



ERICSSON

MICROWAVE TOWARDS 2020

DELIVERING HIGH-CAPACITY AND COST-EFFICIENT
BACKHAUL FOR BROADBAND NETWORKS
TODAY AND IN THE FUTURE



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EXECUTIVE SUMMARY

Mobile coverage and capacity are evolving fast as operators expand and enhance 3G networks, roll-out new 4G networks, bring in complementary coverage/capacity solutions such as micro, pico, Wi-Fi and indoor solutions, and thinking ahead towards 5G.

The rapidly rising capacity demands have led some market observers to point to the need for fiber, especially in metropolitan and suburban areas, and to express the view that microwave solutions will not be able to keep up in the future.

The reality is somewhat different, however. Not only can microwave solutions meet virtually every conceivable backhaul requirement today – with gigabit-per-second capabilities – they will continue to evolve to meet ever-increasing capacity demands and unprecedented levels of flexibility and cost-efficiency.

They will do this by delivering an expanding range of capacity-enhancing technologies, increased spectrum efficiency (across a wider range of frequency bands), support for efficient IP data transmission, and growing levels of optimization and automation.

In this way, microwave solutions will provide a vital element of operators' network evolution – boosting performance and quality of experience while minimizing total cost of ownership – to 2020 and beyond.

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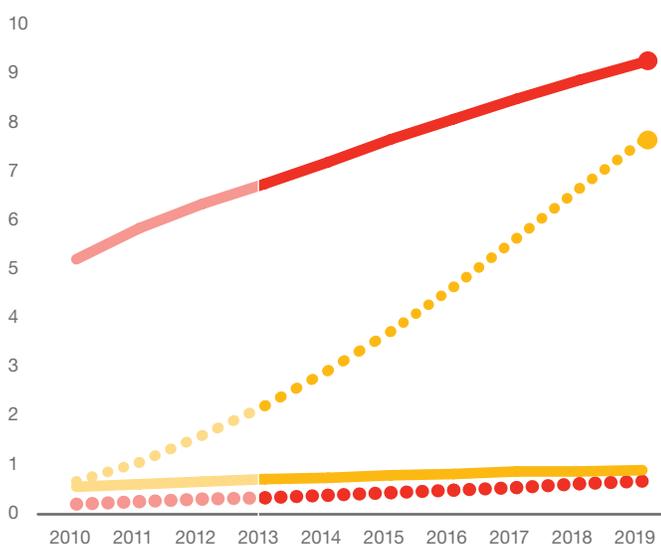


CHANGING BACKHAUL DEMANDS

Over the past 30 years or so, mobile communication systems have evolved from offering basic analog voice to very powerful communication systems that provide hundreds of thousands of different applications to billions of users. This evolution is only the beginning of a transition into a fully connected Networked Society, which will enable people and things to access and share information anywhere, anytime.

By the end of 2019 total mobile subscriptions will top nine billion and, of these, more than four-fifths (7.6 billion) will be for mobile broadband (as illustrated in Figure 1). Over the same period, there will be an exponential rise in mobile data traffic, which is set to increase ten-fold between 2013 and 2019 – growing at a compound annual rate of 45 percent.

Figure 1. The rise of mobile broadband



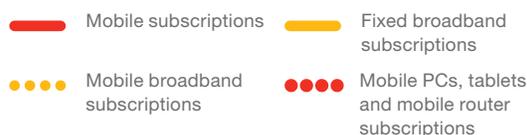
Source: Ericsson Mobility Report, June 2014

9.2 BILLION

mobile subscriptions
by the end of 2019

>80%

of mobile subscriptions
will be for mobile broadband
by the end of 2019



This thirst for mobile broadband is driving the rapid roll-out of mobile broadband networks, so that by 2019 WCDMA/HSPA will serve around 90 percent of the world's population and LTE will serve upwards of 65 percent.¹

But it's not just the volume of mobile data that is changing; the way it's being used is changing too. Mobile broadband is becoming increasingly woven into our daily lives: whether it's enabling a concert audience to share the live experience, subway commuters to catch up on news and e-mails, people to stream HD video or to conduct high-security mobile banking.

This places a new challenge on mobile operators to provide a highly versatile network with the performance to meet or exceed individual user expectations for every device, app and situation.

In a recent Ericsson ConsumerLab study of 12,000 mobile broadband users in 12 countries network performance was found to be the main driver of subscriber loyalty.²

Delivering this performance will require the roll-out of many more multi-band, multi-technology small cells, especially in city centers and other high-traffic areas.

¹ Source: Ericsson Mobility Report, June 2014

² Source: ConsumerLab, 2013

In addition, operators will need new radio access frequency bands, including low bands such as 700 MHz, the refarming of GSM frequencies to mobile broadband, and the introduction of higher bands such as 3,500 MHz.

In parallel, networks are converging into multi-service networks able to handle mobile, fixed and enterprise services. This is driving the need for even higher backhaul capacities, the ability to handle a large number of service instances flexibly, and support for different types of services with different performance requirements. These include broadcast services, mission-critical services and low-latency services.

At the same time, operators need to maintain or improve profitability through cost reduction and higher levels of automation – carrying the increasing levels of mobile broadband traffic in an affordable and sustainable way. This means next-generation networks must offer lower cost and energy consumption per delivered bit.

All this demands an increasing focus on building smarter, seamless end-to-end networks that reduce operating expenditure (OPEX) while increasing performance in a multi-technology and multi-layer environment.

Figure 2. Variation in capacity requirements per base station for operators at different stages of mobile broadband roll-out

2G operator introducing WCDMA in 2013 and LTE in 2019			
	2013	2016	2019
80% of sites	4 Mbps	4 Mbps	25 Mbps
20% of sites	8 Mbps	25 Mbps	90 Mbps
Few % of sites	25 Mbps	50 Mbps	180 Mbps
3G operator introducing LTE in 2013 evolving to LTE advanced			
	2013	2016	2019
80% of sites	50 Mbps	180 Mbps	270 Mbps
20% of sites	180 Mbps	540 Mbps	900 Mbps
Few % of sites	360 Mbps	900 Mbps	1.8 Gbps

Source: Ericsson (2014)

Already well established as the main backhaul transmission medium for mobile networks around the world, microwave's speed of deployment, flexibility, reliability, high capacity and low total cost of ownership (TCO) make it ideal to meet the future needs of both mobile and multi-service networks.

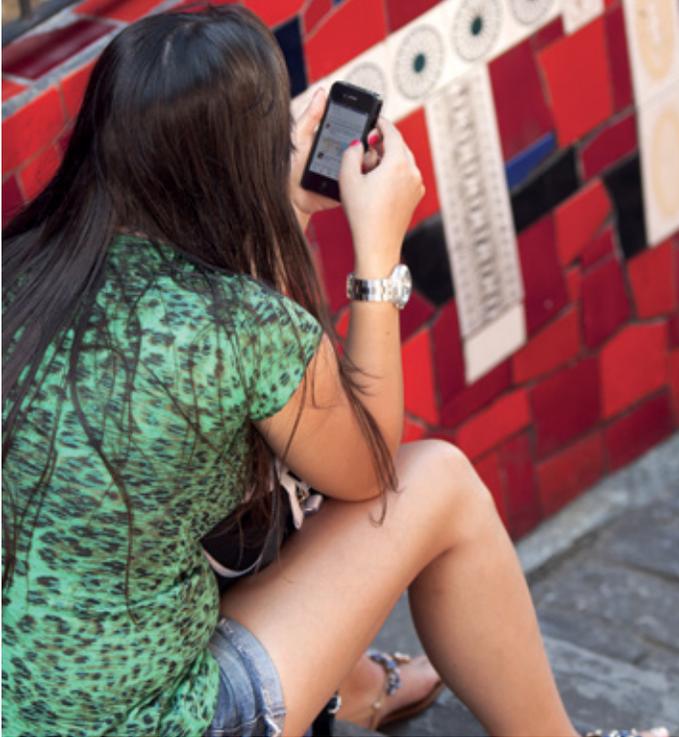
Varying site capacity needs

One noticeable aspect of mobile broadband growth is how varied it is across different countries, operators and local environments. While there is a definite need to increase data capacity in the RAN and backhaul, the timing of this increase will vary from market to market, as well as from site to site. Some markets have yet to deploy HSPA, while others have already deployed LTE on a large scale. Even within countries, the capacity needed per cell site varies hugely between cities, suburban areas and rural areas.

Figure 2 shows the typical mobile base station site capacity needed for two different deployment scenarios up to 2019 (including a 20 percent backhaul overhead). The upper table represents an operator in the launch phase of mobile broadband, which introduces WCDMA in 2013 and LTE in 2019. The lower table represents an early adopter, which introduces LTE in 2013 and evolves to LTE advanced. Most operators are somewhere in between these two positions today.

LTE Advanced with carrier aggregation will grow in importance for operators as a way of making more efficient use of spectrum assets and delivering improved app coverage, with higher peak data rates and better performance across the entire cell. The initial focus of carrier aggregation was to aggregate two 10 MHz channels to provide 20 MHz. Now, operators are shifting their focus to the aggregation of 20 MHz carriers to provide 40 MHz and 60 MHz, for example. Some of the most advanced operators with sufficient spectrum are even discussing aggregation to provide 100 MHz.

This means that by 2019, high-capacity base stations in the more advanced mobile broadband networks will need backhaul capacity in the 1 Gbps range, while lower-capacity base stations will need backhaul capacity in the 100 Mbps range.



Evolution towards 5G

With 5G mobile communication becoming available around 2020, the industry has already started to develop a fairly clear view of the main challenges, opportunities and key technology components it involves. 5G will extend the performance and capabilities of wireless access networks in many dimensions, for example enhancing mobile broadband services to provide data rates beyond 10 Gbps with latencies of 1 ms. But, and perhaps even more important, 5G will broaden the use of wireless systems into new areas such as mission-critical and massive machine-centric connectivity, as well as support for many other new use cases triggered by the networked society. Looking at the breadth of requirements deriving from these new use cases, it is also clear that in order for 5G to be successful, we need to address not only radio, but also transport, core/IP as well as support solutions.

Unlike previous operators which were based very much on the introduction of a new radio interface, for the 5G radio there is less focus on new modulation technologies.

Instead the research is more focused on developing improvements in areas such as advanced antenna solutions including advanced MIMO technologies, efficient multi-site coordination schemes and improvements in energy efficiency. It will also focus on support for new capabilities such as device to device communication, support for device battery life times in excess of 10 years for metering applications. Many of these technology developments can also be introduced in LTE, allowing LTE to evolve into an efficient component of a 5G system in 2020 and beyond.

Another important aspect influencing how 5G networks will manage the expected traffic increase is additional spectrum for mobile wireless communication. The 2015 World Radiocommunication Conference (WRC-15) will focus on the allocation of additional spectrum below 6.5 GHz for use by mobile communication.

However, to fulfill long-term traffic demands and, crucially to enable the very wide transmission bandwidths needed to provide multi-Gbps data rates efficiently, the range of operation for next-generation wireless access needs to be extended into higher frequencies above 10 GHz – an agenda item for WRC-19. Additional spectrum from 10 GHz all the way up to 100 GHz is being considered for 5G, which will enable 5G to be deployed in frequency bands spanning from below 1 GHz up to 100 GHz.



5G MOBILE
communication will be
available around 2020

Microwave is a key element of current backhaul networks and will continue to evolve as part of the future 5G ecosystem. An option in 5G is to use the same radio access technology for both the access and the backhaul links, with dynamic sharing of the spectrum resources. This can provide a complement to microwave backhaul especially in very dense deployments with a larger number of small radio nodes.

BACKHAUL MEDIA FOR THE FUTURE

The growth in mobile broadband has a massive impact on the transmission capacity needed to serve the various flavors of radio access network. In response, we'll see a continuation of the long-established trend in backhaul networks for wireless media to replace copper, which is not scalable enough to meet future demands. Fiber will replace copper and wireless media wherever its additional cost and deployment complexity can be justified.

Today, microwave transmission dominates mobile backhaul, where it connects some 60 percent of all macro base stations. Even as the total number of connections grows, microwave's share of the market will remain fairly constant. By 2019, it will still account for around 50 percent of all base stations (macro and outdoor small cells (see Figure 3). It will play a key role in last mile access and a complementary role the aggregation part of the network.

At the same time, fiber transmission will continue to increase its share of the mobile backhaul market, and by 2019 will connect around 40 percent of all sites. Fiber will be widely used in the aggregation/metro parts of the networks and increasingly for last-mile access.

There will also be geographical differences, with densely populated urban areas having higher fiber penetration than less populated suburban and rural areas, where microwave will prevail for both short-haul and long-haul links.

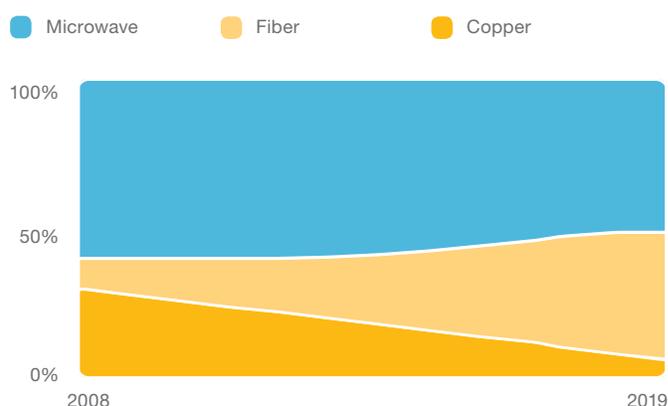
Regional differences

There are wide geographical variations in the penetration of the different backhaul media across different parts of the network, which can be attributed to a number of factors.

The main one is market maturity in fixed and mobile telecoms. More mature regions typically have much higher fiber penetration as a result of capacity needs. The second one is government incentives in some markets.

Cable-based solutions, using fiber or copper, have mainly been deployed for transporting fixed services in both the access and aggregation parts of the network, for example for fixed broadband (such as xDSL), corporate services and more recently FTTH/FTTB. In most cases, mobile backhaul reuses existing cable-based infrastructure since the investment threshold for dedicated mobile backhaul

Figure 3. Microwave will continue to be a major mobile backhaul medium, connecting around 50 percent of all radio sites in 2019



Source: Ericsson (2014)

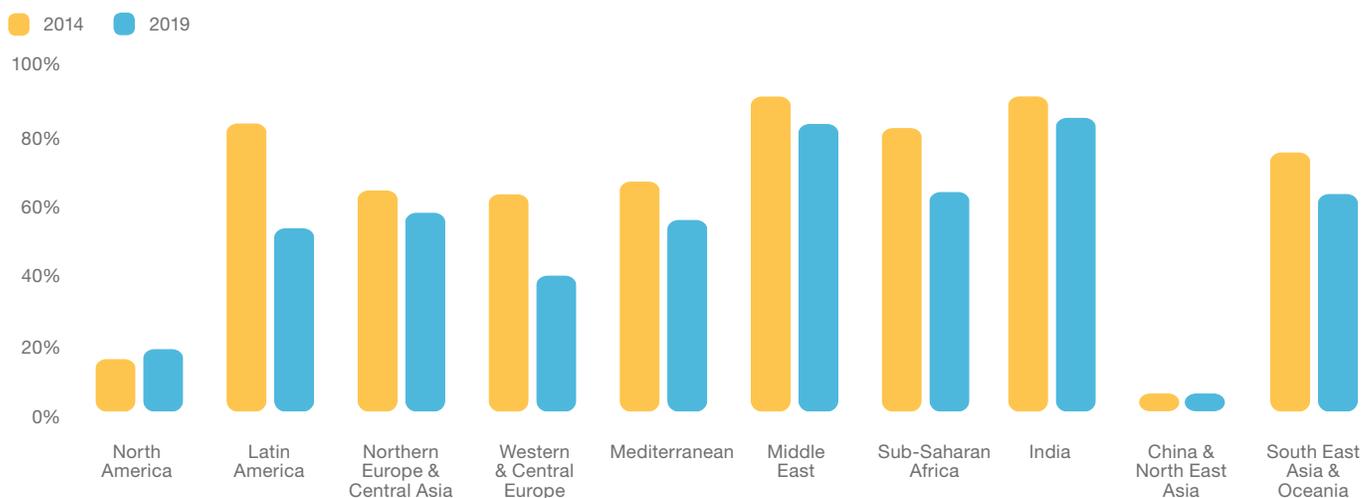
fiber is high, especially in the access part of the network. Even within a region or country there are often large variations in fiber penetration, even in mature markets.

The utilization and availability of owned fiber can also vary widely, according to whether the network is serving fixed and mobile together or mobile alone. For example, in one European country, one operator uses 90 percent microwave transmission, while another uses only 30 percent. There are options to lease capacity or dark fiber, but this is mainly done in the aggregation part of the network, which constitutes around 20 percent of sites in the network.

One example of where government initiatives have had a key influence is China, where fiber is available at the majority of sites; here microwave is used mainly as a complementary technology.

Even as private and government initiatives drive the deployment of fiber to support growing capacity needs, especially in the aggregation network, microwave will continue to be widely used in the access network, especially for outdoor small cells.

Figure 4. Regional differences in deployed microwave backhaul



Source: Ericsson (2014)

Microwave's overall share of the backhaul market may decrease over the coming years, but the volume of macro and small cell base stations will continue to increase, ensuring that the total number of microwave-connected base stations will increase.

Figure 4 shows the wide variation in the proportion of radio base stations connected by microwave in different parts of the world – ranging from single-digit percentages in China and North America, to around 90 percent in India and the Middle East.

 **90%**
connected by microwave
in India and the Middle East

One region with early LTE deployment is North America. Here microwave has increased its share of backhaul deployments over the past few years, driven by the lack of readily available fiber and existing copper-based infrastructure not meeting requirements. Another factor driving microwave deployment here is operators' desire to move from a leased backhaul model to a self-built model to reduce operational costs.

In terms of fiber deployment, Western Europe is a mature market, and this supports the continued introduction of fiber as capacities increase, especially in more densely populated areas.

In other parts of the world, including Africa, India and the Middle East, the transition to fiber will take longer as a result of factors such as rights of way, and here most mobile broadband network will be deployed using microwave backhaul.

Some regions, including Latin America, are expected to undergo rapid transition to fiber. To make this happen, the combination of anticipated government initiatives and operator investments need to be realized.

Looking forward

Higher capacity needs in the metro/aggregation network will continue to drive the deployment of fiber further down into the mobile network. But the speed, flexibility, reliability and low TCO of microwave transmission make it ideal to meet the rapidly expanding capacity needs of the fast-growing numbers of cell sites.

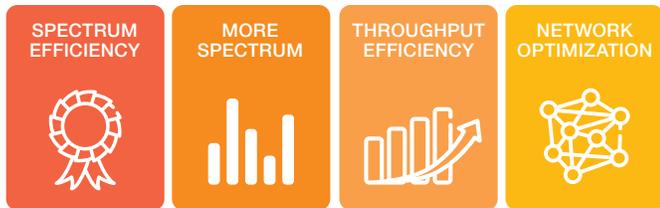
Although microwave capacities will be dimensioned based on actual needs, microwave will evolve to offer fiber-type capacities at the 1 Gb and 10 Gb levels, and multiples of these, as outlined in the following sections.

INCREASING CAPACITY AND SPEED

The main challenge for backhaul networks over the next few years is to support the delivery of higher capacity and download speeds per user. Microwave networks are already capable of delivering Gbps capacity. However they will continue to evolve to make ever better use of available spectrum, through continually improving link gain and features like multi-layer header compression, multicarrier, adaptive modulation and radio link bonding. They will also add capacity by making use of additional spectrum and more effective antennas.

Operators have at their disposal a ‘capacity toolbox’ for getting more capacity out of their microwave backhaul networks over the coming years in four key areas: spectrum efficiency; additional spectrum; throughput efficiency and network optimization (as illustrated in Figure 5).

Figure 5. Microwave capacity toolbox



Source: Ericsson (2014)

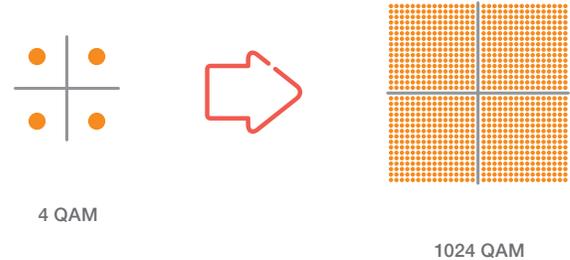
Spectrum efficiency

Spectrum efficiency (that is, getting more bits per Hz) can be achieved through techniques like higher-order modulation and adaptive modulation, the superior system gain of a well-designed solution, and Multiple Input, Multiple Output (MIMO).

Modulation

The maximum number of symbols per second transmitted on a microwave carrier is limited by the channel bandwidth. Quadrature Amplitude Modulation (QAM) increases the potential capacity by coding bits on to each symbol. Moving from two bits per symbol (4 QAM) to 10 bits per symbol (1024 QAM) delivers a more than five-fold capacity increase (as illustrated in Figure 6).

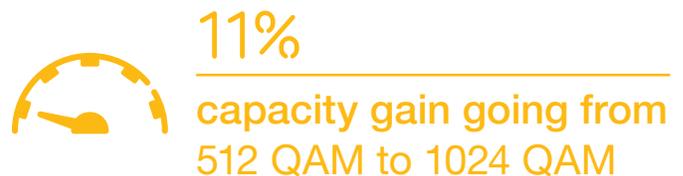
Figure 6. Moving from 4 QAM to 1024 QAM modulation delivers a more than five-fold capacity increase



Source: Ericsson (2014)

Higher-order modulation levels have been made possible through advances in component technologies that have reduced equipment-generated noise and signal distortion. In the future there will be support for up to 4096 QAM (12 bits per symbol), but we are approaching the theoretical and practical limits.

Higher-order modulation means increased sensitivity to noise and signal distortion. The receiver sensitivity is reduced by 3 dB for every increased step in modulation, while the related capacity gain gets smaller (in percentage terms). As an example, the capacity gain is 11 percent when moving from 512 QAM (9 bits per symbol) to 1024 QAM (10 bits per symbol).



Adaptive modulation

Increasing modulation makes the radio more sensitive to propagation anomalies such as rain and multi-path fading. To maintain microwave hop length, the increased sensitivity can be compensated for by higher output power and larger antennas. Adaptive modulation is a very cost-effective solution to maximize throughput in all propagation conditions. In practice, adaptive modulation is a prerequisite for deployment with extreme high-order modulation.

Adaptive modulation enables an existing microwave hop to be upgraded from, for example, 114 Mbps to as much as 500 Mbps. The higher capacity comes with lower availability. For example, availability is reduced from 99.999 percent (5 minutes' yearly outage) at 114 Mbps to 99.99 percent of the time (50 minutes' yearly outage) at 238 Mbps.

System gain

Superior system gain is a key parameter for microwave. A 6 dB higher system gain can be used, for example, to increase two modulation steps with the same availability, which provides up to 30 percent more capacity. Alternatively it could be used to increase the hop length or decrease the antenna size, or a combination of all.

Contributors to superior system gain include efficient error correction coding, low receiver noise levels, digital predistortion for higher output power operation, and power-efficient amplifiers, among others.

MIMO

Multiple Input, Multiple Output (MIMO) is a mature technology that is widely used to increase spectral efficiency in 3GPP and Wi-Fi radio access, where it offers a cost-effective way to boost capacity and throughput where available spectrum is limited.

Historically, the spectrum situation for microwave applications has been more relaxed; new frequency bands have been made available and the technology has been continuously developed to meet the capacity requirements. However in many countries the remaining spectrum resources for microwave applications are starting to become depleted and additional technologies are needed to meet future requirements. Here MIMO at microwave frequencies is an emerging technology that offers an effective way to further increase spectrum efficiency and so the available transport capacity.



SYSTEM GAIN
is a key parameter
for microwave

Unlike 'conventional' MIMO systems, which are based on reflections in the environment, the channels are 'engineered' in point-to-point microwave MIMO systems for optimum performance. This is achieved by installing

the antennas with a spatial separation that is hop distance and frequency-dependent. In principle, throughput and capacity increase linearly with the number of antennas (at the expense of additional hardware cost, of course). An NxM MIMO system is constructed using N transmitters and M receivers. Theoretically there is no limit for the N and M values, but since the antennas must be spatially separated there is a practical limitation depending on tower height and surroundings. For this reason 2x2 antennas is the most feasible type of MIMO system. These antennas could either be single polarized (two carrier system) or dual polarized (four carrier system).

MIMO will be a useful tool for scaling microwave capacity further, but is still at an early phase where, for example, its regulatory status still needs to be clarified in most countries, and its propagation and planning models still need to be established. The antenna separation can also be challenging especially for lower frequencies and longer hop lengths.

More spectrum

The second section of the microwave capacity toolbox involves getting access to more spectrum. Here the millimeter-wave bands – the unlicensed 60 GHz bands and the licensed 70/80 GHz band – are growing in popularity as a way of getting access to new spectrum in many markets (see Microwave Frequency Options section for more information).

These bands also offer much wider frequency channels, which facilitate deployment of cost-efficient, multi-gigabit systems.

Throughput efficiency

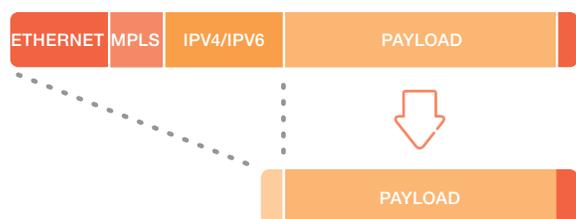
The third section, throughput efficiency (that is, more payload data per bit), involves features like multi-layer header compression and radio link bonding, which focus on the behavior of packet streams.

Multi-layer header compression

Multi-layer header compression removes unnecessary information from the headers of the data frames and releases capacity for traffic purposes, as shown in Figure 7. On compression, each unique header is replaced with a unique identity on the transmitting side, a process which is reversed on the receiving side. Header compression provides relatively higher utilization gain for packets of smaller frame size, since their headers comprise a relatively larger part of the total frame size. This means the resulting extra capacity varies with the number of headers and frame size, but is typically a 5–10 percent gain with Ethernet, IPv4 and WCDMA, with an average frame size of 400–600 bytes, and a 15–20 percent gain with Ethernet, MPLS, IPv6 and LTE with the same average frame size.

These figures assume that the implemented compression can support the total number of unique headers that are transmitted. In addition, the header compression should be robust and very simple to use, for example offering self-learning, minimal configuration and comprehensive performance indicators.

Figure 7. Multi-layer header compression can deliver a capacity gain of up to 20 percent



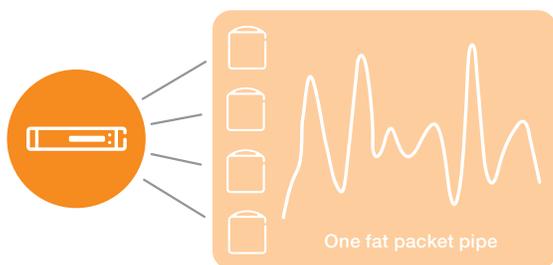
Source: Ericsson (2014)

Radio link bonding

Radio link bonding in microwave is akin to carrier aggregation in LTE and is an important tool to support continued traffic growth, as a higher share of microwave hops are deployed with multiple carriers, as illustrated in Figure 8. Both techniques aggregate multiple radio carriers into one virtual one, so both enhancing the peak capacity as well as increasing the effective throughput through statistical multiplexing gain. Nearly 100 percent efficiency is achieved, since each data packet can use the total aggregated peak capacity with only a minor reduction for protocol overhead, independent of traffic patterns.

Radio link bonding is tailored to provide superior performance for the particular microwave transport solution concerned. For example, it may support independent behavior of each radio carrier using adaptive modulation, as well as graceful degradation in the event of failure of one or more carrier (N+0 protection).

Figure 8. Radio link bonding can be used to deliver a single fat packet pipe with close to 100 percent utilization



Source: Ericsson (2014)

Just like carrier aggregation, radio link bonding will continue to be developed to support higher capacities and more flexible carrier combinations, for example through support for aggregation of more carriers, carriers with different bandwidths and carriers in different frequency bands.

Network optimization

The fourth section of the capacity toolbox is network optimization. This involves densifying networks without the need for extra frequency channels through interference mitigation features like super high performance (SHP) antennas and automatic transmit power control (ATPC). SHP antennas effectively suppress interference through very low sidelobe radiation patterns, fulfilling ETSI class 4. ATPC enables the transmit power to be automatically reduced during favorable propagation conditions (that is, most of the time), effectively reducing the interference in the network.

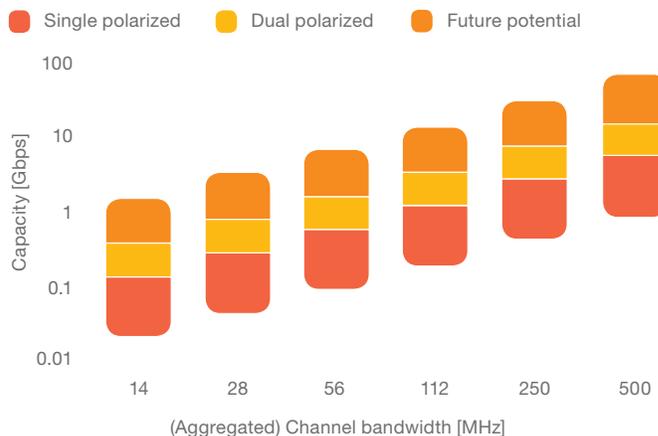
Using these features reduces the number of frequency channels needed in the network and could deliver up to 70 percent more total network capacity per channel.

Interference due to misalignment or dense deployment is limiting backhaul build-out in many networks. Careful network planning, advanced antennas, signal processing and the use of ATPC features at a network level will reduce the impact from interference.

Looking to the future

Over the coming years, these microwave capacity tools will be evolved and enhanced, and used in combination enabling capacities of 10 Gps and beyond as seen in Figure 9. Total cost of ownership will be optimized for common high-capacity configurations, such as multi-carrier solutions.

Figure 9. Evolution of microwave capacities



Source: Ericsson (2014)

MICROWAVE FREQUENCY OPTIONS

With microwave transmission at the center of future mobile broadband evolution, the availability of sufficient microwave spectrum is a crucial factor. More bandwidth and new spectrum are just as important for microwave transmission as they are for radio access to pave the way for mobile broadband. Harmonization around microwave spectrum and how to handle this spectrum in terms of the approach to licensing and spectrum fees are topics that have to be priorities and supported by national regulators, operators and vendors. This will positively contribute to each country's economic development.

Where are we today?

Traditionally, microwave links work in the bands shown in blue in Figure 10, which provides the total global

view of spectrum. It is worth noting that each operator will have access to a different palette of frequency bands in different countries or regions, since not all the bands shown will be available in each market.

The lower part of the bands shown is generally used for longer hop lengths of between 10 and 200 km since they are insensitive to rain. However, the amount of spectrum available in these bands is limited.

The upper part of the bands shown in Figure 10 is used for shorter hop lengths since it is sensitive to rain, with hop lengths lower than 1 km in dense urban areas. The amount of spectrum available in the upper part is larger than in the lower part.

Figure 10. Frequency bands available for microwave transmission



Source: Ericsson (2014)

Continuing with the global view, Figure 11 shows how the higher frequencies above 13 GHz represent the majority of microwave deployments, and 15 GHz represents the biggest frequency band of all. This is not because 15 GHz has the widest spectrum, but more because it is widely used all over the world. Another conclusion is that bands like 26, 28, 32 and 42 GHz are not as widely used as 38 GHz. In summary, there are a couple of bands that are much more heavily used than others, which indicates there is still a large pool of unused spectrum in traditional frequency bands.

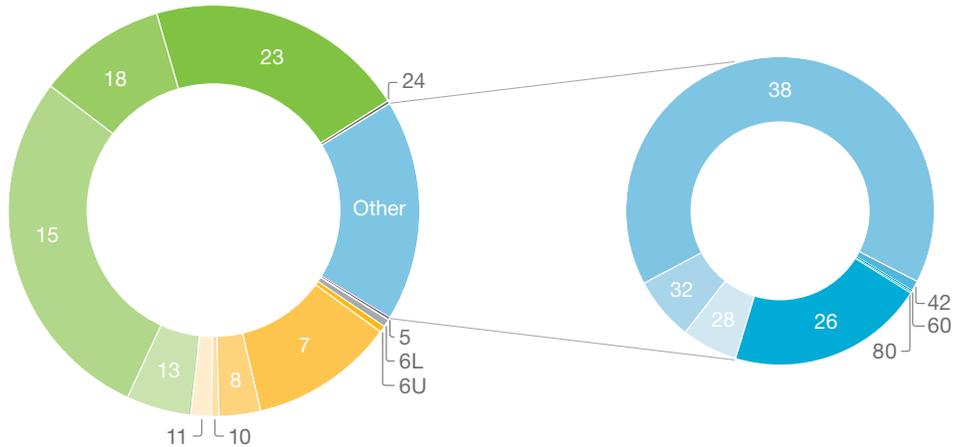
More recently, some new bands – 42 GHz band, 60 GHz and 70/80 GHz – have been made available or are to be made available. However, these are very country – or region-specific, and deployments so far are marginal compared with 38 GHz deployments.

Since these bands are new they have been targeted to offer wider channels than traditional bands, making them ideal for high-capacity, short-range links.

License fees vary massively around the world. For traditional bands, they vary from approximately 50 euro per hop per year to more than 4,000 euro per hop per year. Some countries charge less for the lower frequencies while other countries charge more for the lower frequencies. Other countries charge per channel and not per link.

Some bands have been sold off as frequency blocks by national authorities – such as the old LMDS/PMP bands (10, 26, 28, 32 and 42 GHz). Since these bands are not heavily used NLOS is one application that may intensify deployments into these bands. New bands like the E-band (70/80 GHz) are often priced very low compared with traditional bands to promote them or purely because of light licensing procedures.

Figure 11. Accumulated share of volumes per frequency band, 2006-2013



Source: Ericsson microwave radio shipments (2014)

What's needed for the future?

From a global point of view harmonization of fixed spectrum and how it should be used, including licensing and fees, would be very beneficial for the future. The challenge is that these questions are a national responsibility but national regulators should work together with both operators and microwave equipment vendors to get a common view of how to support mobile broadband evolution.



So what else is needed to be in a good shape for 2020? As stated earlier, it is vital that as much spectrum as possible is available for mobile broadband applications. The near-term focus should be to open spectrum below 100 GHz for deployment. Frequencies above 100 GHz will be needed for mobile backhaul beyond 2020, and in due course regulators should also consider these bands. Consequently, every national regulator should open up as many as possible of the bands that are mentioned in Figure 10 including traditional bands and new bands.

Wider channels are needed to minimize total costs. New bands should preferably have channel plans that support wider channels beyond 56 MHz. Existing bands should be restructured with a revised channel plan to allow for wider channels. Unused bands like the 50 GHz bands should be combined to offer new spectrum with wider channels.

To encourage innovation and flexibility, a mix of different licensing models should be considered. A good mix might be link-by-link licensing for efficient usage of spectrum, in combination with block licensing to offer NLOS links for dense urban applications (such as small cell backhaul), and light licensing to simplify and speed up licensing procedures. The 60 GHz band should preferably be targeted to small cell backhaul and should therefore be unlicensed. Licensing models should also encourage the use of super high performance (SHP) antennas instead of traditional high performance (HP) antennas, to more efficiently use the available spectrum.

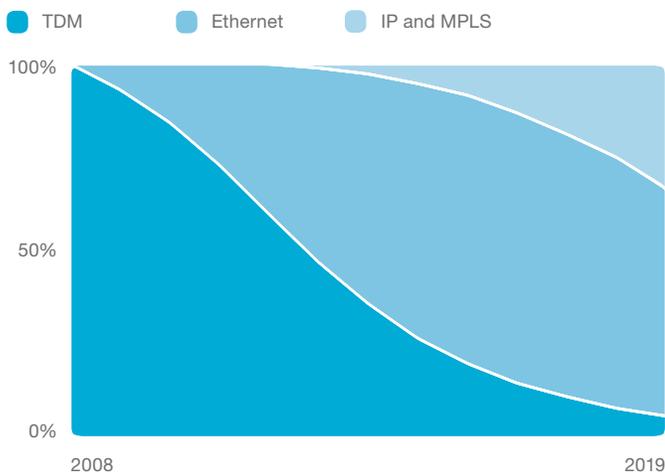
When it comes to spectrum, a fair cost model should be used together with a stable spectrum strategy to support mobile broadband evolution and the wider economic wellbeing of each country. There should not be any competition between different bands in terms of spectrum fees, since this would likely lead to movements between the bands to reduce OPEX.

TAKING THE NETWORK VIEW

Getting the maximum system gain, TCO benefits and overall performance from the backhaul network means taking the whole network into consideration, and not just individual node or link characteristics like modulation schemes or throughput rates.

As mobile networks evolve to 'one network' solutions, capable of handling 2G, 3G, 4G, Wi-Fi and other technologies, taking a network view of RAN and backhaul becomes essential for capacity dimensioning, protection and convergence, especially as IP, Ethernet and Multiprotocol Label Switching (MPLS) become more commonplace. The expected shift from TDM to Ethernet and IP with MPLS over time to 2019 is illustrated in Figure 12. The different networking technologies are described in more detail in the Packet Evolution section.

Figure 12. Indicative transport technology shift in microwave networks until 2019



Source: Ericsson (2014)

Although it is not shown in Figure 12, a few operators will likely have deployed Software Defined Networking (SDN) in their mobile backhaul networks by 2019, although larger scale deployments will probably come later. SDN technologies are further described in the Software Defined Networking section.

This means that, at a high level, microwave will need to serve the needs of two main applications: IP transport and heterogeneous RAN backhaul.

The seamless IP transport network will provide a multitude of services to a huge number of customers and applications (both fixed and mobile), with rapid service provisioning and differentiated performance. Here microwave will provide a fast, flexible complement to fiber – ideally behaving as 'virtual fiber', offering full visibility of the microwave status (in areas such as standardized bandwidth signaling).

 **MICROWAVE**
will be a fast, flexible
complement to fiber

Evolving topologies; supporting heterogeneous networks

As mobile operators enhance the performance of their networks to meet mobile broadband user expectations, the first evolution stage is typically improvement of the macro RAN: usually when WCDMA or LTE is introduced. The key demand on backhaul of this step is increased capacity, and it is natural to evolve to a more scalable packet transport network and to introduce packet synchronization.

The next evolution stage typically involves densifying the macro RAN; adding new sites and deploying fiber further out. The network architecture starts to change – for example moving from chain and tree to a ring structure – and more scalable nodes are needed; not only for capacity, but also to be able to add new links from a hub node, to handle numerous interfaces and to handle a larger number of network nodes.

Depending on capacity requirements and other factors, operators could use E-band microwave (which offers Gbps capacity) either to create high-capacity rings or for redundant protection of fiber links. As there is no single point of failure in a ring structure, the availability of the microwave link can be reduced to increase hop length or throughput.

A further, increasingly common, evolution stage is to add small cells to increase speeds in traffic hot spots as a complement to traditional macro cells as part of a heterogeneous network (please see 'Heterogeneous networks – meeting mobile broadband expectations with maximum efficiency' and 'It all comes back to backhaul – solutions supporting superior end-to-end quality of experience (QoE) for heterogeneous network deployments' (Ericsson white papers), for more detail).

The introduction of small cells in the radio access network as a complement to the macro cell layer will introduce many new sites, and new challenges for backhaul however.

Typically, outdoor small cell sites are installed 3–6 meters above street level on street furniture or building facades, with an inter-site distance of 50–300 meters. Due to the large number of small cells likely to be deployed, they will require more cost-effective, scalable and easy to install backhaul solutions that support a uniform user experience across the entire radio access network.

ENHANCE network performance

Traditional backhaul technologies such as line-of-sight (LOS) microwave are being adapted to meet this emerging need. However due to their positioning beneath roof height, there will be a substantial number of small cells without a clear LOS to an existing macro cell or a fiber backhaul point-of-presence.

In traditional LOS solutions, high system gain is used to support the desired hop length and mitigate fading caused by rain. For short-distance solutions, such as those needed for small cell backhaul, this gain may be used to compensate for non-line-of-sight (NLOS) propagation losses instead. While sub-6 GHz frequency bands may be used for small cell NLOS backhaul, microwave backhaul in bands above 20 GHz outperform sub-6 GHz systems under most NLOS conditions. Due to lack of spectrum 3G, 4G and WiFi will over time use these

sub-6 GHz bands. Hence NLOS deployments will over time be dominated by microwave bands above 20 GHz.

The connection between the radio unit and the baseband is sometimes referred to as the 'fronthaul'. The major drawback of fronthaul connections is the limited scaling and the need for ultra-high performance transport. It is not uncommon for fronthaul links to require tens of Gbps of capacity with sub-millisecond latency. While backhaul solutions can take advantage of statistical multiplexing, fronthaul deployments are always dimensioned for peak throughput to each sector and in addition the required fronthaul capacities are about 10 to 20 times higher than end user peak throughput. It is possible to implement fronthaul systems over high performance wireless links. However due to the very high capacities and wide channels needed, it is mainly as a complement to fiber fronthaul for the few sites that cannot be connected via fiber.

Only by taking a network view of backhaul requirements, rather than a simple site or link view, can such trade-offs be identified and acted on, while ensuring sufficient capacity and resiliency.



Packet evolution

As data traffic in the mobile network increases, so does the need to increase network capacity and handle this traffic more efficiently. Migration to packet-based networking is the obvious route to take.

The evolution of radio technologies means that different radio access types may require different transport technologies:

- > 2G networks have historically used TDM as transport technology. Either native TDM functionality or Circuit Emulation (CES) can be used to provide transport services but migration to multistandard Abis over IP is already ongoing
- > 3G networks were initially deployed using Asynchronous Transfer Mode (ATM) as transport technology in mobile backhaul but have largely been migrated to IP
- > In LTE networks, IP is the only protocol used to support connectivity between the different mobile nodes as defined by 3GPP.

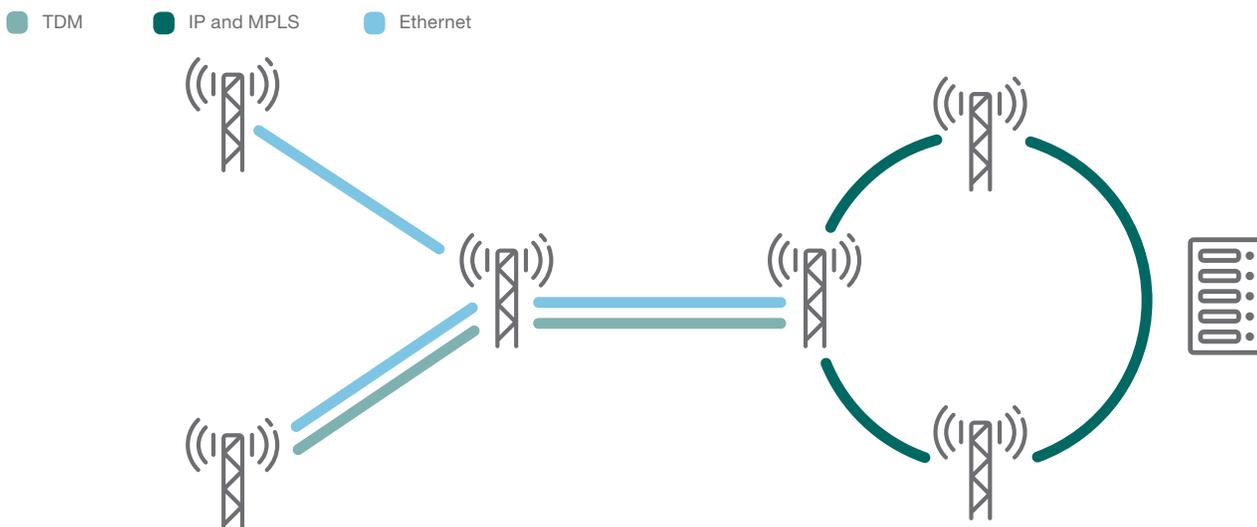
Today, microwave-based packet networks commonly use Ethernet Provider Bridge technology. While this is very good for mobile backhaul, it offers limited scalability in terms of the number of switches and services. IP routing tends to use Ethernet at the link layer and is more scalable than a Provider Bridge network in terms of the number of routers in a network. The resilience characteristics in a large network are also better than with Provider Bridge. However the number of services that can be supported is still limited, as every service has to be configured in every router in the network.

With all services being carried over a converged network, it is important that this network can provide the required capacity, flexibility and separation of multiple services. Separation is especially important if several mobile operators are using a shared network. The required separation of address spaces and network resources can be achieved with VPN technologies and advanced QoS mechanisms. These requirements on bandwidth and multiservice demands both simplicity and predictability in order to manage the network at the required level of performance for good user experience. One way to do this might be to move to a connection-oriented technology such as MPLS, which increases predictability in the more complex parts of the network (ring/mesh topologies). Where tree/star topologies continue to dominate, it makes sense to continue with Ethernet.



In IP/MPLS, the transport layer and the service layer have been separated and are configured separately. This means that adding a new router only requires configuration of the MPLS transport layer and adding a new service only requires configuration in the routers providing this service. In addition, MPLS can carry both IP-only services (Layer 3 VPN) as well as Ethernet services (Layer 2 VPN).

Figure 13. A mix of transport technologies is likely to coexist in most RANs



Source: Ericsson (2014)



Current microwave equipment combines the microwave technology with Ethernet and Provider Bridge technology. As IP routing and IP/MPLS move further out in the access network, it is natural that these technologies will also be integrated in the microwave equipment.

MPLS is also evolving with features like Hierarchical MPLS and Downstream on Demand (DoD) to enhance scalability while still using a unified MPLS technology. In some cases, MPLS-TP will also be used to create a managed network with very robust characteristics in terms of fail-over and control of active and backup paths.

It has always been a strategic imperative to unify network technologies as much as possible in order to simplify deployment and management. Using the same network technology also creates a seamless network that can eliminate problems with supervision and O&M across

technology borders. As a key transport network component, microwave has to support all evolving technologies, as most RANs will continue to employ a mix of transport technologies for some time to come, according to operator preferences and traffic levels.

Due to migration, all networking technologies – TDM, Ethernet Provider Bridge, IP routing and IP/MPLS – may be applicable, depending on the services to be supported and the level in the network hierarchy (access – aggregation – core). From a deployment and service enablement perspective, the technologies will be managed by a unified Network Management System (NMS) which will simplify the operation and supervision of the network. The use of multiple networking technologies also places demands on the mechanisms used for Self-Organizing Network (SON) technologies (see also Operation and Maintenance section).

Software Defined Networking (SDN)

SDN is a new approach to networking in which network control is decoupled from the data forwarding function and is directly programmable. The result is a dynamic, manageable, cost-effective, and adaptable architecture that gives programmability, automation, and control of the networking service. SDN may be applied to many network scenarios and one of them is in transport networks.

There are several challenges with existing transport networks:

- > Complex carrier networks with a large variety of proprietary nodes and hardware appliances, impacting efficiency negatively.
- > Launching new services is difficult and takes too long, and requires just another variety of box, which needs to be integrated.
- > Operation is expensive, due to existing procure-design-integrate-deploy cycle.
- > It is very difficult to test new ideas and strategies to solve the problems found in an existing network running live services.

SDN will enable the following planning, optimization and protection related Improvements:

- > Multilayer planning can save resources in terms of deployed equipment, time and expertise. The path computation algorithm provided by the SDN Transport Network Controller (TNC) can maximize equipment savings with better predictability and good network utilization.
- > As the network evolves and becomes more complex, multilayer resource optimization can make intelligent use of resources. Optimization is performed through a specific application that sits on top of the TNC, allowing the carrier to specify policy and metrics.
- > Applying multilayer protection/restoration removes the need to duplicate protection resources across several layers, and eliminates the conflicts that arise as a result of protection/restoration mechanisms working individually in the different layers.

As microwave nodes are transport nodes, SDN for transport will be equally applicable for microwave.





FREQUENCY

synchronization is key
to good performance

Several protocols are being standardized for SDN, among them are OpenFlow from Open Networking Foundation and PCEP from IETF. There is also an ongoing standardization, ITU-T Y.1731, of bandwidth signaling for microwave using Bandwidth Notification Messages. This can be used to signal bandwidth to neighboring equipment, and will simplify the introduction of SDN.

For wireless backhaul, SDN can enable dynamic resource management, enabling adaptation of microwave links characteristics through adaptive modulation and variable bandwidth in response to fading and changing weather conditions.

SDN can also be used for tighter integration of mobile broadband radio access with the backhaul network, in conjunction with Self Organizing Network (SON) technology. Although it is important to have control and knowledge of the available link resources in all types of networks, it is particularly important in microwave-based networks where the available bandwidth may vary with fading and weather conditions.

SDN can be combined with MPLS, so that the SDN controller establishes the MPLS paths through a network. This opens up a natural path from introducing IP/MPLS to network-wide optimizations with SDN.

These technologies will give operators better real-time knowledge and control of end-to-end network resources, with microwave nodes a fully integrated part.



MANAGE

legacy and
new services

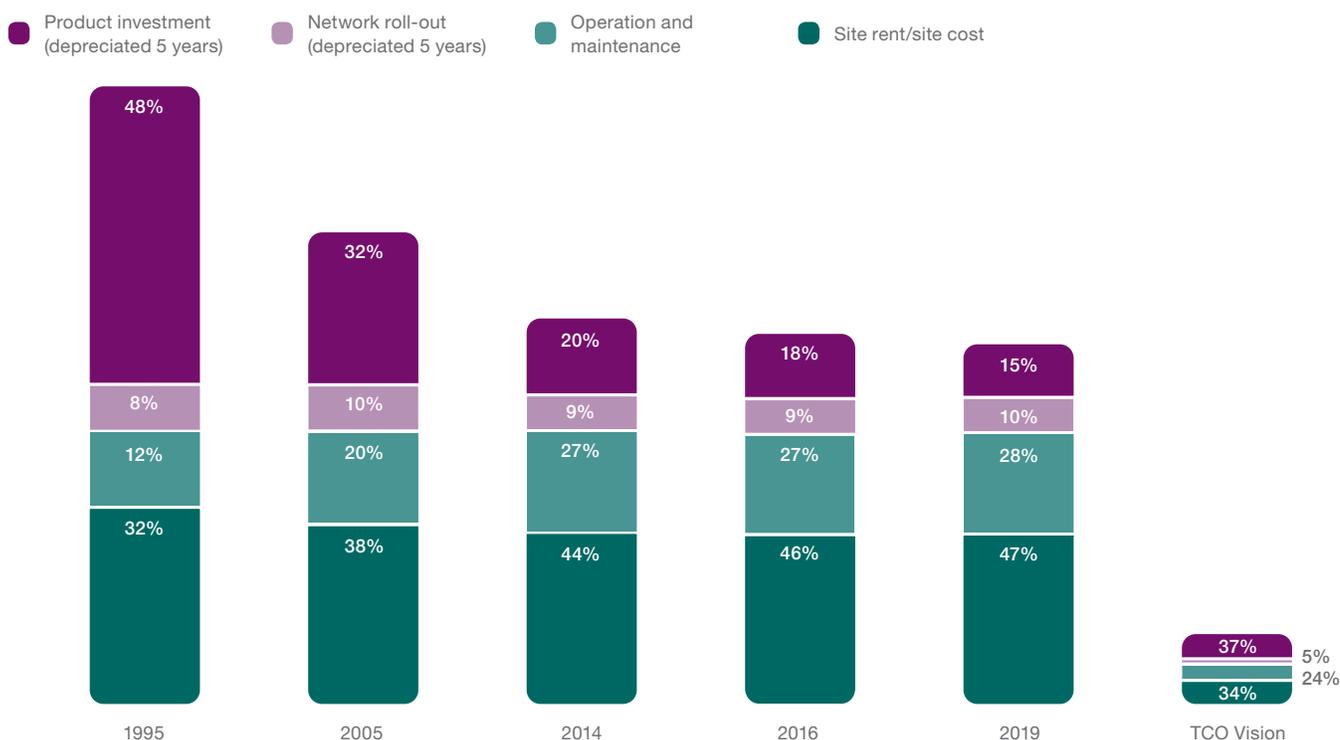
As SDN centralizes the control of the network, an additional advantage is that the SDN Orchestration System will have enhanced control of configuration and service enablement, both at initial deployment but also when new services and nodes are added. The Orchestration System will however handle both SDN and non-SDN network segments as SDN-based networks and legacy networks have to coexist. By using an Orchestration System, configuration and management will be more automated and OPEX will be reduced (see also operation and maintenance section).

REDUCING TOTAL COST OF OWNERSHIP

In order to meet the ten-fold capacity growth requirement, with the deployment of potentially many thousands of sites, it is vital to maintain or reduce TCO and get more and more out of the network. By 2020 we might expect to see roll-out simplified and automated to the extent that no specific radio or microwave competence will be needed to get a small cell site (both RBS and backhaul) up and running in less than 30 minutes.

As Figure 14 shows, the average TCO of microwave hops around the world has come down significantly over the past 20 years or so, and is set to continue to fall. However, network deployment and operation costs represent an increasing share of TCO, as product prices have fallen over time.

Figure 14. Microwave TCO evolution over time (global average cost per hop)



Source: Ericsson Market Research (2014)

These days, product investment accounts for only 20 percent of TCO; the bulk is accounted for by site rental, network roll-out and O&M costs. Operators therefore need to look at the complete picture and focus on the areas that make the most difference in order to reduce TCO further.

Figure 15 shows how product investment, deployment and O&M costs are distributed in a typical microwave backhaul network. The illustration shows the costs of ownership per year, so one-off CAPEX costs like network roll-out and products have been depreciated (over five years). It shows that, on average around the globe, site rental is 44 percent of TCO, O&M costs are 27 percent, product investment are 20 percent and network roll-out costs are 9 percent.

Site rental

In general, site rental costs are increasing in line with rising property prices in urban environments. However, this is being counteracted by the deployment of smaller footprint microwave equipment. There is a clear shift towards smaller antennas (for example from 1.2 m to 0.9 m, from 0.9 m to 0.6 m and from 0.6 m to 0.3 m)³. This is a result of things like improved system gain, decreasing hop lengths, higher frequencies and new designs that blend into the environment – meaning that site rental will remain roughly the same as today over the next few years.

Further reductions in site rental costs, to get down to the levels as described in TCO Vision in Figure 14, will be achieved through all-outdoor solutions, which not only require no indoor footprint but also make more locations

suitable and so drive price competition among landlords. Similarly, NLOS deployments will also reduce site rental costs by increasing the number of possible locations.

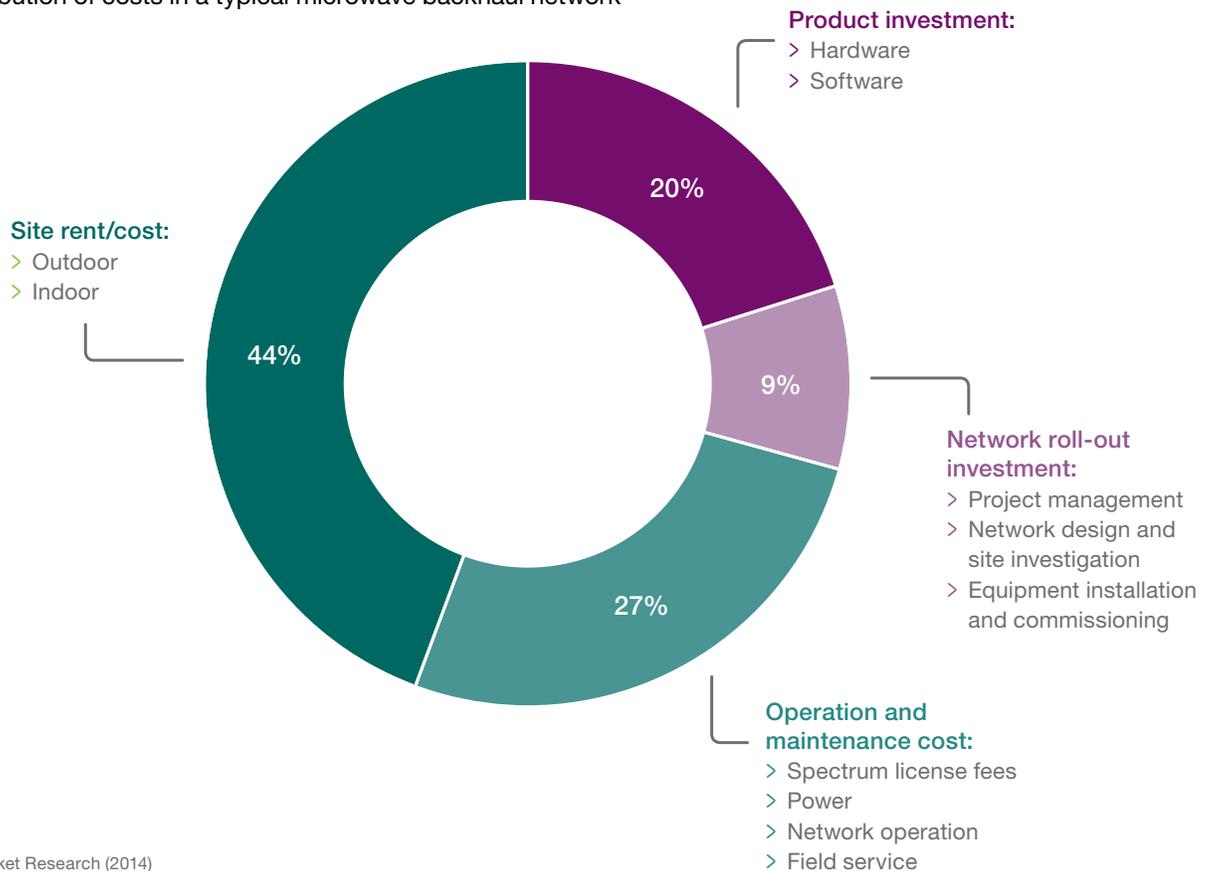


DESIGNS

that blend into the environment

Site rental costs can be reduced by 50 percent through tighter RAN and microwave integration, which reduces the combined footprint required at cell sites.³

Figure 15. Distribution of costs in a typical microwave backhaul network



Source: Ericsson Market Research (2014)

Operation and maintenance

Within O&M, spectrum license fees are the major component, followed by field service costs (including repair and maintenance of links, relating mainly to provision of 24/7 complete geographic coverage), Network Operation Center (NOC) costs, power consumption and spare parts.

Spectrum license fee costs have remained fairly flat over the years. However efficient use of spectrum will reduce the fee cost per hop, since fewer hops will be needed if spectrum use is optimized.

Global average salary costs are set to increase over the coming years, with higher increases in emerging markets and lower increases in mature markets. To keep network operation and field service costs at approximately the same level, network simplification and automation need to at least keep pace with salary increases.

Increasing levels of automation and simplification in troubleshooting, performance management and fault management will also help maintain or reduce network operation and field service costs. They will do this by reducing the level of competence needed among back office personnel and field service engineers. With tighter integration between RAN and microwave systems, field service and network operation can be handled with only minor expansion of the existing RAN workforce. This is required to come down to the levels described in TCO Vision in Figure 14.



To keep a lid on energy costs, power consumption needs to reduce in line with power price increases over the coming years. To reduce power consumption costs further, product features like Automatic Transmit Power Control (ATPC), or adaptive power consumption based on load and sleep mode, will be key. Tighter integration between RAN and microwave will be necessary to achieve substantial site-level power consumption reductions.

Self-Organizing Network (SON) technology is another important area for reducing O&M and network roll-out costs, by reducing the time and competence levels required. In addition, eliminating mistakes during installation leads to increased quality. We'll see increasing levels of end-to-end automation, for example by automatically converting network planning data into product configuration scripts that are automatically downloaded by the equipment when installed.

Network roll-out

As with field service and network operation, roll-out costs are strongly influenced by salary. Once again, keeping network roll-out costs at approximately the same level will require network simplification and automation to at least keep pace with salary increases.



MAINTAIN or reduce network roll-out costs

Again, increasing levels of automation and simplification in product planning and deployment will help maintain or reduce roll-out costs by reducing the need for site visits and the level of competence needed among field technicians and field service engineers.

Over the longer term, automation and simplification have the potential to substantially reduce microwave planning time to around two hours per hop and installation and deployment time to around the same level – both 90 percent lower than current levels. This level, as shown in TCO Vision in Figure 14, will require investments in product features, tighter integration between microwave and RAN, as well as changes in ways of working when deploying microwave networks, with increasing levels of automation and simplification and combined RAN and microwave deployments.

Product competitiveness

While price is always important, providing microwave solutions that enable efficient end-to-end backhaul networks is just as important in optimizing TCO. Microwave solutions need to be able to make even better use of available spectrum, across all available frequency bands, to deliver higher capacity and user download speeds. Operators need the right microwave solution for each part of the network, with investment in line with current site requirements and traffic levels.



HIGHER capacity and download speeds

Tighter integration between microwave and base stations or routers will be key to reduce TCO and increase end-to-end network performance. In small cell solutions, this will be critical to reducing footprint and minimizing deployment, operations and energy costs. Furthermore, tight integration is essential to delivering superior network performance, by aligning features based on end-to-end know-how and providing common management solutions.

Building an efficient microwave backhaul network, with end-to-end functionality, also requires features to be aligned and backward-compatible across different network nodes. Microwave transmission nodes need to be capable of handling single hops as well as advanced hub sites for larger networks. Such node solutions have been shown to reduce product investment by 40 percent compared with a 'hop-by-hop' approach.⁴



CONCLUSION

Over recent years, microwave technology has quickly moved way beyond being used mainly for delivering a few T1/E1 connections. It has made several leaps in capacity capabilities, and there are more to come. Today microwave can deliver gigabit capacity everywhere it's needed, quickly and cost-efficiently.

Thanks to ongoing technical innovation, microwave will continue to be the transmission medium of choice for mobile networks, and support the expansion of mobile broadband as it progresses through 3G, 4G, 5G and beyond.

As well as pushing the capacity limits through technologies like higher-order modulation, wider channels, dual polar operation, radio link bonding, microwave is also evolving to work more efficiently with built-in packet aggregation to minimize initial roll-out cost or network upgrading costs.

Microwave will maintain its dominant position in mobile backhaul transport by continuing to evolve to deliver the required capacity quickly, flexibly and with the lowest possible TCO.

⁴ Source: Ericsson market research

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