Modern microwave: Enhancing capacity to keep up with demand

With the adoption of smartphones and networked tablets, access patterns are changing dramatically. Now, there is a demand for bandwidth from almost everywhere.

New LTE macro cells and small cells can serve most of these needs, but building backhaul networks quickly, and often over difficult terrain, usually points to one solution – microwave. Nothing else meets the need for ubiquity, rapid deployment and scale, and affordability where existing distribution networks are not already in place.

As a result, more than 50% of mobile backhaul connections are met by microwave today. The challenge now is to scale the microwave backhaul network as:

- mobile radios move from 3G to LTE and LTE-Advanced
- small cell sites proliferate

This means interesting engineering challenges. Like any spectrum-based technology, there are real-world limitations to scaling microwave capacity and multiple ways to tackle optimization. The end solution is always a careful balance of technologies to increase spectral efficiency, combat radio interference, address weather-related impairments and contain costs.

In this e-book, we survey a range of optimization solutions for microwave and offer some considered perspectives on best choices. Here are the topics covered:

1. Bad radio propagation conditions such as rain, snow or multipath fading affect or distort the signal. This first section examines **the key countermeasures against selective fading.**
2. In microwave, spectrum is a limited resource. Every bit counts. But what is the math behind this and how much are we talking anyway? Learn more about spectrum efficiency and header compression in this section: **Air throughput: Dare to compare.**
3. As bandwidth-hungry smartphones and wireless tablets become more common, scaling capacity in microwave networks becomes essential. Learn more about **two strategies to scale microwave capacity.**
4. Once an operator has taken full advantage of these first strategies, the only way to get more microwave link bandwidth is to increase the number of radio channels used. Learn how **multichannel radio LAG improves/scales microwave capacity.**
5. The ITU standardization body recently introduced the concept of a packet microwave ring. This section demonstrates how **packet microwave rings optimize capacity and TCO.**
6. Small cells have emerged as an accepted approach to quickly and efficiently get additional capacity and/or coverage deployed to support LTE networks. Yet providing connectivity from those small cells back into the network – i.e., backhauling – remains a challenge. This is where **innovations in microwave networking offer some real opportunities**.
7. MIMO, although more closely associated with LTE and WiMAX, can be leveraged in microwave as well. Learn how operators can **make the most of MIMO.**
8. LTE-Advanced is making progress. This means new devices are coming that are capable of mobile downlink speeds up to 300 Mb/s and uplink speeds up to 100 Mb/s. Read how operators will be **boosting microwave capacity for LTE-Advanced.**

Scaling microwave link and spectral efficiency requires a careful balance. We hope this set of articles helps you with your own balancing act.

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Key countermeasures against selective fading

Roberto Valtolina

HIGHLIGHTS

- Higher modulation increases sensitivity to selective fading
- A powerful equalizer is a key countermeasure against selective fading
- Space diversity digital signal combining is more effective than switching

Selective fading, especially at low-to-medium frequencies, can be the limiting factor when determining the maximum link length for point-to-point microwave links. Microwave systems that offer the right countermeasures against selective fading increase the maximum link length for long-haul links. They also help service providers reduce the number of links with expensive space diversity – or 2-antenna – configurations.

DEFENDING AGAINST SELECTIVE FADING

As the microwave industry adopts higher modulation schemes, effective countermeasures against selective fading become extremely important. Service providers are already deploying 1024 Quadrature Amplitude Modulation (1024 QAM) systems. And 4096 QAM is on the near horizon. These higher modulation schemes are much more sensitive to selective fading than traditional 128 QAM.

Defending against selective fading is particularly important in long-haul links. With point-to-point radio links, many people think "the higher the transmit power, the longer the radio link." This is true, but transmit power is only one of the factors that should be considered in long-haul links. There are significant propagation impairments that cannot be mitigated by just increasing the transmit power. Different technologies, such as powerful equalizers, are needed to combat distortion.

Understanding the factors that affect maximum link length and the key countermeasures against selective fading help service providers evaluate microwave systems.

FACTORS THAT AFFECT MAXIMUM LINK LENGTH

Rain and snow are the main factors that affect maximum link length. The more intense the rain, the higher the signal attenuation, creating long-haul link deployment challenges. And the longer the link, the higher the attenuation effects of the rain. This type of attenuation is commonly called flat attenuation, or flat fading, because the same degree of fading occurs across the entire frequency.

Attenuation due to rain increases at higher frequencies. For example, at a rain rate of 60 mm/h, attenuation is:

- 13 dB/km at 38 GHz
- 0.3 dB/km at 6 GHz

The attenuation is different because the wavelengths are different sizes at high and at low frequencies:

- When the frequency is high, the wavelength is short so the rain attenuates more of the wave energy.
- When the frequency is low, the wavelength is long so the rain attenuates only a portion of the wave energy.

That's why today we see high-frequency short-haul links in the range of 5 to 20 km while low-frequency long-haul links can reach 150 to 200 km.

Knowing these facts, it seems that microwave link dimensioning is as simple as using the rain intensity and the transmission frequency to calculate the maximum link length. For frequencies higher than 13 GHz, it is that easy. When the transmitted power and the rain attenuation (db/km) are known, it is quite straightforward to calculate the maximum link length.

However, for frequencies that are lower than 13 GHz, other second order phenomena that limit link length must be taken into account. And these phenomena must be considered regardless of the attenuation introduced by rain and the amount of transmitted power.

MULTIPATH REFLECTIONS CAUSE SELECTIVE FADING

In low-frequency transmissions over long-haul links or across difficult propagation conditions, such as water, the receiver signal is composed of the main signal plus multipath rays. These multipath rays can be reflected by the ground, the water or the atmosphere.

The 3-rays model, also known as the Rummler model[1], is the universally accepted model to describe the multipath phenomenon in **line-of-sight microwave transmission**. There are 2 main consequences when multipath rays are reflected:

- The attenuation affects the frequency of the transmitted spectrum in different ways – hence the name selective (Figure 1).
- Mitigation techniques that go beyond increasing the transmitted power or the antenna size are needed to counteract distortion.

DIGITAL EQUALIZERS COMBAT DISTORTION

Technologies such as powerful equalizers compensate for and recover the distortion that multipath rays introduce. But not all equalizers are equal in terms of capabilities. It is important to measure the effectiveness of the equalizers and to compare their performance.

The concept of a signature, sometimes called a W-curve[2], is used to compare equalizer performance. The area of the signature helps to determine the maximum link length. The smaller the area of the signature, the better the performance of the equalizer and the longer the maximum link length.

The signature shown in Figure 2 indicates that the equalizer can compensate for fading up to 30 dB without errors:

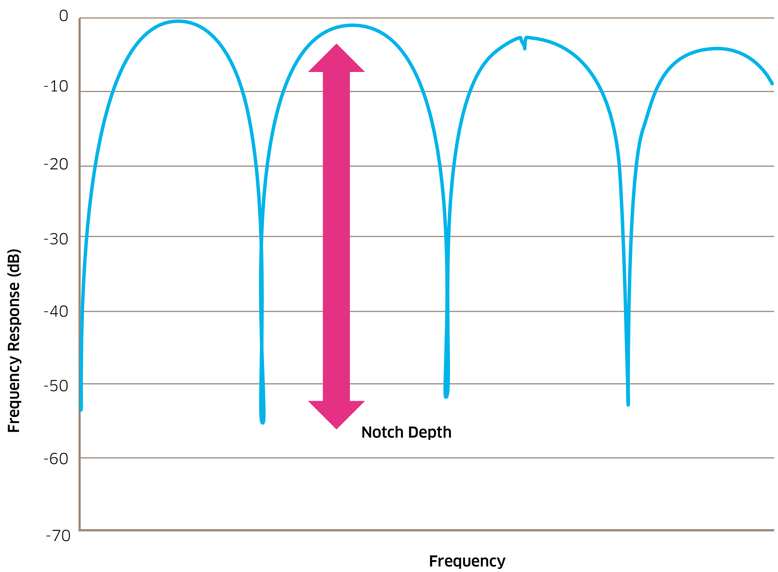
- The x axis shows the system gain including antenna gain.
- The y axis shows the signature depth; the greater the value, the smaller the signature area.

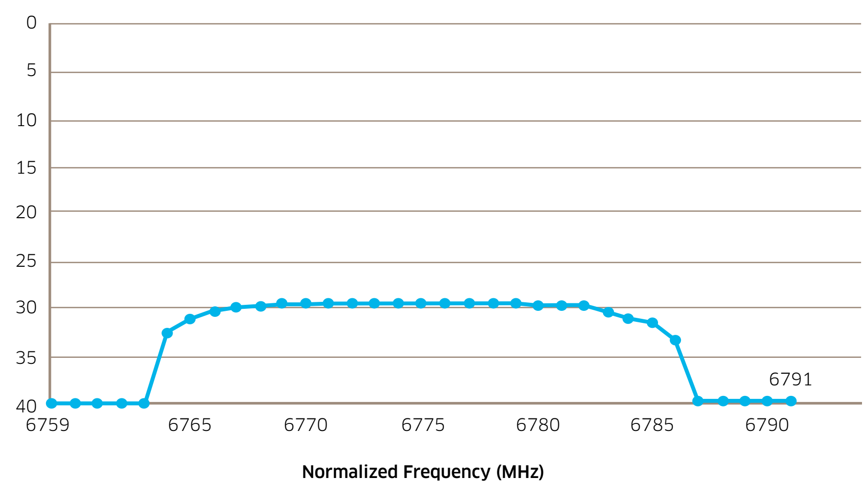
Microwave systems with equalizers that provide a 30 dB signature (in 28 Mhz channel spacing) are the most advanced available today.

System gain plus notch depth determines the maximum link length. If the link system gain is kept constant, an equalizer that improves the signature from 20 dB to 30 dB increases the maximum link length more than 60% from 25 km to 40 km. Figure 3 shows the effect of net system gain and signature notch on maximum link length.

SPACE DIVERSITY HAS PROS AND CONS

While equalizers help to improve the signature area and increase maximum link length, there are cases where they are insufficient. For example, with long-haul





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1. The Rummler model is named after W.D. Rummler, the researcher who proposed this model in the late 1970s after extensive measurements on a 40-km, 6-GHz link from Atlanta to Palmetto, Georgia (US). Bell Technical Journal 1979 "A new selective fading Model: application to propagation data", by W.D. Rummler.

2. The signature, or W-curve, concept is described in ETSI EN 302217-2-1.

links that are more than 50 km long and are over water, multipath propagation effects cannot be sufficiently reduced by an equalizer.

In these cases, space diversity, which is sometimes called antenna diversity, is a more effective countermeasure against selective fading.

With space diversity, the transmitted signal is simultaneously received at two spatially separated antennas – the main antenna and the diversity antenna. This technique is effective because the correlation between the 2 signals is low if the antennas are well separated. If the signal received by one antenna is of poor quality, the signal received by the other antenna is likely good enough.

However, while space diversity improves link availability, it requires double the number of antennas. More antennas mean higher capital and operational expenditures for service providers.

Again, the power of the equalizer in the microwave system is very important. In many cases an equalizer that provides a signature of 30 dB lets service providers avoid using space diversity. They can achieve 99.999% availability on long-haul links in the 30 to 40 km range using a single antenna.

COMBINING IS THE IDEAL SPACE DIVERSITY METHOD

There are still links where space diversity is the only way to guarantee link availability. For these cases, microwave vendors offer 2 different methods to process the pair of received signals:

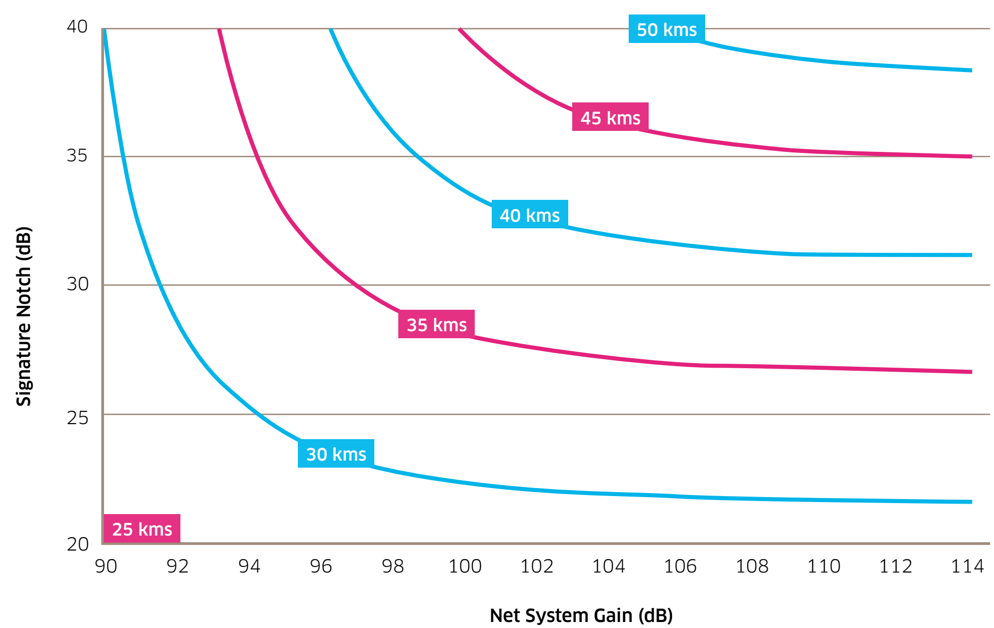
- The switching method chooses the better of the 2 signals, ideally at every instant, to minimize the bit error rate.
- The combining method processes the 2 diversity signals, blending their samples with intelligent algorithms.

The digital signal combining method is a more effective approach because it uses the joint contribution from the 2 signals. The switching method could be considered wasteful because it uses only 1 of the 2 signals at any point in time.

A space diversity system that uses digital signal combining:

- Contributes up to a 3 dB improvement in the signal-to-noise ratio to counter flat fading.
- Outperforms the switching technique. Even if 1 of the 2 signals suffers from 35 dB of fading, the combined signal is error free. Selecting only 1 of the 2 signals means the system cannot be error-free. As illustrated in Figure 2, today's most advanced equalizers provide a signature depth of 30 dB. This means that 35 dB fading cannot be fully eliminated. As a result, 35 dB of fading on a selected channel in a switched system will create errors.

Figure 3. Net system gain plus notch depth determines maximum link length



EVALUATE SYSTEMS CAREFULLY

Microwave systems that provide effective counter-measures against selective fading offer an important differentiator. These systems give service providers a deployable 1024 QAM long-haul link; systems that have simply added points to their QAM constellation to reach 1024 QAM do not.

Equalizers are also critical points of comparison when selecting microwave systems, not nice-to-have features. Equalizers can eliminate the need to deploy 2-antenna space diversity systems. Together, equalizers and digital signal combiners improve performance and link length in conditions where space diversity is required.

Air throughput: Dare to compare

Roberto Valtolina

HIGHLIGHTS

- Intelligent header compression pushes more bits per second into the air
- Header compression breaks all previous limits for air throughput
- The greater the header compression, the more room for payload capacity

BREAKING THE LAWS OF SCIENCE

Intelligent header compression increases Ethernet packet throughput over the air to reach capacities beyond 1 Gb/s. This breakthrough technology breaks the physical laws of science so it finally makes sense to compare air throughput numbers from different microwave system vendors.

Until recently, there hasn't been a lot of point in comparing the air throughput capacities of different **microwave systems**. The amount of information that fits into a radio frequency (RF) channel is governed by the physical and mathematical laws of science. Only very small variations in usable throughput – the number of bits per second transmitted into the air – have been possible. These variations were typically achieved through modulation efficiencies and by reducing the amount of radio overhead transmitted.

Any significant differences in the air throughput data provided by 2 microwave vendors likely meant they were presenting Ethernet throughput differently; one providing Layer 1 throughput rates and the other providing Layer 2 throughput rates.

Now, the intelligent header compression technology used in some **microwave packet radios** is breaking the laws of science put forth by Harry Nyquist and Claude Shannon to push more bits per second into the air.

NYQUIST: CALCULATING SYMBOL RATE AND BIT RATE

In 1928, Harry Nyquist published a paper called Certain Topics in Telegraph Transmission Theory. In the paper he showed that:

- Up to 2B independent pulse samples could be sent through a system with bandwidth B.
- Up to B independent Quadrature Amplitude Modulation (QAM) pulses could be sent through a system with bandwidth B.

What does Nyquist's sampling theorem mean when applied to microwave?

Calculating symbol rate

First, it is important to remember that the available bandwidth B cannot be arbitrarily chosen. Bandwidth is allocated by international regulatory bodies such as the European Telecommunications Standards Institute (ETSI) and the Federal Communications Commission (FCC) in the United States:

- In ESTI-governed countries, the bandwidth allocated for point-to-point microwave transmissions can be 7, 14, 27.5/28, 56 or 112 MHz.
- In the United States, microwave bandwidth is allocated in multiples of 10 MHz, with 30 MHz and 50 MHz being the 2 most popular channel spacing frequencies.

If B=28 MHz channel spacing, it is possible to transmit up to B=28 10e6 QAM symbols per second in an ideal world. In reality, there is always a slight degradation compared to the ideal number, so that:

B = Symbol x (1+alpha)

Alpha is often referred as roll-off. It takes into account all of the implementation-related impairments that reduce throughput. Today, typical roll-off values are in the range of 0.10 to 0.15.

This means that with 28 MHz channel spacing and an alpha value of 0.12, it is possible to transmit around 25 MHz QAM symbol.

The next question is how many bits are transmitted with a QAM symbol?

Calculating bit rate

The answer is pretty easy; it depends on the number of QAM points. For example:

- With 4-QAM, 2 bits per symbol are transmitted.
- With 256-QAM, 8 bits per symbol are transmitted.

The general rule is that for an M-QAM system, LOG2M bits per symbol can be transported. The 28 MHz channel spacing example above indicated that 25 MHz symbol can be transported. With 256-QAM, that results in 25 x 8 = 200 Mb/s throughput.

The only throughput variable is the roll-off factor, but the effects are almost negligible. Using the lowest practical value – 0.10 instead of 0.12 as used in the example – the throughput would be 201.6 Mb/s instead of 200 Mb/s.

Now the question is, how much of the throughput over the air is user information and how much is overhead? Answering this question requires looking at the theory of error correction codes to determine the ultimate performance limit of communications systems.

SHANNON: IMPROVING ERROR CORRECTION

In 1948, Claude Shannon published a theorem to describe the maximum possible efficiency of error-correcting methods compared to levels of noise interference and data corruption.

Known as Shannon's law, the theorem forms the foundation for the modern field of information theory. It states, that given a noisy channel with channel capacity C and information transmitted at rate R, codes must exist that allow the probability of errors at the receiver to be made arbitrarily small. This means that, theoretically, it is possible to transmit information almost error-free at any rate below a limiting rate, C.

Researchers have made many attempts to identify the best way to achieve – or at least get close to – Shannon's limit; that is, to reach Shannon's capacity with an arbitrary low-error probability. Reed-Solomon codes, MLC codes and Viterbi codes are examples of error correction codes that have been widely adopted in the microwave industry.

In 1993, a major step toward achieving Shannon's limit was reached when Claude Berrou and Alain Glavieux introduced turbo-codes in their paper Near Shannon Limit Error-correcting Coding and Decoding: Turbo-codes.

A further, and most probably ultimate, step was achieved with the low-density parity-check (LDPC) code. LDPC is the most recent code introduced by the error correction code community, and it performs very close to Shannon's limit.

LDPC: Error correction at its best

The LDPC code was first conceived in 1960 by Robert Gallager in his Massachusetts Institute of Technology (MIT) thesis, however, implementing it was not practical at the time.

In 1996, David MacKay of Cambridge University and Radford Neal of the University of Toronto developed the first practical LDPC implementation. Today, LDPC remains the most efficient error correction code available.

To reach Shannon's limit, an error correction code must be used. However, by definition, an error correction code always introduces overhead that protects the user information from noise. The higher the overhead, the higher the protection from noise, but the lower the throughput.

The microwave industry has adopted codes with overhead in the range of 5% to 15%. While codes such as LDPC are more efficient than others, the impact on overall throughput must always be considered. With error correction, the previous 200 Mb/s becomes 200×0.9=180 Mb/s in terms of net capacity – the bits sent by users before they are affected by the code.

ETHERNET CHANGED EVERYTHING

Once Ethernet came along, comparing microwave system capacities became much more complicated.

With Time Division Multiplexing (TDM) technology, comparing the air throughput capacities of 2 different radio systems was easy. It was simply a matter of asking how many E1s, DS1s and STM1s are transported?

With Ethernet, the question became "what is the Ethernet throughput?" The answer depends on the packet size and whether throughput is calculated at Layer 1 or Layer 2.

Layer 2 throughput

In an Ethernet system the maximum throughput is equal to the data rate – 100 Mb/s, for example. However, this throughput cannot be achieved due to the frame size.

Smaller frames have a lower effective throughput than larger frames. This is because the preamble and the Interframe Gap (IFG) bytes defined in the Institute of Electrical and Electronics Engineers (IEEE) Ethernet standard are added. These bytes do not count as data throughput.

Table 1 lists the maximum achievable throughput in a 100 Mb/s system for various frame sizes.

Table 1. Ethernet frame size influences data throughput rates

FRAME SIZE	DATA THROUGHPUT
64 bytes	76.19 Mb/s
128 bytes	84.49 Mb/s
256 bytes	92.75 Mb/s
1024 bytes	98.08 Mb/s
1518 bytes	98.69 Mb/s
1522 bytes	98.70 Mb/s

In radio systems with integrated Layer 2 switching, preamble and IFG data is stripped from the incoming data stream and not transmitted over the radio link. At the far-end network interface, the radio equipment reinserts these bytes into the data stream.

Layer 1 throughput

At Layer 1, preamble and IFG bytes are included in the throughput – even if they are stripped – so it appears that the Ethernet capacity is higher than it actually is.

The relationship between Layer 2 and Layer 1 is defined in the following equation:

- Layer 2 Throughput = Frame Length / (Frame Length + Preamble + IFG) x Layer 1 Throughput

For a typical transmission of 256-QAM at 56 MHz that means:

- Layer 2 Throughput = 64 / (64+8+12) x 446.8 = 0.762 x 446.8 = 340 Mb/s

HEADER COMPRESSION IS KEY FOR LTE

As service providers transition to LTE, choosing **microwave backhaul** systems that can squeeze more bits per second into the air becomes crucial. LTE will increasingly use IPv6 IP addresses that occupy an additional 32 bytes of header capacity. This additional overhead must be encapsulated in the Ethernet payload, reducing efficiency when short-length, multi-protocol packets are transported.

Intelligent header compression reduces protocol overhead. The header size that is compressed is constant while the packet payload is variable. The greater the compression, the greater the payload capacity.

Header compression is most beneficial when the network is transporting small packets and when the IPv4 and IPv6 protocols are used. As a result, it is particularly useful in mobile backhaul networks where small packets are common.

Table 2 summarizes the traffic mix observed on mobile backhaul networks around the world.[1]

With the traffic mix shown in Table 2, combining intelligent header compression with IFG and preamble suppression delivers field-proven gains of 30% to 40%.[2] That means service providers can transmit up to 40% more data in the same channel spacing, with the same antennas and with the same link availability.

To take advantage of these gains, service providers should look for microwave systems that combine LDPC error correction with intelligent header compression:

- LDPC error correction codes enable service providers to transmit the maximum near-Shannon limit throughput in a given channel.
- Intelligent header compression increases channel capacity beyond the Shannon limit.

In microwave, spectrum is a limited resource. Every bit counts.

Table 2. In real-world mobile backhaul traffic, small packets are common

		TRAFFIC DISTRIBUTION (FRAME LENGTH IN BYTES)			
NETWORK	**REGION**	**64-127**	**128-255**	**256-511**	**512+**
3G mobile backhaul	Middle East and Africa	78%	12%	2%	8%
3G and LTE mobile backhaul	Americas	47%	41%	3%	9%

1. "*Boost Capacity in Microwave Networks with Advanced Packet Compression*" by Paolo Volpato

2. Based on real-world testing by an Alcatel-Lucent customer

Two strategies to scale microwave capacity

Paolo Volpato

HIGHLIGHTS

- Operators should take a network-based approach to scaling microwave capacity
- Link length, interference and compression levels must be considered
- Multiple scaling methods will be needed to support future microwave demand

As bandwidth-hungry smartphones and wireless tablets become more common, scaling capacity in microwave networks becomes essential.

Moving forward, operators must consider scaling options at the radio layer and at the packet layer. And they must take a network-based approach to scaling capacity; optimizing spectral efficiency on a link-by-link basis is not practical in modern microwave networks. With a network-based approach, operators can:

- Avoid optimizations that are only valid on a small scale.
- Reduce the amount of spectrum used to help save rights-of-use costs.

CAPACITY SCALING MECHANISMS

This article compares 2 methods to scale capacity in modern microwave networks:

- Hierarchical quadrature amplitude modulation (HQAM), which uses higher-order modulation to maximize spectral efficiency over a microwave communications channel.
- Packet compression mechanisms, which reduce the overhead introduced by a frame or packet structure to help increase in spectral efficiency in a full packet-based environment.

HQAM formats increase the density of modulation symbols in a transmitted constellation. For example, 512-state quadrature amplitude modulation (512QAM) and 1024QAM formats provide a combined sequential gain of about 25% in useable traffic capacity compared to 256QAM. And 2048QAM and 4096QAM formats deliver an additional 15% capacity gain over 512QAM and 1024QAM.

Packet compression acts on the protocol overhead portions of IP packets. Fields belonging to Ethernet, Multiprotocol Label Switching (MPLS), IP and TCP/UDP are compressed before transmission and rebuilt at the receiving end of a microwave link. This reduces the number of bits sent across the link, improving capacity for services and applications.

The effectiveness of packet compression depends on the traffic mix and conditions, making it difficult to calculate an average figure. However, if the capacity increase for an Internet mix (IMIX) traffic profile[1] based on IPv4 is 30% to 40%, it almost doubles with IPv6[2]. That means scaling gains from packet compression will become even more significant as operators transition from IPv4 to IPv6.

1. Test Methodology Journal: IMIX (Internet Mix) Journal
2. Packet Microwave: Boosting Capacity For Long-Term Growth

LINK VERSUS NETWORK SPECTRAL EFFICIENCY

Spectral efficiency is often measured on isolated links – links are not impaired by interference or disturbance from neighboring radios, and are not themselves a source of interference. Unfortunately, this approach provides information about ideal link conditions rather than realistic network conditions, where interference may be common.

Optimizing a single link is not practical network design. An optimal network design should provide the requested capacity with minimal occupied spectrum for 2 reasons:

- Spectrum is a limited resource.
- Spectrum has an associated price for its use.

As a result, using less spectrum helps operators cut near-term network operating expenditures (OPEX), and conserves spectrum for future growth.

A network-based approach to scaling capacity puts more emphasis on increasing network capacity than on scaling a single link. Decisions about increasing the modulation format are made from the perspectives of end-to-end network design and the resulting interference levels. This level of analysis implies that:

- Operators should carefully evaluate whether it makes sense to use higher-order modulation formats at dense, short-haul nodal or hub points, and at locations most exposed to impairment.
- Last-mile links are less affected by impairment.

Long-haul microwave transmission is more suitable to high modulation formats: fewer links comprise a network and are less likely to converge at a single geographic point in a network, causing less interference.

A REAL-WORLD NETWORK MODEL

To better understand how higher-order modulation and packet compression methods impact scaling capacity in wireless networks, we analyzed an operational European mobile backhaul network with 890 short-haul links. The largest group of links – 146 links – falls into the 38-GHz band. It includes last-mile connections, or tails, and nodal links. The analysis was performed to:

- Define the theoretical maximum throughput possible in the network. This helps determine the maximum capacity supported by the network without touching any network components.
- Determine the limits of the network before redesign is needed to support HSPA+ and LTE services.
- Provide a guideline for adopting a technology or combination of technologies that increase network capacity.

Figure 1 shows the 38-GHz communications band and how channels are distributed across that portion of the frequency spectrum. This is the starting point for the network analysis. According to current spectrum utilization, the total throughput in the microwave network is around 1.9 Gb/s. All links use fixed modulation to support network availability equal to 99.999%, or 5 minutes of outage time per year.

From this starting point, 2 strategies – HQAM and packet compression – were analyzed for their ability to scale capacity while avoiding incremental capital expenditures (CAPEX) and OPEX.

THE HQAM APPROACH

To model the HQAM approach, the modulation index was increased from the reference modulation level to the maximum level possible to reach 99.995% uptime. Each modulation scale introduces more capacity, but not all links can reach the maximum modulation scheme due to link length and interference.

This approach is a trade-off between modulation scheme scale and network spectrum efficiency. By adopting this method across the entire experimental network, the total capacity increased to 7 Gb/s, or a 4-fold improvement[3 4].

Figure 1. The 38 GHz band consists of 146 last-mile connections and nodal links

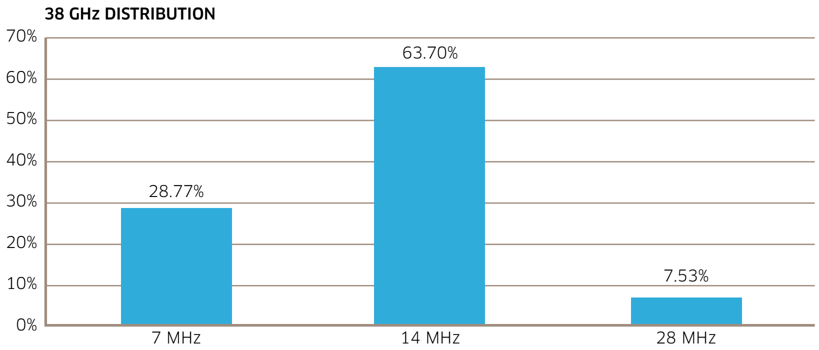
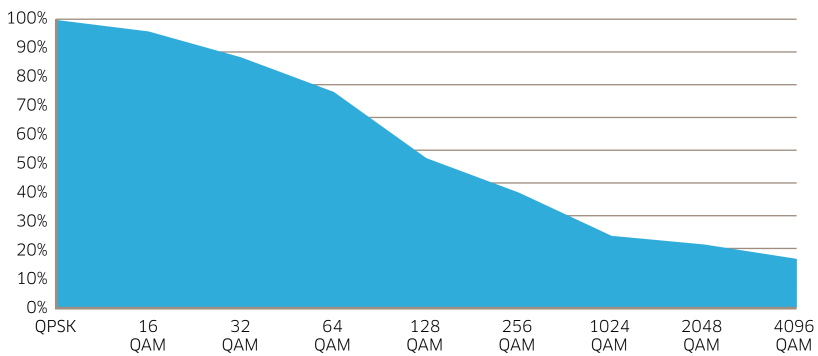


Figure 2 shows the percentage of links – both last mile and nodal – for which a certain modulation index is achievable.

This reveals 3 main points:

- At modulation rates higher than 128QAM, less than 50% of links can sustain a further increase.
- At 1024QAM, the link percentage drops to 25%.
- At rates higher than 1024QAM, the probability of supporting higher modulation keeps declining, but less steeply.

Figure 2. The percentage of links that can sustain capacity increases drops as modulation increases



3. ETSI ATTMTM4(12)000056, Energy efficiency models, Alcatel-Lucent contribution to TR 103 820 Energy efficiency metrics and test procedures for point-to-point fixed radio systems.

4. L. Steenkamp, Mobile capacity solution, France Telecom/Orange presentation at Packet Microwave Forum, October 2012.

THE PACKET COMPRESSION APPROACH

Packet compression gains are directly linked to the lengths and types of packets carried.

Once operators know the packet traffic profile, they can determine the gain from packet compression mechanisms as a percentage of the capacity increase. Knowing the traffic profile is critical because capacity gain from packet compression is a function of packet length; the smaller the packet, the higher the gain. This aspect is particularly important in mobile backhaul applications where voice traffic originates in very small packets of 64 to 128 bytes.

The packet-compression analysis is based on conservative assumptions:

- Traffic distribution is close to the IMIX profile.
- Traffic is carried through IPv4.
- Traffic steering is based on a virtual local area network (VLAN) with a double VLAN tag.

With these assumptions, packet compression achieves a gain of around 40%, bringing total network capacity from 1.9 Gb/s to about 2.7 Gb/s.

Figure 3 contrasts packet compression with the net throughput obtained by scaling the modulation index in a 14-MHz channel. For simplicity, 1024QAM is the maximum modulation displayed. The solid red curve represents the capacity gain provided by packet compression compared to the net radio capacity.

This reveals 2 main points:

- Given a certain capacity value – such as 100 Mb/s, represented by the dashed, dark blue line – capacity can be provided using a lower modulation index. In this example, 128QAM instead of 512QAM when packet compression is used.
- A lower modulation scheme implies less transmitted power. In this example, 5-dB less power is represented by the difference between the two dotted orange lines.

Using less power saves energy costs. It also reduces dangerous radio frequency (RF) pollution and overall interference in the network.

ANALYSIS INFORMS DECISIONS

The analysis highlights key considerations for microwave network design:

- The best potential to improve modulation is found in the tail portions of wireless networks where HQAM can be exploited, or in long-haul transmissions where there is less potential for interference.

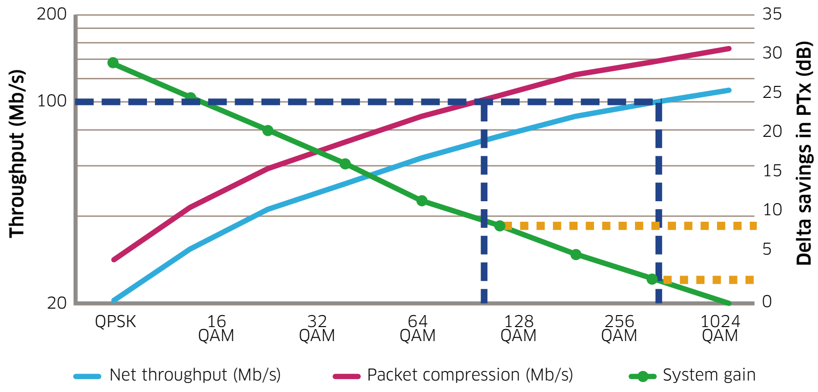
  In short-haul transmissions, HQAM becomes much less applicable beyond a modulation index of 128QAM. Even in tail parts of a network, using 1024QAM and higher-order modulation formats must be carefully considered, unless service availability is not the primary concern. This might be the case in a move from 99.995% availability to 99.99%.

  It may not make sense to scale aggregation links already operating at 64QAM to 128QAM to higher-order modulation formats. Those links are generally designed to operate at 99.999% because their role is to groom traffic in the middle of the network.

- There is some uncertainty when increasing the modulation index is the primary means of scaling capacity in short-haul applications. For example, network status may make it impossible to reach the desired capacity level on a certain link.

  Note: Adaptive Modulation is a valid option to increase the channel bandwidth; this has not been discussed in this article as it is an established technology applicable in the whole network.

Figure 3. System gain decreases as net throughout and packet compression increase



  Cross-Polar Interference Cancelation (XPIC) is an alternative to HQAM with higher feasibility. XPIC is not part of the current analysis, but it provides a 2-fold capacity increase. XPIC is more applicable in a network than HQAM, but brings the cost of new equipment. In contrast, packet compression provides only a 1.4-fold gain, but can be applied everywhere without changes to the radio environment.

- Unless network specifics constrain an operator to 1 mechanism, the best solution might be to mix technologies. For example, in network aggregation where interference might be a serious issue, combining XPIC and packet compression gives operators a 3-fold capacity increase and is applicable everywhere in the network.

HQAM and packet compression are independent technologies that can be applied at the same time to scale microwave link and network capacity. Looking ahead, packet-based scaling technologies will play an increasingly important role in microwave transmission. These technologies support capacity scaling in existing RF without impacting microwave radio-related CAPEX or OPEX.

As LTE, small cells, and **LTE-Advanced (LTE-A)** are more widely used, microwave networks will need even more optimization technologies to sustain backhaul demands.

Editor’s Note: The author would like to thank Scott Larrigan for his contribution to this article.

Multichannel radio LAG improves/scales microwave capacity

Paolo Volpato

HIGHLIGHTS

- Packet microwave systems offer new ways to reliably scale microwave capacity
- Multichannel radio LAG systems squeeze more capacity from scarce radio spectrum
- Multichannel systems enable more flexible microwave network designs

SCALING MICROWAVE CAPACITY TO NEW LEVELS

Today's **modern microwave systems** use techniques such as **advanced packet compression and higher-order modulation** to increase channel capacity. However, at a certain point, the only way to get more microwave link bandwidth is to increase the number of radio channels used.

Modern methods that combine 2 or more microwave channels to create a higher capacity virtual link have several names, including channel bonding, radio link aggregation (LAG) and **multichannel**. Although all methods use multiple channels to scale microwave capacity, implementations and efficiency levels can differ. In this article, a multichannel radio LAG **packet microwave system** is one that merges radio LAG concepts with new techniques that are optimized for microwave. These systems offer a new way to bond microwave channels together to create higher capacity and more reliable microwave links.

MULTICHANNEL RADIO LAG IS DESIGNED FOR MICROWAVE

Multichannel systems are designed to work with features such as:

- High-order adaptive modulation (AM)
- Packet compression
- Carrying legacy time division multiplexing (TDM) services as packet traffic together with IP traffic

Multichannel systems give network operators new flexibility when it comes to designing microwave links and new ways to increase microwave capacity and availability:

- A multichannel approach creates a virtual link from 2 or more underlying channels. The resulting capacity is the sum of every channel's capacity.
- The individual channels in the multichannel bundle can have different profiles for frequency bands, modulation levels and capacities.
- Adaptive modulation can be enabled across all channels in the multichannel bundle. This creates room to increase capacity and service availability according to network design parameters.
- Because modern packet microwave systems packetize legacy TDM traffic, legacy and new IP traffic can use a multichannel virtual link as a whole.
- The rigid association between the capacity a service requires and the capacity a radio channel offers is removed. For example, a packetized synchronous digital hierarchy STM-1/OC-3 circuit can be spread across the channels in a multichannel bundle whose total capacity matches the capacity required.
- Microwave link protection can move from a traditional N+1 spare channel approach to a more effective multichannel N+0 approach. An N+0 approach uses the entire virtual link capacity to increase availability.

In contrast, standard LAG techniques suffer from limitations when used in microwave environments:

- There is a rigid association between a flow and a specific channel in a virtual link. This is because standard LAG hashing algorithms use IP or Ethernet header fields to consistently map a flow to a channel. If these fields do not vary much in value, some channels in a virtual link can become congested while others are only lightly used. Low utilization is a particular challenge when packets are encapsulated in IPsec. In these cases, there is not enough variety in the fields used for hashing algorithms to optimally spread the load across a bundle of channels. As a result, the same channels in the bundle are always selected, leaving the other channels underutilized.

- Every channel in a virtual link must support the same capacity. In microwave networks, this is seldom possible due to the effects of adaptive modulation on individual channels.

These limitations mean that channel capacity must be equal to, or greater than, the highest flow bandwidth. This constrains link dimensioning because radio capacities are typically not correlated with IP service flow capacities. As a result, in some network environments – **LTE backhaul networks**, for example – channel bundles are underused.

Multichannel radio LAG eliminates these issues because it:

- Distributes traffic load evenly based on algorithms that do not leave channels underutilized or impact services, even in the event of a channel failure
- Does not require each channel in a bundle to have the same capacity as the most demanding service

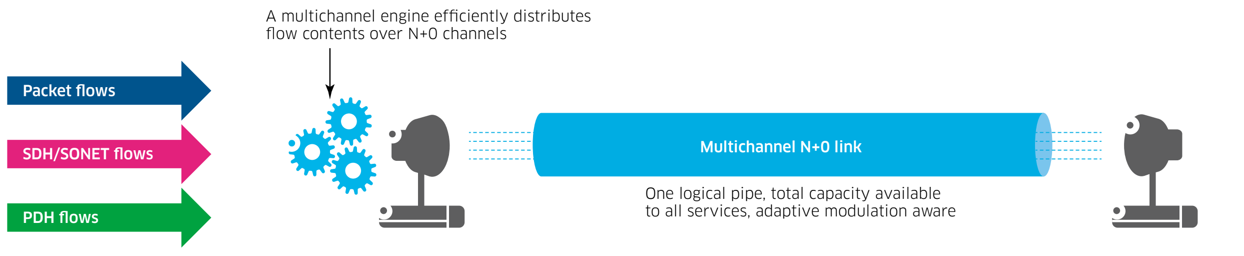
THE MULTICHANNEL RADIO LAG ENGINE

The multichannel engine is the key component in a multichannel system. It distributes packets over the channel bundle in an optimal way, while preserving the correct packet sequence for each flow (Figure 1). Each flow is distributed according to current channel capacity levels. However, each channel can have a different profile and bandwidth capacity. For example, a 2-channel bundle can be comprised of a 14-MHz channel and a 28-MHz channel.

In Figure 1, N is equal to 4 channels. Throughput could reach 3 to 5 Gb/s depending on factors such as packet compression efficiency, modulation format and link dimensioning. Multichannel links with an N value between 8 and 10 channels can be used to scale capacity to the 10 Gb/s range.

The multichannel engine is aware of traffic flow quality of service (QoS) requirements to ensure that service level agreements (SLAs) are maintained. When multichannel link capacity varies, the multichannel engine uses the real-time status of the entire virtual link to adjust traffic distribution across the channel bundle and improve spectral efficiency.

Figure 1. The multichannel engine distributes packets in an optimal way



SPARE CAPACITY, NOT SPARE PROTECTION

Unlike traditional N+1 techniques to scale microwave link capacity, multichannel systems do not require spare protection channels to protect link capacity. Instead, multichannel systems use the concept of spare capacity across a bundle of active channels.

When adaptive modulation is used, a channel does not have to be in an 'on' or an 'off' state; it can be in a partially working state, although at a reduced capacity. In the rare case where the capacity available in the multichannel bundle is lower than requested, high-priority committed traffic is preserved and only best-effort traffic is discarded.

From a network design standpoint, the probability of delivering the committed traffic is very high. That's because the degradation on one channel can be compensated for with the excess capacity available on other channels in the bundle.

Traditional N+1 link protection mechanisms do not support the spare capacity concept when scaling and protecting microwave links. If channel capacity drops, all traffic is moved to a dedicated protection channel, stranding any remaining capacity on the degraded channel.

INCREASE MICROWAVE CAPACITY AND AVAILABILITY

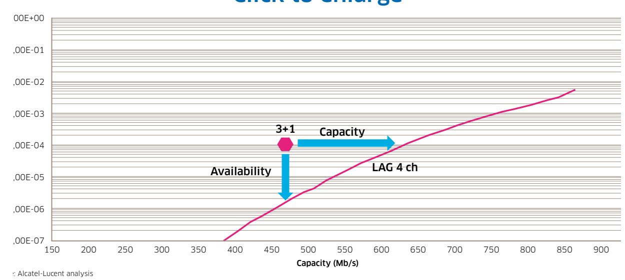
There are 2 ways to take advantage of the benefits that multichannel provides:

- Increase availability and maintain the same capacity as a traditional microwave system
- Increase capacity and maintain the same availability as a traditional microwave system

Figure 2 shows what is possible when the goal is to increase availability while maintaining capacity levels. It compares the availability of a traditional 3+1 system to a 4+0 multichannel system.

Figure 2. Multichannel systems can increase availability and maintain capacity

Click to enlarge



The behavior of a multichannel system is represented by a curve that is associated with the entire set of channel capacity and availability levels. It is not represented by a pre-defined single point as is the case with a traditional N+1 system. Availability in a multichannel system is increased from about 10-5 to about 3×10-7 when compared to the capacity of an N+1 system. This is equivalent to 99.9999% availability.

If the goal is to maintain the same availability value, the multichannel system offers 25% more capacity than a 3+1 system, with the same number of channels used. This extra capacity can potentially lead to link redesign to reduce antenna size requirements, which can further minimize network total cost of ownership (TCO).

The benefits of multichannel are also realized when traditional TDM applications are packetized using circuit emulation.

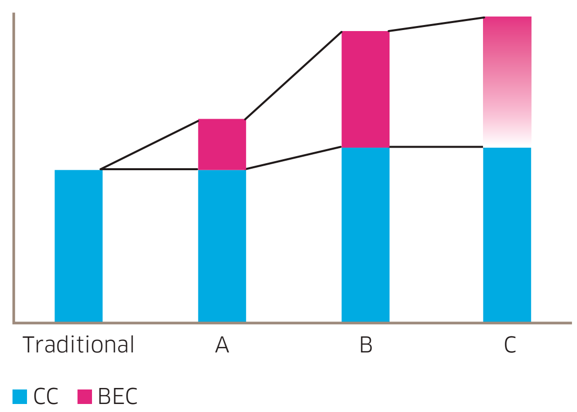
MULTICHANNEL SYSTEMS ENABLE BETTER DESIGNS

In multichannel systems, the capacity needed between any two points in a network becomes the main design factor, enabling better network designs.

Figure 3 compares the committed capacity (CC) and best-effort capacity (BEC) in a traditional 3+1 link design to an incremental multichannel design:

- Committed capacity must always be provided, for example to carry circuit-emulated traffic or premium data traffic.
- Best-effort traffic can be interrupted, for example when adaptive modulation levels are decreased to support communication during bad weather.

Figure 3. Moving from N+1 to multichannel designs improves spectrum use



Traditional link design

A traditional 3+1 link design provides room for committed capacity only. Typically, a 3+1 system uses 4 28-MHz radio channels (3 active channels and 1 protection channel) with fixed 128 quadrature amplitude modulation (QAM) to carry 3 STM-1/OC-3 circuits. There is no room for occasional, best-effort traffic.

Step A: Multichannel 4+0 link design

In step A, an existing 3+1 arrangement is upgraded to a multichannel 4+0 configuration. Actively using the fourth channel increases the microwave link bandwidth by 25% when modulation levels are not affected by adverse weather.

Step B: Add adaptive modulation

Step B is a multichannel 4+0 design that uses adaptive modulation with 1024 QAM. The higher modulation rate increases the microwave channel and link capacity by 30%. Because adaptive modulation is active on all 4 channels, both committed and best-effort capacity are increased.

Step C: Add flexible spectrum use

Step C adds more flexible use of spectrum to step B. Instead of using 4 28-MHz channels, the following channel widths are used:

- 1 56-MHz
- 1 28-MHz
- 2 14-MHz

This type of deployment shows how multichannel systems can take advantage of available spectrum and potentially decrease right-of-use costs for channels.

There are also cases where moving from an N+1 to an N+0 multichannel design reduces the number of channels required. In an N+0 design, spare capacity is better used so the spare channel associated with a N+1 design is not needed. Multichannel configuration parameters can also be tuned to improve the link budget, which in turn improves network availability. With the introduction of multichannel packet microwave systems the progressive decommissioning of N+1 installations is possible.

MOVE AHEAD WITH A MULTICHANNEL MICROWAVE SYSTEM

Multichannel allows packet microwave systems to address the microwave capacity and availability demands of modern IP networks. Compared to traditional N+1 and N:1 mechanisms, multichannel systems offer a more flexible, efficient and reliable approach to scaling microwave capacity.

With multichannel, microwave link designers can focus on the actual capacity required, with less emphasis on the availability of frequency bands and channel spacing. This gives link designers more flexibility. Most importantly, it helps network operators make better use of scarce radio spectrum and decrease network operational expenses.

Editor’s Note: The author would like to thank Scott Larrigan for his contribution to this article.

Packet microwave rings optimize capacity and TCO

Paolo Volpato

Microwave backhaul networks have historically relied on daisy chain and tree network topologies, ring network topologies were rarely deployed due to bandwidth inefficiencies associated with the SDH/ SONET protocols available at the time. Specifically, dedicated protection capacity had to be reserved up-front, and this network capacity was only optimally used in the rare event of network failure, resulting in the waste of scarce microwave spectrum in environments characterized by fast-growing capacity demand. However, this has all changed with the introduction of standards-based **ITU-T G.8032v2 packet microwave rings**. In this blog, I'll use a case study to demonstrate the financial advantages of moving to packet microwave ring topologies, and to demonstrate how packet microwave rings optimize network capacity and minimize network TCO.

New Carrier Ethernet technology based on the ITU-T G.8032v2 standard has emerged to take the place of legacy **SDH/SONET** networking capabilities. This standard was designed to address IP and LTE packet network requirements while also efficiently exploiting the inherent advantages of ring based network topologies:

- Traffic is sent in two directions around a ring, so network capacity is doubled.
- Reduced capital expenditures (CAPEX) by eliminating the need for fully protected sites.

Given these advantages, together with the explosive capacity demands to support new LTE based services it didn't take long for ITU-T G.8032v2 implementations to get deployed.

PACKET MICROWAVE RING ADVANTAGES

The following analysis is based on a live Middle East and Africa region mobile backhaul deployment that has enabled a mobile evolution to more 3G capacity and support a **future move to LTE**.

In this network most of the existing links were deployed in a 1+1 protected, or Hot-Standby, arrangement in a daisy chain based network topology. The capacity demands on the network forced an evaluation of the best alternatives available to provide the highest network capacity at the lowest network **total cost of ownership** (TCO).

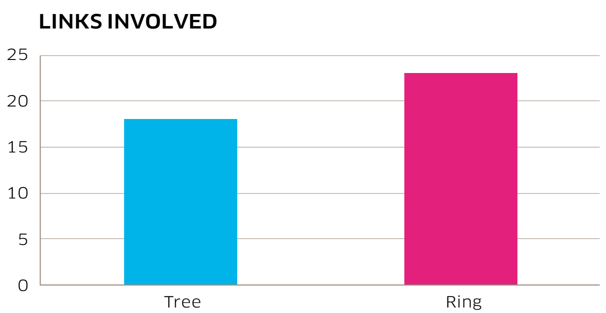
Two approaches were considered:

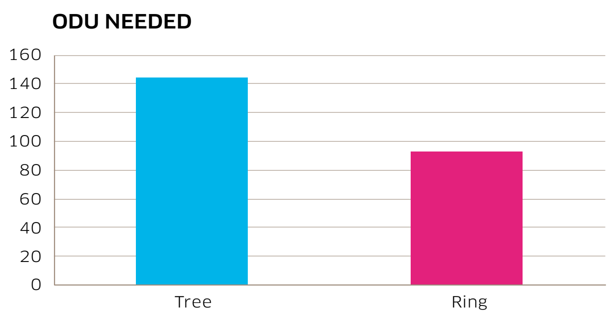
1. Maintain a 1+1 link, daisy chain network-based design philosophy. This approach required a move to 2 sets of 1+1 links to support higher capacities, resulting in 8 microwave radios – two working and two protection at each end of the microwave connection. Although this approach doubled the microwave connection capacity, it could not leverage the ring topology advantage of doubling network capacity.
2. Utilize an ITU-T G.8032v2-based network design together with 2+0 multichannel links to network high capacity hub/nodal sites together in a ring topology; 2+0 **multichannel links** leverage 2 underlying active microwave channels to create higher capacity virtual microwave links. This approach efficiently doubles microwave link capacities, and it also increases network capacity at key points in the network by leveraging the ring topology's ability to double network capacity.

PACKET MICROWAVE RINGS: 36% FEWER OUTDOOR UNITS

In addition to network capacity advantages, the ring-based approach resulted in the need for 36% fewer microwave radio outdoor units (ODUs) as depicted in the following graphs. This is despite the fact that the ring-based approach required a few more interconnected microwave network sites/links (23 versus 18) to create ring topologies.

The significant reduction of ODUs is due to the fact that higher capacity sites in the daisy chain model need 8 ODUs per high capacity microwave connection, whereas the ring approach only requires 4 ODUs per microwave connection.





Using fewer ODUs also means coupler utilization can also be reduced or eliminated (a coupler is a device that is used to get channels connected to the same microwave antenna). In the case of 2+0 multichannel ring links the network could be designed so that no couplers were required, whereas the daisy chain approach required couplers to bring channels on to the same antenna, adding to the daisy chain deployment cost.

Even though the ring approach required a few more interconnected microwave network sites/links together with supporting antennas, the overall expense of the increased number of antennas was counter-balanced by a reduction of antenna size. Nearly 80% of the antennas had a diameter of either 30 cm or 60 cm (1 or 2 feet respectively). This size reduction is extremely important since smaller size antennas require less space on microwave towers and reduced installation effort, further minimizing network TCO.

In the end the packet microwave ring technology from Alcatel-Lucent helps operators to optimize network capacity and minimize network TCO. Specifically, the packet microwave ring approach offered the lowest network TCO by reducing the number of radios and couplers required, reducing antenna sizes, and doubling network capacity.

For more information:

- **Microwave Backhaul for Long-Term Evolution** application note
- **Evolving to microwave ring protection with Alcatel-Lucent 9500 MPR and ITU-T G.8032v2** application note

Microwave improves small cell backhaul for LTE

James Ries

Small cells have emerged as an accepted approach to quickly and efficiently get additional capacity and/or coverage deployed to support LTE networks. Yet providing connectivity from those small cells back into the network – i.e., backhauling – remains a challenge.

This is where innovations in microwave networking offer some real opportunities.

Mobile operators should consider small cell backhaul solutions that can address the capacity and networking requirements of LTE, while also simplifying backhaul installation, provisioning and operations.

FIBER OPTIC CONSTRAINTS

High capacity fiber optic cables are ideal to connect small cell sites to mobile services and the Internet. Unfortunately, not all small cell sites will have access to fiber. That's because small cells will be deployed in locations as varied as street lamps, bus stops, and the sides of buildings. Consequently, the majority of the world's small cell sites will leverage some form of wireless backhaul connectivity, such as microwave.

CHALLENGES OF CURRENT TOPOLOGY

For simple point-to-point backhaul microwave links, many full outdoor microwave radio solutions can be used.

However, existing full-outdoor microwave systems won't work in all scenarios. For example, when you need to support more advanced network topologies such as rings, or combine microwave channels into a higher capacity virtual links.

You could introduce an indoor device to provide an aggregation and/or switching function. But this leads to the need for a costly cabinet or shelter – driving up both OPEX and CAPEX.

BRINGING INDOOR NETWORKING UNITS OUTDOORS

What if you took the indoor networking device and made it deployable in a full outdoor backhaul environment just like the radio it supports, and also gave it the capability to power the full outdoor radio?

What if that device supported common networking and management with the indoor units deployed at the macro cell site?

This approach would solve the challenge of providing more advanced networking, simplify the deployment and provisioning of the outdoor small cell, and drive significant cost reductions.

The design challenges for a full outdoor backhaul product are obviously more stringent than designing a product for an environmentally protected cabinet with a heat exchanger or a cool air conditioning unit. So any new device should solve those challenges.

Alcatel-Lucent has just introduced the 9500 MPR MSS-O (Microwave Service Switch – Outdoor). It is a rugged networking device suitable for outdoor deployments, and supports both AC and DC powering options. It provides the same networking features and functions as the indoor unit:

- Fully hardened to comply with the IP67 standard. It is robust against severe climate change, and can even be submerged under water if a cell site becomes flooded.
- Follows Telcordia's GR-3180 Class 4 criteria for fully exposed equipment. This includes a 30 day salt fog test, which simulates 30 years of continued outdoor exposure to harsh environment!

Find out more about how the new full outdoor unit can facilitate the introduction of small cells to support higher capacity and coverage in LTE heterogeneous networks.

RELATED MATERIAL

- Small Cells Outdoor Solution page
- 9500 MPR MSS-O (Microwave Service Switch – Outdoor) datasheet
- Watch TechZine over the next few weeks for other posts in this mobile backhaul series

Corrosion that can occur in an outdoor environment

Click to enlarge

9500 MPR full outdoor units in salt fog chamber

Click to enlarge

Making the most of MIMO

Roberto Valtolina

HIGHLIGHTS

- MIMO uses multiple transmit and receive antennas to increase capacity
- Different principles apply when MIMO is used in microwave systems
- MIMO makes sense in microwave systems with high frequencies, short hops

With the right deployment strategy, Multiple Input Multiple Output (MIMO) technology can increase capacity in LTE, WiMAX and microwave networks. But MIMO works differently in line-of-sight networks such as LTE and WiMAX than it does in line-of-sight microwave networks. To take full advantage of MIMO's benefits, service providers need to understand MIMO, how it works, and why it works differently in different networks.

THE MIMO ADVANTAGE

MIMO uses at least 2 – sometimes several – antennas on the transmit (Tx) side and on the receive (Rx) side to transmit a single channel. This approach increases data rates and spectral efficiency. For example, adding 6 antennas on each side delivers the same capacity increase as adding 100 times more power to a Single Input Single Output (SISO) channel.

The techniques used in MIMO increase capacity linearly with the number of antennas. In contrast, the approaches used in SISO, Single Input Multiple Output (SIMO) and Multiple Input Single Output (MISO) systems increase capacity logarithmically. Linear capacity increases provide a much more efficient path to higher capacities than logarithmic increases.

The transmitter and receiver used in MIMO are more complex than in SISO, SIMO and MISO transmissions, but they don't use more power.

The MIMO advantage is so clear that many standards have already incorporated the technology. They include the:

- International Telecommunications Union (ITU) High Speed Downlink Packet Access (HSPDA) standard, which is part of the Universal Mobile Telecommunications System (UMTS) standard.
- Institute of Electrical and Electronics Engineers (IEEE) 802.11n standard used in wireless routers for the home.
- IEEE 802.16 standard for the mobile WiMAX technology used in cell phones.
- ITU LTE standard.

MIMO MEETS SHANNON

When MIMO systems were first described in the mid-to-late 1990s by Gerard Foschini and others, the dramatic bandwidth efficiency enabled seemed to violate Shannon's law. In reality, the diversity and signal processing used in MIMO transform a single point-to-point channel into multiple parallel channels.

Shannon's law is based on a noisy channel with channel capacity C and information transmitted at a rate R. It then states that if R is less than C, there must be codes that allow the probability of error at the receiver to be made arbitrarily small. This means that, theoretically, it is possible to transmit information nearly without error at any rate below a limiting rate, C.

This capacity is usually expressed in the form:

$$C = W \log_2(1 + S/N)$$

Where:

- C is the channel capacity in bits per second
- W is the bandwidth in Hertz
- S/N is the signal-to-noise ratio (SNR)

To determine the capacity of a channel with an SNR of 50 dB and bandwidth of 20 MHz, the math looks like this:

$$C=20*\log_2(1+50)=20*5.6=112 \text{ Mb/s}$$

The capacity increases as a log function of the SNR, which is a slow increase.

This example uses a 20 MHz channel, the channel spacing that is typically used in **LTE** and **LTE-Advanced**. But LTE-Advanced capacity at 20 MHz is 500 Mb/s or higher – clearly well beyond Shannon's limit.

One way to go beyond Shannon's limit is to boost the SNR and the power transmitted by the base station. But even with an SNR of 100, throughput with 20 MHz channel spacing is only 133 Mb/s, far short of the 500 Mb/s that is possible with LTE-Advanced.

That's where MIMO comes in. It's the not-so-secret ingredient in this high-capacity recipe.

MIMO IN LTE AND WIMAX NETWORKS

The formula below is used to calculate the Shannon limit for MIMO. The maximum capacity that a MIMO system can achieve depends how the channel is created, not just the SNR as is the case in SISO systems. In mathematical terms, MIMO system performance depends on the condition of the channel matrix H and its properties.

$$C = \max_{\mathbf{R}_{ss}} \log_2 \det(\mathbf{I}_{nR} + p\mathbf{H}\mathbf{R}_{ss}\mathbf{H}^{H})$$

Think of the H channel matrix as a set of simultaneous equations. Each equation represents a received signal composed of a unique set of channel coefficients that are applied to the transmitted signal.

The system performs best when the H matrix is full rank, with each row and column meeting conditions of independence. In other words, a matrix is full rank if the linear system defined by the matrix can be solved.

This means that optimal system performance is only possible when each channel is fully independent of all others. And channels can only be fully independent of one another in an environment with extensive scattering, fading, reflections and other effects.

Although this seems like a counter-intuitive statement, the only way to extract the transmitted information is when the H matrix is invertible. The H matrix can only be invertible if all of its rows and columns are uncorrelated, a concept taught in linear algebra. And, rows and columns can only be uncorrelated when scattering, fading, reflections and other effects are present.

This is the typical scenario for LTE and WiMAX networks, especially in dense urban areas.

MIMO IN POINT-TO-POINT MICROWAVE NETWORKS

In a point-to-point **microwave system**, a matrix might consist of 2 transmit antennas and 2 receive antennas, as shown in Figure 1. This is referred to as a 2×2 MIMO system.

If H12 represents the traffic traveling from transmit antenna 1 to receive antenna 2, the matrix becomes:

- r1 = h11 t1 + h12 t2
- r2 = h21 t1 + h22 t2

Where:
r1 = signal received at antenna 1
r2 = signal received at antenna 2

In a line-of-sight system:
r1 = t1 + t2
r2 = t1+ t2

So that, H =
1 1
1 1

Even with limited knowledge of math, it is clear that the equation has no solution and cannot be solved.

With these results, it seems that MIMO does not apply to point-to-point microwave systems. The reality is that MIMO does apply to point-to-point microwave systems, but with different principles.

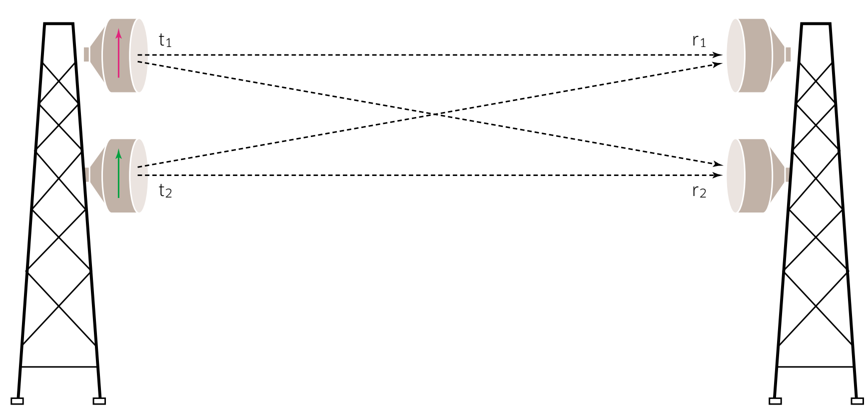
LINE-OF-SIGHT MIMO FOR MICROWAVE

In point-to-point microwave systems, MIMO does not rely on the fact that the received signals are uncorrelated due to scatter, reflections and fading to increase capacity. Instead, it relies on geometric spacing among receive and transmit antennas.

With the right spacing among antennas, the interfering signal can be cancelled to double capacity between endpoints. To cancel the interfering signal, the propagation difference between the 2 paths must allow the 2 received signals to be orthogonal to each other at the receiver modems.

In conventional MIMO systems, the differences in path propagation can be created using physical objects in the environment. This approach is not possible with microwave links because they are typically line-of-sight connections and use highly directional antennas.

Figure 1. A point-to-point microwave matrix uses multiple transmit and receive antennas



However, microwave links use high carrier frequencies. This makes it possible to use antenna spacing to design a 2×2 MIMO channel with the required orthogonal phase difference between short and long paths at the receiver end. This is commonly referred to as a Line-of-Sight (LoS) MIMO system.

In a 2×2 MIMO system, the required phase difference between paths at the receiver end is 90°. Figure 2 illustrates this principle.

When the ideal phase difference of 90° is in place, the interfering signal can be completely cancelled. This creates two independent channels, effectively doubling the available channel capacity.

The high frequencies used in microwave have very short wavelengths. However, the geometric characteristics of the propagation path mean that relatively large spaces are required between antennas to achieve the ideal phase shift.

The graph in Figure 3 shows the optimal antenna spacing for different hop lengths and microwave frequencies.

The antenna spacing requirements for shorter hop lengths and higher frequencies are achievable. However, for systems with low frequencies and long links, the antenna spacing requirements become quite high, making them impractical or impossible to meet.

MIMO MAKES SENSE

MIMO is a powerful technique to increase capacity in non-LoS LTE and WiMAX networks. And LoS MIMO can play an important role in increasing capacity in certain point-to-point microwave scenarios. Service providers that understand when and where MIMO makes sense will be in the best position to make the most of MIMO.

Figure 2. The right antenna spacing cancels the interfering signal to double capacity

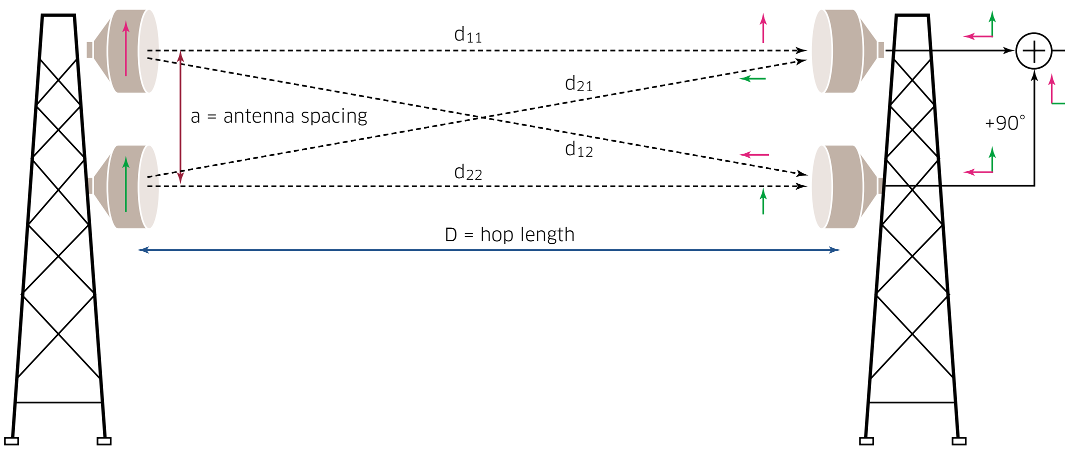
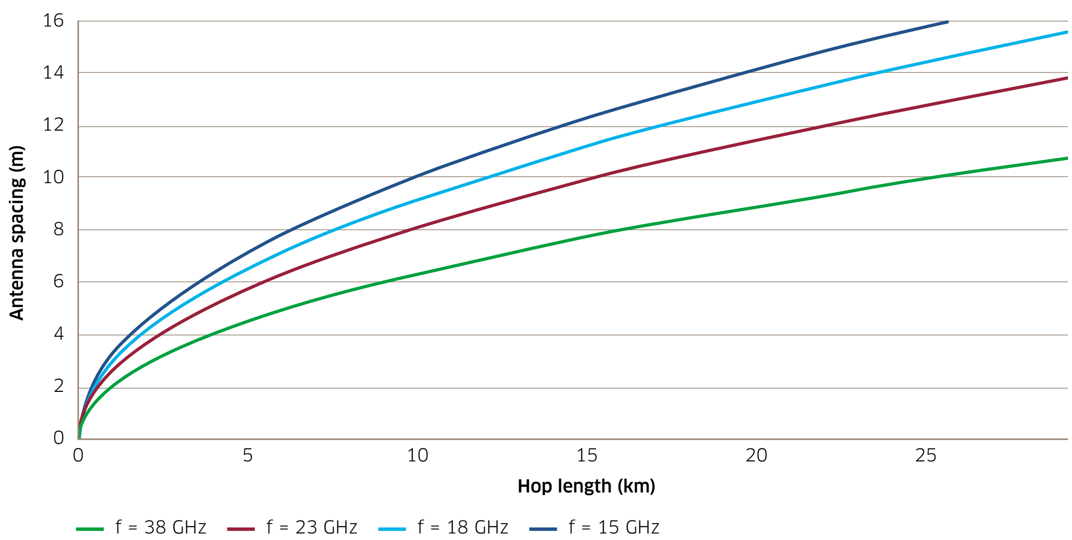


Figure 3. LoS MIMO makes sense with higher frequencies and shorter hops



Boosting microwave capacity for LTE-Advanced

Paolo Volpato

HIGHLIGHTS

- LTE-Advanced devices require faster mobile backhaul connections
- Packet microwave systems support mechanisms to scale backhaul capacity
- Multiple strategies can increase capacity of both existing and new links

Customers will be using LTE-Advanced Category 6 user devices within the next year*. Capable of mobile downlink speeds of 300 Mb/s and uplink speeds to 100 Mb/s, these devices threaten to overwhelm cellular backhaul networks. But capacity-enhancing features for packet microwave systems can help you meet this need for speed.

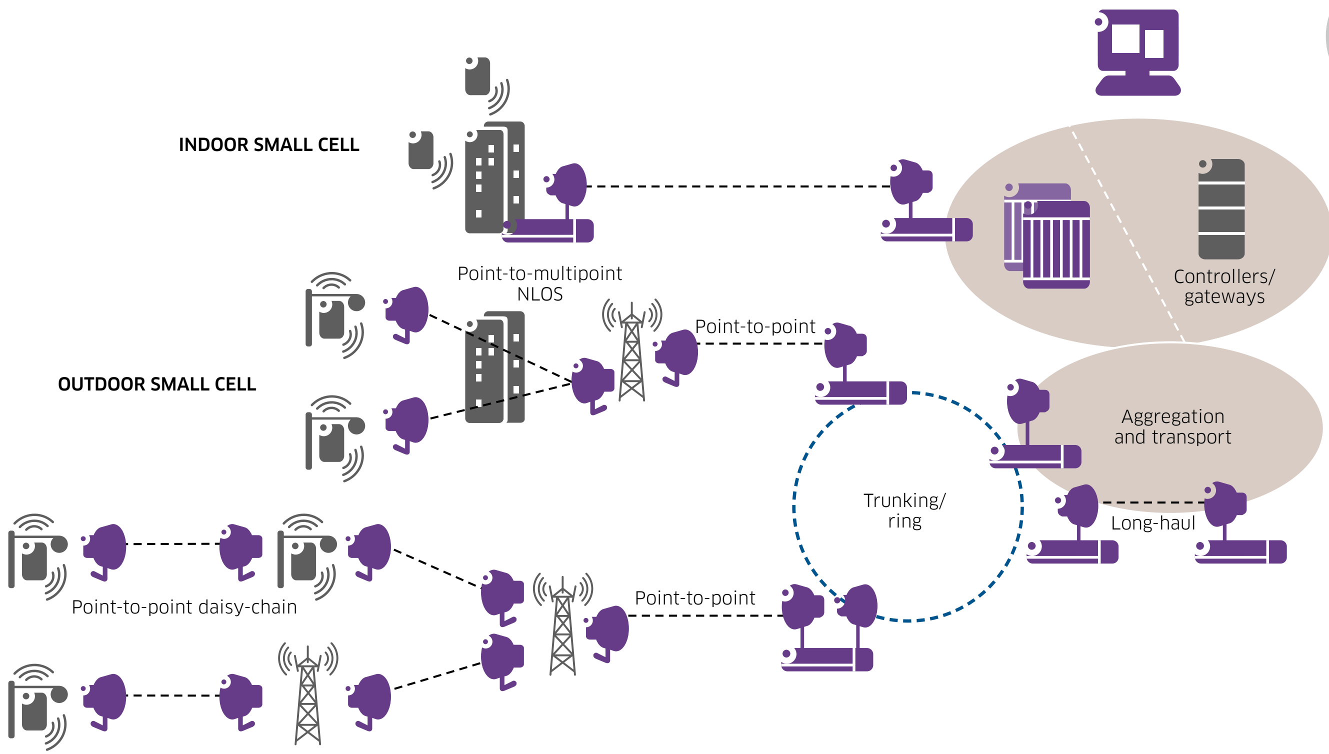
LTE-ADVANCED AND THE PUSH FOR FASTER MOBILE SPEEDS

LTE-Advanced is a 3rd Generation Partnership Project (3GPP) initiative to provide faster mobile connections. It uses advanced technologies such as carrier aggregation, coordinated multipoint operation, and enhanced interference control to provide higher peak downlink and uplink speeds.

The LTE Category 4 user devices sold today make downloading content faster than previous technology, allowing peak downlink speeds of 150 Mb/s and peak uplink speeds of 50 Mb/s. LTE-Advanced Category 6 user devices will push these speeds even higher, supporting 300 Mb/s downlink and 100 Mb/s uplink.

Mobile service providers are concerned about the impact this bandwidth will have on their backhaul networks. Many have deployed or are planning to deploy wireless transmission/microwave to support their small cells, macro cells, cell site aggregation and long-haul transport (Figure 1). Over half of cell sites use microwave links for their backhaul connections, and upgrading many of these connections to fiber optic cable would be too expensive. For LTE and LTE-Advanced to succeed, increasing microwave capacity so mobile backhaul networks can handle increased radio access network (RAN) traffic is critical.

Figure 1. Higher mobile speeds require end-to-end microwave network support



* REPORT: Status of the LTE Ecosystem", GSA (Global mobile Suppliers Association), July 2014

HOW MUCH CAPACITY IS ENOUGH?

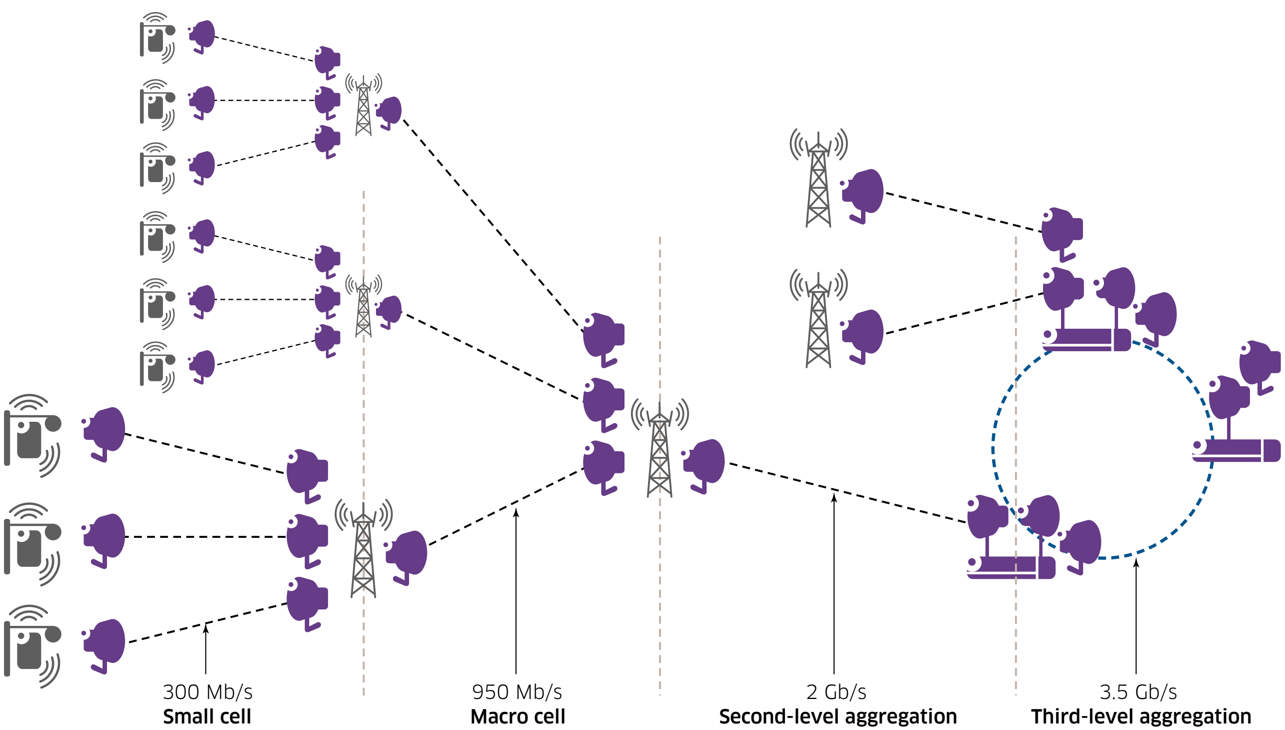
Capacity estimates are provided here by analyzing a simple model (Figure 2). The network is structured in layers: small cell, macro cell, second-level aggregation and third-level aggregation. Capacity shown at the macro cell is as proposed by the **Next Generation Mobile Networks (NGMN) Alliance** in its **Guidelines for LTE Backhaul Traffic Estimation**. The capacities for second and third stages of aggregation are based on established traffic engineering assumptions.

SATISFYING LTE-ADVANCED BACKHAUL DEMANDS

Fortunately, packet microwave systems are also continuously evolving their capabilities to handle increased 4G/LTE, and LTE-Advanced RAN capacities in mobile backhaul networks. Available advanced features include:

- Cross-polarization interference cancelation (XPIC) to double frequency capacities
- Adaptive modulation-aware high-order quadrature amplitude modulation (H-QAM)
- Advanced packet compression to increase packet microwave link throughput
- Reliably bonding channels together into higher-capacity microwave links
- Standards-based (ITU-T G.8032v2) networking to double microwave network capacity

Figure 2. Potential 2017 LTE-Advanced cell site backhaul network capacity needs example



INCREASING CAPACITY FOR EXISTING LINKS

Existing backhaul links are generally limited in how they can use allocated microwave spectrum:

- Standard frequency bands of 6 GHz to 38 GHz are normally used.
- Spectrum allocation may vary according to region.
- Links are operated under licenses that force service providers to follow specific design rules.

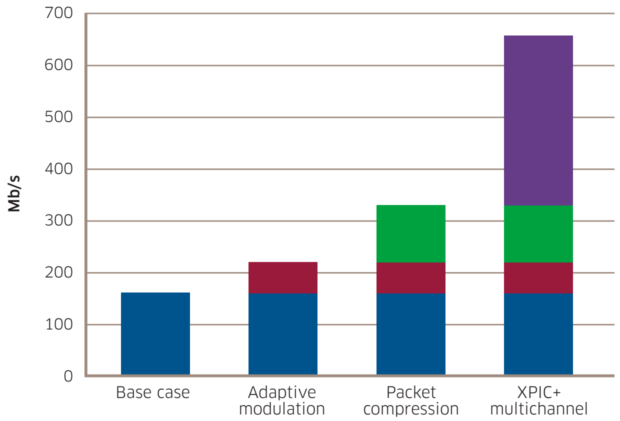
Service providers must make both operational and design decisions when determining how capacity can be increased on existing links, as changes may cause service outages or require a costly site visit. With that in mind, a realistic strategy to increase capacity on existing links can include the following steps:

1. Enable packet compression, which does not impact radio setup or link design
2. Enable adaptive modulation (AM) together with higher-order modulation schemes
3. Deploy an XPIC option that uses both horizontal and vertical frequency polarizations to double frequency capacity, and use multichannel 2+0 radio configuration to optimally balance load over the two XPIC channels

The total increase in capacity available from using these techniques depends on the specific configuration. Figure 3 depicts results for the following base case scenario:

- 28 MHz channel operating at 128 QAM fixed modulation
- 50% of the carried IP traffic consists of smaller sized packets
- Net capacity of around 150 Mb/s to 170 Mb/s

Figure 3. Increasing backhaul capacity in existing links



These techniques increase capacity from 150 Mb/s to around 650 Mb/s as follows:

- Packet compression provides about a 40% gain (conservatively)
- 1024 QAM-capable adaptive modulation adds another 20% to 25%
- XPIC together with 2+0 doubles throughput

Ultimately, deploying a second XPIC radio unit doubles channel capacity. While this doesn't meet the 950 Mb/s macro cell backhaul capacity that will be needed by 2017, it does represent a significant microwave link gain.

Service providers can meet the 950 Mb/s mark using the following capacity enhancements:

- More efficient packet compression, which occurs naturally when moving from IPv4 to IPv6
- Moving to 4+0 multichannel arrangements to reach capacities beyond 1 Gb/s
- Reorganizing spectrum and adopting wider channels. Using two 56 MHz channels increase capacity to approximately 1.3 Gb/s, which would accommodate RAN capacity advancements beyond 2017

INCREASING CAPACITY FOR NEW LINKS

The design of new links can use all available mechanisms to scale capacity, including these 3 main applications:

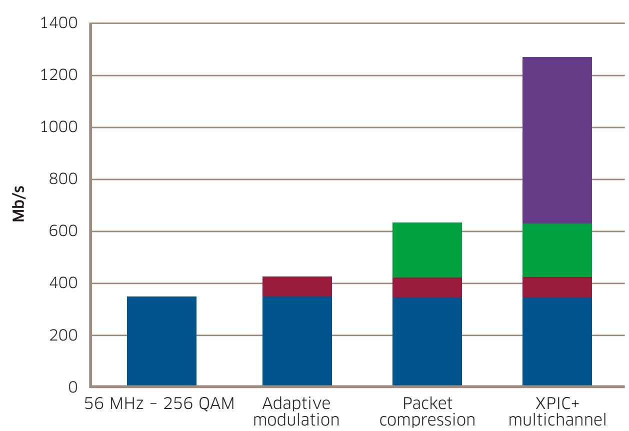
1. Short-haul urban links using traditional microwave frequency bands (13 GHz to 38 GHz)
2. Short-haul urban links using millimeter-wave frequency bands
3. Aggregation links using traditional longer-reach microwave frequency bands

Typical methods of scaling short-haul urban link capacity include using:

- Wider channels (e.g., 56 MHz)
- Adaptive modulation combined with H-QAM (e.g., 1024 QAM)
- Header compression to increase throughput capacity
- Multichannel and XPIC to double frequency capacities

Figure 4 compares the effect of incrementally applying these methods to a base case using 256 QAM. This example shows a multichannel 2+0 XPIC arrangement using two 56 MHz channels: AM and 1024 QAM. Packet compression can provide bandwidth as high as 1.3 Gb/s, well beyond the forecasted traffic requirements of an LTE-Advanced macro cell in 2017.

Figure 4. Scaling new short-haul link capacity using traditional frequency bands

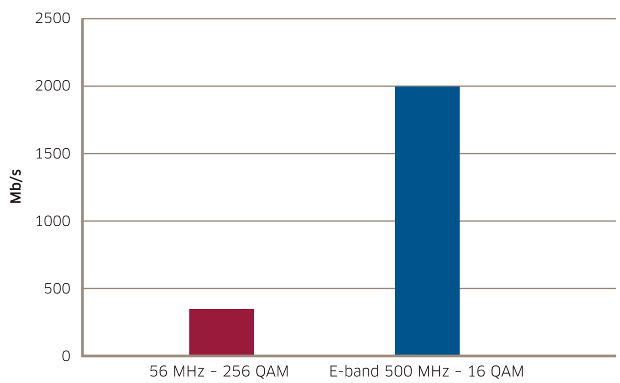


Service providers can use one of two methods to handle second-stage aggregation:

1. Deploying four 56 MHz channels using a 4+0 multichannel configuration to obtain 2.5 Gb/s capacity
2. Using two 112 MHz channels, in a 2+0 multichannel configuration to deliver 5 Gb/s capacity (if further spectrum grooming is possible)

Short-haul urban links can use millimeter-wave E-band frequencies (e.g., 70/80 GHz). Millimeter-wave propagation characteristics can support 2.5 Gb/s over a single 500 MHz channel operating at 16 or 64 QAM. Figure 5 compares a 56 MHz channel working at 256 QAM in fixed modulation to a 500 MHz E-band channel at 16 QAM.

Figure 5. Scaling new short-haul link capacity using E-band channels



E-band offers more capacity, but can only be considered for links less than 3 km due to millimeter-wave propagation characteristics. This means E-band can only be used for the first two stages of aggregation in urban or semi-urban environments.

Key requirements for long-haul aggregation microwave links are:

- High capacity and high availability
- Support for advanced network topologies

Long-haul aggregation nodes typically act as hubs for multiple links, and connect to the rest of the network through a ring topology. New advanced Carrier Ethernet ring protocols, such as ITU-T G.8032v2, provide benefits over traditional SDH ring mechanisms. Optimal exploitation of available ring bandwidth (both east and west directions carry full traffic simultaneously) requires fewer radio units than standard linear connectivity.

Newly designed long-haul microwave networks can use the following mechanisms to scale capacity:

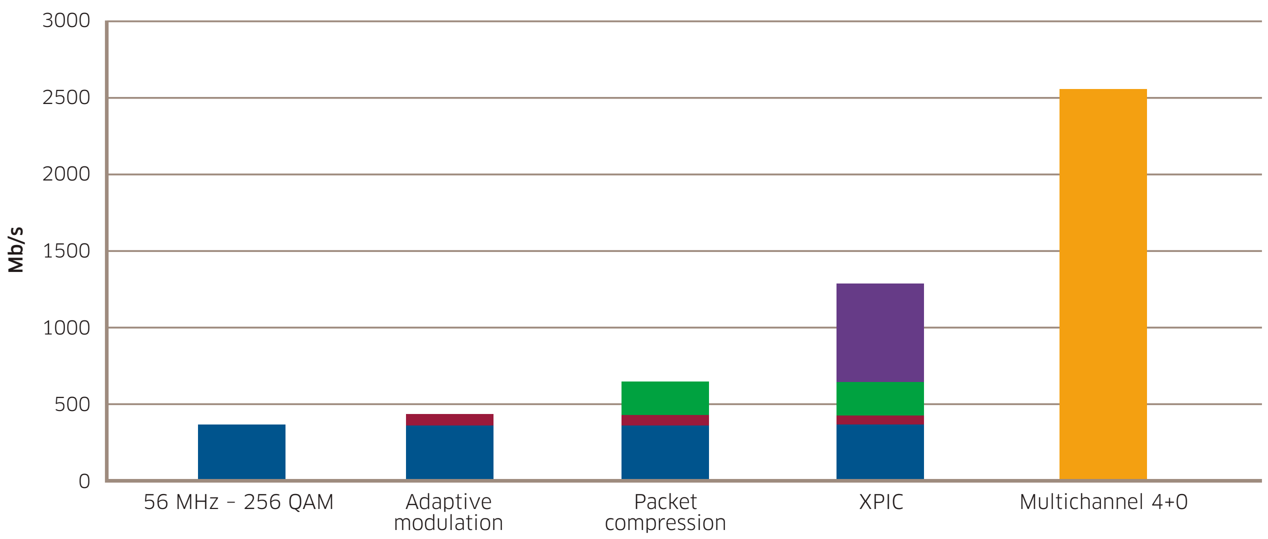
- Wider channels (e.g. 56 MHz)
- Adaptive modulation combined with HQAM (e.g. 1024 QAM)
- Header compression to increase throughput capacity
- Multichannel and XPIC to double frequency capacities
- New ring topologies based on ITU-T G.8032v2

Figure 6 shows the effect of incrementally applying these technologies, with the base case using 256 QAM.

Each microwave link direction of a ring aggregation site can be set up with a 4+0 multichannel configuration that uses 2 frequencies, with 2 polarizations per frequency. This delivers a total link capacity of 2.5 Gb/s per ring direction using only two frequencies.

Using these 4+0 virtual links in a Carrier Ethernet ring topology effectively doubles this capacity to 5 Gb/s, since both directions around the ring can carry traffic. This is enough to support the aggregation of three branches consisting of 4 macro cells and 9 small cells each, for a total of 12 LTE-Advanced macro cell sites with 27 subtended small cells sites, as described in Figure 2.

Figure 6. Scaling capacity over new long-haul aggregation links



Modern microwave systems also support adapting traditional 2G TDM to packet. This allows them to support a common backhaul system for 2G and 3G, as well as LTE/LTE-Advanced. Supporting these types of deployments doesn't generally impact the capacity requirements, as they are addressed with the aforementioned capacity scaling mechanisms.

In summary, by using the capacity scaling techniques described above packet microwave networks are well positioned to address the backhaul needs of LTE-Advanced mobile networks.

To find out more about Microwave Transmission solution, visit our website at www.alcatel-lucent.com/microwave-transmission

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