



White Paper

Second-Generation E-Band Solutions: Opportunities for Carrier-Class LTE Backhaul



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Executive Summary

Mobile broadband demand is at an all-time high, with some operators reporting a doubling of data traffic each of the last five years. With increasing adoption of sophisticated smartphones and tablet devices, more and more users are turning to mobile broadband (MBB) as their primary means for Internet access, content, applications, communications and messaging. In particular, video streaming, content downloading, gaming and other high-bandwidth, data-intensive multimedia applications are accelerating mobile data traffic growth. We are reaching a point of network saturation as more smart devices are penetrating the market, enabling users to satiate their hunger for advanced services and applications. As such, we expect mobile data traffic to grow 30-fold over the next few years and 100-fold over the next 10 years.

Mobile broadband technologies have evolved along the roadmap from 2G to 3G HSPA or EVDO, to HSPA+ and 4G LTE mobile broadband, in order to provide increased data capacity at a lower cost per bit, while reducing latency and improving the customer experience. In many countries, competitive and market forces have combined to accelerate deployment, aggressive marketing and rapid adoption of 4G LTE. A recent GSA report indicates that 97 LTE networks were commercially launched during 2012, and that 234 new LTE networks will be launched in 83 countries by the end of 2013.

Mobile broadband operators are under increasing pressure to deploy more backhaul transmission capacity both in the form of more links for new radio sites (including hetnets) and as more capacity to support new, high-bandwidth LTE services on existing radio sites. A recent report from the Metro Ethernet Forum estimates that more than 60 percent of the world's cellular base stations are connected by some form of microwave transmission.

There are a number of reasons why operators have thus far preferred microwave to other forms of backhaul. Microwave radio links are typically quick to deploy, sites and planning permissions are relatively easy to obtain, and microwave installations incur lower capex/opex than fiber-based solutions, for example. Still, hard capacity limits on traditional microwave radios and their associated bands are approaching.

Many operators are now looking for alternative, high-capacity backhaul solutions, and new forms of backhaul are also expected to offer economic benefits as mobile broadband competition mounts. One such option is to deploy E-band, point-to-point, line-of-sight (LOS) microwave radios – sometimes called "millimeter wave" or "mmW" – using radio frequencies from 71-86 GHz, well above the 6-38GHz band used for traditional cellular backhaul. Manufacturers of E-band solutions will typically provide E-band radios in the 71-86GHz range, as defined by the ITU.

The most important drivers for E-band backhaul solutions are as follows:

- More capacity per backhaul link: Supporting LTE as a high-capacity layer on top of 2G/3G networks
- Network densification: More high-capacity backhaul links in urban areas to meet broadband demand
- Lowering costs: The cost per unit bandwidth (\$ per Mbit/s) needs to be reduced to improve MNO profitability

A Closer Look at LTE Backhaul Requirements

This *Heavy Reading* white paper examines the potential for mobile operators using second-generation E-band solutions to address carrier-class backhaul needs based on an objective analysis of actual scenarios faced by operators. To understand the most important driver – i.e., the evolution toward LTE-capable backhaul – it is important to know how much backhaul capacity is required to support LTE base stations.

The following example calculation shows that high-capacity microwave radios are much needed today (unless operators choose to invest in higher-cost, dug fiber solutions):

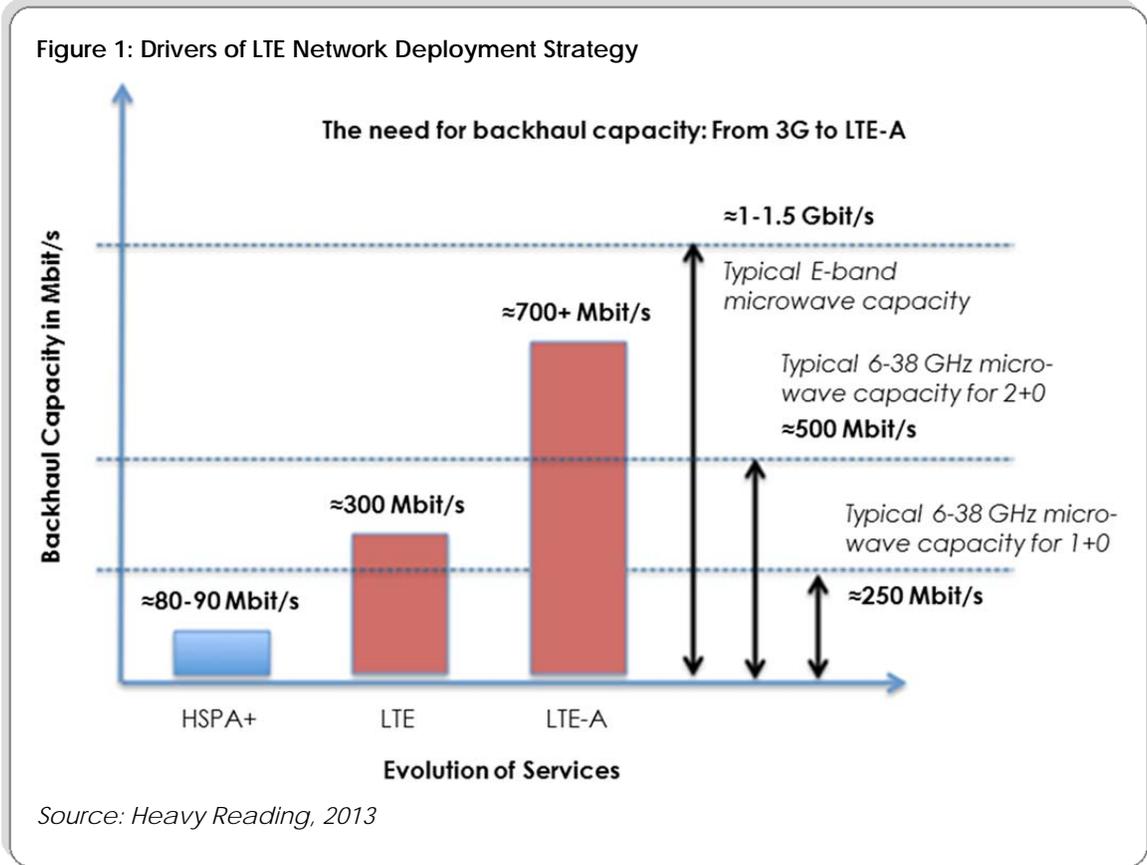
- The transmission requirement to and from a single three-sector (three-cell) LTE base station (on the so-called S1 interface) can be estimated by comparing the peak throughput rate for a single sector with three times the average throughput rate per cell plus some signaling overhead. The LTE peak rate for a single cell (assuming 4x4 MIMO and 20 MHz bandwidth) is about 300 Mbit/s, while three times the average rate is $3 \times 2.67 \times 20 =$ about 160 Mbit/s. As 300 Mbit/s is the larger value of the two, this value is often used as a guideline.*
- If we carry out the same exercise for 3G only (three sectors each with two 3G carriers at 5 MHz, SISO only) a similar exercise gives a peak rate of 84.4 Mbit/s, while three times the average rate gives $3 \times 0.79 \times 10 = 23.7$ Mbit/s. In this case the 84.4 Mbit/s serves as the guideline value for 3G/HSPA+ but note also that *the LTE backhaul requirement of 300 Mbit/s is nearly three times higher than the equivalent HSPA+ requirement.*

The 300 Mbit/s rule-of-thumb value for LTE backhaul is already on the borderline for the typical single bitstream capabilities of packet microwave radios operating in the traditional bands. Add to this the need to transport multiple backhaul traffic streams (aggregating traffic from several LTE sites into a single microwave stream in a ring topology), and operators will be challenged to provide this capacity on existing microwave bands. One option is to employ parallel traditional radios on each link (i.e. 2+0 configurations) to double single radio capacities, although microwave bands for such a scheme may not always be available.

The example above explains why many operators in mature markets are in the process of deploying fiber links to their 3G/LTE base station sites (either through own fiber or by leasing stretches of fiber). However, fiber can be an impractical and expensive alternative in many cases, as costs (especially capex) and lengthy deployment procedures can be prohibitive. In city or suburban areas, dug fiber requires permissions; and in practice it may be unrealistic to dig up pavements and sidewalks to reach the right geographic locations.

* The 160 Mbit/s average value is the equivalent continuous throughput rate for a three-sector 4x4 MIMO LTE base station site at a bandwidth of 20 MHz. The value of 2.67 is the system spectral efficiency (in bits/s per Hz) for LTE. Real rates may fluctuate around this value, i.e. up to short bursts of three times the peak rate of 3×300 Mbit/s = 900 Mbit/s. Note that dimensioning of real microwave links will always be a compromise between equipment costs and the probability of blocking and congestion when e.g. all three sectors are loaded to peak values during short periods. The latter situation is statistically unlikely, which is why such high requirements for backhaul are normally not pursued.

Figure 1 depicts the evolution of backhaul capacity needs when mobile broadband services evolve from 3G/HSPA+ to LTE and LTE-A (LTE-A assumes doubling the bandwidth of the LTE service to 2x40 MHz). The assumptions for this analysis only apply to point-to-point links, and aggregated backhaul traffic (e.g. in ring topologies) will need much more capacity than stated here. The capacity ranges for microwave backhaul is a rough estimate as real values may vary a great deal depending on radio conditions.



The Advent of "Second-Generation" E-Band

The E-band is defined by the ITU as radio frequencies from 71-86 GHz, meaning well above the 6-38GHz band used for traditional cellular backhaul. Some vendors also offer 60GHz radios that are sometimes marketed as ideal short-range LOS microwave systems because the frequencies lie within the oxygen absorption band and thus offer very low co-channel interference. These are relevant for a range of similar applications but are otherwise outside the scope of this paper.

E-band radios were developed initially for use in military, radar and automotive specialty markets. E-band radios have for a number of years been used by enterprises to connect office locations and extend LANs. Such "first-generation" products have been used for backhaul by only a few mobile carriers, including Clearwire in the U.S.

One characteristic of first-generation E-band is that such radios have used very large channel widths, typically around 1GHz or even more. Most first-generation equipment uses low-level modulations requiring in excess of 1GHz spectrum to transmit capacities of 1Gbit/s. Such products do not typically provide channel-spacing options.

As indicated in **Figure 2**, so-called "second-generation" E-band products use 250MHz or 500MHz channel-spacing options and provide for much more configuration flexibility, lending themselves to a wider range of applications. These second-generation E-band radios also embody a range of carrier-class features that previously have been unavailable for E-band products.

The carrier-class designation also means that new E-band products can be configured to comply with typical high link availability standards. They can be deployed, operated and managed according to the operational standards that apply to existing microwave equipment operating in traditional bands.

Figure 2: Milestones of E-Band Microwave Development

2007	2012	FUTURE
First Generation	Second Generation	Active Antennas
Enterprise Campus Markets	Telecom Carrier Markets	High Capacity 5-10 Gbit/s
1Gbit/s = QPSK/BPSK@1GHz	2.5Gbit/s = 64QAM@500MHz 1.25Gbit/s = 64QAM@250MHz	Sub 250 MHz
Simple QoS and NMS	Powerful E2E NMS and OAM	Fronthaul Links with CPRI
Only SynchE	E2E Frequency and Phase Synch for LTE	
Spectral Efficiency: 1 bit/s per Hz	High Spectrum Efficiency: 64 QAM up to 5 bit/s per Hz	
Regional Supply, Less Delivery Experience	Quick Installation, Fast Deployment	

Source: Heavy Reading

Most Important E-Band Applications

Today's E-band solutions are point-to-point, LOS radios capable of (to some extent and depending on e.g. inter-site distances, mounting accuracy, etc.) replacing the lower-capacity, traditional LOS microwave radios. New E-band solutions are typically incorporated into a single outdoor unit (ODU) for zero-footprint installation at the cellular base station or transmission hub sites.

Second-generation E-band, due to cost, form factor and regulatory issues, does not appear to be suitable for small cell backhaul in high-density urban environments at the street level, except in some specific cases. But E-band radios have technical characteristics that make them well suited to form a part of the "toolkit" of technologies that will be needed for small cell backhaul. For example, it may often be possible to achieve LOS alignment between higher macrosite locations and clusters of small cells at the street level. Most operators currently assume that anywhere from 20 percent to 70 percent of links will be of the LOS type for aggregating traffic from small cell 3G and/or LTE network layers. *Heavy Reading* expects that E-band radios may eventually – i.e., in the course of the next few years – be capable of meeting up to 70 percent of the total high-capacity backhaul requirements in urban and suburban areas.

There is also a further benefit of using E-band for high-density base station deployments: E-band radio beams are inherently much narrower, and therefore co-channel interference between E-band radio bands is much less likely to occur. This leads to fewer planning requirements and (depending on prevalent radio conditions) higher link quality. E-band "pencil beams" are not achievable in the traditional 6-38GHz bands.

As indicated below, second-generation E-band radio systems can be used for the standard network topologies, such as point-to-point, spurs and rings. E-band solutions also support standard hardware link redundancy and protection schemes including G.8032 Ethernet Ring Protection Switching. In this way E-band radios comply with practically all carrier-class specifications for microwave backhaul. Because of their high capacity, E-band radios are likely to be used for interconnecting main transmission nodes, i.e. for example linking of ring-topology hub-sites to the core transmission network. Depending on the size and complexity of the backhaul network, such hub sites may be plentiful. At the time of writing, large quantities of street level of 3G and LTE microcells have not yet been deployed commercially, although many industry experts and mobile operator executives believe that such deployments will need to happen in order to meet capacity needs through densification of mobile broadband networks. *Heavy Reading* believes that the applicability of E-band radios to small cell scenarios will grow modestly to reach a few percent of the total number of small cell mesh links over the next two to three years.

The most promising applications for E-band radio include:

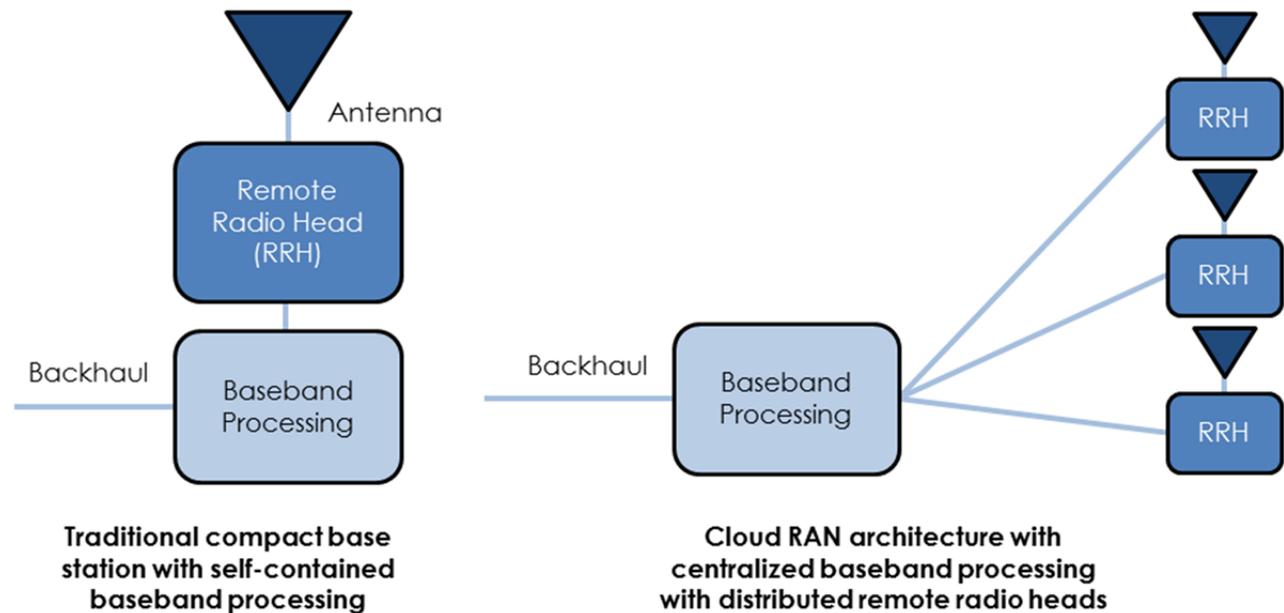
- High-capacity links between main transmission nodes in the radio network
- High-capacity replacement for current microwave links to serve multi-mode 3G/LTE macrocells
- Connecting LOS high-capacity metrocels or smaller cells
- Last mile for new small cell or Wi-Fi mesh at street level

Using E-Band for Cloud RAN Fronthaul

Today most major 3G/LTE radio access solution providers offer so-called distributed radio systems, i.e. radio base station products where the radios (remote radio heads) and the baseband units may be deployed at separate locations. As indicated on **Figure 3**, these two components are then interconnected via a high-capacity fiber link using the CPRI or OBSAI protocols. The benefits of such a setup are numerous, including better radio performance, increased deployment flexibility, less power consumption, lower costs and more.

The evolution of the distributed radio concept is sometimes called cloud RAN – that is, where a "base station hotel" (pool of baseband resources) connects tens or even hundreds of remote radio head units. As E-band radios in some ways are similar in performance to fiber, it is theoretically possible to use E-band radios for such applications. Current OBSAI/CPRI requires extremely high bandwidths, ranging from 1.25 Gbit/s to 10 Gbit/s. Thus the peak rates of E-band may be applicable to OBSAI/CPRI if 1.25 Gbit/s is needed.

Figure 3: Baseband Pooling Requires Gigabit Fronthaul for Cloud RAN



Source: Heavy Reading

Availability & Bandwidth for the E-Band

The delivery of a high – data-rate stream of bits between 3G/LTE base stations (or toward the 3G/LTE core) over the air depends on the availability of radio spectrum for microwave communications. Within the two main E-band spectrum windows – defined by the ITU as 71-76 GHz and 81-86 GHz – all of 10 GHz of spectrum is available. This is the largest contiguous swath of spectrum available for microwave transmission today. As other microwave bands are getting increasingly scarce, this is a main reason why E-band radios are now gaining momentum as an attractive high-capacity solution relevant for mobile carriers.

The E-band channels (meaning the bandwidth of spectrum used per radio link) are usually all 250 MHz or 500 MHz wide. This is at least five to ten times wider than equivalent channels in the traditional microwave bands. As a starting point, E-band radios will therefore provide at least *five to ten times the throughput capacity of traditional microwave radios*. This fact alone should be sufficient to make E-band radios the subject of serious study among mobile carriers worldwide. Even at robust modulation types (QPSK), E-band radios offer gigabit-level throughput rates.

Figure 4 illustrates the peak throughputs in Mbit/s for various combinations of bandwidth and modulation types. E-band radios typically employ adaptive modulation techniques – that is, the system will itself select the highest acceptable modulation type given actual radio link conditions.

Figure 4: Peak Throughputs for Various Bandwidths & Modulation Types

MODULATION TYPE	CHANNEL BANDWIDTH	PEAK THROUGHPUT RATE
QPSK Strong	250 MHz	530 Mbit/s
	500 MHz	1,000 Mbit/s
QPSK Standard	250 MHz	1,000 Mbit/s
	500 MHz	1,800 Mbit/s
16QAM	250 MHz	1,900 Mbit/s
	500 MHz	2,500 Mbit/s
32QAM	250 MHz	2,300 Mbit/s
	500 MHz	≥2,500 Mbit/s
64QAM	250 MHz	≥2,500 Mbit/s
	500 MHz	≥2,500 Mbit/s

Source: Heavy Reading

Typically, higher throughput rates (such as 2.5 Gbit/s) are only achievable at a shorter range with higher-gain (larger diameter) antennas. E-band equipment vendors also expect that the next generation of E-band radio technology will evolve toward even higher bitrates, reaching peak rates of 3-5 Gbit/s over the next few years. It is technically possible to incorporate wider channel spacing, e.g. 1,000 MHz, higher-order modulation and MIMO into the radios to boost capacity.

Regulation of the E-Band

Since the ITU defined the 71-76GHz and 81-86GHz bands in 1979, the E-band has required operating licenses in most countries. Regulators in many countries have recognized the unique aspects of high-frequency propagation and have chosen to open the E-band frequencies for high-data-rate and ultra-high-capacity point-to-point communications. However, due to the extremely high frequencies involved, and the narrow initial size of the market, regulators have been inclined to exempt E-band from the licensing rules that apply to most other frequency bands used for wireless networks.

The unique transmission properties of very high frequency millimeter-waves enable much simpler frequency coordination, interference mitigation and path planning than lower frequency bands. As a starting point, the two 5GHz bands are not channelized, so frequency coordination is usually not needed, making E-band frequency planning easier. In order to promote the technology, regulators in some countries have chosen so-called "light licensing" schemes that reflect the ease of coordinating, registering and licensing, as indicated in **Figure 5**.

Figure 5: Regulatory & Licensing Schemes for E-Band Spectrum

LICENSE REQUIREMENTS	COUNTRIES	TYPICAL LICENSE FEES
Unlicensed	Czech Republic Russia	Free Minimal Fee
Light License	US UK	\$75 for 10 years \$100 per year
Licensed	Ireland UAE	\$1,500 per year \$1,200 per year

Source: Heavy Reading

The U.S. and U.K. were the first two countries to open E-band for commercial use, using similar "light licensing" procedures and fees. These regulators tend to set license fees that cover administrative costs, but do not penalize the high data rates and bandwidths that are required for ultra-broadband services.

Range & Availability of E-Band Radios

The range of an E-band microwave radio link will depend on the link budget and will be defined by frequency band, power output, sensitivity, modulation type, antenna gain and atmospheric conditions. Generally, E-band radios do not provide for long-range links, but they will lend themselves well to typical inter-site distances between 3G/LTE base stations in urban or suburban areas – that is, 1 to 5 kilometers. In rural areas where the inter-site distance can be much longer, it is unlikely that E-band radios will be used.

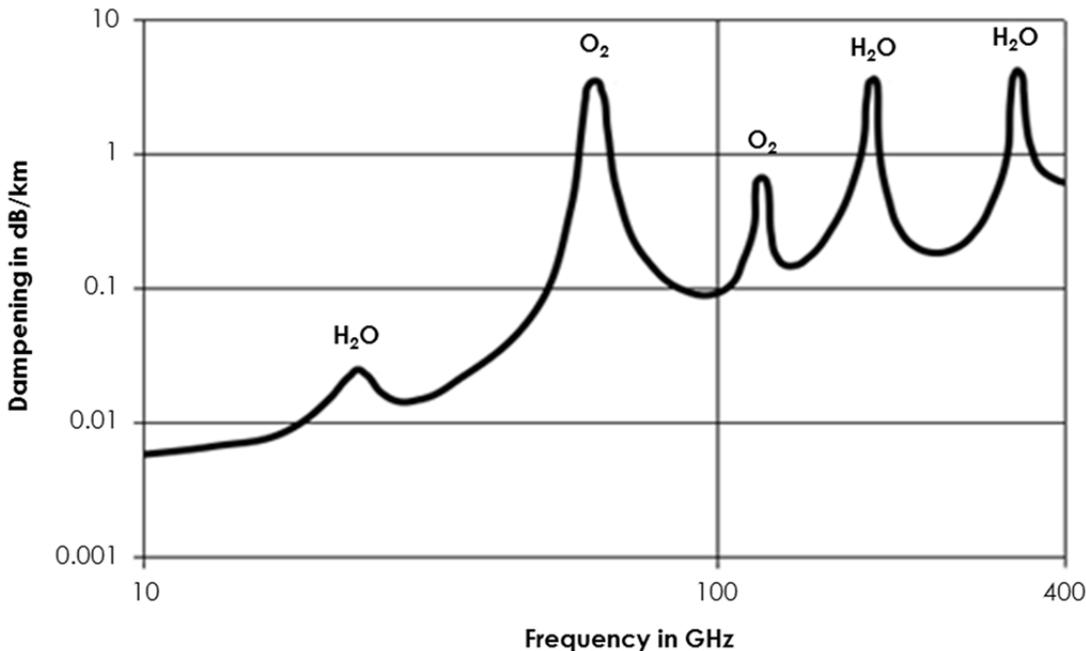
There is an inherent tradeoff between link distance and capacity: The longer the distance, the lower the acceptable order of modulation and the capacity. The E-band link distance also trades off against the severity of climatic conditions.

E-Band Ranges & Atmospheric Conditions

E-band radios are capable of delivering a 1 Gbit/s bit stream at 99.9 percent availability to a distance of 5 kilometers everywhere except within the tropical rain regions of the world, defined by the ITU as regions of type N or P. Outside such regions, 99.999 percent availability can be achieved when the range is reduced to about 1.5 kilometers.

Figure 6 examines the atmospheric damping characteristics of E-band radios, which operate beyond the peak oxygen-damping band (around 60 GHz) and thus offers similar attenuation characteristics as for the 6-38GHz bands.

Figure 6: Atmospheric Damping of E-Band Radios



Source: Heavy Reading

Although E-band frequencies are much higher than traditional microwave bands, the absorption loss per kilometer of range is comparable to traditional microwave at 0.35 dB/km (the absorption loss for 6-38GHz radios is about 0.1 dB/km). This only marginally reduces the maximum link distance for E-band radios. E-band radios are therefore – at least in theory – capable of providing high-capacity links at carrier-grade availability if backhaul networks are kept within given limits.

E-Band LOS & Radio Planning

E-band radios require LOS deployment in the same manner as microwave radios operating in the traditional bands. But E-band radios will be much more sensitive to the geometric accuracy of the deployment as any small deviation in the LOS may disrupt signals severely. This is because the radio wavelength at E-band frequencies is only a few millimeters.

On the positive side, the narrow beam of high-frequency radios renders co-channel interference between the signals emitted E-band radios much less likely. E-band radio beams are only a few degrees wide (typically less than 4 degrees) while e.g. 24GHz radios are three to four times wider in their radiation pattern. In fact, the law of diffraction states that the beam width is inversely proportional to the frequency of the radio wave.

As a result, E-band radio systems do not need the detailed radio network planning that is required by the lower bands, i.e. E-bands can be much more freely used, as individual links are unlikely to interfere with each other. This reduces planning costs and may speed up deployment. For the same reason E-band radios lend themselves well to scenarios where new transmission links are needed on short notice or temporarily, such as for temporary coverage of sports events, political events, concerts, etc.

Can E-Band Radios Deliver Fiber-Like Speeds?

E-band radios are – as a result of their high throughput capacity – often marketed as being "equivalent to fiber." This is a somewhat optimistic view, considering that fiber-based transmission networks today offer rates on commercially available equipment of up to 400 Gbit/s per fiber pair (using point-to-point DWDM and carrier Ethernet). Today's second-generation E-band radios deliver up to about 2.5 Gbit/s under ideal radio conditions and at 500MHz channel bandwidth.

In defense of the above statement, it is true that E-band radios are expected to evolve to even higher, multi-gigabit capacities. There are a number of known methods that are likely to be applied over the next few years in order to achieve this. They include wider channel bandwidth (perhaps up to 1 GHz), MIMO and higher-order modulation beyond 64QAM.

In further defense of the "fiber-like speeds" statement is the fact that some manufacturers today use GPON fiber technology for cellular backhaul. GPON is a fiber-based transmission standard – originally developed and still used for fiber-to-the-home (FTTH) services – reaching a peak of a couple of Gbit/s per connection. This is similar to the maximum data rates that can be achieved on the E-band today.

E-Band Cost Analysis

Heavy Reading's cost analysis of E-band microwave is summarized below. Due to the lower current production volumes of E-band radios (and their somewhat more complex design) E-band second-generation radios are currently priced about 60 percent higher than traditional band radios. If the capex for the two solutions is compared on a per-Mbit/s basis, the savings in capex per Mbit/s of backhaul is apparent: Assuming 300 Mbit/s for a 6-38GHz radio and 2.5 Gbit/s for a 60 percent pricier E-band radio, the estimated savings per Mbit/s is about $1.6/[2,500/300]*100$, which is approximately 80 percent. The capex cost per unit capacity is therefore significantly lower for E-band radios when compared directly in this manner.

Other capex components in carrier deployment of E-band systems may be higher. Because of the very small wavelength, LOS alignment is critical, and installation locations need to be more rigid to withstand (within a displacement of millimeters) any vibrations induced by wind or other factors. This may incur additional civil works costs for tower strengthening and/or redesign.

Carrier opex for microwave radios is usually tied to the regulatory license fees for microwave spectrum. In the case of E-band, licenses can typically be acquired for comparatively very low fees. In the U.S., the FCC imposes a cost of less than \$100 per link for a 10-year license, and the licensing application process is online. A number of other countries have adopted this "light licensing" approach, although it is not yet universal.

Highlights of our cost analysis of E-band microwave are:

- Capex for E-band radios can be 80 percent lower per unit of backhaul bandwidth (\$ per Mbit/s)
- Prices are likely to further reduce over the next two to three years as production volumes ramp up
- E-band solutions may incur additional civil works capex, e.g. for increasing the stability of towers
- Opex related to licensing costs very low in some "light licensing" countries (such as the U.S. and U.K.)
- Opex related to radio network planning is low as E-band planning is easier and faster

Carrier-Class Network Requirements

Heavy Reading has conducted research regarding some of the major mobile broadband network operators to better understand where E-band radio solutions may support their requirements for LTE network backhaul at wireless fiber speeds. While by no means exhaustive, the following brief case studies demonstrate the experience to date with using first-generation E-band solutions, and where second-generation E-band may be used in the future. **Figure 7** summarizes these case studies with information drawn from press reports, announcements and direct interviews with MNO representatives whenever possible.

Figure 7: LTE Backhaul Strategies for Leading MNOs

OPERATOR	SPECTRUM BAND	BACKHAUL SOLUTION	COUNTRIES
Clearwire	2.5GHz WiMax	Microwave/E-band	U.S.
Sprint Nextel	1900 MHz	Microwave/Fiber	U.S.
Telenor	2.6 GHz	Microwave/E-band	Norway Sweden Denmark
Vodafone	800 MHz	Microwave/E-band	Germany

Source: Heavy Reading

Mobile Network Operator Use Case: Clearwire USA

Clearwire USA operates one of the world's largest microwave-based transmission networks, in support of its countrywide WiMax-based mobile broadband services. The company currently operates about 30,000 microwave radio units to interconnect about 15,000 base station sites. Approximately 12 percent of the installed base of Clearwire microwave radios uses the E-band. Clearwire uses E-band radios to deliver 1Gbit/s data rates on aggregate traffic hops – that is, the E-band radios are not used on the last mile to the cellular base station, but rather as a substitute for leased fiber on transmission rings where high capacities are required.

Clearwire's E-band radios are installed on outer building walls (typically for rooftop-to-rooftop hops) rather than on lattice or monopole towers. This is because E-band radio mounting requires high structural stability in order to avoid LOS misalignment. Clearwire's expressed preference is to use microwave technology over fiber-based transmission wherever possible because – depending on area and service provider – lead times for leased fiber can be long, and in some cases lease costs can be high. Clearwire also prefers to be in full operational control of its own transmission network in order to maintain efficiency and quality. Also, microwave radios (including E-band solutions) are often a much more cost-efficient option when compared to leased line fiber connections.

Clearwire is not currently using any second-generation E-band units, but the company is carefully monitoring developments for use in its TD-LTE network planned for deployment in 2013.

Mobile Network Operator Use Case: Sprint

Sprint is the first U.S. operator that adopted a "single RAN" strategy for deploying new multi-standard base stations as a common platform to add LTE while replacing legacy networks. With its older and less-efficient legacy 2G/3G network, with its "Network Vision" program, Sprint is now making a strategic, long-term investment in new multimode base stations to dramatically increase coverage and capacity, deliver better signal strength, increase data speeds, improve coverage, increase backhaul capacity and enhance in-building penetration. Having committed to the investment to replace its 3G CDMA/EVDO network, Sprint is also phasing in a new nationwide LTE network over a three- to five-year period that will optimize the use of its owned spectrum assets, initially using 5MHz of paired FDD spectrum in existing PCS Band 25 (1900 MHz).

Sprint currently has no operational experience with E-band backhaul, but is carefully investigating these solutions under its technology Development Strategy Unit within the CTO function. Sprint commercially launched its LTE network in July, 2012 and LTE service was available in 49 markets at year end 2012. With a large Softbank investment, Sprint will add another 115 LTE cities in the coming months, and plans to have 250 million LTE pops coverage by end 2013 and continue fill in of smaller markets with LTE from early 2014.

Sprint is considering E-band radios to be an important element in its "tool kit" of radio solutions as it deploys backhaul for both macro base stations and aggregating traffic from small cells for LTE. Sprint is interested in non-LOS point-to-multipoint and LOS point-to-point backhaul for small cells. Sprint noted that proper management systems for non-LOS point-to-multipoint are not yet available to allow for as yet. Sprint is already testing 60GHz LOS radios for point-to-point and point-to-multipoint backhaul and sees the benefit from their small footprint, unlicensed and narrow beam LOS configuration. Sprint has several E-band radios in its lab for proof-of-concept testing, and has confirmed they offer superior high-data-rate performance over an extended range. Sprint also predicted the cost of E-band radios will be coming down in line with other backhaul solutions over time. Sprint also noted that E-band radios may be adapted for use in fronthaul links between remote radio heads and baseband pooling centers to enable cloud RAN architectures in the near future.

Mobile Network Operator Use Case: Telenor

Telenor Group is one of the world's major mobile operators with close to 150 million mobile subscribers, a leading position in the Nordic region and a strong footprint in Central and Eastern Europe and Asia. Telenor was among the first operators in the world to deploy LTE networks in Europe, using 2.6GHz band spectrum in Sweden, Denmark and Finland.

Telenor commercially launched LTE in Denmark and Norway in 2012. In Norway, Telenor has launched its 4G LTE network in 11 cities and towns, and is developing the network at a rapid pace to provide 4G coverage to one third of Norway population by the end of 2012. In addition to expanding 4G throughout Norway by the end of 2015, Telenor is extending its 3G-coverage to provide the faster internet services at the same time. Telenor and Telia have agreed to merge their 4G, 3G and 2G mobile networks in Denmark. Telenor and Telia have established a joint 4G network, and when 4G sharing begins coverage will naturally be the same for both companies – 75 percent of the population.

In Sweden, Telenor constructed its LTE network as part of the Net4Mobility 4G joint venture with Tele2 and launched its LTE service in 27 cities, with plans to launch LTE services in a further 100 cities by the end of 2012. Having completed a base station IP-based revamp, Telenor plans to deploy LTE networks on a large scale, using an end-to-end IP microwave solution for LTE backhaul. Telenor is most interested in an LTE backhaul solution that enables high bandwidth, smooth evolution, quick deployment and easy management. Telenor has also established into a three-year strategic architecture for IP microwave technologies, under which a full outdoor microwave and second-generation E-band solutions will be widely deployed.

Mobile Network Operator Use Case: Vodafone

Vodafone, the world's second-largest mobile operator, owns and operates mobile networks in more than 30 countries and has partner networks in more than 40 additional countries. Vodafone has yet to unveil an LTE deployment strategy at a corporate level. Vodafone benefits from the LTE deployment experience of Verizon Wireless, and Vodafone Hutchison Australia is replacing its entire wireless network using single RAN base stations to simultaneously launch new HSPA+ and LTE services.

Vodafone was the first operator in Germany to rapidly launch commercial LTE services using 10 MHz of 800MHz spectrum. Vodafone used a network overlay strategy to meet the stringent license obligations by deploying LTE in 1,000 "white spots" or municipalities with inadequate broadband service in Germany. Vodafone offers LTE-only USB modems to date, and plans to use other LTE spectrum bands to cover the rest of Germany and has 25 MHz of TDD spectrum available for future use. Vodafone has 260,000 LTE customers and 3,700 LTE base stations live in Germany as of year end 2012.

Vodafone is also preparing for the launch of LTE in the U.K. in 2013, by announcing "a new ultra-fast network" called Vodafone 4G that will deliver LTE network coverage to 98 percent of the population. Although we were unable to complete a direct interview with a company representative, Vodafone provided some general data usage updates for its European networks that could drive the need E-band radios for LTE backhaul links in the future:

- The average utilization of its 3G networks in Europe is 35 percent at year end 2012, and 6 percent of its 3G base station sites have reached 90 percent or higher peak use.
- 51 percent of base station sites in Europe use a second frequency carrier, and 7 percent of sites use a third carrier for additional radio capacity.
- Data usage per customer among iPhone and Android device subscribers is up 25-30 percent, while tablet usage in general was up 60 percent compared with last year.
- In Europe, 44 percent of Vodafone's base station sites have been upgraded to single RAN, supporting multiple technologies (2G GSM, 3G WCDMA, 4G LTE) – up from just 13 percent in the same period last year.
- Globally, 50 percent of Vodafone's base station sites are shared with other operators where backhaul requirements will exceed its own traffic requirements.

During the operator's year end 2012 earnings presentation, Vodafone highlighted how much backhaul capacity has been built into its network during the past year. At the close of 2012, Vodafone had backhaul capacity of 1 Gbit/s or higher across 47 percent of its European network footprint. That's up from 29 percent of its European network at the same time last year. Vodafone executives believe this is enough capacity per base station site to meet current traffic levels.

Vodafone's CTO office was asked to develop a theoretical maximum throughput that a base station site could achieve running LTE at 2600MHz, LTE at 800MHz, 3G at 2100MHz and 3G at 800MHz on three sectors, and if each technology hit peak speeds the total throughput would, by Vodafone's calculation, reach 930 Mbit/s – just under the 1Gbit/s backhaul capacity. This would suggest that Vodafone is a good candidate to benefit from E-band gigabit backhaul for its LTE networks in the near future. However, this is a theoretical maximum throughput level, and current demands placed on actual base stations don't reach those levels, giving Vodafone some room to grow into that network capacity (at least for now).

Conclusions: E-Band for LTE Backhaul

The key conclusions of this paper are as follows:

- E-band microwave radios are technically solid solution where high capacity is required on microwave links to LTE-capable base station sites and when single or aggregate traffic streams area required
- E-band radios provide the right capacity level for LTE-capable sites when traditional microwave band (6-38GHz) capacity has been exhausted
- The cost of E-band license fees is lower (and in some cases free) and bands in the E range will typically be easier to obtain from regulators
- Second-gen E-band is best suited for high-capacity backhaul, including the aggregation network, fiber protection/complement and ultra-high-capacity LTE macro backhaul. Due to cost, size and regulation, it does not yet appear to be the ideal solution for street-level small cell backhaul
- E-band radios are likely a strong upgrade option when macrocellular sites at 1-4km inter-site distances need upgrades in capacity to support LTE
- Second-gen E-band radios are capable of providing the right quality of service levels required for carrier-class LTE backhaul
- On a cost-per-capacity basis, E-band radios offer 80 percent capex savings; this number will rise as E-band radios are produced in larger volumes

Figure 8 summarizes the benefits and drawbacks of E-band microwave radios for carrier-grade LTE backhaul.

Figure 8: Summary of Benefits & Drawbacks of E-Band Radios

BENEFITS	DRAWBACKS
Very high capacity compared to traditional microwave (up to 2.5 Gbit/s)	Relatively short range for high availability and high throughput (<2 kilometers for 2.5 Gbit/s)
Excellent availability of band and (in some cases) "light licensing" for low opex	Highly sensitive to instability of physical mounting (millimeter stability required) and is most applicable for wall mounting
Low price per Mbit/s ratio (capex) and easy network planning for lower opex	Significantly higher cost (capex) per radio unit at the first stage (currently +60%)
Well suited for capacity upgrade of microwave links to macro-cellular sites in urban/suburban areas	Not well suited for microcellular or small cell deployment because of LOS requirement and fewer mounting options
Supports all standard topologies and redundancy schemes for carrier operation	More sensitive to signal degradation due to rain and thus not widely applicable for deployment in tropical regions
Very low likelihood of interference due to "pencil thin" radio beams	

Source: Heavy Reading