, because the propagation characteristics of the link can be used to improve its reliability where range is not a prime factor (see Figure 6).

The highly directional beam in a millimeter wave link transmits data between two transceivers and transports it in a straight line with little or no fading or multipath radio interference. This is a highly efficient use of spectrum because multiple millimeter wave transceivers can function within a few feet of each other and reuse the frequency band for transmitting separate data streams.

Figure 6

Potential Working and Frequency Reuse Ranges of the Millimeter Wave GHz Band



Source: Ofcom

These very high frequency backhaul links have a number of additional deployment advantages that can count in their favor:

- Multiple E-Band Radio Co-Location Possible: The very narrow beams associated with 70/80 GHz radios enables a number of E-band radios to be installed on the same rooftop or even on the same mast. Co-located radios operating in the same transmit and receive frequency ranges can be isolated from one another based on small lateral or angular separations and the use of cross-polarized antennas. V-band (60 GHz) has the added advantage of not requiring a license, but traction in the V-band has been limited, to date.
- Physical Security: E-band and V-band vendors report that there is a high degree of inherent physical security with these narrow beam LoS transmissions. In order to intercept the signal, a third party would have to locate a receiver that is lined up on the exact same trajectory, and in the immediate locale of the targeted transmitter. Furthermore, the intercepting receiver would have to be tuned to the carrier signal of the transmitting radio and be in the main beam in order to ensure reception. As a result, the presence of this third-party radio would block/degrade the transmit path of the transmitting radio and, therefore, reveal its presence to the network manager.

5.4.2 V-BAND (60 GHz)

The V-band ostensibly ranges from the 41 GHz to the 75 GHz band. Parts of that band of spectrum are used for millimeter wave radar and various scientific applications. The 60 GHz band has been attracting considerable interest recently. There is only 70 MHz available in the 2.4 GHz band and 500 MHz in the 5

GHz band for Wi-Fi, compared to 7 GHz available in 60 GHz V-band.

They are well suited to high-capacity, short-hop (<2 km) communications with narrow beams. The Wi- Fi 802.11ad low-power, very short-range devices will operate in the 60 GHz band, potentially offering data throughputs of up to 10 Gbps.

EC 60 GHz Rule Change

In late 2013, the European Commission (EC) issued a decision, the 2013/752/EU, that made a number of amendments to a prior policy document (2006/771/EC). The main objective of the revised policy document is to constrain transmission power levels to ensure they do not interfere with other wireless equipment. In the case of the short-range devices operating in the 57 GHz to 66 GHz band, they are restricted to 40 dBm Equivalent Isotropically Radiated Power (EIRP) and 13 dBm/MHz EIRP densities. Fixed outdoor installations are excluded from complying with these restrictions. Furthermore, it will ensure that these short-range devices do not become a serious source of interference for backhaul links in the 57 GHz to 64 GHz band.

FCC 60 GHz Rule Change

In late 2013, the FCC voted unanimously to change the rules governing the 60 GHz unlicensed band and said that the new raised power levels would improve the use of unlicensed spectrum for high- capacity, short-range outdoor backhaul, which is particularly useful for small cells.

There are several reasons why this rule change was important for small cell backhaul. In the 60 GHz band, wireless transmissions are attenuated by oxygen absorption and moisture or “rain fade,” which limits their range; also, the signal will not penetrate foliage or buildings, requiring a clear LoS. At this high frequency, the antenna is a small dish that matches the small form factor of the small cell and can be installed unobtrusively outdoors.

The FCC raised the power limit for outdoor links operating in the 57 GHz to 64 GHz band on an unlicensed basis. The EIRP limit was raised from 40 dBm (equivalent to 10 Watts) to a maximum of 82 dBm (158,489 Watts), depending on how high the antenna gain is. The new power limit is comparable to others the FCC has in the fixed microwave services. The FCC believes this will support higher-capacity outdoor links, such as small cells, extending to about 1 mile (1.6 km). The FCC also eliminated the need for outdoor 60 GHz devices to transmit an identifier. Indoor 60 GHz devices (for example, those based on WiGig’s 802.11ad standard) are still constrained to the much lower power limitations, which prevents interference with outdoor fixed link devices.

5.4.3 70+ GHz BANDS

Since ABI Research’s previous spectrum survey 4 years ago, regulators have taken significant steps to make spectrum available in the 70 GHz and higher bands. Frequencies in the E-band (70 GHz, 80 GHz, and even 90 GHz bands) are being allocated on a licensed or “lightly” licensed basis. This licensed, or indeed lightly licensed approach to backhaul spectrum allocation does give the operator a high degree of service delivery assurance that the 60 GHz unlicensed spectrum does not have. In the case of the 60 GHz band, it is the technical specifications (modulation, beam width, and network design) that must assure the backhaul link’s QoS.

The United States was one of the first countries to rule that spectrum at 71 GHz to 76 GHz, 81 GHz to 86 GHz, and 92 GHz to 95 GHz be available for high-density fixed wireless services. According to ABI Research’s survey, 16 countries, up from just 8 countries 4 years ago, including France, Germany, Malaysia, the Czech Republic, Poland, the United States, Nigeria, South Africa, and the United Arab Emirates (UAE) have allocated the 80 GHz band for wireless backhaul. It is noticeable that a significant number of emerging markets have issued spectrum in these high millimeter bands for backhaul. This is a big change from the last survey.

Table 10

Backhaul Spectrum Summary, >50 GHz Bands
Countries Surveyed by Region

Country	Backhaul Band (GHz)
Western Europe	
Denmark	57–59
	71–76
	81–86
France	71–76
	81–86
Germany	55.78–57
	71–86
	92–95
Italy	—
United Kingdom	57–66
	71–76
	81–86

Country	Backhaul Band (GHz)
Eastern Europe	
Croatia	—
Czech Republic	60
	70
	80
Poland	70
	75

Country	Backhaul Band (GHz)
Asia Pacific	
Australia	50–52.6
	66–76
	81–86
India	—
Indonesia	56–76
	81–86
Japan	—
Malaysia	55.78–76
	81–86
	92–94
	94.1–100
	102–109.5
	111.8–114.25
	122.25–123
	130–134
	141–148.5
New Zealand	71–76
	81–86
Singapore	50.4–52.6
	66–76
	71–76
	81–86

Country	Backhaul Band (GHz)
North America	
Canada	71–76
	81–86
	92–95
United States	71–76
	81–86
	92–95

Country	Backhaul Band (GHz)
Latin America	
Brazil	57–64
	71–76
	81–86
Uruguay	50
	60
	71–76
	81–86

Country	Backhaul Band (GHz)
Middle East	
Saudi Arabia	—
UAE	80

Country	Backhaul Band (GHz)
Africa	
Nigeria	55.78–76
	71–74
	81–86
	92–100
South Africa	57–66
	71.125–75.125
	73.375–75.875
	81.125–83.125
	83.375–85.875

Note: PTP

Source: ABI Research

5.4.4 STAKEHOLDERS ANALYSIS

Just 4 years ago, the 70/80 GHz (E-bands) were relatively sparsely used, but that has changed now, as small cell deployments have built up. The V-band (the 60 GHz band) has had more muted adoption, with fewer indications from regulators that they have made the V-band available for unlicensed backhaul use.

Despite the propagation-limiting characteristics of the 60 GHz band that make it suitable for spectrum re-use in dense urban areas, vendor support for the unlicensed/lightly licensed 60 GHz band is not as extensive as for other microwave backhaul bands. There are six V-band vendors (BridgeWave Communications, DragonWave, Ericsson, NEC, Siklu Communications, and Vubiq Networks) versus 11 E-band backhaul vendors (Aviat Networks, BridgeWave Communications, Ceragon, DragonWave, E-band Communications, Ericsson, Huawei, LightPointe Wireless, Loea Communications, NEC, and Siklu Communications).

ABI Research believes that the characteristics of the 70/80 GHz spectrum bands, such as short distance transmissions, the assurance of licensed spectrum (even if it is lightly licensed), and the wider channel sizes that permit potential 10 Gbps to 25+ Gbps throughput, are drawing interest from the hardware vendor community.

5.5 Potential regulatory considerations

Use of the 60 GHz V-bands for backhaul has only had limited adoption in the countries surveyed by ABI Research. The spectrum is becoming increasingly available. The 60 GHz band has been set aside for unlicensed outdoor applications in a number of countries, including the United States, Canada, Australia, and a number of European countries such as Switzerland, Austria, and Slovenia.

One challenge is that the bands are not harmonized across markets. In the United States, Canada, and Korea, 7 GHz has been put aside in the 57.05 GHz to 64 GHz range. In Europe, 7 GHz has been allocated in the 57 GHz to 66 GHz band, and Australia has set aside 3.5 GHz in the 59.40 GHz to 62.90 GHz bands.

Complementing this, a larger proportion of the 70/80 GHz bands compared to the 60 GHz bands can be dedicated to backhaul services. Not only will LTE and LTE-Advanced contribute to the growth in traffic, but 5G will need high-speed wireless backhaul, with 5G reaching commercial implementation by 2020. Fiber-optic cannot be deployed in all cell site scenarios. The 70/80 GHz E-band has excellent characteristics for small cell wireless backhaul (see Table 6 in Section 5.1), in particular short link distances allowing for spectrum re-use and very wide channel sizes to permit data throughputs of 10+ Gbps.

6 Spectrum backhaul licensing procedures

Wireless backhaul national licensing procedures are almost as diverse as the spectrum bands they manage. They have evolved in response to local conditions. But what are the different wireless spectrum backhaul licensing approaches? And what are their relative merits?

6.1 Types of licensing procedures

There are effectively five licensing models:

- Per link
- Block spectrum
- Shared license
- Lightly licensed spectrum
- Unlicensed spectrum

As shown in Chart 12, per link has been the most favored model to date, with 60.6% of countries opting for this model.

6.2 Per link spectrum licensing

The per link spectrum licensing method has been the traditional way to license mobile backhaul spectrum. Spectrum is issued to operators upon request. Across different regions, a majority of countries issue the spectrum bands for backhaul links on a per link basis only. Some countries, such as France and the United Kingdom, use per link as well as block spectrum licensing methods for backhaul links frequency allocation.

There has been a shift toward an increasing allocation of block spectrum licensing. In the United Kingdom, for example, Ofcom has reported a reduction in the number of backhaul PTP links between 20 GHz and 45 GHz due to this increased use of block-assigned spectrum. Ofcom wishes to devolve backhaul spectrum link management and indeed empower mobile service providers with greater flexibility to manage their backhaul infrastructure.

6.2.1. SWOT ANALYSIS

Per link licensing is effective for PTP backhaul connections. Deployments are highly localized due to directed antennas with narrow beam widths. Therefore, spectrum can be reused. Regulators find that it is a model that works, even if it is not perfect. They often keep the spectrum on a very short leash with license durations typically of 1 to 2 years. This means that the spectrum is comparatively cheap. However, the operator may have to acquire microwave link hardware with different spectrum band configurations, which can impact the cost of equipment. Furthermore, the short duration of many licenses means operators may not have long-term assurance that they have access to the PTP spectrum.

Table 11

SWOT Analysis
Per Link Licensing

Strengths	Weaknesses
• Effective for PTP backhaul connections • Spectrum can be efficiently used • A tried and tested licensing model • Spectrum is comparatively cheap	• May have to acquire microwave link hardware with different spectrum band configurations • Can have a heavy licensing administrative overhead
Opportunities	**Threats**
• It is a fairly mature licensing model; some regulators and operators would like to move away from the licensing model where possible	• Licenses are often very short duration but invariably renewed; operator cannot be 100% certain they have the spectrum for the long term

Source: ABI Research

6.2.2 SPECTRUM BAND ANALYSIS

Per link spectrum licensing was, by far, the most common form of wireless spectrum backhaul licensing in the markets that ABI Research surveyed; 20 out of 22 countries used this licensing model. Per link was largely associated with PTP backhaul deployments. Per link licensing typically takes place from 18 GHz to 42 GHz, with exceptions in certain markets or PMP backhaul applications.

6.3 Block spectrum licensing

Per block licensing has been gaining traction in the higher spectrum bands (28 GHz and higher). Regulators like Ofcom have taken steps to minimize the administrative and financial overhead of wireless backhaul licensing. Block spectrum licensing represented 21.2% of license models in operation.

6.3.1 SWOT ANALYSIS

Block spectrum licenses have been used by some regulators and operators for PTP links, but they are also increasingly being used for PMP links. Block spectrum allocation does give the operator more certainty of operation. Regulators would want to see that there was substantial need by the operator for block spectrum licensing. Principally, the operator would need to demonstrate that it is planning to connect a number of macrocell sites and/or small cell sites with PMP services. Given the anticipated growth in small cells, ABI Research believes that block spectrum needs to become a more prevalent form of licensing in a number of markets.

Table 12

SWOT Analysis Block Spectrum Licensing

Strengths	Weaknesses
• Can be used for PTP links, but are particularly useful for PMP application scenarios • Gives the operator more certainty of operation	• License cost can be significantly higher than per link licensing
Opportunities	**Threats**
• Could grow in use by regulators • They would need to see that there was substantial demand for it; this would come from small cell deployments	• Issuing licenses can take a long time thus delaying rollouts • Licensing fees need to be affordable for mobile backhaul; operators already pay significant amounts in access spectrum license fees

Source: ABI Research

6.3.2 SPECTRUM BAND ANALYSIS

Per block spectrum licensing has been primarily associated with the ex-LMDS bands in 23 GHz to 28 GHz in Europe and the 31 GHz bands in the United States. Only a handful of countries use the per block spectrum method for the majority of their backhaul needs. Italy uses the block assignment method exclusively. Allocated spectrum blocks are from bands 26 GHz and 28 GHz and are not shared. France allows block and per link allocation together in bands 23 GHz, 26 GHz, 32 GHz, 38 GHz, and 70/80 GHz. South Africa has allocated spectrum on a per block basis in a number of bands, including the 26 GHz, 28 GHz, 38 GHz, and 42 GHz bands. Operators are required to share the spectrum.

6.4 Lightly licensed spectrum

In a number of markets, regulators are striving to reduce the burden of regulation on operators. Where there are technical solutions to mitigate interference, there are then opportunities for implementing a "lightly licensed" approach. In a lightly licensed approach, the licensee pays a comparatively smaller fee for a non-exclusive license. The licensee then pays an additional nominal fee for each wireless backhaul link that it deploys. The operator must take measurements and perform an interference analysis to assess the probability of affecting any existing users in the vicinity. All backhaul transmitters must be identifiable in the event that they cause interference to any existing operators in the vicinity. If interference is caused between the licensees that cannot be mediated by an immediate technical solution, licensees are required to resolve the dispute between them.

Table 13

SWOT Analysis Lightly Licensed Spectrum Licensing

Strengths	Weaknesses
• Reduced regulatory/administrative burden on the operator • License fees can be comparatively low as the license is not exclusive • Still quite fast to roll out • Some moderate guarantees against interference	• Operator needs to take proactive measures to ensure its backhaul links do not cause interference to any neighboring existing users • If there is interference, often the two operators are required to resolve the interference issue themselves
Opportunities	**Threats**
• Likely to grow in use by regulators • Operators are keen on it, especially if there is a low probability of interference	• Unresolved interference conflicts are a possibility, but usually the regulator can step in as a last resort

Source: ABI Research

6.4.2 SPECTRUM BAND ANALYSIS

A major push into light licensing has been seen in the 71 GHz to 76 GHz, 81 GHz to 86 GHz, and 92 GHz to 95 GHz bands. Regulatory implementation is building, including in 18 of the 22 markets surveyed by ABI Research. The majority of these were developed markets, but a number of emerging markets have also implemented light licensing. ABI Research expects that more markets, both in developed and emerging markets, will adopt light licensing regimes as a means to give telcos greater flexibility with their backhaul rollout plans.

6.5 Shared spectrum licensing

In many respects, the shared licensing regime is a variant of the light licensing regime. The administrative requirements are reduced, but there is also an explicit requirement to share a block of spectrum with one or more participants. In the shared spectrum licensing method, microwave backhaul frequencies are not exclusive for any operator and are to be shared with other operators on a first-come, first-served basis in a particular location. Shared spectrum licensing represented 9.1% of license models in operation. Regulators are actively reviewing shared spectrum licensing, but it may prove challenging to implement shared spectrum for backhaul due to the high QoS requirements.

6.5.1 SWOT ANALYSIS

A few regulators have dabbled in issuing shared spectrum licenses where there is a primary and a secondary user, or there is a first-come, first-served policy in a given location. The first to deploy has primacy, and the second cohabiting licensee is prohibited from causing interference in that location. The incentive is to encourage effective utilization of the wireless backhaul spectrum by the operator community.

Table 14

SWOT Analysis Shared Spectrum Licensing

Strengths	Weaknesses
• Has many of the same traits as lightly licensed • Reduced regulatory/administrative burden on the operator • License fees can be comparatively low as the license is not exclusive • Still quite fast to roll out	• Greater risk of interference • Operator needs to take proactive measures to ensure backhaul links do not cause interference to existing neighboring users • If there is interference, often the two operators are required to resolve the interference issue themselves
Opportunities	**Threats**
• Regulators are investigating the potential of shared licensing	• Unresolved interference conflicts are a possibility, but usually the regulator can step in as a last resort • Operators have some concerns about quality of service

Source: ABI Research

6.5.2 SPECTRUM BAND ANALYSIS

Quite separate from unlicensed spectrum bands where a number of participants may "share" a block of spectrum, regulated shared spectrum bands, where two or more operators explicitly share spectrum, can be found in India, Singapore, and Nigeria. Regulators are assessing assured shared spectrum licensing models. Such assured shared spectrum arrangements permit cohabitation in a given spectrum band, but rules define where, when, and how the respective participants can use the spectrum band.

6.6 Unlicensed spectrum

Unlicensed spectrum can be used for backhaul links in certain circumstances. Under this approach, operators do not need to pay a license fee. The unlicensed model has been adopted in a number of markets, but feedback has been largely negative. Complaints regarding interference from a growing number of public and private Wi-Fi access points are frequent. At present, unlicensed backhaul is using the Wi-Fi spectrum bands (2.4 GHz and 5 GHz bands) or the much higher 60 GHz band. Unlicensed spectrum represented 9.1% of backhaul models in operation.

6.6.1 SWOT ANALYSIS

Historically, operators have been wary of unlicensed spectrum, especially in the Wi-Fi bands. In a world where operators need assured data throughput, low latency, and versatile capacity, using 2.4 GHz and even 5 GHz unlicensed spectrum is often the plan of last resort. However, the allocation of spectrum in the high 50/60 GHz bands is serving to redeem the unlicensed model. A "zero" administrative model is to be welcomed. Technical solutions to mitigate interference, as well as an open dialog between operators to address sources of interference, are essential. A first-come, first-served policy in terms of siting backhaul links is at the heart of what makes the model work.

Table 15

SWOT Analysis Unlicensed Spectrum

Strengths	Weaknesses
• No licensing requirements; therefore, reduced administrative burden • No licensing fees to be paid • Fast rollout • Can provide temporary spectrum solutions for locations that need "immediate" spectrum coverage, e.g., an event	• Heavy reliance on topology, proximity, and technical expertise to mitigate the impact of interference
Opportunities	**Threats**
• Spectrum is available in 2.4 GHz, 5 GHz, and 60 GHz	• Very real threat of loss of connection as the "noise floor" rises to mask the operator's transmissions • 2.4 GHz and 5 GHz do not provide long-term viable spectrum solutions

Source: ABI Research

6.6.2 SPECTRUM BAND ANALYSIS

Unlicensed wireless backhaul has proven to be an anathema to most operators. Higher data throughputs and lower latencies are becoming pressing requirements for mobile operators as their 3G and 4G subscriptions and traffic grow. This attitude should start to change as unlicensed V-band (60 GHz) solutions gain commercial traction in the market and the cost of equipment drops. Significant amounts of spectrum are available (7 GHz of license-exempt spectrum is available in the 57 GHz to 64 GHz band), and the short propagation distances should also help mitigate against interference. The FCC and the EC have taken a proactive approach to the 60 GHz V-band and have recommended a license-exempt approach to the active use of the 57 GHz to 64 GHz band. Furthermore, both regulatory authorities have tightened up the power transmit allowances for short-range, largely indoor applications (<40 dB EIRP) and outdoor, high-power V-band transceivers intended for backhaul applications.

However, in ABI Research's latest survey, 4 years after the last iteration, there does not appear to be significant traction in the adoption of the unlicensed spectrum for backhaul links, even using the ultra-wide channels available in the 60 GHz bands. ABI Research believes mobile operators have preferred to opt for the lightly licensed 70/80 GHz bands that also assure very high-capacity links (10 Gbps to 25 Gbps), which is important for an essential component of the network.

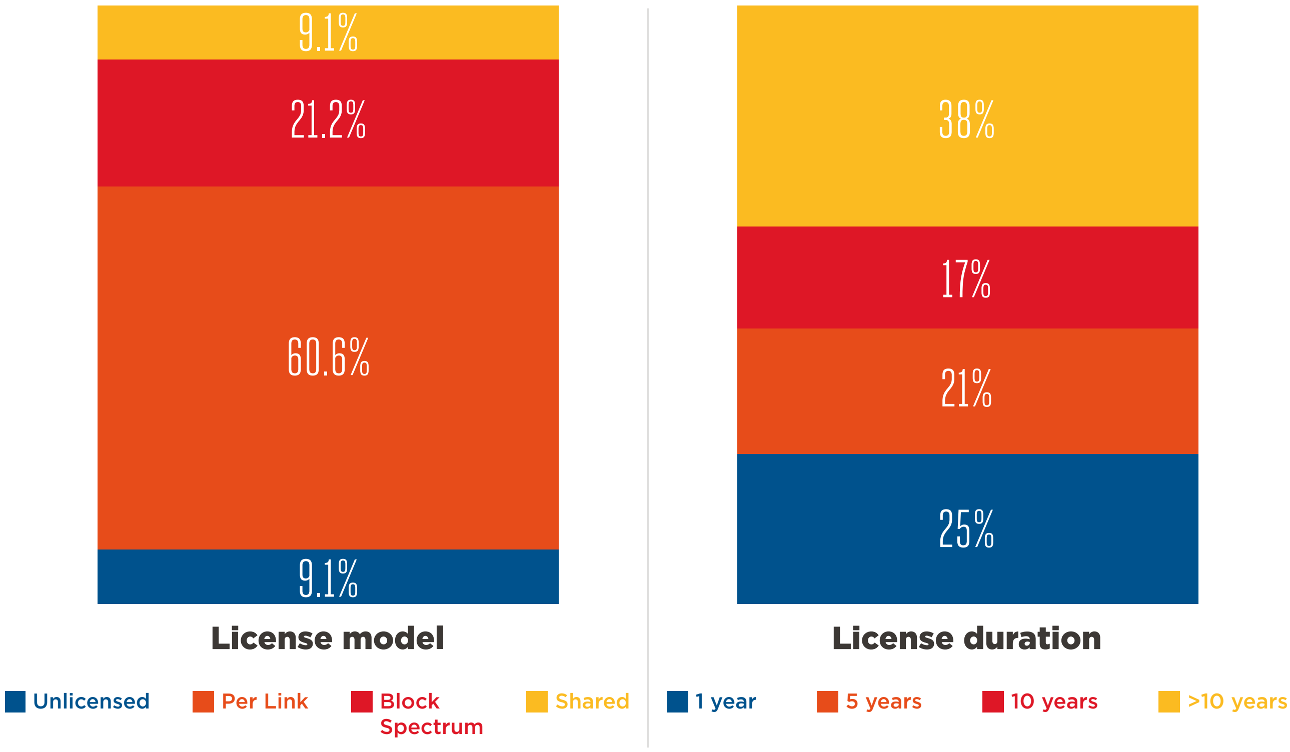
A number of operators have used the 2.4 GHz and 5.8 GHz bands for wireless backhaul, but they seem to be deploying them as an act of last resort. These bands have been used in India and Brazil. In the case of Brazil, carriers were using the bands for temporary backhaul coverage at major events, including carnivals, New Year's Eve, and sporting events. The growth in 2.4 GHz and 5 GHz access points and client devices has had a detrimental effect on backhaul using such spectrum bands.

6.7 Quantitative spectrum license summary

Based on research carried out by ABI Research, the per link licensing model is predominant, with 60.6% of all license models deployed. This was followed up by block spectrum with almost 21.2%, and then shared and unlicensed with an equal 9.1% (see Chart 12).

Chart 12

Backhaul Spectrum License Model & Duration Summary
World Markets, 2017



Source: ABI Research

In terms of license duration, ABI Research estimates that 25% of licenses are of 1-year duration, whereas 5-year license durations represented 21%. Licenses with 10 or greater licenses durations increased to 54%, which is a significant increase compared to 4 years ago. As demands on backhaul have increased due to mobile data traffic, mobile operators have needed greater assurance in planning and placing their network infrastructure. Mobile operators now have between 10,000 and 100,000 base stations to manage.

The short-term, 1- to 2-year licenses that are associated with PTP links are likely to remain a licensing mainstay for government regulators, especially for the sub-10 GHz and 20 GHz to 40 GHz bands, as that spectrum could be potentially re-allocated to access-related services for FWA or mobility services.

In these bands, regulators have a general, but unbinding principle of honoring the renewal of the 1-year license for a further term. The rationale given by regulators is that they wanted to prevent mobile operators from sitting on unused per link backhaul licenses. Generally speaking, wireless backhaul spectrum license fees in the 10 GHz and above bands have been priced well below the spectrum pricing fees of end-user access spectrum. A more detailed segmentation by country can be found in Table 16.

Table 16

Regional Backhaul Spectrum License Summary
World Markets

Country	Unlicensed	Per Link	Block Spectrum	Shared	1 Year	5 Year	10 Year	>10 Year
Western Europe								
Denmark		●						●
France		●	●					●
Germany		●					●	
Italy			●					●
United Kingdom	●	●	●					
Eastern Europe								
Croatia	●	●				●		
Czech Republic		●				●		
Poland		●					●	
Asia Pacific								
Australia		●						●
India	●	●		●				●
Indonesia		●				●		
Japan		●				●		
Malaysia		●	●					●
New Zealand		●						●
Singapore		●	●	●	●			
North America								
Canada		●			●			
United States		●					●	
Latin America								
Uruguay		●						●
Middle East								
Saudi Arabia		●	●		●			
UAE		●			●			
Africa								
Nigeria		●		●	●	●	●	●
South Africa			●		●			
World-wide Analysis								
Total	3	20	7	3	6	5	4	9
Spectrum Share	9.1%	60.6%	21.2%	9.1%	25%	21%	17%	38%

Source: ABI Research

6.8 Stakeholders analysis

In the context of licensing procedures and mandates, the regulators inevitably come to the fore. They outline the parameters of how a license should be secured, the terms and conditions of the license, and invariably are in charge of the overall strategic recommendation of how the wireless spectrum resources of a country should be allocated in the long-term interests of the citizens of the country.

One critical aspect is to put a focus on the long-term sustainability of the industry and not just on securing the maximum tax receipts from the auction or leasing of spectrum. A number of operators and equipment vendors have expressed concern that end-user access-type spectrum valuations could be potentially applied to backhaul spectrum bands.

6.9 Potential regulatory considerations

6.9.1 TYPES OF LICENSING MODELS

Based on the research interviews conducted with the operator and equipment vendor community, there is concern surrounding the unlicensed model for backhaul. The greatest concern was for the 2.4 GHz and even the 5 GHz bands, due to the potential interference and congestion from Wi-Fi users. As the amount of traffic continues to increase and the need to compensate by using higher order modulation schemes (e.g., from 256 Quadrature Amplitude Modulation (QAM) to 1024 QAM) grows, there is concern that ambient background transmissions from other unlicensed backhaul links could degrade the QoS for all active participants. The 60 GHz V-band is a more viable solution, but operators have yet to fully embrace the 60 GHz band for their backhauling needs. After 4 years, the adoption of the 60 GHz band for backhaul has been marginal (less than 3% of backhaul links in 2017).

Based on discussions with various stakeholders in the ecosystem, per link licensing for PTP deployment in the main microwave bands is "fit for purpose" for macrocell site deployments. Interference is minimal and the first-come, first-served award of license links is reasonably efficient. The light licensing approach appears to be gaining traction, especially in relation to the 70/80 GHz band. There has also been a shift toward "block" or "area-wide" licensing, which has helped the operators to more efficiently plan their base station and backhaul links.

The duration of licenses has also increased over the past 4 years. This has been appreciated by the mobile operator community. Four years ago, of the 23 countries surveyed, 40% relied on 1-year, rollover type license agreements. As of the end of 2017, 1-year, rollover licenses had dropped to 25% of the overall total of license model in operation. Licenses with a duration of 5 years or more represent 75% of the total.

6.9.2 TRADING SPECTRUM FOR WIRELESS BACKHAUL

If operators were to be able to acquire more of their spectrum for wireless backhaul via per block licensing and those licenses were of longer license duration, it would also be advantageous to be able to trade spectrum with other stakeholders. This would dis-incentivize operators from sitting on unused backhaul spectrum and allow operators with a greater need for backhaul spectrum to be able to secure it. Mechanisms could be put in place to "limit" the amount of spectrum any one particular operator can secure. This would prevent anti-competitive hoarding of spectrum.

7 Recommendations and policy options

Mobile operators have a challenging time backhauling the mobile voice and data traffic from varied environments, such as urban, suburban, rural, offices, residential homes, skyscrapers, public buildings, tunnels, etc. Table 17 outlines how mobile operators need a variety of technical and spectrum backhaul solutions.

Table 17

Mobile Backhaul Technology Trade-Offs
Wireless versus Fixed versus Satellite

Segment	Microwave (7–40 GHz)	V-Band (60 GHz)	E-Band (70/80 GHz)	Fiber-optic	Copper (Bonded)	Satellite
Future-Proof Available Bandwidth	Medium	High	High	High	Very Low	Low
Deployment Cost	Low	Low	Low	Medium	Medium/High	High
Suitability for Heterogeneous Networks	Outdoor LRAN/Access	Outdoor LRAN/Access	Outdoor LRAN/Access	Outdoor LRAN/Access /Core	Indoor Access Network	Rural only
Support for Mesh/Ring Topology	Yes	Yes	Yes	Yes where available	Indoors	Yes
Interference Immunity	Medium	High	High	Very High	Very High	Medium
Range (Km)	5~30, ++	1~	~3	<80	<15	Unlimited
Time to Deploy	Weeks	Days	Days	Months	Months	Months
License Required	Yes	Light License/ Unlicensed	Licensed/ Light License	No	No	No

Note: Shading indicates preferred choice for 5G mobile backhaul. LRAN = Local Regional Access Node

Source: ABI Research

The shaded cells indicate attributes that particularly benefit 4G, and in particular, 5G mobile backhaul. Fiber-optic does have its role to play in specific scenarios, and microwave links in the 6 GHz to 40 GHz bands have been a mainstay of wireless backhaul for macrocell sites. However, the E- band, the W-band, and even the V-band (the 60 GHz unlicensed band) will steadily play a more prominent role in mobile operators' backhaul networks. Migration to the 70/80 GHz and the 90 GHz band is well underway.

As a result, a complex evolution is going on in small cell backhaul usage. Fiber-optic's prevalence is currently at 40.7% on a worldwide basis, but will grow to 49.7% by 2025, although mobile service providers will still need to rely on LoS microwave for much of their backhaul needs. Microwave in the 7 GHz to 40 GHz band decreases from 34.9% in 2017 and to 21.3% in 2025, but microwave 41 GHz to 100 GHz grows from 13.5% to 21% over the same time period. Copper-line, as well as licensed and unlicensed sub-6 GHz, provides a marginal role for the mobile service provider. Satellite has a usage-based model, but can play an essential role for edge of network scenarios, as well as for temporary deployment scenarios.

This usage outlook reflects the maturing of technical solutions that will need spectrum support from national regulators. This pressure to support backhaul solutions and spectrum for the macrocell site market is also reinforced by the need to support the backhaul connectivity for small cell deployments that are expected to reach 4.3 million by 2025 on a worldwide basis.

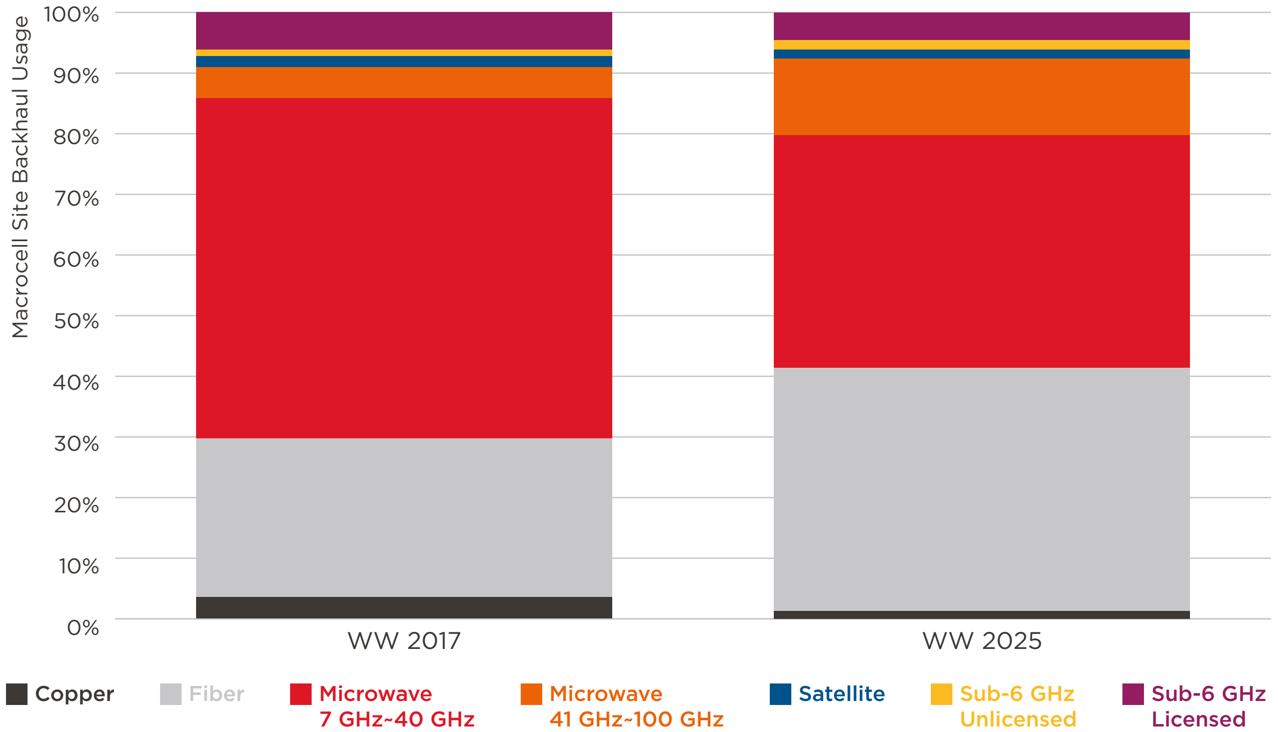
7.1 The changing face of cell site backhaul

While the macrocell microwave LTE backhaul market will not grow at the same rate as small cell microwave backhaul, it does show consistent growth. In 2017, the majority share of backhaul links deployed is the traditional microwave LoS (7 GHz to 40 GHz, 57.4%).

The higher bandwidth requirements of 4G LTE and the 2020 arrival of 5G are also driving a significant share for fiber and, to a lesser degree, microwave in the 41 GHz to 100 GHz (4.5%). Transmission distances are contained to 1 km to 3 km or so, but being able to support data throughput of up to 25 Gbps makes it suitable for macrocell sites in downtown locations with high-levels of traffic. OFDM NLoS sub-6 GHz backhaul links could be used for macrocell sites, but deployment would be largely redundant and better suited to small cell site deployment scenarios.

Chart 13

Macrocell Backhaul by Method
World Markets, 2017 and 2025



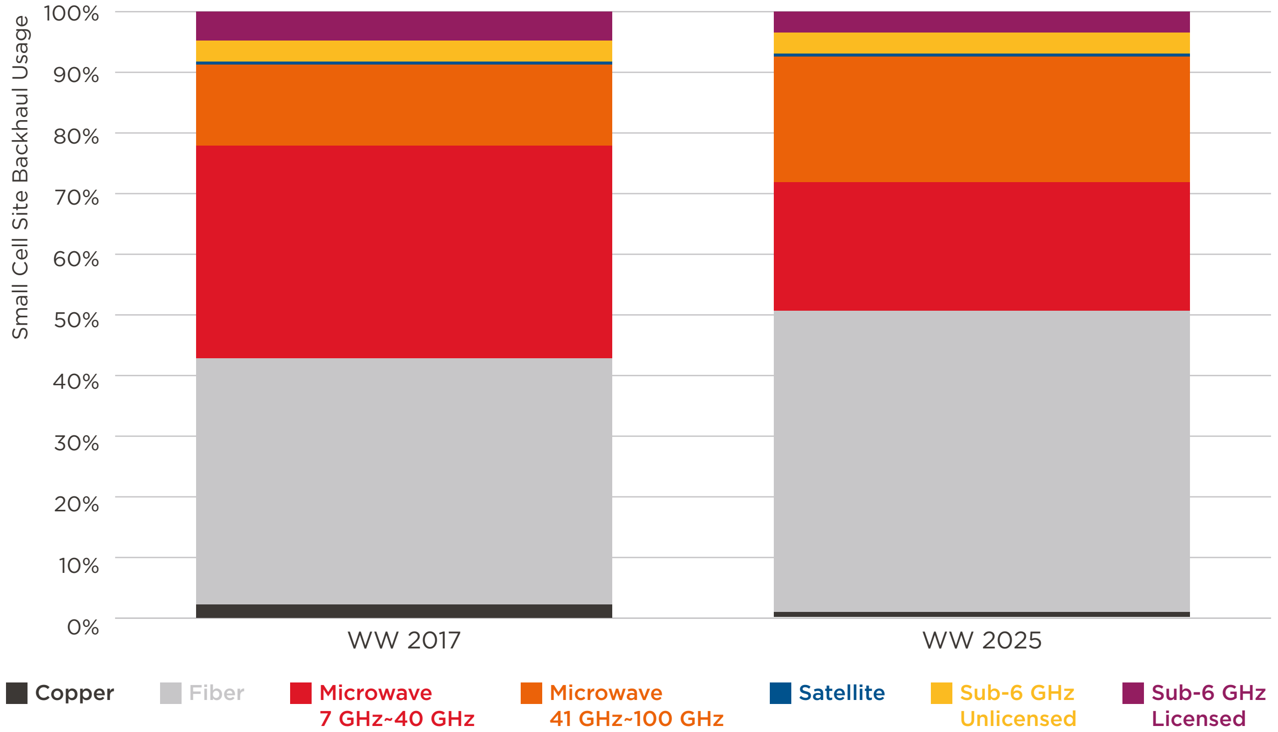
Source: ABI Research

Over the past 4 years, there has been a significant shift in the commitment by telcos to roll out fiber for macrocells, but especially in relation to small cells. Mobile service providers have taken a long-term view of the backhaul provisioning of macro and small cell sites. Fiber-optic provisioning has also been boosted by the wider rollout of fiber to business and residential premises. As a result, fiber-optic provisioning of small cells stood at 25.3% in 2017 and is expected to grow to 37.3% by 2025.

Microwave and millimeter wave captured 62% in 2017, but will decline to 53.4% by 2025, as most small cell sites are within urban or commercial business districts, which are being increasingly provisioned by fiber-optic. What is significant is that millimeter wave usage (microwave: 41 GHz to 100 GHz) is expected to grow from 4.5% in 2017 to 10% in 2025. Licensed sub-6 GHz for NLoS is still a viable small cell solution in 2017, representing 6.2%, but it will be challenged by sufficiently available sub-6 GHz spectrum. The higher bandwidth and data rates available in the 70/80 GHz band and the light licensing regime means that this technology will become a popular option as links are daisy-chained and aggregated for transport back to the network core.

Chart 14

Small cell Backhaul by Method
World Markets, 2017 and 2025



Note: Detailed total worldwide, and by region, 2G, 3G, 4G and 5G segmentations for backhaul links by method of transmission can be found in Appendix 1 on page 72.

Source: ABI Research

7.2 Modulation schemes and multi-band aggregation

There has been continued innovation in backhaul technology. Higher order modulation equipment has helped compress more data per Hertz (Hz). However, while modulation schemes up to 2048 QAM are now available, most equipment vendors and operators have stated that equipment supporting 512 QAM and higher are likely to deliver limited additional benefit, given the greater link margins required and the increased sensitivity of such equipment to unwanted interference.

However, combining low- and high-frequency microwave links has been a win-win for mobile service providers. One example is backhaul links that aggregate a longer, but high propagation availability link in 18 GHz with a high capacity link in the 70/80 GHz band using a single dual-band antenna.

Figure 7

Backhaul Bandwidth Requirements
World Markets, 2017, 2022, and 2025

Mobile broadband introduction	2017	2022	Towards 2025
80 percent of sites	25 Mbps	75 Mbps	100 Mbps
20 percent of sites	75 Mbps	200 Mbps	300 Mbps
Few percent of sites	150 Mbps	450 Mbps	600 Mbps

Advanced mobile broadband	2017	2022	Towards 2025
80 percent of sites	150 Mbps	350 Mbps	600 Mbps
20 percent of sites	300 Mbps	1–2 Gbps	3–5 Gbps
Few percent of sites	1 Gbps	3–10 Gbps	10–20 Gbps

Source: Ericsson (2017)

As a result of these innovations, Ericsson forecasts that, by 2022, the typical backhaul capacity for a high-capacity cell site will be in the 1 Gbps range, but will increase to 3 Gbps to 5 Gbps by 2025. It should be noted that 80% of cell sites in an advanced mobile broadband network will be operating in the 350 Mbps range in 2022 and the 600 Mbps range by 2025.

7.3 Ecosystem development and recommendations

There are at least 25 vendors in the wireless backhaul ecosystem. Some may argue that the ecosystem is too fragmented, but ABI Research argues that this level of competition is healthy for the current status of the backhaul market. The backhaul market has been a hotbed of innovation. This is beneficial because operators will need a wide range of fixed and wireless backhaul solutions from a larger number of manufacturers to cater to the various deployment scenarios that they need to address.

In the mainstream macrocell microwave backhaul market, the largest vendor is Ericsson with a majority share of the market. NEC is in second place with a strong backhaul product portfolio. Huawei, Nokia, and DragonWave-X also have strong traction in the marketplace.

Small cell site deployment represents a potential line of disruption to the incumbents. Vendors such as Tarana Wireless, Cambridge Broadband Networks, CCS, Siklu Communication, and VubIQ Networks are providing novel solutions.

The level of competition is intense and not every vendor will remain commercially viable in the long term. There has been consolidation over the past 4 to 5 years, and that process will continue to intensify. A number of the smaller vendors have merged with larger vendors as top tier operators have selected their primary and secondary suppliers. A small percentage of operators will opt for multi-vendor (three or more) arrangements, but given that the vast majority of backhaul vendors have proprietary solutions, operators will not be able to use these backhaul solutions in a modular manner.

One particular characteristic of innovation that is shifting the potential costs of wireless backhaul manufacturing is digital and signal processing. Vendors have been innovating at the silicon level and bringing advanced digital and signal processing techniques to bear on the problem so that link performance is maximized and interference is mitigated in complex PMP and NLoS topologies. Data throughputs have demonstrated a 3× to 5× increase.

7.4 Regulatory recommendations

A number of regulatory initiatives need to be put in place.

7.4.1 ACTIVE PROMOTION OF THE E-BANDS AND W-BANDS FOR WIRELESS BACKHAUL

- **Key Takeaway:** More active promotion of the 70/80 GHz E-bands and the 92 GHz to 114.25 GHz W-band for wireless backhaul in the international regulatory community.
- Fiber-optics cannot be deployed in all cell site scenarios. The 70/80 GHz E-band has excellent characteristics for small cell wireless backhaul, in particular for short link distances, allowing for spectrum re-use and very wide channel sizes to permit data throughputs of 10 Gbps to 25 Gbps. The spectrum is to be lightly licensed or licensed, which gives the mobile operator a high level of assurance over QoS. Furthermore, it has better signal propagation characteristics compared to the 60 GHz band.

7.4.2 ACTIVE PROMOTION OF THE 60 GHz V-BAND FOR WIRELESS BACKHAUL

- **Key Takeaway:** Promotion of the 60 GHz V-band for wireless backhaul in the international regulatory community.
- Based on ABI Research's investigation, use of the 60 GHz V-bands has only had limited adoption, so far, in the countries surveyed.
- Operators have preferred to opt for the 70/80 GHz and even the 90 GHz bands where licensing is in place and the bands are not as susceptible to atmospheric attenuation of ambient interference. However, the 60 GHz V-band is unlicensed and vendors have continued to enhance their solutions.
- It is a promising band for backhaul services and can complement the 70/80 GHz bands. The 60 GHz band has been set aside in a number of countries. In the United States, Canada, and Korea, 7 GHz has been put aside in the 57.05 GHz to 64 GHz range. In Europe, 7 GHz has been allocated in the 57 GHz to 66 GHz band, and Australia has set aside 3.5 GHz in the 59.40 GHz to 62.90 GHz bands.

7.4.3 NEED TO EVALUATE THE D-BAND FOR FUTURE PROVISIONING

In order to prepare for the inevitable future requirements for additional capacity in the backhaul architecture, there will be a need to consider the possibility of additional spectrum in the 130 GHz to 174.8 GHz (D-band) bands to complement the use of 70/80 GHz and the 60 GHz bands. These are likely to be needed for ultra-fast, high-density small cell deployments. Mobile service providers have stated they anticipate backhaul will need to evolve beyond the current traffic capacities of 1 Gbps to 10 Gbps, expanding to 30 Gbps to 50 Gbps in the 2020 timeframe. By 2025, some backhaul links will be carrying 100 Gbps and higher.

7.4.4 PROMOTION AND SUPPORT FOR PMP BACKHAUL SPECTRUM AND APPLICATIONS

- **Key Takeaway:** Active promotion and support for spectrum are needed for PMP backhaul applications, with the associated need for per block licensing in the 10 GHz to 15 GHz, 32 GHz, and making use of the unlicensed 60 GHz bands. Mesh, daisy-chain routing technologies are at the heart of PMP. PMP is an attractive technology because it helps route backhaul through the concrete and glass landscape that can block or deflect microwave and millimeter wave transmissions.

- At present, there is PMP spectrum support mainly in the 10.5 GHz, 26 GHz, and 28 GHz bands. There are, however, complications with the 26 GHz and 28 GHz bands, as they are likely to be re-allocated for 5G access services. The United States, Japan, and Korea prefer the 28 GHz band, while Europe and much of the rest of the world are likely to opt for the 26 GHz band. Official regulatory guidance has yet to materialize from country regulators, so operators have already started to migrate away from the 26 GHz to 28 GHz bands. It is anticipated that the 32 GHz band will become the preferred spectrum band for PMP and even PTP backhaul links. The propagation characteristics make the spectrum band effective for mid-distance backhaul (5 km to 10 +/- km).
- The PMP community is interested in using the 60 GHz V-band. In many markets, there has yet to be substantial traction in the 60 GHz band for PMP, but it should be an option in the operator's toolkit for future backhaul deployment, especially for small cells.

7.4.5 10 GHz TO 42 GHz MICROWAVE BANDS WILL EXPERIENCE MIGRATION

- **Key Takeaway:** The 15 GHz to 23 GHz spectrum will remain an essential workhorse for mobile backhaul. The bands are likely to be an invaluable complement to the E-band using multiband carrier aggregation equipment. Demand for these combo bands are likely to be worldwide. However, it is a reality that, in the long term, parts of the 24 GHz to 42 GHz spectrum will be increasingly used by 5G services and less by microwave backhaul. In some of these bands, such as the 26 GHz and the 38 GHz in Europe, there are a significant number of operational microwave links.

7.4.6 NEED TO SUPPORT WIDER CHANNEL SIZES ACROSS ALL BANDS

- **Key Takeaway:** There has been a migration to higher frequency bands. The reason for this is not driven by the need to secure access to additional spectrum bands for backhaul, but to gain access to wider channels for backhaul.

- The lack of spectrum supporting wide channel bandwidths has been identified as a potential bottleneck for microwave backhaul. Until quite recently, regulators had put forward plans that allow for bandwidths of up to 112 MHz in bands below 40 GHz. However, as mobile data traffic has grown, having wider channels has become essential. The availability of higher spectrum bands have encouraged regulators to widen their backhaul channel allocations. For example, CEPT's Electronic Communications Committee has put forward a recommendation for a maximum channel bandwidth of 224 MHz in the 42 GHz band, 2500 MHz in the 60 GHz band, 4500 MHz in the 70/80GHz and 400 MHz in the 90 GHz band.

7.4.7 THERE IS AN EVOLUTION IN LICENSING MODELS

- **Key Takeaway:** From the research interviews conducted with the operator and equipment vendor community, there is concern about the unlicensed model for backhaul. The greatest concern was for the 2.4 GHz and even the 5.x GHz bands, due to the very real possibility of interference and congestion from public and private Wi-Fi users. A number of operators cited situations where they had deployed ISM band backhaul links, only to experience high levels of interference. Many operators referred to sub-6 GHz unlicensed backhaul as the "backhaul solution of last resort."
- The 60 GHz unlicensed V-band is a more viable solution, but operators have yet to fully embrace the 60 GHz band for their backhauling needs because they have concerns about interference and QoS assurance in the mid to long term. Strong growth is expected in 802.11ad Wi-Fi devices over the next 5 to 10 years, which has already been allocated the 60 GHz band.
- Based on discussions with various stakeholders in the ecosystem, per link licensing for PTP deployment in the main microwave bands is "fit for purpose" for macrocell site deployments. Interference is minimal and the first-come, first-served award of license links is reasonably efficient. In some countries, the administrative workload of preparing the PTP application could be streamlined. Light licensing models have taken root in a number of markets and this is a good sign for mobile service providers. Nevertheless, more needs to be done to promote the model, perhaps highlighting best practice, and this could be advocated to regulators in emerging and developed markets.
- As the deployment of base stations shifts from macro cells to small cells, there will be a greater need for block spectrum licensing for PMP mesh links using the 70/80 GHz (or even higher) backhaul applications.
- Given the increased investments that mobile operators will have to make in wireless backhaul, it is essential that mobile operators are given "greater assurance of spectrum tenure" for their backhaul assets, even for PTP applications. Over the past 4 years since ABI Research's previous survey, the situation has improved. Four years ago, out of 23 countries, 40% relied on 1-year, rollover type license agreements, but fast forward to the end of 2017 and that figure has dropped to 25%, and 54% of licenses are now 10 years or more. ABI Research recommends that a term of 5 years be made the default timeline for PTP licenses. For PMP per block licenses, a 5- to 10-year license period would help reassure operators that they can recoup their investment.

7.4.8 SUPPORT WIRELESS BACKHAUL SPECTRUM TRADING

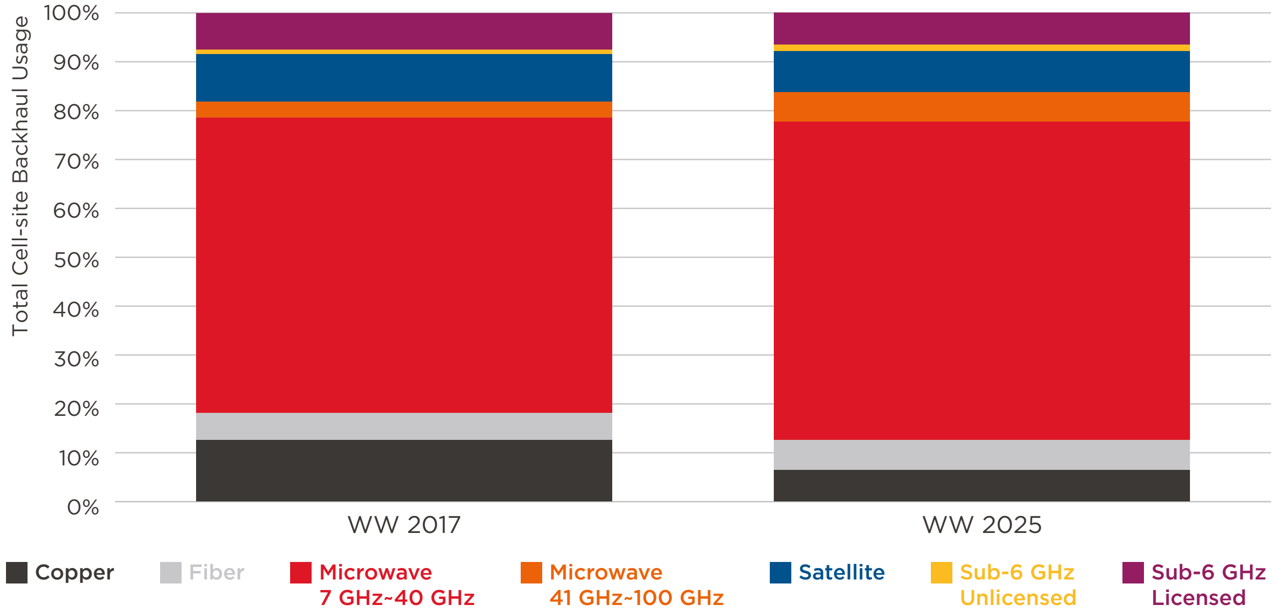
- **Key Takeaway:** If there is to be a larger amount of per block licensing and longer license duration, it would also be advantageous to be able to dispose, and acquire, spectrum from other stakeholders. This would dis-incentivize operators from sitting on unused backhaul spectrum and allow operators with a greater need for backhaul spectrum to be able to secure it. Mechanisms could be put in place to limit the amount of spectrum any one particular operator can secure to prevent anti-competitive hoarding of spectrum.

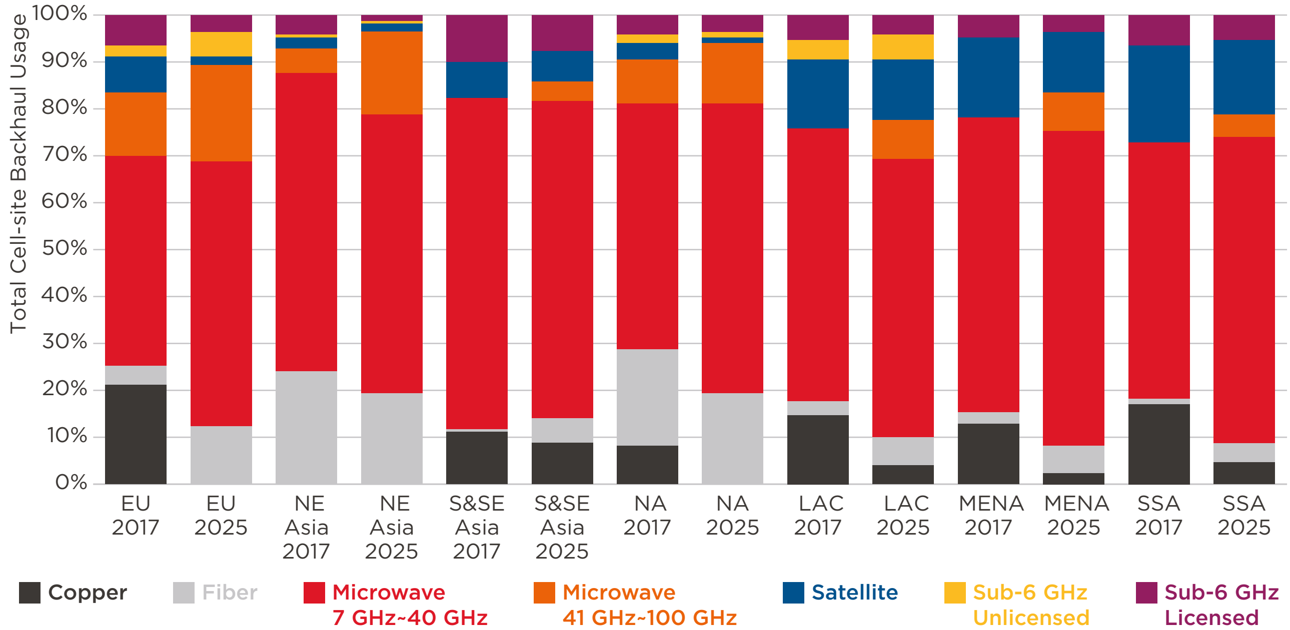
Appendix 1

Total (Small Cell & Macro BTS) Base station Backhaul Links Charts

Chart 15

2G Total (Small Cell & Macro BTS) Base station Backhaul Links
By Method and Region, Historical 2017 and Forecast 2025

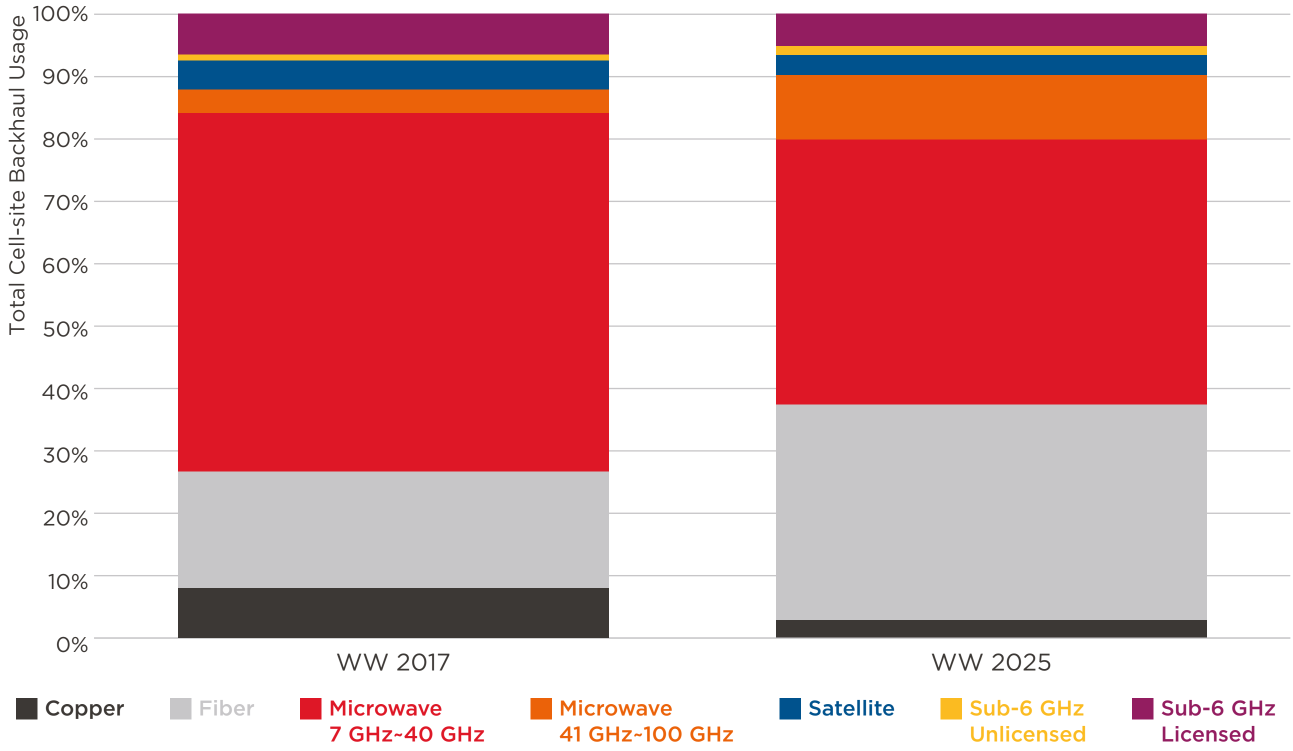


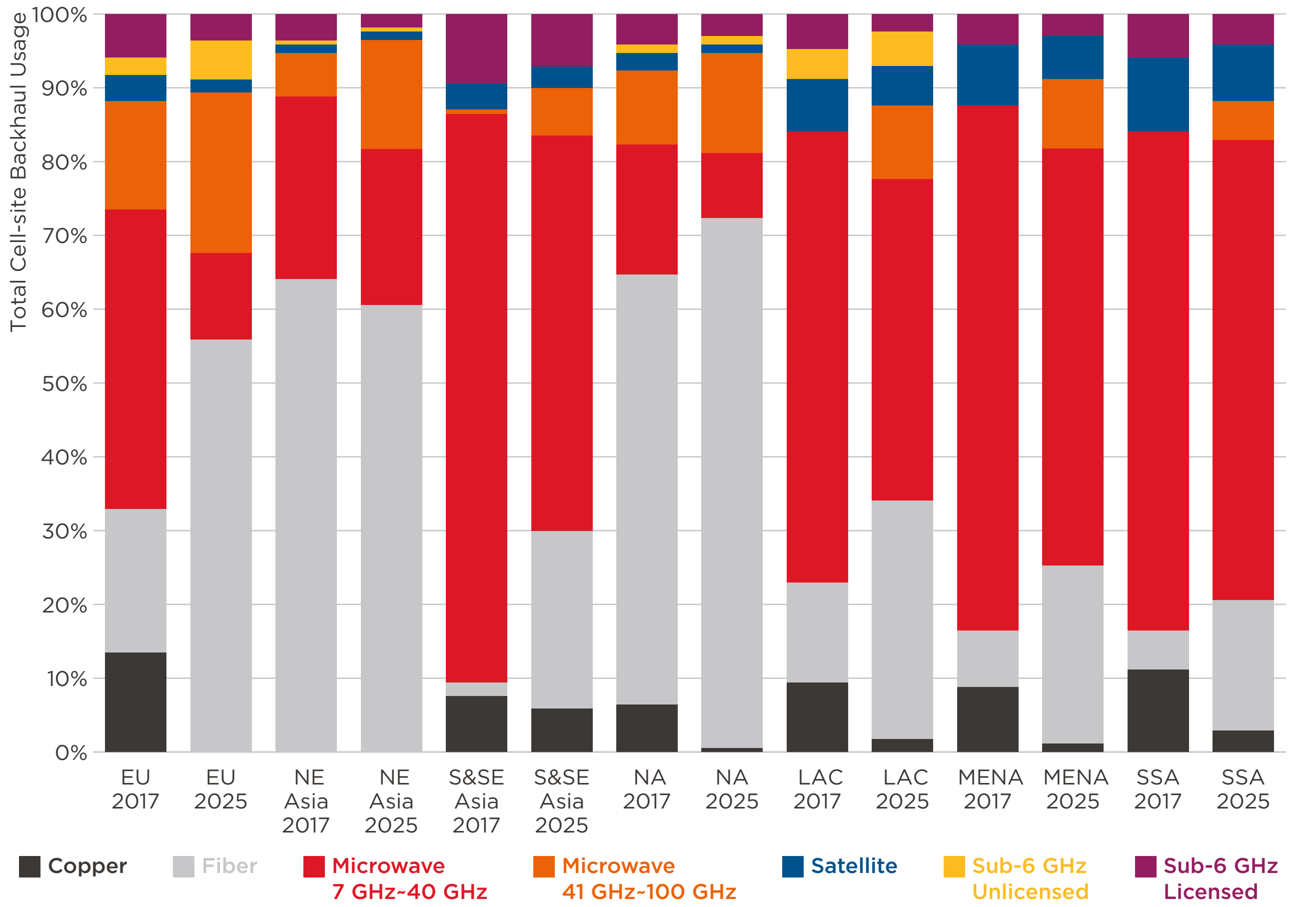


Source: ABI Research

Chart 16

3G Total (Small Cell & Macro BTS) Base station Backhaul Links
By Method and Region, Historical 2017 and Forecast 2025

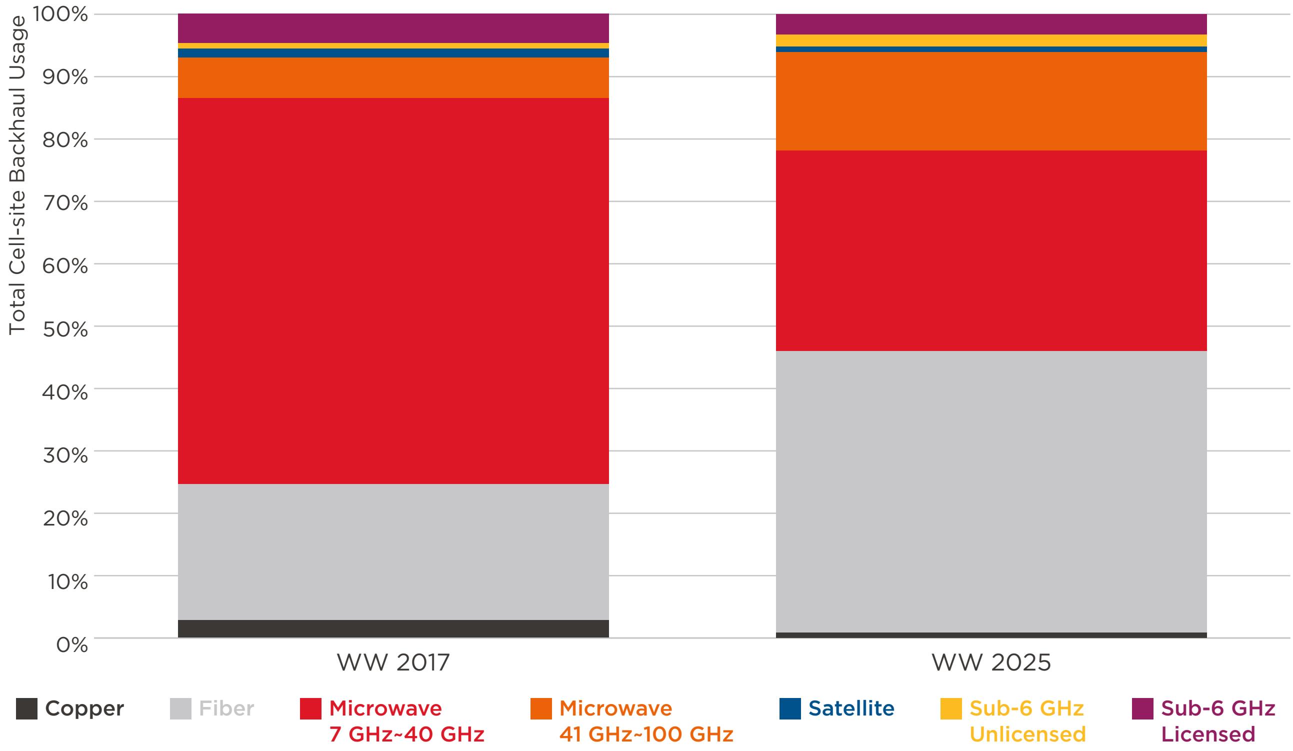


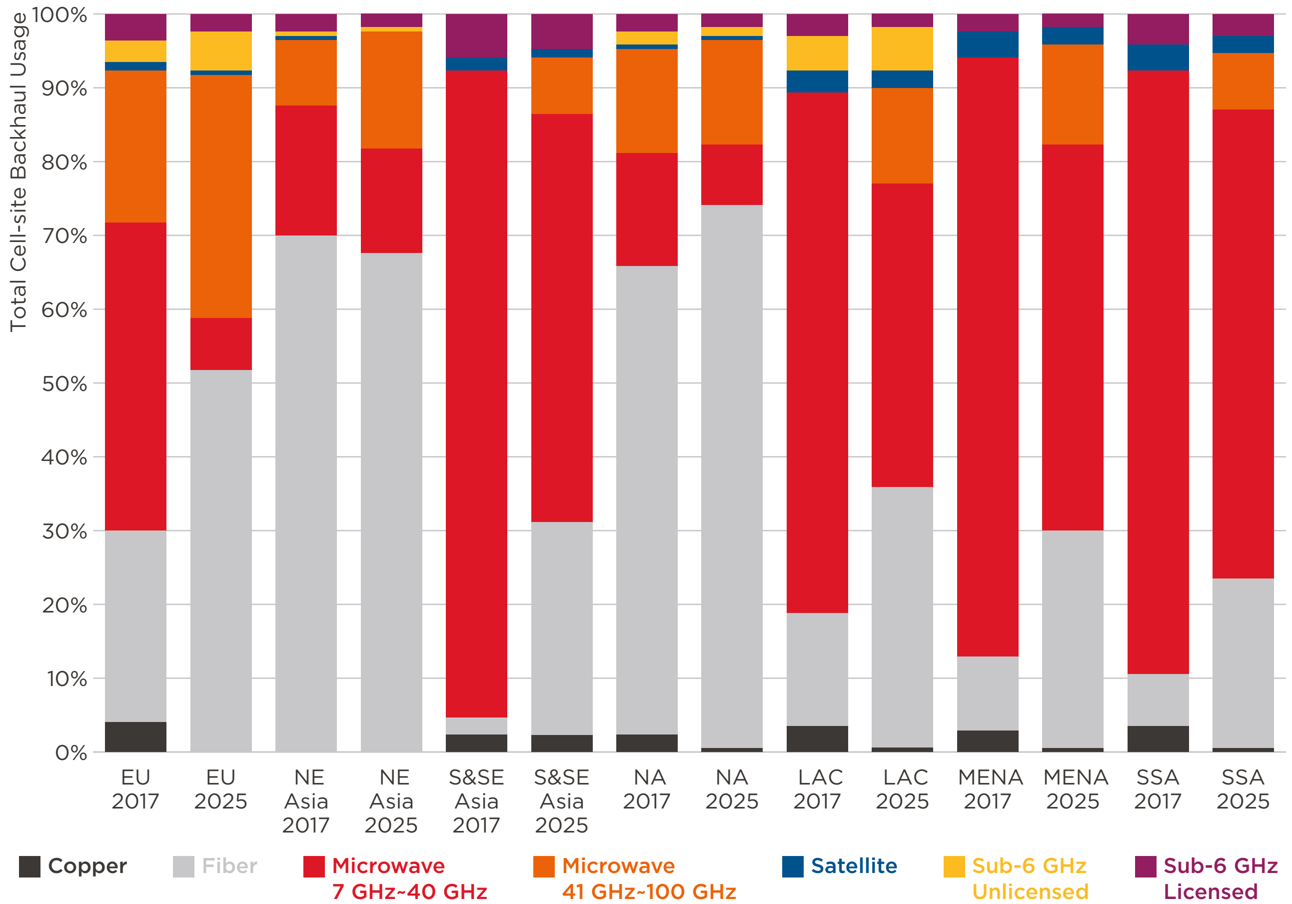


Source: ABI Research

Chart 17

4G Total (Small Cell & Macro BTS) Base station Backhaul Links
By Method and Region, Historical 2017 and Forecast 2025

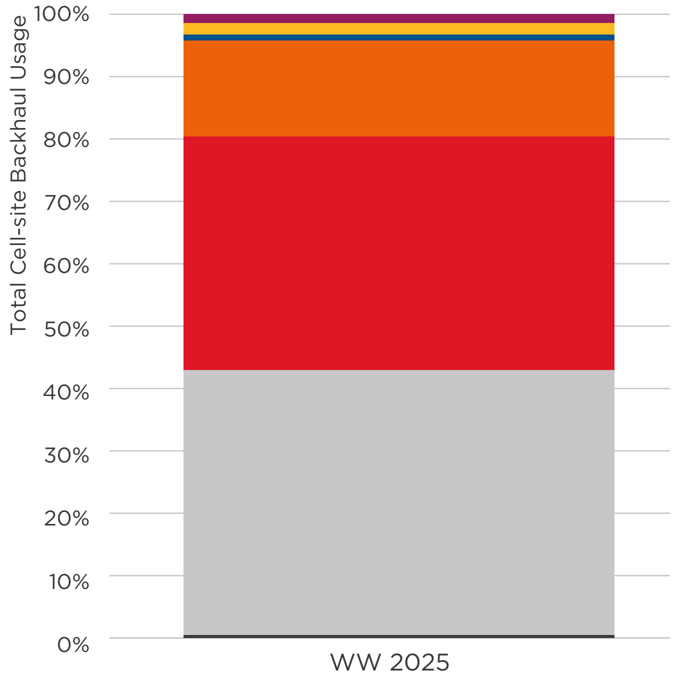




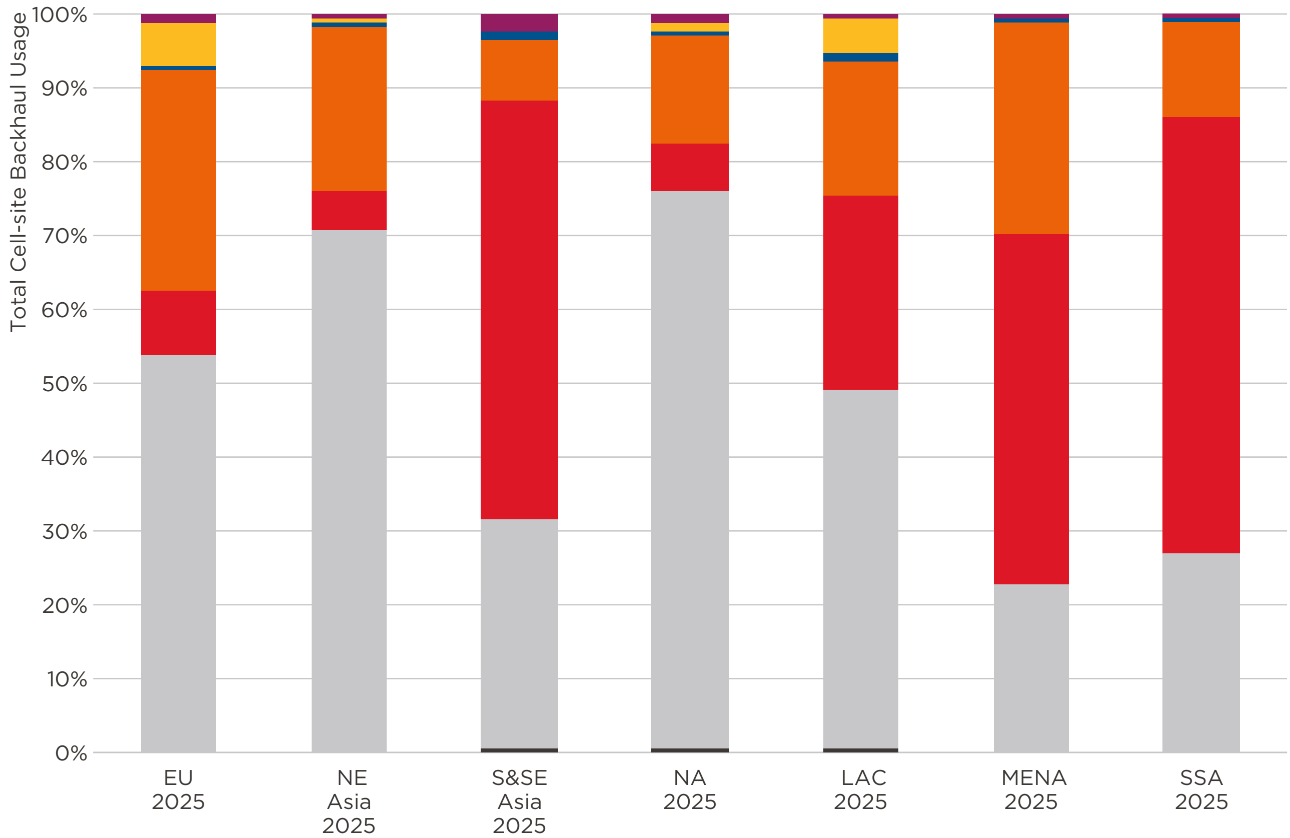
Source: ABI Research

Chart 18

5G Total (Small Cell & Macro BTS) Base station Backhaul Links
By Method and Region, Forecast 2025



Copper | Fiber | Microwave 7 GHz~40 GHz | Microwave 41 GHz~100 GHz | Satellite | Sub-6 GHz Unlicensed | Sub-6 GHz Licensed



Copper | Fiber | Microwave 7 GHz~40 GHz | Microwave 41 GHz~100 GHz | Satellite | Sub-6 GHz Unlicensed | Sub-6 GHz Licensed

Source: ABI Research

Appendix 2

Backhaul Spectrum Allocation Summary, Countries Surveyed by Region

Country	Spectrum (GHz)	Licence Type	Licence Duration	PTP/ PTMP	Spectrum for future consideration	Comments	Licence Fees
Western Europe							
Denmark	7 10 18 28 38 57–59 71–76 81–86	Per Link	15 years	PTP	EU to propose minimum spectrum license duration of 25 years	Most crowded bands are 7 GHz, 12 GHz, 15 GHz, 18 GHz and 23 GHz bands	Fees depend on frequency band and bandwidth. The lower frequency and the higher bandwidth the higher price. Regional licenses are issued in 18 GHz band and higher frequency band (18 GHz, 23 GHz, ...).
France	3.5 3.4–3.8 6 26 71–76 81–86	Per Link Block Spectrum	15 years to 20 years	PTP PTMP			The annual amount, expressed in euros, of the management fee is equal to the product of a reference constant "G" by the number of assignments. The annual amount of the availability fee due is specified in the corresponding authorizations. The annual amount, expressed in euros, of the management fee is equal to the product of a reference constant "G" by the number of megahertz alloted.
Germany	0.41–0.42 22–23.6 2 3.8–4.2 4.5–26.5 5.925–6.425 27.5–29.5 6.425–7.125 31.8–33.4 7.125–7.425 37–39.5 7.425–7.725 40.5–43.5 12.75–13.25 55.78–57 14.5–15.35 71–86 17.7–19.7 92–95	Per Link	10 years	PTP PTMP			Apply Licence fee and annual frequency usage fee. Prices are calculated based on frquency band and bandwidth. (eg <28 MHz: EUR 100 to 300, 14 MHz channel at 7.2 band : EUR 680, 28MHz and 56MHz channels cost about 1500 Euro for frequency bands (0.4–7.5 GHz), and are cheaper at higher frequencies: fees between 300–1088 Euro, 80 GHz costs 1100–1500 Euro)
Italy	3.4–4.2 6 24.5–26.5 27.5–29.5	Block Spectrum Allocation (Only block spectrum allocation is used. Currently 72 blocks are assigned. 48 blocks in 26 GHz band and the rest in 28 GHz band.)	15 years			AGCOM is looking to allocate the remaining blocks as a response for the growing demand for more backhaul. AGCOM is in the process of assigning 3.6GHz and 3.8GHz bands which operators expressed interest in them for LTE and small cells. Another band that might be open for backhaul in the future is 40GHz	Fees are computed based on geographical area, interest rates and duration of rights. In addition to administration fees, all fees are paid once . Price varies between EUE 60,000 to 1,000,000. 28GHz and higher are more expensive
United Kingdom	1–3 10 28 32 40 65 57–66 71–76 81–86	Per Link Light Licensing: Light licensed bands include 5.8 GHz, 65, 75 and 85 GHz bands.	Unlimited duration			Potential for shared access of spectrum at 3.6-4.2 GHz for wireless broadband use and NLoS small cell backhaul. Potential use of spectrum at 55-100 GHz for fixed wireless services for mobile backhaul. The dominant use of these spectrum bands today is for the provision of backhaul within mobile networks, accounting for more than 80% of the current fixed link licence base.	In Light-Licensing, the users of a band are awarded non-exclusive license which are typically available to all and are either free or only have a nominal fee attached to them.

Country	Spectrum (GHz)	Licence Type	Licence Duration	PTP/ PTMP	Others	Licence Fees
Eastern Europe						
Croatia	3.6–3.8, 6, 7, 8, 11, 13, 14, 18, 23, 38	Per Link	5 years (25 years proposed)	PTP	Highest demand: 6L, 7.5G, 8L, 13, 18, 23 and 38. There had been block allocation in the past in band 23 and 38 for few operators but it is not official. 70/80 has more capacity, larger channel sizes starting with 66M, and lower fees	Operators with a total gross revenue over HRK 1 million in the past calendar year to pay a fee of 0.20% of their total gross revenue. The operators are required to report their total gross revenue for the previous calendar year to HAKOM by the end of March of the current year.
Czech Republic	3.6–3.8, 4.2–59, 6, 7, 10, 11, 28.2205–28.4445, 29.2285–29.4525, 31, 32, 38, 13, 15, 18, 23, 26, 60, 70, 80	Per Link	5 years (25 years proposed)	PTP	Duplex sub-bands 28.2205–28.4445 GHz and 29.2285–29.4525 GHz are designated for utilization in the fixed service and for fixed links of mobile networks infrastructure. Number of rights for use of radio frequencies is limited. Only 3 current operators can use these sub-bands. Each operator has a radio frequencies assignment for 56 MHz. Rest of the spectrum is used as guard-bands. Other bands allocated for fixed wireless point-to-point links can be used by all users.	10 GHz (licence exception band, see general authorization). 70/80 GHz (licence exception band, see general authorization).
Hungary	5, 10–12.5, 24, 26, 42.5, 65–74, 79	Per Link	15 years	PTP		In each frequency bands concerned, the product of a unit price of HUF 7,500 per kHz per month and the amount of frequencies acquired within a given Package, multiplied by the band multiplier applicable to the frequency band at hand, with the proviso that the band fee stipulated in the administrative contract
Poland	6, 7, 8, 11, 13, 15, 18, 23, 26, 32, 38, 70, 75	Per Link Light Licensing Light Licensing	Up to 10 years			Apply issuing fee EUR 465 and annual frequency utilization fee based on frequency

Country	Spectrum (GHz)	Licence Type	Licence Duration	PTP/ PTMP	Spectrum for future consideration	Others	Licence Fees
Asia Pacific							
Australia	3.575–3.7 4.8–4.9 5.6 7 10.5 15 20.2-21.2 23 24.25–27.5 30–31 31.8–33.4 37–43.5 45.5–52.6 66–76 81–86	Per Link	Up to 15 years	PTP PTMP		Currently in Australia, the majority of bands are lightly to moderately utilized; however, the limited spectrum below 3 GHz has resulted in a shift to further use spectrum within the 6 to 8 GHz range. It is anticipated that all of the bands above 7 GHz will experience a growth in demand, in particular within the bands 50 GHz, 58 GHz, 71–76 GHz and 81–86 GHz. Although it is thought that there is sufficient spectrum to meet increased backhaul requirements, the ACMA anticipates that in highly dense areas, demand may exceed supply in 10 years within certain frequency bands (i.e. 7.5 GHz, 13 GHz, 15 GHz and 22 GHz).	Apply licence issure fee and licence tax. There are fees (taxes) they must pay as operators of radio telecommunications apparatus. These fees (taxes) are paid the the regulator and are around $AUS40 per year per apparatus set (ie. studio to transmitter link, broadcast transmitter and so on).
India	6 7 13 15 18 21	Issued per region to 22 licence areas	20 years	PTP	26 28 42 60 70 80	Nearly 80% of backhauls use microwave link. 20 years Licence is issued to the regions demanded for spectrum. Operators need to apply spectrum from regional management. Operators are able to use spectrum as long as the length of regional license.	Spectrum fee is charged based on the AGR (annual gross revenue). AGR= revenue operators earn minus mobile termination charges, mobile roaming charges, etc. Operators have to pay certain % of AGR to the license fees
Indonesia	3.3 3.7–4.2 4.2–6 10.5 32–33 56–76 81–86	Per Link	5 years	PTP			The licence fee is around 100–1000 USD per year for SHF band (<23 GHz) regarding some parameters power, bandwidth, zone,
Japan	1.427-1.429 1.429-1.453 1.453-1.45535 1.4535-1.4759 1.4759-1.501 1.501-1.50335 1.50335-1.518 17.85-17.97 18.6-19.72 22.21-22.5 22.5-22.55 22.55-22.6 23-23.2	Per Link	5 years	PTP PTMP			Annual Spectrum fee applies based on frequency, transmitter power output, classification of radio station
Malaysia	3–9 3.155–3.4 10–14 14.3–15.35 15.7–23.6 24.45–31.3 31.5–31.8 33.4–52.6 55.78–76 81–86 92–94 94.1–100 102–109.5 111.8–114.25 122.25–123 130–134 141–148.5	Per Link	Up to 20 years	PTP PTMP			The application fee is RM60.00 per application for Mobile Services, Station Fee (RM 120 for 30 MHz up to 3 GHz, RM 240 for more than 3 GHz), Annual Fee with respect to bands per station

Country	Spectrum (GHz)	Licence Type	Licence Duration	PTP/ PTMP	Spectrum for future consideration	Others	Licence Fees
Asia Pacific							
New Zealand	0.45–0.47 4.4–5 5.925–6.42 6.42–8.5 10.5–10.68 10.7–11.7 23 24–28 71–76 81–86	Per Link	20 years Renewable annually	PTP	Currently no plan		Standard annual fee of $150, Average annual fee of approximately $150, There will be an amateur licence fee category for repeaters, beacons and fixed links, set at $50 annually, There will be two fee categories for multiple location licences for land mobile radio services only. For licences covering up to a maximum of five locations the fee is $600 (annually), and for licences covering an unlimited number of locations the fee is $1,500 (annually)
Singapore	3.4–3.6 5.725–5.85 5.875–5.925 24.25–29.5 31.8–33.4 37–43.5 45.5–50.2 50.4–52.6 66–76 71–76 81–86	Per Link	1 year	PTP PTMP			Application and Processing Fee for Commonly Assigned Frequencies (for temporary or occasional use): $300, Licensed (Fee payable per annum): $400 to $10700 for All Frequency Bands, Unlicensed (Fee payable per annum): Below 10 GHz – $300 to $1800, From 10 GHz to 15.7 GHz – $300 to $1200, From 15.7 GHz to 21.2 GHz – $300 to 900 , Above 21.2 GHz – $300 to $700
North America							
Canada	1.7–1.71 1.78–1.85 2.025–2.11 2.2–2.285 3.7–4.2 5.295–6.425 6.425–6.930 7.125–7.25 7.3–7.25 7.725–8.275 10.55–10.68 10.7–11.2 11.2–11.7 12.7–13.25 14.5–15.35 14.975–15.35 17.8–18.3 19.3–19.7 21.8–22.4 23–23.6 24.25–24.45 25.05–25.25 25.25–26.5 27.5–28.35 38.6–40 71–76 81–86 92–95	Lightly licensed Lightly licensed Lightly licensed	1 year	PTP	The study prepared by RedMobile concluded that demand for backhaul spectrum in frequencies below 38 GHz will grow from 878 MHz in 2010 to between 2603 MHz and 3394 MHz by 2015, depending on the modelling scenario. Extrapolating this forecast using a linear regression suggests that a total of 3438–4435 MHz of backhaul spectrum will be required by 2017. Over the same period, traffic carried over wireless backhaul links is assumed to increase with the rapid growth in fixed and mobile broadband traffic	Because of propogation characteristics and population centres, deployments are not distributed uniformly across the country or within the frequency bands. As indicated in Industry Canada's Radio Spectrum Inventory, although on average approximately 65% of all backhaul links in Canada are located outside of metropolitan areas, the number of assignments in these urban areas tends to be greater in bands above 15 GHz. Multiple backhaul solutions in Canada including fibre optics, leased lines, microwave and satellites . Canadian operators requested 71–76 GHz, 81–86 GHz, 92–95 GHz for fixed point-to-point services. Rogers commented that deployment of advanced wireless access technologies, such as HSPA and LTE, which support mobile broadband services, Roger is in need of access to more spectrum for fixed point-to-point backhaul services. In June 2012, Industry Canada announced that the Department will issue spectrum licences in the bands 71–76 GHz, 81–86 GHz and 92–95 GHz. Licensing for all areas will be on an FCFS basis and all licensees will have shared access to the spectrum.	Apply a monthly fee. anual fee and telephone channel equivalencies (license fees payable for a radio licence authorizing opeartion on certain frequencies for radio apparatus installed in a fixed station or space station)
United States	3.7–4.2 5.925–6.425 6.425–6.7 6.7–6.875 10.55–10.6 10.6–10.68 10.7–11.7 38.6–40 71–76 81–86 92–95	Per link Lightly licensed Lightly licensed Lightly licensed	License for stations under fixed wireless service will be issued for a period not to exceed 1 year	PTP	In Aug 2013, FCC on voted to change rules in the 57–64 GHz band, that it said will improve the use of unlicensed spectrum for high-capacity, short-range outdoor backhaul, especially for small cells.	In March 2014, Mimosa said its proposal to free spectrum in the lower part of the 10 GHz band, pursuant to Subpart Z rules, would address the need for efficient microwave backhaul to serve both fixed and mobile wireless broadband services. Lightly licensed users of the newly freed 10 GHz spectrum would refer to a spectrum database for link planning.	

Country	Spectrum (GHz)	Licence Type	Licence Duration	PTP/ PTMP	Spectrum for future consideration	Licence Fees
Latin America						
Brazil	4.9 17–19 21–23 57–64 71–76 81–86	Per Link	Up to 20 years	PTP	There are ongoing regulatory discussions ongoing for the E Band (70/80 GHz) and V band (60 GHz) but no firm decisions when these will be opened. Indications are that opening of the E Band frequencies might happen in 2015. Operators are pushing for 60 GHz as well.	Approximately $3,000 to grant each service authorisation. After authorisation for the provision of a specific telecoms services has been granted, the company must also license its telecoms stations. The issue of a licence certificate for the operation of a station is subject to the payment of an installation inspection fee; once the station is licensed, the company must also pay an annual operating inspection fee. The fees vary according to the telecoms service for which the station is used.
Mexico	3.4–3.7 5.725–5.85 7.11–7.725 10.15 14.5–15.35 21.2–23.6 37–38.6 71–76 81–86	Per Link	Up to 20 years	PTP PTMP		
Venezuela	3.4–3.6 3.7 4.2 5.725–5.85 5.9–6.4 9–10.6	Block Licensing Unlicensed	Up to 10 years	PTP PTMP		
Argentina	3.3–3.6 4.2 6.4 7 12.2–12.7 15 17.8 40 42.5 60 76 81–86	Per Link	Up to 10 years	PTP		Based on the costs of processing spectrum licence applications, i.e. not reflecting the economic value of the spectrum.
Uruguay	6 7 8 13 15 24 28 50 60 71–76 81–86	Per Link	No limit, if not used, authorization takes away the spectrum	PTP		Monthly prices for each channel, depending on bandwidth are: Up to 3,00 MHz of BW $ 1.644,00, Up to 5,00 MHz of BW $ 2.117,00, Up to 15,00 MHz of BW $ 3.662,00, Up to 20,00MHz of BW $ 4.231,00, More than 20,00MHz of BW $ 4.724,00 (US$1=$23.3)

Country	Spectrum (GHz)	Licence Type	Licence Duration	PTP/ PTMP	Others	Licence Fees
Middle East						
Saudi Arabia	3.4–3.8 7 11 13 15 18 23 26 28 32 38	Per Link	1 year	PTP PTMP		Spectrum fee is calculated based on bandwidth, antenna height, mobile or non- directional antenna factor, power factor, spectrum demand density factor, high-usage cities factor, geographical coverage factor.
UAE	3.6 6–80	Per Link	1 year	PTP	As most cell sites are connected to fiber-optic, operators are less likely to apply for microwave backhaul. More than 70% of base stations use fiber-optic backhaul.	Application Fee Dirham 500, Spectrum Fee is calculated based on Frequency range factor and bandwidth factor
Africa						
Nigeria	3.6–4.2 4.4–5.03 5.15–5.35 5.47–8.75 10–10.68 10.7–14 14.3–15.35 17.3–23.6 25.25–29.5 31–31.3 31.5–31.8 33.4–52.6 55.78–76 71–74 81–84 81–86 92–100	Per Link	1, 5, 10, 15 years	PTP	All request for microwave tranismission link frequencies may be granted. NCC will howerver reserve the right to allocate whatever frequency it deems fit to any hop as dictated by frequency co-ordination requirements in that region.	The price of spectrum (excluding microwave frequencies) is calculated on an annual per state basis using the following formula; Spectrum Fee = (U) × (B) × (K1) × (K2) per State, U = Unit Price: This varies according to Licensing Region/ Tier of the State in which the applicant seeks to operate ranging from 831USD/ MHz/Year to 8310USD/MHz/Year, B = Assigned Bandwidth (Spectrum Size) in MHz, K1 = Band Factor from 2.0 to 0.5 depending on spectrum size, K2 = Tenure Duration Factor from 0.3 to 10.4 for 3 months to 15 years respectively. (Duplex/ Simplex For simplex channel, unit price per State will be half of equivalent duplex channel.) Microwave frequencies are not priced on State basis. Unit price is uniform throughout the Federation and subject to review, from time to time.
South Africa	1.35–1.525 2.025–2.285 3.5 5.725–8.496 10.7–11.7 12.75–13.25 14.5–15.35 21.2–23.6 24.549–26.453 27–29.5 37–39.5 40.5–43.5 57–66 71.125–73.125 73.375–75.875 81.125–83.125 81–86 83.375–85.875	 Block Licensing, Light Licensing Block Licensing, Light Licensing Block Licensing, Full Licensing Block Licensing, Full Licensing Block Licensing	1 year	PTP PTMP		Apply Application fee and Licence Fee

Acronyms

h versus f	In analytical tables, **Historical (h)** data relates to all years reported up to 2017; **Forecasts (f)** thereafter
802.11ac	IEEE standard; supports Wi-Fi services in the 2.4 GHz band and 5.8 GHz data throughput
ASA	Authorized Shared Access
BTS	Base Transceiver Station
D-band	Relates to 130–174.8 GHz band.
E-band	Specifically it covers the 71-76 GHz and 81-86 GHz but often it is referred to as the “70/80 GHz” Band
EC	European Commission
EIRP	Effective Isotropically Radiated Power; the amount of power that a theoretical isotropic antenna (distributes power in all directions) would emit to produce thevwv peak power density observed in the direction of maximum antenna gain
FCC	Federal Communications Commission (USA)
FTTT	Fiber to the Tower
IMDA	Info-communications Media Development Authority (national regulator of Singapore)
IoT	Internet of Things. Data-centric modules that are connected to the internet with via short or long-range wireless
ISM	Industrial, Scientific, and Medical
LMDS	Local Multipoint Distribution Service (a broadband wireless access technology originally designed for digital television transmission)
LoS	Line-of-Sight
LTE-TDD	LTE Time Division Duplex
LTE-FDD	LTE Frequency Division Duplex
Microwave	In this report, Microwave addresses spectrum from 7 GHz up to 100 GHz. However, ABI Research does segment Microwave from 7 GH to 40 GHz and 41 GHz to 100 GHz. Microwave backhaul applications in the 41 to 100 GHz offer very ultra-high capacity links (e.g. potentially 10 to 25 Gbps).
MMW	Scientifically, Millimeter Wave relates to frequencies that have a wavelength of less than 10 millimeters. Most Millimeter Wave backhaul solutions are typically in the 60 and 70/80 GHz bands. ABI Research has avoided using the term “millimeter wave” but just make specific references to bands such as the E-band (70/80 GHz), etc.
Ms	millisecond or 0.001 second
MCI	Ministry of Communication and Informatics, Indonesia
NLoS	Non-Line-of-Sight
nLoS	Near-Line-of-Sight
OBSAI	Open Base Station Architecture Initiative
PoP	Point of Presence
PMP	Point-to-Multipoint
PTP	Point-to-Point
QoS	Quality of Service
RSPG	Radio Spectrum Policy Group
SON	Self-Organizing Network
SRD	Short Range Devices (often low power (<40 dB))
TVWS	TV White Space
TRAI	Telecom Regulatory Authority of India
V-band	Specifically it covers 57 GHz to 66 GHz but often known as the “60 GHz” band
W-band	Relates to 92 to 114.25 GHz bands
WiGig	Wireless Gigabit Alliance (promotes use of SRD in 60 GHz band)
X2 Mesh	The X2 interface enables eNodeBs to communicate directly between each other. This allows for interference management (especially in HetNets) and seamless handover

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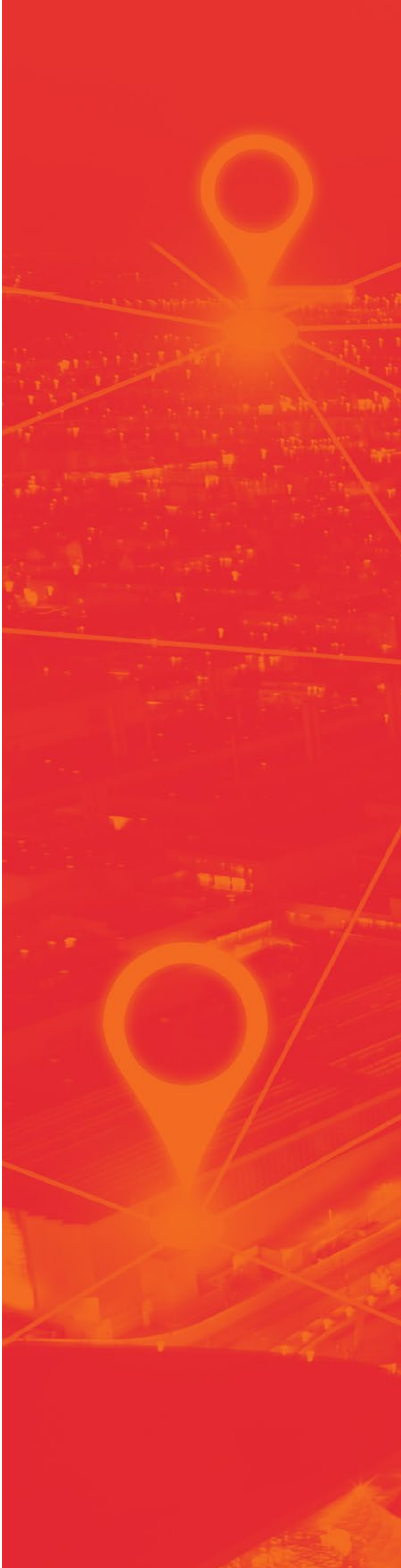

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