Wireless Backhaul Evolution

Delivering next-generation connectivity

February 2021

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Published February 2021

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1. EXECUTIVE SUMMARY

1.1. Overview

The transition to 5G will need a sizable backhaul evolution to accommodate growing traffic and new network capabilities. Despite the growing importance of fibre, wireless backhaul is set to play a central role in these developments. This means regulators have a vital role as their decisions moving forward will impactfully help or hinder the fledgling 5G market. This report aims to assess the evolution of wireless backhaul over the 5G era and, particularly, the role played by new backhaul bands and technologies. A major focus is on the cost of the network infrastructure and spectrum fees on which this evolution relies.

It concludes that higher capacity backhaul bands will be vital in meeting 5G traffic demands and that high backhaul spectrum costs can present a significant burden to mobile operators, and even deter technology upgrades. The report recommends regulators carefully consider future backhaul spectrum needs so the right bands can be made available at the right time. It also encourages regulators to carefully consider backhaul spectrum pricing and ensure the formulas used to set fees are reasonable and do not disincentivize the use of wider channels and encourage the use of advanced technologies.

1.2. 5G Evolution

5G is set to have a significant impact on backhaul networks in the coming years. For the top 30 markets, 5G mobile subscriptions are expected to grow by a 41.2% Compound Annual Growth Rate (CAGR) between 2021 and 2027, increasing from 378 million subscribers in 2021 to 4.2 billion in 2027. Similarly, the traffic in those markets is estimated to increase to 6,268 exabytes annually by 2027, with 5G accounting for 83% of total traffic by the end of the period.

1.3. Backhaul Technology Evolution

5G networks are expected to see an evolution from a tree structure to a star-based backhaul network topology. This will be driven by the growth of a denser concentration of small cells, which will connect to a growing number of fibre Points of Presence (PoPs). Mobile operators have a set of technologies to help increase the capacity and efficiency of their backhaul networks. These include:

- **Cross Polarisation Interference Cancellation** (XPIC) involves transmitting signals on both the horizontal and verticals planes using the same radio channel; eliminating the interference form the second polarisation and doubling spectrum efficiency.

- **Band and Carrier Aggregation** (BCA) bonds multiple channels even in different frequency bands to support greater capacity. These can help extend the life of traditional narrower microwave channels.
- **Integrated Access Backhaul** (IAB) allows parts of the (in band or out of band) spectrum to be used for both access (*i.e.,* the connection between user terminals and base stations) and backhaul.
- **Line of Sight (LOS) Multiple Input, Multiple Output (MIMO)** allows several radio transmissions over the same channel.

1.4. Backhaul Bands, Characteristics, and Licensing Approaches

The significant increases in backhaul capacity required to support 5G also necessitate a move to wider bandwidth solutions. While fibre will play an important role, microwave backhaul will account for the majority of global backhaul links from 2021-2027, with around 65% market share. However, the continued use of wireless backhaul will require an evolution toward higher frequency bands that can support wider channels and have a greater total amount of spectrum available.

The E-band (70/80 Gigahertz (GHz)) will be important across all regions and is expected to enjoy exceptional growth with an 11.6% CAGR from 2021 to 2027. In more developed markets, even higher frequency bands are likely to be important. The W-band (92 GHz to 114 GHz) and D-bands (130 GHZ to 175 GHz) are expected to start to gain global traction from 2025 onward and could have around 310,000 and 389,000 deployed links, respectively, by 2027. The E-band, D-band, and W-band is expected to support channel sizes of up to 2 GHz compared with 7/14 MHz to 224 MHz in traditional ITU microwave bands (*i.e.*, 6 GHZ to 42 GHz). However, it should be acknowledged that real-world support from the worldwide operator community will reflect additional considerations, such as service providers' use cases, technology capabilities readiness, and the respective equipment costs.

Traditional microwave bands continue to have an important role to play, especially as they can cover longer distances with fewer hops. However, their narrower channel sizes make supporting 5G traffic challenging, so it is important that regulators support wider channels and permit operators to aggregate spectrum in these bands.

Wireless backhaul bands are made available through a variety of licensing regimes; most commonly per link and block licenses, and, to a lesser extent, unlicensed, shared, and lightly licensed. Hybrid approaches allow a band to be reserved on a block basis, but operators have the flexibility to self-coordinate within the block on a per link basis. This helps manage costs and helps coordinate with other users in adjacent bands. Long licenses (*i.e.*, 10 years or more) are offered by 60% of countries with renewal options to protect and incentivise long-term backhaul network investments. Shorter licenses (*e.g.*, 1 year) are also relatively common (18%) but provide fewer safeguards for continued access.

1.5. Pricing Analysis

This study looks at backhaul spectrum prices in 31 markets and finds significant variation even when comparing similar spectrum. The highest spectrum prices in some markets were found to be 22X higher than the global median and 59X higher than the lowest priced markets. This can place a significant burden on operators in some markets, making it more difficult to quickly roll out faster broadband services with better coverage.

Some countries were also found to place a technology dis-incentivisation fee on operators that adopt innovative backhaul technologies that make more efficient use of spectrum. For example, some countries charged operators double the price of a single radio channel link when the operator employed secondary polarisation technology, which doubles spectrum efficiency.

Crucially, the pricing formulas regulators use to set backhaul spectrum fees often failed to adapt effectively to the much wider channels available in higher frequency bands. In practice, costs generally scaled linearly, making newer, much wider channel sizes expensive. Formulas need to take into account improved geographical spectral efficiency, higher frequency reuse, and the larger channel size availability/requirements, especially in higher frequency bands.

1.6. Evolving Backhaul Costs

The study built a Total Cost of Ownership (TCO) model for a radio access and backhaul network in the 5G era (2021 to 2027) with a developed and developing market as a baseline. This incorporated the network equipment, spectrum fees, and cell sites, including site rental and power. It considered a range of backhaul strategies to improve capacity, including new technologies and bands.

In developed markets, it was found that new backhaul technologies and traditional microwave backhaul bands alone were not sufficient to meet traffic demands, so new bands, such as the E-band and, eventually, the D-band and W-band, will be vital, especially toward the end of the period. In developing markets, new backhaul technologies and traditional microwave backhaul bands were again also unable to meet increasing traffic alone, so the E-band will be crucial to addressing increasing traffic and speeds.

High backhaul spectrum costs were found to have a significant impact on the total cost of networks in the 5G era. Applying the maximum spectrum fees across all the microwave and millimetre wave bands for a network in a developed market can result in an average per year aggregate network TCO of US$1.68 billion, which is 266% higher than the minimum spectrum fee scenario. Similarly, the annual TCO of a network in a developing market was US$427 million and would be 59% higher than the minimal spectrum fee scenario. Regulators that charge high backhaul spectrum prices should expect that 5G network investment will be impacted and, therefore, the rollout of services delayed.

1.7. Five Policy Recommendations

This study suggests five key policy recommendations for regulators based on the research findings:

I. Regulators must recognise microwave and millimetre backhaul as a critical component of national-level Information and Communication Technology (ICT) strategy.

II. Regulators need to be realistic and recognize that license fees that scale linearly with channel sizes serve as large financial burdens for operators. They should also incentivise spectral efficient methods (*e.g.*, XPIC, BCA, IAB, and LOS MIMO).

III. There must be regulatory push toward wider channel sizes to support 5G.

IV. The E-band will play an especially important role in all markets in the 5G era.

V. Regulators should consult the industry to make the D-band and W-band available when needed.

2. 5G BACKHAUL

Key Takeaways

- 5G is set to have a significant impact on backhaul networks in the coming years. For the top 30 markets, 5G mobile subscriptions are expected to grow by a 41.2% CAGR between 2021 and 2027, increasing from 378 million subscribers in 2021 to 4.2 billion in 2027. Similarly, the traffic in those markets is estimated to increase to 6,268 exabytes annually by 2027, with 5G accounting for 83% of total traffic by the end of the period. This increase in data traffic is not only from Enhanced Mobile Broadband (eMBB) services, but also from Ultra-Reliable Low-Latency Communications (URLLC) and Massive Machine-Type Communications (mMTC) applications.

Microwave Backhaul Has Been the Dominant Backhaul Technology

- While fibre will play an important role, microwave backhaul will account for the majority of global backhaul links from 2021 to 2027, with around 65% market share. However, the continued use of wireless backhaul will require an evolution toward higher frequency bands, such as the E-band, W-band, and D-band, which can support wider channels and have a greater total amount of spectrum available.

- The need to further densify the network to support 5G will result in additional macro cells, and small cells in particular, being deployed in urban areas to handle the traffic. While fibre will be deployed, not all urban cell sites can be supported by fibre. Microwave and millimetre wave backhaul links are versatile and can handle significant data rates. The millimetre-wave bands (E-band, D-band and W-bands) can handle between 15X and 50X more traffic than the typical mid-microwave band (14 GHz to 25 GHz) backhaul links.

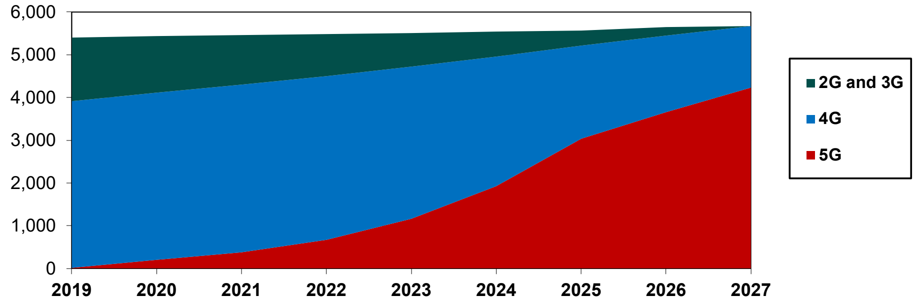
2.1. Wireless Backhaul Path to Evolution

This report aims to assess the evolution of backhaul over the 5G era, specifically how the role of technological innovations and the use of higher millimetre wave frequency bands would meet the increasing traffic growth of 5G. A major focus is on how an operator's wireless backhaul costs may evolve over this time period as it tries to increase network capacity.

This report 1) assesses different spectrum pricing approaches; and 2) assesses how different mixes of new technologies and frequency bands can impact a network's TCO, while also meeting predicted traffic levels. It then concludes by recommending public policy approaches pertaining to spectrum. These recommendations were formulated to ensure that an operator's backhaul network can scale in a cost-efficient manner to meet the inevitable growth of data traffic in 5G.

2.2. 5G Outlook

Figure 1. Cellular Mobile Subscriptions Technical Generation Split

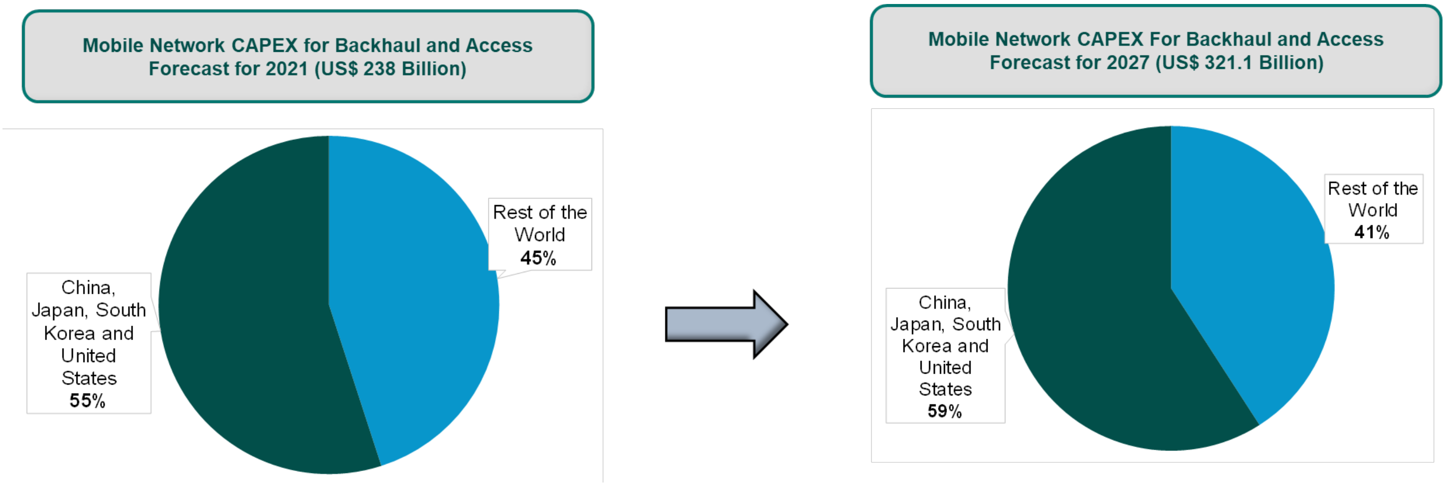


2.2.1. 5G Subscriptions

The global cellular mobile subscriptions forecast is based on 30 countries from ABI Research's *Network Technology and Market Tracker 2Q 2020* report (MD-NWMT-104). The adoption rates of 2G and 3G will maintain a consistent downward trend and are estimated to be phased out by 2027. 4G mobile subscriptions will reach a peak of about 3.9 billion subscribers in 2021 and gradually taper off from 2022 onward. 4G adoption is projected to be reduced to around 1.4 billion subscribers by 2027. 5G mobile subscriptions will experience an estimated 41.2% CAGR between 2021 and 2027, increasing from 378 million subscribers in 2021 to 4.2 billion in 2027.

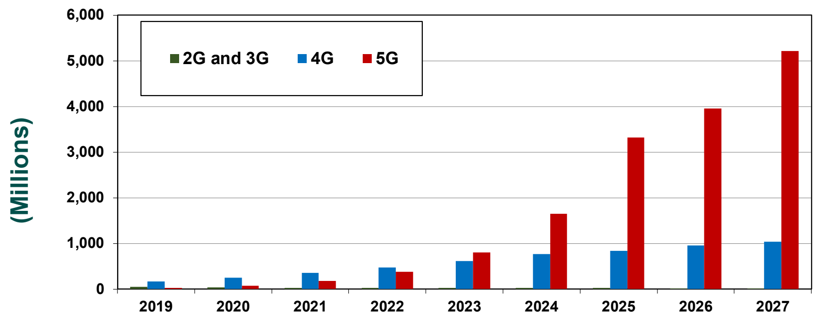
2.2.2. Leaders in 5G Adoption

Figure 2. Leaders in 5G Adoption



China, South Korea, Japan, and the United States are currently leading the world in 5G deployments. Partnerships and collaboration among regulators, network operators, and infrastructure providers have paved the way for China Mobile, China Unicom, and China Telecom to offer their 5G services at affordable prices. In the middle of 2020, the Chinese operators have further reduced their basic 5G plan offerings at an estimated reduction of 30% from the original launch price of 128 yuan (US$18.09). In South Korea, 5G subscriptions reached 7 million at the end of May 2020, increasing by around 535,000 subscribers in May 2020, a figure that surpasses the monthly record of 521,000 additional subscribers. Meanwhile in the United States, AT&T and T-Mobile have already achieved nationwide coverage as of July 2020.

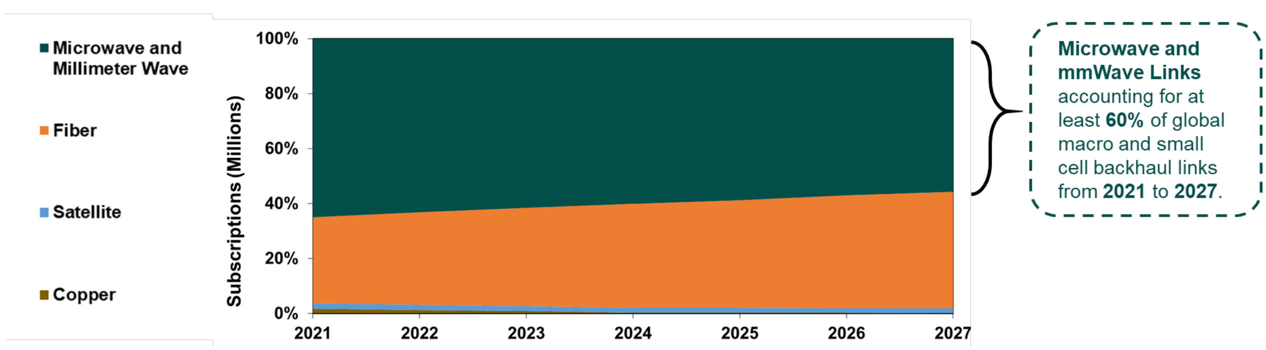
Figure 3. Cellular Mobile Traffic per Year by Technical Generation Split



Mobile data traffic and voice demand is expected to increase to about 6,268 exabytes by 2027 with 5G data traffic accounting for 83% or 5,210 exabytes of the overall data consumption in 2027. Aside from the demands of eMBB services, the surge in mobile traffic is also attributed to enterprise centric URLLC and mMTC use cases. Generally, diverse data-intensive applications that require better quality/more cost-efficient sensors, high resolution video streaming, and cloud computing will boost demand for bandwidth even more.

2.2.3. Adoption Trends of Backhaul Technologies

Figure 4. Installed Macro and Small Cell Backhaul Links by Technology



Generally, a combination of backhaul solutions are employed by operators, with service providers tending to favor a mix of fixed line and fixed wireless solutions for increased capacity and expansive coverage. Operators generally prefer fibre backhaul solutions due to its unmatched capacity and throughput capabilities. Relying solely on fibre deployments for network densification, however, requires a significant commitment of Capital Expenditure (CAPEX), time, and manpower.

Microwave backhaul, on the other hand, has its relative advantages in immediacy of deployment, cost, and accessibility. Operators will increasingly incorporate fixed wireless backhaul in their network planning. Microwave and millimetre wave backhaul links would make up at least 60% of the global macro and small cell backhaul links from 2021 to 2027.

2.3. Conclusions

Operators are bracing for an uptick in the momentum of 5G rollouts. 5G mobile subscriptions are expected to increase by an estimated 41.2% CAGR between 2021 and 2027, increasing from 378 million subscribers in 2021 to 4.2 billion in 2027. China, South Korea, and the United States will lead this momentum, with these countries expected to cumulatively account for an estimated 59% of global mobile network CAPEX by 2027.

Network densification efforts are geared toward supporting higher mobile data traffic and voice demand and expected to increase to about 6,268 exabytes by 2027. Of the overall data consumption in 2027, 5G accounts for 83% or 5,210 exabytes. This increase in data traffic is not only from eMBB services, but also from diverse URLLC and mMTC scenarios.

3. TECHNOLOGICAL INNOVATIONS FOR SPECTRAL EFFICIENCY *in Microwave BackhauL*

Key Takeaways

Operators' 5G networks are expected to see an evolution from a daisy chain to a star-based backhaul network topology. This will be driven by the growth of a denser concentration of small cells that will connect to a growing number of fibre PoPs. In addition to using additional spectrum, mobile operators have the following set of technologies to help increase the capacity and efficiency of their backhaul networks:

- **XPIC** involves transmitting signals on both the horizontal and verticals planes using the same radio channel and eliminating the interference form the second polarisation; doubling spectrum efficiency.
- **Band and Carrier Aggregation** (BCA) bonds multiple channels in different frequency bands to support greater capacity. These can help extend the life of traditional narrower microwave channels.
- **Integrated Access Backhaul** (IAB) allows spectrum to be used for both access (*i.e.*, the connection between user terminals and base stations) and backhaul.
- **LOS MIMO** allows several radio transmissions over the same channel.

In some countries, regulation does not allow the use of some of these technologies and, in some cases, discourage their use by charging for it. Backhaul network topology is changing and will see an increase in density of use.

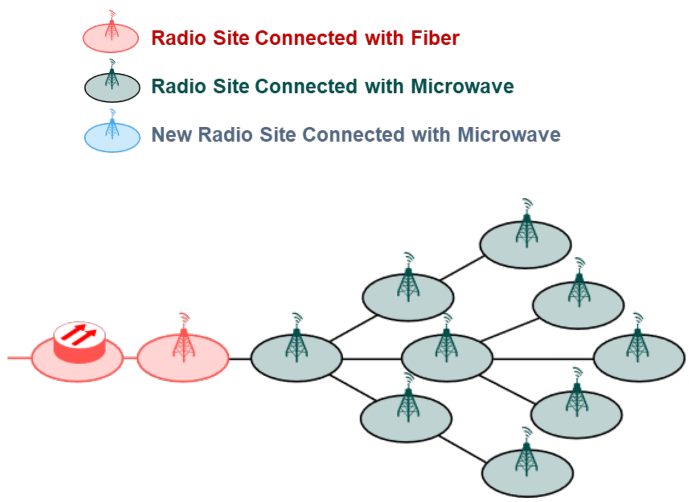
3.1. Evolving 5G Network Topologies

The evolution of the macro cell backhaul network for 5G and the evolution of ring/tree topologies to star topologies are driven by three factors:

1) Network Densification with the goal of optimising overall network capacity and latency performance
2) RAN sharing and consolidation of operators
3) Increased fibre penetration from core networks to the edge

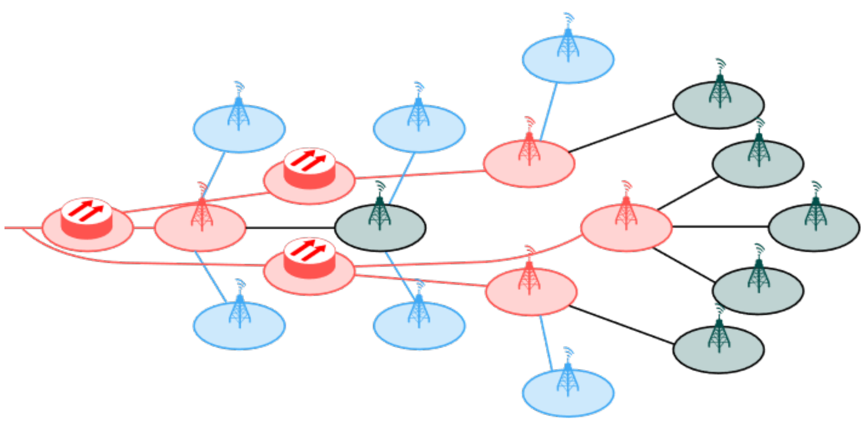
The combination of network infrastructure densification (propelled by millimetre wave frequencies with shorter-hops) with more fibre PoPs call for an evolution from daisy-chain relay connections to star topologies that cater to an increasing number of different directions.

Figure 5. Tree Topology



The tree topology of typical networks (as shown in Figure 5) requires distinguishing between tail links (that connect just one terminal mobile site) and aggregation links (which can carry the traffic of multiple terminal sites).

Figure 6. Star Topology



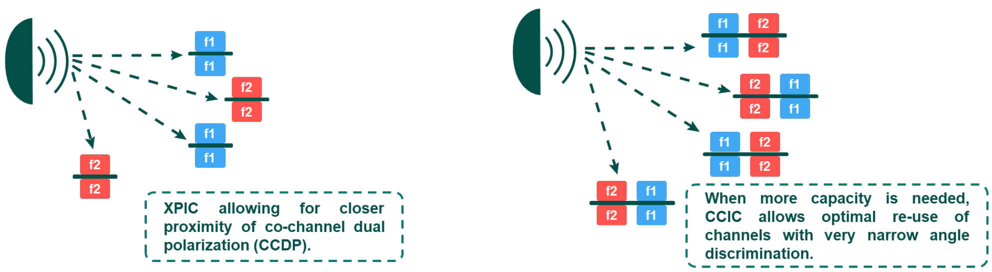
In a star topology (as shown in Figure 6), the increased number of links and more fibre PoPs would allow for a more efficient network densification.

3.2. Second Polarisation and Channel Reuse

Second Polarisation or **XPIC** is a common technique that can double the spectral efficiency by propagating two signals in horizontal and vertical signals over the same channel. To better exploit the utility of spectrum, it is advisable to increase not only the single channel spectral efficiency, but also the channel reusability in a given area, guaranteeing "interference-free operation." License fees should be made to incentivise "geographical spectral efficiency" and allow for channel re-usability to cover wider geographical areas with more links.

Nodal configuration and Cross-Polar Discrimination (XPD) are key issues to address for XPIC configurations. ETSI Class 4 antennas allow better performance of directly adjacent channels by lowering angle discrimination and help in optimal nodal configurations. XPIC technology, on the other hand, can help reduce XPD by isolating polarisations and compensating for any link or propagation-induced coupling.

Figure 7. XPIC



3.3. Band and Carrier Aggregation

BCA for backhaul involves bonding multiple channels across different frequency bands to build higher capacity Point-to-Point (PTP) connections. BCA for backhaul comes in many variations, with different frequency pairings catering to different deployment scenarios. For BCA combinations that support long-haul coverage with boosted capacity, channels within the ITU traditional microwave frequencies (6 GHz to 42 GHz) can be combined with channels in the E-band frequencies (71 GHz to 86 GHz).

Figure 8. BCA: Long-Haul Coverage and Unlicensed Spectrum

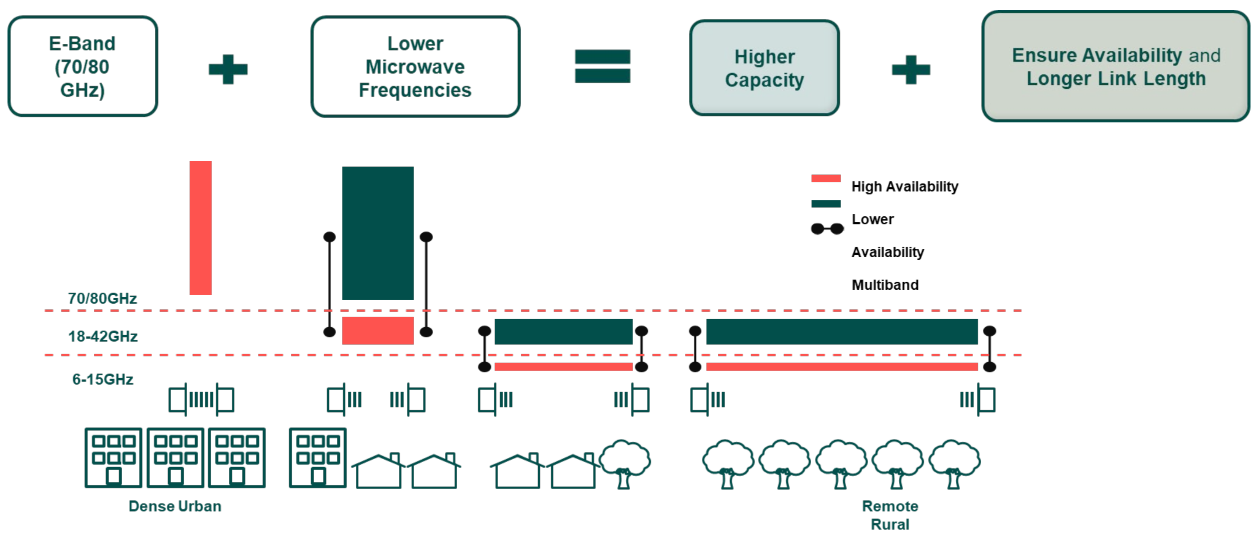
Combining ITU traditional microwave frequencies with unlicensed spectrum (*i.e.*, the V-band) is also another method of BCA. The benefits of this combination are mainly based on the cost savings for the operator as licensing costs would not be a consideration for unlicensed spectrum. The operational costs savings of this form of BCA, however, come at a sacrifice. Issues like signal interference, capacity limitations, and lowered latency performance are huge obstacles that must be overcome.

Mobile operators are increasingly combining a lower band microwave link with a licensed/lightly licensed millimetre wave link (*i.e.*, channel/s within the E-band) to increase capacity. This pairing also assures reliable link availability; BCA links can circumvent atmospheric attenuation (rain and oxygen attenuation) and can, thus, provide resilient, higher capacity coverage over longer distances.

The link in the lower band is used to meet the carrier-grade availability (*i.e.*, 99.995%); ensuring that high-priority traffic meets with the availability requirements of the network (especially in instances of links in higher band fading). Higher capacity links through higher millimetre wave frequencies is provided for lower-priority/best-effort traffic.

Combining lower bands (*e.g.*, 15, 18, or 23 GHz) with the E-band using dual-band antennas would allow links to cover 7 km to 10 km with capacities that can exceed 10 Gigabits per Second (Gbps). BCA of this type are ideal for deployments that are geographically challenging, sparsely populated, and lack fibre (*e.g.*, in rural areas).

Figure 9. BCA with E-Band

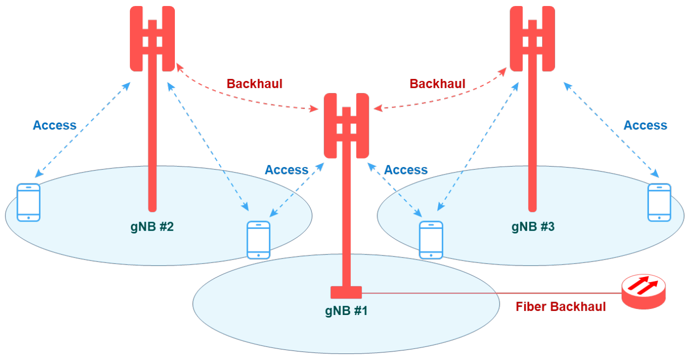


3.4. Integrated Access Backhaul

IAB involves using access spectrum to backhaul data traffic to the core network. According to the 3GPP, IAB includes scenarios where access and backhaul links partially overlap in frequency, creating half-duplexing or interference constraints. This implies that the IAB node cannot effectively transmit and receive simultaneously on both links. IAB, so far, has had limited adoption as it eats into the spectrum resources that are allocated for radio access.

However, the arrival of millimetre wave 5G NR is reopening conversations of the viability IAB. The larger bandwidth and beamforming features of 5G (IAB will work with 5G in both Standalone (SA) and Non-Standalone (NSA) modes) would satisfy the capacity demands and lower the interference risks of IAB. IAB also has higher equipment cost efficiencies as both access and backhaul would be sharing the same radio hardware unit and have similar operation/maintenance systems. Furthermore, IAB can help lower equipment costs, as cell sites do not require separate transmitter-antennas for backhaul links.

Figure 10. Integrated Access Backhaul



Verizon is preparing to add IAB technology to its network-deployment toolkit in 2020; allowing it to deploy 5G more easily and cheaply into locations where fibre is unavailable. Verizon could ultimately use IAB in up to 10% to 20% of its 5G sites, once the technology is widely available.

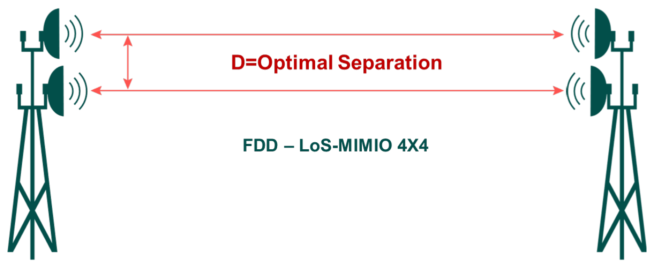
IAB can be deployed in all 5G-related spectrum bands, although the C-band 3.5 GHz and the 26/28 GHz bands will be the most prevalent. If the 26/28 GHz band is to be used, the regulator will need to have licensed it for access use, with different markets moving at varying pace in opening up the 26/28 GHz band. If the 26/28 GHz band has been licensed in addition to the C-band, the operator has to the option to roll out IAB using the 26/28 GHz band for urban small cells, while using the C-band for rural IAB deployments. While it is feasible that operators use the 26/28 GHz band where it is impossible to secure a fibre-optic link to the cell site, there is great versatility for IAB with the 3.5 GHz band where there can be challenges backhauling traffic from the cell site, such as those serving remote communities.

3.5. LOS MIMO: Line of Sight Multi Input Multi Output

A LOS 2x2 MIMO wireless link consists of two transmitters and receivers that are connected to two antennas on each side. A 4X4 MIMO link can also be executed in this setup by using four transmitters and receivers in both H and V polarisation.

Optimal antenna separation between signals is achieved by having them arrive separately, while maintaining constant phase difference of the different antennas. Two differing signals are embedded on the identical frequencies and polarisation and, therefore, the “interfering” signals cannot be higher and should instead be of equal power to that of the “desired” signals.

Figure 11. LOS MIMO



LOS MIMO enables transmission of two independent bitstreams over the same frequency and same polarisation. This means 100% more capacity in a 2X2 MIMO configuration compared to a 1+0 Single Input, Single Output (SISO) link without wasting additional spectrum resources. Using both polarisations of a frequency channel, *i.e.*, employing a 4X4 MIMO scheme, enables transmission of four independent bitstreams over the same frequency channel and an effective gain of 4X more capacity than a standard 1+0 SISO link or 2X more capacity than a 2+0 SISO XPIC link.

Capacity enhancements of LOS MIMO would equate to enhancing spectral efficiency, allowing more data to be transmitted over the same allocated/purchased frequency of the operator. Having a progressive licensing scheme that does not penalize operators in their efficient usage of spectrum will play a role in the future success of LOS MIMO. Regulators should incentivize operators to use spectrally efficient technologies and best-effort capacity links.

3.6. Conclusions

Where regulation permits, operators have employed these spectral efficient methods to maximise spectrum utility and efficiency. These technological innovations are key to lowering spectrum expenses as operators can support their backhaul networks without having to buy more spectrum.

XPIC is a common technique that can double the spectral efficiency by propagating two signals in horizontal and vertical signals over the same channel. Efficiency of **XPIC** is illustrated through denser reuse of channels. To better exploit the utility of spectrum, it is advisable to increase not only the single channel spectral efficiency, but also the **channel reusability** in a given area, guaranteeing "interference-free operation." The spectral efficiency and cost savings of this method would be negated if regulators opt to charge the operators for the resulting increased bandwidth from XPIC.

BCA for backhaul involves bonding multiple channels across different frequency bands to build higher capacity PTP connections. Combining frequencies in lower bands with E-band frequencies using dual band antennas would ensure higher availability rates and higher capacity links over longer distances.

IAB technology allows operators to use spectrum for both access and backhaul; allowing them to densify network coverage without the need to proportionately densify its transport network. The larger bandwidth and beamforming features of 5G (IAB will work with 5G in both SA and NSA modes) would satisfy the capacity demands and would lower the interference risks of IAB.

LOS MIMO enables transmission of two independent bitstreams over the same frequency and same polarisation. This means 100% more capacity in a 2X2 MIMO configuration compared to a 1+0 SISO link without wasting additional spectrum resources.

Furthermore, network infrastructure densification and more fibre PoPs calls for an evolution from daisy-chain relay connections to **star topologies** that can cater to an increasing number of different hop directions.

4. SPECTRUM CHARACTERISTICS AND DEVELOPMENTS

Key Takeaways

- The significant increases in backhaul capacity required to support 5G also necessitates a move to wider bandwidth solutions. While fibre will play an important role, microwave backhaul will account for the majority of global backhaul links from 2021 to 2027, with around 65% market share. However, the continued use of wireless backhaul will require an evolution toward higher frequency bands, which can support wider channels and have a greater total amount of spectrum available.

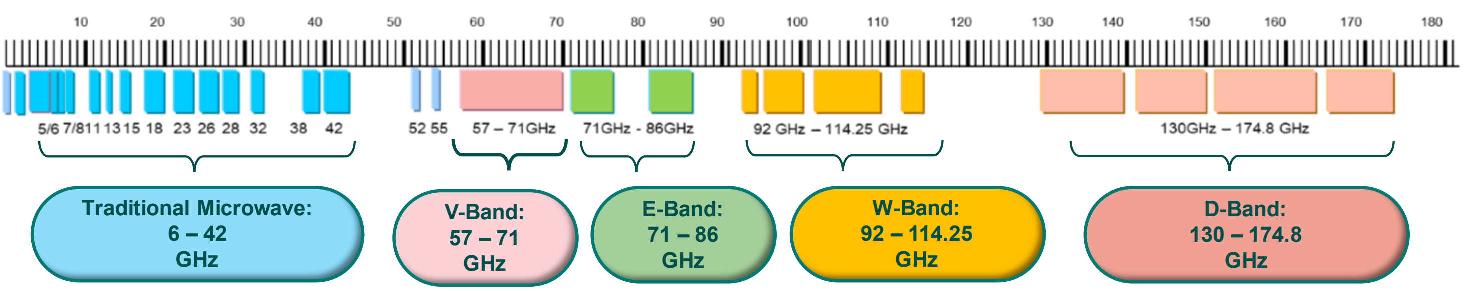
- The E-band (70/80 GHz) will be important across all regions and is expected to enjoy exceptional growth with an 11.6% CAGR from 2021 to 2027. In more developed markets, even higher frequency bands are likely to be important. The W-band (92 GHz to 114 GHz) and D-band (130 GHz to 175 GHz) are expected to start to gain global traction from 2025 onward and could have around 310,000 and 389,000 deployed links, respectively, by 2027. The E-band, D-band, and W-band is expected to support channel sizes of up to 2 GHz compared with 56 MHz to 224 MHz in traditional microwave bands (*i.e.*, 6 MHz to 56 MHz).

- Traditional microwave bands (*i.e.*, within 6 GHz to 42 GHz) continue to have an important role to play, especially as they can cover longer distances with fewer hops. However, their narrower channel sizes make supporting 5G traffic challenging, so it is important that regulators support wider channels and permit operators to aggregate spectrum in these bands.

4.1. Spectrum Table

Source: ITU

Figure 12. Frequency Table: Traditional Microwave to D-Band



Sufficient spectrum must be allocated toward the RAN and microwave backhaul links to accommodate the capacity/throughput standards of commercial 5G services.

Due to local factors, such as environmental climate, distances between cell sites, and national spectrum regulations, there are large regional and national variances on how much different frequency ranges are priced and the frequency bands being used for backhaul today.

Furthermore, the mobile telecommunications sector is just one of the many services that rely on radio frequencies to transmit information. The increasing plurality of services using radio frequencies is creating a trajectory toward an imminent **"spectrum crunch**."

Coping with larger data traffic demands of 5G through fixed wireless backhaul would require a reconfiguration of the *status quo* of a regulator's respective frequency allocation table and backhaul spectrum pricing. Regulators must prioritize mobile communications in the era of 5G by widening channel sizes; encouraging migration toward higher frequencies (in the E, W, and D bands); and incentivizing operators to use spectrally-efficient technologies and best-effort capacity links.

4.2. Spectrum Characteristics and Developments

4.2.1. Sub-5.x GHz

Low frequencies are less sensitive to rain, so these bands will continue to be used for **long hop distances** and are essential in geographical areas with typically higher rain rates. However, capacity limitations exist due to their typically narrow channels. These frequencies are increasingly congested and costly as sub-5.x GHz frequencies are mainly used by other radio services.

4.2.2. 6-42 GHz: ITU Traditional Microwave Frequencies

These are the most widely used microwave bands globally today and will continue to be very important in the coming years. The introduction of wider channels (28 MHz to 56 MHz and eventually toward 112 MHz to 224 MHz) has started, which, together with new spectrum-efficient technologies (*i.e.*, BCA, XPIC, IAB, LOS MIMO), will further boost capacity.

4.2.3. 57-71 GHz: V-Band

In many countries, the V-band is encouraged for widespread use as it is unlicensed. Only a few countries retain the V-band for licensed or defence applications. The most popular application in the Federal Communications Commission (FCC) area is WiGig (based on the 802.11ad standard), which can be used for indoor or outdoor applications.

Europe and Singapore regulate this frequency band for outdoor links through licensed/light licensing schemes. The rationale for this is based on the concern that being a highly dense urban environment, it was prudent to regulate the location of high-powered links to ensure that there is no interference between band receivers. The main drawback for unlicensed bands is that the non-exclusive use of the spectrum makes links susceptible to interference.

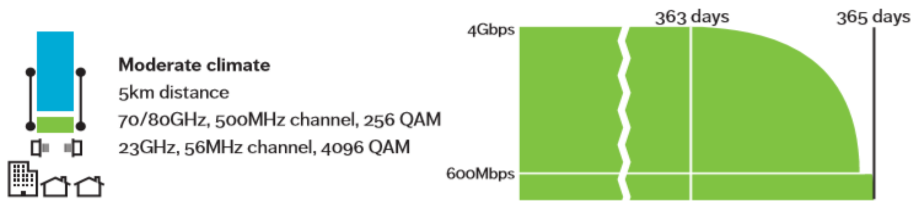
4.2.4. 71-86 GHz: E-Band

The E-band has large bandwidth (10 GHz) capabilities, allowing transmission of high-speed data over short distances (2 km to 3 km). E-band's frequencies enable P2P and LOS radio communication. The importance of the E-band will increase as 5G networks are rolled out because it will boost capacity in dense urban sites and is also the ideal high frequency complement with traditional microwave frequencies in BCA combinations in suburban sites.

Figure 13. E-Band Frequency Performance

*An example of **achievable distance** and **capacity** with **70/80 GHz**, 500 MHz channel, 256 QAM paired with **23 GHz,** 56 MHz channel, 4096 QAM*

Source: Ericsson



Frequencies in the E-band are generally being allocated on a licensed or lightly licensed basis. This lightly licensed approach to backhaul spectrum allocation does give the operator a high degree of service delivery assurance that the V-band unlicensed spectrum does not have.

Figure 14. E-Band Pricing Estimates

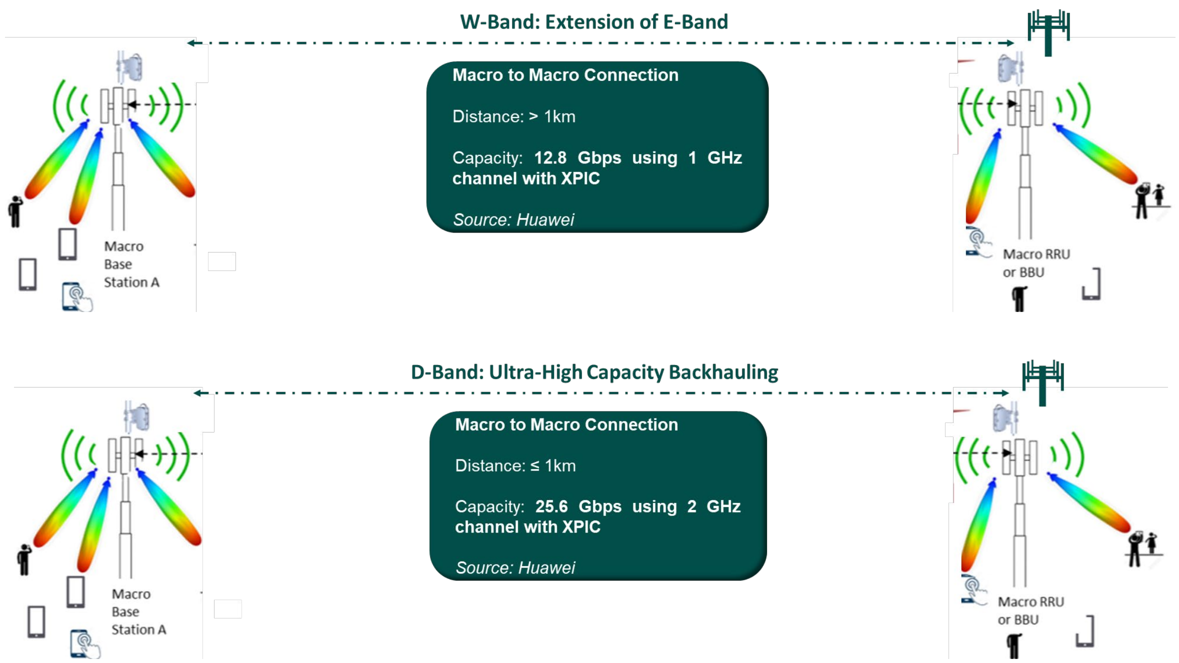
E-Band Adoption, Price Estimates		
Country	**License Structure**	**License Fee**
Australia	Light License	US$ 122.78 per year
Russia	Light License	Minimal Registration Fees
United States	Online Light License	US$ 75 for 10 years
Bahrain	Traditional PTP	1% of generated revenue
Jordan	Traditional PTP	US$ 282.09 per year
Ireland	Traditional PTP	US$ 1,056 per year
UAE	Traditional PTP	US$ 1,225 per year
Source: National Institue of Public Finance and Policy New Delhi		

4.2.5. 92 GHz to 114 GHz: W-Band and 130 GHz to 175 GHz: D-Band

The search for more spectrum has prompted operators, equipment vendors, and regulators to explore frequencies in the W and D bands. The W-band offers 17.9 GHz of available spectrum, while the D-band houses a total of 31.7 GHz. The combination of wider channels and spectrum efficient methods can be used for ultra-high capacity backhauling and Fixed Wireless Access (FWA). The **W** and **D Bands** are two ideal propagation windows with **low atmospheric gas attenuation.** D-band's **path loss** is **only 6 Decibels (dB) worse than the E-band** with minimal dB attenuation due to rain.

The long-term technical targets of the D-band are providing capacity of up to 100 Gbps (4x25 Gbps MIMO) in 5 GHz channels in and extending link length of up to 2 km (a length that is comparable to the E-band).

Figure 15. W-Band and D-Band Characteristics



4.3. Conclusions

The mobile telecommunications sector is just one of many services that rely on radio frequencies to transmit information and the increasing plurality of services using radio frequencies is creating a trajectory toward an imminent “spectrum crunch.” Sufficient spectrum must be allocated toward the RAN and microwave backhaul links to accommodate the capacity/throughput standards of commercial 5G services.

Coping with 5G data traffic through microwave would, therefore, require a reprioritisation of the *status quo* of a regulator’s respective frequency allocation tables to the telecommunications sector. This can be done by widening existing channels in traditional frequency bands, using higher frequencies (in the E, W, and D bands) and modifying current pricing formulas that incentivize operators to use spectrally efficient technologies and best-effort capacity links.

Millimetre wave frequencies (V, E, W, and D bands) play a pivotal role in 5G backhaul. These higher frequencies offer larger amounts of spectrum and higher capacity links. Aside from the additional spectrum, these millimetre wave frequency bands are in differing regulatory stages. Operators have already gained access to the V and E bands through either licensed or unlicensed use. The W and D bands are not yet open.

In many countries, the V-band is encouraged for widespread use as it is unlicensed. Only a few countries retain the V-band for licensed or defence applications. The main drawback for unlicensed bands is that the non-exclusive use of the spectrum make links susceptible to interference.

The E-band has large bandwidth (10 GHz) capabilities allowing, transmission of high-speed data over short distances (2 km to 3 km). E-band frequencies enable more efficient P2P, LOS communication through its pencil beams. The importance of the E-band will increase as 5G networks are rolled out, as it will boost capacity in dense urban sites and is the ideal high frequency complement with traditional microwave frequencies in BCA combinations in suburban sites.

Frequencies in the E-band are generally allocated on a licensed or lightly licensed basis. This licensed approach to backhaul spectrum allocation gives the operator a high degree of service delivery assurance (as interference risk is managed by the operator or regulator) that the V-Band unlicensed spectrum does not have.

The search for more spectrum has prompted operators, equipment vendors, and regulators to explore frequencies in the W and D bands. The W-band offers 17.9 GHz of available spectrum and the D-band houses 31.7 GHz. The combination of wider channels and spectrum-efficient methods can be used for ultra-high capacity backhaul and FWA.

5. SPECTRUM ALLOCATION MANAGEMENT

Key Takeaways

License Analysis

- Wireless backhaul bands are made available through a variety of licensing regimes; most commonly per link and block licenses, and, to a lesser extent, unlicensed, shared, and lightly licensed. Hybrid approaches allow a band to be reserved on a block basis, but operators have the flexibility to self-coordinate within the block on a per link basis. This helps manage costs and helps coordinate with other users in adjacent bands.
- **Per Link:** Conventional link-by-link coordination and managed by the administration's regulation. This is currently the most popular method for PTP networks, accounting for about **45%** of the countries surveyed. Interference checks are included under the administration's responsibilities.
- **Shared Licensing:** Of the countries surveyed, shared licensing is the least used licensing approach at only **6.9%.**
- **Long-Term Licenses: 10-** or **>10-Year** licenses, consisting of **60%** of the countries surveyed, are the most common license duration types. These licenses are typically sold to operators with ongoing renewals to protect their capital investment.
- **Short-Term Licenses:** In contrast, license durations that last for **1 year** (accounting for **18%**) is the least preferred license duration amongst the countries surveyed.

5.1. Types of Licenses

Figure 16. Types of Licenses

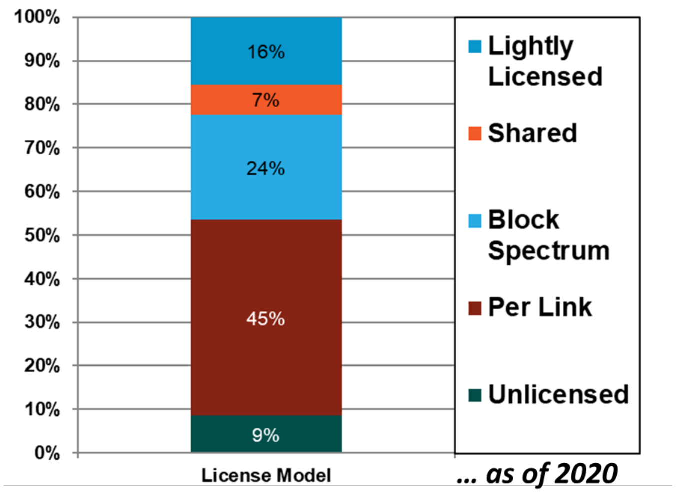
Individual Authorisation *(Individual Rights of Use)*		**General Authorisation** *(No Individual Rights of Use)*	
Individual License	**Light Licensing**		**License Exempt**
Individual frequency planning/coordination	Individual frequency planning/coordination	No individual frequency planning/coordination	No individual frequency planning/coordination
Traditional procedure for issuing licenses (either through **Block** or **Per Link** licensing schemes)	Simplified procedure compared to traditional procedure for issuing licenses	Registration and/or notification	No registration and/or notification
	With limitations in the number of users	No limitations in the number of users nor need for coordination	

Spectrum prices for fixed wireless backhaul are established using either an administrative method, a market-based method, or a combination of both administrative and market-based mechanisms.

ABI Research has conducted an analysis of the license types and license durations of the 40 countries surveyed. A country may have more than one license type. For example, Singapore has three types of licensing frameworks: per link, block, and shared across all frequency segmentations. The same method also applies for license durations. For example, Nigeria has license durations that can span from annual renewals to long-term licenses that can last for 10 or more years. The percentages calculated are derived from the proportion of countries that use that specific license type/license duration (more info can be found in Appendix 5).

5.2. License Framework

Figure 17. Types of Licenses



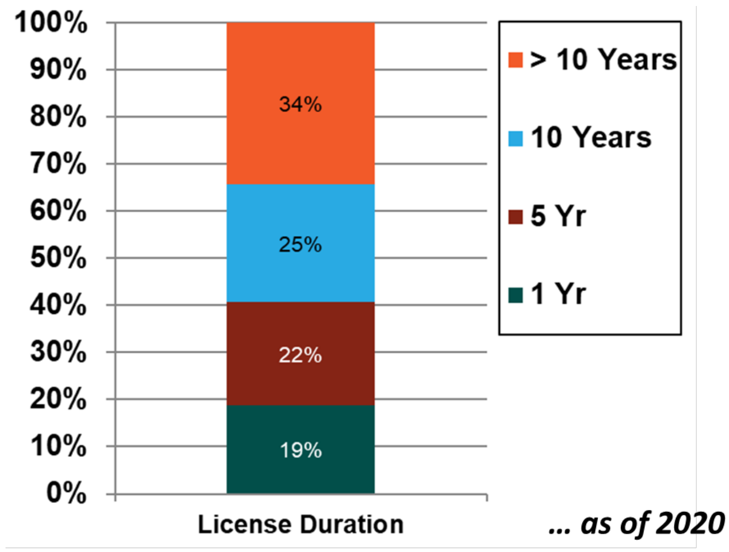
Conventional **link-by-link** coordination, made by an administration's regulation, is currently the most popular method for PTP networks, accounting for about **45%** of the countries surveyed. Interference checks are included under the administration's responsibilities.

Microwave backhaul frequencies in **shared licenses** 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 licenses require additional administrative complexity that pertains to issues, such as the management of different classes of users, delineation of usage periods, implementing enforcement mechanisms, *etc*. Of the countries surveyed, shared licensing is the least used licensing, approaching only **7%**.

5.3. License Duration

Types of license duration across block, per link, shared, and light licensing were analysed across all frequencies of selected 40 countries. A country may have more than one license duration type. (More information can be found in Appendix 5.)

Figure 18. License Duration



10- or **>10-Year** licenses are the most common license duration types across the surveyed countries in 2020; accounting for **59%** of the licenses surveyed. These licenses are typically sold to operators with ongoing renewals to protect their capital investment in their respective network infrastructure and to ensure consistent revenue generation for the regulators. However, the long durations give incumbents extended monopolies over important portions of spectrum. This would give them undue leverage on a share of returns from new use cases, which could serve as an obstacle of innovation.

In contrast, license durations that last for **1 year**, accounting for **19%** of licenses surveyed, is the least preferred license duration among the countries surveyed. The shorter duration does not protect revenue generation (from the regulators' perspective) and does not ensure technological continuity (from the perspective of the licensee). Conversely, having short, yearly license durations gives operators more adaptability in evolving spectrum developments. Short licenses allow operators more flexibility in their network planning, as they are not tied down to frequency bands for a long time; this allows for quicker network development, as they can quickly move their links to different bands that have more available spectrum.

5.4. Conclusions

Per Link: Conventional link-by-link coordination, made by administration's regulation. This is currently the most popular method for PTP networks, accounting for about **45%** of the countries surveyed. Interference checks are included under the administration's responsibilities.

Shared Licensing: Of the countries surveyed, shared licensing is the least used licensing, approaching only **7%.**

Long-Term Licenses: 10- or **>10-Year** licenses, accounting for **59%** of the countries surveyed, are the most common license duration types for block allocated spectrum. These licenses are typically sold to operators with ongoing renewals to protect their capital investment in their respective network infrastructure and to ensure consistent revenue generation for the regulators.

Short-Term Licenses: In contrast, license durations that last for **1 year** (accounting for **19%**) is the least preferred license duration among the countries surveyed. The shorter duration does not protect revenue generation (from the regulators' perspective) and does not ensure technological continuity (from the perspective of the licensee).

6. BACKHAUL LINKS FORECAST

Key Takeaways

- Microwave backhaul accounts for the majority of global backhaul links from 2021 to 2027; in terms of deployed number of links from 2021 through 2027, microwave backhaul accounts for around 65% of overall links.
- There is a migration toward the higher frequency bands within traditional microwave and within the millimetre wave frequencies. In general, regulators are gradually migrating backhaul links toward higher frequencies of 14 GHz to 25 GHz (1.9% CAGR) and 26 GHz to 56 GHz (10.3% CAGR).
- Among the selected segmentations, the 70/80 GHz band (or E-band) is expected to demonstrate exceptional growth (CAGR of 11.6%) from 2021 to 2027.
- The adoption of the higher frequency ranges of W-Band (92 GHz to 114 GHz) and D-band (130 GHz to 175 GHz) is estimated to gain global traction from 2025 onward and will have around 310,000 and 389,000 deployed links, respectively, by 2027.
- Macro cell links will increase from around 8.1 million links in 2021 to 11.1 million links in 2027 at a growth rate of 4.6% between 2021 to 2027.
- Small cell backhaul links across the frequencies of Sub-5.x GHz to the D-band will experience more robust growth rates compared to macro cell links from 2021 to 2027. Small cell backhaul links are forecast to increase from 1.6 million links in 2021 to 6.1 million in 2027 at a CAGR of 25.8%.

6.1. Methodology

Data from the 40 countries identified were fed into the regional models, indicating the number of links per band as done for the previous report. Traditional microwave frequencies are regarded as 6 – 56 GHz in this analysis.

The number of backhaul links have been segmented by **macro cells** and **small cells**, broken down by backhaul platform (as shown in Figure 19).

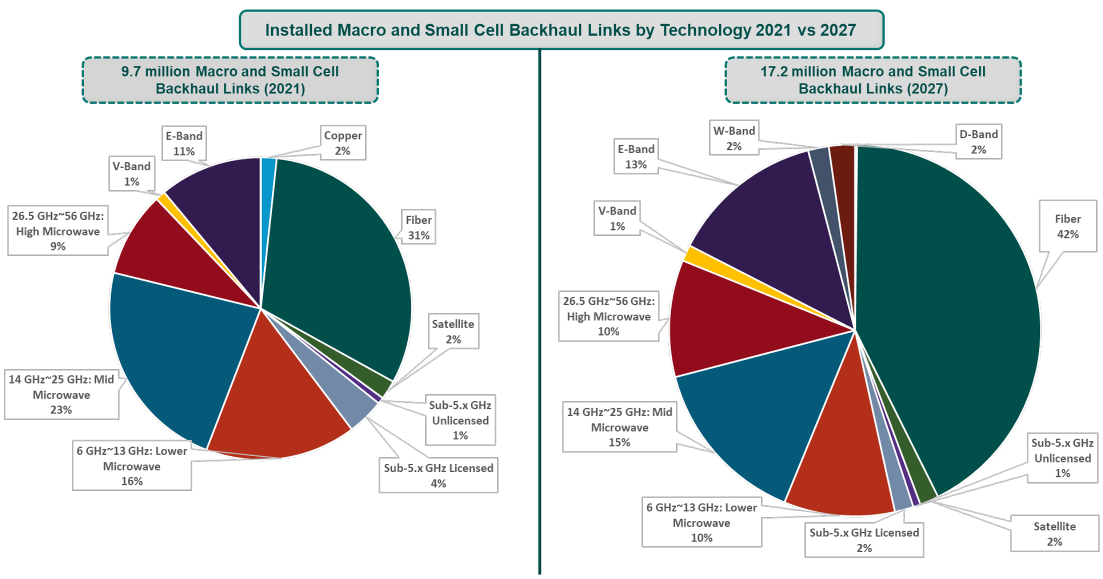
Figure 19. Frequency Segmentations

Frequencies
Sub-5.x GHz
6 GHz to 13 GHz: Lower Microwave
14 GHz to 25 GHz: Mid Microwave
26 GHz to 56 GHz: High Microwave
71 GHz to 86 GHz: E-Band
92 GHz to 114 GHz: W-Band
130 GHz to 175 GHz: D-Band

Research leverages primary and secondary research on 40 countries, including operators and regulators, what bands are currently deployed, impact of future regulation on higher frequencies, and projected number of links deployed. Commentary and insight from backhaul vendors (especially microwave) were also taken into consideration during the construction of the model.

6.2. Outlook Forecast: 2021 versus 2027

Figure 20. Installed Macro and Small Cell Backhaul Links by Technology 2021 versus 2027



Installed Macro and Small Cell Backhaul Links by Technology 2021 versus 2027

ABI Research forecasts a **CAGR** of **13.4%** for fibre-optic adoption, increasing from around **3 million links** in **2021** to approximately **7.3 million links** in **2027**. By contrast, copper backhaul links will experience a considerable dip as operators upgrade their fixed backhaul infrastructure to fibre. Copper links will decrease from **164,000 links** in **2021** to around **30,000 links** in **2027** (with a **-21.5% CAGR**)

Due to its relative advantages of immediacy of deployment, cost, and accessibility, microwave backhaul is the dominant method in terms of deployed number of links from 2021 through 2027, accounting for around 60% of overall links. Despite this, the industry still favours fibre-optic; as evidenced by its adoption rate (as measured by its **CAGR** of **13.4%**) outpacing microwave (with a **CAGR** of **6.2%**). There would be a minimal increase of links in the 6 GHz to 13 GHz range as regulators gradually migrate backhaul links toward higher frequencies of 14 GHz to 25 GHz (**1.9% CAGR**) and 26 GHz to 56 GHz (**10.3% CAGR**).

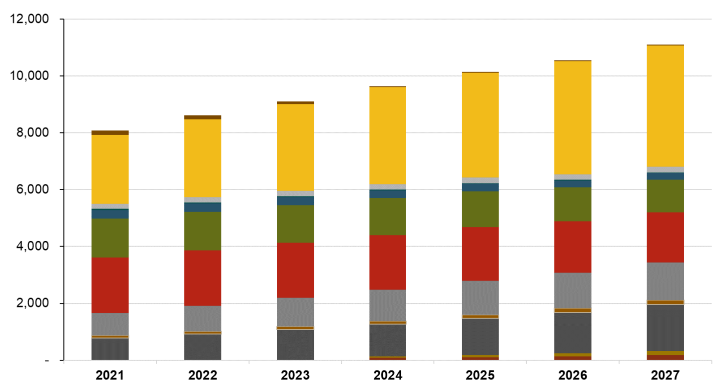
Among the selected segmentations, the **70/80 GHz** band (or **E-band)** has demonstrated an exceptional growth (CAGR of **11.6%**) from 2021 to 2027. This bullishness can be attributed to the increasing relevance of band and carrier aggregation solutions that use E-band frequencies to augment traditional microwave links. It is forecast that the total number of E-band links (**2.3 million**) will account for **71%** of overall millimetre wave links (V, E, W, and D bands) by **2027**.

The adoption of the higher frequency ranges of the **W-band (92 GHz to 114 GHz)** and **D-band (130 GHz to 175 GHz)** is estimated to gain global traction from **2025** onward and will have around **310,000** and **389,000 deployed links**, respectively, by **2027**.

Despite the promise of large amounts of unused spectrum and wider channels in the W and D bands, operators and equipment manufacturers believe that the technology and regulatory environments for these bands are still in nascent stages. A majority of equipment vendors have expressed a partiality toward the **D-band** due to its larger contiguous spectrum and wider channels, which would enable throughput of up to 60 Gbps (supplemented by spectrally efficient technologies). The **W-band** is considered a natural extension of the **E-band** and can offer as much as 17.9 GHz of untapped spectrum that can be used for backhaul.

6.2.1. Macro Cell

Figure 21. Installed Macro Cell Backhaul Links by Technology 2021 versus 2027 (000s)



D-Band
W-Band
E-Band
V-Band
26.5 GHz~56 GHz: High Microwave
14 GHz~25 GHz: Mid Microwave
6 GHz~13 GHz: Lower Microwave
Sub-5.x GHz Licensed
Sub-5.x GHz Unlicensed
Satellite
Fiber
Copper

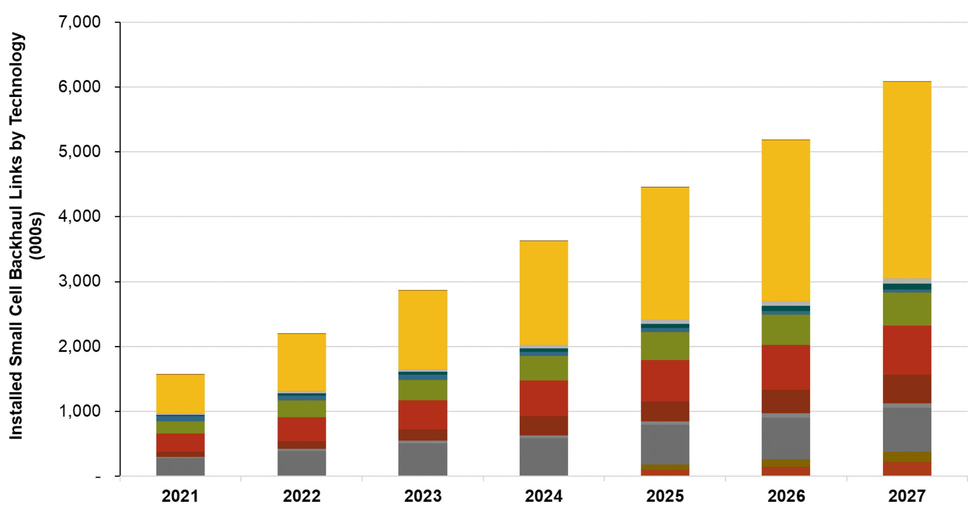
Macro cell links would increase from around **8.1 million** links in **2021** to **11.1 million links** in **2027** at a growth rate of **4.6%** between **2021 and 2027.** There will be a general trend of migration toward higher frequencies during this time period, lower microwave (6 GHz to 13 GHz) at -**2.4% CAGR** and mid-microwave at –**1.3%** (14 GHz to 25 GHz) will experience a gradual reduction as backhaul links migrate to higher frequencies. The higher microwave frequencies (between 26 GHz and 56 GHz) would conversely have a positive **7.3% CAGR**.

Fibre is the dominant means of backhaul with more than **4.3 million links** by **2027;** accounting for **38.4%** of 2027's total macro cell backhaul links.

Macro cell links will also experience a steady increase in the E, W, and D bands. E-band links will grow from **785,000** links in **2021** to **1.6 million** links in **2027** at a CAGR of **11.1%**. The adoption of **W** and **D band** frequencies for macro cells is estimated to begin in **2025.** The promise of higher capacity links will contribute to the robust adoption rates of frequencies in the **W-band** (**22.1% CAGR**) and **D-band** (**18.1% CAGR**). Through ABI Research's interviews with Tier One equipment vendors, there is industry partiality toward the **D-band** due to its higher capacity and wider channels.

6.2.2. Small Cell

Figure 22. Installed Small Cell Backhaul Links by Technology 2021 versus 2027 (000s)



D-Band	W-Band	E-Band
V-Band	26.5 GHz~56 GHz: High Microwave	14 GHz~25 GHz: Mid Microwave
6 GHz~13 GHz: Lower Microwave	Sub-5.x GHz Licensed	Sub-5.x GHz Unlicensed
Satellite	Fiber	Copper

Industry preference of fibre-optic also applies to small cell backhaul deployments, as is reflected by the forecast number and CAGR of small cell links supported by fibre from 2021 to 2027. ABI Research forecasts that fibre will be the most popular mode of backhaul for small cells with a leading **3 million links** by **2027**. Small cell adoption rate of fibre between 2021 and 2021 will have a more robust **CAGR of 26.3%**, compared to an average **CAGR** of **14.4%** for microwave (Sub 5.x GHz to 56 GHz) links over the same time frame.

Small cell backhaul links across the frequencies of **Sub-5.x GHz** to the **D-band** will experience similar robust growth rates from 2021 to 2027. In terms of absolute number of links, the **E-band** is estimated to be the most popular millimetre wave frequency range for small cells, growing from around **280,000 links** in **2021** to **668,000** small cell backhaul links in **2027 (13.2% CAGR)**. The E-band's popularity as a frequency for wireless transport is due to its versatility, delivered capacity/throughput, and complementarity with lower frequency bands across different deployment sites (throughput rates in suburban, urban, and dense urban sites range from 10 Gbps to 20 Gbps).

The use of **W** and **D band** frequencies is expected to start at **2025**. By 2027, W-band links are expected to increase to about **166,000 links** (**26.5% CAGR**), while D-band links will grow to **214,000 links** (**28% CAGR**).

6.2.3. Conclusions

Microwave backhaul is expected to account for the majority of global macro and small cell backhaul links from 2021 to 2027. Due its relative advantages in immediacy of deployment, cost, and accessibility, microwave backhaul is the dominant method in terms of deployed number of links from 2021 through 2027, accounting for around 65% of overall links.

Due to the growing congestion of the lower frequency bands, there is an expected migration toward the higher frequency bands within traditional microwave and also toward millimetre wave frequencies. There will be a minimal increase of links in the 6 GHz to 13 GHz range (0.9% CAGR), as regulators gradually migrate backhaul links toward higher frequencies of 14 GHz to 25 GHz (1.9% CAGR) and 26 GHz to 56 GHz (10.3% CAGR).

Among the selected segmentations, the 71 GHz to 86 GHz band (or E-band) has demonstrated exceptional growth (CAGR of 11.6%) from 2021 to 2027. This uptick can be attributed to the increasing relevance of BCA solutions and the product maturity of the accompanying equipment that supports E-band link deployments. It is forecast that total number of E-band links (2.3 million) will account for 71% of overall millimetre wave links (V, E, W, and D bands) by 2027.

The adoption of the higher frequency ranges of the W-band (92 GHz to 114 GHz) and D-band (130 GHz to 175 GHz) is estimated to gain global traction from 2025 onward as regulation and radio equipment first has to mature for operators to effectively implement them within their network planning. The W and D bands will have around 310,000 and 389,000 deployed links, respectively, by 2027.

Macro cell links will increase from around 8.1 million links in 2021 to 11.1 million links in 2027 at a growth rate of 4.6% between 2021 and 2027.

Small cell backhaul links across the frequencies of Sub-5.x GHz to the D-band will experience more robust growth rates compared to macro cell links from 2021 to 2027. Small cell backhaul links are forecast to increase from 1.6 million links in 2021 to 6.1 million in 2027 at a CAGR of 25.8%.

In terms of absolute number of links, the E-band is estimated to be the most popular millimetre wave frequency range for small cells; growing from around 280,000 links in 2021 to 668,000 small cell backhaul links in 2027 (13.2% CAGR).

7. BACKHAUL LINKS CAPACITY ANALYSIS

Key Takeaways

- The frequency bands of 6 GHz, 7 GHz, 10 GHz, and 13 GHz frequencies are commonly used, as these bands allow for longer distance propagation (better coverage) and can provide higher standards of capacity and reliability (through higher modulations schemes and other spectral efficient methods that overcome the capacity limitations).
- Highest activity is present in the 6 GHz frequency with all 37 out of 38 countries in the spectrum backhaul allocation table showing activity in this frequency band for fixed link services.
- The favoured frequencies within the mid microwave: 14 GHz to 25 GHz range are the 15 GHz, 18 GHz, and 23 GHz bands.
- As commercial 5G New Radio (NR) rollouts progresses in between 26.5 GHz to 29.5 GHz for access. A majority of countries surveyed (28 out of 38 countries) that were relying on these frequency bands for backhaul will see a migration to other bands, including the 32 GHz band (31.8 GHz to 33.4 GHz), in the mid to long term.
- Typical channel dimensions in the microwave bands between 6 GHz to 56 GHz will essentially double by 2027. Minimum channel sizes between 6 GHz and 25 GHz will be 56 MHz and can go up to 80 MHz (in the 6 GHz to 13 GHz bands) and 112 MHz (in the 14 GHz to 25 GHz bands). Channels in the higher microwave frequencies of 26 GHz to 56 GHz bands will eventually offer channels up to 224 MHz wide.
- The regulators surveyed have allocated an average of 55.7% of spectrum in their lower microwave frequencies (6 GHz to 13 GHz) and 57.7% of spectrum in their mid-microwave frequencies (14 GHz to 25 GHz) to fixed wireless backhaul. Backhaul allocation in the high microwave percentage (26 GHz to 56 GHz) has far less backhaul allocation at 44.9%.

Regulators must be open to opening the higher millimetre wave frequencies to adapt to modern 5G capacity demands.

- **V-Band** (57 GHz to 71 GHz) reports an underwhelming activity despite earlier promise as a viable backhaul band. The non-exclusive nature of the V-band (due to it being unlicensed) creates higher vulnerabilities of signal interference; other applications aside from telecommunications, such as WiGig, can be used. There are only 22 countries that have opened up the frequencies in the V-band; of which, there are only 2 countries that are using the full segmentation (57 GHz to 71 GHz), while there are 19 countries that only use the lower frequencies (57 GHz to 64 GHz) of the V-band for backhaul. This should be considered in the next steps of the 6 GHz considerations.

- Data throughput increases in wider channels in the unlicensed V-band segmentation are moderated due to its higher vulnerability to unlicensed potential interference. This explains why the projected 2.16 GHz sized channel in 2027 will only yield up to around 4 Gbps, while a similar channel of 2 GHz in size will yield up to 12.8 Gbps in the licensed/lightly licensed E-band.

- Regulators have recognized **E-band** as the favoured millimetre wave to cope with current and near-term increasing capacity requirements, allocating an average of 94.9% of the frequencies to fixed wireless backhaul.

- Despite larger available spectrum (at 17.9 GHz and 31.7 GHz) and expected larger channel sizes (of up to 2 GHz), the adoption of the W and D bands by operators will require an established licensing regulation that opens up the usage of these frequency bands. The opening of these bands will give operators more spectrum resources to handle 5G data traffic demands.

7.1. Methodology

The table in **Section 7.2** represents the evolution of channel sizes from **2020** to **2027** and the corresponding theoretical data throughput increases from the widened channels. The data throughput increases from 2021 to 2027 are agnostic of any spectrally efficient methods and can only be attributed to the widened channels. Traditional microwave frequencies are regarded as 6 – 56 GHz in this analysis.

The data from the **average spectrum allocated for backhaul in 2020** is derived from the respective frequency allocation tables of **38** countries. The **total spectrum available** is the total overall spectrum within each frequency segmentation.

Backhaul allocation 2020 is a percentage calculation that is derived by dividing **average spectrum allocated for backhaul in 2020** by **total spectrum available** in the respective frequency segmentations; with a high percentage representing high utility in the frequency band and *vice versa*.

The visuals in **Section 7.3** to **7.5** provide a snapshot of the spectrum backhaul allocation for **38 countries**.

7.2. Backhaul Links: Capacity, Spectrum, and Backhaul Allocation Analysis

Figure 23. Channel Sizes, Data Throughput, Backhaul Allocation Summary

Capacity, Spectrum and Backhaul Analysis							
Main Backhaul Bands	Typical Channel Sizes in 2020 (MHz)	Data Throughput (GBps)	Typical Channel Sizes in 2027 (MHz)	Data Throughput (GBps)	Average Spectrum Allocated for Backhaul (GHz)	Total Spectrum Available (GHz)	Backhaul Allocation 2020 (%)
6-13 GHz	28	0.25	56	0.5	4.46	8.0	**55.7%**
	40	0.36	80	0.7			
14-25 GHz	28	0.25	56	0.5	6.92	12.0	**57.7%**
	56	0.5	112	1.0			
26-56 GHz	56	0.5	112	1.0	13.92	31.0	**44.9%**
			224	2.0			
V-Band (57-70 GHz)	100		2160	> 4.0	5.80	14.0	**41.4%**
E-Band (71 - 86 GHz)	500	3.2	500	3.2	9.49	10.0	**94.9%**
	1000	6.4	1000	6.4			
			2000	12.8			
W Band (92 - 114 GHz)	Not Available	N/A	1000	6.4	0	17.9	**0.0%**
			2000	12.8			
D Band (130 - 175 GHz)	Not Available	N/A	2000	12.8	0	31.7	**0.0%**
			4000	25.6			

Source: ABI Research

Figure 23 represents the evolution of channel sizes from **2020** to **2027** and the corresponding theoretical data throughput increases from the widened channels. The data throughput increases from 2021 to 2027 are agnostic of any spectrally efficient methods and can only be attributed to the widened channels. The data from the **average spectrum allocated for backhaul in 2020** is derived from the respective frequency allocation tables of **38 Countries** while the **total spectrum available** is the total overall spectrum within each frequency segmentation. **Backhaul allocation 2020** is a percentage calculation that is derived by dividing **average spectrum allocated for backhaul in 2020** by **total spectrum available** in the respective frequency segmentations; with a high percentage representing high utility in the frequency band and *vice versa*.

General Observations

Typical channel dimensions in the microwave bands (6 GHz to 56 GHz) will eventually double in 2027. The analysis extends the ITU benchmark of traditional microwave frequencies from 6 – 42 GHz to 6 – 56 GHz in order to have comprehensive assessment of spectrum allocation per country.

Minimum channel sizes between 6 GHz and 25 GHz will be 56 MHz and can go up to 80 MHz (in the 6 GHz to 13 GHz bands) and 112 MHz (in the 14 GHz to 25 GHz bands). Channels in the higher microwave, 26 GHz to 56 GHz bands will eventually offer channels up to 224 MHz wide.

Data throughput increases in wider channels in the unlicensed V-band segmentation are moderated due to its higher vulnerability to interference. This explains why the projected 2.16 GHz-sized channel in 2027 will only yield up to around 4 Gbps, while a similar channel of 2 GHz in size will yield up to 12.8 Gbps in the licensed/lightly licensed E-band.

The regulators surveyed have allocated an average of 55.7% of spectrum in their lower microwave frequencies (6 GHz to 13 GHz) and 57.7% of spectrum in their mid-microwave frequencies (14 GHz to 25 GHz) to fixed wireless backhaul.

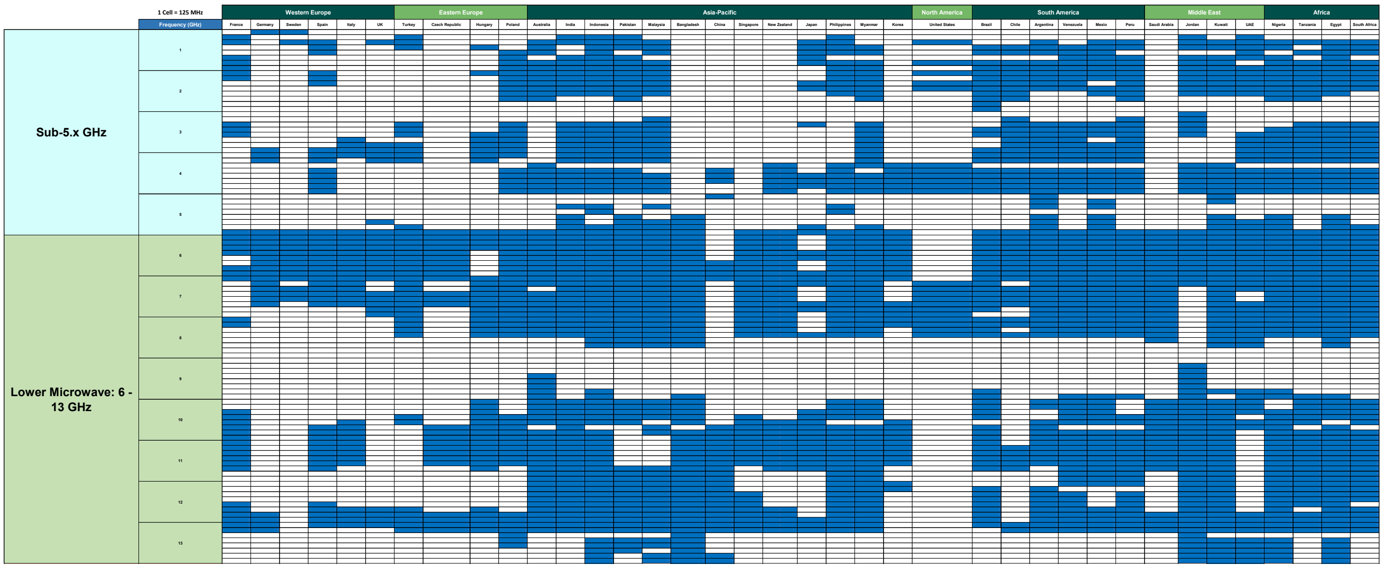
Backhaul allocation in the high microwave percentage (26 GHz to 56 GHz) has far less backhaul allocation at 44.9%. Regulators must be open to opening the higher microwave frequencies to adapt to modern 5G capacity demands.

Thirty-five out of the 38 countries have already opened up their E-band frequencies for backhaul. Regulators have recognized the E-band as the millimetre wave frequency bands to cope with current and near-term increasing capacity requirements, allocating an average of 94.9% of the frequencies to fixed wireless backhaul. The total available spectrum for the W (17.9 GHz) and D bands (31.7 GHz) and the 0% backhaul allocation for both these frequency bands depict how underused these frequencies are, given the abundant amount of spectrum available (at a combined 49.6 GHz). By opening up spectrum in these frequency bands, regulators will equip operators to handle the inevitable growth in 5G capacity demand for fixed wireless backhaul. Since 2018, regulation is in place in the European Conference of Postal and Telecommunications Administrations (CEPT), but not yet implemented at a national level.

7.3. Spectrum Backhaul Allocation Summary: Sub-5.x GHz to Lower Microwave: 6 GHz to 13 GHz

The figures in **Section 7.3** to **7.5** provide a snapshot of the spectrum backhaul allocation for **38 countries**.

Figure 24. Sub-5.x to Lower Microwave 6 GHz to 13 GHz Backhaul Allocation

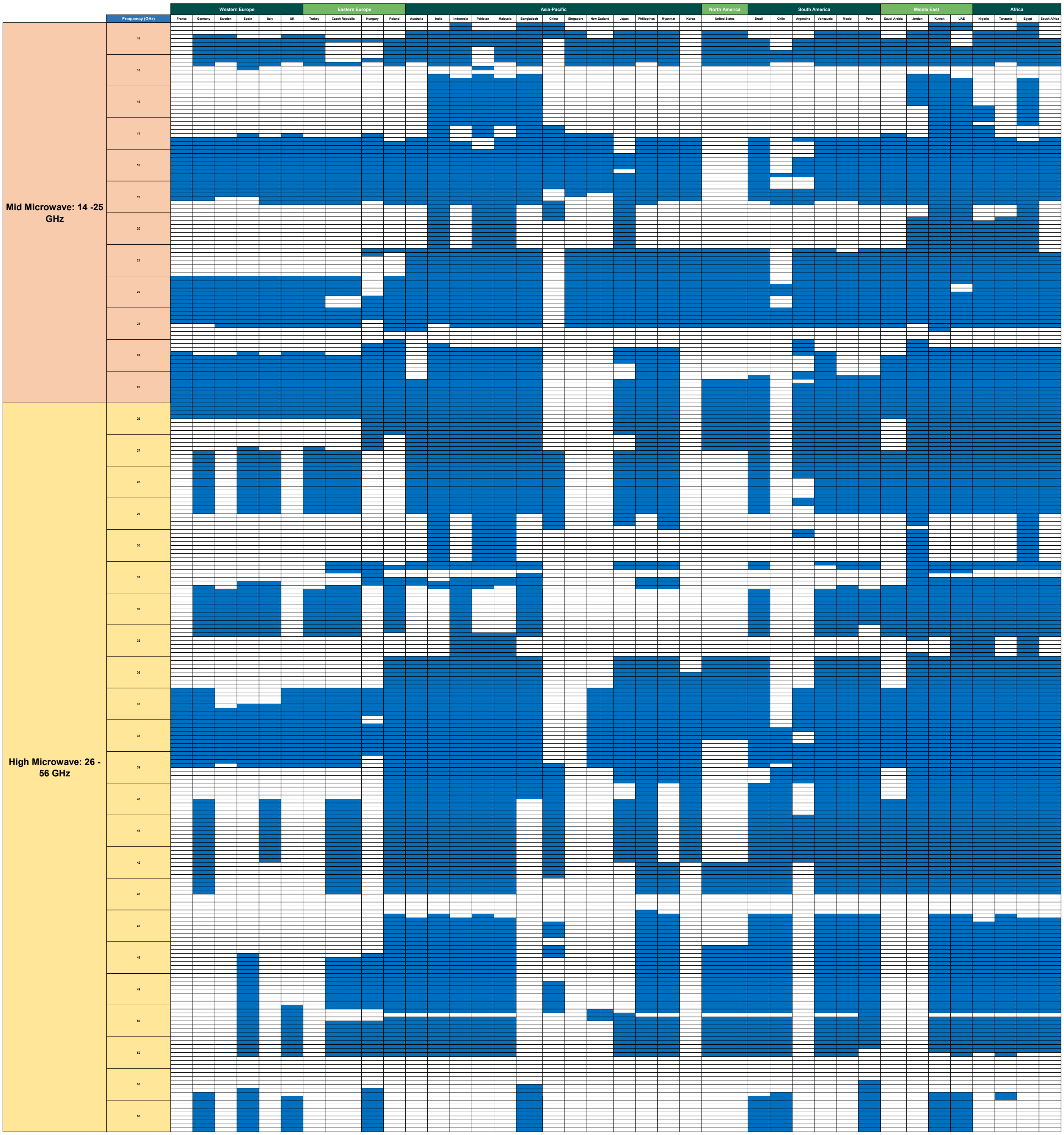


The highest activity is present in the 6 GHz frequency with 37 out of the 38 countries in the spectrum backhaul allocation table using this frequency band for fixed link services. This particular band is currently facing a crossroads as the Wi-Fi Alliance, along with Facebook, Apple, Microsoft, and Google, have been lobbying to open up the 6 GHz band for unlicensed usage.

The frequency bands of 6 GHz, 7 GHz, 10 GHz, and 13 GHz are commonly used, as these bands allow for longer distance propagation (better coverage) and can provide higher standards of capacity and reliability (through higher modulations schemes and other spectral efficient methods that overcome capacity limitations).

7.4. Spectrum Allocation Summary: Mid Microwave: 14 GHz to 25 GHz to High Microwave: 26 GHz to 56 GHz

Figure 25. 14 GHz to 25 GHz to High Microwave: 26 GHz to 56 GHz Backhaul Allocation



The favoured frequencies within the mid microwave: 14 GHz to 25 GHz range are the 15 GHz, 18 GHz, and 23 GHz bands. Usage of these frequencies is spread across regions; the 18 GHz band is particularly well used in Asia-Pacific.

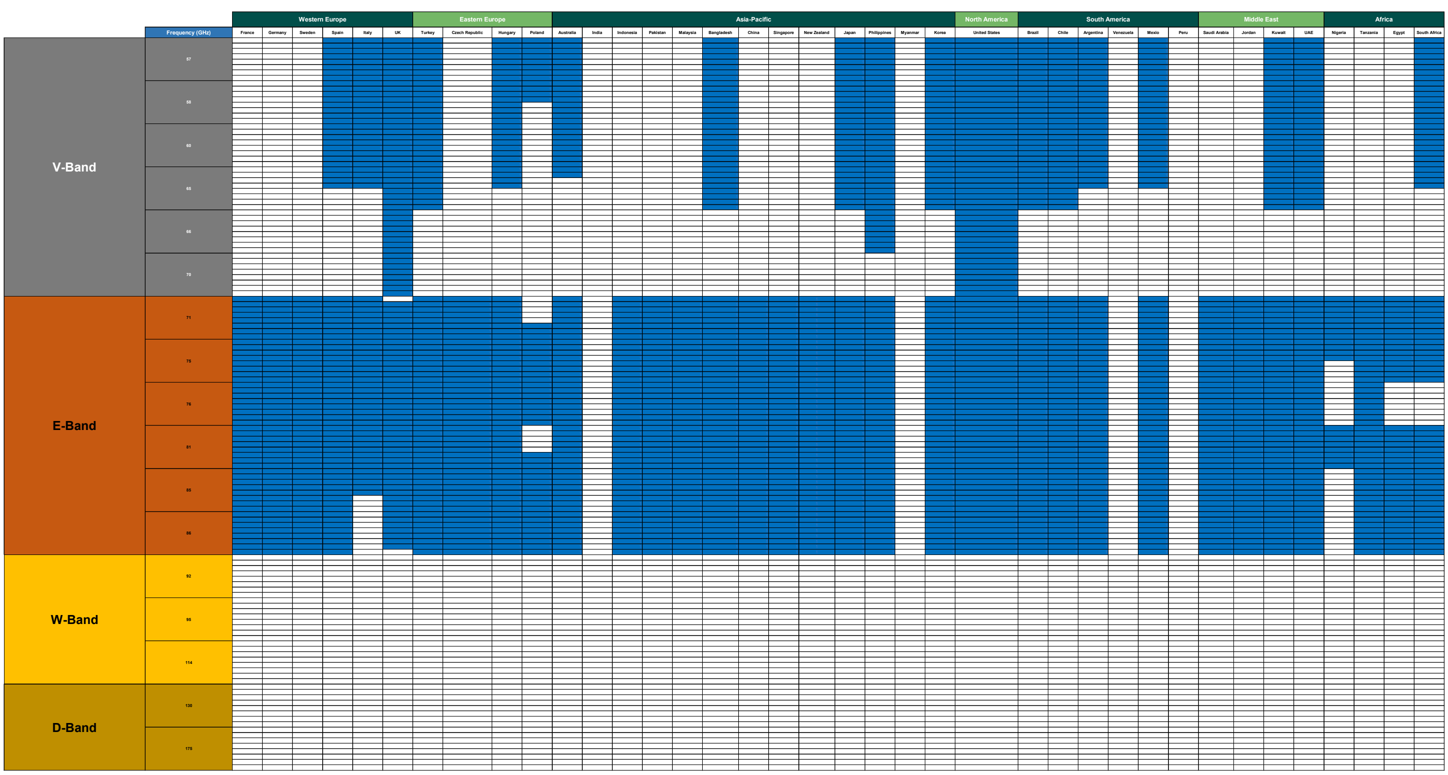
Compared to the low and mid microwave bands, frequencies within the high microwave: 26 GHz to 56 GHz have relatively low usage rates.

The exceptions are the 26 GHz to 28 GHz and the 38 GHz frequency bands; commonly used frequencies for higher capacity microwave fixed links for PTP or Point to Multi-Point (PTMP) backhaul used especially in urban areas.

Commercial 5G NR rollouts are focusing on the frequency ranges between 26.5 GHz and 29.5 GHz for access. However, a majority of countries surveyed (28 out of 38 countries) rely on these frequency bands for backhaul. As global growth of 5G networks picks up, there will be an inevitable need to migrate the fixed wireless incumbents to other bands. The 32 GHz band (31.8 GHz to 33.4 GHz), originally proposed for radio access, is now currently a strong candidate as a key microwave backhaul replacement for the mid to long term.

7.5. Spectrum Allocation Summary: Millimetre Wave V-Band (57 GHz to 71 GHz) to D-Band (130 GHz to 175 GHz)

Figure 26. V-Band (57 GHz to 71 GHz) to D-Band (130 GHz 175 GHz) Backhaul Allocation



- V-band (57 GHz to 71 GHz) allocation for backhaul reports an underwhelming activity despite earlier promise as a viable backhaul band. The frequency range possesses around 13 GHz of available spectrum at little to low cost (mostly unlicensed/lightly licensed in most countries). The non-exclusive nature of the V-band (due to it being unlicensed) creates higher vulnerabilities of signal interference; other applications aside from telecommunications, such as WiGig, can be used. Only 22 countries have opened the frequencies in the V-band; of which, only 2 countries are using the full segmentation (57 GHz to 71 GHz), while 19 countries are only using the lower (57 GHz to 64 GHz) frequencies of the V-band for backhaul. This should be considered in the next steps of the 6 GHz considerations.

  The E-band has high receptivity across the countries surveyed, with 35 out of 38 countries using portions between 71 GHz and 86 GHz for backhaul. As compared to the V-band, E-band frequencies have the advantage of less interference and less susceptibility to environment for longer distance coverage (attenuated only by rain, while the V-band is attenuated by rain and oxygen).

  There is no activity in the W and D bands as of yet. The adoption of the W and D bands by operators would require a combination of the following:

  - Developed equipment that can support high-capacity, low-distance links
  - Established licensing regulation that offers wider channels (in orders of GHz) in these bands.

7.6. Conclusions

The evolution toward 5G requires operators to have more bandwidth and regulators must proceed with allocating larger channels to operators. Typical channel dimensions in the traditional microwave bands (6 GHz to 56 GHz) are expected to double by 2027. Minimum channel sizes between 6 GHz and 25 GHz would be 56 MHz and can go up to 80 MHz (in the 6 GHz to 13 GHz bands) and 112 MHz (in the 14 GHz to 25 GHz bands). Channels in the higher microwave frequencies of 26 GHz to 56 GHz bands would also eventually offer channels up to 224 MHz wide.

The regulators surveyed have allocated an average of 55.7% of spectrum in their lower microwave frequencies (6 GHz to 13 GHz) and 57.7% of spectrum in their mid-microwave frequencies (14 GHz to 25 GHz) to fixed wireless backhaul. Backhaul allocation in the high microwave percentage (26 GHz to 56 GHz) has far less backhaul allocation at 44.9%.

The frequency bands of 6 GHz, 7 GHz, 10 GHz, and 13 GHz frequencies are commonly used frequency bands, with the highest activity present in the 6 GHz frequency with all 37 out of 38 countries in the spectrum backhaul allocation table showing activity in this frequency band for fixed link services.

As commercial 5G NR rollouts progress in between 26.5 GHz to 29.5 GHz for access. A majority of countries surveyed (28 out of 38 countries) that were relying on these frequency bands for backhaul will see a migration to other bands including the 32 GHz band (31.8 GHz to 33.4 GHz), in the mid to long term.

V-band allocation for backhaul reports an underwhelming activity, despite earlier promise as a viable backhaul band. The non-exclusive nature of the V-band (due to it being unlicensed) creates higher vulnerabilities of signal interference; other applications aside from telecommunications, such as WiGig, can be used.

On the other hand, regulators have recognized the E-band as the favoured millimetre wave to cope with higher capacity requirements of the future. The E-band has high receptivity across the countries surveyed, with the countries using all or most of the spectrum between 71 GHz and 86 GHz for backhaul.

Despite larger available spectrum (at 17.9 GHz and 31.7 GHz) and expected larger channel sizes (of up to 2 GHz), the adoption of the W and D bands by operators would require an established licensing regulation that opens up the usage of these frequency bands. Opening these bands will give operators more spectrum resources to handle 5G data traffic demands.

8. SPECTRUM PRICING ANALYSIS

Key Takeaways

- This study looks at backhaul spectrum prices in **31 countries** and found significant variation, even when comparing similar spectrum bands and conditions. The highest spectrum prices in some markets were found to be 22X higher than the global median and 59X higher than the lowest priced markets. This can place a significant burden on operators in some markets, making it more difficult to quickly roll out faster broadband services with better coverage.
- High backhaul spectrum fees have a significant impact on the total cost of networks in the 5G era. Section 9 describes how applying high representative maximum spectrum fees across all the microwave and millimetre wave bands for a network in a developed market can result in an average per year aggregate network TCO of US$1.68 billion, which is 266% higher than the minimum spectrum fee scenario.
- Some countries were also found to place a technology dis-incentivization fee on operators that adopt innovative backhaul technologies that make more efficient use of spectrum. For example, some countries charged operators double the price of a single radio channel link when the operator employed secondary polarisation technology, which doubles spectrum efficiency.
- Crucially, the pricing formulas regulators use to set backhaul spectrum costs often failed to adapt effectively to the much wider channels that are available in higher frequency bands. In practice, costs sometimes scaled linearly, making newer, much wider channel sizes (*e.g.*, 2 GHz, rather than 56 MHz to 224 MHz) very expensive. Formulas need to take into account improved geographical spectral efficiency, higher frequency reuse, and the larger spectrum availability/requirements, especially in higher frequency bands.
- Operators are subject to the prices in the frequency fee table, which can be quite sizable in a number of countries. While the pricing formulas surveyed do include additional variables that correspond to different deployments, these variables are subjective and fall under the full discretion of the regulator.

Key Takeaways

- Formulas must have factors that can mitigate escalation of prices from larger bandwidth purchases and encourage spectrally efficient methods. License fees that linearly scale with channel sizes serve as large financial barriers for operators. The current costs of spectrum per MHz are mostly based on outdated formulas where capacity requirements were not as pertinent; during periods when smaller channel bandwidths of 3.5 MHz, 7 MHz, or 14 MHz were the primary channel sizes of choice.
- In some countries, spectrum fees factor into the revenue being generated by the operator. This is problematic, as it can potentially penalise the operator that has a large subscriber base of lower margin subscribers, such as low-income households or rural communities. A straightforward pricing formula would be more favourable, as it gives an operator more control over their budget planning.
- There is increasing interest in “hybrid licensing schemes” that combine the features of block and per link licensing. This type of licensing enables the protection of large up-front investments from block licensing, while also avoiding the spectral usage inefficiencies of per link licensing.

8.1. Methodology

This section focuses on demonstrating the diversity of price points across different backhaul frequencies in **31 countries**. The metric ABI Research is using is the **PPP adjusted US$ per MHz per year**, derived from the respective pricing formulas of the surveyed countries. Normalization is needed due to how channel allocations are issued in different sizes and spectrum is organized in different segmentations across the various pricing formulas. Traditional microwave frequencies are also regarded as 6 GHz to 56 GHz in this analysis.

The analysis identifies three countries per spectrum category; each representing the **max**, **mid,** and **low** price points of respective spectrum categories (as show in Figure 27 below). Price points for the W-band and D-band frequencies are not included, as countries have not opened up these bands.

8.2. Spectrum Pricing Analysis (Max, Mid, and Low)

The results of ABI Research’s spectrum pricing analysis are shown in Figures 27 to 29.

Figure 27. Global Spectrum PPP Adjusted Spectrum Pricing by Frequency Segmentation (US$/MHz/Year)

Frequency Segmentations	Country	Low (US$/MHz)	Country	Mid (US$/MHz)	Country	Max (US$/MHz)
Sub-5.x GHz	Spain	16.73	Italy	44.62	Bangladesh	996.24
6 GHz to 13 GHz	Spain	14.64	Nigeria	42.07	Bangladesh	626.90
14 GHz to 25 GHz	Spain	10.46	Italy	33.46	Bangladesh	376.14
26.5 GHz to 56 GHz	Czech	3.29	Jordan	28.04	Bangladesh	313.45
E-Band (71 GHz to 86 GHz)	Japan	0.02	Poland	2.25	U.K.	**71.41***

Source: ABI Research

UK: Double regime approach, which reflects the UKP50 fixed fee per wireless backhaul link

Figure 28. Max Spectrum PPP Adjusted Spectrum Pricing by Frequency Segmentation (US$/MHz/Year)

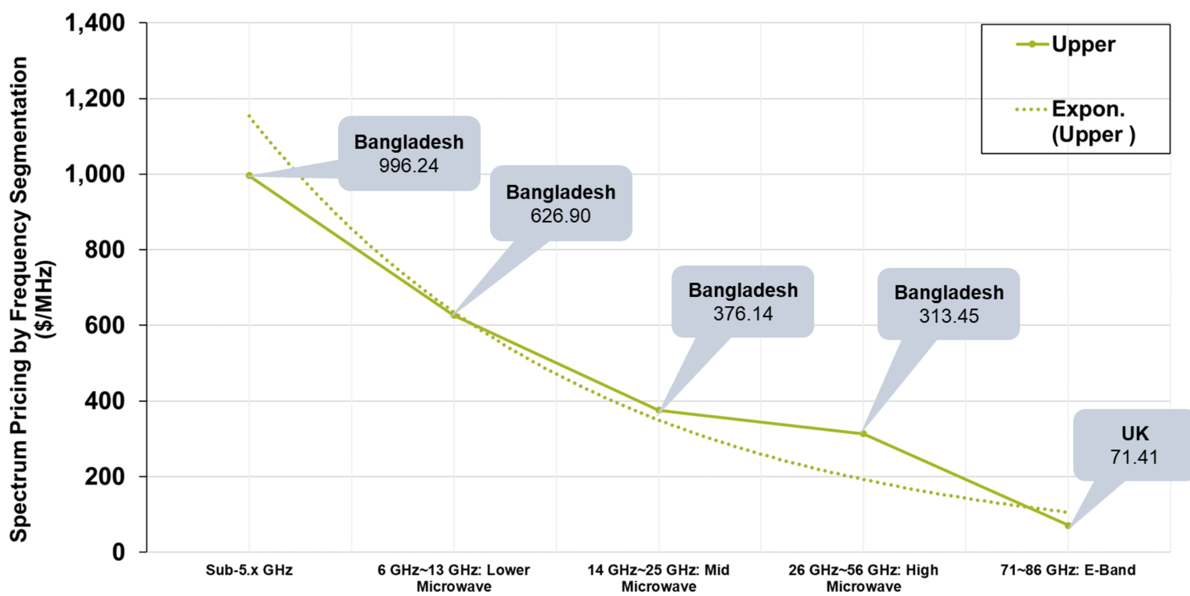
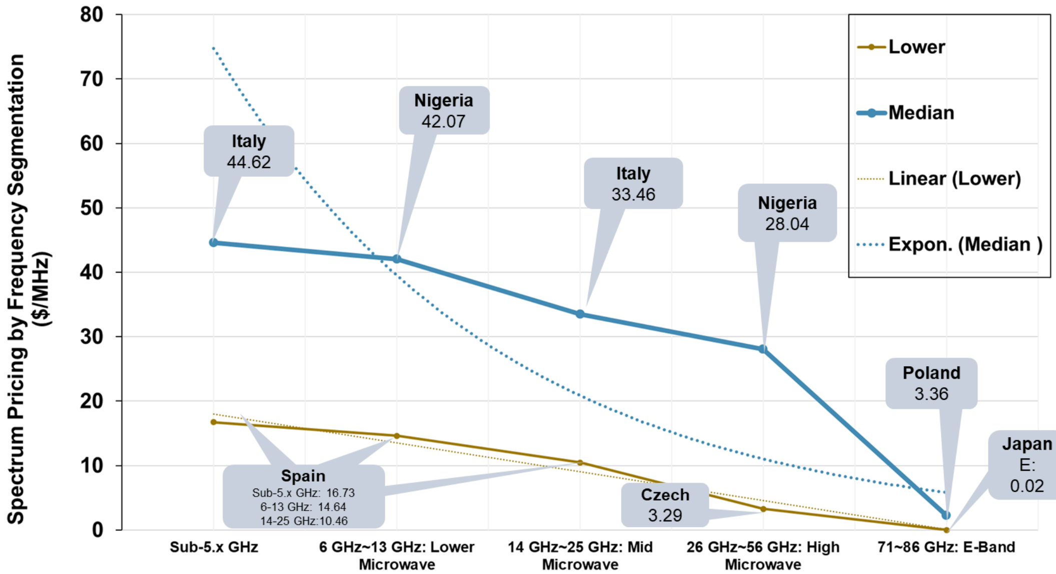


Figure 29. Mid and Low Spectrum PPP Adjusted Spectrum Pricing by Frequency Segmentation (US$/MHz/Year)



8.2.1. Why Bangladesh's Sub-5.x GHz Pricing Is So Much Higher than Spain's

The Bangladesh Telecommunication Regulatory Commission (BTRC) charges **US**$996.24 per MHz per year in the sub-5.x GHz band; the costliest backhaul spectrum pricing for that frequency segmentation in the sample. The high price of US$996.24 per MHz per year can be attributed to the substantially higher base price per kHz at the lower frequency bands (at US$6.30 per kHz) in the BTRC's pricing matrix for backhaul links. Spectrum is charged on a per link basis and the fee also includes the power charge; a fee that is charged based on the output power of the used transmitter.

By contrast, Spain's National Commission on Markets and Competition (NCMC) follows a more nuanced pricing formula compared to Bangladesh. Bangladesh's pricing formula is based on only two components, the addition of a nominal per kHz or per MHz frequency fee, and a power charge fee. Spain's pricing formula, on the other hand, is based on the product of seven variables divided by a fixed value. Spain's pricing formula is more versatile as it accounts for more variables; more variables mean more commensurate spectrum costs across different deployments. (For more information on the pricing formulas for Bangladesh and Spain, please refer to Appendix 2).

Figure 30. Pricing Formula Variables Comparison between Bangladesh and Spain

Bangladesh	Per KHz or Per MHz Nominal Frequency Fee	Power Charge Fee					
Spain	Area of Coverage	Bandwidth	Frequency Congestion	Type of Service	Band of Spectrum	Equipment and Technology Used	Economic Value Derived

As mentioned, the control of an operator over spectrum costs is restricted to only the amount of spectrum that an operator plans to purchase. This is seen in the pricing formula of Bangladesh, in which operators are confined to the high prices in the frequency fee table and power charge fee table—prices that are made under the full discretion of the regulator.

This is also seen in Spain's pricing formula. While Spain's pricing formula does account for additional variables that correspond to different deployments, these variables are categorical and are still under the full discretion of the regulator. Spain's low sub-5.x GHz pricing of US$16.43 per MHz per year is still primarily based the on low-cost variables set by the NCMC, rather than the increased nuance that the additional variables bring.

The only way that operators can decrease their spectrum costs is to reduce the quantity of spectrum purchased or somehow make compromises on their network's Quality of Service (QoS), by reducing cell site power consumption, expanding only to regions with low population densities, or minimizing area coverage. Employing these measures is counterproductive in dealing with the increased capacity demands of 5G.

Formulas must have factors that can mitigate escalation of prices from larger bandwidth purchases and account for spectral efficient methods. License fees that linearly scale with channel sizes serve as large financial barriers for operators. The current costs of spectrum per MHz are mostly based on outdated formulas where capacity requirements were not as pertinent; during periods when smaller channel bandwidths of 3.5 MHz, 7 MHz, or 14 MHz were the primary channel sizes of choice.

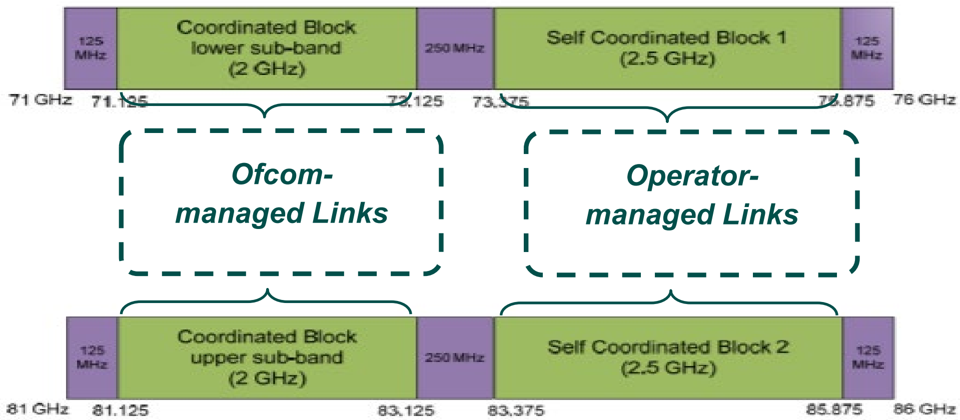
Accounting for spectral efficient methods in pricing formulas will give operators more control over their network planning. Including and incentivizing the use of technological innovations, such as XPIC, BCA, IAB, and LOS MIMO would provide tremendous assistance for operators that want to maximise limited amounts of spectrum. On the other hand, countries should not charge operators for the additional capacity that they have attained through technological innovations; for example, countries like Indonesia, Nigeria, and Peru that charge double fees when operators use XPIC to double link capacity.

8.2.2. United Kingdom and Japan E-Band Pricing Comparison

E-band frequency band in the United Kingdom is subdivided into two parts or regimes: coordinated and self-coordinated. In the **coordinated regime**, operators buy predetermined channel sizes from the regulator (Ofcom). Spectrum fees are bandwidth-based. In the **self-coordinated regime**, operators register and manage their own links. Links are based on fixed fees, irrespective of capacity.

The segmentation of these two regimes is shown in Figure 31.

Figure 31. Coordinated and Self-Coordinated Regimes



The difference in how an operator can acquire backhaul capacity between the coordinated regime and the self-coordinated regime will result in different price points (US$/MHz/Year) for E-band frequencies in the United Kingdom.

For the **bandwidth-based, coordinated regime pricing**, operators will buy a channel of bandwidth; at an estimated cost of **€630 for the 250 MHz channel.**

In terms of channelization within the coordinated block, Ofcom will permit 8 x 250 MHz channels, 4 x 500 MHz channels, 1 x 750 MHz channel, and 1 x 1000 MHz channel. The PPP adjusted cost for a 250 MHz channel is US$910. The PPP adjusted US$/MHz for the coordinated regime will, therefore, be US$3.64/MHz.

For the **self-coordinated regime pricing**, links are registered separately, **irrespective** of capacity. This produces two iterations of the PPP adjusted US$/MHz/year for this regime. Theoretically, an operator buying a link with 1 MHz capacity would be paying £50/MHz/year or a PPP adjusted US$71.4/MHz/year. If we assume that operators buy links with 250 MHz capacity, the PPP adjusted priced would be US$0.30/MHz/year.

Figure 32. E-Band Pricing: United Kingdom

E-Band Pricing Info: United Kingdom	
Coordinated Regime	US$ 3.64/MHz/Year
Self Coordinated Regime Fixed £50 fee, irrespective of capacity	For a 1 MHz Link: US$ 71.4/MHz/Year
	For a 250 MHz Link: US$ 0.30/MHz/Year

Source: ABI Research

E-Band pricing in Japan adopts a single, per link licensing regime that charges 5€ or 600 Yen for 250 MHz. This would amount to PPP adjusted US$0.02/MHz.

Figure 33. E-Band Pricing: Japan

E-Band Pricing Info: Japan	
Per Link License Regime	US$ 0.02/MHz/Year

Source: ABI Research

Figure 34. E-Band Pricing: E-Band Price Comparison between Japan and the United Kingdom

Comparative Pricing Summary: UK vs. Japan	
UK; Coordinated Regime vs. Japan	182x More Expensive
UK; Self Coordinated Regime (1MHz Link) vs. Japan	3,570x More Expensive
UK; Self Coordinated Regime (250 MHz Link) vs. Japan	15x More Expensive

Source: ABI Research

As shown in Figure 33, Japan's E-band pricing is drastically lower than the United Kingdom's E-band pricing across all three scenarios. This disparity is, again, mainly because of the lack of flexibility for operators in reducing their spectrum fees as more links are set up within the network.

E-band frequency bands are becoming more integral in an operator's backhaul strategies due to the growing relevance of band and carrier aggregation solutions and it is the product maturity of the equipment that supports E-band link deployments.

It is important for regulators to recognise the E-band's importance in 5G and ensure that its pricing does not heavily impact the commercial viability of deploying the significant amount of links required.

8.2.3. Pricing Formulas Analysis

There are several similar elements that have been identified among the pricing formulas analysed. Spectrum prices are usually derived from these common factors:

Spectrum Fees (per microwave link) → V x F x BW x G x E:

- Nominal Base Value of the Spectrum **(V)**:
    - This fixed value is representative of the economic position of the regulator's country and also accounts for the prices of backhaul alternatives like fibre or satellite.
        - For example**,** the United Kingdom has a nominal spectrum price of **£88** or US**$110** incorporated in its pricing formula.
        - Nigeria also has a similar unit price of **18,000 Naira** or **US$47** that is also part of one of the multiple variables multiplied in its pricing formula.
        - Turkey has an "economic development factor" that impacts spectrum pricing.
- Frequency Range **(F)**:
    - The frequency range variable denotes the variance of value among the frequency ranges. Lower frequency bands offer better propagation capabilities with lower capacity, while high frequencies offer more capacity, but have more limited propagation distances. Lower frequencies are valued higher than higher frequencies by virtue of their coverage capabilities; operators with lower frequencies are better equipped to provide connectivity on a national scale.
        - The United Kingdom has a bandwidth factor that is a modifier that distinguishes prices for links in different frequency bands. The 7.5 GHz band has a bandwidth factor of 0.74, while the 38 GHz band has a bandwidth factor of only 0.26.

- Amount of Bandwidth **(BW)**:
    - This factor is based on either the precise number of channels or MHz that an operator plans to obtain. The factor has a linear relationship with the amount of spectrum that an operator wants to obtain—the more spectrum an operator wants to obtain, the higher the BW factor would be.
- Geographical Factor **(G)**:
    - Regulators want to differentiate spectrum pricing with respect to coverage area. Regions with high population densities will have a higher geographical value compared to sparsely populated rural areas.
        - Poland has a multiplier of 2 for links in urban areas; effectively doubling spectrum price in urban areas.
        - South Africa has unique geographic multipliers that differentiate high and low geographical density areas; with high density areas using a multiplier of 1 while low density areas use a reduced to 0.1.
- Exclusivity **(E)**:
    - The value of this factor varies depending on the exclusivity of the assigned spectrum. Spectrum that has shared agreements will have lower exclusivity (translating to a lower price), while exclusive spectrum solely used by one operator will have a higher exclusivity value.
        - South Africa uses a multiplier of 1 or exclusive usage, while it uses a multiplier of 0.5 for shared usage.

From the perspective of an operator, agency over their spectrum pricing cost-efficiency is restricted to only the amount of spectrum **(BW)** that they plan to purchase. The other parameters **(V, F, G,** and **E)**, on the other hand, are pre-determined by the regulator.

8.2.4. Fees Based on Power Consumption

Saudi Arabia also includes a power factor that increases when operators use higher millimetre wave frequencies:

Annual Spectrum Price = U x B x H x M x ***Power Factor*** *x W x L x G*

For example, the power factor used in calculating the price for a 28 MHz channel in the 23 GHz band is P = 15, while the power factor for a channel in the E-band is increased to P = 20.

Charging operators for the energy consumption increases of 5G is unfavourable. The benefits of 5G can only be achieved through network densification; increased number of cell sites, along with more advanced 5G NR technology and the previously mentioned technological advancements will certainly create unavoidable consequences of energy consumption. Regulators must revise or eliminate the power consumption element in their spectrum pricing formulas as 5G networks will consume more energy than their network predecessors.

8.2.5. Fees Based on Revenue

India's pricing formula integrates an operator's Annual Gross Revenue (AGR) in its fees. The Department of Telecommunications (DoT) charges around 8% of an operator's annual gross revenue as license fees and 4% as spectrum usage charges. Jordanian regulator, Telecommunications Regulatory Commission (TRC), also includes annual license fees based on a percentage of the operating revenue arising from an operator's licensed activities. The percentage is determined by the TRC but would not exceed 1% of such revenue.

From an operator's perspective, spectrum fees based on revenue is problematic as it prevents predictability of how an operator should allocate its budget. A straightforward pricing formula would be more favourable as it gives an operator more control over their budget planning.

8.2.6. Conclusions

The challenge with current backhaul spectrum pricing formulas is that the variables within them do not give operators enough control and flexibility in controlling their spectrum costs. From the perspective of an operator, agency over their spectrum pricing cost-efficiency is restricted to only the amount of spectrum that it plans to purchase.

Operators needing to acquire more spectrum for increased capacity will have no avenues for curbing their spectrum costs as the variables and values in current pricing formulas are predetermined with discretion by the regulator. The only way that operators can decrease their spectrum costs is to reduce the quantity of spectrum purchased, or make unfavourable compromises in the QoS, by reducing cell site power consumption, expanding only to regions with low population densities, or minimizing area coverage. Employing these measures is obviously counterproductive in dealing with the increased capacity demands of 5G.

Formulas must, therefore, have factors that can mitigate escalation of prices from larger bandwidth purchases and account for spectral efficient methods. License fees that linearly scale with channel sizes serve as large financial barriers for operators. The current costs of spectrum per MHz are mostly based on outdated formulas where capacity requirements were not as pertinent; during periods when smaller channel bandwidths of 3.5 MHz, 7 MHz, or 14 MHz were the primary channel sizes of choice.

Accounting for spectral-efficient methods in pricing formulas will give operators more control over their network planning. Including and incentivizing the use of technological innovations, such as XPIC, BCA, IAB, and LOS MIMO will provide tremendous assistance for operators that want to maximize a limited amount of spectrum. On the other hand, countries should not charge operators for the additional capacity that they have attained through technological innovations; for example, countries like Indonesia, Peru, or Nigeria that charge double fees when operators use XPIC to double link capacity.

Implementing a robust microwave backhaul network is a critical component of national-level Information, Communications, and Technology (ICT) strategy. Regulators must balance their commitments from operators by serving more people (especially in rural areas) and providing better quality of connectivity with updated backhaul spectrum fee formulas that do not excessively charge operators during their 5G network densification process.

8.2.7. Pricing Formulas Recommendations

Spectrum formulas must have factors that can mitigate escalation of prices from larger bandwidth purchases and incentivise spectral efficient methods. The pricing formulas surveyed do not have provisions that allow regulators to lower spectrum costs as operators buy more bandwidth.

Spectrum Fees (per link) → V x F x BW x G x E x ***Technology Factor***

The non-linear relationship between pricing and bandwidth will reduce the financial burden of an operator migrating to larger channels for their network. Deciding to switch from 112 MHz channel to a 250 MHz channel would, therefore, not correspond to a 2.2x (250 divided 112) price increase if the operator applies spectral efficient technologies to boost capacity and throughput performance from procured spectrum.

The European Telecommunications Standards Institute (ETSI) has recommended a hybrid licensing formula that accounts for technological innovation and for larger spectrum availabilities, larger spectrum bandwidth purchases and channel reusability (shown in Figure 35).

Figure 35. Hybrid Licensing Scheme

	Impact	Function in Formula	Formula Factor
Larger Spectrum Availability	**Cost per MHz** will decrease in the higher frequencies	License fee will be proportional to the ration between Channel Bandwidth (**BW**) and Overall Band Size (**Bsize**)	**BW/Bsize**
Higher Frequency Reuse	More links per square km as same spectrum can be licensed **several times over the same area**	Coordination area reduction goes with the square of Carrier Frequency (**fc**). License fee would be proportional to the inverse of coordination area	**$(1/fc)^2$**
Address Lower Link Availability at Higher Frequencies	When E-band is used on links (*via* BCA) that are longer than link propagation distance (**dmax**), license fee incentives will be included	Regulator to establish **dmax** for a standalone E-band link, **BCA** discount factor is formulated if link distance (**d**) exceeds **dmax**	**BCA** = dmax/d
Promote Channel Re-use with Small Angles in Nodal Configurations	**More link density** in the same geographical area	Factor inversely proportional to Number (**N**) of links/carriers in the same site/node/area re-using same channel	**1/N**

Hybrid License Formula → k x BCA x $(1/fc)^2$ x (BW/Bsize) x (1/N)

Application	Regulators arrange for block **reservation** for the operator and **link-by-link** declaration by the same operator. Regulator would be aware of actual spectral usage and consumption.
Coordination	**Operator will manage self-coordination of links within the reserved block**; coordination among operators using adjacent blocks will be ensured by filter/antenna discrimination and guard bands

Source "ISG mWT view on V-Band and E-Band Regulations", mWT-0014v2.0.0, Dec 2017

This formula is based on the principles of a **hybrid licensing** scheme, which combines the features of block and per link licensing.

This type of licensing enables the protection of large up-front investments from **block licensing**, while also avoiding the cost inefficiencies **per link** licensing. Operators' license fees would be aligned with respect to their actual usage of spectrum and would not require wholesale purchase of a block of spectrum.

9. EVOLVING BACKHAUL COSTS

Key Takeaways

- This study built a TCO model for a radio access and backhaul network in the 5G era (2021 to 2027) with a developed and developing market as a baseline. This incorporated the network equipment, spectrum fees (which vary country by country), and cell sites, including site rental and power. It considered a range of backhaul strategies to improve capacity, including new technologies and bands.

- In developed markets, it was found that new backhaul technologies alone were not sufficient to meet traffic demands, so new bands, such as the D-band and W-band, will be vital, especially toward the end of the period. In developing markets, new backhaul technologies were again also unable to meet increasing traffic alone, so the E-band will be crucial to address increasing traffic and speeds.

- High backhaul spectrum costs were found to have a significant impact on the total cost of networks in the 5G era. Applying the maximum spectrum fees across all the microwave and millimetre wave bands for a network in a developed market can result in an average per year aggregate network TCO of US$1.68 billion, which is 266% higher than the minimum spectrum fee scenario. Similarly, the annual TCO of a network in an emerging market was US$427 million and will be 59% higher than the minimal spectrum fee scenario. Regulators that charge high backhaul spectrum prices should expect that 5G network investment will be impacted and, therefore, the rollout of services.

- Key Highlights from the Developed Market, Europe, (A Series) Scenarios:

  - **A1) Baseline Scenario**: the baseline scenario reflects the current operational parameters for backhaul deployment for a mobile operator where the min, mid, and max spectrum fees demonstrate the sizable impacts of spectrum pricing over the overall backhaul TCO. Using the minimum spectrum pricing in the A1 Baseline scenario would make backhaul TCO 22% of the overall TCO, while inputting max pricing would drastically increase the overall backhaul TCO to 51%. In terms of traffic congestion, the A1 baseline reaches the 100% threshold by 2024.

  - **A2) Add W-Band Scenario**: The W-band's very wide channels (500 MHz to 2 GHz) boost data throughput and applies for use cases with increased links density and demanding capacity requirements, where the E-band is highly exploited or when the E-band's availability is limited. The W-band is expected to have a light licensing regime and low spectrum fees per MHz structure.

  - **A3) Add D-Band Scenario**: The D-band's development trajectory is similar to the W-band's in many respects. Despite its higher frequency band status (130 GHz to 175 GHz), it does seem to have wide support from the infrastructure vendor community. Its commercial value is the very large channel sizes (2 GHz to 4 GHz), as well as a similar licensing regime and fee structure as the W-band. The D-band and W-band scenarios were very effective in managing traffic.

Key Takeaways (continued)

- **A4) Combined XPIC, BCA, and LOS MIMO Scenario**: This scenario attempted to see if a heavy-duty technology-centric approach could help manage traffic throughout the forecast period. The gains from the technology-centric approach were constrained because XPIC and BCA were deployed in the A1) baseline scenario, so there was not additional gain.

- **A5) IAB Scenario**: For urban macro cells and urban Rooftops, the capacity of 3.5 GHz IAB-enabled cell sites was considered insufficient to meet the backhaul capacity needs of the 5G community. However, for the rural scenario, macro cell site rooftop and small cell locations were considered viable for IAB. However, it is likely IAB will only be deployed in niche locations where there is a need to reduce TCO to make the cell site commercially viable or as a short-term solution.

- **A6) All Strategies**: The combination of spectrum tools and technological enhancements leads to the most substantial reductions in overall network congestion throughout the forecast period. Fundamentally, mobile operators will need a range of tools to manage their traffic in the 5G era.

- Key Highlights from the Developing Market, Africa, (B Series) Scenarios:

  - **B1) Baseline Scenario**: B1, the baseline scenario reflects the current operational parameters for backhaul deployment for a mobile operator where the min, mid, and max spectrum fees demonstrate the sizable impacts of spectrum pricing over the overall backhaul TCO. Using the minimum spectrum pricing in the B1 baseline scenario would make overall backhaul TCO 31%, while inputting max pricing would drastically increase the overall backhaul TCO to 42%. In the baseline scenario, the network maxes out its capacity by a very substantial margin (206%).

  - **B2) Add E-Band Scenario**: The E-band does a very effective job of handling traffic. Overall TCO costs are driven up by the deployment of E-band equipment, which is more expensive on a per unit basis, but it comprehensively improves capacity. However, rain fade in tropical countries and licensing availabilities may limit effectiveness.

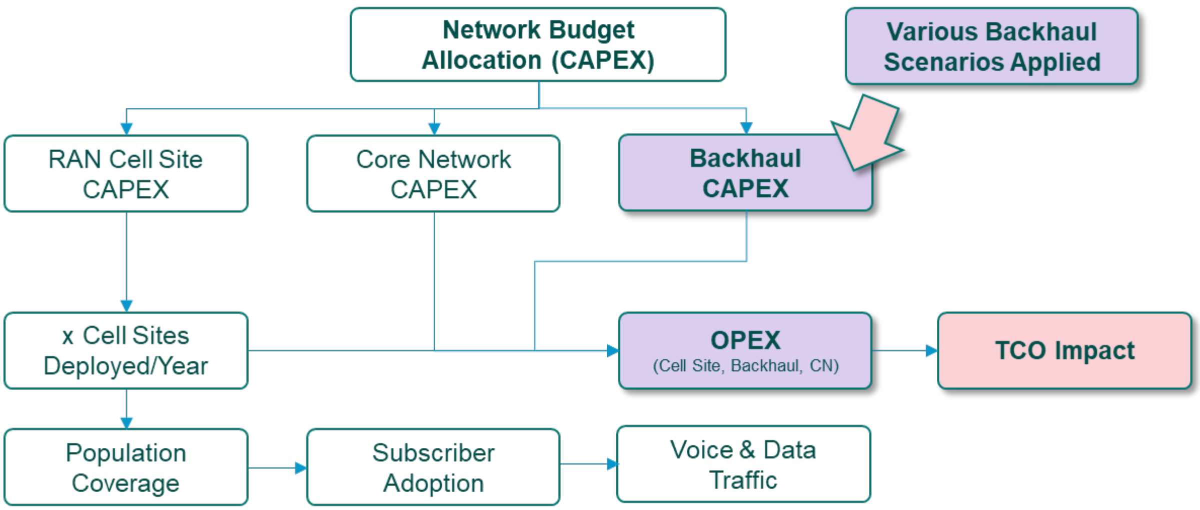
  - **B3) Combined XPIC, BCA, and LOS MIMO Scenario**: ABI Research concluded that while the technology-centric approach did noticeably boost capacity, it was not sufficient on its own for the entire forecast period. While there are some capacity gains *vis-à-vis* the B1) baseline scenario, the additional equipment costs cancel out the cost savings from the overall backhaul links management.

  - **B4) IAB Scenario**: In this scenario, the Communication Service Provider (CSP) has used 3.5 GHz for backhaul in either a shared access/backhaul strategy or relied on LTE frequencies for access coverage at the cell site. From the model's perspective, IAB is comparatively effective at managing the operator's traffic loads and TCO. The 3.5 GHz band would give the operator reasonable propagation distances, but IAB should not be considered a backhaul "free lunch." While the operator does not need to install backhaul equipment at the cell site, there is an opportunity cost from allocating cell site access equipment to backhaul.

9.1. TCO Analysis

The key objective of the TCO analysis was to build a backhaul TCO model that factors in all the RAN and backhaul equipment, their respective operating costs, spectrum and licensing fees, and the need for cell site densification in relation to the growth of 4G and 5G end-user traffic. It was essential the TCO model factor in the backhaul requirement for urban versus rural environments, as shown in Figure 36.

Figure 36. Overview of TCO Model



(Source: ABI Research)

Sub-objectives included:

- Assessing the impact of backhaul equipment costs as the mobile operator migrates to higher bands, such as the E, W, and D bands. It should be noted that the channel sizes for each band that were used in the TCO model analysis were E-Band (500 MHz), W-band (2 GHz) and D-band (2 GHz). It is possible that up to 2 GHz channel sizes could be issued by proactive regulars for the E-band but in general regulators have been cautious in the allocation of spectrum to ensure it is effectively utilized. The D-band may get 4 GHz channels but again ABI Research kept to a prudent allocation as commercial licensing is still several years away.

- Collect estimated global generic costs of equipment for new bands.

- Take into consideration that higher bands propagate less far and, therefore, ascertain whether there is spike from deploying additional backhaul equipment.

- Higher spectrum bands may be cheaper on a per-MHz basis, but operators are purchasing larger channel sizes and there may be additional CAPEX and OPEX costs

- Certain backhaul link platform elements are kept "steady state" throughout the modelling and were not varied, so that they have a neutral impact on the TCO modelling. Those backhaul link platforms included:
    - Fibre-optic backhaul links are expected to grow incrementally throughout the forecast as operators steadily (when it becomes economically viable to build out) install fibre-optic connectivity to business and residential districts.
    - Sub-6 GHz and copper are legacy solutions and being deprecated throughout the forecast as equipment is swapped out.
    - Satellite backhaul is assumed to be serving the needs of very remote rural communities where fibre or microwave is not economically viable.

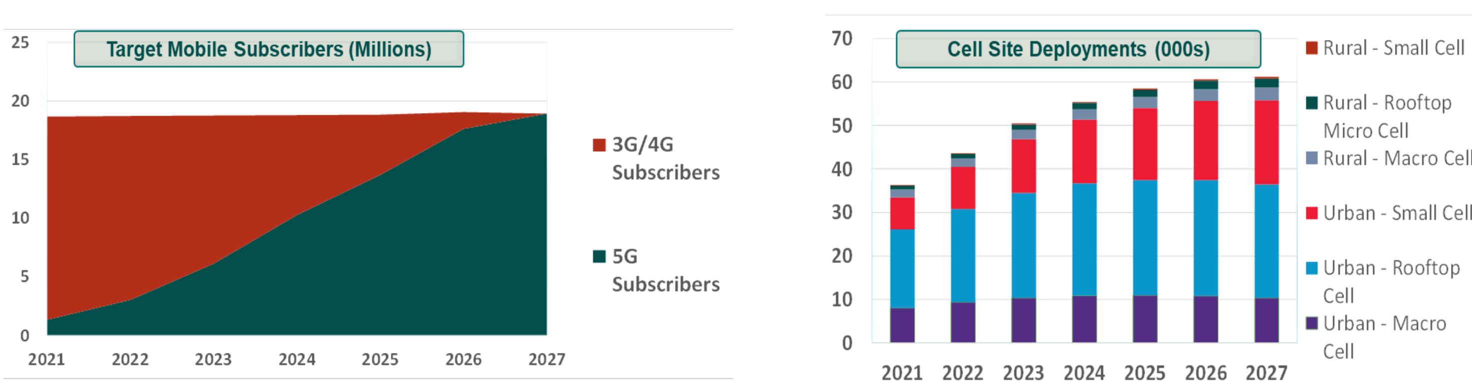
9.2. Developed Market TCO Analysis

For the developed market, a large European country was selected as a representative market for the challenges of backhauling traffic from a mixture of macro-cell, rooftop, and small cell deployments in both urban and rural settings.

9.2.1. Developed Market Assumptions

For the market in question, total subscriptions stood at 5G subscribers and will grow from 1.4 million in 2021 to 18.9 million in 2027. Conversely, 3G/4G subscribers will decrease from 17.3 million subscribers to being phased out by 2027. 5G traffic will drastically increase from about 10,600 megabytes/user/month in 2021 to 26,000 megabytes/user/month in 2027. To address this traffic, total urban cell sites will need to increase from around 33,000 in 2021 to 55,794 in 2027 (at a CAGR of 7.6%). Rural cell sites will also experience a slightly higher pace of growth (CAGR of 9.4%), expanding from 2,900 sites in 2021 to 5,400 sites in 2027.

Figure 37. Developed Market, Europe, Underlying Assumptions



For the developed market, a series of scenarios were tested in the model to assess the impact of various spectrum and technology solutions on the capacity and TCO for the mobile operator.

9.2.2. Developed Market A1), Baseline Scenario

The purpose of the A1) baseline scenario is to set up a reference set of output analysis to compare the subsequent additional scenarios (A2 to A6). Therefore, the baseline scenario is intended to apply "current market conditions" over the next 7 years. The baseline scenario should reflect the spectrum and technology choices of a typical operator in the European country market. In addition to low, mid, and upper microwave backhaul links being deployed, E-band millimetre wave backhaul links are being rolled out for certain cell sites. Furthermore:

- No V, W, and D bands are deployed.
- XPIC and BCA is deployed in a limited fashion (macro cells) for "resilience" purposes in the low, mid, and high microwave.
- E-band BCA with microwave on macro cells for capacity build-out.

The backhaul links deployment profile for the A1) baseline scenario, along with all the other scenarios, can be seen in Figure 21, in Section 6.2.

Disposition: Throughout all the series A scenarios, fibre-optic grows from 34% to 44% by 2027. The underlying assumption is that operators will increase the prevalence of fibre-optic to cell sites where that is economically viable. However, there are limitations. The majority of wireless links are in the mid and high microwave bands (49% in 2021). E-band millimetre wave backhaul links (500 MHz channels) are already finding their way into operator networks (4.9% in 2021). It should be noted that while the percentage ratio drops to 4.6%, the total installed base of E-band links grows from 1,760 to 2,800 over that period.

9.2.3. Developed Market A2) and A3) Augmenting E-Band with W-Band or D-Band

For the second and third scenarios, A2) and A3), the principal assumptions of the baseline model remain, such as cell site deployments, subscriber adoption, and traffic generated. Furthermore, existing fixed and wireless backhaul link trends, where reasonable, were kept; for example, fibre-optic deployment and long distance backhaul links, as well as respecting the life cycle of existing backhaul equipment. Where it was appropriate, new cell sites, mostly small cell and rooftop, were provisioned with W-band or where legacy cell sites came to the end of their existing equipment life cycle and W-band equipment was suitable.

Disposition: In scenarios A2 and A3, the E-band was boosted from 4.9% to 17.7% (2021). The D band (2 GHz channels) and W bands (2 GHz channels) are only likely to be deployed onto some urban rooftop and small cell sites. Furthermore, from the research conducted during the project, it is very likely that the D and W bands' backhaul equipment will only become available in the 2025 timeframe, so the D and W bands' equipment will only be deployed on 5% to 6% of equipment.

9.2.4. Developed Market A4) Impact of XPIC/BCA/MIMO Approach

For scenario A4), the prime objective was to see if a 'technology-centric" approach where XPIC, BCA, and LOS MIMO are deployed aggressively can address the long-term traffic management requirements of the mobile operator.

Disposition: Spectrum-wise the deployments are identical to A1) baseline scenario. However, in the low, mid, and high microwave and the existing E-bands that the operator has secured, XPIC, and BCS were deployed. 2x2 LOS MIMO was deployed on macro cell sites and rooftop sites. No deployment has taken place in the W-band and D-band.

9.2.5. Developed Market A5) Impact of IAB

The technical merits of IAB were discussed in Section 3. In many respects, IAB is not a mainstream backhaul solution, such as fibre-optics, microwave, or millimetre backhaul. However, there will be cost-challenged scenarios where IAB could reduce the TCO for the operator to ensure cell site deployment is more financially viable. While IAB reduced the TCO profile of the cell site by up to 50% of the spectrum allocated for the cell site, it has to be used for the IAB backhaul. In the developed market, the 3.5 GHz band was used for the integrated backhaul and access functions of the cell site.

As noted in Section 3.4, IAB can be deployed in all 5G-related spectrum bands, although the C-band 3.5 GHz and the 26/28 GHz bands will be the most prevalent. While it is feasible that operators will use the 26/28 GHz band where they are unable to secure a fibre-optic link to the cell-site, there is substantial versatility for IAB with the 3.5 GHz band where there can be challenges backhauling traffic from the cell site, such as those serving remote communities. The 3.5 GHz band was used for the IAB analysis as it represents an immediate and versatile IAB solution for urban and rural scenarios. If the deployment scenario could be justified for IAB in the C-band, it can substantiate the rationale for IAB in the 26/28 GHz band. Although IAB in the 26/28 GHz band will be constrained to urban small cell scenarios.

Disposition: In this model, urban small cell scenarios, along with rural macrocell, rooftop, and small cell site scenarios were considered to be suitable for IAB. All backhaul links from those cell sites were switched to IAB in order to clearly delineate the TCO and traffic management impact of IAB. This was for the purposes of the modelling, but in reality, operators would be more selective. The number of IAB backhauled cell sites grows from 16.7% in 2021 to 20.3% by 2027.

9.2.6. Developed Market A6) ALL Optimized Backhaul Strategies

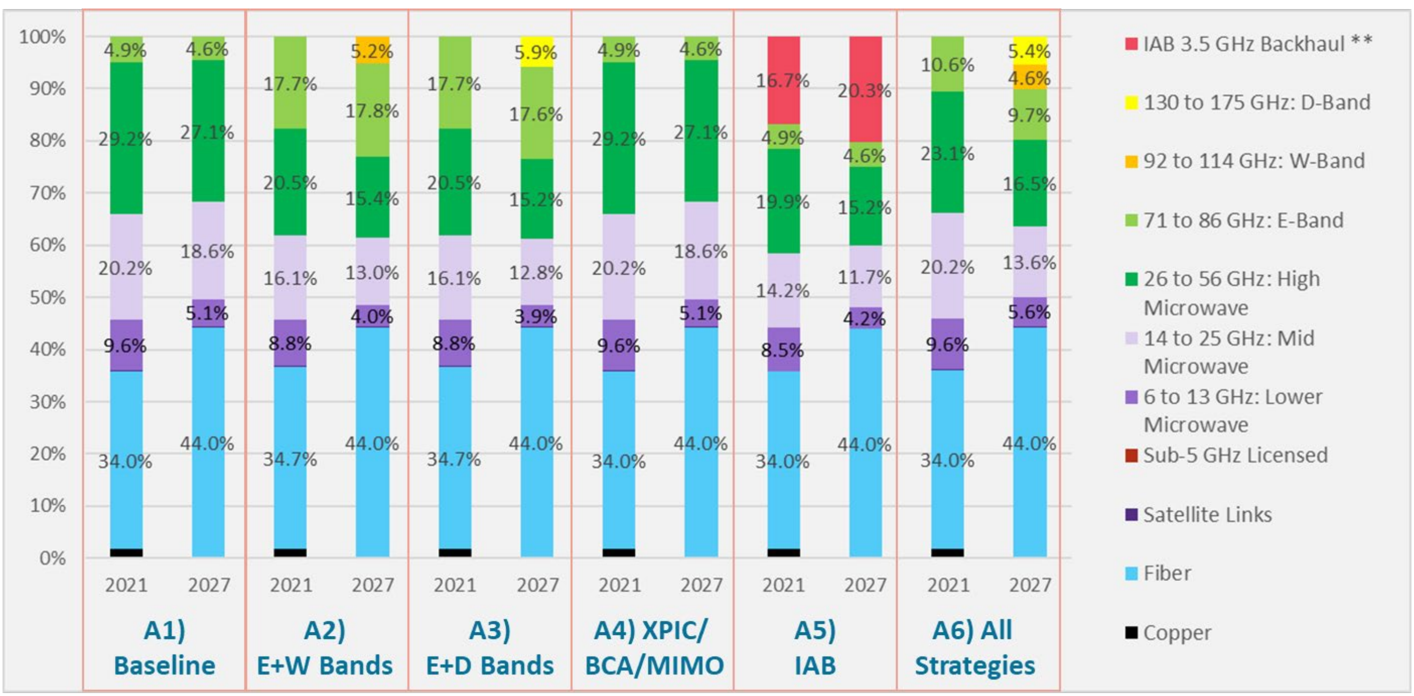
Scenario A6) is essentially an "All In" approach, where in addition to making the maximum use of the E-band, the D and W bands are used, and technology upgrades, such as XPIC, BCA, and LOS MIMO, are aggressively deployed.

Disposition: The low and mid microwave backhaul allocations are kept similar to the baseline A1) scenario, while 20% of the high microwave allocation was freed up for allocation to the E-band (doubled to 10.6%), while allocating around 5% to the D-band and W-band.

9.2.7. Aggregate Backhaul Links Deployed in the Model

Figure 38 provides an aggregate snapshot of backhaul links, on a percentage basis for 2021 and 2027, for all six scenarios for the developed European country analysis. In 2021, the backhaul links are serving 36,300 cell sites, but by the end of 2027, the cell site count increases to 61,000. In the respective urban and rural radio access domains, the links are backhauling traffic from microcell, rooftop, and small cells.

Figure 38. Backhaul Links Deployed by Aggregate Percentage, Series A1 to A6, European Country Operator, per Average Year



Note: The full data for the chart can be found in Appendix 1. There is also additional commentary on the per cell site TCO and Outlook. The disposition shown for a single operator and assumptions are set for the purpose of testing various scenarios.

9.3. Impact of Spectrum Fees

From the per cell site TCO analysis, it is clear how spectrum licensing fees can have significant impact on costs. The spectrum costs displayed above are based on the input **high** spectrum fees per MHz reported in Section 7.2, Spectrum Pricing Analysis. A summary of the **low**, **mid,** and **high** backhaul spectrum pricing points can be found in Figure 39. The **low**, **mid,** and **high** buckets of spectrum fees were based on a weighting analysis per country.

Figure 39. Developed Market Spectrum Pricing Assumptions, Sourced from European Markets, US$ per MHz PPP-Adjusted

Frequency Segmentation	Lower	Mid	High
Sub-5.x GHz	16.73	37.64	101.59
6 GHz~13 GHz	14.64	36.39	405.10
14 GHz~25 GHz	10.46	27.60	202.55
26.5 GHz~56 GHz	4.55	16.61	158.35
71~86 GHz: E-Band	0.91	3.36	17.71
92~114 GHz: W-Band	0.78	2.49	14.17
130~175 GHz: D-Band	0.66	1.84	7.08

Source: ABI Research
W- and D-Band Pricing are extrapolated

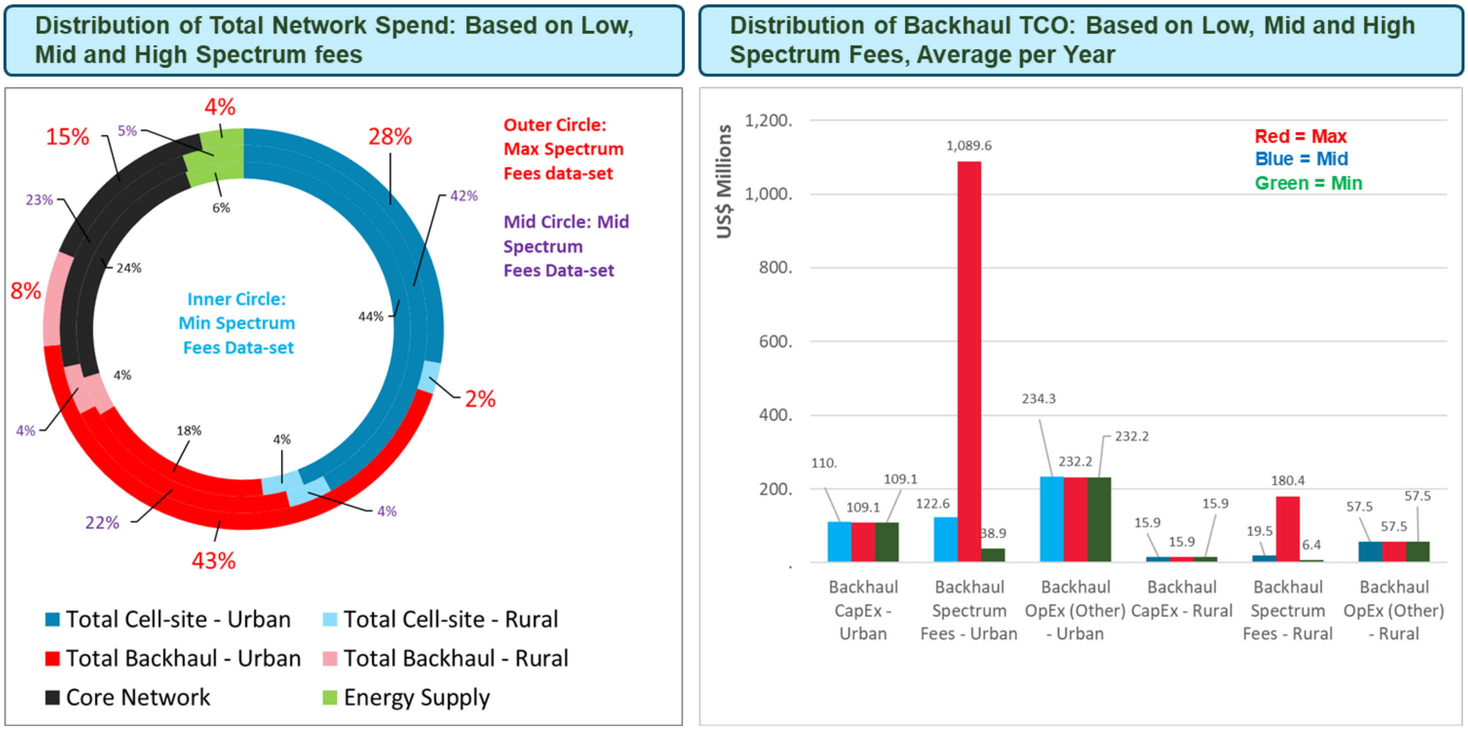
The most expensive category is the 6 GHz to 13 GHz band, where fees can go as high as US$405 per MHz per year, followed by the 14 GHz to 25 GHz band with US$202. While the channel sizes may “only” be 28 MHz or 56 MHz wide, the fees can rapidly accumulate. The fees for the W-band and D-band are extrapolated from the spectrum pricing analysis ABI Research performed (Section 7), but they are in line with expectations. Based on the high spectrum dataset, spectrum related OPEX can add up to 51% of the TCO (A1) baseline). By comparison, if the lower spectrum pricing dataset is used, spectrum costs only incur 3.6% of per cell site TCO.

9.4. Impact on Total Network TCO

A mobile operator has a number of cost considerations when deploying and operating its network. In addition to rolling out and managing macro, rooftop, and small cells across the country, the operator has to manage its backhaul infrastructure and upgrade its core network, as well as ensure that all of its infrastructure assets are provisioned with electricity and other relevant utilities.

For an operator in a **high** spectrum fee country, the total urban and rural backhaul fees can jump to 51% of overall total network fees, whereas in a low spectrum fees market, backhaul costs equate to 22%. The chart on the right-hand side in Figure 40 shows the breakdown of expenses that relate to backhaul, as well as the degree to which spectrum fees can contribute to overall backhaul TCO.

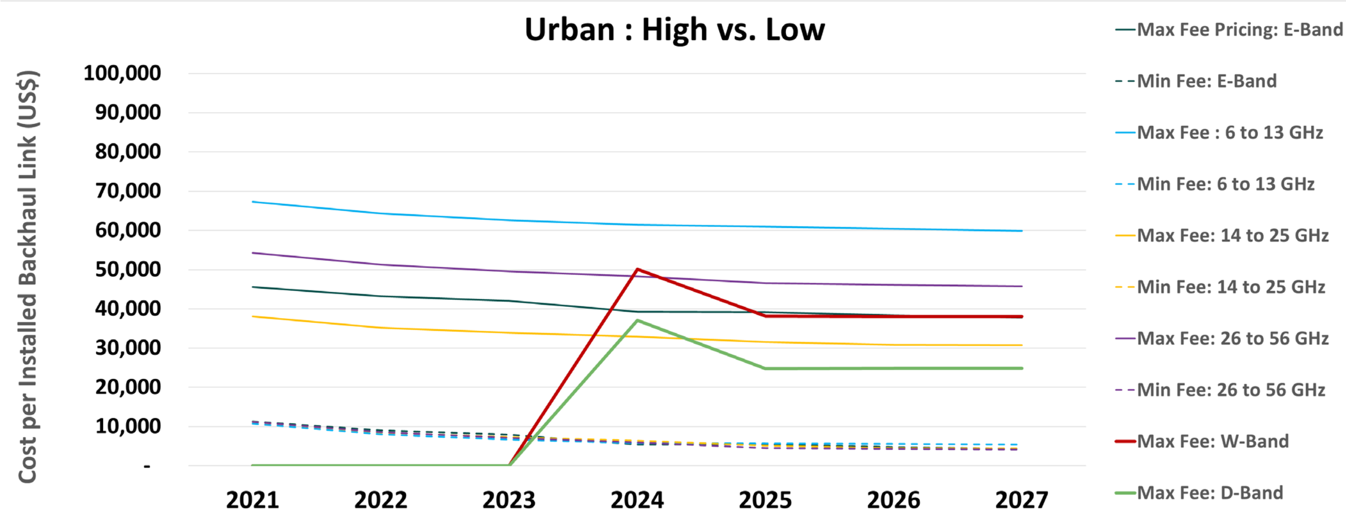
Figure 40. Comparative Analysis of Essential Mobile Operator Costs (CAPEX and OPEX), European Country, A1 Scenario

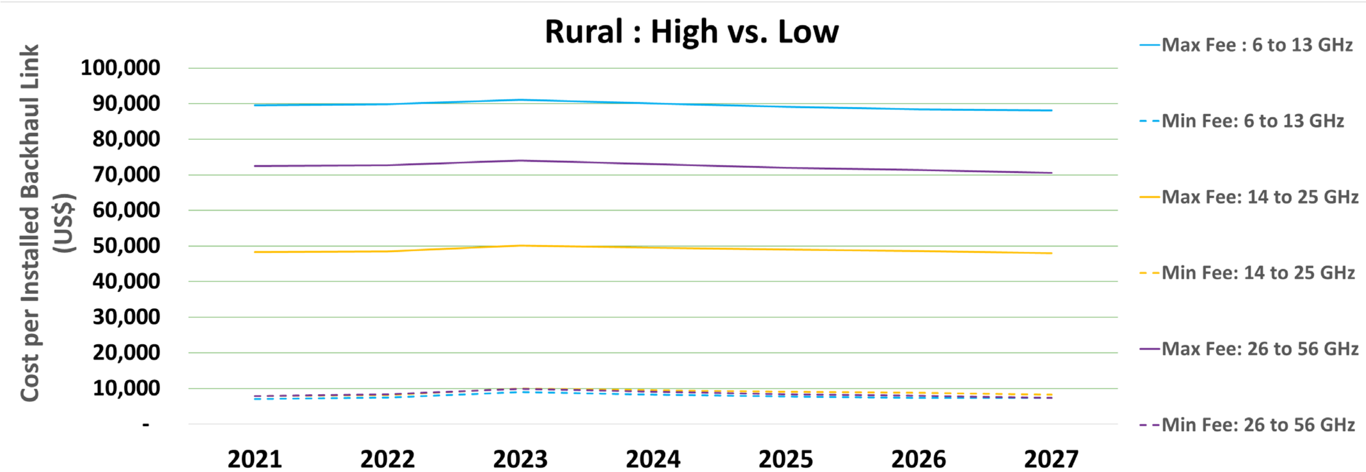


9.4.1. Backhaul TCO per Link by Platform

The impact of spectrum fees on TCO for the operator can also be seen in the TCO per backhaul link on a per platform basis, see Figure 41.

Figure 41. Urban and Rural Developed Market (A Series) TCO Cost per Link: High versus Low Comparison





The charts in Figure 41 above reflect the TCO inclusive of CAPEX, as well as OPEX due to spectrum fees and site rental/utilities for the urban and rural domains. The continuous lines are based on the maximum spectrum fees, while the dotted lines are based on the minimum spectrum fees. In the minimum *versus* maximum scenarios, CAPEX and OPEX (Other) were kept identical, it was just the spectrum fees that were varied.

It can, therefore, be seen that there are some quite significant differentials between the low and the high TCOs based on spectrum fees. In the case of E-band (urban), TCO cost per link when using the high spectrum price is 4X higher than TCO cost per link using low spectrum price in 2021. By 2027, it is 8.7X higher. In the case of the low microwave 6 GHz to 13 GHz tranche of spectrum, there was a differential of 12.7X.

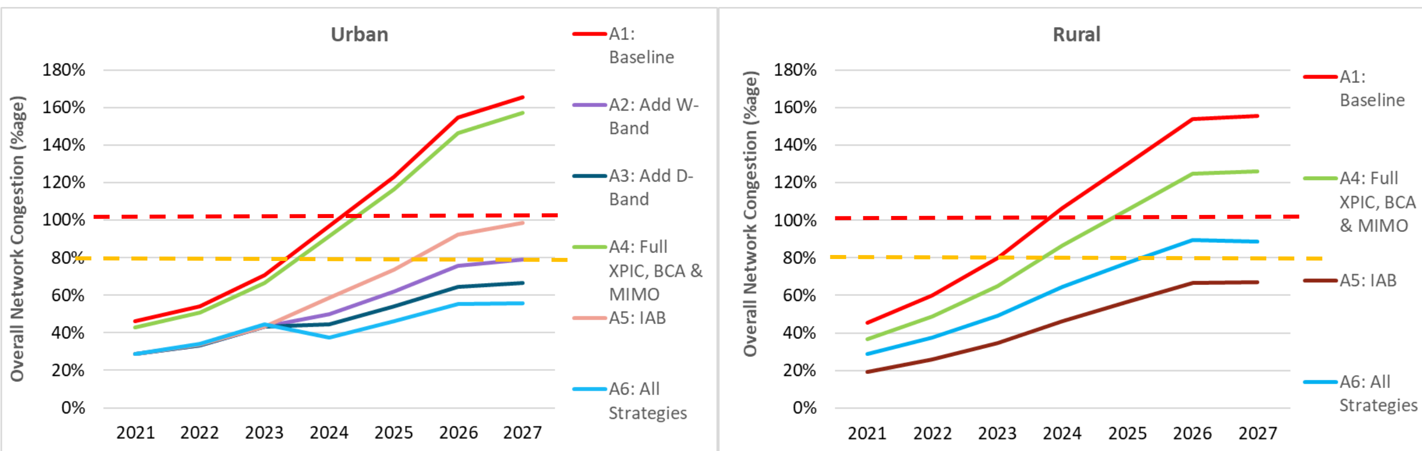
While spectrum fees do have a major influence on TCO, equipment costs will evolve due to economies of scale and innovation. Millimetre wave equipment for the D-band and W-band are anticipated to potentially enter the market by 2024/2025. In the case of the W-band, it is expected that the required Radio Frequency (RF) components could be made available earlier and could become more mature for usage sooner compared to the D-band. However, a number of Original Equipment Manufacturer (OEM) vendors are backing R&D for the D-band, so it is entirely possible that millimetre wave equipment for the D and W bands will become commercially available in the same time frame. Also, as production volumes increase, the TCO cost per link for the W-band will decrease from US$50,100 per link in 2024/2025 to US$38,100 in 2027. TCO cost per link for the D-band will decrease from US$37,100 per link in 2024/2025 to US$24,850 in 2027. The equipment cost will be influenced by the R&D design needed, as well as the levels of demand for the equipment (economies of scale) over time.

9.5. Impact on Network Congestion

The prime function of a mobile operator's infrastructure is to backhaul the burgeoning network traffic. Managing network traffic is a complex task. Traffic is not just a function of the number of subscribers on the network and what handset they have, but also time of day, location of the end user, weather/seasons, and even Internet fads and fashions. Therefore, operators need to provision their networks for peak busy hours. Also, operators have a number of strategies to constrain the ramp-up of traffic onto their network, but the danger is they downgrade the QoS experience for their end users. ABI Research discussed some of the network capacity parameters that shape a network in Section 7.2.

Figure 42 below show the overall network congestion capacity for the mobile operator in question in the model. For each scenario, "the operator" has made a number of backhaul solution choices that are applied to the 7-year forecast period.

Figure 42. Overall Network Congestion Ratio

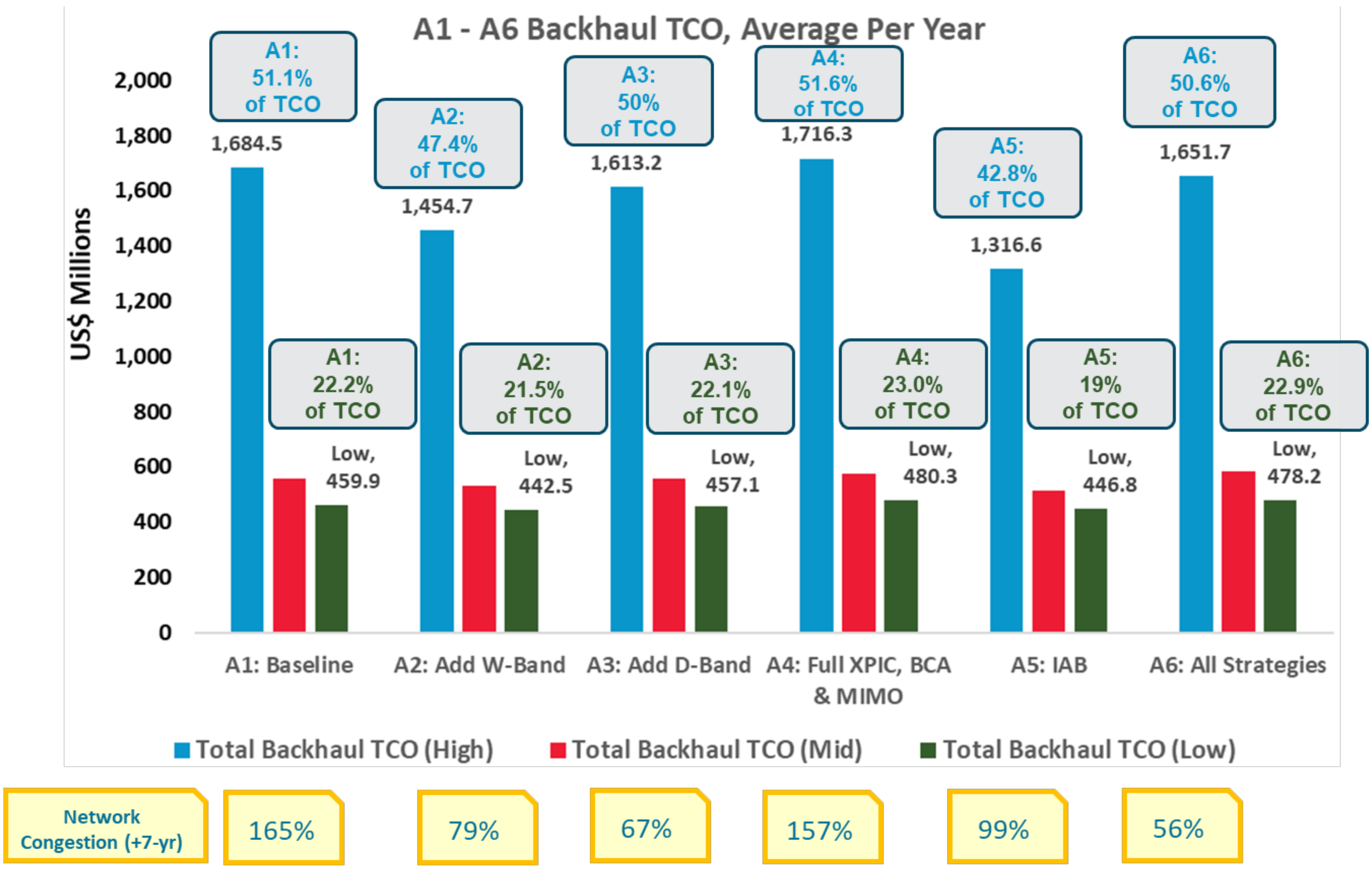


The key reference scenario is A1) baseline, which reflects the *status quo* conditions a typical "real world" operator is facing. For the first 3 years, the operator has more than ample network capacity to meet the QoS expectations of its end users. However, from 2024/2025, traffic volumes pass through the 100% threshold, resulting in substantially degraded experiences for its end users. Implementing XPIC, BCA, and LOS MIMO (A4) also has minimal impact as XPIC and BCA were being applied for many of the default deployments in the baseline (A1) scenario. Deploying D-band or W-band backhaul solutions substantially helps to keep traffic within healthy thresholds.

Fundamentally, scenario A6), all strategies, is the most telling. Deploying additional backhaul links using the E-band and/or the D and W bands, in addition to making the maximum use of the latest technical solutions, such as XPIC, BCA, and LOS MIMO, is necessary to manage overall traffic. IAB is a standout. On the face of the analysis, it can manage traffic throughout the forecast period, but it comes close to 100% congestion by 2027. It is particularly effective in the rural domain. The caveat is that operators would not deploy IAB on such an extensive scale as ABI Research has done so in this report. However, it could be useful for specific urban and rural scenarios.

9.5.1. Conclusions for Market Series A

Figure 43. Developed Market Series A: Backhaul-Related TCO, Average per Year



A1 Baseline Scenario: A1, the baseline scenario, reflects the current operational parameters for backhaul deployment for a mobile operator where the low, mid, and high spectrum fees demonstrate the sizable impacts of spectrum pricing over the overall backhaul TCO. Using the low spectrum pricing in the A1 baseline scenario would make backhaul TCO 22% of the overall TCO, while inputting high pricing would drastically increase the backhaul TCO to 51% overall TCO. In terms of traffic congestion, the A1 baseline reaches the 100% threshold by 20x and by the end of 2027, would have reached 165%. Of course, ABI Research is testing an MS Excel-based traffic and TCO model to assess the consequences of operational decisions. In the “real” world, operators would be managing their traffic on a yearly, if not quarterly basis.

For all the scenarios, TCO per link for rural is higher than urban due to the additional number of “cascaded” backhaul links needed. Furthermore, backhaul links tend to use the lower microwave links that have higher per MHz frequency costs and less capacity.

A2) Add W-Band Scenario: W-band’s wide channels (of 500 MHz to 2 GHz) will boost data throughput and is suitable for use cases with increased link density and demanding capacity requirements, where E-band is highly exploited or when E-band’s availability is limited. In the TCO model, a “typical” W-band channel size was assumed to be 1 GHz. The W-band is expected to have a light licensing regime and low spectrum fees per MHz structure.

A3) Add D-Band Scenario: D-band’s development trajectory is similar to W-band’s in many respects. Despite its higher frequency band status (130 GHz to 175 GHz), it does seem to have wide support from the infrastructure vendor community. Its commercial value is the very large channel sizes (2 GHz to 4 GHz), as well as a similar licensing regime and fee structure as the W-band. In the model, ABI Research used 2 GHz as a “likely” channel size, especially given the overall spectrum available.

The D-band and W-band scenarios were the most effective in managing traffic. Indeed, by the end of 2027, the D-band congestion threshold stood at 67%, while the W-band scenario stood at 79%. The D-band has a slightly better traffic management profile because the channel sizes were set at 2 GHz, whereas the assumed W-band channels were set at 1 GHz. The TCO profiles also reflected the traffic management capacities of the two solutions. Both the D-band and the W-band solutions make for efficient traffic management that reduces the needs for additional lower capacity and lower frequency links. Therefore, the TCO profiles are lower than the A1) baseline, but D-band (A3) had higher costs due to the larger amounts of spectrum purchased (2 GHz *versus* 1 GHz).

A4) Combined XPIC, BCA, and LOS MIMO Scenario: In this scenario, ABI Research attempted to see if a heavy-duty technology-centric approach could help manage traffic throughout the forecast period. Channel bonding was deployed between links in the 14 GHz to 26 GHz and E-Band in the A1) baseline scenario, but in the A4) scenario, XPIC, BCA, and 2x2 LOS MIMO were deployed. The gains from the technology-centric approach were constrained because XPIC and BCA were deployed in the A1) baseline scenario. As to be expected, the TCO profile for the technology-centric approach was higher than the baseline scenario due to the additional value of equipment on-site. These backhaul technologies are invaluable, and it is anticipated that additional capacity gains will be achieved, but mobile operators have already been fairly proactive with their upgrades when the life cycle of the existing equipment, ROI, and available funds for new equipment arises. Therefore, operators do need access to new spectrum to manage future traffic requirements.

A5) IAB Scenario: For urban macro cells and urban rooftops, the capacity of IAB-enabled cell sites was insufficient to meet the backhaul capacity needs of the 5G community. However, for the rural scenario, macro cell site rooftop and small cell locations were considered viable for IAB. For the purposes of the modelling exercise, where IAB is considered viable, ABI Research applied IAB in order to generate an unequivocal TCO and traffic management perspective. Regarding network congestion, the solution does keep traffic below the 100% threshold throughout the whole period, but in reality, QoS would start to diminish from 2025, plus it is likely the repurposed cellular antennas acting as backhaul links may not have the real-time, dynamic capacity to fully address all scenarios. It is also likely that IAB is deployed in niche locations where there is a need to reduce TCO to make the cell site commercially viable (*e.g.* for a remote community) or as a short-term solution.

A6) All Strategies: The combination of spectrum tools and technological enhancements leads to the most substantial reductions in overall network congestion throughout the forecast period. Fundamentally, mobile operators need a range of tools to manage their traffic in the 5G era.

9.6. Developing Market TCO Analyses

It is also essential to assess the impact of 5G on backhaul traffic for developing markets. As seen with the evolution to 4G, the innovation cycle continues to speed up. All markets have realized the integral nature that mobile communications play in society and the economy. For the chosen developing market, a large African country was selected as a representative market for the challenges of backhauling traffic from a mixture of macro cell, rooftop, and small cell deployments in both urban and rural settings.

9.6.1. Developing Market Scenarios

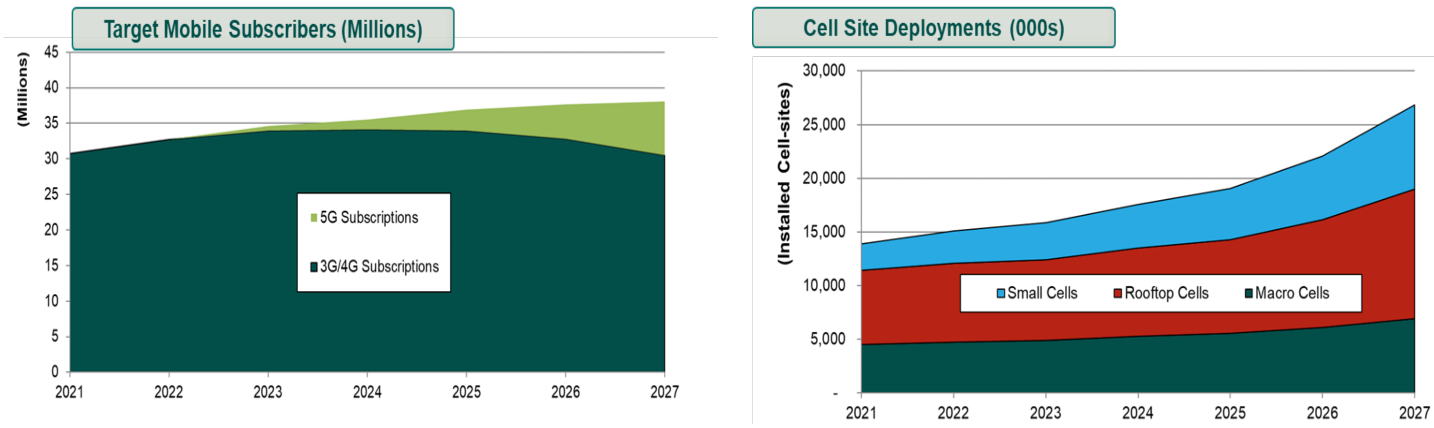
For the African country cellular model, underlying assumptions to dimension the network included:

- **Target Mobile Subscribers**: 5G subscribers will grow from 0.7 million in 2023 to 7.6 million in 2027. Conversely, 3G/4G subscribers will decrease from 34.1 million subscribers in 2023 to 30.5 million by 2027.

- **Cell Site Deployments**: Total urban cell sites will increase from around 13,900 in 2021 to 26,800 in 2027 (at a CAGR of 12.1%). Small cell sites will experience the highest pace of growth (CAGR of 21%), expanding from 2,500 sites in 2021 to 7,800 sites in 2027.

- **Target Mobile Operator Traffic**: Total traffic will grow from 236 petabytes annually in 2021 to 1,740 petabytes in 2027.

Figure 44. Developing Market, Africa, Underlying Assumptions



For the developing market, a series of scenarios were tested in the model to assess the impact of various spectrum and technology solutions on the capacity and TCO for the mobile operator.

9.6.2. B1) Developing Market, Baseline Scenario

The purpose of the B1) baseline scenario is to set up a reference set of output analysis to compare the subsequent additional scenarios (B1 to B4). Therefore, the baseline scenario is intended to apply "current market conditions" over the next 7 years. The baseline should reflect the spectrum and technology choices of a typical operator in the African country market. Only <6 GHz, lower and mid microwave bands are deployed. No 26 GHz to 56 GHz high microwave, E, V, W, or D bands were deployed. However, "resilience-based" XPIC and BCA were deployed. Urban and rural input assumptions were modelled for all the markets, with the exception of B2, for which only backhaul assumptions for urban scenarios (macro cell, rooftop, and small cell) were varied.

Disposition: Fibre-optic deployment is ramping up, but it is often only found in the large urban centres in central business districts or more up-market residential neighbourhoods (12% in 2021 but growing to 19% by 2027). It should be noted these percentage units applied to the overall installed base of cell sites, which grows from 13,900 in 2021 to 26,800 in 2027.

The backhaul links deployment profile for IAB Baseline scenario, along with all the other scenarios, can be seen in Figure 21, in Section 6.2.

9.6.3. B2) Developing Market, Africa, Augmenting with E-Band

For the second scenarios, B2), the principal assumptions of the baseline model are kept, such as cell site deployments, subscriber adoption, and traffic generated. Furthermore, existing fixed and wireless backhaul link trends, where reasonable, were kept; for example, fibre-optic deployment and long distance backhaul links, as well as respecting the life cycle of existing backhaul equipment. Where it was appropriate, new cell sites, mostly small cell and rooftop, were provisioned with the E-band or where legacy cell sites came to the end of their existing equipment life cycle and E-band equipment was suitable. The purpose of the E-band backhaul equipment is to anticipate the build-up of traffic coming from 4G and, increasingly, 5G subscribers in the more populated urban areas serviced by rooftop and small cell sites.

Disposition: By 2027, E-band was deployed on 17% of urban backhaul links, from an initial starting point of 13% in 2021. E-band spectrum (500 MHz channels) has been made available for licensing since 2017, but it has not been deployed in many developing markets, partly because operators are only starting to see the need for the solution, also regulators have been slow to release the spectrum and a number of operators are trying to evaluate the impact of rain fade on the E-band in their (often in tropical or sub-tropical) markets.

9.6.4. B3) Developing Market, Impact of XPIC, BCA, and LOS MMO

For scenario B3), the prime objective was to see if a "technology-centric" approach, where XPIC, BCA, and LOS MIMO are deployed aggressively, can address the long-term traffic management requirements of the mobile operator.

Disposition: Spectrum-wise, the deployments are identical to the B1) baseline scenario. However, in the low, mid, and high microwave bands that the operator has secured, XPIC and BCA were deployed. 2x2 LOS MIMO was deployed on macro cell sites and rooftop sites. No deployment has taken place in the E, W, and D bands. However, backhaul links were deployed in the high microwave band.

9.6.5. B4) Developing Market, Africa, Impact of IAB

In the developing market, the 3.5 GHz band was used for the integrated backhaul, but 4G LTE was used to provide the end-user coverage functions of the cell site.

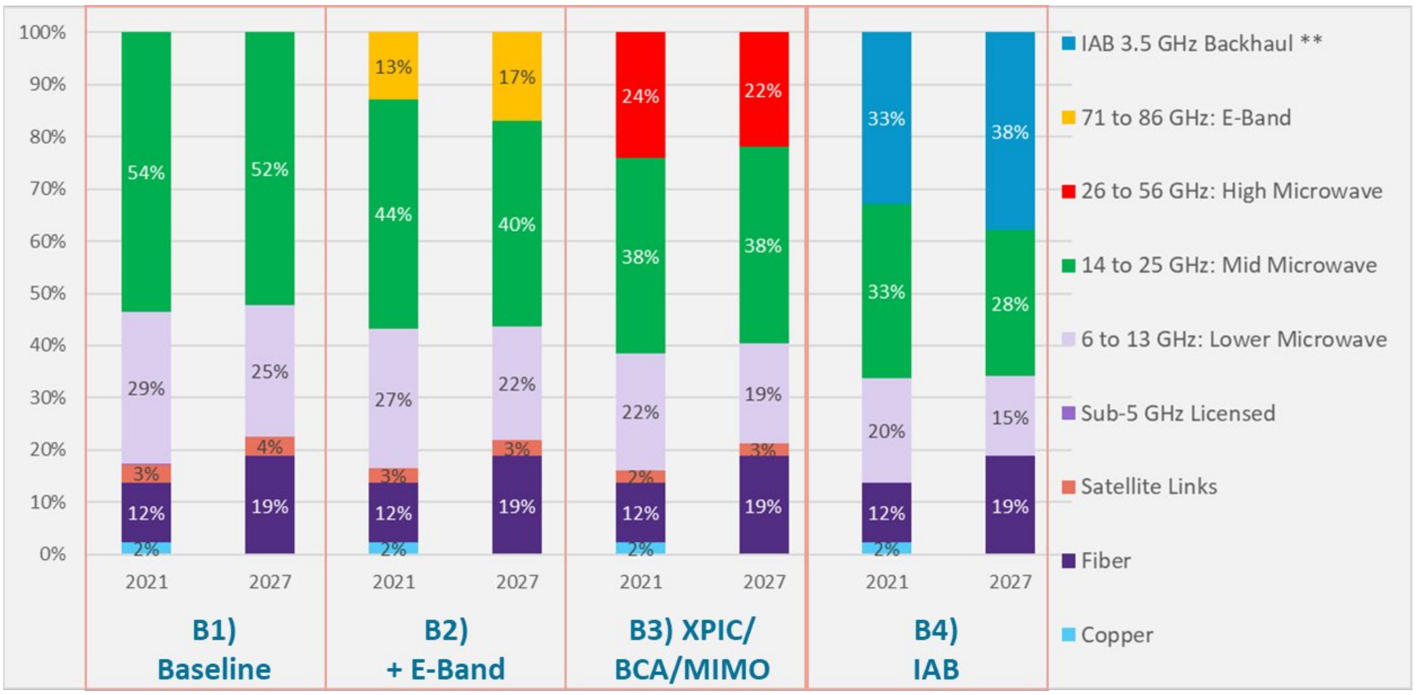
As noted in Section 3.4, IAB can be deployed in all 5G-related spectrum bands, although the C-band 3.5 GHz and the 26/28 GHz bands will be the most prevalent. While it is feasible that operators use the 26/28 GHz band where they are unable to secure a fibre-optic link to the cell site, there is substantial versatility for IAB with the 3.5 GHz band. Cell site densification is likely to be lower in developing markets, therefore the 3.5 GHz band is likely to be a more versatile IAB solution for urban and rural scenarios.

Disposition: In the B series Africa country model, urban small cell scenarios, along with rural macro cell, rooftop, and small cell site scenarios, were considered to be suitable for IAB. All backhaul links from those cell sites were switched to IAB in order to clearly delineate the TCO and traffic management impact of IAB. This was for the purposes of the modelling, but in reality, operators would be more selective. The number of IAB backhauled cell sites grows from 33% in 2021 to 38% by 2027.

9.6.6. Aggregate Backhaul Links Deployed in the Model

Figure 45 provides an aggregate snapshot of backhaul links, on a percentage basis for 2021 and 2027, for all four scenarios for the developing African country analysis. In 2021, the backhaul links are serving 13,900 cell sites, but by the end of 2027, the cell site count increases to 26,800. In the respective urban and rural radio access domains, the links are backhauling traffic from microcell, rooftop, and small cells.

Figure 45. Backhaul Links Deployed by Aggregate Percentage, Series B1 to B4, African Country Operator, per Average Year



Note: The full data for the chart in Figure 45 can be found in Appendix 1. There is also additional commentary on the per cell site TCO and outlook. The disposition shown for a single operator and assumptions are set for the purpose to testing various scenarios.

9.7. Impact of Spectrum Fees

Similar to the developed market, it is clear the significant impact spectrum licensing fees can have on TCO expenses. The spectrum costs displayed above are based on the input **high** spectrum fees per MHz reported in Section 7.2, Spectrum Pricing Analysis. A summary of the **low**, **mid**, and **high** backhaul spectrum pricing points can be found Figure 46. The **low**, **mid**, and **high** buckets of spectrum fees were based on a weighting analysis on a per country basis for Africa.

Figure 46. Developing Market Spectrum Pricing Assumptions, Sourced from African Markets, US$ per MHz PPP-Adjusted

Frequency Segmentation	Lower	Mid	High
Sub-5.x GHz	51.42	66.84	141.34
6 GHz~13 GHz	42.07	54.41	121.15
14 GHz~25 GHz	32.72	42.57	94.99
26.5 GHz~56 GHz	28.04	32.92	50.30
71~86 GHz: E-Band	0.52	9.19	27.04
92~114 GHz: W-Band	0.37	3.68	8.11
130~175 GHz: D-Band	0.26	2.21	4.87

Source: ABI Research
W- and D-Band Pricing are extrapolated

The impact of these spectrum fees is lower than the developed market analysis, but they can still be a hefty operational cost for the mobile operator. In the case of the developed market, spectrum related OPEX can add up to 51% of TCO (A1) baseline). In the case of the African country market, the spectrum-related OPEX can weigh in at 34% of per-cell site TCO. By comparison, if the low spectrum pricing dataset is used, spectrum costs only incur 13% to 18% of per-cell site TCO.

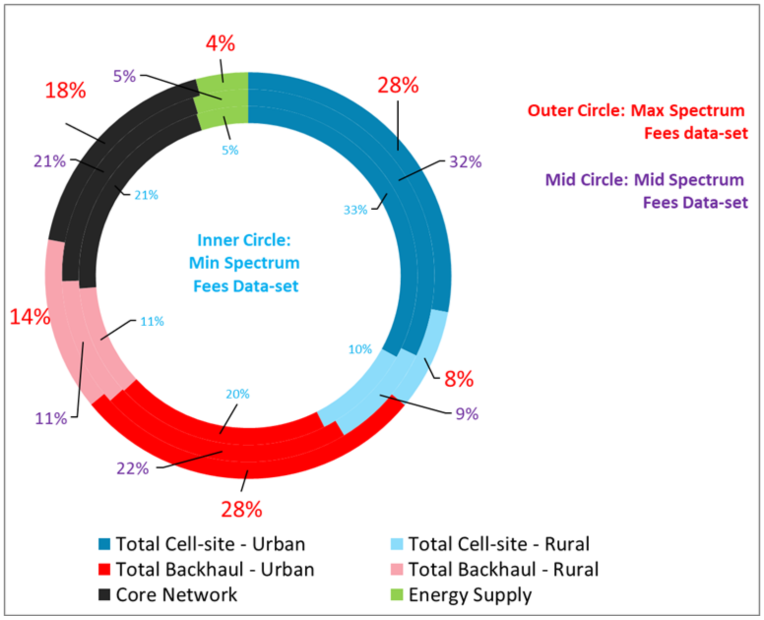
9.8. Impact on Total Network TCO

At a network level, the operator has to manage a range of radio access, core network, backhaul, and energy supply assets. While these are considered the "essential" network elements, operators also have to invest in data centres and cloud storage, as well as incur marketing and sales costs.

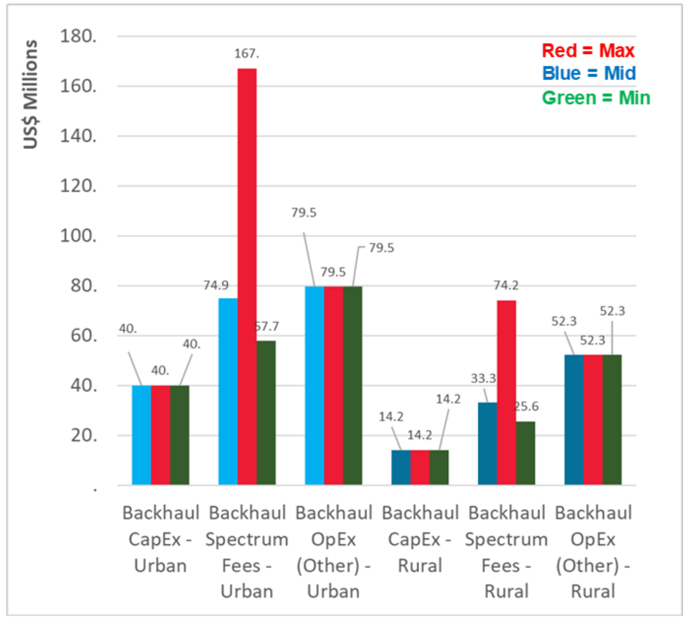
For an operator in a **high** spectrum fee country, the total urban and rural backhaul fees can jump to 39% of overall total network fees, whereas in a **low** spectrum fees market, backhaul costs equate to 31%. The chart on the right-hand side in Figure 47 shows the breakdown of expenses that relate to backhaul, as well as the degree to which spectrum fees can contribute to overall backhaul TCO.

Figure 47. Comparative Analysis of Essential Mobile Operator Costs (CAPEX and OPEX), African Country, B1 Scenario

Distribution of Total Network Spend: Based on Low, Mid and High Spectrum fees



Distribution of Backhaul TCO: Based on Low, Mid and High Spectrum Fees, Average per Year

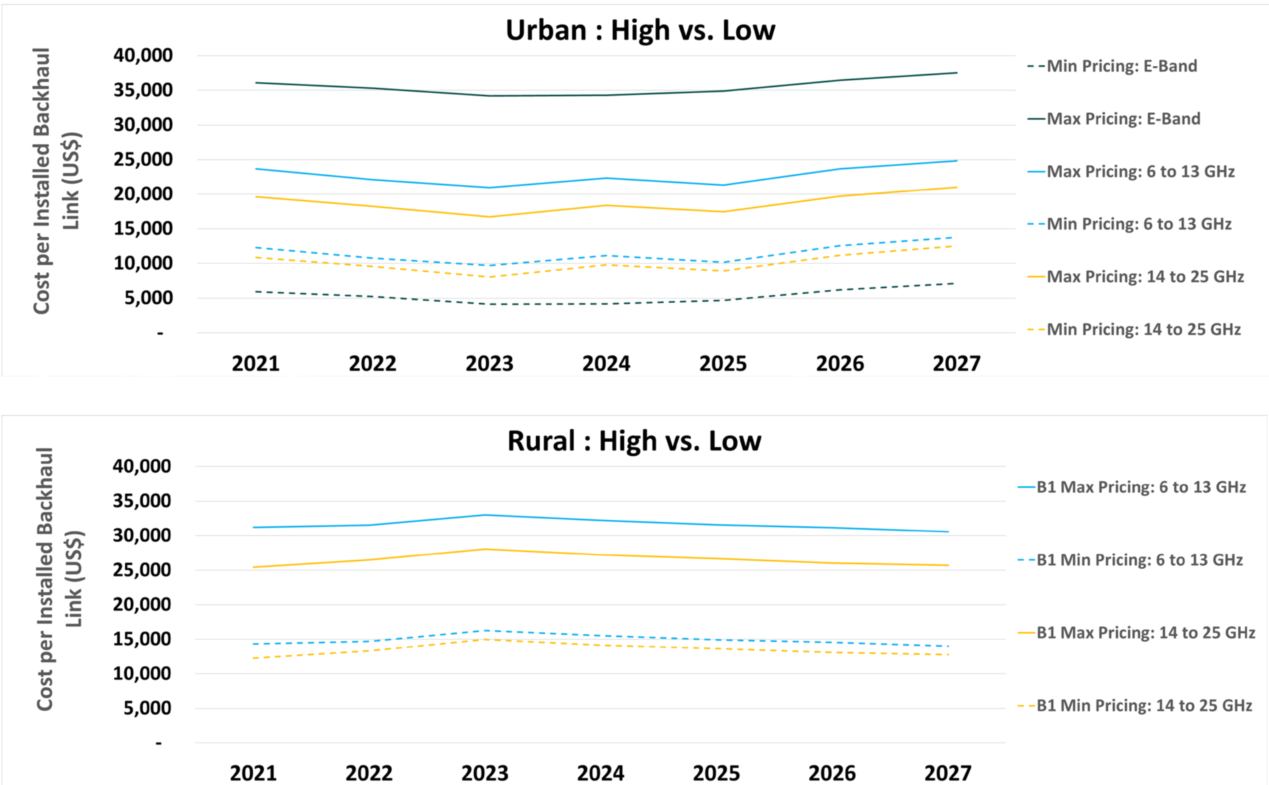


It is interesting to note that while the impact of spectrum fees on the B series mobile operator modelling exercise does not show quite the same degree of range from low to high (21% to 51%), the burden of spectrum fees is noticeably higher (31% *versus* 21%) for the developing market in Africa.

9.8.1. Backhaul TCO per Link by Platform

Another way to see the impact of spectrum fees on TCO for the operator is to compare the TCO per backhaul link on a per platform basis, see Figure 48 below.

Figure 48. Urban and Rural Developing Market (B Series) TCO Cost per Link: High versus Low Comparison



The charts reflect the TCO inclusive of CAPEX, as well as OPEX due to spectrum fees and site rental/utilities for the urban and rural domains. The continuous lines are based on the high spectrum fees, while the dotted lines are based on the low spectrum fees. In the high *versus* low scenarios, CAPEX and OPEX (other) were kept identical, it was just the spectrum fees that varied.

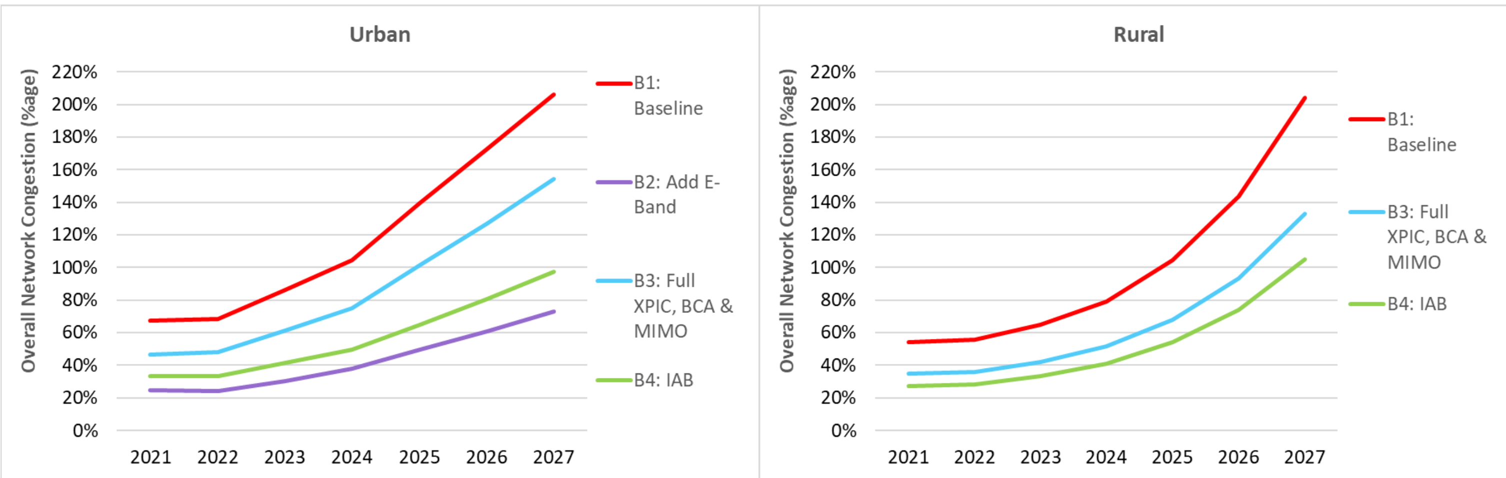
The most extreme variation in cost is witnessed in the E-band (urban) where there is a 6x differential. The mid microwave (urban), 14 GHz to 25 GHz, demonstrated a 1.7x higher ratio, while the low microwave (rural), 6 GHz to 13 GHz, showed a 2.2x weighting. While the variation in overall TCO is not as great as in the developed market European country market (Series A), developing market operators have significantly less margin to operate in, as the disposable income of their customers is much less.

9.9. Impact on Network Congestion

Similar to the developed market in Europe, ABI Research assessed the level of traffic on the mobile network within the model. For many operators in developing markets, the focus is on "coverage," but they cannot ignore the need to build out capacity. In many developing markets, the usage and habits of end users are not radically different from developed markets. The difference is the average revenue generated per user, which gives the operator less financial margin to arrange their investments. Further explanation of the network capacity parameters that shaped the modelling exercise for networks is in Section 7.2.

Figure 49 below show the overall network congestion for the mobile operator in question in the model. For each scenario, "the operator" has made a number of backhaul solution choices that are applied to the 7-year forecast period.

Figure 49. Overall Network Congestion Ratio, Developing Market, Africa



The key reference scenario is B1) baseline, which reflects the *status quo* conditions a typical "real world" operator is facing. By 2024, traffic volumes pass through the 100% threshold resulting in substantially degraded experiences for end users. Implementing XPIC, BCA, and LOS MIMO (scenario B3) does extend operating capacity by a year, but after 2025, traffic starts to explode.

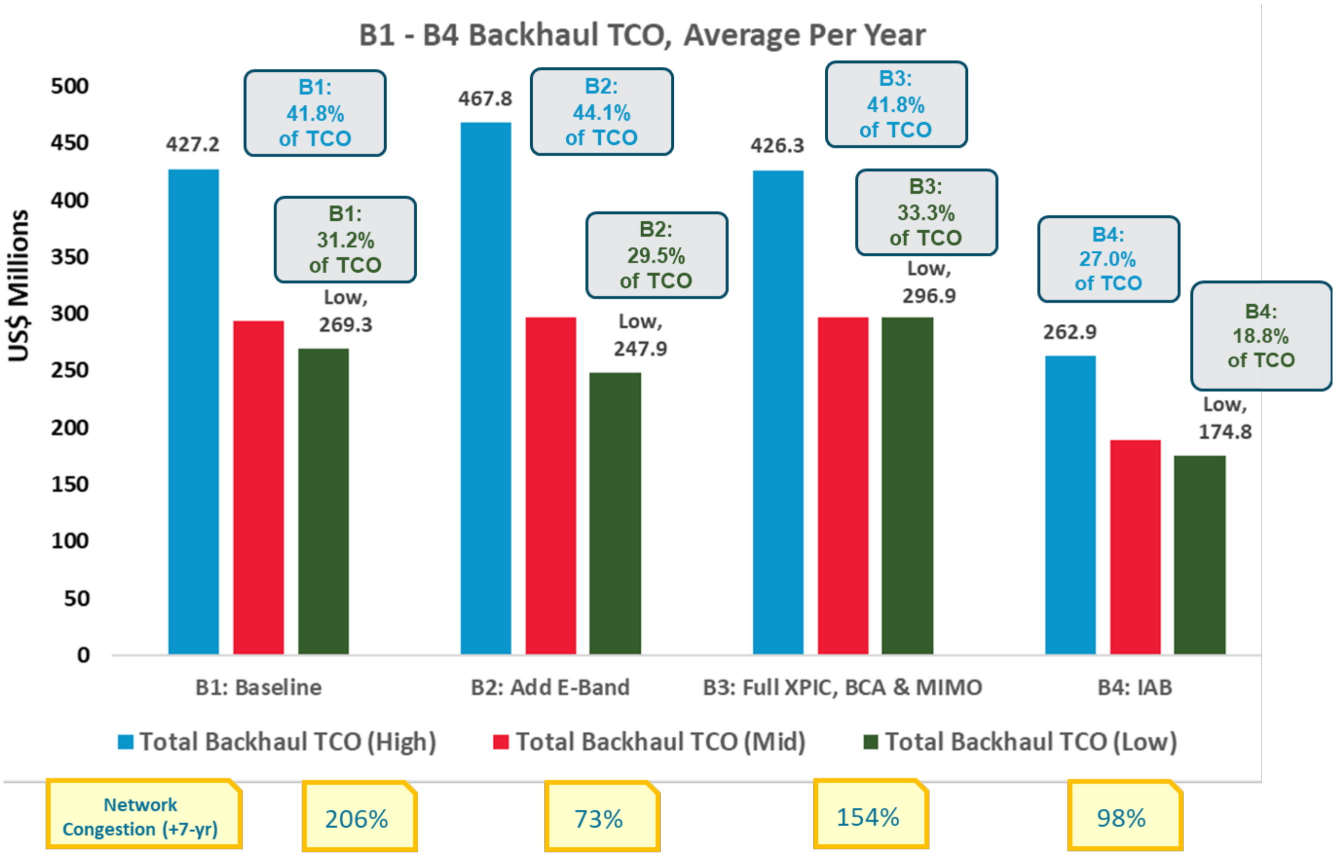
For B2), augmenting the network with E-band, E-band backhaul solutions were only deployed on urban rooftop and small cell sites and not in the rural domain. This is because rural cell sites in developing markets are more dispersed and, therefore, for most situations, the E-band is not suitable. Nevertheless, deploying E-band backhaul infrastructure (scenario B2) substantially helps keep traffic under the 100% threshold until 2027, but the operator is likely to run into difficulties thereafter. The operator may be able to manage future traffic by further densifying the network, introducing more rooftop and small cell installations. Also, more capacity could be generated through wider channel sizes. The model used a 500 MHz channel size, but the E-band can support 1 GHz channel. However, the regulator will need to take steps to widen these channels.

Similar to the developed market *analysis, IAB does appear to manage traffic*, *while also managing costs. The caveat is* that *operators would not deploy IAB on such an extensive scale*, *as ABI*

Research has done in this report. While IAB will be deployed in developed *markets, IAB does hold significant promise in* developing *markets, as rural communities are often widely dispersed but with low population densities in those clusters. While IAB could backhaul the traffic on a 3.5 GHz channel, the operator will more than likely wish to use 4G LTE for the local area coverage. Over time, the operator could use Dynamic Spectrum Sharing (DSS) to manage the traffic loads from 4G and 5G end users.*

9.9.1. Conclusions for Market Series B

Figure 50. Developing Market Series B: Backhaul-Related TCO, Average per Year



B1 Baseline Scenario: B1, the baseline scenario reflects the current operational parameters for backhaul deployment for a mobile operator where the low, mid, and high spectrum fees demonstrate the sizable impacts of spectrum pricing over the overall backhaul TCO. Using the minimum spectrum pricing in the A1 baseline scenario would make backhaul TCO 31% of the overall TCO, while inputting max pricing would drastically increase the backhaul TCO to 42% overall TCO.

In the B1 baseline scenario, the network maxes out its capacity by a very substantial margin (206%). In general, mobile operators in developing markets have less operational capacity than their developed market counterparts due to the fact that their network investment profiles are more constrained by the disposable incomes of their end users. Therefore, additional spectrum and technical solutions are needed to address future needs.

B2) Add E-Band Scenario: The assumptions of the baseline model remain; however, the backhaul links are upgraded with the E-band. The E-band does a very effective job of handling traffic. Overall TCO costs are driven up by the deployment of E-band equipment, which is more expensive on a per unit basis, but it comprehensively improves capacity. At the end of the forecast period, urban network congestion stood at 73%. However, rain fade in tropical countries and licensing availabilities may limit effectiveness.

B3) Combined XPIC, BCA, and LOS MIMO Scenario: In this scenario, ABI Research attempted to see if a heavy-duty technology-centric approach could help manage traffic throughout the forecast period. ABI Research concluded that while the technology-centric approach did noticeably boost capacity, it was not sufficient on its own for the entire forecast period, even with an additional high microwave tranche of spectrum used. For 5 out of the 7 years network traffic is kept below 100%, but then the congestion ratio increases to 154% by 2027. While there are some capacity gains *vis-à-vis* the B1) baseline scenario (154% *versus* 206% in 2027), the additional equipment costs cancel out from the cost savings from the overall backhaul links management.

B4) IAB Scenario: In developing markets, distances between cell sites are 20% to 30% greater. In this scenario, the CSP has used the 3.5 GHz for backhaul in either a shared access/backhaul strategy or relies on LTE frequencies for access coverage at the cell site. From the TCO model's perspective, IAB is comparatively effective at managing the operator's traffic loads (urban network congestion stood at 98% in 2027).

The 3.5 GHz band would give the operator reasonable propagation distances, but IAB should not be considered a backhaul "free lunch." While the operator does not need to install backhaul equipment at the cell site, there is an opportunity cost from allocating a cell-site antenna (and, therefore, its sector) for backhaul. However, if the cell site has a low-density population, IAB could be a viable solution. ABI Research has assumed these to be urban small cells situations, as well as rural macro, rooftop, and small cell sites. The model has taken 100% of cell sites in these locales for IAB to see what the impact would be on traffic management, as well as the overall TCO, but in the "real world," the operator would not take such a wholesale approach. IAB is most likely to be deployed on a selective basis where there was a strong need to control the overall TCO spending or as a short-term solution.

10. POLICY INSIGHTS AND RECOMMENDATIONS

Key Takeaways

- **Regulators**: This study suggests five key policy recommendations for regulators based on the research findings:

  I. Regulators must recognize microwave and millimetre backhaul as a critical component of national-level ICT strategy.

  II. Regulators need to be realistic and recognize that license fees that scale linearly with channel sizes serve as large financial burdens for operators. They should also incentivize spectral efficient methods (*e.g.*, XPIC, BCA, IAB, and LOS MIMO).

  III. There must be a regulatory push toward wider channel sizes to support 5G.

  IV. E-band will play an especially important role in all markets in the 5G era.

  V. Regulators should consult the industry to make the D and W bands available when needed.

Comprehensive, national-scale coverage is expedited through wireless microwave's immediacy of deployment, cost, and accessibility. Despite the continued momentum of fibre being the preferred choice for operators, wireless microwave solutions are much-needed fixtures in an operator's portfolio of backhaul solutions.

10.1. 5G Backhaul Insights and Recommendations

1) **Regulators must recognize microwave and millimetre backhaul as a critical component of national-level ICT strategy.** Balancing an enabling regulatory environment alongside network planning with commitments from operators to serve more people and to provide better quality of connectivity should drive policy formulation. As wireless backhaul technologies are critical for successful and timely 5G rollouts, spectrum regulation and pricing should motivate high volumes of wireless backhaul links deployments.

2) **Regulators need to be realistic and recognise that license fees that scale linearly with channel sizes serve as large financial burdens for operators. License fees should be adapted to the modern 5G capacity demands**. The current costs of spectrum per MHz are mostly based on outdated formulas when capacity requirements were not as pertinent; during periods when 3.5 MHz to 7 MHz to 14 MHz were the primary channel sizes of choice. Spectrum fees will need to drop exponentially in relation to frequency.

   Spectrum formulas must have components that can mitigate escalation of prices from larger bandwidth purchases and incentivise spectral efficient methods (*e.g.*, XPIC, BCA, IAB, and LOS MIMO). The pricing formulas surveyed do not have provisions that allow regulators to lower spectrum costs as operators buy more bandwidth. Accounting for spectrally efficient methods in pricing formulas will give operators more control over their network planning. Including and incentivising the use of technological innovations would provide tremendous assistance for operators that want to maximise its limited amount of spectrum. On the other hand, countries should not charge operators for the additional capacity that they have attained through technological innovations; for example, countries that charge double fees when operators use XPIC to double link capacity.

While some of the pricing formulas surveyed do include additional variables that allow for more context-based pricing based on different parameters of deployment (geography, exclusivity, power consumption), these variables are subjective and are still under the full discretion of the regulator.

PTP has been a tried and tested licensing solution for wireless backhaul, but it is cumbersome and encourages short-term planning and management, both on the side of the regulator and the operator. Many operators would prefer a hybrid block licensing approach that allows them to streamline their backhauling efforts.

3) **There must be a regulatory push toward wider channel size.** The number of backhaul links deployed in the lower microwave bands are likely to plateau, but they do have their utility in the network as they support comparatively long-distance transmissions that are useful for connecting islands to the mainland or for traversing expansive rural areas. The D-band and W-band do have tremendous capacity, but only certain downtown/urban cell sites will suit those bands. In other scenarios, a combination of low and high microwave bands or mid microwave bands with the E-band may be better suited for deployments.

   Aside from the migration toward higher microwave and millimetre wave frequencies, the need for more bandwidth also extends to widening existing channel sizes. The lack of spectrum supporting wide channel bandwidths has been identified as a potential bottleneck for microwave backhaul. Typical channel dimensions in the traditional microwave bands (identified as 6 GHz to 56 GHz in this analysis) should move toward higher channel sizes ranging from 56 MHz to 250 MHz. Higher millimetre wave frequencies in the E, W, and D bands should also have large channels to accommodate broader 5G use cases. As the 5G market matures, wider channel sizes would prove beneficial to mobile operators.

   The importance of capacity in 5G has already prompted some regulators to widen their backhaul channel allocations. CEPT's Electronic Communications Committee has put forward a recommendation for a maximum channel bandwidth of 224 MHz in the 42 GHz band, 2,500 MHz in the 60 GHz band, 4,500 MHz in the 70/80GHz, and 400 MHz in the 90 GHz band.

4) **Reinforce the role of E-band in backhaul.** The E-band will prove invaluable in the short to mid-term as a capacity booster for the operator. The E-band should serve the needs of operators up to 2025 in developed markets and up to 2028/2030 in emerging markets. However, 5G traffic will

generate heavy-duty traffic loads and as subscribers migrate to 5G, the traffic load on the network will build rapidly. From 2025, mobile operators and, therefore, their national regulators will need to legislate for D-band and W-band licensing.

ABI Research considers the E-band an essential spectrum "tool" not just for developed market operators, but also for emerging market operators. Data usage and mobile Internet aspirations in emerging markets are not far behind developed markets. 5G coverage may be more constrained to commercial business districts and dense residential neighbourhoods, but 4G LTE has a number of technological upgrades (*e.g.*, LTE-Advanced and LTE-Advanced Pro that can support Gigabit LTE). LTE will incrementally supplant 3G coverage even in rural areas. As LTE subscriber adoption and traffic levels mature, the E-band will be necessary to backhaul traffic.

While fibre-optic rollouts are continuing to take place in all emerging markets, throughout the forecast period, the level of fibre-optic penetration will be well behind developed markets. Emerging markets will need to resort to the D-band and W-band in the very long term (circa 2030), but E-band can address backhaul requirements from dense urban and suburban locales in the mid-term. This is further supported by backhaul vendor innovations that have seen E-band channel bonded with mid microwave band transceivers that can extend coverage from ~2 km to closer to 5 km.

5) **Promote BCA in backhaul.** BCA effectively creates wider channel sizes, which certainly helps with transmitting traffic. It can also help deliver a hybrid solution that combines a lower microwave channel (*e.g.*, 18 GHz band) that may have a narrow channel size, with the E-band that has very wide channel sizes. The resulting hybrid solution will then have mid-range transmit capabilities, but still deliver high data throughputs.

6) While innovative backhaul technologies, such as XPIC, BCA, and MIMO, have helped boost capacity, **operators will need access to additional spectrum bands**. Mobile operators have already been fairly proactive with their upgrades when the life cycle of the existing equipment, ROI, and available funds for new equipment have materialized.

7) **A concerted coordination of efforts, consultations, and awareness of the D-band and W-band.** Building legislative momentum for spectrum policy can take time in most countries. In fact, CEPT has already defined regulation for these bands since 2018. If the D-band and W-band are to be ready for the 2025 to 2027 timeframe, steps need to be taken in the 2021 to 2023 timeframe. By 2022, most regulators should be able to gain insight into how 5G is gaining traction worldwide, as well as within their own markets.

   Opening up and using the W and D bands would be instrumental in satisfying the exponential increase in data consumption of a 5G network. While the prominence of E-band millimetre wave frequencies would remain through 2027, W and D bands would offer ultra-high capacity links through the GHz channels available in these bands. Operators and equipment manufacturers believe that the technology and regulatory environments for these bands are still in nascent stages.

A majority of equipment vendors have expressed a strong interest in the D-band over the W-band due to its larger swaths of contiguous spectrum and wider channels that can enable higher throughput. While the D-band may have larger channel sizes, it is likely its propagation distances will be slightly shorter than E-band and W-band backhaul deployments.

In either option, the spectrum fee and administrative framework for the D-band and W-band needs to be more in line with countries that have made light licensing available for the E-band. Operators do need to contribute to national building through their tax returns, but they also provide an essential communications utility for end users, businesses, and government. The licensing approach, therefore, needs to be proportionate and incentivize the mobile operator to take a long-term view on operator infrastructure investment. Operators are likely to need several hundreds, if not thousands of E-bands, and/or D-bands and W-bands to support their network densification efforts.

However, it should be acknowledged that real-world support from the worldwide operator community will reflect additional considerations, such as service providers' use cases, technology capabilities readiness, and the respective equipment costs.

11. APPENDIX 1: ADDITIONAL TCO NOTES

The sub-sections below contain additional notes regarding the TCO analysis.

11.1. Aggregate Backhaul Links Deployed in the Model

The figures below provide the full data for the charts in the figures found in Sections 9.2.7 and 9.6.6 for the developed market, Europe, series A and the developing market, Africa, series B.

Figure 51. Backhaul Links Deployed by Aggregate Percentage, Series A1 to A6, European Country Market, per Average Year

Total Backhaul Links	Units	A1) Baseline		A2) Boost E-Band & W-Band		A3) Boost E-Band & D-Band		A4) XPIC, BCA & MIMO		A5) Impact of IAB		A6) ALL Optimized	
Year		2021	2027	2021	2027	2021	2027	2021	2027	2021	2027	2021	2027
Copper	%age	1.8%		1.8%		1.8%		1.8%		1.8%		1.9%	
Fiber	%age	34.0%	44.0%	34.7%	44.0%	34.7%	44.0%	34.0%	44.0%	34.0%	44.0%	35.4%	44.0%
Satellite Links	%age	0.2%	0.4%	0.2%	0.4%	0.2%	0.4%	0.2%	0.4%			0.2%	0.4%
Sub-5 GHz Unlicensed	%age	0.2%	0.3%	0.2%	0.3%	0.2%	0.3%	0.2%	0.3%			0.2%	0.3%
Sub-5 GHz Licensed	%age	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%			0.02%	0.02%
6 to 13 GHz: Lower Microwave	%age	9.6%	5.1%	8.8%	4.0%	8.8%	3.9%	9.6%	5.1%	8.5%	4.2%	10.8%	5.6%
14 to 25 GHz: Mid Microwave	%age	20.2%	18.6%	16.1%	13.0%	16.1%	12.8%	20.2%	18.6%	14.2%	11.7%	17.8%	13.6%
26 to 56 GHz: High Microwave	%age	29.2%	27.1%	20.5%	15.4%	20.5%	15.2%	29.2%	27.1%	19.9%	15.2%	23.1%	16.5%
56 to 71 GHz: V-Band	%age												
71 to 86 GHz: E-Band	%age	4.9%	4.6%	17.7%	17.8%	17.7%	17.6%	4.9%	4.6%	4.9%	4.6%	10.6%	9.7%
92 to 114 GHz: W-Band	%age				5.2%								4.6%
130 to 175 GHz: D-Band	%age						5.9%						5.4%
IAB 26/28 GHz Backhaul **	%age									16.7%	20.3%		
Were Urban Assumptions Varied?		**Acts as baseline**		Applied to Urban		Applied to Urban		Applied to Urban		Applied to Urban		Applied to Urban	
Were Rural Assumptions Varied?		**Acts as baseline**		Rural kept static		Rural kept static		Applied to Rural		Applied to Rural		Applied to Rural	

Figure 52. Backhaul Links Deployed by Aggregate Percentage, Series B1 to B4, African Country Market, per Average Year

Total Backhaul Links	Units	B1) Baseline		B2) Boost E-Band		B3) XPIC, BCA & MIMO		B4) Impact of IAB	
Year		2021	2027	2021	2027	2021	2027	2021	2027
Copper	%age	2%		2%		2%		2%	
Fiber	%age	12%	19%	12%	19%	12%	19%	12%	19%
Satellite Links	%age	3%	4%	3%	3%	2%	3%		
Sub-5 GHz Unlicensed	%age								
Sub-5 GHz Licensed	%age	0%	0%	0%	0%	0%	0%		
6 to 13 GHz: Lower Microwave	%age	29%	25%	27%	22%	22%	19%	20%	15%
14 to 25 GHz: Mid Microwave	%age	54%	52%	44%	40%	38%	38%	33%	28%
26 to 56 GHz: High Microwave	%age					24%	22%		
56 to 71 GHz: V-Band	%age								
71 to 86 GHz: E-Band	%age			13%	17%				
92 to 114 GHz: W-Band	%age								
130 to 175 GHz: D-Band	%age								
IAB 26/28 GHz Backhaul **	%age							33%	38%
Urban Scenario Varied?		**Acts as baseline**		Applied to Urban		Applied to Urban		Applied to Urban	
Rural Scenario Varied?		**Acts as baseline**		Applied to Rural		Rural kept static		Applied to Rural	

11.2. Developed Market, Europe (Series A) per Cell Site TCO and Outlook

Figure 54 below provides the annual average blended capital and operational spend per existing cell site, including macro, rooftop, and small cells, across the urban and rural radio access domains. A proportion of the cell sites are new deployments, while the majority will be up and running (on average, 93%). Note the swap-out of equipment due to wear and tear replacement has been excluded. The CAPEX and OPEX incurred by the operator for the BTS radio access equipment and the backhaul CAPEX and OPEX were divided by the number of cell sites serviced and then averaged over the 7-year period to derive a per cell site average yearly TCO. Both for cell site and backhaul, OPEX generates a much larger share of TCO, as every cell site installed incurs maintenance fees, tower management (or landlord fees) fees, fees due to utilities, *etc*.

Regarding the backhaul CAPEX and OPEX, the TCO reported is a "blend" of all the backhaul solutions deployed across the network by the operator. This includes fibre-*optic, microwave,* millimetre *wave, etc. However,* fibre-*optic and satellite, along with some of the marginal backhaul solutions*, *such as sub-6 GHz backhaul and unlicensed backhaul*, *were kept static across the six scenarios. The cost components for the various backhaul solutions can be found earlier in the report, in Section 9.1.*

Figure 53. Typical Operator per Cell Site TCO Stack, Series A1 to A6, European Country Market, per Average Year

Average Per Year TCO (with Maximum Spectrum Fees)	Units	A1) Baseline Scenario	A2) Boost E-Band & W-Band	A3) Boost E-Band & D-Band	A4) Impact of XPIC, BCA & MIMO	A5) Impact of IAB	A6) ALL Optimized Backhaul Strategies
Urban Total BTS - CAPEX	US$	7,065	7,065	7,065	7,065	7,425	7,065
Urban Total BTS - OPEX	US$	11,936	11,936	11,936	11,936	12,304	11,936
Backhaul Links CapEx - Urban	US$	2,267	2,230	2,301	2,581	2,040	2,551
Backhaul Links Spectrum Fees - Urban	*US$*	*22,643*	*18,541*	*21,450*	*22,911*	*18,748*	*21,577*
Backhaul Links OpEx (Other) - Urban	US$	4,825	5,217	4,773	4,870	4,657	5,413
TCO Stack per Cell-site - Urban	**US$**	**48,736**	**44,989**	**47,525**	**49,364**	**45,175**	**48,541**
Rural Total BTS - CAPEX	US$	8,719	8,719	8,719	8,719	10,206	8,719
Rural Total BTS - OPEX	US$	11,483	11,483	11,483	11,483	13,851	11,483
Backhaul Links CapEx - Rural	US$	3,881	3,882	3,882	4,547	1,416	4,505
Backhaul Links Spectrum Fees - Rural	*US$*	*43,999*	*34,553*	*43,712*	*43,712*	*-*	*43,456*
Backhaul Links OpEx (Other) - Rural	US$	14,019	14,020	14,020	14,020	8,680	13,999
TCO Stack per Cell-site - Rural	**US$**	**82,101**	**72,657**	**81,816**	**82,482**	**34,152**	**82,162**
Maximum Spectrum Fees of Cell-site TCO	**%age**	**51%**	**45%**	**50%**	**51%**	**24%**	**50%**
If Minimum Spectrum Fees of Cell-site TCO Applied	**%age**	**3.6%**	**2.7%**	**3.6%**	**3.5%**	**1.1%**	**3.7%**

Source: ABI Research Note: "Average" reflects Macro, Rooftop & Small Cell sites, installed & new builds

Across all the scenarios, the backhaul TCO cost per link for rural is substantially higher than for urban due to the additional number of "cascaded" links needed. Plus, on the cell site side, the rural domain has a larger ratio of macro cells. Spectrum fees for the rural scenario are higher per link than urban due to the additional hops needed.

The cell site costs were essentially the same across all the scenarios, with the exception of scenario A5), assessing the impact of IAB. Radio access-related expenses are increased due to the required management of traffic over the IAB link, as well as configuration of antennas. IAB also has reduced costs due to the reduction in associated fees from the urban small cell, the rural microcell, rooftop, and small cell sites being switched to IAB. In reality, operators would not migrate these cell site domains wholesale to IAB. It was, however, necessary to assess the IAB impact on TCO and on network capacity.

The impact of the D-band and W-band does not have a significant impact on the overall TCO for the operator, although as the overall network congestion analysis shows, the deployments can have a positive impact on managing traffic in the latter half of the forecasts.

W-band spectrum is incrementally above the E-band, with many of the same propagation characteristics, but with channel sizes of 500 MHz to 2 GHz. Its commercial value is the very large channel sizes, light licensing regime, and low spectrum fees per MHz issued. Some observers advocate that the W-band is potentially seen as a "natural" extension to the E-band, which helps with R&D cost management.

D-band spectrum is substantially above the E-band but seems to have substantial vendor support and very substantial (2 GHz to 4 GHz) channel sizes. The solution could be potentially used in LOS mesh situations in downtown urban areas. D-band spectrum is only likely to be commercially used in the 2025 timeframe.

The A5) scenario favours a technology-centric, rather than a spectrum-centric approach to managing traffic. It should be noted that XPIC and BCA were deployed in the A1) baseline scenario as those two technologies are currently available to today's operators. However, in the A4 scenario, XPIC and BCA have been deployed. Furthermore, 2x2 MIMO also contributed to increased capacity.

11.3. Developing Market, Africa (Series B) per Cell Site TCO and Outlook

Figure 55 below provides the annual average blended capital and operational spend per existing cell-site – inclusive of macro, rooftop and small cells – across the urban and rural radio access domains. A proportion of the cell-sites are new deployments while the majority will be up and running (on average 91%). Additional notes regarding the benchmark methodology can be found in Section 9.6.

Figure 54. Typical Operator per Cell Site TCO Stack, Series B1 to B4, African Country Market, per Average Year

Table XX. Typical Operator Per Cell-site TCO Stack, Series B1 - B4 Africa Country Market, Per Average Year					
Average Per Year TCO (with Maximum Spectrum Fees)	**Units**	**B1) Baseline Scenario**	**B2) Boost with E-Band**	**B3) Impact of XPIC, BCA & MIMO**	**B4) Impact of IAB**
Urban Total BTS - CAPEX	US$	7,684	7,684	7,684	8,131
Urban Total BTS - OPEX	US$	11,904	11,904	11,904	12,275
Backhaul Links CapEx - Urban	US$	2,753	2,694	3,387	2,295
Backhaul Links Spectrum Fees - Urban	*US$*	*11,492*	*15,053*	*11,501*	*9,259*
Backhaul Links OpEx (Other) - Urban	US$	5,470	4,761	4,975	3,448
TCO Stack per Cell-site - Urban	**US$**	**39,304**	**42,096**	**39,451**	**35,408**
Rural Total BTS - CAPEX	US$	8,719	8,719	8,719	10,206
Rural Total BTS - OPEX	US$	11,483	11,483	11,483	13,851
Backhaul Links CapEx - Rural	US$	3,457	3,457	4,545	648
Backhaul Links Spectrum Fees - Rural	*US$*	*18,096*	*18,096*	*18,607*	*-*
Backhaul Links OpEx (Other) - Rural	US$	12,752	12,752	10,420	3,540
TCO Stack per Cell-site - Rural	**US$**	**54,506**	**54,506**	**53,774**	**28,244**
Maximum Spectrum Fees of Cell-site TCO	**%age**	**29%**	**34%**	**32%**	**25%**
If Minimum Spectrum Fees of Cell-site TCO Applied	**%age**	**13.7%**	**13.0%**	**18.3%**	**5.6%**

Note: "Average" reflects Macro, Rooftop & Small Cell sites, installed & new builds

Source: ABI Research

TCO cost per cell site for rural is substantially higher than for urban due to the additional number of “cascaded” hops needed. Plus, a larger proportion of backhaul links are comparatively shifted to the more expensive low microwave frequencies. Another contributing factor for the higher rural per cell site TCO costs includes satellite backhaul for around 3% of cell sites. The up-front CAPEX costs of satellite are lower than fibre-optic/fixed wireless, but OPEX from pay-per-use traffic fees can generate 2.5X that of fibre-optic and almost 19X that of microwave. However, it should be acknowledged that satellite links are assigned on a dynamic basis where the satellite backhaul capacity can be “pooled” across a number of remote cell sites, which helps manage costs.

The provisioning of the E-band does drive up overall TCO per cell site but can be a potential game changer when it comes to managing increased loads of 4G LTE traffic, as well as 5G traffic. The

E-band, while it can only transmit in the range of 2 GHz to 3 GHz in a standalone capacity, does have the advantage of potential channel sizes of 500 MHz to 1 GHz. In the analysis, the TCO per installed backhaul link increased from US$14,230 in 2021 to US$15,300 in 2027.

The B3) scenario did not have a substantial impact on average per cell site TCO costs compared to the B1) baseline scenario, as XPIC and BCA had been deployed in the B1) scenario in many of the low and mid microwave channels. Furthermore, 2x2 MIMO also contributed to increased capacity. The overall average TCO cost per backhaul links increases to US$17,250 (2027) due to new BTS builds.

IAB has a lower cost profile because the backhaul spectrum fees are substantially reduced. For the purposes of the model, IAB was deployed on all urban small cells, as well as rural microcell, rooftop, and small cell sites. As mentioned in the A5) developed market commentary, it is very likely that IAB could be useful for specific sites where more traditional backhaul solutions may be costly. There are questions about IAB, such as reliability of connection as a "mass deployment solution."

11.4. Cell Site Cost Assumptions

Figure 55. Cell Site Cost Assumptions, TCO Model

Urban - Cell-site BTS Equipment		
Cost of Macro Cell Hardware $	US$	170,000
Cost of Rooftop Micro BTS Hardware $	US$	110,000
Cost of Small Cell BTS Hardware $	US$	35,000
Cost of BTS Installation		
Macro Cell $	US$	20,000
Rooftop Micro BTS $	US$	12,000
Small Cell BTS $	US$	8,000
Annual Maintenance Cost per Cell-Site		
Maintenance Cost - Macro Cell $	US$	17,100
Maintenance Cost - Rooftop Micro BTS $	US$	13,300
Maintenance Cost - Small Cell BTS $	US$	7,600

Rural - Cell-site BTS Equipment		
Cost of Macro Cell Hardware $	US$	150,000
Cost of Rooftop Micro BTS Hardware $	US$	90,000
Cost of Small Cell BTS Hardware $	US$	30,000
Cost of Installation (Baseline Scenario)		
Macro Cell $	US$	18,000
Rooftop Micro BTS $	US$	10,000
Small Cell BTS $	US$	7,000

Source: ABI Research

The GSMA and ABI Research wanted the TCO analysis to capture the CAPEX and OPEX of an end-to-end network. Therefore, while input assumptions for the backhaul domain could be varied, other network cost elements were factored in, but kept in a steady state. These included:

- **RAN**: Cell -site costs for base station equipment, masts, antennas, *etc*. for urban and rural locales were built into the model. Furthermore, cell sites were subdivided into macro, rooftop, and small cell configurations. These RAN cost elements were held as fixed components in the TCO model.
- **Core Network**: The TCO for the core network were not modelled in depth as it is beyond the focus of this project. Core network costs were kept as a fixed ratio to RAN costs. This allowed ABI Research to build a complete network TCO profile. Therefore, core network costs are steady state.

11.4.1. Backhaul Modelling Considerations

The exact details for each scenario can be found in **series A** (based on a representative large developed market in Europe, as well as the **series B** market based on a representative, large developing market in Africa.

Over time, the operator in the TCO model experienced the migration of subscribers from 4G to 5G and, where applicable, from 3G to 4G. This results in additional rollouts of cell sites as the operator maximises coverage and builds capacity to handle the growth in data traffic per user.

There are some considerations that need to be taken into account regarding the r*elationship between* access traffic generated *and* backhaul capacity. *ABI Research assumed that each cell site has "one" backhaul link*, *but the capacity of that link will vary. In the case of microwave/*millimetre *wave backhaul links*, *additional radios may be installed to boost capacity. This is reflected in additional CAPEX.*

Figure 56. Backhaul Cost Assumptions, TCO Model

Baseline TCO Model		
Wireless Backhaul Solutions	**OPEX: Share of Rental Fees + Misc per Site ($)**	**CAPEX: XPIC BCA & 2x2 MIMO ($)**
Sub-5 GHz Unlicensed **	5,000	**17,000
Sub-5 GHz Licensed **	5,000	**18,700
6 GHz - 13 GHz: Lower Microwave	5,300	30,300
14 GHz - 25 GHz: Mid Microwave	5,150	33,700
26.5 GHz - 56 GHz: High Microwave	5,150	33,700
56 GHz -71 GHz: V-Band	4,400	37270
71 - 86 GHz: E-Band	4,400	35,270
92 - 114 GHz: W-Band (2024)	4,160	32,900
130 - 175 GHz: D-Band (2024)	4,160	32,900
*** Excludes XPIC & 2x2 MIMO, 2% price decline will be applied*		
Source: ABI Research		

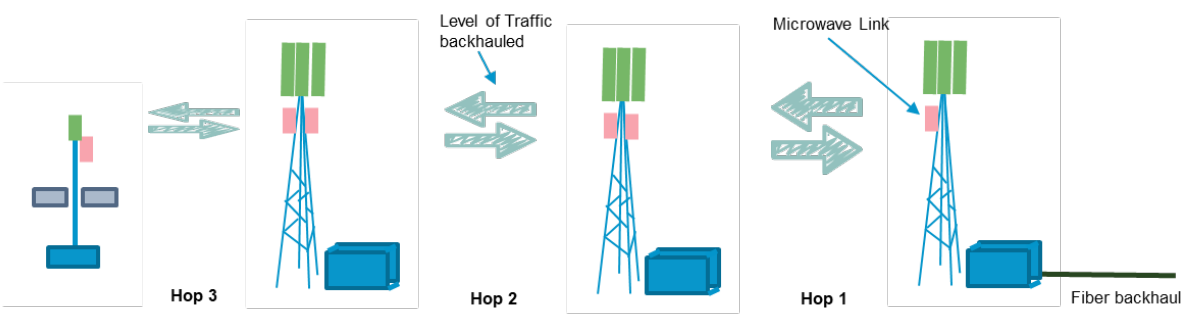
Other Backhaul Cost Assumptions TCO Model		
Other Backhaul Solutions		
Copper		
Initial CAPEX (Carrier-class Router)/Connection $	US$	5,000
Yearly OPEX/Connection $	US$	2,880
Fiber		
Initial CAPEX/Connection $	US$	30,000
Yearly OPEX/Connection $	US$	40,000
Satellite Links		
Initial CAPEX (VSAT Equipment)/Connection $	US$	500
Hub, Antenna & Installation (1 time cost) $	US$	750
Yearly OPEX (Pay as You Go Traffic)/Connection $	US$	100,800
Source: ABI Research		

Integrated Access Backhaul (IAB) Cost Delta to Existing Cell-site Expenses		
Urban		
Small Cell: 26/28 Equipment Delta	US$	8,950
Small Cell: 26/28 Equipment OpEx Delta	US$	1,350
Rural		
Macro Cell: 26/28 Equipment Delta	US$	18,500
Rooftop: 26/28 Equipment Delta	US$	16,300
Small Cell: 26/28 Equipment Delta	US$	8,950
Macro Cell: 26/28 Equipment OpEx Delta	US$	2,800
Rooftop: 26/28 Equipment OpEx Delta	US$	2,450
Small Cell: 26/28 Equipment OpEx Delta	US$	1,350
Note: Backhaul hardware is ZEROed out for IAB		
Source: ABI Research		

Furthermore, except for some backhaul links in the 7 GHz to 13 GHz band being used for long-haul transportation links, each backhaul "hop" also hosts cell site access equipment providing coverage. Through interviews with mobile operators and backhaul infrastructure vendors, the majority of backhaul links either are, or are evolving into, a "star" configuration. The central backhaul node then backhauls the traffic *via* a fibre-optic link. While at the end of each "hop" there is cell site access equipment, there are differences in the number of microwave/millimetre transceivers on each mast and in the amount of traffic each site has to manage. The cost of microwave/millimetre equipment is largely a function of the capacity of the microwave/millimetre radio.

Figure 57. No. Backhaul "Cascaded Hops" Required for Each Deployment Scenario, Backhaul Assumptions

	Urban (Ave)	Rural (Ave)
Macrocell	2	3
Rooftop	1.5	2.5
Small Cell	1	2



Source: ABI Research

A third consideration was that the mobile operator is using the optimal modulation scheme for the transmit distance and climate/weather conditions that the backhaul equipment must handle. The real-life data throughput will vary throughout the day and the seasons. ABI Research estimates the data throughput is 75% of the average spectrum allocated for backhaul in 2020 (GHz) as stated in Figure 58. It should also be noted that a Frequency Division Duplex (FDD) configuration was applied as it the most common arrangement, although Time Division Duplex (TDD) is also possible. FDD is preferred as it maximizes capacity and reduces interference.

Figure 58. Backhaul Links Capacity Assumptions, TCO Model

Max. Sustained Throughput, with XPIC, BCA (and MIMO in Upper Bands)	Spectrum Channel Size	Max. Sustained Mbit ps
Urban - Copper	n/a	25
Urban - Fiber	n/a	1,000
Urban - Satellite Links	Varies	50
Sub-5 GHz Unlicensed	80	270
Sub-5 GHz Licensed	40	27
6 GHz~13 GHz: Lower Microwave	56	270
14 GHz~25 GHz: Mid Microwave	56	378
26 GHz~56 GHz: High Microwave	112	540
56 GHz~71 GHz: V-Band	100	810
71~86 GHz: E-Band	500	5,400
92~114 GHz: W-Band	1,000	10,800
130~175 GHz: D-Band	2,000	27,000

Source: ABI Research

11.4.2. Backhaul Scenarios

The objective of each scenario analysis was to vary the spectrum and technology solutions deployed and assess the impact on overall network TCO and backhaul TCO, in particular. At a particular cell site, there is variability in the TCO (CAPEX plus OPEX) of the different backhaul solutions, but what is the aggregated impact of these options from a total network TCO point of view?

For the **A series developed market** (European country) and the **B series emerging market** (African country), a baseline scenario was set up to reflect a *status quo* approach. The *status quo* baseline scenario reflects a "typical" backhaul deployment architecture and investment that can handle the traffic requirements of 2019, but not necessarily the entire forecast period. The additional TCO scenarios in each series then evaluates different spectrum and technology options and assesses their impact on TCO.

11.4.3. Overall Network Congestion Calculation

In addition to calculating the TCO spending, both in terms of CAPEX and OPEX, ABI Research tracked and calculated the level of traffic congestion on the network. Coverage of the population is increasingly rolled out and subscriber adoption starts to build. Furthermore, end users migrate from 4G to 5G services. Additional cell sites are built to serve that traffic. The traffic is then backhauled through the various backhaul solutions that have been installed. ABI Research is, therefore, able to calculate the available capacity and the traffic load on the network. As a result, ABI Research could calculate the overall network congestion (as a percentage). The TCO model tested a number of spectrum and backhaul technology options (developed European country, series A1 to A6; and developing market, African country, series B1 to B4) across the forecast period.

There are limitations to this process, as ABI Research is striving to achieve “meaningful” and “unambiguous” results. For example, IAB was applied to all urban small cells, as well as rural macro, rooftop, and small cells, as IAB was considered not to have sufficient capacity to handle the backhaul needs of urban macro cell and rooftops. The reality is an operator should deeply embed IAB on a select number of cell sites. Furthermore, operators should review their traffic loading scenarios yearly and make the appropriate investments.

Nevertheless, the **overall network congestion percentage (reported at the “+3 year” and +7 year” marks) gives an index of the level of congestion the operator’s network is experiencing**. Once the index goes over 100%, there are going to be increasing periods of time when end users will experience a degraded Quality of Experience (QoE).

12. APPENDIX 2: SPECTRUM PRICING NOTES

12.1.1. Bangladesh Formula

Figure 59. BTRC per kHz/per MHz/Year Pricing and Power Charge Fee

Sl	Symbol	Frequency Range (Lower Limit Exclusive, Upper Limit Exclusive)	Charge per 1 KHz of Necessary Bandwidth of Emission/Year per Site^{-1} in Taka	PPP Adjusted
1	VLF	3-30 KHz	200	**6.269**
2	LF	30-300 KHz	200	**6.269**
3	MF	300-3000 KHz	200	**6.269**
4	HF	3-30 MHz	300	**9.403**
5	VHF	30-300 MHz	100	**3.134**
6	UHF1	300-1000 MHz	50	**1.567**
7	UHF2	1000-3000 MHz	30	**0.940**
8	SHF	3-16 GHz	20	**0.627**
9	SHF2 & EHF1	1-65 GHz	10	**0.313**
10	EHF2	65-300 GHz	1	**0.031**

	Weighted Average (Taka/MHZ)	PPP Adjusted ($/MHz)
Sub 5.x GHz	31.8	996.24

Power Charge Table for SHF 1, 2, and EHF:

(e) SHF 1, SHF 2 & EHF

Sl	*Output Power from the final stage of the Transmitter*	*Rate in Taka*
1	Less than 100 mW	500.00
2	100 mW~500mW	1000.00
3	500 mW~1 watt	1500.00
4	1 watt~3 watt	2000.00
5	3 watt~5 watt	3,000.00
6	5 watt~10 watt	5,000.00
7	10 watt~20 watt	10,000.00
8	20 watt~50 watt	20,000.00
9	Above 50 watt each additional watt or part thereof	2,000.00

Note 01: ***Power of a Radio Transmitter is referred to in accordance with class of emission specified in radio regulation annexed to the International telecommunication Union Convention.***

Note 02: ***In case of standby or supplementary transmitter, a quarter of the radio transmitter output power charge specified above shall be levied.***

Note 03: ***Transmitter power level indicated is exclusive of lower limit and inclusive of upper limit.***

12.1.2. Spain Formula

Spain's multi-variable across different deployment scenarios allow operators to pay for spectrum that is more commensurate with their usage and deployment type.

Figure 60. Spain Formula

Frequency Fee = [S (km2) x B (MHz) x (C1 x C2 x C3 x C4 x C5)] / 0.166386

In which:
S: value equals to "link length" multiplied by 1KM
B: Channel Bandwidth
C1~C5: values shown the right, represent the frequency congestion, area of usage, type of service etc.
0.166386: Fixed value, totally decided by government used to control the license fee

13. APPENDIX 3: "BLUE SKY" ALTERNATIVE BACKHAUL TECHNOLOGIES

This section includes excerpts from the project that were requested as research items by the GSMA Task Force but were considered outside the principal analysis of the project. These were Free Space Optical (FSO) and TV White Space (TVWS) technologies. After they were initially profiled, they were deemed not to be viable backhaul solutions for carrier-grade 4G/5G-related traffic.

13.1. Free-Space Optical

As previously explained, BCA involve pairing a traditional microwave frequency with a millimetre-wave frequency. This combination would leverage the advantages and negate the disadvantages of the respective physical properties inherent in traditional microwave frequencies (higher distance coverage, but lower capacity links) and the E-band (high capacity links, but vulnerable to rain attenuation). In terms of capacity performance, however, the traditional microwave (<1 Gbps) E-band (around 10 Gbps) hybrid solution would still be insufficient, as only a portion of the data transmitted would benefit from the resiliency of the lower microwave bands (not as susceptible to rain fade).

Figure 61. FSO and E-Band

FSO is an optical communication technology that can provide even higher capacity wireless transmissions. Visible or infrared light is modulated with the information bits and transmitted through the free space. The combination of **FSO** and the **E-band** demonstrates similar synergies that traditional microwave and e-band possess.

Besides higher capacity performance, FSO does not require spectrum licensing for operation and E-band licenses are relatively cheaper, as they are mostly either lightly licensed or unlicensed. While FSO links' distance coverage has been increasing due to growing evolution of FSO equipment vendors, these distances are still below what traditional microwave + E-band combinations can cover.

FSO, as mentioned, has certain distance limitations that prevent it from being integrated as a mainstream option for fixed wireless microwave backhaul. The main drawback of FSO systems is that signal transmissions are highly vulnerable to environmental factors, such as physical obstructions, temperature variations (scintillation), geometric losses, and atmospheric weather conditions; obstacles that would negatively impact availability rates.

13.2. TV White Space Technology

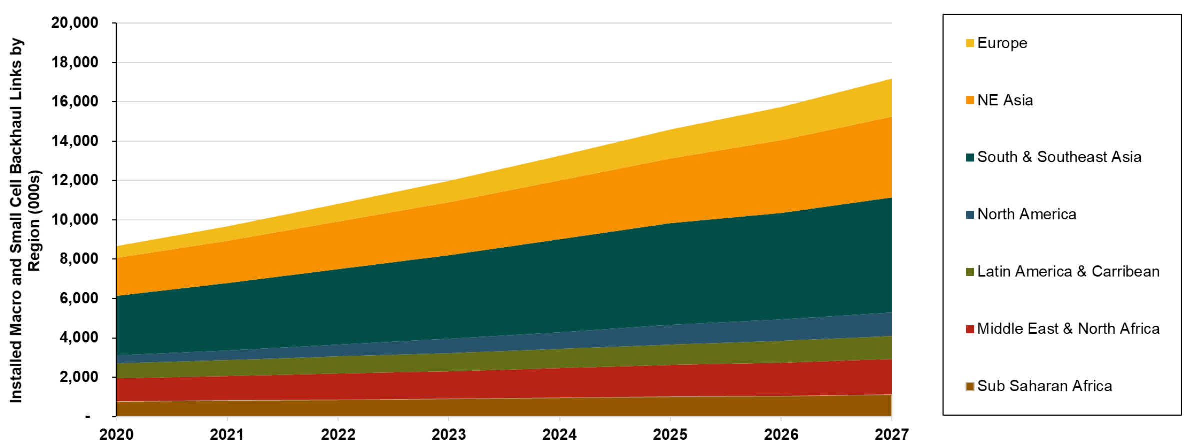
Microsoft has launched the **Airband Initiative**, a group that plans to provide connectivity to rural areas through unused guard-band spectrum between TV channels. The TVWS are frequencies that have not been assigned or are otherwise not being used by broadcasters and other licensees in the VHF and UHF broadcast bands.

Capacity performance of TVWS is typically measured in the 10s of Mbps. The addition of higher modulation schemes (256 QAM = 20% to 30% throughput increase), channel bonding and antenna technologies (MIMO; double/quadruple throughput) would enhance delivery to 100s of Mbps. With access to additional TVWS spectrum (beyond one or two channels), throughput can increase, so long as the spectrum is interference-free. Current (4 x 6 MHz channels) TVWS radios can deliver a throughput of up to 186 Mbps (8 MHz TV channels in Europe, Africa, and Asia also allow channel bonding up to 24 MHz).

Interference is the main obstacle for widespread adoption of TVWS. Residual signals from TV transmissions exist, such as in-band emissions from TV masts or emissions from adjacent channels from near-proximity TV transmitters. The unlicensed nature of this spectrum allows for other users to transmit on the same channels, which would be another cause of interference.

14. APPENDIX 4: MACRO AND SMALL CELL FORECAST PER REGION

Figure 63. Global Installed Macro and Small Cell Backhaul Links by Region, Forecast: 2020 to 2027



14.1. Macro Cell Backhaul Links Forecasts by Region

Figure 64. European Installed Macro Cell Backhaul Links, Forecast: 2020 to 2027

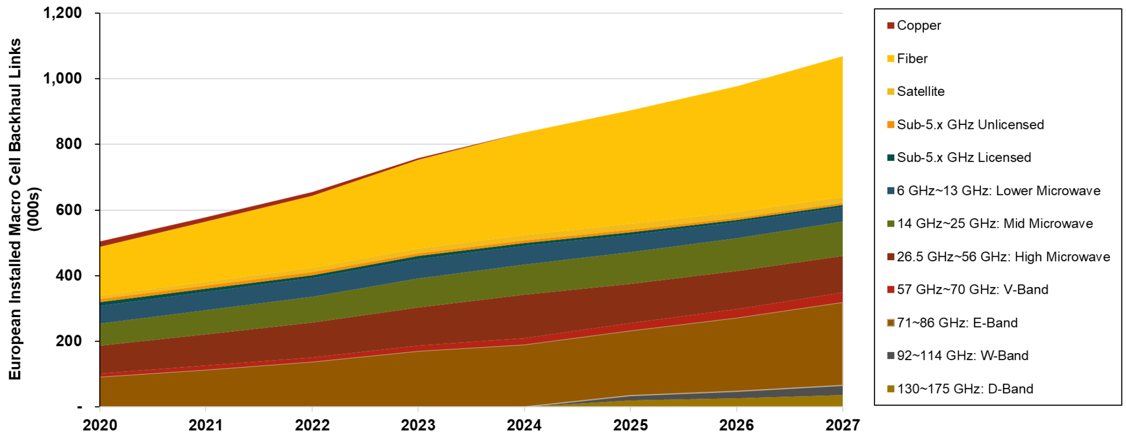


Figure 65. Northeast Asia Installed Macro Cell Backhaul Links, Forecast: 2020 to 2027

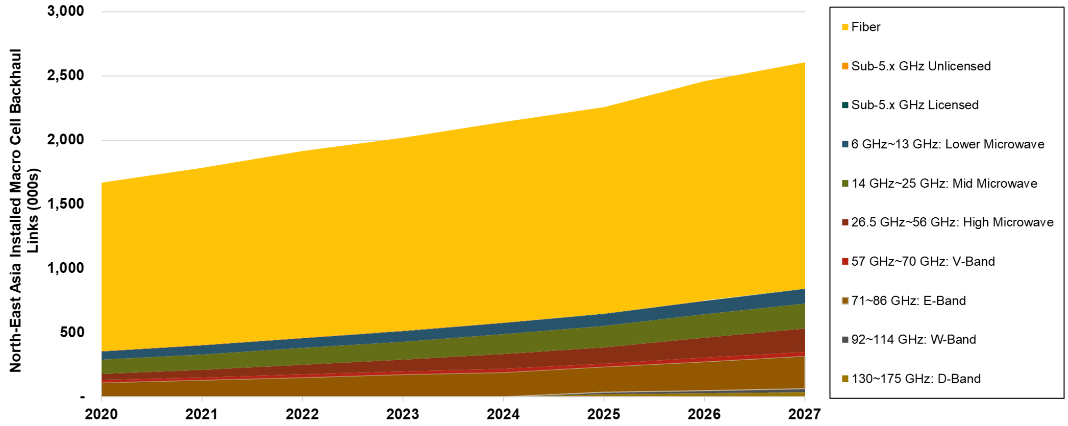


Figure 66. South & Southeast Asia Installed Macro Cell Backhaul Links, Forecast: 2020 to 2027

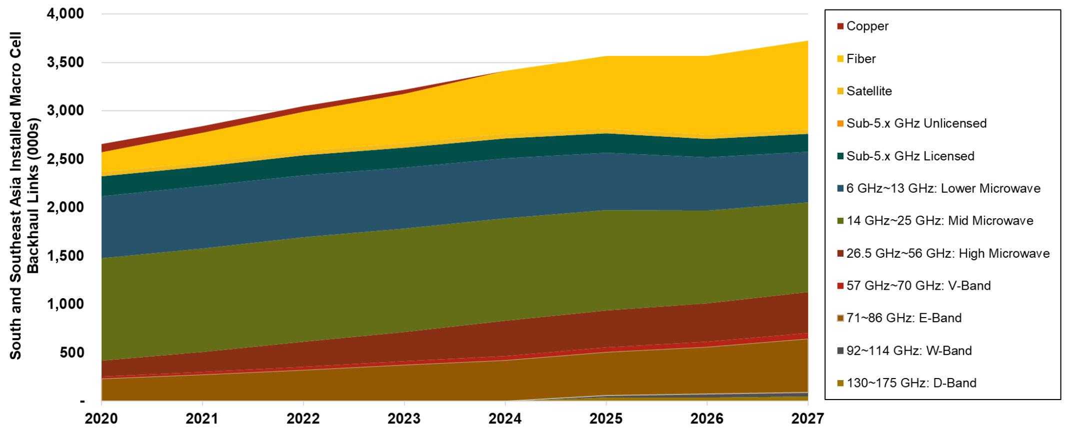


Figure 67. North America Installed Macro Cell Backhaul Links, Forecast: 2020 to 2027

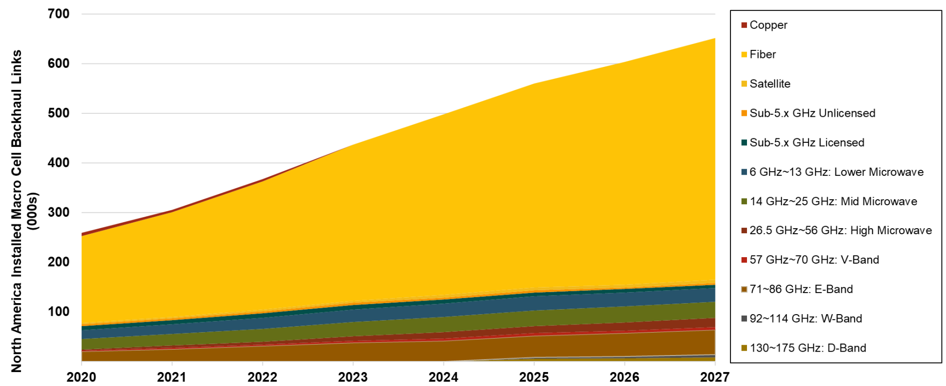


Figure 68. Latin America Installed Macro Cell Backhaul Links, Forecast: 2020 to 2027

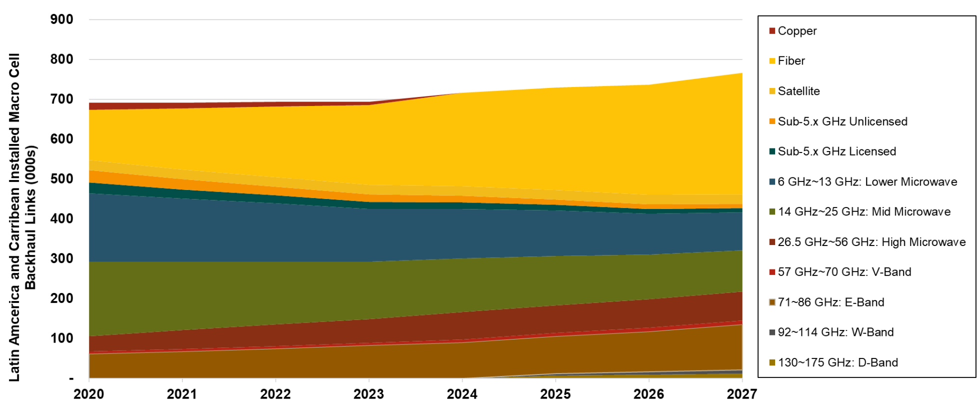


Figure 69. Middle East & North Africa Installed Macro Cell Backhaul Links, Forecast: 2020 to 2027

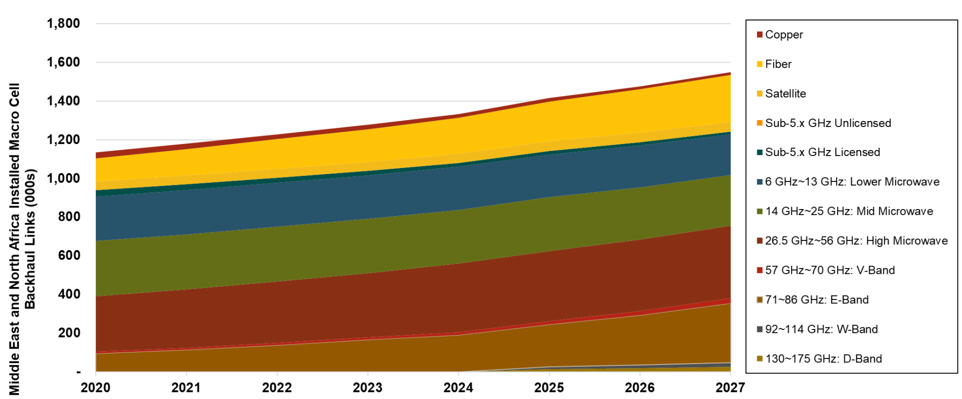
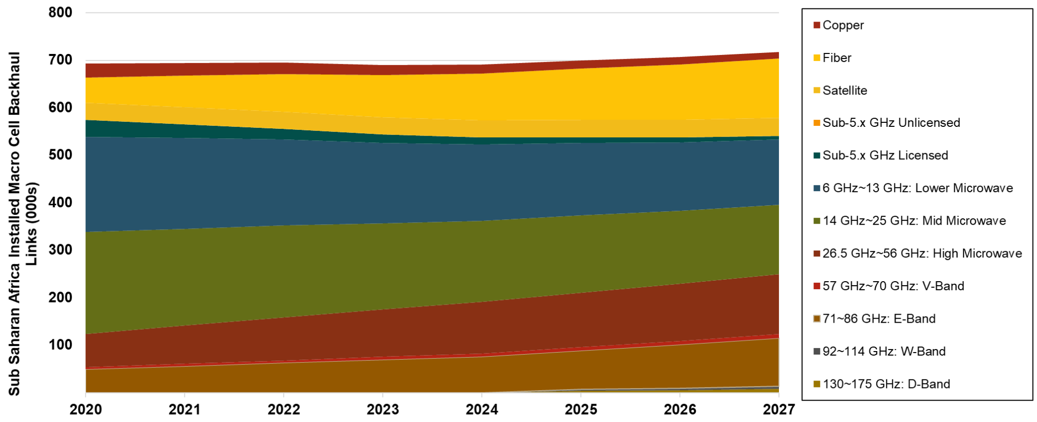


Figure 70. Sub-Saharan Africa Installed Macro Cell Backhaul Links, Forecast: 2020 to 2027



14.2. Small Cell Backhaul Links Forecasts by Region

Figure 71. European Installed Small Cell Backhaul Links, Forecast: 2020 to 2027

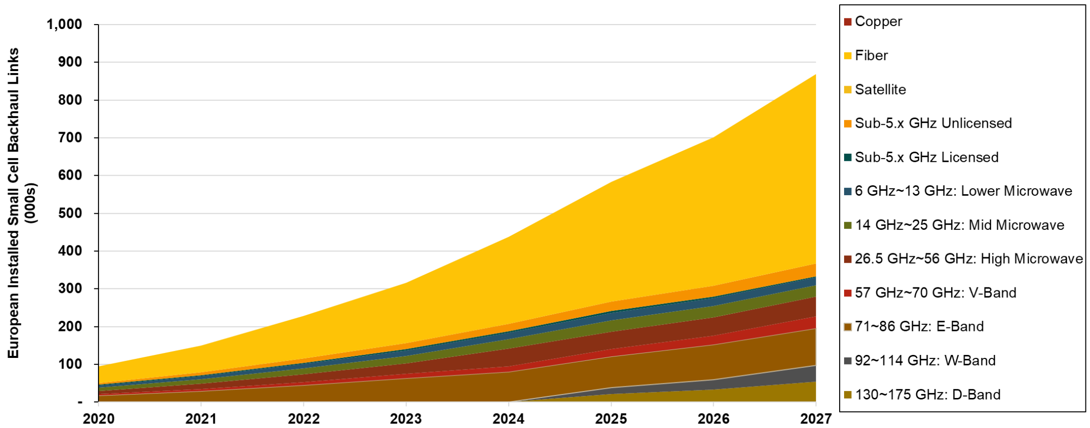


Figure 72. Northeast Asia Installed Small Cell Backhaul Links, Forecast: 2020 to 2027

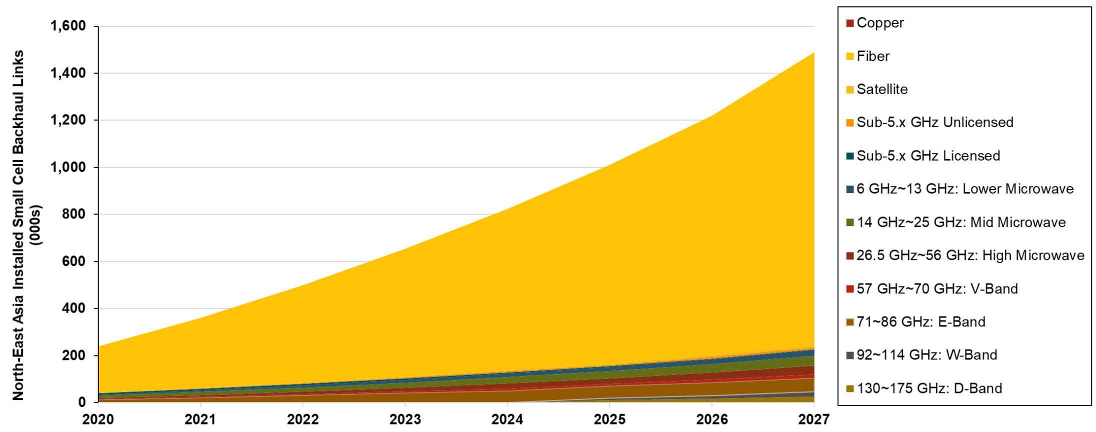


Figure 73. South & Southeast Asia Installed Small Cell Backhaul Links, Forecast: 2020 to 2027

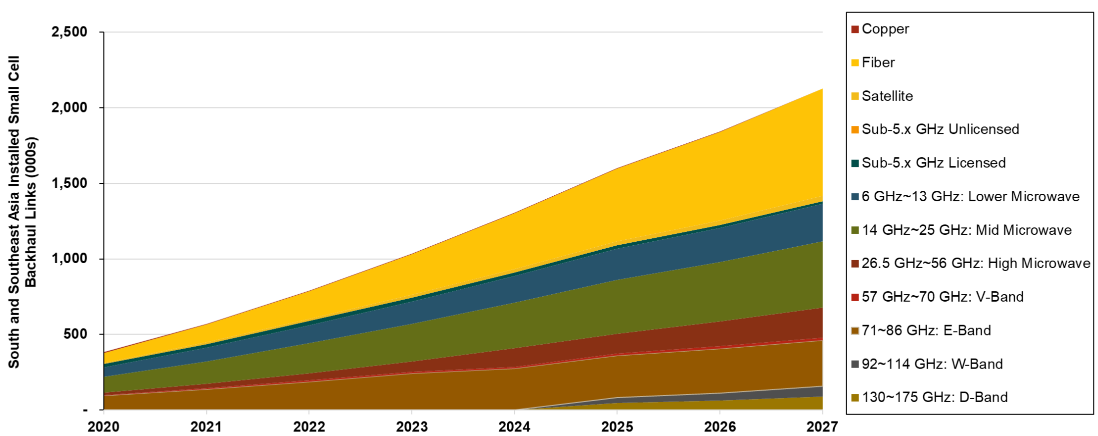


Figure 74. North America Installed Small Cell Backhaul Links, Forecast: 2020 to 2027

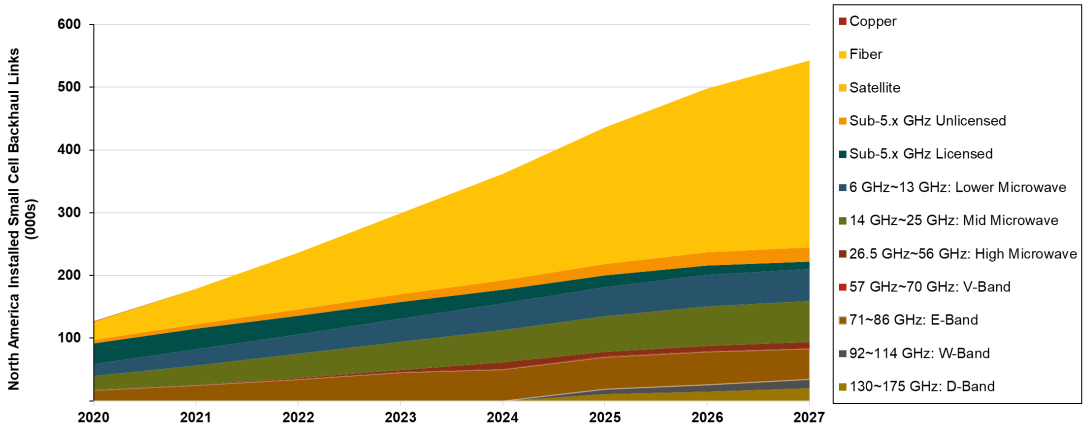


Figure 75. Latin America Installed Small Cell Backhaul Links, Forecast: 2020 to 2027

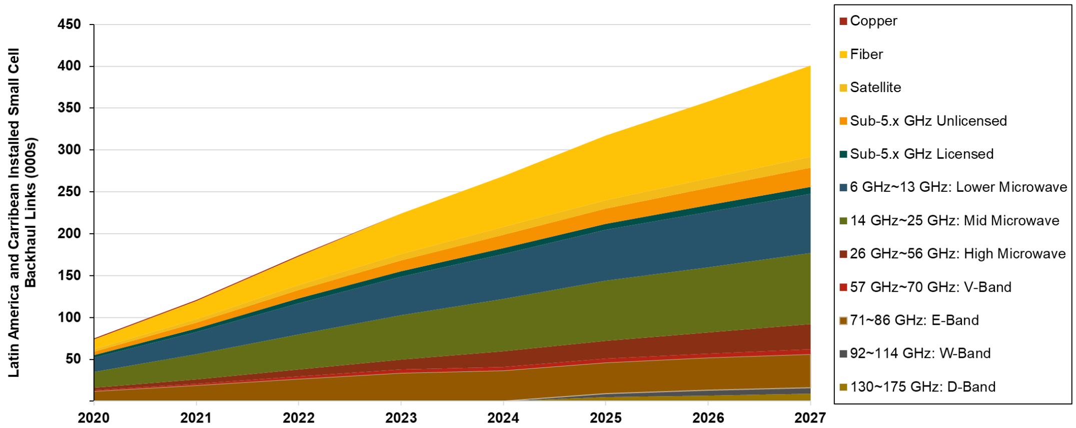


Figure 76. Middle East & North Africa Installed Small Cell Backhaul Links, Forecast: 2020 to 2027

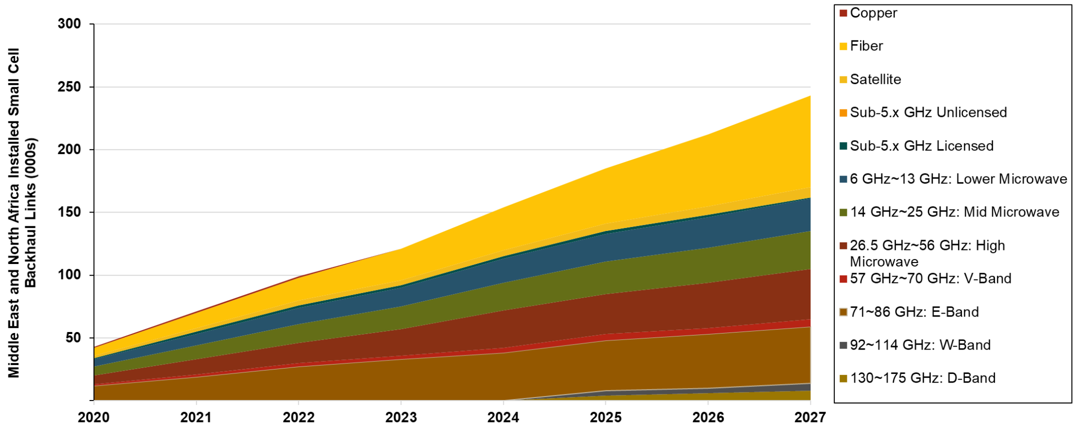
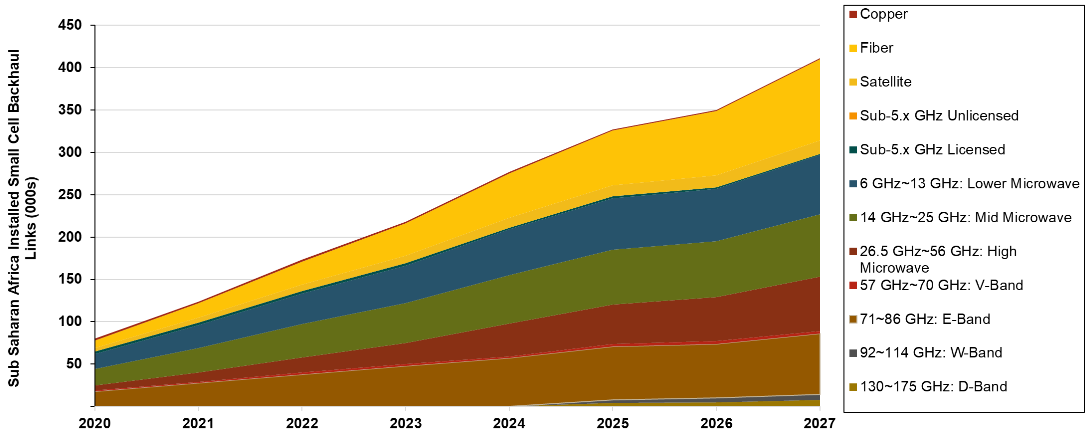


Figure 77. Sub-Saharan Africa Installed Small Cell Backhaul Links, Forecast: 2020 to 2027



15. APPENDIX 5: LIST OF COUNTRIES

Figure 78. Available Country Data Used per Chapter

	Chapter 2	Chapter 2	Chapter 2	Chapter 2	Chapter 5	Chapter 5	Chapter 6	Chapter 7	Chapter 7	Chapter 8
	Cellular Mobile Subscriptions Technical Generation Split (From ABI MD-NWMT-104)	Leaders in 5G Adoption (From ABI MD-NWMT-104)	Cellular Mobile Traffic per Year by Technical Generation Split (From ABI MD-NWMT-104)	Installed Macro and Small Cell Backhaul Links by Technology	License Framework Analysis	License Duration Analysis	Macro and Small Cell Forecast	Backhaul Links – Capacity, Spectrum and Backhaul Allocation Analysis	Backhaul Allocation Sections 7.3 - 7.5	Pricing Information
Argentina				1	1	1	1	1	1	
Australia	1	1	1	1	1	1	1	1	1	1
Austria	1	1	1							
Bangladesh				1	1	1	1	1	1	1
Belgium	1	1	1							
Brazil	1	1	1	1	1	1	1	1	1	1
Canada	1	1	1							1
Chile				1	1	1	1	1	1	1
China	1	1	1	1	1	1	1	1	1	
Czech Republic				1	1	1	1	1	1	1
Egypt				1	1	1	1	1	1	1
Finland	1	1	1							
France	1	1	1	1	1	1	1	1	1	1
Germany	1	1	1	1	1	1	1	1	1	
Hungary				1	1	1	1	1	1	1
India	1	1	1	1	1	1	1	1	1	1
Indonesia	1	1	1	1	1	1	1	1	1	1
Ireland	1	1	1							
Israel	1	1	1							
Italy	1	1	1	1	1	1	1	1	1	1
Japan	1	1	1	1	1	1	1	1	1	1
Jordan				1	1	1	1	1	1	1
Kuwait				1	1	1	1	1	1	
Malaysia				1	1	1	1	1	1	1
Mexico	1	1	1	1	1	1	1	1	1	1
Myanmar				1	1	1	1	1	1	
Netherlands	1	1	1							
New Zealand				1	1	1	1	1	1	1
Nigeria				1	1	1	1	1	1	1
Norway	1	1	1							
Pakistan				1	1	1	1	1	1	
Peru				1	1	1	1	1	1	1
Philippines				1	1	1	1	1	1	
Poland	1	1	1	1	1	1	1	1	1	1
Russia	1	1	1	1	1	1	1			
Saudi Arabia	1	1	1	1	1	1	1	1	1	1
Singapore				1	1	1	1	1	1	1
South Africa				1	1	1	1	1	1	1
South Korea	1	1	1	1	1	1	1	1	1	1
Spain	1	1	1	1	1	1	1	1	1	1
Sweden	1	1	1	1	1	1	1	1	1	
Switzerland	1	1	1							
Taiwan	1	1	1							
Tanzania				1	1	1	1	1	1	1
Turkey	1	1	1	1	1	1	1	1	1	1
UAE	1	1	1	1	1	1	1	1	1	1
United Kingdom	1	1	1	1	1	1	1	1	1	1
United States	1	1	1	1	1	1	1	1	1	1
Uruguay				1	1	1	1			
Venezuela				1	1	1	1	1	1	1
Total	30	30	30	40	40	40	40	38	38	31

Figure 79. Backhaul Licensing Regime Analysis by Country

Chapter 5	Global Licensing Analysis 2020

Country	Unlicensed	Per Link	Block Spectrum	Shared	Lightly Licensed	1 Yr	5 Yr	10 Years	> 10 Years
Europe									
France									
Germany									
Italy									
Spain									
Sweden									
UK									
Czech Republic									
Hungary									
Poland									
Russia									
Turkey									
NE Asia									
China									
Japan									
Korea									
South & Southeast Asia									
Australia									
Bangladesh									
India									
Indonesia									
Malaysia									
New Zealand									
Pakistan									
Philippines									
Singapore									
Myanmar									
North America									
United States									
Latin America & Carribean									
Argentina									
Brazil									
Chile									
Mexico									
Peru									
Uruguay									
Venezuela									
Middle East & North Africa									
Jordan									
Kuwait									
Saudi Arabia									
UAE									
Sub Saharan Africa									
Egypt									
Nigeria									
South Africa									
Tanzania									
World-wide Analysis									
Total	5	26	14	4	9	6	7	8	11
Spectrum Share	8.6%	44.8%	24.1%	6.9%	15.5%	19%	22%	25%	34%

Source: ABI Research

16. LIST OF ACRONYMS

Acronym	Definition
5G NR	5G New Radio
5G NSA	5G Non-Standalone Network
5G SA	5G Standalone Network
AGR	Annual Gross Revenue
ARPU	Average Revenue Per User
BCA	Band and Carrier Aggregation
BTS	Base Transceiver Station
BTRC	Bangladesh Telecommunications Regulatory Commission
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCIC	Co-Channel Interference Canceller
CSP	Communications Service Provider
DoT	Department of Telecommunications (India)
DSS	Dynamic Spectrum Sharing
eMBB	Enhanced Mobile Broadband
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
GDP	Gross Domestic Product
IAB	Integrated Access Backhaul
ICT	Information, Communication, and Technology
IoT	Internet of Things
LOS MIMO	Line of Sight Multiple Input, Multiple Output
LTE	Long-Term Evolution (4G Network)
mMTC	Massive Machine-Type Communications
NCMC	National Commission on Markets and Competition
Ofcom	U.K. Office of Communications
OPEX	Operating Expenditure
PPP	Purchasing Power Parity
PTMP	Point-to-Multi-Point
PTP	Point-to-Point
QoE	Quality of Experience
RAN	Radio Access Network
ROI	Return on Investment

Acronym	Definition
SISO	Single-Input Single-Output
TCO	Total Cost of Ownership
TDD	Time Division Duplex
TRC	Telecommunications Regulatory Commission (Jordan)
URLLC	Ultra-Reliable Low-Latency Communications
XPD	Cross-Polar Discrimination
XPIC	Cross Polarisation

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Published: February 24nd, 2021

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