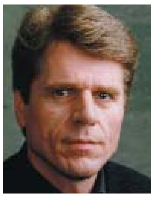
Gigabit Radio Links for Flexible and Efficient Broadband Mobile Backhaul Networks

TERJE TJELTA



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Mobile network traffic shows a dramatic growth, particularly due to new broadband services. The backhaul is becoming increasingly important in providing competitive broadband mobile services. Microwave links is one of the most common backhaul technologies for mobile network base stations. The transition from basic voice services to mobile broadband services now taking place in all markets will require significantly higher backhaul capacity, and traditional 2 Mbit/s or a few Mbit/s lines are not sufficient. One option is the recently developed single carrier gigabit radio links, particularly for the network sections close to the base station site. These radio systems operate in the millimetre bands, ie. 60–90 GHz and are characterised by offering 1 Gbit/s capacity in a single radio channel while being developed towards even higher bitrates. The possible range for such systems is a few kilometres depending on the local climate.

1 Introduction

Since digital mobile and wireless access systems were introduced in the 1990s the capacity offered to the end users has increased exponentially. The fourth generation (4G) mobile systems now being developed will deliver several tens Mbit/s, heading towards 100 Mbit/s and even more [1]. This is actually already seen in the first tests of the emerging long term evolution (LTE) technology being performed these days. It seems to still continue to evolve towards even higher capacities. The technology push will continue for several years. Currently there is a very high development effort to establish internationally standardised and recommended 4G solutions to gain access to the radio frequency spectrum allocated and identified for international mobile telecommunications (IMT) [2]. With global standards the broadband mobile systems become ubiquitous, and high capacity core and backhaul networks will be needed where people live and work and machine or sensor networks require connections.

The new mobile broadband 4G technology is designed to make much better use of access network spectrum compared to current and earlier systems. Both due to an increased spectrum efficient code and high frequency reuse factors, perhaps approaching single frequency networks, the degree of spectrum utilisation will be higher [3].

The consequence for the backhaul network is apparent; introducing next generation mobile systems means also to provide much higher capacity for the same operator's bandwidth compared to traditional cellular networks. In addition, operators will require more bandwidth to support the expected higher capacity demand increasing the pressure on backhaul even further, as there are physical limits to what can be provided in a given bandwidth for area coverage [4].

It is a significant challenge to provide backhaul networks with sufficiently high capacity at a reasonable cost. Fibre optic cables, as used widely particularly in the core network, can without any difficulty deliver the capacity needed. This is also a good long term choice for many base station sites. Point-to-point radio links remain, however, as a good option for many backhaul cases [5]. Radio links can also easily be re-located to other places in the network according to emerging needs, eg. when the base site is served by fibre optics. Initial cost estimates indicate that gigabit radio link technology is competitive with fibre technology where new cable trenches are needed and emerging gigabit Ethernet radio links is a candidate technology to consider combined with fibre for backhaul networks.

It is also noted that a very high number of mobile base station sites is needed, and the higher the capacity offered the denser the base station sites will become. This is a direct effect of the shorter range for high capacity broadband mobile systems technology and the number of users possible to serve per base station. As the number of mobile customers approaches the majority of the world's population there will, as well, be several million base station sites needed on a global scale. It is understood that the relative cost of the backhaul network is increasing and has to be considered carefully for any broadband mobile scenario [6][7].

There is a shift towards packet based networks and Internet protocol (IP) data will more and more dominate the traffic [8]. The trend is towards an all-IP packet switched network. Already in legacy circuit switched networks for time division multiplex (TDM) traffic there is an increasing amount of data traffic. The technology used for legacy backhaul such as plesiochronous digital hierarchy (PDH), synchronous

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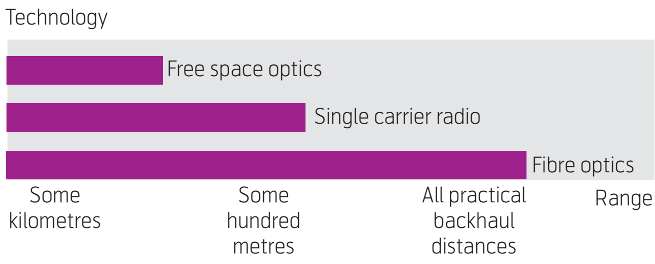

Figure 1 Range for backhaul gigabit technology

digital hierarchy (SDH), and asynchronous transfer mode (ATM) are also used for the IP data. However, it seems that Ethernet and multiprotocol label switching (MPLS) technology for packet data traffic is more suitable and cost efficient for the future backhaul, although there is still competition from existing solutions, in particular for operators having legacy TDM traffic to consider [9], at least in the short term perspective.

The recently developed products of gigabit radio links are of particular interest for backhaul in combination with fibre optics. Few alternative solutions are able to offer gigabit backhaul. One alternative wireless technology is free space optics (FSO), another is traditional microwave links. But FSO has a significant problem with network availability for hop length beyond a few hundred metres, and traditional microwave requires multiple radio channels and will most likely be more expensive.

The gigabit radio links operate as single carrier systems in the 60-90 GHz range and can connect two-way 1 Gbit/s Ethernet systems. Furthermore, the

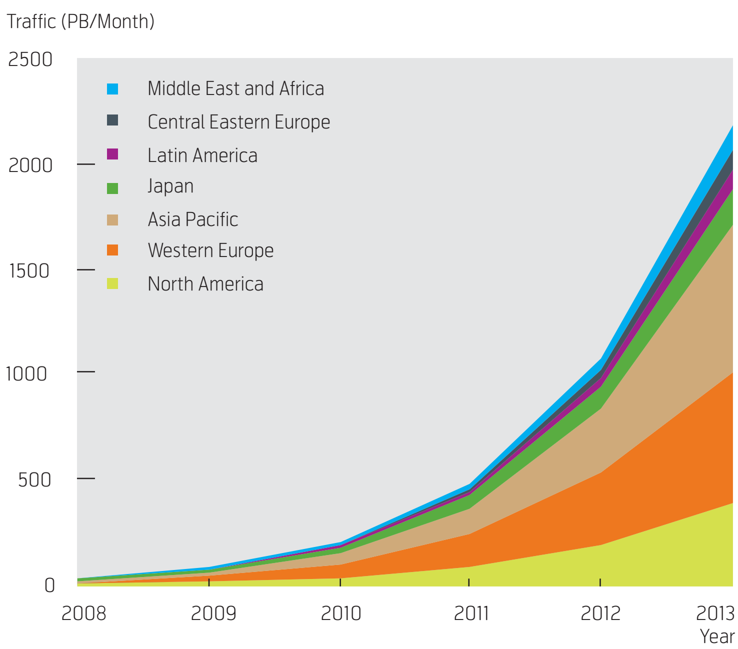

Figure 2 Mobile IP traffic (PB/Month) forecast by region [10]

vendors aim at higher capacity as well, ie. 10 Gbit/s is mentioned but launching 2.6 Gbit/s first. The range is of key interest as illustrated in Figure 1.

At the high frequency range of 60-90 GHz the radiowave propagation impact allows hop lengths of a few kilometre, depending on the climate and in particular the rainfall in the area considered. The narrow antenna radiation beams make such links suitable in a high density network design, say that a number of base stations or access points are connected together and to the backbone in a mesh topology.

With respect to regulation the licence exempt band at 60 GHz and preferably light licensing for the 70 – 90 GHz bands, makes it quickly possible to establish very high capacity complete backhaul networks from scratch.

This article is organised in five sections, where Section 2 presents some traffic considerations leading to the required gigabit backhaul and backhaul technology, wireless gigabit technology in Section 3 focussing on propagation effects limiting the maximum range, application guidance for some climate regions in Section 4, and conclusion in Section 5.

2 Broadband Mobile Backhaul

2.1 Mobile Data Traffic

As 4G mobile systems is increasingly being rolled out the IP packet data will dominate. Mobile network operators have already observed a dramatic increase in traffic when providing high speed packet access (HSPA). The trend is exponential, illustrated in Figure 2, and the total mobile IP traffic (mobile phones, lap-tops with cards, and mobile broadband gateways) doubles every year [10], compared to the total IP traffic doubling every second year. Still, mobile IP is a small fraction of the total, but the growth rate is twice as fast.

2.2 Backhaul Network Technology

The backhaul network is the element between the core and the base station sites. There may be just one link or a tree structure with aggregation, as illustrated in Figure 3. Future solutions may also include mesh or other topology structures.

The data traffic increases with time and the network migrates towards all-IP. In the current situation there is still a significant amount of TDM traffic. Providing packet data services over the technology dimensioned for voice services is not efficient and does not scale well. Business models and new technology for packet data traffic have to be considered.

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Operators wanting to provide both telephony service using switched circuit TDM and data traffic using packet switching have to either build a parallel network for the data traffic, or provide both types of traffic within the same network, indicated in Figure 4. The latter may not be possible if the backhaul is dimensioned for TDM with a few 2 Mbit/s lines of backhaul. At least not much data traffic can be supported. For a newcomer just building a data packet network, the TDM traffic can be handled using emulation techniques, called pseudowire. One important part is synchronisation needed for the TDM application. It is expected that the opportunity window of pseudodwire solutions is limited, say around 2012, and that an all-IP solution will take over [9].

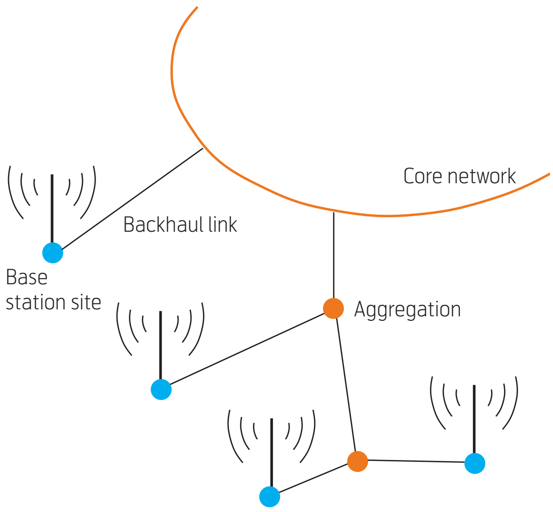

Figure 3 The backhaul network for base station sites

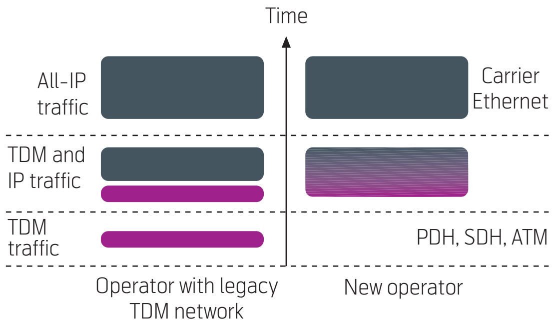

Figure 4 Migration from time division multiplex data to all IP

3 Wireless Solutions for Gigabit Backhaul

3.1 Gigabit Radio Link Equipment for the 70/80 GHz Band

Since its launch a few years ago there is now off-the-shelf equipment from a number of vendors. The equipment is lightweight and easy to install, at least from a mechanical point of view. Relevant standards have been developed, such as ETSI [11] and CEPT [12] dealing with spectrum utilisation, transmit power, and radio channel arrangements. The standard envisages equipment at the 70/80 GHz band estimating radio interface capacities up to 19 Gbit/s, so far equipment with radio interface capacity of 1.25 Gbit/s is available for full duplex 1 Gbit/s Ethernet interface.

The radios deploy robust two-level modulation, such as binary phase shift keying (BPSK), but there is a development towards higher modulation order to make better use of spectrum and also provide products for several markets. The equipment deploys error correction schemes and has a low latency within a few µs.

The equipment may provide automatic transmit power control (ATPC). Also adaptive solutions are available allowing the link to dynamically operate under more difficult propagation constraints at lower data rate, down to 100 Mbit/s. The basic protocol is Ethernet, which is of main interest for this type of product, but there is equipment for other interfaces such as SDH and hybrid combinations. Equipment with adaptive modulation has delays in the order of 60 µs.

The frequency band consists of two 5 GHz sub-bands, 71-76 GHz and 81-86 GHz, eg. for frequency duplex operation with 10 GHz duplex distance. Also time division duplex (TDD) can be used as well as narrower duplex distance for FDD. Other services also have primary allocation in these bands [13], but fixed service radio link seems to be the application that starts off using the band.

The quality of the equipment varies from vendor to vendor. Considering system gain, defined as the difference between the output of transmit amplifier and the receiver radio threshold, typical values are in the range of 70 to 85 dB for the 1 GBit/s systems. Alternatively, the noise figures are around 10 dB or somewhat less. The ETSI standard [11] provides for information two tables; one showing the radio interface capacity and occupied bandwidth (in 250 MHz resolution as specified by CEPT) and another showing calculated receiver input signal level per MHz required for systems with a different number of modulation states for a bit error ratio better than 10^{-6} and 10^{-8} and an equipment noise figure of 12 dB. These data give system receiver thresholds as shown in Table 1. The same standard indicates maximum power of 35 dBm at the input of the antenna feeder. This gives system gains ranging from 73.5 to 94.9 dB

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Modulation states	1 Gbit/s		2.5 Gbit/s		10 Gbit/s	
	Bandwidth MHz	Threshold dBm	Bandwidth MHz	Threshold dBm	Bandwidth MHz	Threshold dBm
2 (PSK)	1750	-59.1	4250	-55.2		
4	1000	-58.5	2250	-55.0		
16	500	-54.5	1250	-50.5	4250	-45.2
32	500	-51.5	1000	-48.5	3500	-43.1
84	500	-48.5	750	-46.7	3000	-40.7
128	250	-48.5	750	-43.8	2500	-38.5

Table 1 Occupied bandwidth and radio receiver threshold (@BER 10^{-6}) for typical 70/80 GHz systems according to ETSI [11] shown for 1 to 10 Gbit/s capacity

and 250 to 1750 MHz occupied bandwidth in delivering 1 Gbit/s for the various modulation states ranging from 2 to 128 levels. There are clear individual vendor variations checking receiver thresholds, some better and some as indicated. The noise figure is in fact coming down significantly from the 12 dB used in these estimates. The occupied bandwidth goes in steps of 250 MHz, according to the CEPT recommendation [12], such that for some figures quoted in Table 1 the capacity can be well above the value indicated in the actual column.

The radio consists of a small package mounted back-to-back to the antenna, either 30 cm or 60 cm diameter reflector antenna. At these frequencies the gains are about 51 dB and 44 dB, for 60 cm and 30 cm antennas, respectively. The feeder loss is small.

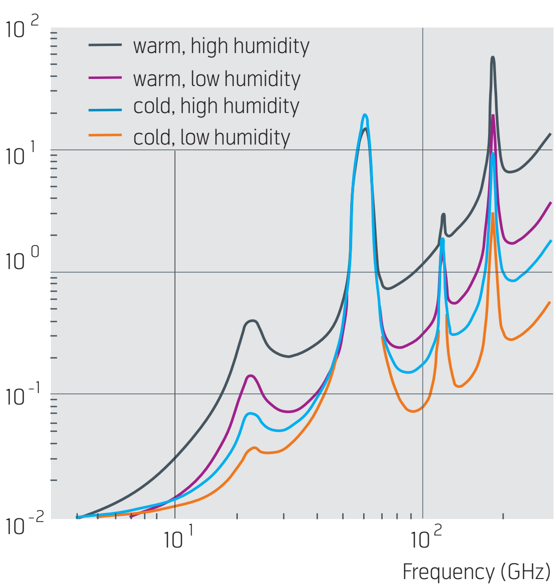

Figure 5 Atmospheric gases attenuation of radiowaves in the frequency range 4-300 GHz

CEPT provides guidlines for spectrum utilisation including light licensing procedures, such as implemented by Ofcom [14] and FCC [15].

3.2 Radiowave Propagation Conditions

Several radiowave propagation effects have to be taken into account in order to dimension the radio links satisfactorily with respect to wanted quality, ie. link availability. A typical requirement for radio link hop is five or four and a half nines, ie. 99.999% or 99.995% of an average year.

3.2.1 Gaseous Attenuation

The atmospheric gases attenuate radiowaves and the attenuation increases with the frequency, from insignificant attenuation at low frequency towards very high attenuation for certain high frequencies leaving a number of ‘windows’ that can be used for communication purposes. Figure 5 shows the specific attenuation in db/km for the atmosphere at 1013 hPa, ie. normal air pressure at the surface of the Earth. Four different types of atmospheric conditions are chosen combing cold (-10ºC) and warm (20ºC) with low relative humidity (30%) and high relative humidity (90%) [16]. It is noted that for most frequencies there is significantly more attenuation for a warm atmosphere with high relative humidity. The explanation is that the partial pressure of water vapour is larger the more water vapour the atmosphere can contain, and the specific attenuation due to water vapour is higher than the rest of the gases expect around 60 GHz. At this particular frequency, or actually band between 50 and 70 GHz, there are many single frequencies with strong interaction between oxygen molecules and the electromagnetic wave resulting in heavy attenuation. At the surface of the Earth the individual absorption lines merge creating a broad attenuation band around 60 GHz. Since the total pressure is unchanged in the calculation the total attenuation is in fact reduced at 60 GHz for the high humidity atmosphere compared to the dry atmosphere.

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At the frequency of interest, around 70/80 GHz, the attenuation will generally be below 1 dB per km. For a 60 GHz system the nominal gaseous attenuation is 16 dB/km with some variation, resulting in a very limited range.

3.2.2 Attenuation Caused by Hydrometeor Precipitation

The effects of atmospheric gases are there all the time, but the attenuation is not very significant. Sometimes variable phenomena may however cause deep attenuation and have to be accounted for in order to estimate the correct maximum hop length for wanted availability. The effect of rainfall is very significant, and by way of specific attenuation these effects will dominate. It rains only part of the time and in part of the area. Therefore, when calculating the possible link length taking rain or other hydrometeor precipitation into account, the time and spatial variability has to be modelled as well.

The specific rain attenuation [17] is illustrated in Figure 6 for vertical polarised radiowaves for the same frequency range as shown for gaseous attenuation in Figure 5. It is noted that the attenuation increases dramatically with rainfall intensity, measured in mm/h, and frequency. Below 10 GHz the attenuation is generally small, particularly for moderate rainfall intensity, and above 100 GHz the attenuation levels out.

The rainfall rate varies significantly from one climate to another causing the range limit to vary considerably as well, see next section for calculated examples. The horizontal polarised waves are slightly more attenuated than vertical polarised waves because or large drops being flattened or shaped more like to an ellipsoid with the 'flat' bottom aligned parallel with the Earth.

3.2.3 Attenuation Caused by Fog and Clouds

Fog and clouds also attenuate radiowaves. The specific attenuation depicted in Figure 7 shows four examples using the ITU-R model [18]: cold (-10ºC) and warm (20ºC) atmosphere with low (50 m) and intermediate (300 m) visibility. It is noted that attenuation at 70/80 GHz in winter fog or cloud can be a few dB per kilometre.

Although models exist for specific attenuation for all relevant atmospheric conditions it is only the method for precipitation attenuation that provides a statistical distribution such that availability can be estimated. Neither for attenuation due to gases nor for attenuation due to fog and clouds is there any method for the typical variability of the year. Since the effect is very small at lower frequencies there has not been a focus on these issues. However, moving up in frequency also gases and fog/clouds should be accounted for in accurate radio link dimensioning. A practical rule for the time being can be to add 1 dB per kilometre link the attenuation estimated due to precipitation and ignore the effects of fog and clouds as these effects will not normally appear during periods of rainfall.

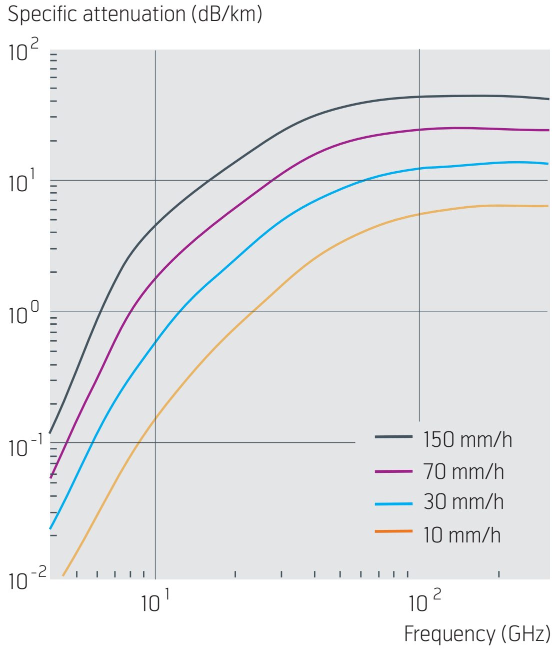

Figure 6 Specific attenuation due to rainfall for vertical polarised radiowaves

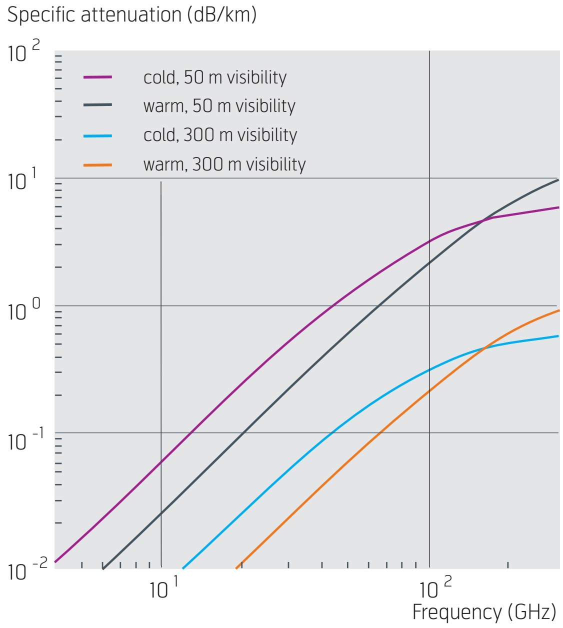

Figure 7 Specific attenuation due to fog and clouds

3.2.4 Adaptive Solutions

Under adverse propagation conditions an adaptive radio may change modulation and throughput capac-

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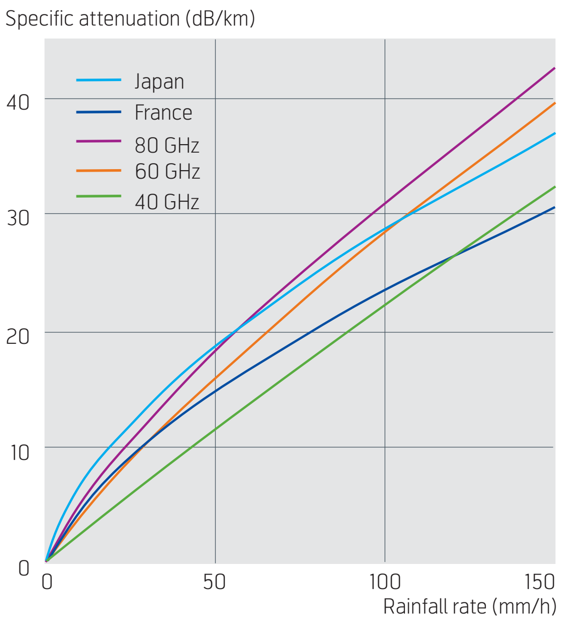

Figure 8 Specific attenuation due to rainfall at 40, 60, and 80 GHz and optical wavelength using the available models 'Japan' and 'France' [19]

ity to continue to provide service. Given that the network can handle this it may be an interesting solution to keep part of the traffic longer and perhaps avoid disruption. Such systems need some time before decision and change, and there is therefore more delay – more than 60 µs is indicated. Furthermore, the delay at the temporary lower rate is longer, above 200 µs.

3.2.5 Hybrid Radio and Free Space Optics Links

Since high frequency radio links basically suffer under periods of rain, and free space optics is basically limited by fog, a hybrid solution should perform very well such that the combiner or switch maintains a high performing network. The basic assumptions seem to be that free space optics is not severely limited by rainfall, and clearly radio links are not severely attenuated by fog. Furthermore, dense fog does not appear at the same time as heavy rainfall.

However, the specific attenuation for free space optics links under rainfall, in particular using model 'Japan', is significant [19], see Figure 8, and not very different from 70/80 GHz links, but better than 40 GHz links or perhaps 60 GHz in this respect. Figure 8 illustrates that the 40 GHz system has the lowest specific attenuation for all rainfall rates under consideration. However, higher frequencies radio and the optics are comparable. At very high rainfall intensity the optical system is less attenuated than radio; however, at mid and low rainfall intensity this is not the case.

This makes it likely that a diversity improvement can be achieved from hybrid free space optics and radio systems at very high rainfall rates. Using the curves in Figure 8 and applying them for short hybrid FSO and 60 GHz links the most pessimistic FSO rain attenuation method (Japan) shows that diversity improvement is possible for rainfall rates beyond 100 mm/h rainfall rate, and using the most optimistic FSO rain attenuation method (France) the improvement is possible beyond 30 mm/h rainfall rate. It depends on the local climate whether the hybrid system can offer five nines availability, but the dimensioning can be done using rain attenuation methods for FSO systems. Considering the longer reach 80 GHz system only for regions with rainfall rates beyond 60 mm/h may a hybrid solution offers better availability than the radio system on its own.

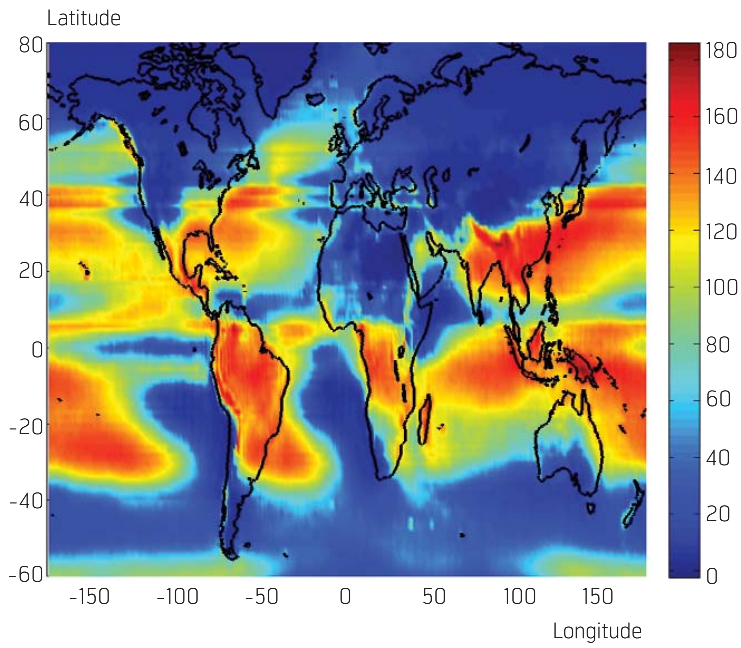

Figure 9 Global rainfall rate (mm/h) exceeded at 0.01% of an average year [20], the probability used for dimensioning purposes

4 Application Guidance Using Gigabit Radio Links

The main interest is whether the maximum range gigabit radio links can be used and still meet operators' availability requirements. It is the local rainfall climate that limits the possible path length for a given radio system. The ITU-R [20] recommends using the map shown in Figure 9 as the dimensioning input rainfall rate parameter, or alternatively, to use local long term measured data. The map shows a significant variability across the globe with tropical and low latitude regions showing significantly higher intensities than temperate mid latitude or high latitude regions. For dimensioning purposes the current recommendation [21] uses only the rainfall rate at 0.01% independent of the availability percentage wanted for the system evaluation, ie. the same distribution form

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is used for all climates just using the value at 0.01% as the input. Furthermore, the concept of effective path length is used to account for the rainfall spatial variability from widespread front of rain to confined heavy rainfall showers.

For a given system it is now possible to calculate a good estimate for the maximum range for wanted availability taking the equipment characteristic into account as well as the local climate [21]. The equipment quality can be characterised by its system gain, and adding antenna gains the maximum range is given allowing for propagation effects. Assuming a standard atmosphere in terms of atmospheric pressure, temperature and humidity and noting rainfall variability the expected maximum range at 99.995% availability is as shown in Figure 10 for Europe for an 83.5 GHz system with 85 dB system gain, 50 dB gain antennas and no branching loss.

Similarly, for the same radio link characteristics the maximum range is shown for South East Asia (Figure 11) and for the India/Bangladesh region (Figure 12).

For all these areas the typical maximum hop length satisfying a 99.995% availability varies from 1.5 to about 6 km.

In practical design the wanted availability due to propagation limitations will be five nines, or four and a half, ie. 99.999% or 99.995% of an average year. The possible range can be increased if the availability requirement is relaxed, shown in Figure 13. It almost seems as the maximum range can be doubled for one decade lower availability, eg. hop lengths can be about 1.5 km or 3 km in Islamabad for 99.999% or 99.99% availability, respectively.

There is a limited number of long term measurements of millimetre radio performance due to propagation effects. In the literature there have been a few test beds studying specific attenuation. For 70/80 GHz radio in practical hop length suitable for the backhaul network Telenor has undertaken measurements in Norway and Hungary. Results are available for one year or a longer measurement period from a test link in Oslo [22]. With respect to rainfall attenuation the results indicate that the ITU-R method is close, but slightly optimistic. Variation in attenuation due to atmospheric gases can be accounted for allowing 1 dB/km of the link margin. Effects of fog is likely, but it has not been possible to single this out. However, it will affect the link at low or insignificant rainfall rates. If the link is dimensioned with respect to rainfall the fog effect can be ignored.

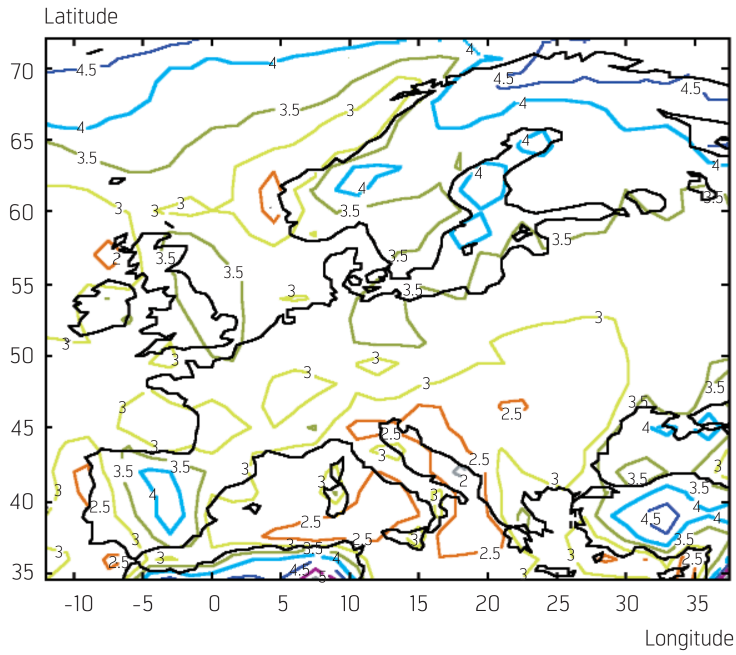

Figure 10 Europe: Maximum hop length for an 83.5 GHz gigabit radio link with 85 dB system gain and 60 cm diameter reflector satisfying 99.995% availability

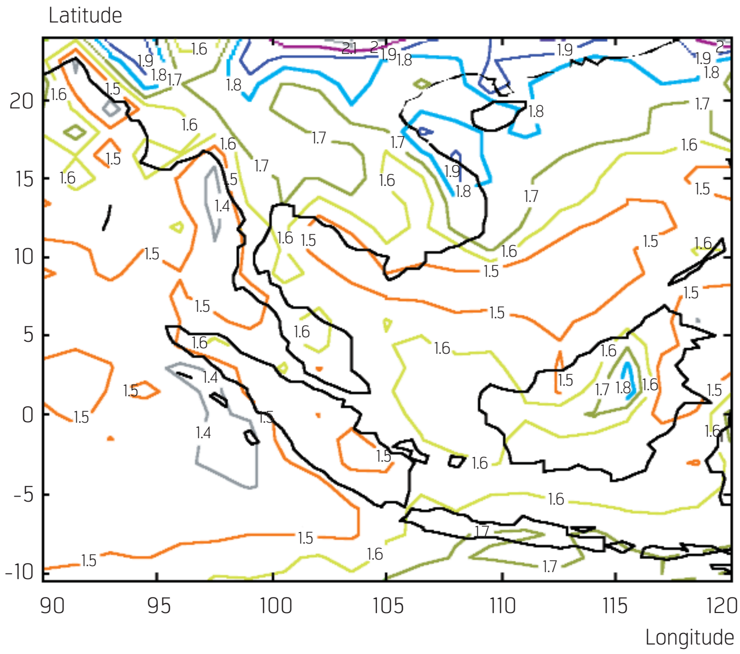

Figure 11 South East Asia: Maximum hop length for an 83.5 GHz gigabit radio link with 85 dB system gain and 60 cm diameter reflector satisfying 99.995% availability

5 Conclusion

The introduction of broadband mobile services leads to a dramatic increase in the traffic challenging current solutions for backhaul. Future backhaul networks will become more important also considering the cost of mobile operations. Mobile systems packet data IP traffic is expected to increase exponentially in the coming years with a yearly doubling rate, twice as high growth compared to the total IP traffic growth

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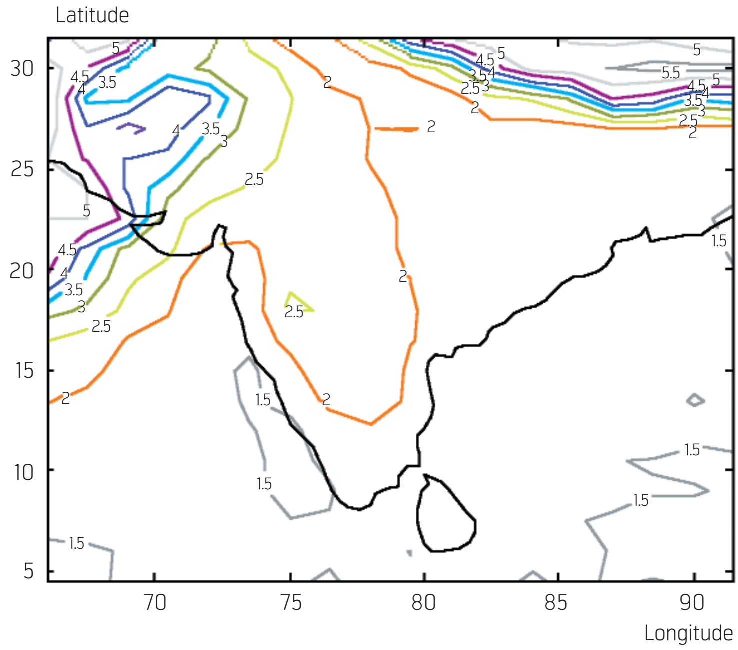

Figure 12 India and Bangladesh: Maximum hop length for an 83.5 GHz gigabit radio link with 85 dB system gain and 60 cm diameter reflector satisfying 99.995% availability

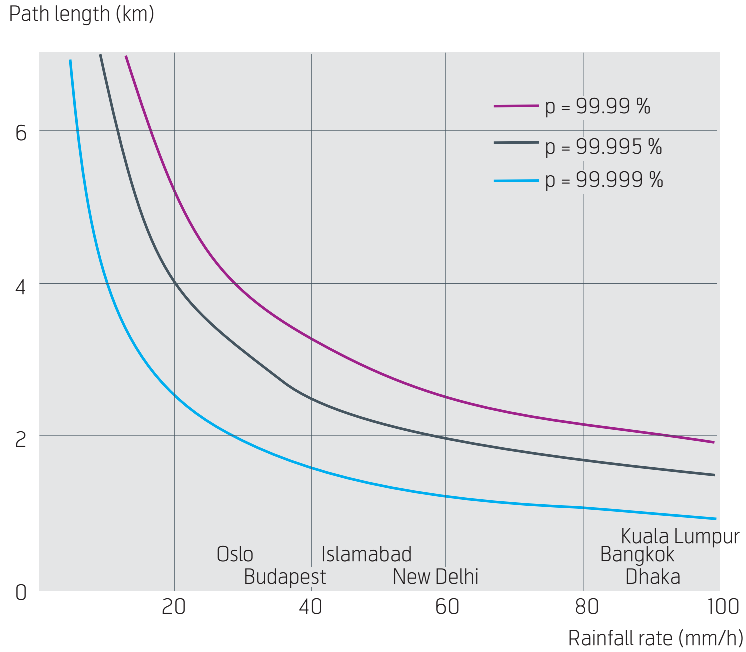

Figure 13 Possible path length versus 'dimensioning' rainfall rate exceeded at 0.01% of the time for an 83.5 GHz gigabit radio link with 85 dB system gain and 60 cm diameter reflector for three different link availabilities (p). Rainfall climate is indicated for some selected cities

considering all networks. With the next generation mobile system offering more than 100 Mbit/s to end users the backhaul has to deliver gigabit capacities.

Besides optical fibre the single carrier radio link technology at the 70/80 GHz band is an interesting option. Such links can be used for hop lengths of up to a few kilometres depending on the local climate and availability requirements. Even for tropical areas with heavy rainfall events four and a half or five nines availability can be provided for a kilometre hop length. In climates with less high intensity rainfall the link lengths can be 2-5 kilometres, in dry climates even longer.

Judged by one test result in the Oslo region of Norway the available prediction method for possible link lengths is slightly optimistic. It should be noted that these methods are currently only tested for accuracy up to 40 GHz due to a lack of measurements. More long term tests should be performed to check the methods and develop and validate them for the 70/80 GHz frequency range as well.

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 ISSN 0085-7130 ©Telenor ASA 2010