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Ericsson Microwave Outlook

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Executive summary

As 5G is switched on at an incredible pace, several transport aspects like spectrum usage, differentiated availability and the mix of fiber and microwave become important.

Contents

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5G is here, meaning that backhaul capacity requirements will increase for Radio Access Network (RAN) sites. In 2025, the needs in urban areas will vary from 3Gbps to 20Gbps, as communications service providers deploy different amounts of New Radio (NR) spectrum and advanced RAN features. In rural areas, it could vary from as much as 300Mbps to 2Gbps in 2025.

To support these demands, the perfect balance of fiber and microwave backhaul will be essential. Fiber will be very important to core and inner-city aggregation sites with extremely high capacity requirements. Microwave will mainly be used as last-mile access in urban and dense urban areas, whereas a combination of last-mile and aggregation links will be appropriate for suburban and rural areas. By 2025, 38 percent of backhaul connections are predicted to be based on microwave globally. This corresponds to 62 percent when excluding the fiber-dense countries China, South Korea and Japan.

One key aspect of ever-increasing capacity is that it becomes even more important to differentiate the availability of the backhaul. Our simulations show that availability can be relaxed in capacity-demanding services like video without negative impact on user Quality of Experience (QoE). This stresses that a properly dimensioned backhaul can have much lower availability for the higher capacities, while maintaining high availability for lower rates. Therefore, E-band and Multi-band booster solutions are well positioned as future-proof wireless backhaul technologies when the traffic loads increase in 5G and beyond.

Wider channels have been released over time to handle the need for higher capacities. With this gradual development, spectrum usage can become scattered, potentially hindering capacity growth. Our studies in the Czech Republic, Sweden, India and Bangladesh show that the situation differs around the world. However, some general actions can be applied in most markets to continue to satisfy the demand for more capacity, such as wide channels, flexible channel plans, refarming, opening up the E-band and spectrum fees that encourage spectrum-efficient technologies.

A hot topic in backhaul spectrum is how we will use 6GHz in the future. The US has decided to allow unlicensed use in the 5.925–7.125GHz range, while in Europe, there is an ongoing review as to whether to allow unlicensed use in the 5.925–6.425GHz range. The 6GHz and 7/8GHz bands are commonly used for backhauling in many countries. Interference from unlicensed use can reduce throughput and, in the worst case, cause complete outage of a licensed microwave backhaul link. A cautious and conservative approach is recommended, as licensed backhaul is ultra-reliable and provides critical services. Microwave analytics tools can play an important role in the future.

Backhaul capacity evolution

There must be a continuous focus on a backhaul able to deliver the performance required for a full 5G experience.

5G NR sees continued momentum as deployments increase, with more and more service providers announcing commercial 5G services.[1] The forecasts for 5G mobile subscriptions and mobile network traffic carried by 5G in 2025 are foreseen to be about 30 and 45 percent respectively.[2] The availability of more spectrum assets, especially in higher frequency bands, will enable increased throughput. It is expected that mobile chipsets will enable peak rates up to 10–15Gbps by 2025, by aggregating spectrum, RF radio front-end refinement and baseband processing optimization.

Figure 1 shows typical backhaul capacity requirements. The table includes distributed sites with backhaul connectivity, as outlined in Figure 2. Centralized RAN (CRAN) and higher-layer split virtualized RAN (HLS VRAN) centralized unit (CU) sites are omitted, as they normally connect directly to larger metro networks and not through traditional backhaul transport.

As seen in Figure 1, capacity variations in each segment are relatively large, as service providers will deploy different bands, varying amounts of NR spectrum and advanced RAN features.

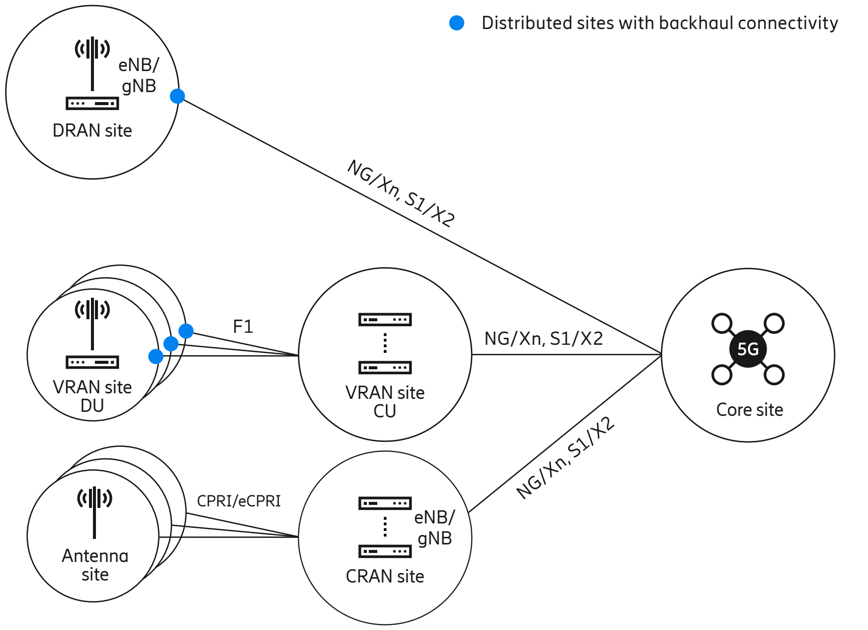
Figure 1's upper table reflects markets with a selective 5G rollout, initially focusing on urban areas. The lower table reflects markets that are early adopters of 5G NR, with both showing a faster rollout in all areas and, typically, using more spectrum to achieve higher throughput. Notably, the urban segment is expected to reach very high capacities in both markets, driven by the requirements for ever-higher end-user throughput in the major cities. This capacity increase is enabled by deploying small cell sites and higher frequency spectrum, both well suited for urban environments.

Figure 1: Backhaul capacity per distributed site

		2020	2022	2025
3G/4G and selective 5G	Urban	250Mbps–500Mbps	450Mbps–5Gbps	3Gbps–10Gbps
	Suburban	100Mbps–250Mbps	200Mbps–1Gbps	500Mbps–3Gbps
	Rural	50Mbps–100Mbps	75Mbps–250Mbps	200Mbps–1Gbps
3G/4G and ubiquitous 5G	Urban	500Mbps–1Gbps	1Gbps–10Gbps	5Gbps–20Gbps
	Suburban	200Mbps–500Mbps	500Mbps–2Gbps	1Gbps–5Gbps
	Rural	100Mbps–150Mbps	150Mbps–350Mbps	300Mbps–2Gbps

Source: Ericsson (2020)

Figure 2: Distributed sites with backhaul connectivity



[1] www.ericsson.com/en/5g#live-5g-networks
[2] Ericsson Mobility Report (June 2020)

Latest on spectrum

The future use of 6GHz is the new hot topic in backhaul spectrum.

Spectrum is a finite and very valuable resource, which is why its efficient use is regularly reviewed by regulators. At the World Radiocommunication Conference 2019 (WRC-19), a global IMT (5G) identification was decided for the high bands: 26GHz (24.25–27.5GHz), 40GHz (37–43.5GHz) and 66–71GHz. As a result, usage of backhaul will eventually be transitioned from some of these bands, such as 26GHz in Europe. The timing of the transition will vary between countries, depending on the demand for 5G NR balanced against the importance of existing backhaul. The 32GHz (31.8–33.4GHz) and 80GHz (71–76 paired with 86GHz) bands were not identified for 5G and remain essential for backhaul.

At the conference, an agenda was also decided for the next WRC in 2023, which will consider IMT (5G) identification of mid-band spectrum. With its combination of coverage and capacity, additional contiguous mid-band spectrum is crucial in supporting 5G. One of the candidate bands is 6.425–7.125GHz, also known as upper 6GHz, which is today commonly used for backhauling; see Figure 3.

There is another use considered for the 6GHz backhaul band. The possibility to expand license-exempt wireless access into the band, without causing harmful interference with the licensed backhaul use, has been studied in the US and Europe. Some administrations see this as an important opportunity to enhance wireless broadband, utilizing Wi-Fi 6E, 5G NR Unlicensed (NR-U) and other unlicensed technologies.

The US has decided[1] to allow unlicensed use in the 5.925–7.125GHz range, of which 5.925–6.425GHz and 6.525–6.875GHz are heavily used for backhauling; see Figure 4. Unlike many other countries, the 7/8GHz (7.125–8.5GHz) backhaul band is in the US reserved for federal use. In Europe, there is an ongoing review to allow unlicensed use[2] in the 5.925–6.425GHz range, also known as lower 6GHz. The 6GHz and 7/8GHz bands are commonly used for backhauling in Europe, but the relative use differs from country to country.

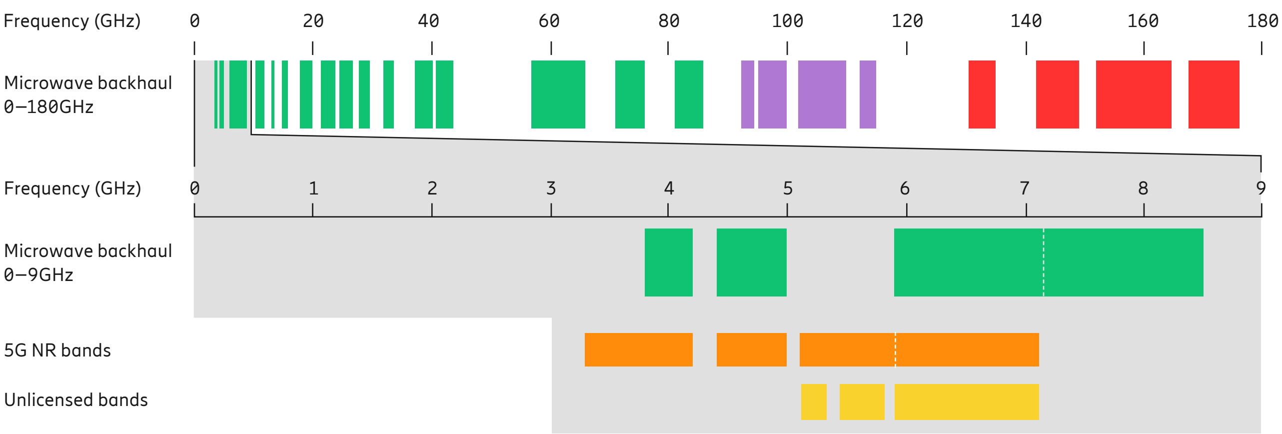
The bands below 10GHz are essential for long-range backhaul due to their superior propagation characteristics.

Introducing unlicensed use in a licensed backhaul band raises many concerns. Regulatory studies assess the probability of interference using statistical simulations, complemented with the analysis of realistic critical scenarios.

New technical and operational rules should strike a delicate balance between new unlicensed use and maintaining reliable licensed backhaul. Administrations may have different levels of concern on the balance, depending on how common and strategically important the backhaul use is in a country.

There are some differences between the unlicensed rules in the US and Europe; see Figure 5. The draft European decision also includes a Country Determination Capability (CDC) to address the need for additional protection measures in some countries. Three different unlicensed device categories are discussed: Standard Power (SP), Low Power Indoor (LPI) and Very Low Power (VLP). There are also requirements for client devices. The allowed Equivalent Isotropic Radiated Power (EIRP) is limited for each unlicensed device category to protect the backhaul.

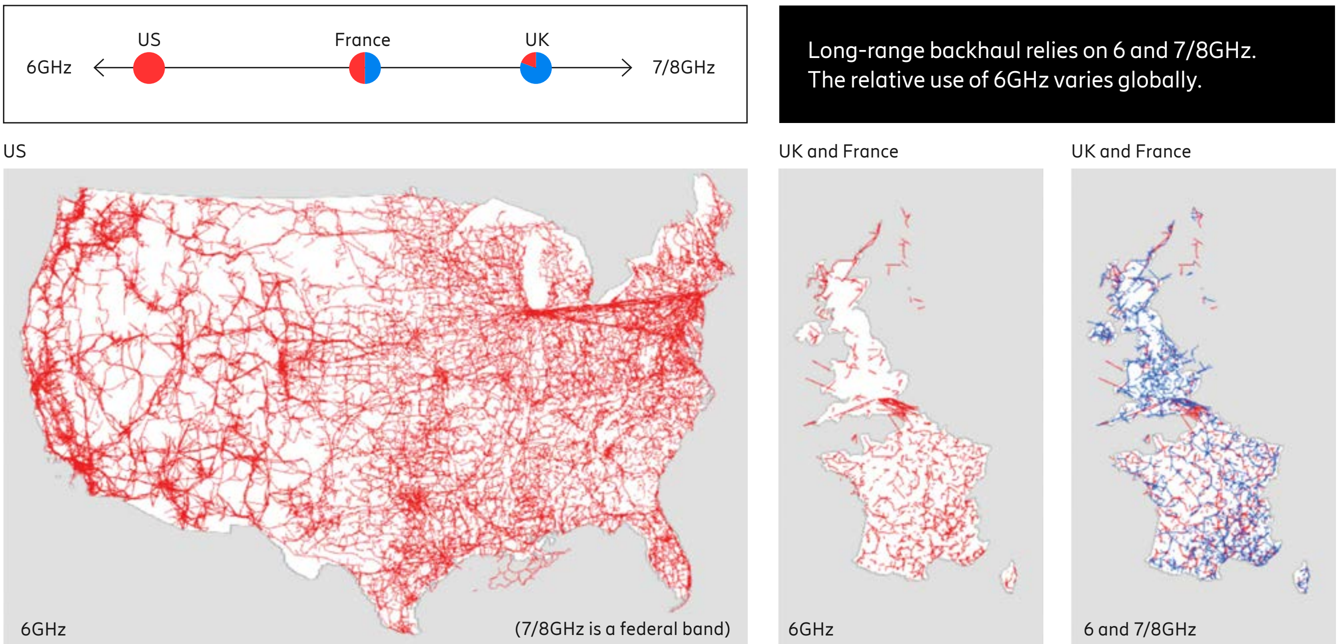
Figure 3: New usage considered for the 6GHz microwave backhaul band



Source: Ericsson (2020)

[1] Report and Order, FCC 20–51
[2] Draft ECC Decision (20)01

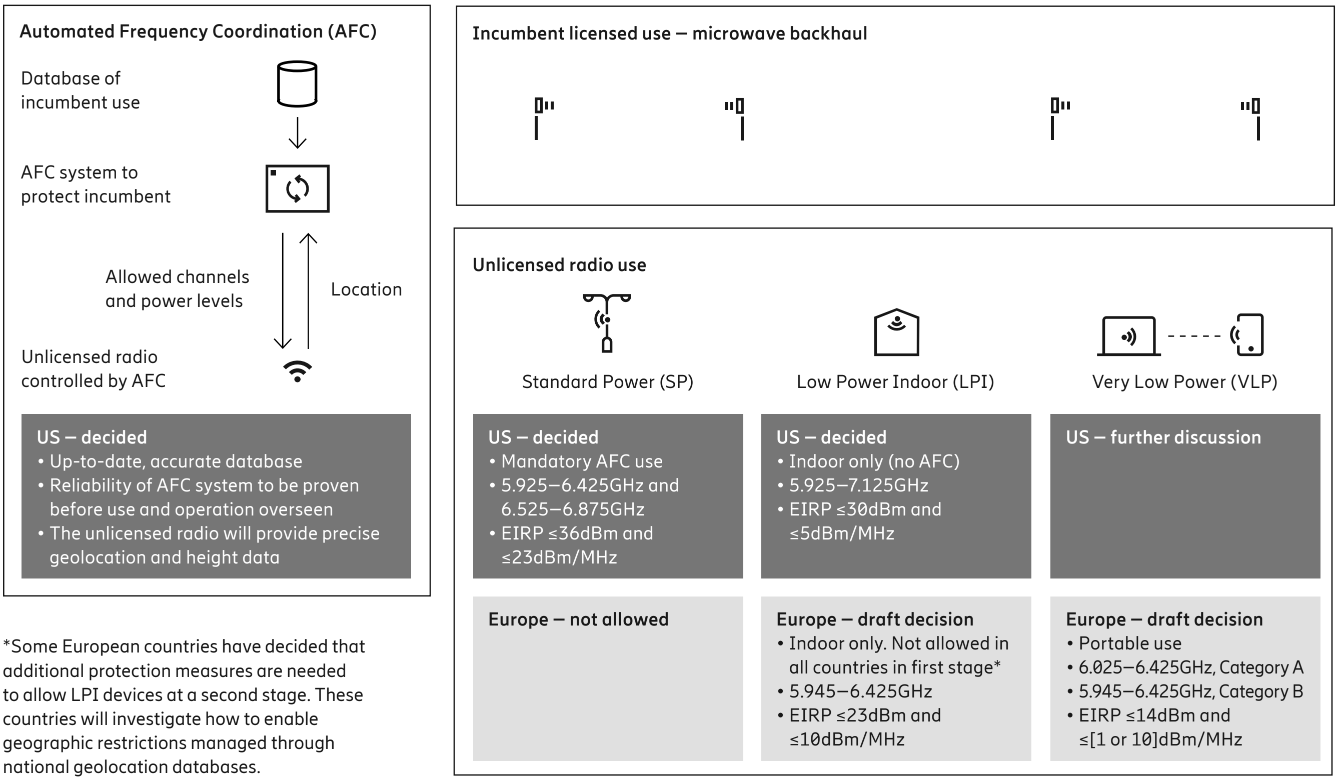
Figure 4: The use of 6GHz for long-range backhaul



A new geolocation concept is introduced in the US for SP devices – the Automated Frequency Coordination (AFC) system. The AFC receives the geographic location and operating parameters of the licensed backhaul from a database. It also requires the geographic coordinates and height above ground of each unlicensed device. The AFC then uses specified propagation models and backhaul interference protection criteria to determine which frequencies and power levels are available for use. The introduction of a geolocation database concept is also part of the proposed rules in Europe for LPI devices, as the second stage of implementation.

Interference from unlicensed use can cause reduced throughput and, in the worst case, complete outage of a licensed microwave backhaul link. Microwave Analytics tools[3] can be used to indicate interference as the root cause of a link problem. But the time it takes to find the interference source and resolve the issue is essential. There are concerns that this could take days or even weeks. In theory, the AFC is a promising approach to avoid interference, but its accuracy and reliability should be proven before being relied on in the field. A cautious and conservative approach is recommended, as licensed backhaul is ultra-reliable and provides critical services.

Figure 5: Regulatory overview for the unlicensed operation in 6GHz



*Some European countries have decided that additional protection measures are needed to allow LPI devices at a second stage. These countries will investigate how to enable geographic restrictions managed through national geolocation databases.

Source: Ericsson (2020)

[3] https://www.ericsson.com/en/portfolio/networks/ericsson-radio-system/mobile-transport/microwave/microwave-analytics-/advanced-microwave-insights-

A balanced mix of fiber and microwave

To support the high transport demands, a balanced mix of fiber and microwave backhaul will be vital.

Global total mobile data traffic reached around 33EB per month by the end of 2019, and is projected to grow by a factor close to 5 to reach 164EB per month in 2025.[1] This large increase will need to be handled by the backhaul network. 5G will handle an increasing part of mobile traffic, requiring both high capacity and low latency. The total cost of ownership (TCO) and a fast time to market are also key factors to consider when deploying a 5G backhaul network.

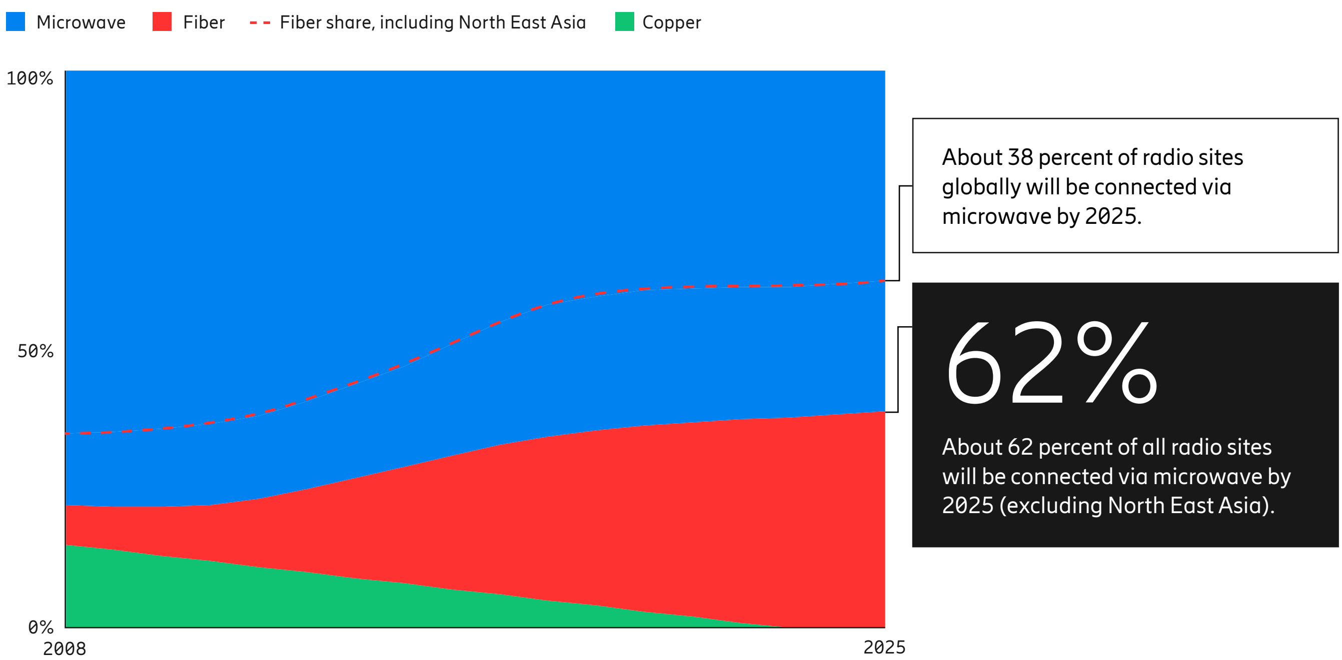
Fiber will be very important to core and inner-city aggregation sites with extremely high capacity requirements, such as dense urban C-RAN sites. C-RAN sites will mainly be used where the fiber penetration is already high. The amount of fiber will continue to increase as some authorities are heavily pushing for a build-out of the fiber network; for example, fiber to the home (FTTH). Microwave will mainly be used as last-mile access in urban and dense urban areas, whereas a combination of last-mile and aggregation links will be appropriate for suburban and rural areas.

Some service providers want to be the first to market with 5G, for increased market share and revenue. Another factor is to have good population coverage. The main learning from the COVID-19 pandemic is that good broadband connectivity is not only vital in dense urban areas, but everywhere. If there is no fiber available, microwave is the fast and cost-effective rollout choice. For 5G, E-band and Multi-band solutions are particularly interesting as they achieve high capacity, with the right hop length and availability. Even in fiber-dense countries like China, the interest in E-band is starting to rise.

Looking at Figure 1, the capacities expected in 2025 at distributed sites are all fully within microwave's capability. Microwave technology has continuously developed, like radio, and is today capable of much higher capacities.

As Figure 6 shows, there will be a slight increase in fiber usage with the introduction of 5G. This is due to both the increasing number of aggregation sites in dense urban areas, as well as the amazing speed of 5G deployment in fiber-dense countries like the US, Japan and China. Still, microwave-dense areas like Europe, the Middle East and Latin America are following suit, and microwave will remain a vital part of the 5G transport network. Thirty-eight percent of backhaul connections are expected to be based on microwave by 2025, globally. This corresponds to 62 percent when excluding the fiber-dense countries China, South Korea and Japan.

Figure 6: Global backhaul media distribution



Source: Ericsson (2020)

[1] Ericsson Mobility Report (June 2020)

Lessons learned from long-haul use around the globe

Over the last decade, traffic has moved from TDM to packet. Significant capacity gains could be made with a more modern network plan.

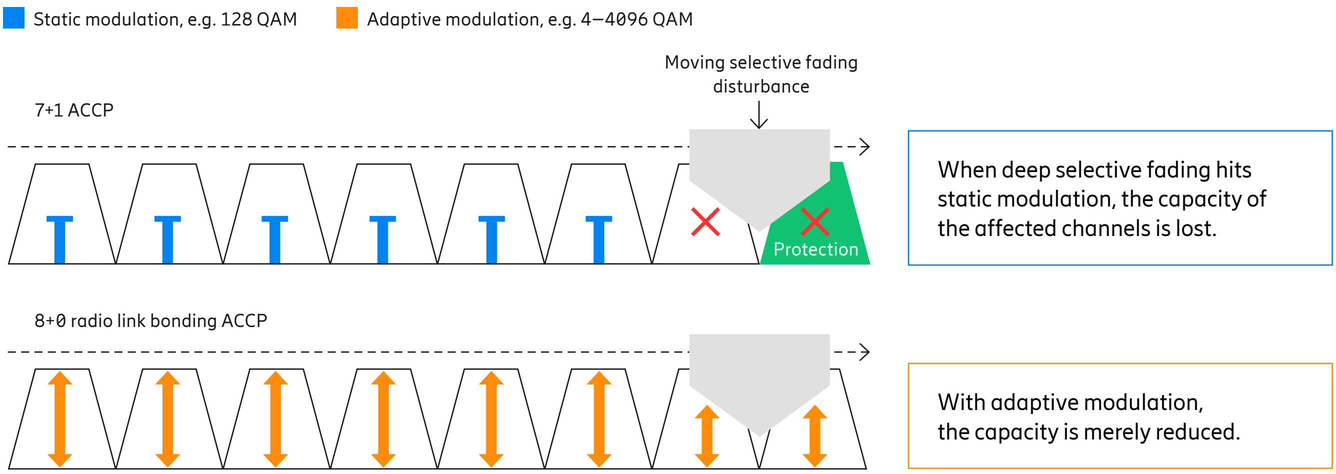
Traditional planning beliefs can be questioned with packet traffic and improved antennas. The new shorthaul techniques can now be implemented for long haul, such as Multi-band booster.

Are the old truths in radio planning ready to be revised?
The requirements concerning radio performance per TDM channel have guided our radio link planning for over 50 years.

Today, most radio traffic is packet-based while the remaining TDM traffic is migrating towards packet-based transport. Therefore, some old "truths" may need to be revisited since modern traffic has different radio channel performance requirements.

Can adaptive modulation and N+0 increase service availability and capacity?
Traditional radio link planning focuses on one channel at a time based on a single TDM service being transported over the channel, such as an STM-1/OC-3 with 155Mbps. If the radio channel fails, the service fails. Long-haul systems were used to carry multiple services in parallel; see the upper part of Figure 7. While the individual radio channel is performing, each service (STM-1/OC-3) is functional.

Figure 7: Impact of deep selective fading moving across channels



Source: Ericsson (2020)

Figure 8: The capacity of 8+0 adaptive modulation compared to 7+1 SDH

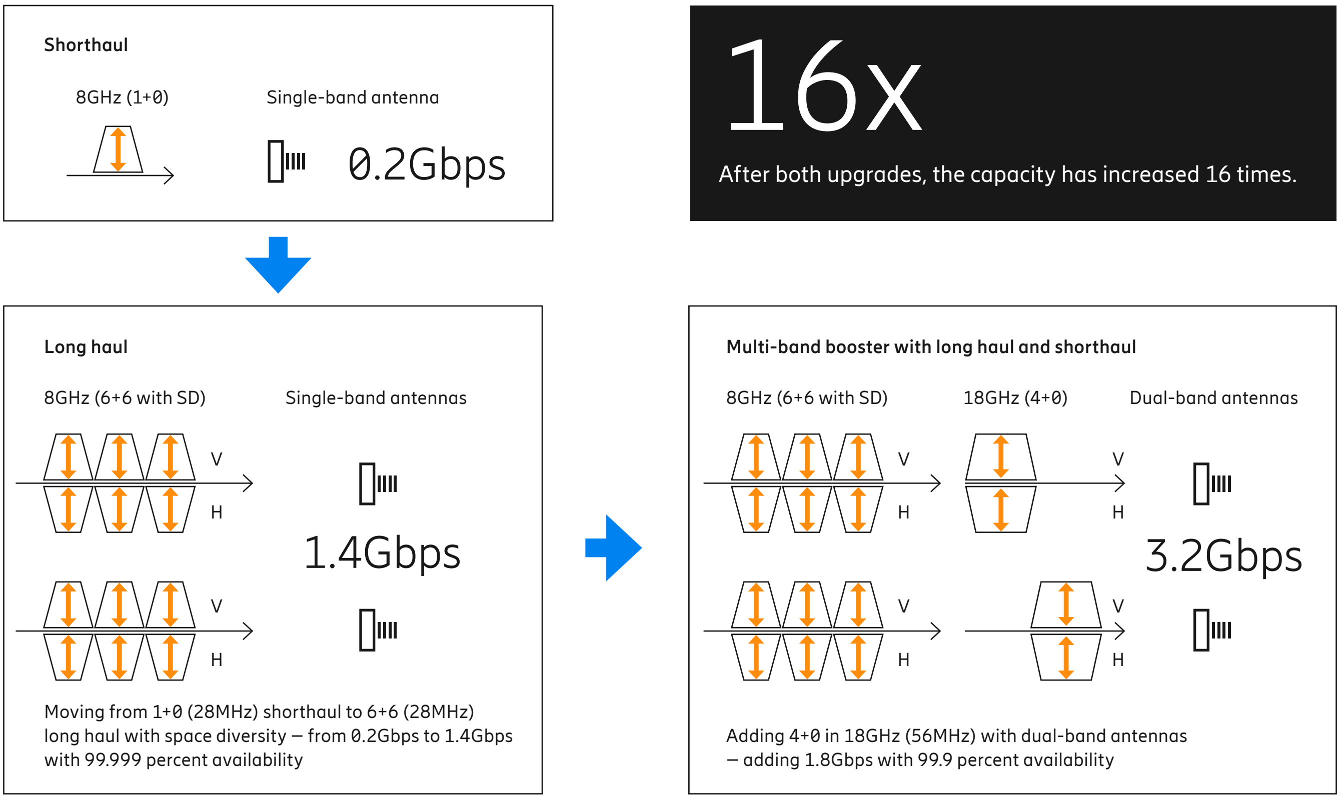
Availability	Modulation	Capacity
99.9%	4096 QAM Light	203%
99.99%	1024 QAM	172%
99.999%	128 QAM	119%
99.9999%	64 QAM	100%
99.99999%	4 QAM Strong	27%
99.999%	128 QAM (SDH 7+1)	100%

Source: Ericsson (2020)

2x

Double capacity is possible when using 8+0 and adaptive modulation compared to a 7+1 SDH link.

Figure 9: Long-haul and dual-band antennas increase capacity



Example from a real hop, 13km

Source: Ericsson (2020)

However, a modern packet link using multiple channels works differently. In a packet network, you want one big stream of packets, even when using multiple radio channels to transport this information. In the lower part of Figure 7, we see how all the packets distributed over the combined capacity of the radio channels impacts total capacity. The more each can contribute, the better, and when one underperforms, the others carry the load. This way, the performance of the aggregated sum of channels is mirrored in the service.

More specifically, as Figure 8 shows, it means that for 99.9 percent of the year, capacity is up to twice as high as traditional radio links. Since we are now dealing with low-band, long-haul frequencies, where selective fading is dominant, only one or two channels are severely impacted at the same time. Therefore, a full set of four to eight radio channels will always have better availability and capacity performance than the individual radio channel during the year. Unfortunately, current radio planning only considers availability channel by channel, and not for the aggregated capacity. For selective fading dominated links, this becomes too conservative and does not reflect the true availability of the aggregated service over the long-haul link.

The old truth of antennas

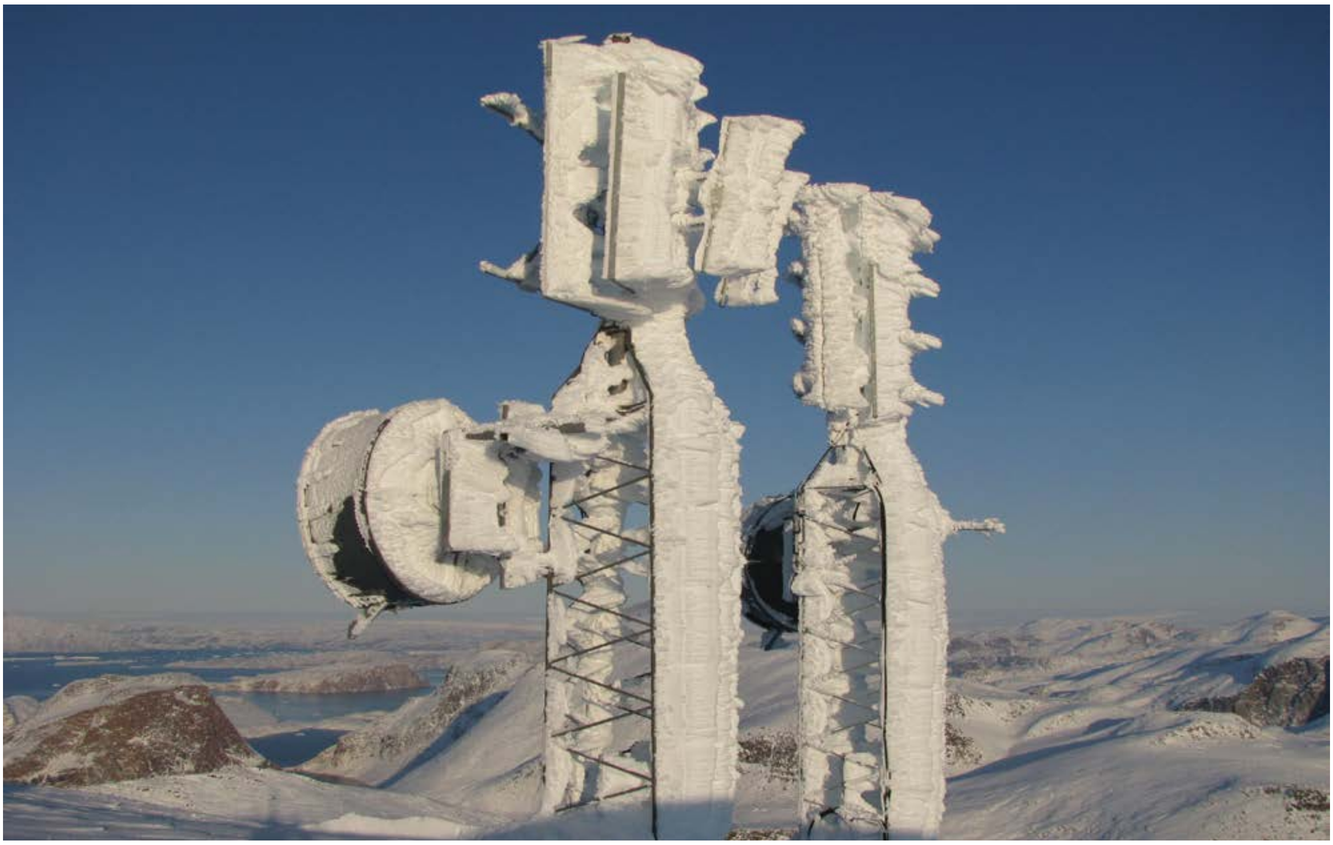
The silicon revolution over the past 50 years has moved from high-quality mechanical and analog solutions towards DSP-based algorithms with better performance. Today, most challenges are solved in the modern DSPs on modems containing equalizers and advanced XPIC solutions, enabling even better performance through antennas with worse return loss and cross-polarization discrimination (XPD) values. For the modern digital link, it is more about having a good enough antenna to reach the maximum performance of the microwave link, as the solution is no longer in the analog circuits.

When planning a long and difficult microwave link, old-school planning suggested that spending money on antennas with extremely high return loss and very high XPD value would help achieve better performance and availability for the hop. With the modern digital microwave link, this is only true up to what we call the requirement level. Beyond this, you will not achieve any improvement on the radio link. Therefore, it is better to look at a larger antenna if possible, or add a second antenna for space diversity or a Multi-band booster channel. This means that using an antenna with better return loss and XPD values than needed does not hurt, but it will not produce better performance either. Thus, the added value from these antennas has decreased.

Multi-band solutions for capacity

Combining two or more frequency bands for one link is increasingly common in our mobile networks as we search for greater transport capacity. This is becoming more common in shorthaul, even though the antennas are fairly small. One antenna instead of two antennas still reduces site rental costs. In long haul, it is more of an issue if additional antennas are required, as you often have two very large antennas for space diversity, running between 1.2m and 4.6m. Adding two more of these might mean building a much more robust tower or even a second tower, rapidly increasing civil engineering costs. Therefore, it is better to have the same antennas for two adjacent frequency bands, such as 6L+6U or 7+8GHz, to significantly reduce the antenna and tower costs while enabling a capacity increase thanks to the added spectrum.

Figure 9 describes a real customer case. They were running a single 28MHz channel, providing 0.2Gbps capacity. As they plan to evolve to 5G, they wanted a path towards 2–3Gbps. At most, they could get three frequency channels in the current 8GHz band. A first option was to migrate to long-haul technology and add a space diversity antenna for better availability at high modulations, resulting in 1.4Gbps capacity, a 7x capacity increase with five-nines availability over 6 channels.



Ice buildup can be severe and weigh several tons

To reach the 2–3Gbps target, they need even more capacity. To maintain site rental cost, a dual-band antenna can be used; however, physics must be considered. It is harder to produce a dual-frequency support antenna in a single feeder if the two frequency bands are too close, but not close enough to be considered wideband support. Here, they will interfere with each other. Dual-band support is easier if there is some distance between the frequency bands, but then the propagation characteristics will be different; see Figure 9.

The two frequency bands used in the combined dual-band antenna will have different availability figures. Using the 18GHz band enables easy access to 4 channels, 2 frequency channels in CCDP, since space diversity is not needed at 18GHz and, therefore, the radios placed on the original SD antenna can be used as normal radios in this band. This part of the total 3.2Gbps capacity will have a three-nines availability, so you cannot reach full capacity for 8–9 hours per year. This valuable additional doubling of capacity to the original service performance in the low long-haul bands will greatly improve customer quality of service.

Do icy antennas put a freeze on capacity?
In some parts of the world, it is a reality to see towers with antennas covered in heavy snow and ice. ITU-R is quite clear that: Ice formation on an antenna, or its cover or window can cause large additional attenuations. It is not considered practicable to formulate a global model for this effect since, for reliable operation under freezing conditions, antennas should be kept clear of icing.[1] Aside from the mechanical stress on the tower and antenna, a fair question to ask is how the system can function at all when it looks like this.

Research from the 1950s up to today has repeatedly shown that dry ice and snow have a rather low attenuation compared to water, whereas wet ice and snow can have extremely high attenuation, as the whole block of snow or ice becomes more akin to water.[2] This is also true for snowfall. Dry snow below the 0-degree isobar has quite low attenuation compared to rain, whereas wet snow, that is, in the 0-degree isobar, has higher attenuation than the same downpour of rain. This is because water-covered ice particles are larger than the equivalent raindrops and, therefore, attenuate the lower frequencies more than rain.

For a dry ice or snow layer on the antenna, this means that the attenuation is limited. But when the ice or snow starts to melt, it will quickly increase the attenuation and may cause the link to fail. This is also why the snow and ice that can build up inside the radiating aperture must be limited.

Therefore, these sites use technology, such as an ice shield and/or radome, to protect the equipment. The ice shield is a strong metal grid mounted over the antenna to protect against ice falling from the tower. A radome can be anything from a thin membrane wall at the antenna's front to complete coverage of the tower or site in panels with good dielectric performance for the used frequencies. In some installations, heating is fitted for controlled melting of the snow and ice before it becomes too great. The downside is increased power consumption since such heating is outdoors on a surface subject to cold air.

Radomes are also used to protect antennas from sand or dust buildup. But in some cases, they tear and birds and squirrels nest inside them, causing link failures. In conclusion, antennas should always be free from ice, snow, sand, dust and animals for trouble-free radio link performance.

[1] ITU-R, Recommendation ITU-R P.530–17 (12/2017), page 15
[2] IEEE Transactions on Antennas and Propagation, Vol. 58, No. 5, May 2010, Terje Tjelta, Member, IEEE, and David Bacon

Resolving scattered spectrum

Increasingly wider channels have been released to satisfy capacity demand. With gradual development, spectrum usage can become scattered, potentially hindering capacity growth. So, what is the current situation and what measures can be taken?

The amount of accessible spectrum and wide channels, as well as the use of different licensing regimes, vary greatly around the globe. For deeper insight into the current situation, we have conducted a detailed study of a couple of microwave-centric markets in different continents: the Czech Republic in Europe, and India in Asia. Sweden and Bangladesh have also been investigated to widen the scope and to see whether there are similarities between countries within a region.

In each case, we have selected sites in dense urban and suburban areas. For each site, the number of transmitters within a 50km radius, corresponding to the coordination distance, is plotted versus frequency. All transmitters within this area must be taken into account when planning for a new link from this site. These plots give a high-level understanding of how congested and scattered the spectrum is.

European case – Czech Republic

The Czech Republic is a Central European country with a long tradition of using microwave as a backhaul media. The country is not only extensively using traditional bands but it is also an early adopter of E-band spectrum. Multiple frequency bands are accessible and the total available spectrum bandwidth is relatively high in the traditional bands as well as E-band. In 2019, the percentage of E-band links was already as high as 20 percent.[1] In the traditional frequency bands, link by link licensing is used, increasing the possibilities for all service providers to find free channels for new links.

Looking at a classic band, such as 18GHz, we can see in Figure 10 that it is moderately to highly utilized. 110MHz channels that enable gigabit capacity are available and there is room for additional use of these channels, especially in suburban sites. For highly congested areas, it is also possible to use 2x55MHz Carrier Aggregation when 110MHz is not accessible.

In the relatively new 32GHz band, there is naturally more room; see Figure 11. We know that 56MHz is currently the widest channel allowed while 224MHz of spectrum has been reserved for the future. This could be used for two 112MHz channels. Until wider channels are available, 2x56MHz Carrier Aggregation will enable gigabit capacity in a single radio. Today, the 32GHz band has been divided into blocks. In each block, only one channel size is allowed, putting some limitations on how to use the band most efficiently.

In addition to using 32GHz as stand-alone, the good spectrum availability in the 32GHz band could be used as a capacity booster in a Multi-band configuration with a lower band, for longer links in suburban and rural areas.

The situation in the 18 and 32GHz bands has also been analyzed for Sweden. The results show similarities to the Czech Republic, with a good deal of spectrum available. Link by link licensing is used and the availability of wide channels is good. Work is also ongoing to allow wider channels in more bands.

Asian case – India

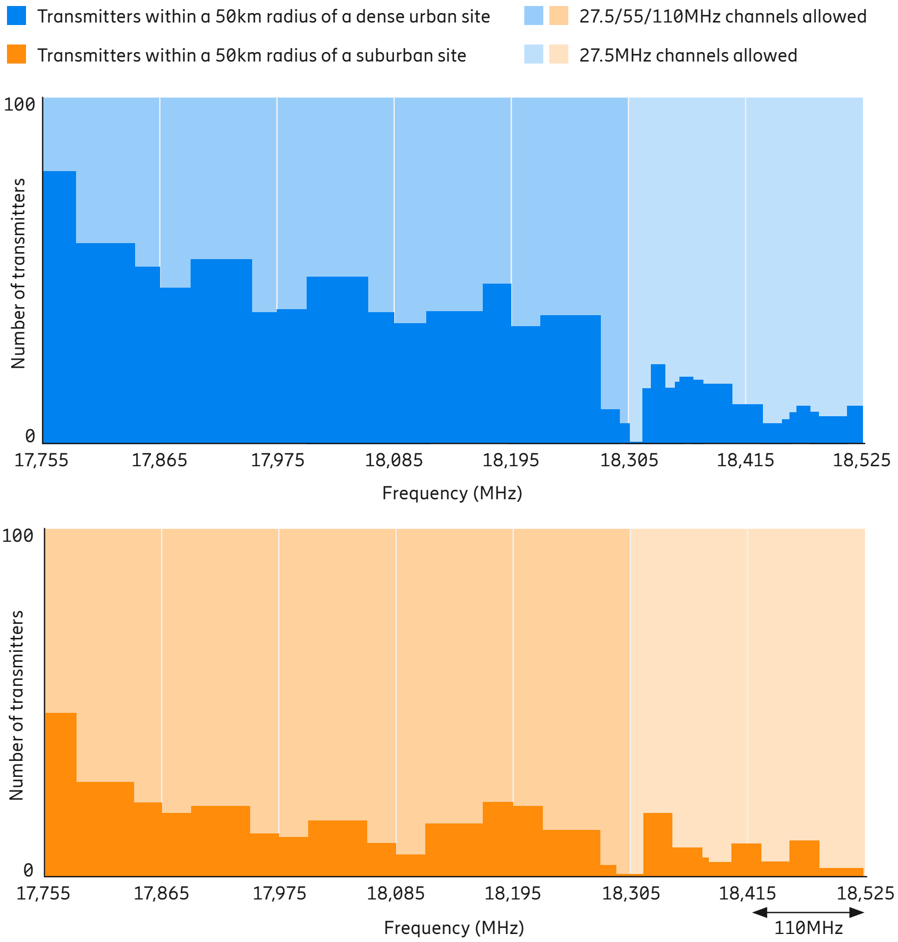
The situation in India is very different from that of the Czech Republic. Only a handful of bands are available and the vast majority of links can be found in the 15GHz band where block licensing is used.[2] Within the assigned blocks, service providers reuse the channels as much as possible, since the spectrum fee for using one additional channel is very high. This means that in some dense urban areas, the limits are pushed on how many links can be used while having an acceptable level of interference; see Figure 12.

Only 28MHz channels are allowed in India, making it very difficult to grow capacity. Extra hardware is needed for every new channel, instead of enabling a wider channel through software. In addition to the lack of 56 and 112MHz channel plans, the assigned blocks are often fragmented. So, even if wider channels were allowed, the huge installed base would make it difficult to access wider channels. Therefore, Carrier Aggregation and MIMO are highly relevant functions for the Indian market to grow in capacity in the traditional bands. It is also very important to open up the E-band, as this would enable many more possibilities for higher capacities. E-band can be used both stand-alone and in Multi-band configurations with a traditional band.

Bangladesh's spectrum situation is better than India's. There are many more bands available and in use but, similarly to India, block licensing is used with narrow channels like 14, 28 or 40MHz. On the positive side, the blocks are usually contiguous, but a single service provider rarely has access to a 112MHz block. These blocks are moderately to highly congested, so finding wider channels is much more challenging compared to Europe.

[1] Ericsson Microwave Outlook (2019)
[2] Ericsson Microwave Outlook (2016)

Figure 10: 18GHz transmitters within a 50km radius of a dense urban site and a suburban site in the Czech Republic



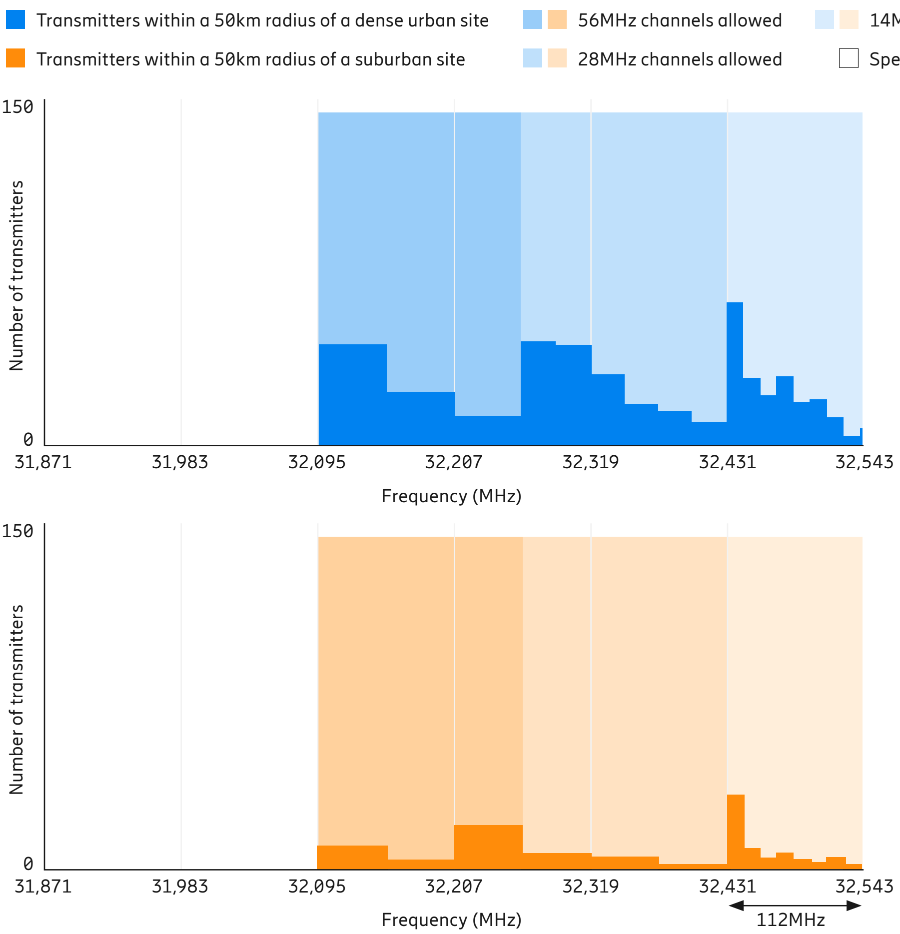
Czech Republic 18GHz
- Link by link licensed spectrum
- 110MHz channels available in the channel plan
- Moderately to highly utilized

Dense urban sites
- Some room for additional use of 110MHz channels
- Use 2x55MHz Carrier Aggregation in highly congested areas

Suburban sites
- Room for additional use of 110MHz channels

Source: Ericsson (2020)

Figure 11: 32GHz transmitters within a 50km radius of a dense urban site and a suburban site in the Czech Republic

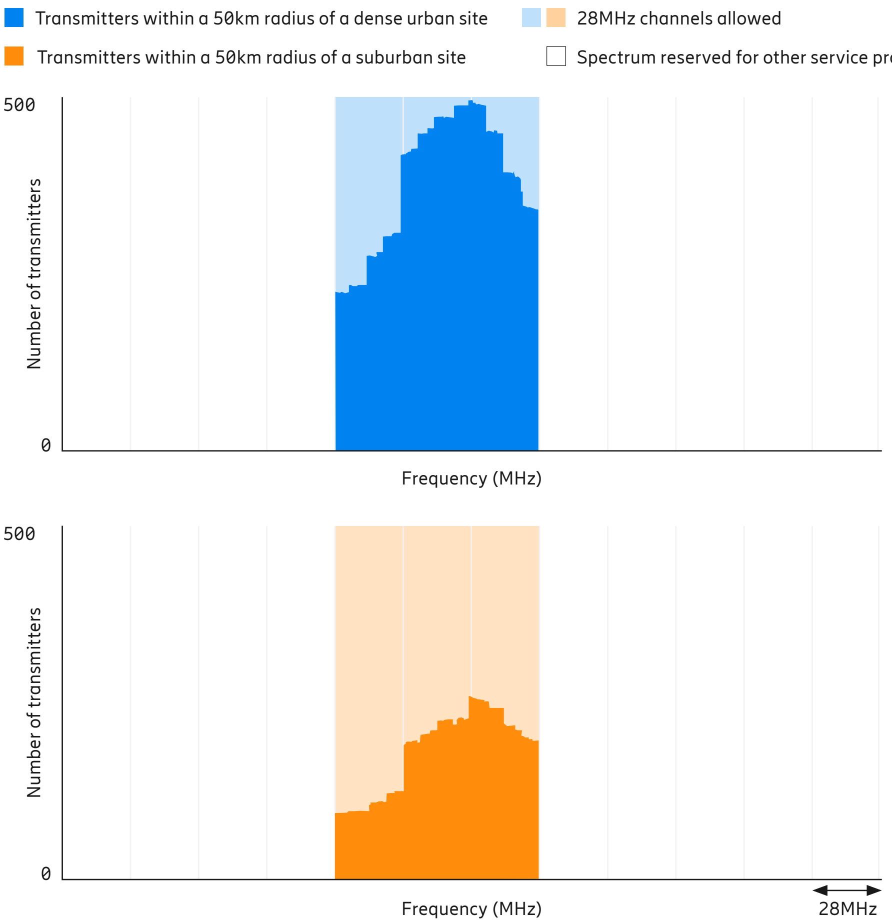


Czech Republic 32GHz
- Link by link licensed spectrum
- 112MHz channels currently unavailable in channel plan
- 56MHz, 28MHz and 14MHz channels in separate frequency blocks
- Moderate to low utilized since rather new band

Dense urban and suburban sites
- Use 2x56MHz Carrier Aggregation until 112MHz channels are available
- Can be used in a Multi-band configuration to boost capacity

Source: Ericsson (2020)

Figure 12: 15GHz transmitters within a 50km radius of a dense urban site and a suburban site for one Indian service provider



India 15GHz
- Block licensed spectrum per service provider in 28MHz blocks
- Spectrum situation varies per region and service provider, and is often fragmented
- Highly to heavily utilized

Dense urban and suburban sites
- Use 2x28MHz Carrier Aggregation or MIMO for capacity growth
- Wider channels and E-band would simplify capacity growth

Source: Ericsson (2020)

The way forward

Depending on the available spectrum, licensing regime and other factors, the situation looks very different around the globe, from markets with hardly any spectrum limitations to those with tremendous challenges; for example, scattered spectrum and lack of wide channels. However, some general actions can be applied in most markets, to continue to satisfy the ever-growing demand for more capacity.

It is clear that microwave supports the ever-growing capacity demands, now and in the future. Action from both regulators and manufacturers will make this journey even smoother.

Regulatory considerations
- Wide channels, up to 112 or 224MHz, in as many bands as possible
- Flexible channel plans, including overlapping plans,[3] and the possibility to use wide channels anywhere in the full band
- Refarming within and between bands to move links (in frequency) that hinder the usage of wider channels
- Opening up the E-band
- Spectrum fees that encourage spectrum-efficient technologies

Technology features
- Wide channels, up to 112 or 224MHz, in as many bands as possible
- Spectrum-efficient high modulations, up to 8k QAM
- Carrier Aggregation, both adjacent and non-adjacent channels
- MIMO
- Multi-carrier solutions, both in shorthaul and long haul
- Bonding of different frequency bands
- Super high performance antennas (ETSI class 4)
- Dual-band antennas

[3] When creating a plan for channels that is twice as wide as current channels, these combinations are normally used: ch1+2, ch3+4, ch5+6, etc. In an overlapping channel plan, these combinations are also allowed: ch2+3, ch4+5, ch6+7, etc. This creates more wide-channel combinations and flexibility

The importance of differentiated availability

With ever-increasing capacity in today's networks, it becomes even more important to differentiate backhaul availability.

In modern, packet-based backhaul systems with such functions as packet retransmission, adaptive modulation and adaptive power control, it is possible to design a radio link with differentiated availability. For example, the link can have very high availability for a baseline capacity to ensure that the overall system fulfills its basic operation, as well as lower availability for a significantly higher peak capacity.

Figure 14 illustrates capacity versus availability for three different microwave solutions. The curves depend on the dimensioning of the links and planning process. For example, a wideband E-band link can have high peak capacity with lower availability, while a narrowband system at a lower traditional frequency typically experiences lower peak capacity but with higher availability. By combining these, a Multi-band booster can take advantage of both E-band's high peak capacity and the traditional band's high availability.

We know that higher frequencies are more prone to rain fading and are better suited to shorter distances. If the peak rate's availability requirement is relaxed, a high-frequency link's hop length can increase. However, this depends on the desired capacity and availability.

The relentless push for higher capacity makes it increasingly challenging – and expensive – for future systems to maintain the high availabilities of peak capacity. This leads to the interesting question: What availabilities and corresponding capacities are needed for good end-to-end system performance?

To address this, we have performed network simulations that evaluate the combined effect of RAN and backhaul transport on end-user satisfaction, when backhaul capacities and availabilities are relaxed.

Video streaming scenario
Different services have various availability requirements. Here, we assume a very challenging video streaming use case. Video is driving network capacity, which makes it an interesting use case to study.

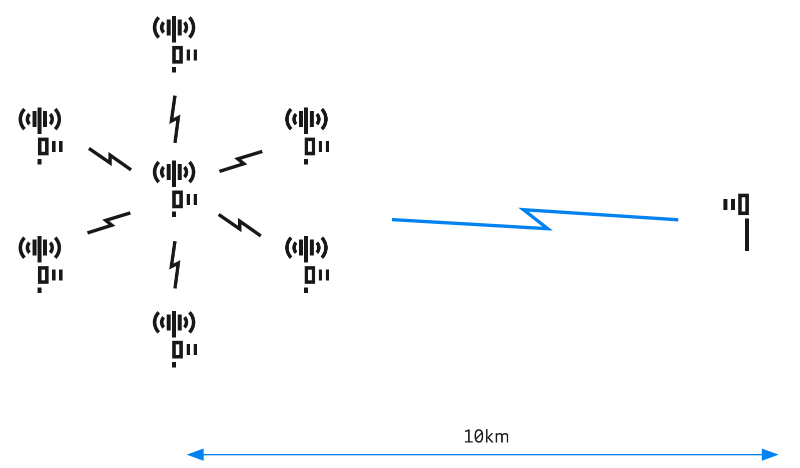
To evaluate the effect of relaxed availability on the backhaul in a RAN, we defined a QoE metric. We assume that there is a fixed number of network users, who are all consuming 4K video streams that require an average download rate of 25Mbps per user.

If the user rate falls below 25Mbps, the video quality reduces and, consequently, the user becomes unhappy.

The traffic load varies with changing the number of video users. It is possible to evaluate the user QoE by counting the fraction of users who are happy versus unhappy when system parameters, such as backhaul availability and traffic load, are changed.

Figure 13 illustrates network deployment with an aggregation link and the used backhaul parameters. The backhaul transport between the macro radio sites and aggregation site is ideal (infinite capacity with 100 percent availability), while the 10km aggregation link is a wireless backhaul link with relaxed capacity and availability to evaluate its impact on user QoE.

Figure 13: Simulation scenario with 10km aggregation link

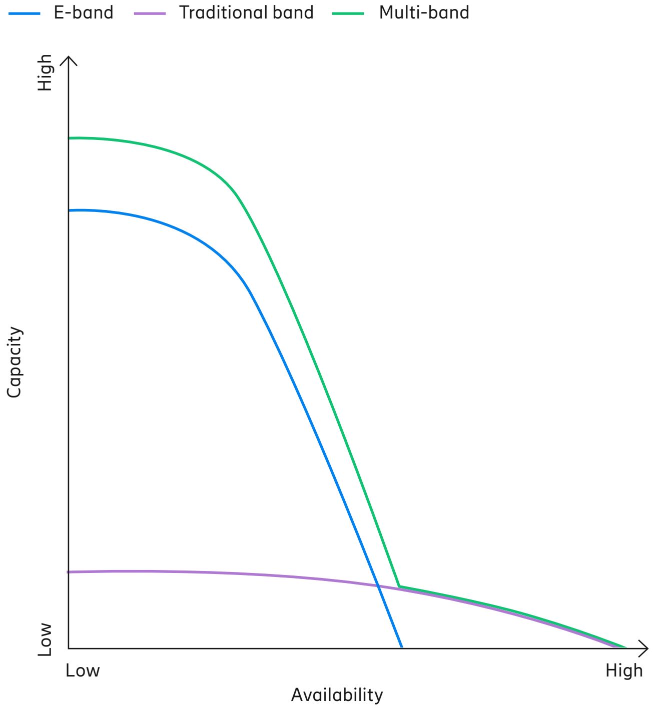


Backhaul from end nodes to aggregation node is considered ideal.

Microwave backhaul
Aggregation link, 10km, aggregating 7 radio sites, 21 sectors:
- Multi-band booster, 60cm dual-band antenna
  - E-band: adaptive modulation, 1,000MHz channel
  - 23GHz: adaptive modulation, dual-polarized, 56MHz channel
- Rain zone: exceeding 35mm/h, 0.01 percent of the year

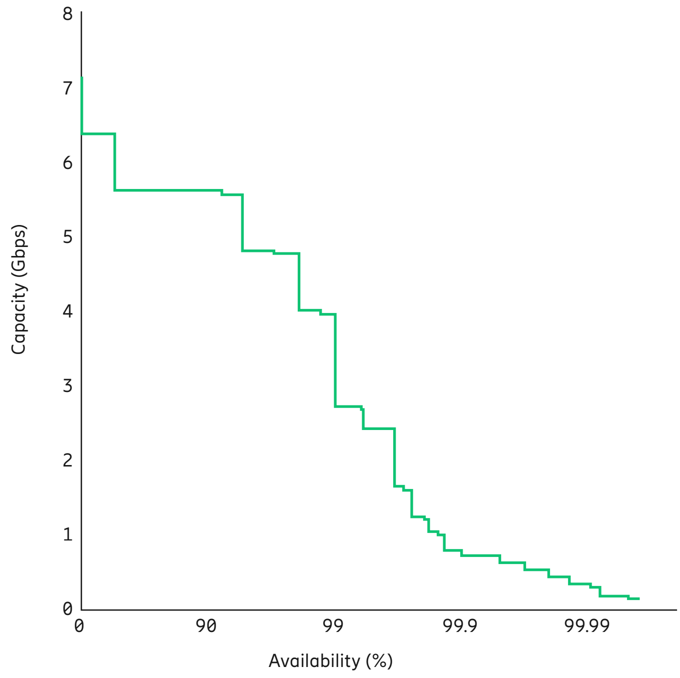
Source: Ericsson (2020)

Figure 14: Capacity versus availability for three different microwave solutions



Source: Ericsson (2020)

Figure 15: Capacity versus availability for a Multi-band booster configuration that does not reduce user QoE (based on the video streaming scenario)



Source: Ericsson (2020)

The RAN deployment is a macro-only 5G NR system operating in the 100MHz TDD spectrum at 3.5GHz. Each radio site has 3 sectors and is deployed above rooftops in an urban area with an inter-site distance of 500m. There is a total of 7 radio sites and 21 sectors deployed on a hexagonal grid in the network. N users are randomly distributed in the network with N/21 users per sector on average.

The aggregated user traffic from all 21 sectors is transported over the 10km microwave backhaul link. Each user demands a 25Mbps download rate and the served user rate depends on each user's propagation channel quality, interference, traffic load, backhaul quality, and so on. The DL peak rate is 580Mbps/sector. Three different network loads are simulated – low load (21 users), medium load (102 users) and high load (147 users) respectively.

Results from the simulations

Figure 16 shows the aggregated rates from all 21 sectors alongside capacity distributions of 3 different backhaul solutions for the 10km aggregation link. For the backhaul not to limit the end-to-end performance, its rate must be higher than the aggregated RAN rate with high probability.

Now we will look at the effect of varying the backhaul availability and capacity. Figure 17 shows the user QoE (percentage of happy users in the network) versus backhaul availability for 3.2Gbps, which corresponds to capacity where 128 users can be served 25Mbps each. Please note, even if the availability on the x-axis is specified for 3.2Gbps, the availability for all capacities is varied and not for 3.2Gbps only.

The maximum user QoE at low, medium and high loads is 100, 95 and 74 percent respectively. These maximum QoE numbers are also attained by using an ideal backhaul with 100 percent availability for infinite capacity.

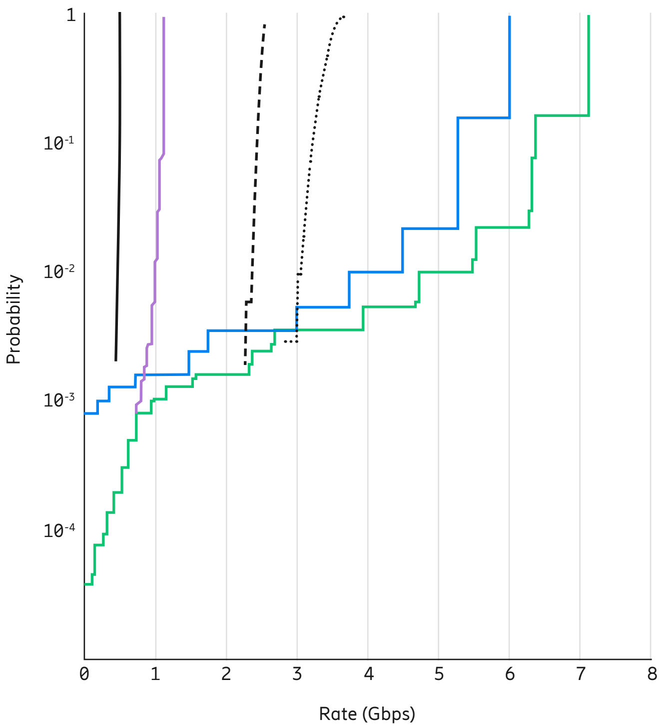
Thus, users can be unhappy with ideal backhaul due to RAN limitations, such as interference, resource sharing between multiple users and poor user channel quality due to propagation challenges. The higher the network load, the more pronounced some of these limitations become.

In Figure 17, at low load, user QoE is not impacted when the availability is reduced, and the wireless backhaul is never limiting. At medium load, user QoE remains at 95 percent in the 99–99.999 percent availability range. If availability is reduced below 99 percent, user QoE decreases as the backhaul starts to limit end-to-end performance. However, at medium load, the reduction in user QoE can be regarded as minor (only a few percent units), while at high load, the drop when availability is reduced below 99 percent is much more dramatic. One key point is that even if the percentage of happy users is reduced when the network load is increased, the total number of happy users is much greater at high loads simply because there are more active users in the network.

In the simulated network scenario, 99 percent availability of 3.2Gbps seems to be the breaking point when the backhaul starts to limit user QoE if it is relaxed even further. Figure 15 shows the remaining capacities and corresponding availabilities in the Multi-band booster, configured for 3.2Gbps with 99 percent availability. This indicates the capacity levels and corresponding availabilities needed for the backhaul to not limit user QoE; for example, 90 percent availability for 5.6Gbps and 99.9 percent for 0.8Gbps.

Our simulations show that the availability can be relaxed in capacity-demanding services like video without a negative impact on user QoE. This stresses that a properly dimensioned backhaul with differentiated availability can have much lower availability for the higher capacities while maintaining high availability for lower rates. Therefore, E-band and Multi-band booster solutions are well positioned as future-proof wireless backhaul technologies when traffic loads increase in 5G and beyond.

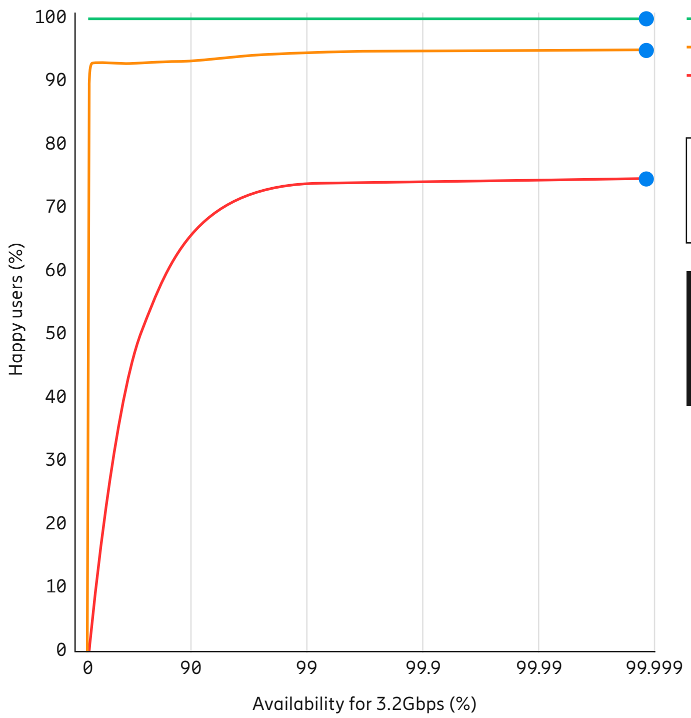
Figure 16: RAN and backhaul rate distributions



E-band and Multi-band are well positioned to handle high loads in RAN.

Source: Ericsson (2020)

Figure 17: User QoE (percentage of happy users) versus backhaul availability



User experience is mainly driven by RAN performance.

Differentiated availability enables cost-efficient backhaul without affecting user experience.

Source: Ericsson (2020)

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