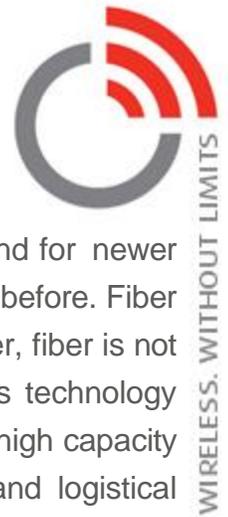




Licensing Considerations for Multi-Gigabit E-band Systems



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As network operators race to keep pace with mobile data traffic growth, demand for newer technologies to deliver this high capacity backhaul transport is higher than ever before. Fiber is the preferred transport technology for high capacity backhaul needs. However, fiber is not always practical, feasible or can be cost-prohibitive. Millimeter wave wireless technology (using the 71-76 and 81-86 GHz ITU spectrum) presents the potential to offer high capacity transport technology comparable to that of fiber, but without the financial and logistical challenges of deploying fiber. However, being a wireless radio frequency technology, millimeter wave does have key considerations that are needed for the coordination and licensing of the radio frequency use.

In this paper, we outline the key factors and recommendation for the allocation and licensing of the millimeter wave spectrum, that promote the adoption of millimeter wave technology as a wireless transport solution for **multi-gigabit data rate services over longer distance**.

Market Drivers

Introduction of the iPhone in 2007 started a tsunami of demand for more data. The growth of smarter, more powerful, and more connected devices is exploding and has been a global phenomenon. The types of communication and the content has moved beyond the early years of voice and email, to the next generation video, multimedia, peer-to-peer multimedia, smart grids, machine-to-machine, etc. The use of cloud technology and the proliferation of data centers have accelerated the consumption of huge amounts of data. This global instant data consumption phenomenon follows the key trends of “any place, any device, and any time” mobile computing.

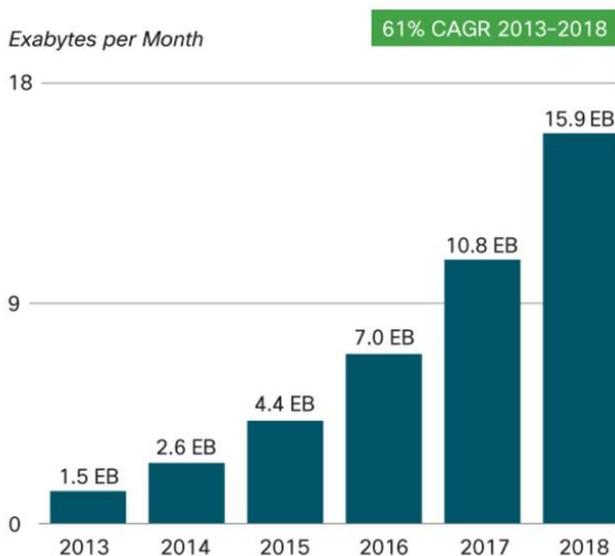


Figure 1: Smarter, more powerful, more connected devices



Figure 2: Diversity of Communications

The diversity of communications is driving tremendous increase in data consumption both via mobile networks as well as fixed line networks. The forecasted growth in mobile data traffic consumptions is staggering with an average smartphone to generate 2.7 GB of traffic per month by 2018 (5 fold increase over 2013 averages). Figure 3 shows the forecasted growth in mobile data traffic over the next 5 years.



Source: Cisco VNI Mobile, 2014

Figure 3: Global Mobile Data Traffic Forecast

Wireless Transport Requirement Driven by Application Demands

The massive growth in data consumption and the forecasted data traffic puts a tremendous strain on the underlying transport networks that form the backbone of the information highway. The underlying transport networks that were designed to carry voice and minimal amount of data traffic require a critical upgrade to handle multi-gigabits of data. This multi-gigabit transport networks itself fall under two major categories based on distances:

1. **Short distance networks:** Path lengths less than 1 km
2. **Long distance networks:** Path lengths greater > 1 km

Figure 4 shows a heterogeneous network that combines several short distance and long distance networks for mobile backhaul application.

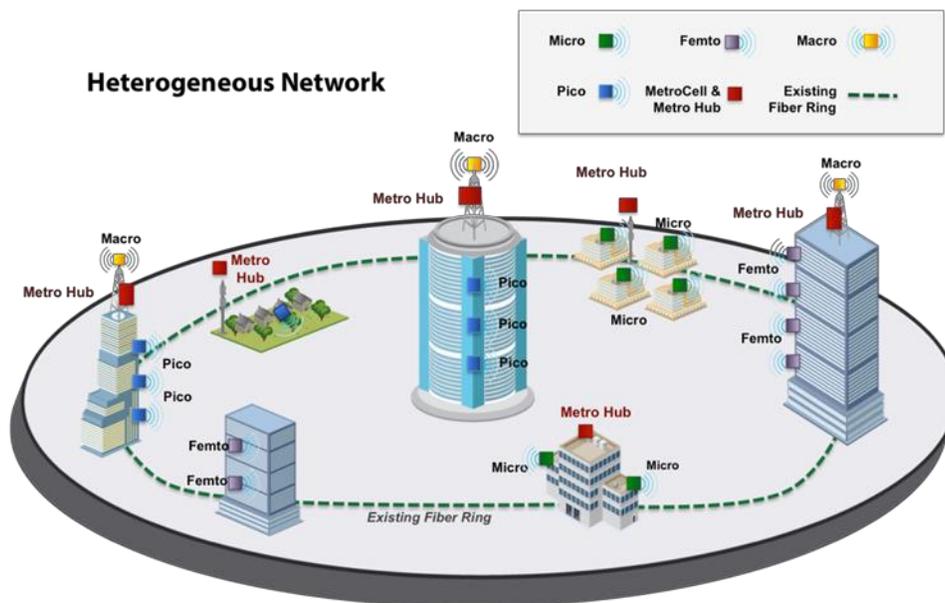


Figure 4: Heterogeneous Networks Addressing the Emerging Data Demands

Small cells are key example of application that drives the requirement for short distance networks. Small cell are low-power wireless access points that provide improved coverage, capacity. There are various types of small cells ranging from femtocells, picocells, metrocells and microcells as shown in Figure 5. The types of small cells are broadly categorized based on the increasing size of their coverage in distance, ranging from femtocells (the smallest) to microcells (the largest).

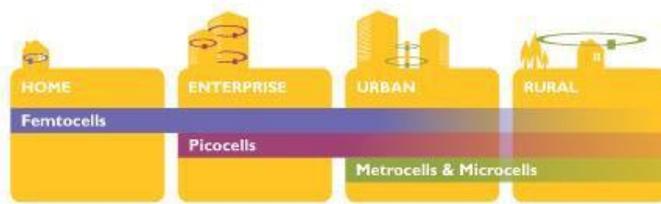


Figure 5: Short Distance application in Mobile Networks

Wireless Transport requirements for short distance networks:

Capacity: 1 Gbps or less (Typical 150 Mbps)

Distance: Short, typically less than 1km (backhaul from site to nearest cell tower)

Availability: From 99.9% to 99.99% (acceptable link outage ranges from 50 min to 500 min per year)

Long distance applications and the associated requirement for transport networks

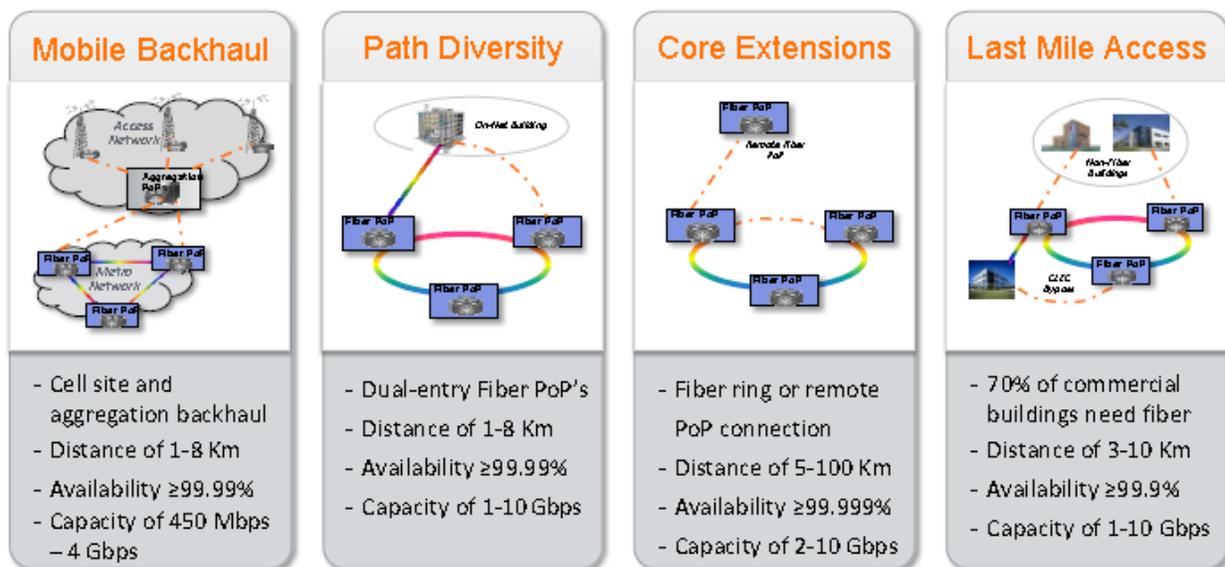


Figure 6: Long Distance Application and Associated Transport Requirements



Figure 7: Additional Long Distance Application with Multi-Gigabit Transport Needs

Last Mile Access:

There are several commercial buildings that lack fiber infrastructure and are in need of multi-gigabit capacities. These commercial buildings are typically in the range of 1-10 km away from the nearest fiber point-of-presence (POP). Wireless transport would be very suitable for extending multi-gigabit transport from the fiber POP to these commercial buildings in a cost effective manner and with short deployment timeline that maximizes new revenue opportunities or cost savings. Typical capacity demands for such last mile access solutions are in the range of 1-10 Gbps with typical availability of 99.99%.

Fiber Path Diversity:

There are several on-net buildings that are already connected via fiber infrastructure and consume multi-gigabits of data. These on-net buildings typically host critical enterprise data and are in need of transport redundancy via an alternate fiber or dual-entry fiber POP's. Finding a second fiber entry to these on-net buildings is a challenge. Wireless transport could provide a suitable technology with fiber-like performance characteristics thus matching the demand for multi-gigabit transport with the expected availability of typically 99.99% or higher and fiber like distances.

Core Extensions:

Fiber infrastructure for core networks is typically deployed in ring architecture with multi-gigabit capacities. There are several occasions where the core fiber ring paths cannot be completed due to the lack of suitable trenching options. The workarounds options can be cost prohibitive or, when utilizing low capacity wireless transport options (such as traditional microwave technologies) can create mismatch in ring capacities which in turn create bottlenecks in the core infrastructures. High capacity wireless technology could complement the core fiber infrastructure and even speeding up the deployments of the core infrastructure.

Remote Broadcast:

High-definition television signals and the expansion of internal video operations in major remote venues have vastly increased bandwidth requirements. These remote venues are typically associated with temporary events such as live sport coverage, music and other shows. High capacity wireless transport eliminates the need for laying miles of fiber for sustaining the bandwidth needed for such remote broadcast events. It can be installed quickly on existing structures delivering high bandwidth and high availability as long as it is needed, then taken down.

In addition to above core long distance applications that have multi-gigabit capacity demands, there are several other long distance applications where the high capacity wireless technology can be a good fit, such as datacenter connectivity, connectivity for machine-to-machine type communications, transport for video surveillance/border security, transport solutions for disaster relieve or emergency situations, etc.

Wireless Transport requirements for long distance networks:

Capacity: 1-10 Gbps

Distance: 1-100 km

Availability: From 99.99% to 99.999% (acceptable link outage ranges from 5 min to 50 min per year)

Technology Overview and Deployment Challenges

The previous sections described several applications with demands for simultaneous high capacity, high availability and long distances. Such demands can typically be met with wired infrastructure solutions such as fiber based networks. However, there are several situations where fiber is either not available, practical or financially viable. In such situations, fiber alternatives such as wireless transports technology become highly desirable.

We now evaluate the various wireless technology options to meet the key demands for simultaneous multi-gigabit capacity, high availability and long distances.

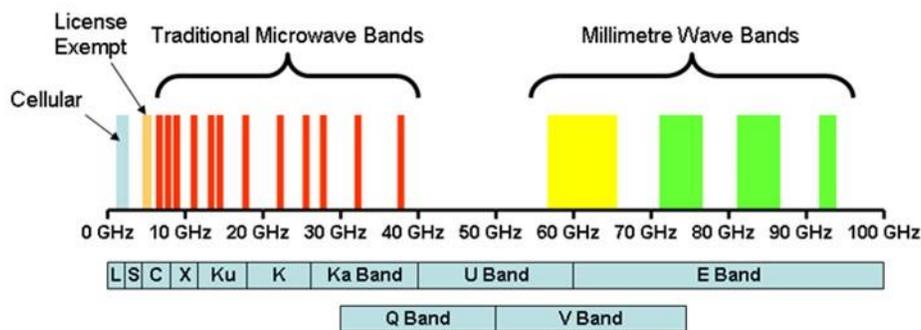


Figure 8: Spectrum for the Various Wireless Transport Technologies

Traditional wireless frequencies belonging to the microwave bands (as shown in Figure 8) range between 2 GHz and 40 GHz. These frequency bands have become severely congested, often resulting in poor quality and interruptions. An additional and very frequent constraint is lack of availability of enough channel bandwidth at these frequencies. A common outcome of these congested, and lack of wider frequency channels in these microwave bands, is their limited capacity support typically 360 Mbps or less.

The millimeter wave bands, specifically the 71-76 GHz and 81-86 GHz bands (widely known as “E- band”) were established for Fixed Link services by the ITU in 1979 and adopted, following minor modifications, in its present form by the ITU in 2000. With the 5 GHz of spectrum available in each of these two bands, the total spectral bandwidth available exceeds that of all allocated bands in the microwave spectrum. By pairing the available 5 GHz in each of the 70 and 80 GHz bands , duplex transmission with 10 GHz channel separation can be easily achieved.

Equipment and system being designed for these E-band frequencies can deliver high data rates (1 Gbps and above) using a myriad of technology innovations such as adaptive modulation, use of small channel sizes, advanced modulation techniques, etc. While being cognizant of the technology innovations in this frequency band, one needs to be aware of few key challenges and the associated implications when deploying solutions and equipment in this frequency range.

Assessment of Modulation Techniques

A key consideration in the deployment of E-band equipment is the use various modulation techniques and its resulting impact on the system capacity, distance and availability.

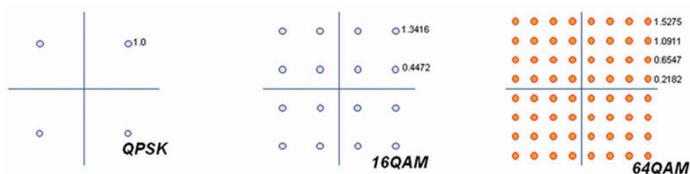


Figure 9a: Modulation Techniques

QAM Level	Number of Bits Per Symbol	Efficiency over Previous QAM Level
4 QAM	2	
8 QAM	3	50.00%
16 QAM	4	33.33%
32 QAM	5	25.00%
64 QAM	6	20.00%
128 QAM	7	16.67%
256 QAM	8	14.29%
512 QAM	9	12.50%
1024 QAM	10	11.11%

Number of bits represented by one symbol at all QAM levels

Figure 9b: Efficiency of the Various Modulation Techniques

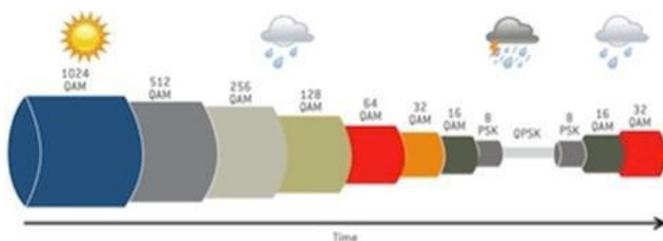


Figure 9c: Adaptive Modulation Compensation for Weather Condition

Modulation techniques range from simple modulations schemes such as BPSK, QPSK to more complex and higher order modulation schemes such as QAM16, QAM64, etc. By using higher order modulation techniques, it certainly enables higher capacity systems with less channel spectrum by carrying more bits per symbol as shown in Figure 9a and 9b.

While higher order modulation rates are able to offer much faster data rates and higher levels of spectral efficiency for the radio system, this comes at a price. The higher order modulation schemes are considerably less resilient to noise and interference. As a result, systems utilizing higher order modulation schemes require much higher signal to noise ratio (SNR). A higher SNR system in turn is quite vulnerable to weather conditions. Two common mitigation schemes used to manage the SNR in systems utilizing higher order modulation techniques are:

1. Reducing the distance and or availability
2. Reducing the data rate i.e. capacity via dynamic rate adaption.

Dynamic rate adaption is typically achieved by utilizing dynamic modulation techniques as shown in Figure 9c. The implication of dynamic rate adaption is that the system can offer high capacity utilizing higher order modulation such as 1024 QAM in good weather conditions, but will down rate adapt under adverse weather conditions such as rain by using more robust modulation schemes such as QPSK. A typical downside of using such dynamic rate adaption is that it makes network design quite challenging as the wireless systems cannot guarantee constant data rates under all weather conditions.

The following two examples convey the importance of utilizing simple and robust modulation techniques for applications requiring constant multi-gigabit capacity over longer distance and higher availability.

Example 1: Assuming an application that requires fixed distance of say 3.5 km with fixed capacity of 1Gbps in a region with an average rainfall of 22 mm/hr. As can be seen in Figure 10, by utilizing the QPSK modulation over wider channel bandwidth of 1GHz, the availability of system is 3 times better than those systems utilizing higher order modulation technique of 64 QAM over narrow channels of 250 Mhz.

Fixed Distance = 3.52 KM; Data Rate = 1 Gbps; Average Rainfall = 22 mm/h		
Modulation	Channel Size	Availability
QPSK	1 GHz	99.99 % (52 min/year outage) (~3 times more)
64 QAM	250 MHz	99.97 % (157 min/year outage)

Figure 10: Impact of Robust Modulation for Fixed Distance Application

Example 2: Assuming an application that requires fixed availability of say 99.99 % with fixed capacity of 1Gbps in a region with an average rainfall of 22 mm/hr. As can be seen in Figure 11, systems utilizing QPSK modulation over wider channel bandwidth of 1Ghz offer 32% longer distance than those systems utilizing higher order modulation technique of 64 QAM over narrow channels of 250 Mhz.

Fixed Availability= 99.99% ; Data Rate = 1 Gbps; Average Rainfall = 22 mm/h		
Modulation	Channel Size	Distance
QPSK	1 GHz	3.52 KM (~32% more)
64 QAM	250 MHz	2.65 KM

Figure 11: Impact of Robust Modulation for Fixed Availability Application

Based on these simple examples, it can be concluded that **wider channels with simpler modulations enable multi-gigabit capacities over longer distance and higher availability.**

Assessment of Interference in E-band Frequencies

A common myth assumed with E-band systems is the concern of interference with other co-located systems. While such interference concerns are legitimate for systems utilizing lower frequency band such as the microwave spectrum, the same concerns in the E-band are not warranted. As can be seen in Figure 12a, E-band frequencies produce a typical 3dB beam width of 0.9° (using 12” antenna) and 0.4° (using 24” antenna). These pencil width beams (of less than 1 degree) facilitate minimal interference risk and enable very high spatial reuse of the frequency. Furthermore as can be seen in Figure 12b, Fresnel zone for E-band frequency is very short. As a result, interference by obstacles near the path of a radio beam is reduced significantly. For example, Fresnel zone for a 5km wireless link hop using E-band frequencies is approximately 2.2 meters and for 10km link hop is approximately 3.1 meters. These key properties of **E-band systems with extremely narrow beams and very short Fresnel zone distance mitigate interference risks, thus enabling high spatial reuse of the frequencies.**

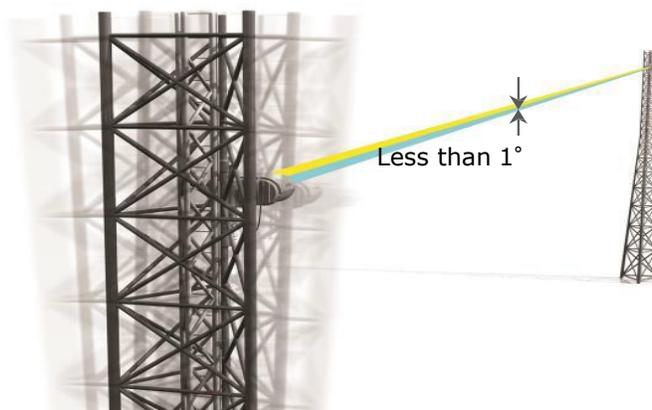


Figure 12a: Narrow Beam Widths associated with E-band Systems

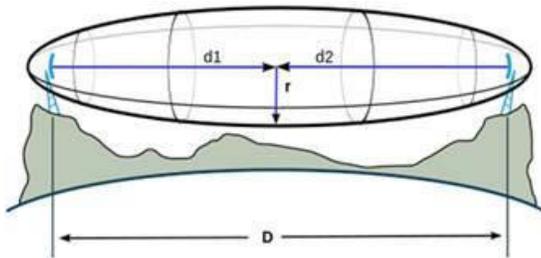


Figure 12b: Short Fresnel Zone of E-band Systems

Worldwide Spectrum Allocation Strategies & Licensing Trends

Strategy#1 Un-channelized Bands:

In the USA, full spectrum is open without any channelization i.e. 2 x 5 GHz in FDD mode is available without any segmentation as shown in Figure 13. Access to this band is granted to a user after they have applied for and received a nationwide license. After this, each link is self-coordinated on a first-come, first-served basis with no further FCC involvement. Similarly, Australia has implemented 2x4.75 un-channelized bands in FDD mode.

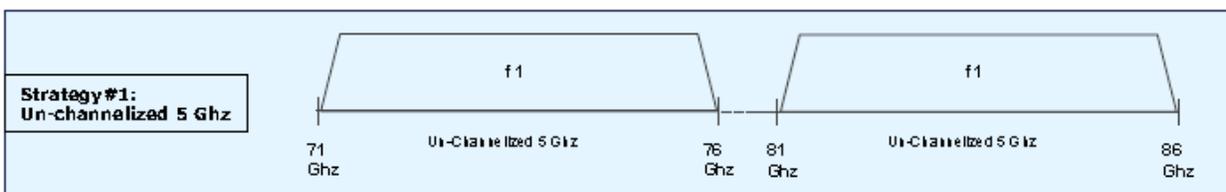


Figure 13: E-band spectrum allocation strategy using un-channelized frequency bands

Strategy#2 Channelized Bands:

Within Europe, or to be more precise the 42 CEPT administrations, follow the guidelines and recommendation as described ECC/REC(05)07. The recommendation enables 2x250 MHz channel size and allowing up-to 19 contiguous channels (i.e. 4.75 GHz) for FDD operations as shown in Figure 14. Those countries that have implemented the decision in full and thus have the full bands open include Belgium, Croatia, Denmark, Estonia, France, Germany, Greece, Iceland, Ireland, Luxembourg, Montenegro, Netherlands, Portugal, Romania and Spain.

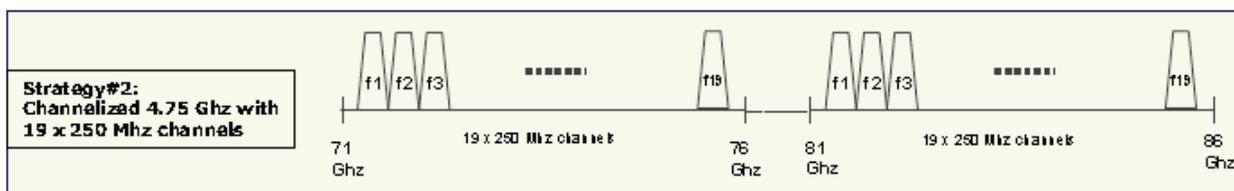


Figure 14: E-band spectrum allocation strategy using channelized bands



Strategy#3 Mix Management Approach:

While the United Kingdom (UK) has the full band open; it has its own regulation that does accommodate systems complying with the ECC recommendation. However UK has recently adopted a mixed managed approach as shown in Figure 15. This mix management approach entails combination of self-coordinated 2x2.5 GHz as well as 2x2GHz of coordinated frequency bands. The mix management approach caters to applications requiring more capacity by enabling more channel bandwidths. At the same time, by enabling self-coordination it enables rapid deployment.

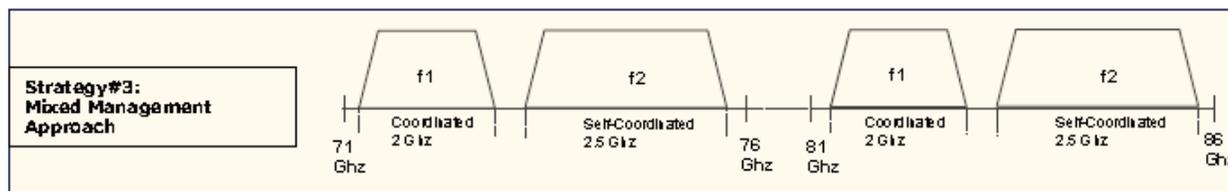


Figure 15: E-band spectrum allocation strategy using mix of channelized and un-channelized bands

Cost Consideration for E-band Licensing:

As can be seen in Figure 16, there are three key approaches being adopted worldwide for the licensing and charging of E-band systems.

Unlicensed:

The first approach is that of unlicensed approach where the E-band systems is treated similar to Wi-Fi systems and can be deployed without the need for any licensing or fees. Countries following the unlicensed approach to E-band systems are Russia, Hong Kong, Mexico and Czech Republic.

Light License (Self Coordination):

The second approach is that of light license approach where the E- band systems is licensed with very small annual or one-time fee. Access to E-band frequency band is granted to a user after they have applied for and received a nationwide license. After this, each link is self-coordinated on a first-come, first-served basis. Countries following light licensing approach include USA, Australia, and UK.

Traditional Point-to-Point License :

The third approach is that of traditional point-to-point licensing similar to that used for microwave frequency bands. Even in this approach, a higher frequency factor is applied in the calculation of licensing fees and as can be seen in Figure 16, the licensing costs for E- band frequencies are kept very low. Countries adopting this approach include Japan, New Zealand, Jordan, UAE, and Ireland.

Licensing Requirements	Countries	E-band Channels	Licensing Fees
Unlicensed	Czech	74-76 and 84-86 GHz	Free
	Russia	71-76 and 81-86 GHz	Free
	Hong Kong	71-76 and 81-86 GHz	Free
	Mexico	71-76 and 81-86 GHz	Free
Light License (self-coordinated)	USA	71-76 and 81-86 GHz	\$75 for ten years
	UK	71.125-75.875GHz & 81.125-85.875GHz	\$100 per year
	Australia	71.125-75.875GHz & 81.125-85.875GHz	\$175 per year
Licensed (Traditional Point-to-Point Microwave model)	Japan	Traditional PTP	\$10 per year
	New Zealand	71.125-75.875GHz and 81.125-85.875GHz	\$170 per year
	Jordan	Traditional PTP	\$300 per year
	UAE	Traditional PTP	\$1200 per year
	Ireland	Traditional PTP	\$1500 per year

Figure 16: Worldwide Cost for E-band Licensing

Conclusions and Recommendations

Given the explosion of mobile data traffic and high capacity broadband services worldwide, there is a dire need for high capacity wireless solutions to either supplement or complement fiber based transport solutions. Countries looking at alternate wireless transport technologies should embrace and promote the adoption of high data rate services using the millimeter wave spectrum (E-band). It is strongly recommended that they should follow the examples of other countries that have had strong success with light licensing policy for the E-band spectrum such as the U.S., Mexico, U.K. and other EU countries.

Countries employing “light licensing” or licensing schemes that do not penalize higher bandwidth systems in non-scarce frequency bands are seeing widespread adoption of E-band systems.

The adoption of the “light licensing” process is supported by the fact that systems using the E-band spectrum have very narrow beams and therefore potential interference between systems is minimized. The possibilities for frequency re-use and co-locations are much higher/easier in the E-band compared with microwave, and as such E-band systems can be deployed in larger volumes. This in turn has allowed those countries with “light licensing” process to offer favorable ultra-high capacity transport solutions for several market verticals including mobile backhaul, enterprise connectivity and other broadband services.

Furthermore, it is recommended to allow for a minimum of 2 x 2.5 GHz in FDD mode to enable flexibility and diversity in multi-gigabit transport solutions beyond fiber. The traditional wireless solutions (such as Microwaves) in the lower bands cannot deliver such multi gigabit capacity as demanded by market needs. Limiting the allocation of spectrum (bandwidth) in the E-band spectrum would defeat the benefits of opening up the E-band by relegating the solutions to lower capacity or limited availability and limited distances.

A specific recommendation on the spectrum allocation strategy for South Africa as shown in Figure 17 is based on the mixed management approach utilized in the UK. Adopting this specific mixed management approach will enable multi-gigabit solutions for longer distance or high availability by allocating a minimum of 2x2.5 GHz un-channelized bands. At the same time it will cater to short distance applications by keeping the multiple channelized bands 32x62.5 MHz similar to proposed approach in other African countries.

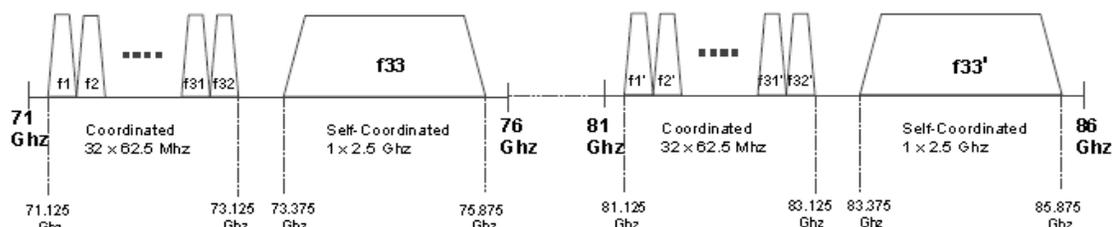


Figure 17: Recommended Spectrum Allocation Strategy in South Africa for E-band Frequencies