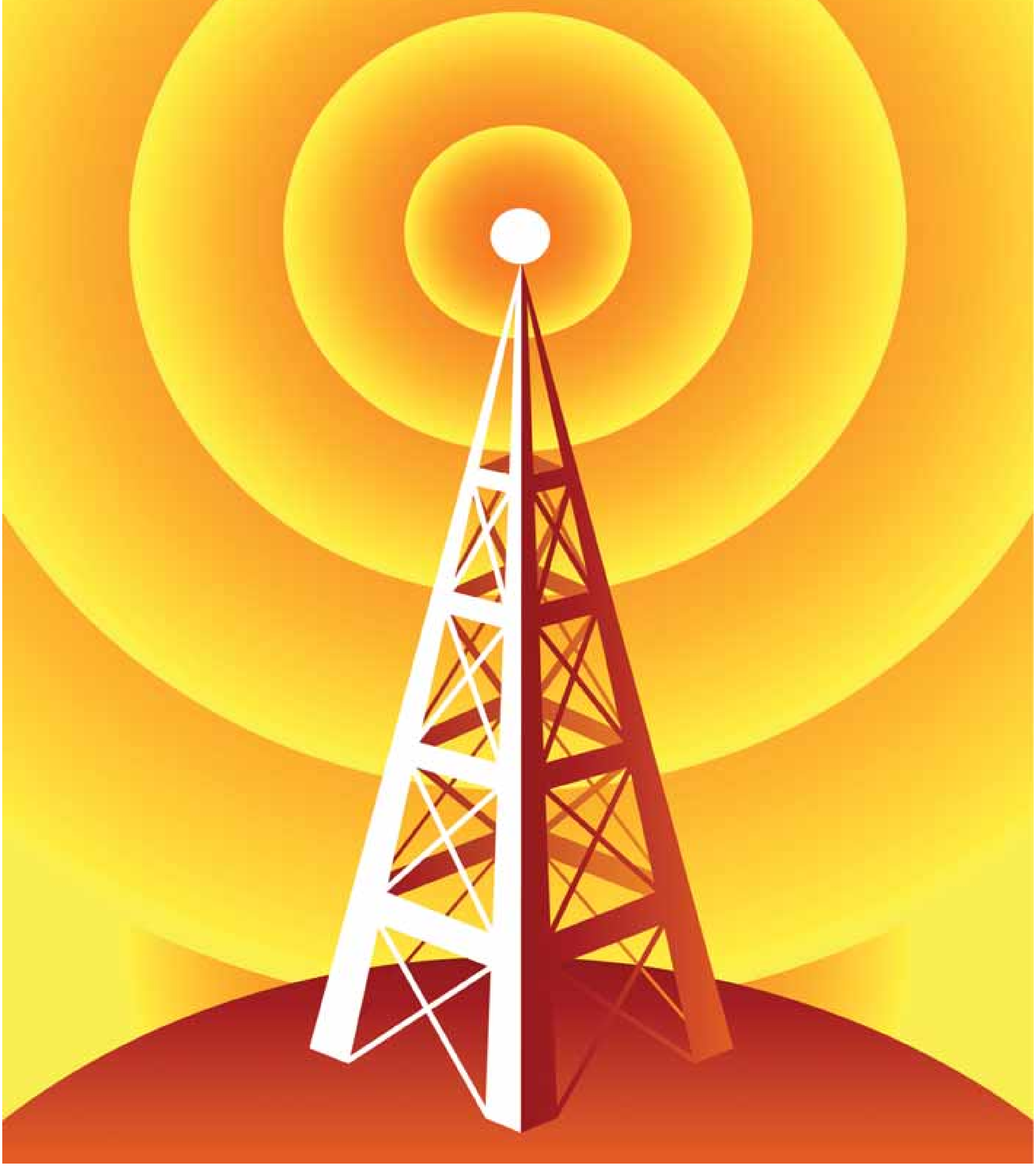
# RADIO SYSTEMS
## MICROWAVE AND MILLIMETRE-WAVE



# ANDY SUTTON

## Spotlight on digital point to point systems

**Modern digital microwave radio systems provide very high throughput with low latency and high availability making them ideal for a wide range of connectivity requirements. CCTV backhaul, mobile backhaul, high-frequency trading, corporate connectivity, Internet access and more can all be addressed with wireless solutions. Andy Sutton explains.**

This article explores the state-of-the-art in microwave as well as millimetre-wave radio systems. The microwave band is correctly defined as 3GHz to 30GHz while the millimetre-wave band extends from 30GHz to 300GHz. Practical applications of radio systems in these bands are found between 4 and 86GHz today while research is on-going into higher frequency bands, in particular the 92GHz to 95GHz band. This article focuses on point-to-point applications of microwave and millimetre-wave radio technologies. Figure 1 illustrates a microwave radio hub site with a number of links utilising a range of antenna sizes from 30cm to 1.8m.

A short history of digital point-to-point microwave radio systems is available [1] however this article focuses on the state-of-the-art and therefore considers radio systems designed to carry Ethernet or Carrier Ethernet.

The telecommunications industry has witnessed a significant shift from Time Division Multiplex (TDM)-based transmission to Carrier Ethernet over the last decade, an evolution driven by the work of the MEF (Metro Ethernet Forum)[1]. Specific to this topic, the MEF has published a white paper focused on the use of microwave radio technologies for the transmission of Carrier Ethernet services [2]. This evolution from TDM to Carrier Ethernet has introduced a number of technical challenges and required significant work within International Standardisation bodies such as ETSI and the ITU to ensure Carrier Ethernet can support the levels of service and capability previously provided by TDM systems. These requirements range from network synchronisation which was effectively free with TDM E1 circuits due to the use of High Density Bipolar 3 line code, through to Operations, Administration, Maintenance and Provisioning which was integrated from the outset within the Synchronous Digital Hierarchy standards.

**Figure 1:** Point-to-point microwave radio hub site

Most microwave radio products intended for access applications are of a split-mount configuration which refers to a two-piece terminal consisting of what is commonly referred to as an In Door Unit (IDU) and a separate Out Door Unit (ODU). This differs from typical trunk radio systems which tend to be much lower in frequency and may be configured as all-indoor radios although lower frequency links are also available nowadays in a split mount configuration.

The IDU contains the baseband and radio frequency (RF) modem and has Input/Output ports which includes alarm connections, network management interface and user data connections. Additionally the IDU will have a power supply connection, often operating at a nominal -48V DC. The baseband function will, amongst other things, provide an aggregation function to combine the multiple user input streams into a single aggregate traffic flow which is applied to the modulator and then up-converted to an Intermediate Frequency (IF) for transmission via the IF cable to the ODU.

The IF cable is a single 50 ohm coaxial cable which carries multiple frequencies within the 70 to 400MHz range. Generally the transmit signal is towards the higher end of the range whereas the receive signal is lower. Additionally a local IDU to ODU telemetry connection is provided for operations and maintenance purposes along with a DC voltage to power the ODU. Providing power over the coaxial connection removes the need for a separate DC power cable. The ODU receives the IF and up-converts, nowadays typically via frequency multiplications (although there was a period in the 1990s when direct conversion using Gunn diodes[2] was common but they proved to be unreliable) to the desired microwave operating frequency. In addition, the ODU will provide power amplification to the desired output power. Typical maximum transmit power levels are in the range of 10 to 30dBm (10mW to 1W) although the actual link planning budget will determine the actual transit power required for a given link. Microwave radio link planning is a detailed topic in its own right [3]. The transmit signal is then applied to the microwave antenna, typically a parabolic reflector via a feed horn or cassegrain reflector. On the receive path the process is reversed. A typical minimum receive threshold for a Bit Error Ratio of 10-6 would be between -90 and -60dBm depending upon channel bandwidth and modulation scheme.

[1] See: http://www.metroethernetforum.org/

[2] A Gunn diodes are widely used in high-frequency electronics, typically electronic oscillators to generate microwaves for applications such as radar speed guns and microwave relay data link transmitters. Named after the physicist John Battiscombe Gunn.

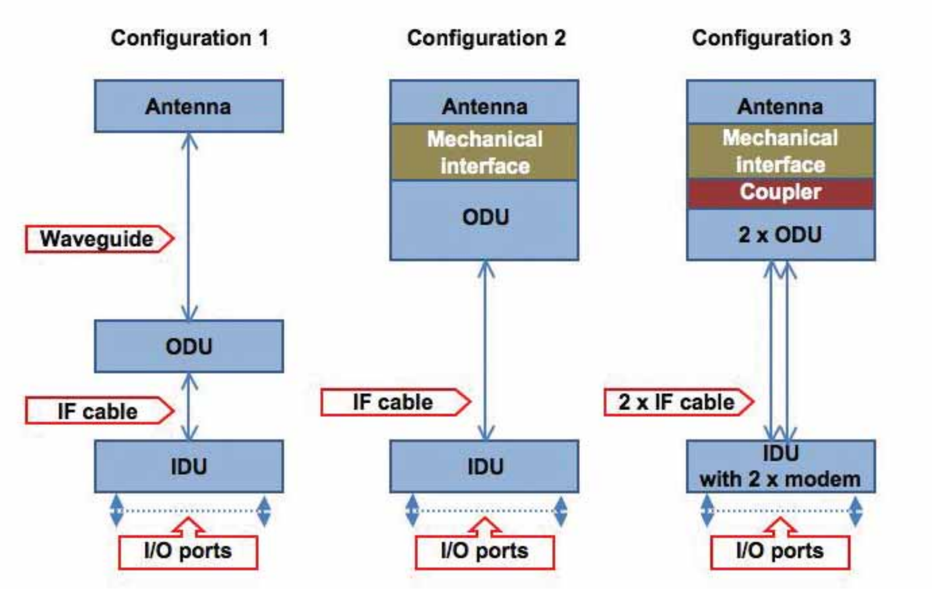



**Figure 2:** Common microwave radio system configurations

There are a number of common microwave radio configurations; three of which are illustrated in Figure 2. Configuration 1 is a 1+0 system, meaning there is a single IDU and ODU pairing with no equipment protection. This configuration utilises a waveguide to carry the RF signal between the ODU and the antenna. The waveguide may be a short length of flexible waveguide, maybe a metre or two, or a longer run of possibly some tens of metres from an ODU installed at the base of the tower to the antenna. Use of waveguide has some advantages, particularly for maintenance purposes as the active RF components can be located with easy access at the base of the tower. From a technical perspective, the waveguide is another component to fail and it also introduces signal attenuation in both the transit and receive paths which must be accounted for within the microwave link path budget calculation. Configuration 2 is also 1+0 but the overall system Mean Time Between Failure should be higher as there is no waveguide component. That said, the system Mean Time To Repair may be higher as the access to the active RF ODU may require a tower climb (it could of course be a roof top installation and therefore less of an issue). The mechanical interface between the ODU and antenna will be proprietary and fitted during the manufacturing process to a standard antenna. Configuration 3 introduces a second modem card to the IDU (it is quite common for the baseband to be unprotected even in a 1+1 configuration although the Mean Time Between Failure of these components is greater than it is for the RF modem), along with a second IF cable and second ODU, this enables a 1+1 configuration and therefore provides greater system availability through the use of equipment protection. It is possible to configure this as 2+0 which allows an increased system throughput, more on this later.

## Scaling microwave radio systems for the broadband era

To support future capacity requirements it is essential that microwave radio systems can scale to hundreds of Mbit/s, even Gbit/s and beyond for certain applications. There are many techniques available to scale the capacity of microwave radio systems, these are reviewed below:

1. **Wider RF channels** – These enable higher data rates for a given modulation scheme. Increasing channel bandwidth is one of the first options for increasing the link data rate (alongside higher order modulation schemes (see 2 below). There is a fundamental limit on the data rate through any transmission channel, the main restricting factors being channel bandwidth and noise level, or signal-to-noise ratio as it is commonly known.

2. **Higher order modulation schemes** – These enable more information to be transmitted for a given symbol rate, therefore modulation schemes for point-to-point microwave radio systems have evolved from simple two level Amplitude Shift Keying and Frequency Shift Keying to 16 Quadrature Amplitude Modulation (QAM) and through to 128, 256, 512, 1024 and 2048QAM with even higher order systems under development (4096QAM).

3. **Co-channel dual polarisation operation** – This is increasingly common although not usually the first step of a capacity upgrade process. This involves transmitting the same frequency channel on two polarisations, typically vertical and horizontal, via a single dual-polarised antenna. This technique is often referred to as polarization multiplexing. Ideally we need the two channels to remain orthogonal to avoid interference with each other although this is difficult to realise in real operating environments and therefore a technique known as Cross Polarisation Interference Cancellation is implemented. This is realised through digital signal processing by sharing the received signal with both modems to enable cancellation of the interfering signal.

4. **Header and/or payload compression/ optimisation** – The header/payload approaches work in similar ways and a vendor may implement one or both of these techniques. The header compression or optimisation technique makes use of the fact that much of today's data traffic is IP-based and it is therefore quite reasonable to consider compressing the IP header on a point-to-point link. Given that the IP header appears on every packet and the packet only has one destination the transmitting radio can remove information that is not needed in cooperation with the far-end receiver which will reinsert this

[1] See http://www.surrey.ac.uk/5gic

information for onwards transport. Payload compression is similar although slightly more difficult to realise and, again, the receive end reinserts all data for onwards transport.

5. **Multiple Input Multiple Output (MIMO) systems** – These are common in cellular and WiFi radio networks and they rely on the multi-path environment, effectively using these as multiple individual channels to increase the robustness of a given link or increase overall system capacity. By the very nature of line-of-sight point-to-point microwave radio systems design we tend not to have multi-path environments during normal operation. In certain scenarios we may encounter destructive multi-path and these cases have traditionally been addressed through the use of space diversity receive systems. MIMO for point-to-point systems is an evolving technique, often referred to as Line-of-Sight MIMO, in which two transit and two receive antennas are configured [4]. Other techniques are in research labs at the moments although very little information is shared in the public domain as equipment vendors strive for competitive advantage.

References can be found to a technique known as Adaptive Coding and Modulation that is often stated as a mechanism for increasing link throughput although it does this at the expense of atmospheric availability. Alternatively Adaptive Coding and Modulation links can be planned for the desired availability at the highest throughput with the feature being used to increase link availability by reducing throughput during atmospheric fading conditions [3].

## Microwave antenna systems

Modern microwave radio antennas are still mainly of parabolic design. The antenna system itself may consist of waveguide and an antenna although, as discussed above, the ODU is increasingly integrated directly with the antenna and therefore the antenna system is often just the antenna as shown in Figure 3. Microwave antennas have evolved considerably even within the parabolic 'dish' form format. Examples of early parabolic antennas can be seen towards the end of the previously referenced article on the history of microwave radio systems [1]. The size of a microwave antenna is not related to a given frequency band in the same way as traditional antennas are although there is a minimum size for a given frequency band.

To illuminate a microwave antenna a feed mechanism is required in front of the parabolic reflector. By its very existence the feed mechanism both enables the operation of the antenna but reduces the efficiency that can be achieved by the parabolic reflector. There are a couple of popular mechanical arrangements for feeding the antenna and great care is taken to minimise the impact of reflections and therefore scattering caused by the implementation. Antennas nowadays tend in the main to be what is known as Class 3 [5] compliant. This refers to ETSI Class 3 technical specifications for the Radiation Pattern Envelope (RPE). The RPE is optimised to direct as much of the RF energy in the wanted direction as possible while still offering possibilities for cost-effective manufacturing of antennas.

Additionally ETSI specifies a Class 4 [5] antenna RPE although for many years it was not cost-effective to manufacture such antennas and therefore Class 3 was the best available antenna and as such was deployed extensively. Recent advances in manufacturing techniques have made it possible to build Class 4 antennas for a minimal cost premium above a Class 3 and as such the benefits of Class 4 antennas are currently being realised by early adopters and certainly studied by many microwave radio network operators around the world. Figure 4 illustrates the radiation patterns for Class 2, Class 3 and Class 4 antennas. The tighter the RPE the less interference is generated and therefore the tighter the frequency reuse which can be achieved. It is also possible to use a smaller antenna in certain use cases given the higher directional gain of the Class 4 RPE. Figure 5 illustrates the range of microwave antenna in use

**Figure 3:** Direct mount arrangement with ODU connected to parabolic antenna

supporting mobile backhaul from an operational core network site.

## Millimetre wave radio systems

The start of this article gave the correct definitions of microwave and millimetre-wave frequency bands. In reality they are often stated slightly differently and, although incorrect, the use is generally accepted as the norm within the industry. Generally point-to-point systems between 4 and 42GHz are referred to as microwave. The use of the term 'millimetre-wave' has become common over the last few years as wireless transmission engineers discuss bands between 50 and 90GHz due to operational equipment becoming available in the V and E-bands. V-band refers to spectrum in the 57 to 66GHz range while E-band refers to the 71 to 76GHz and 81 to 86GHz.

V-band point-to-point links operate in unlicensed spectrum (although 64 to 66GHz is lightly licensed in the UK, 57 to 64GHz is unlicensed), something which network operators have traditionally avoided to date although such an approach has found favour amongst other verticals for a range of connectivity applications. New use cases have resulted in operators revisiting their strategies for unlicensed spectrum, particularly with regards V-band for point-to-point applications.

One of the key use cases is small cell backhaul – connecting small public access pico-cells, typically 3G or 4G, to aggregation hubs or fibre points-of-presence for connectivity back to the core network. The main volume use case for pico-cells is area capacity density within urban and dense urban environments with deployments at street level on lampposts, street furniture and exterior walls of buildings. Other common use cases for V-band include CCTV backhaul and campus connectivity while E-band is growing market share for mobile backhaul and corporate connectivity solutions in either lightly licensed or fully licensed spectrum. In the UK E-band is split across two licensing regimes depending on the level of protection the user wishes to pay for. Figure 6 illustrates the positioning of millimetre-wave spectrum that is currently being deployed or, in the case of 92 to 95GHz (W-band), being researched, in relation to the traditional microwave bands.

The move towards ever higher frequency bands is driven by the need for greater capacity and an increasingly diverse range of use cases. Although the higher frequency bands offer a shorter link length than lower bands for a given configuration, they do allow for a greater frequency reuse and therefore a greater link density; an important consideration in urban areas. Channel bandwidths in V-band are based on multiples of 50MHz with the possibility to aggregate channels while E-band channels are 250MHz wide with the possibility of aggregating multiple channels to create a 1000MHz (or even wider) channel, something quite impossible in the lower frequency bands.

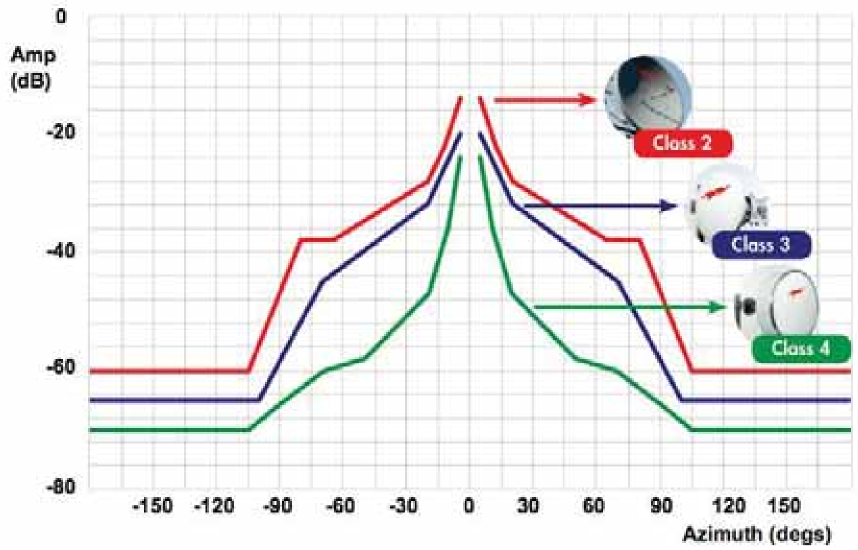



**Figure 4:** ETSI microwave antenna radiation patterns *(Source: Commscope (Andrew Antennas))*

**Figure 5:** Microwave antennas in use at an operational mobile network operator's core switch site

Discussions are on-going within standardisation bodies to formalise narrower E-band channels of 62.5 and 125MHz as increasingly efficient modulation schemes are introduced. Therefore the millimetre-wave radio link planning engineer has a flexible set of parameters to select from when designing a given link. Given the channel bandwidths and relative immaturity of millimetre-wave technology in this point-to-point application, the modulation schemes are in the main quite conservative although in the last few years, systems have evolved from QPSK and 16QAM to support 64 and even 256QAM with lots more to come.

The impact of atmospheric conditions is another important consideration when selecting a millimetre-wave band. This is not a simple linear extrapolation from the microwave bands but rather a complex consideration which varies not only by frequency but also with altitude. V-band has significantly higher atmospheric attenuation than E-band despite being a lower frequency, this is due to V-band being centred on the Oxygen absorption peak. Moving up in frequency we find that loses reduce as frequency increases towards E-band before starting to increase again for different reasons. This issue is not necessarily a problem as quite often it is advantageous to be able to plan a short link,

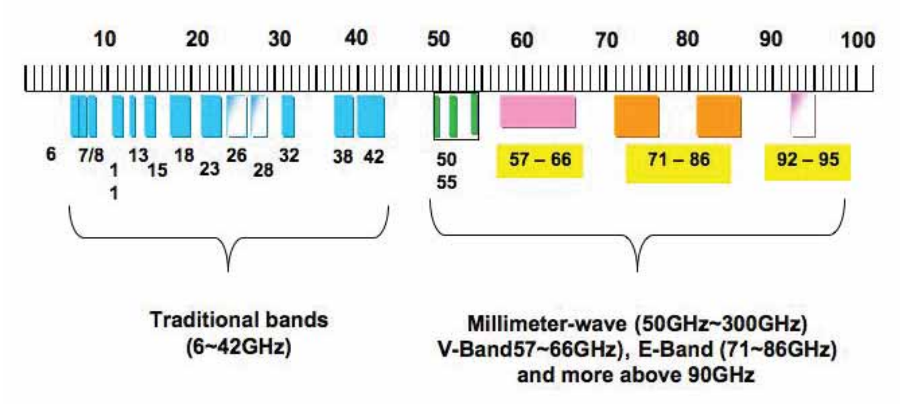



**Figure 6:** Current millimetre-wave spectrum bands of interest *(Source: ETSI mWT ISG)*

some hundreds of metres, and then reuse that channel elsewhere in the same area, increasing overall area capacity density. This is one of many topics which is being studied and explained by the ETSI mWT ISG [6] through a series of deliverables planned for 2015 and 2016.

## AUTHOR'S CONCLUSIONS

Microwave radio systems continue to offer cost-effective and high-performing connectivity solutions to address a wide range of applications. Despite the increased availability of optical fibre cables, the deployment of microwave, and increasingly nowadays millimetre-wave, radio systems continues to grow due to the ongoing evolution of such products, the speed of deployment and relative low-cost. Advances in parabolic antenna technology enable ever denser networks while new flat panel antennas offer exciting new opportunities for the future.

The evolution of radio systems in the microwave bands and adoption of millimetre-wave radio systems will support the need for ever greater connectivity and enable future solutions such as 4G heterogeneous networks and 5G technology. It is not a case of fibre or wireless, rather finding the optimal mix of the two technologies. Due to the use of millimetre wave frequencies the radios are all outdoor and often fully integrated with their antennas. All outdoor radios are becoming increasingly common in traditional microware bands too.

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## ABOUT THE AUTHOR

**Andy Sutton**
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Andy is an architect with responsibilities for the radio access network architecture evolution and mobile backhaul strategy and architecture. He has 30 years of experience within the telecommunications industry, mainly in radio access, transmission and transport network strategy, architecture and design. During the last 20 years in the mobile industry, Andy has worked for Orange, France Telecom Group, H3G and EE. He is a Chartered Engineer, Fellow of both the Institution of Engineering and Technology and British Computer Society and a Member of the ITP. Andy is a research mentor and industrial partner of the 5GIC at the University of Surrey, and holds the post of Visiting Professor at the University of Salford.

## ABBREVIATIONS

| | |
|---|---|
| IDU | In Door Unit |
| IF | Intermediate Frequency |
| MEF | Metro Ethernet Forum |
| MIMO | Multiple Input Multiple Output |
| ODU | Our Door Unit |
| PCU | Packet Control Unit |
| QAM | Quadrature Amplitude Modulation |
| RF | Radio Frequency |
| RPE | Radiation Pattern Envelope |
| TDM | Time Division Multiplex |