Examination of issues related to spectrum efficiency of point-to-multipoint and mesh multimedia wireless system architectures proposed for 40.5-43.5 GHz

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GLOSSARY

MWS	Multimedia Wireless Systems
BFWA	Broadband Fixed Wireless Access
PMP	Point-to-Multipoint
BS	Base Station
QPSK	QuadriPhase Shift Keying
QAM	Quadrature Amplitude Modulation
C-QPSK	Continuous Envelope QuadriPhase Shift Keying
EIRP	Effective Isotropic Radiated Power
TDMA	Time Division Multiple Access
FDMA	Frequency Division Multiple Access
CDMA	Code Division Multiple Access
FDD	Frequency Division Duplex
TDD	Time Division Duplex
ATM	Asynchronous Transfer Mode
IP	Internet Protocol
ATPC	Automatic Transmitter Power Control
PSTN	Public Switched Telephone Network
TDM	Time Division Multiplex
CIR	Carrier-to-Interference Ratio
ACR	Adjacent Channel Rejection

The material in this report is based on discussions between Aegis and a number of equipment manufacturers and potential operators. Thanks are due to these organisations for their help and co-operation. Every effort has been made to represent views expressed during these discussions accurately.

It should be noted that some of the assumptions made at the time of writing the report (March/April 2000) may have been superseded by the delay[1] in publication (December 2001).

1 INTRODUCTION

This report describes a study undertaken between January and March 2000 by Aegis Systems Limited for the Radiocommunications Agency on spectrum efficiency issues relating to the network architectures for Multimedia Wireless Systems (MWS) proposed for the 40.5-43.5 GHz frequency band.

The constraints and limitations of wired technology together with an ever increasing demand for high bit rate services have created a growing international interest in the development of broadband wireless access networks. Wireless technology offers high capacity, fast and easy deployment and low infrastructure investment.

The geography of the service area, user density, services offered and available technology are important parameters that will enable operators to choose to deploy different technologies and network architectures to serve the potential users. Currently, point-to-multipoint (PMP) and mesh type architectures are proposed for broadband wireless access systems.

The principal objective of the study was to identify the main factors that are likely to affect the relative spectrum efficiency of PMP and mesh network architectures.

This report commences with an overview of the main features of PMP and mesh architectures. It moves on to discuss factors that are likely to have a significant influence on the capacity, performance and spectrum utilisation efficiency of both architectures. Then, an analytic (high level) comparison of the spectral efficiency is presented. Finally, the key conclusions of the work are outlined.

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[1] Due to removing the commercially sensitive aspects from the report.

2 KEY FEATURES OF PMP AND MESH ARCHITECTURES

Literature indicates that a number of microwave and millimetre wave wireless access systems have been proposed to support broadband services. Some of these systems are listed in the following table.

System	Architecture	Frequency Band
AIReach Broadband (Hughes Network Systems)	PMP	3.4–3.6 GHz 10.15-10.65 GHz 24.549-26.453 GHz 27.5-31.3 GHz 38.6-40.0 GHz
Reunion (Nortel Networks)	PMP	24GHz to 38 GHz
Mini-Link BAS (Ericsson)	PMP	24-31GHz
AB-Access (Adaptive Broadband)	PMP	Below 6 GHz
Worldpipe	Mesh	28 GHz, 40 GHz
Radiant	Mesh	28 GHz, 40 GHz

Table 2-1: Broadband Microwave Wireless Access Systems

Using the technical data available, the key system parameters are summarised in Table 2-2.

	PMP			
	AIReach (38.6-40.0 GHz)		**Reunion**	**Mini-Link BAS (24-31 GHz)**
Carrier Bandwidth (MHz)	14			28
Modulation Technique	QPSK	64-QAM		Continuous envelope-QPSK (C-QPSK)
Capacity (Mbps / carrier)	13.8	43.0		37
Number of Sectors	4 - 16			4
BS Antenna Gain (dBi)	16 (90^0), 19 (45^0), 22 (22.5^0)			
BS & Subscriber Transmitter Power (dBW/ carrier)	-6			-2
Subscriber Antenna Gain (dBi)	40.5			34 (24cm at 27 GHz)
BS EIRP (dBW/carrier)	10 - 16			
Subscriber EIRP (dBW/carrier)	34.5			32
Cell Radius (km)	1 – 3.5		2 - 5	≤ 10
Multiple Access	TDMA / FDD		TDMA or FDMA	TDMA / FDD
Typical Base Station Antenna Height (m)	≈ 20 – 30			
Subscriber Antenna Beamwidth (3 dB) (degrees)	2 – 4			

	Mesh
	Radiant
Carrier Bandwidth (MHz)	28
Modulation Technique	QPSK – 64-QAM
Capacity (Mbps/ carrier)	36 – 108
Antenna Beamwidth (3 dB) (degrees)	9 & 12
Antenna Gain (dBi)	25 - 35
Transmitter Power (dBW/carrier)	(-14) - (-10)
EIRP (dBW/carrier)	11 – 25[2]
Typical Hop Length (km)	< 1 (longer paths might be used (≈5 km) to provide interconnectivity when the density is low)
Typical Antenna Height (m)	10 (seed node and interconnection node antennas might be higher)

Table 2-2: System Parameters

In the following sections, the PMP and mesh network system characteristics are briefly discussed.

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[2] The quoted EIRPs are maximum values. Nominal values are general lower and ATPC is used.

2.1 PMP Networks

A typical broadband PMP network architecture comprises base stations, subscriber units and network management system equipment (Figure 2-1).

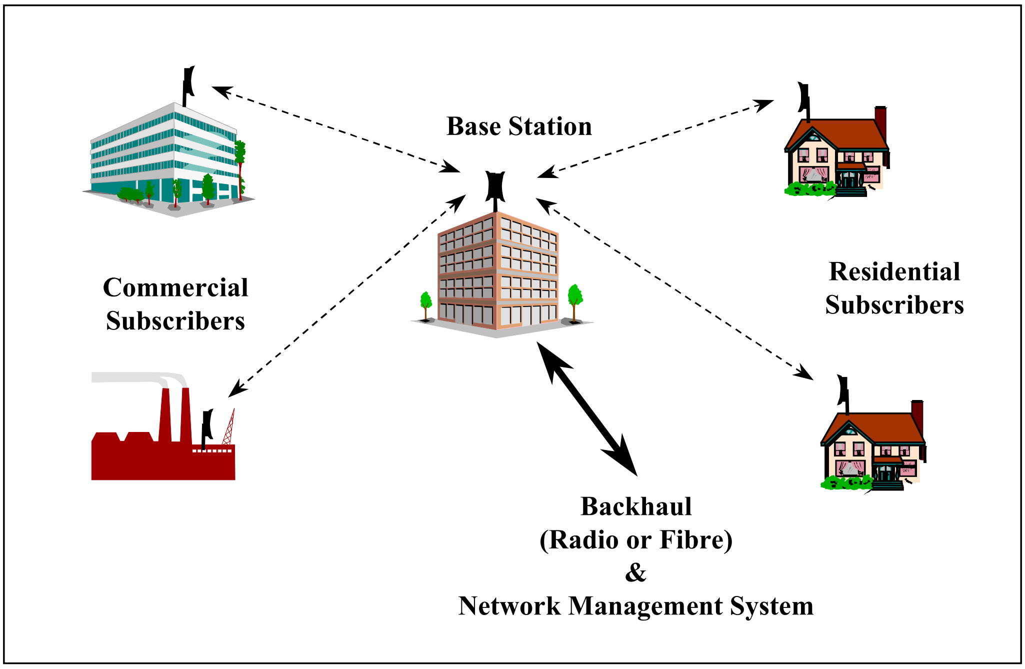

Figure 2-1: PMP Cell

In general, the PMP networks are similar in design to cellular phone systems. The area to be served is split into a number of cells, with a base station located at the centre of each cell and its antenna typically mounted on a top of a roof or a pole to provide good line-of-sight to remote subscriber units situated at residential/commercial user premises. Cells are repeated in the form of a regular pattern and a cell radius up to a few km is achieved in the 40 GHz band.

Local clutter (vegetation and buildings) and high capacity demand are two important factors limiting the cell size. The need to ensure line of sight propagation within a cell area limits the single base station coverage. The figures quoted for single base station coverage percentages varies between 30-90% of potential users depending on antenna height. The coverage issue is discussed in detail later in the report.

The coverage percentage can be increased by allowing multiple base station coverage for service areas that cannot be served adequately by a single base station. Multiple overlapping base stations may also reduce the impact of interference by enabling the subscriber unit to switch to an alternative base station, though this is likely to require antenna re-alignment.

In the case of high local demand for service, i.e. urban deployment, each cell is split into sectors. In practice, 4 and 6 sector cells are most commonly deployed. In each sector, a specific set of radio frequencies together with wide antenna azimuth beamwidths are used. Base station azimuth beam widths typically lie in the range 60° to 90°. Sectorisation reduces the likelihood of interference between cells because of the limited azimuth beam width of the base station antenna. This, in turn, enables the network to re-use the available frequencies. The correspondingly higher antenna gain also improves the link budget, enabling greater distances to be served. In rural applications, coverage and capacity objectives may be satisfied by unsectored cells.

In specific situations (e.g. the coverage of small towns), a service area might be served by placing multiple base stations at the outskirts (Figure 2-2). In this type of arrangement, base stations re-use the available spectrum by taking the advantage of subscriber antenna discrimination.

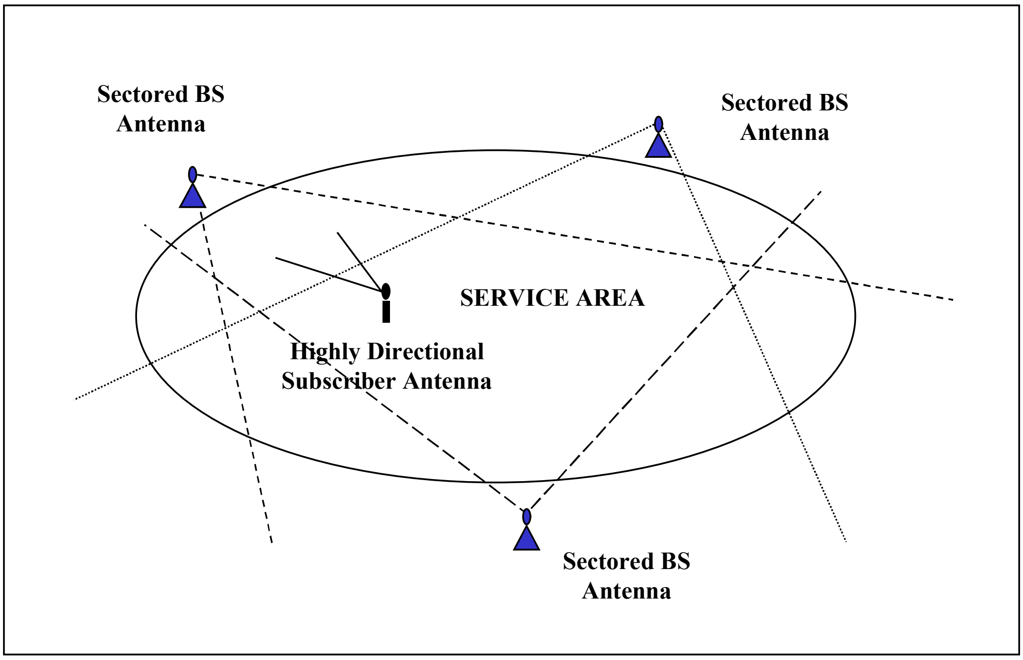

Figure 2-2: Multiple BS Coverage

Base stations communicate with the cell's fixed subscriber units and the high capacity trunk network connecting the individual base stations to the centrally managed control centre. Although subscriber unit configurations may be somewhat different for various system designs, all configurations include outdoor mounted microwave equipment and digital equipment to support modulation, demodulation, control and interface functionality. Typically, narrow beam antennas directed towards the most appropriate cell sector are deployed at subscriber sites.

Each base station is connected to the control centre via high capacity backhaul links which could employ either wired or wireless technology. Choice of backhaul links is an important economic factor in the broadband PMP network design process and also has a bearing on overall spectrum efficiency.

PMP network management facilitates the operations, administration, maintenance and provisioning of the network functions. Typically, a network manager workstation located at an appropriate point in the network enables operators to view and optimise the network performance.

The type of service to be delivered to subscriber sites and the access technique determines the carrier transmission rate. Current broadband PMP networks aim to support maximum transmission rates typically ranging from 14 Mbps to 43 Mbps per carrier. In general, this capacity is shared dynamically between a number of subscribers within a cell sector.

As far as the multiple access schemes are concerned, TDMA and FDMA are commonly used. FDMA provides efficiency in delivering high volumes of data in applications requiring fixed capacity allocation. TDMA together with fast dynamic capacity allocation handles bursty traffic efficiently.

The uplink traffic flowing from the subscriber units to the network and downlink traffic flowing from the network to the subscriber units is separated by employing either Frequency Division Duplex (FDD) or Time Division Duplex (TDD). The choice of duplexing scheme is largely dependent on traffic profile. TDD is more suitable when the traffic profile is largely unknown while FDD performs better when the traffic pattern is known and fixed over time.

The majority of PMP broadband wireless access systems use Asynchronous Transfer Mode (ATM) cells as the primary transport mechanism. ATM technology offers a flexible approach in allocating network capacity by enabling users to choose from a range of qualities of service for the two-way transmission of mixed voice, data and video. The transport of various applications and protocols, such as Internet Protocol (IP), is also supported on ATM-based PMP networks.

Due to the limited frequency spectrum, it is essential that networks use the available spectrum efficiently in order to achieve higher data rate transmissions. The frequency re-use plan, antenna radiation patterns, terrain conditions, power control schemes, multiplexing, multiple access and modulation techniques all play a significant role in determining the spectral usage.

During the course of the study, the implications of these factors on the spectrum efficiency of PMP networks were considered.

2.2 Mesh Networks

A mesh architecture distributes the base station functionality across the network and, therefore, removes the need for base station deployment. Mesh networks comprise an interconnected network of short point-to-point links and a network management system (Figure 2-3).

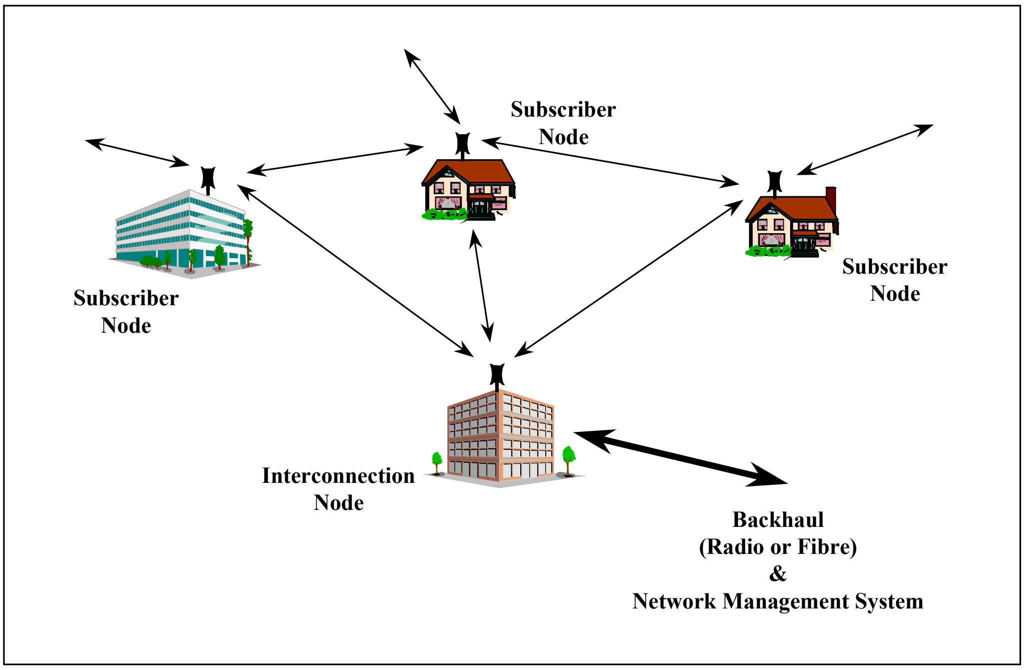

Figure 2-3: Mesh Network Architecture

In typical mesh architecture, each subscriber radio node can act as either a repeater station or a transmitter/receiver station.

In establishing links, radio nodes are used as intermediate repeaters. At 40 GHz, while typical hop lengths are up to 1 km, a few links could extend to 3 km[3] depending on subscriber and traffic density. Multiple directional antennas are located at each subscriber site to provide routing diversity and to overcome line of sight problems.

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[3] Link lengths up to 5 km may be used in backhaul links.

In the mesh architecture, inter-node connections are based on low power, narrow point-to-point radio beams. Subscriber antennas are mounted at a roof-top to minimise the effect of local clutter.

The direction of the links and the choice of frequencies for each link are determined by the traffic routing and channel assignment algorithms. Overall network performance can be significantly affected by the efficiency of these algorithms.

Another important aspect relating to mesh network performance is the use of automatic transmitter power control (ATPC). The principal objective of ATPC is to decrease global interference within the network and to enable more intensive frequency re-use.

In a typical mesh network, there are specific system radio nodes in addition to subscriber radio nodes. The first set of specific nodes, often referred to as seed nodes, are used to provide initial inter-connectivity within a network when the number of subscribers is too low, for example at early stages of the network roll-out. The second set of specific nodes, referred as interconnection nodes, enable the network to connect to an infrastructure (trunk) network. If the number of interconnection points is relatively smaller the bandwidth requirement could be larger as the network traffic is concentrated at these nodes.

The mesh network management system provides global network level control and monitors the performance of the mesh nodes.

Proposed mesh networks aim to support ATM data transport protocols and data rates similar to those supported by the PMP networks. Due to cost implications, initial deployments are likely to target business customers by providing video conferencing and multimedia services. The residential market is likely to be addressed in the longer term where services may include video-on-demand, interactive television, Internet access and telephony services.

3 DISCUSSION ON ISSUES DETERMINING SPECTRUM USAGE

A number of factors that are likely to have a significant influence on the spectrum efficiency of both network architectures are discussed in this section.

3.1 Technological Factors

The implications of technological factors including antenna characteristics, backhaul requirements, duplexing techniques, multiple access schemes, modulation techniques, power control mechanisms, polarisation, routing and channel assignment algorithms are examined in the following sections.

3.1.1 Antenna Characteristics

The performance of both mesh and PMP networks is likely to be affected by the antenna characteristics. In particular, antenna directivity and height play a significant role.

3.1.1.1 Antenna Directivity

In PMP networks, sectored base stations are expected to be used in most cases. Horizontal beamwidths of 60 & 90 degrees are widely encountered while narrow elevation beamwidths are chosen to reduce the impact of interference into other systems.

In a cellular PMP network deployment, the use of directional base station antennas implies that available frequency spectrum could be split between sectors and re-used more efficiently. As the gain of directional antennas is higher (16-22 dBi) than an omnidirectional antenna, the power into the antenna will be lower and, therefore, interference from antenna side lobes into neighbouring cell sites will be reduced. The main drawback of sectorisation is an increased cost.

PMP network subscriber antennas are highly directional in both azimuth and elevation planes (3 dB beamwidths of 2-4 degrees). In a typical uplink interference scenario, the use of highly directional subscriber antennas will reduce interference into co-frequency cell sites, as the power into each subscriber antenna will be lower. In the case of downlink interference, high subscriber receiver antenna gain implies low transmit power from base station and, therefore, reduced interference into subscriber nodes operating in the neighbouring co-frequency cells. The main difficulties associated with narrow beam antennas are alignment problems and increased cost of manufacturing.

In mesh networks, radio nodes use multiple directional antennas (3 dB beamwidths of 9-12 degrees). In a reasonably dense deployment, the mesh hop lengths are likely to be relatively short (≈ 1 km) and require low transmitter power ((-28)-(-24)dBW/1MHz). These features coupled with efficient routing and channel assignment algorithms are claimed to significantly improve the overall network performance and spectrum efficiency.

3.1.1.2 Antenna Height

Propagation in the 40 GHz band requires that wanted links be line-of-sight. In PMP networks, base stations are, therefore, placed at elevated locations to provide line-of-sight visibility to the maximum number of subscriber antennas within a cell coverage area. Typically, antenna height values ranging between 20-30m are quoted. This, in turn, increases the probability of interference into subscriber antenna receivers operating co-frequency in neighbouring cell sites. However, the impact of interference at victim subscriber sites is reduced due to shielding provided by the local clutter, and by down tilting the base station antennas.

In the case of base stations operating with a TDD scheme, interference between adjacent base stations becomes important due to high antenna heights and wide antenna beamwidths.

Very high base station antennas may also cause co-ordination problems with other terrestrial systems operating in the same or adjacent geographical areas.

Mesh networks do not employ base stations and subscriber nodes are roof mounted. Therefore, local clutter will in some instances be advantageous in reducing interference between simultaneously operating co-frequency radio nodes. However, it is worth noting that the subscriber nodes are still required to be high enough (typically, 10m above ground level (a.g.l.)) to ensure that there are line-of-sight paths in several directions for mesh network interconnectivity.

3.1.2 Backhaul Requirements

The provision of backhaul capacity is an important economic factor in broadband wireless network design. Radio and fibre backhaul links, depending on subscriber density and network size, are deployed as infrastructure networks for the transmission of backhaul data.

Radio backhaul links need to have large bandwidths in order to be able to carry significant amount of backhaul data. This high bandwidth requirement and the high density of base stations imply the use of millimetre wave fixed link bands where the necessary spectrum capacity is available (for example, 38 and 55 GHz). However, backhaul provision in the 40 GHz band itself might also be feasible where access traffic is relatively low. This approach is economically attractive as the required investment is minimal, but in-band interference into service links could be problematic. Higher order modulation is likely to be employed to make the best use of available bandwidth. The use of higher order modulation might necessitate a higher power spectral density to achieve the minimum C/(N+I) required. This, in turn, might increase the amount of interference into broadband service links operating in adjacent bands or adjacent geographic areas. If in-band backhaul links are to be used, it is important that the same interference/availability criteria are used for the backhaul as for the access in order to avoid interference problems.

Fibre links or dedicated fixed link spectrum is more likely to be employed for backhaul networks when traffic density is high and the allocated bandwidth is intensively used by service links but there are potentially high cost implications.

In PMP networks, each base station is connected to a control centre via backhaul links. High capacity transmissions to/from other networks (for example, PSTN & data networks) are provided through the control centre. In base station design, a significant portion of the cost is attributed to the provision of backhaul capacity.

In mesh applications, the network traffic is concentrated at interconnection nodes providing high capacity connections to the backhaul network through which transmission to/from other networks is achieved. It is important to note here that there is a trade off between the number of interconnection nodes and the amount of spectrum required as the mesh network traffic is concentrated around the interconnection nodes. This is discussed in more detail later in the report.

3.1.3 Modulation, Duplexing and Multiple Access Techniques

The implications of modulation, duplexing and multiple access schemes can be summarised as follows:

3.1.3.1 Modulation

For both mesh and PMP networks, the choice of modulation technique is mainly determined by spectrum availability and the required coverage distance. High level modulation techniques (for example, 64-QAM) make an efficient use of available bandwidth. However, these techniques are more sensitive to interference and, therefore, require higher minimum C/(N+I) values to be achieved, reducing the potential coverage area. Low level modulation techniques (for example, QPSK) require relatively larger bandwidth but perform better in the presence of high interference and extend the available coverage area or hop length.

It is noted that some of the proposed PMP frequency reuse patterns lead to C/(N+I) ratios as low as 14-16 dB. In such circumstances, the use of high level modulation is not possible.

Another approach is to assign different modulation levels to different users taking account of individual link conditions. This scheme is claimed to be more appropriate for meeting the dynamic bandwidth requirements of different users.

3.1.3.2 Duplexing

In PMP network design, the prediction of the network traffic pattern plays a key role in choosing an appropriate duplexing scheme.

In TDD, a single radio frequency channel is used for both downlink and uplink traffic separated in time over the traffic frame. TDD provides flexibility by allowing uplink/downlink time apportionment to be adjusted in each sector according to traffic demand. However, this flexibility is limited in that the same adjustment has to be applied for each sector, as the adjacent channel interference might be unacceptably high if one sector antenna receives while others transmit in adjacent bands. In other words, sectors may need to be synchronised.

In the case of unsynchronised TDD, each sector has the ability to make adjustments depending on the traffic demand within its sector. This provides increased flexibility and efficient use of spectrum. However, adjacent channel interference might be severe.

FDD is more structured but less flexible. A radio frequency band is used for downlink traffic and a separate band for uplink traffic. The size of the downlink and uplink bands may depend upon the likely degree of symmetry between the two traffic flows, but once determined the size of the bands cannot easily be changed. Therefore, traffic patterns need to be predictable before the system becomes operational in order to create an appropriate frequency band plan. In the case of very asymmetric traffic prediction (for example, video-on-demand), more channels will be made available to downlink than uplink. If symmetric traffic (for example, telephony) is expected then equal number of channels will be allocated for uplink and downlink traffic.

Mesh networks are distributed architecture systems and rely on dynamic use of network resources. This suggests that TDD could be more advantageous for mesh deployment as a designated uplink and downlink frequency band plan is not required.

3.1.3.3 Multiple Access

The choice of multiple access scheme for a specific wireless access network is largely application dependent. FDMA systems are more favourable for providing broadband services to business users where continuously available fixed bandwidth might be required. TDMA systems are capable of handling dynamic capacity allocation requirements efficiently by implementing statistical multiplexing of bursty traffic sources. Current 40 GHz broadband fixed wireless access systems do not propose to use CDMA techniques. The main reasons are quoted as strict power control requirements, increased complexity and the very high bandwidth requirement for the spreading codes.

3.1.4 Power Control

When the broadband wireless systems are deployed, the transmitter power, at each subscriber terminal, is adjusted at initial link set-up according to distance. The main objective of this power setting is to minimise the intra-system interference and, therefore, increase the re-usability of available spectrum.

The broadband wireless systems also employ Automatic Transmitter Power Control (ATPC) to compensate for fading caused by rain.

In PMP systems, in general, the uplink power setting and ATPC ensure that signals arriving at the base station receiver are at similar levels (usually a few dB above the minimum required carrier level). This, in particular, helps the base station receiver to demodulate bursty traffic carriers. In the downlink direction, the base station transmit power is fixed to ensure that receiver terminals at cell edges are able to receive the carrier at a level above the minimum required.

In mesh networks, the use of efficient power setting mechanisms and ATPC play a significant role in increasing spectrum efficiency. The power setting and ATPC are employed at each transmitting node to ensure that the received power level for each hop is just above the minimum required level and, therefore, interference into other simultaneously operating co-frequency links is minimal.

The use of ATPC implies an increased design cost. Therefore, systems providing services to subscribers requiring dedicated channels for fixed traffic volume might choose not to use power control to bring down the system cost. At an initial link set-up this power would be set at a sufficiently high level to overcome rain fading and meet a minimum GOS requirement.

3.1.5 Polarisation

Low level modulation techniques require less stringent C/N+I performance criteria to be satisfied. In the 40 GHz band, the use of horizontal and vertical polarisation together with low level modulation techniques might improve the system frequency re-use. This improvement could be significant for short transmission paths where cross-polar discrimination is most effective. Interference between PMP base stations, where there is likely to be better control over antenna alignment, is also likely to be significantly reduced by cross-polar discrimination.

In the case of higher order modulation, polarisation discrimination might not improve the frequency re-use significantly as the level of cross polar products become important.

In PMP systems, dual polarisation might bring additional complexity if the system uses repeaters to improve the cell coverage. In such systems, repeaters are required to change the incoming signal polarisation in order not to cause multipath interference at subscriber units by transmitting a delayed co-polar version of the weak signal arriving from the base station.

3.1.6 Routing and Channel Assignment Algorithms

Routing and channel assignment algorithms are of particular importance to mesh networks. The primary objective of traffic routing and channel assignment algorithms is to increase the system capacity by making the best use of available bandwidth.

Traffic routing algorithms define methods for the selection of radio nodes to be used as repeaters for other transmissions. Channel assignment algorithms define mechanisms to provide traffic channels for each hop on a link. Optimum routing and channel assignments ensure that the link uses the minimum number of hops and channels while satisfying the minimum link performance requirement.

3.2 Operational Factors

In this section, the implications of operational factors on the choice of broadband wireless network architecture are investigated.

3.2.1 Traffic Pattern

A key broadband wireless network design issue is the prediction of demand for different types of services. The choices for system design factors, including network architecture, modulation technique, duplexing scheme and multiple access technique, are all influenced by the predicted traffic pattern.

In general, it is often argued that the PMP architecture might support one-to-many (for example, video broadcast) applications most efficiently while the mesh architecture might be more suitable for one-to-one (for example, e-mail or video-on-demand) services.

A number of views have been expressed as to what types of service might be supported. The general view is that high bit rate Internet applications might be the biggest potential market driver for MWS. In addition, a high demand for applications including multi-channel TV, video-on-demand and teleconferencing might occur. It is also argued that Intranet applications (for example, broadband Intranet to provide services for estate agents, solicitors, accountants) could be widely supported by broadband wireless networks. Another view is to broadcast large volumes of data to subscriber terminals typically overnight thereby ensuring that subscribers are able to retrieve the data of interest during day time from a local ‘cache’.

As far as the potential market is concerned, it has been suggested that initial broadband wireless deployment will be targeted towards the business market. The residential market is likely to be served when the system cost is reduced and large scale deployments become economically feasible. The experience of cellular telephony and the massive growth in consumer Internet services suggests that such a deployment may well take place within a few years of MWS launch.

3.2.2 Coverage

In the 40 GHz band, propagation characteristics and local clutter determine the system coverage and interference levels. Wanted paths are required to be strictly line-of-sight to overcome, mainly, the implications of scintillation of transmitted signals due to dynamic multipath mechanisms.

In cellular PMP applications, the strict line-of-sight propagation requirement might result in coverage ratios (i.e. the proportion of subscribers that can be served from each base station) as low as 30%. Therefore, in most applications, overlapping base station cell coverage is likely to be required. The requirement to ensure a line of sight path to a maximum number of potential subscribers per cell also places a significant constraint on potential base station locations. Base stations are typically located on top of high buildings. This approach might increase interference into other cell sites operating at the same frequencies. Therefore, a balance needs to be struck between the coverage and interference.

However, it is worth noting that, from the spectrum efficiency point of view, the line-of-sight propagation requirement might be advantageous in that the network spectrum utilisation might be enhanced by enabling intensive frequency re-use. Considerable benefit, in terms of protection from interference, can be derived from the additional isolation/shielding introduced by local clutter (principally buildings and vegetation), though as noted above this is offset by a reduction in the percentage of coverage achieved.

In mesh networks, coverage requirements are less demanding. Typically, multiple directional antennas are placed at each subscriber site to provide network interconnectivity with an acceptable grade of service. Line of sight paths are only needed between these individual antennas. Antenna discrimination together with shielding provided by local clutter enable relatively nearby subscriber antennas to reuse the allocated frequency.

3.2.3 Implementation

Various topics related to the network implementation are discussed briefly in the following sections.

3.2.3.1 Cost

It is claimed that mesh network performance is significantly influenced by routing and channel assignment algorithms, which, in turn, might increase the cost of individual radio nodes. In addition, the use of multiple antennas at each subscriber site also has potential cost implications.

In the case of PMP networks, it is argued that the base station requirement at each cell site increases the system cost. A requirement for overlapping cell sectors to increase the cell coverage might increase the network cost further.

It is important to note here that there is no clear evidence one way or the other. A more detailed per user economic analysis is required.

3.2.3.2 Statistical Multiplexing

In PMP networks, single hop connections are setup between a base station and a relatively large number of subscribers. The mesh architecture, on the other hand, comprises radio nodes with a multiple directional antennas to be used in establishing multihop connections. PMP networks achieve spectral efficiency through the effect of statistical multiplexing. In a mesh network the statistical multiplexing process takes place but in a different way, because more than one radio hop is involved. A procedure is used to assign timeslots and channels dynamically across the whole mesh system, so as to maximise traffic capacity

3.2.3.3 Predictability

When PMP networks are implemented in the form of regular arrays of cells, it is argued that this regularity allows the system designer to predict the minimum performance requirement within a cell area regardless of terminal location. In the case of mesh deployment, it is claimed that the prediction of performance is relatively difficult as the system has a distributed architecture and the terminal locations are not known until the system becomes operational.

3.2.3.4 Access Delay

As mentioned earlier, PMP networks provide single hop access connections while mesh topology involves multihop links. It is, therefore, argued that mesh network access delay might become significant due to the increased number of hops required to set-up links, in particular, when traffic volume is high. This is unlikely to be a problem for packet based applications (for example, internet and intranet access), but may affect performance for real-time applications such as telephony.

3.2.3.5 Subscriber Access

It is claimed that, in mesh networks, the use of subscriber equipment as a relay node for other links might bring about difficulties in that access to subscriber premises might not always be possible in the case of node failure. Therefore, the mesh will need to reconfigure quickly to maintain connectivity and information will need to be routed through other nodes which, in turn, may affect the bit rate capability. Another view argues that the churn of subscribers might also cause difficulties in maintaining network interconnectivity

3.2.3.6 Capacity Increase

In cellular PMP applications, one way of handling a capacity increase is to reduce the original cell size. This implies that subscriber antennas now outside the smaller cell need to be re-pointed. In mesh applications, capacity increase can be accommodated by adding new radio nodes to the existing mesh without affecting existing subscribers.

4 COMPARISON OF SPECTRUM REQUIREMENT AND EFFICIENCY

In this section, an attempt has been made to determine the spectrum requirement of mesh and PMP networks for a given set of assumptions.

4.1 PMP Network

It is assumed that a given area is to be provided with broadband wireless services using a PMP architecture. The density of subscribers can be determined as follows:

Consider the well known hexagonal arrangement shown on Figure 4.1 representing an even distribution of subscribers.

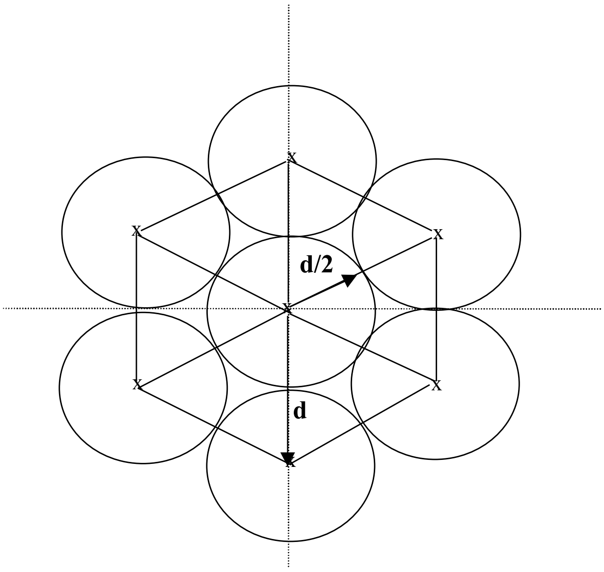

Figure 4.1: Subscriber Density

This arrangement implies that the distance between subscribers is d. If a circle is drawn around each subscriber (radius = d/2, area = $\pi d^2/4$) then the whole area is uniformly covered (with no overlap, but with some small areas not covered). Hence the subscriber density is (approximately) the inverse of the area thus associated with a single subscriber. The density is therefore approximately $4/\pi d^2$. This assumes that the area being covered is large and edge effects can therefore be ignored, and that the small areas not covered are insignificant.

The amount of required spectrum per base station could then be calculated as follows:

Parameter	Assumed Value(s)	Notes
Traffic type	symmetric	Assume FDD is used and the traffic is split 50:50 between both directions
Average traffic demand per subscriber in one direction (Mbps)	1.3 Mbps	Assume 1.3 Mbps is required in one direction
Average bandwidth demand per subscriber in one direction (MHz)	1	Assume QPSK (1.3 bps/Hz)

Number of sectors in each cell		6		Assume 60 degrees directional antenna coverage for each sector
Overlap Factor		1		Assume one BS provides satisfactory coverage within a cell area
Cell radius (km)		0.3 to 3		In 40 GHz band, assume cell radius could vary within 0.3 to 3 km range
Mean distance between subscribers (km)		***0.1***	***0.5***	Assume two values
Subscriber density (per km^2)		127	5	Subscriber density = 4/ (πd^2) where d = mean distance between subscribers
Number of subscribers within each sector	Cell radius=0.3	6	0.2	Sector area= π cell radius^2/ no of sectors
	Cell radius=1	67	3	
	Cell radius=3	599	24	
Bandwidth demand per sector in one direction (MHz)	Cell radius=0.3	6	0.2	Bandwidth demand per sector in one direction= Number of subscribers within each sector * Average bandwidth demand per subscriber in one direction
	Cell radius=1	67	3	
	Cell radius=3	599	24	
Total bandwidth demand per BS (MHz)	***Cell radius=0.3***	***72***	***2.4***	Total bandwidth demand per BS= Bandwidth demand per sector in one direction *2*number of sectors
	Cell radius=1	***804***	***36***	
	Cell radius=3	***7,188***	***288***	

Table 4-1: PMP Spectrum Requirement

On the basis of the assumptions, the required amount of spectrum per BS varies between 2.4 MHz and 7,188 MHz depending on cell radius and average distance between subscribers (i.e. subscriber density). For the 3 km cell radius case, the calculated spectrum requirement of 7,188 MHz indicates that a smaller cell radius should be selected in these circumstances in order to arrive at a “reasonable” total spectrum requirement.

It should also be noted that any arbitrary spectrum efficiency could be achieved by reducing a PMP network cell size. However, in such circumstances, the system cost per user becomes a critical parameter.

For the purposes of comparison it has been assumed that the cellular architecture is able to achieve a frequency reuse of “1” and that the coverage achieved under these circumstances is satisfactory. This should be considered as optimistic.

In theory, the multiple overlapping base stations requirement for the provision of satisfactory coverage does not have a significant impact on the required spectrum as subscribers will be “divided” between these base stations. In practice, a small additional overhead might be expected in the overall spectrum requirement. Some sources imply that any need for overlapping base stations leads to a significantly increased spectrum requirement. This is based on the false premise that, for a given area, each of the multiple overlapping base stations requires the same amount of spectrum as would be required if a single base station were to be used to provide coverage. In practice, as noted above, the subscribers would be “divided” between base stations thereby leading to the same aggregate amount of spectrum required (with perhaps a small overhead).

As far as the system cost is concerned, the use of multiple overlapping base stations implies an increased cost. Both operators and equipment manufacturers indicated that a flexible approach to coverage was required when addressing a particular set of circumstances. For example some of the coverage configurations being considered are:

- **Edge coverage.** For small or medium sized towns some consider it possible to provide coverage from base stations at the edge of the town, effectively pointing inwards. Coverage would be overlapping (i.e. co-frequency), thereby providing diversity and consequently a higher probability of line-of-sight within the area. The subscriber terminal antenna provides the necessary discrimination.
- **Cellular coverage.** For larger towns and cities there is some expectation that a traditional (approximately regular) cellular approach will be appropriate. There are various proposals regarding sectorised coverage patterns. For example, 4 x 90° sectors based on 2 frequencies and 2 polarisations, and 6 x 60° sectors based on 6 frequencies. These configurations appear to go hand in hand with an expectation of a frequency reuse of 1.
- **Irregular coverage.** In recognition of the difficulty involved in using regular coverage patterns in an urban environment when line-of-sight connections are essential, consideration is being given to irregular coverage patterns based on sectors. Inevitably such an approach is heavily dependent on the nature of the area being covered. While it is clear that such an approach is likely to lead to a more optimal use of frequencies, it is more difficult to arrive at general conclusions regarding its efficiency.

Combinations of these approaches are also possible.

When addressing the coverage of PMP systems a number of issues need to be considered, recognising that they are all inter-related:

- **Level of coverage.** At present there is no agreement as to the level of coverage that might be obtained in an area with respect to a single transmitter, given the fundamental requirement for a line-of-sight path at these frequencies. Figures in the range 30 to 90% have been variously claimed. In some circumstances, where an operator is only trying to service a known set of customers at particular locations (for example, a business park), a low general coverage figure will not matter if the base station can be sited appropriately. However, where an operator is offering a service to business in general or the population at large, coverage approaching 100% becomes necessary. Under these circumstances it is clear that an operator will either have to implement repeaters or provide coverage overlap in order to ensure that all (or nearly all) locations have a base station in line-of-sight.

- **Frequency reuse.** In the case where it has been assumed that regular cellular coverage is appropriate the frequency patterns proposed (4 x 90° sectors based on 2 frequencies and 2 polarisations, and 6 x 60° sectors based on 6 frequencies) provide C/I ratios in the region of 14-17 dB. Levels such as this will not allow for higher order modulation schemes to be implemented.
- **Polarisation.** This is already being factored into some of the frequency plans. However some concern has been expressed about how the use of repeaters might be introduced when using polarisation translation which will add complexity.
- **Propagation conditions.** It has been claimed that the rain fading encountered at these higher frequencies will prevent the proposed frequency plans from working effectively. This has yet to be confirmed one way or the other.

More detailed traffic calculations need to consider the impact of statistical multiplexing by taking account of dynamics of modulation, duplexing and multiple access schemes. For this purpose, typical deployment scenarios need to be simulated.

4.2 Mesh Network

Similarly, mesh network spectrum requirement can be determined by applying the following simplified methodology.

4.2.1 Methodology

The methodology, firstly, calculates the total number of required carriers to serve a given area on the basis of frequency reuse characteristics. Then, the bandwidth of each carrier is calculated using the subscriber traffic demand.

4.2.1.1 Number of Carriers

The method assumes that the mesh network is relatively large and the radio nodes (subscribers, seed nodes and interconnection points) are randomly distributed. Furthermore, it is assumed that the network uses TDD/TDM scheme where time is divided into frames and each frame into time slots. In order to simplify the calculations, the time slots are assumed to be allocated in Tx/Rx pairs. The following parameters are defined:

Node valency (number of other nodes to which a node can be connected)	V
Used valency (no of active links per node on average)	kV
Number of nodes in mesh	N
Mean distance between nodes (km)	d
Mean link length (km)	r
Mean non-reuse range (km)	D
Antenna beamwidth to –20 dB (radians)	θ

Total no of time slot-pairs (channels) per carrier	s
Mean no of time slot-pairs (channels) used per link	m

Table 4-2: Defined Parameters

- As the mean distance between nodes is “d”, the node density is $4/(\pi d^2)$
- As the mean non-reuse range is “D” and the mean link length is “r”, the carrier-to-interference ratio (CIR) is $(D/r)^2$
- As the total no of time slot-pairs (channels) per carrier is “s” and the mean no of time slot-pairs (channels) used per link is “m”, the total carrier bandwidth used per link is m/s
- As the number of active links per node is “kV” and the total number of nodes in a mesh is “N”, the mean number of links in mesh is N*kV/2
- Considering the 20 dB beamwidth “θ”, for a single link, the non-reuse area can be calculated as two 20dB beamwidth “segments” (i.e. taking account of both ends of the link) as follows

$$2 * \pi * D^2 * \theta/(2\pi) = \theta * D^2 = \theta * CIR * r^2$$

- As the mean distance between nodes is “d” and the total number of nodes in mesh is “N”, the total mesh area is $N*(\pi d^2)/4$
- As the mean number of links in mesh is N*kV/2 and the total mesh area is $N*(\pi d^2)/4$, the link density is $2*kV/(\pi d^2)$
- As the non-reuse area is $\theta * CIR * r^2$ and the link density is $2*kV/(\pi d^2)$, the mean number of other links in the non-reuse area can be calculated as

$$\text{non-reuse area} * \text{link density} = 2 * CIR * kV * \theta * r^2 / (\pi d^2)$$

- Considering the 20 dB beamwidth “θ”, the number of possible link orientations is $2\pi/\theta$
- As the mean number of other links in the non-reuse area is $2 * CIR * kV * \theta * r^2 / (\pi d^2)$, the total carrier bandwidth used per link is m/s and the number of possible link orientations is $2\pi/\theta$, the mean number of links in the non-reuse area using the same antenna orientation, Tx/Rx polarity and slot-pair as the wanted link can be calculated as

$$\text{mean number of other links in non-reuse area} * m/s * \theta/2\pi =$$

$$2 * CIR * kV * \theta * r^2 / (\pi d^2) * m/s * \theta/2\pi$$

- the number of additional carriers required for reuse is equal to the mean number of links in non-reuse area on same orientation, Tx/Rx polarity and slot-pair as the wanted link

$$\text{number of additional carriers required for reuse} =$$

$$2 * CIR * kV * \theta * r^2 / (\pi d^2) * m/s * \theta/2\pi$$

- As the number of additional carriers required for reuse is given by the expression above, the total number of carriers required is

$$1 + 2 * \mathrm{CIR} * \mathrm{kV} * \theta * r^2 / (\pi d^2) * m/s * \theta/2\pi =$$

$$1 + \mathrm{CIR} * \mathrm{kV} * (m/s) * (\theta/\pi)^2 * (r/d)^2$$

- It is claimed that detailed modelling has shown that the mean link length "r" does not reduce directly as "d" reduces. The approximate relation is claimed to be $r=\sqrt{d}$. Therefore, the total number of carriers is

$$1 + \mathrm{CIR} * \mathrm{kV} * (m/s) * (\theta/\pi)^2 * (1/d)$$

- Assuming adjacent channel rejection is ACR, the total number of carriers can be calculated as

$$1 + (1 + 2/\mathrm{ACR})*(\mathrm{CIR} * \mathrm{kV} * (m/s) * (\theta/\pi)^2 * (1/d))$$

4.2.1.2 Carrier Bandwidth

The following calculations assume that traffic is flowing between interconnection nodes and subscriber nodes. It does not take account of;

- load concentration around interconnection points,
- effects of topological limitations
- edge effects.

The following parameters can be defined for each subscriber node:

Throughput of node (i.e. total throughput - directly related to carrier bandwidth) (Mbps)	B
Number of time slot pairs (channels) per carrier	s
Mean no of time slot-pairs (channels) used per link	m
Average subscriber traffic (Mbps)	S

Table 4-3: Additional Parameters

- As the throughput of each node is "B" and the number of slot pairs (channels) per carrier is "s", the throughput of one slot pair is B/s
- As the mean no of time slot-pairs (channels) used per link is "m" and the throughput of one slot pair is B/s, the throughput of a link is m*B/s
- As the average subscriber traffic is "S" and the throughput of a link is m*B/s, the subscriber loading is S/(m*B/s)=s*S/(m*B) where a subscriber call is assumed to be one time slot pair worth of throughput for the period of the call
- From the detailed modelling and assuming that all the mesh traffic is destined for the trunk network through an appropriate number of interconnection nodes, it is known that an acceptable level of blocking is obtained if the subscriber loading remains below 0.3.

- Therefore, the required throughput of a node can be determined from B=s*S/(0.3*m)
- Assume that the mesh carriers operate in TDD mode. Therefore, where a node throughput is described as “B” this means that the node is sourcing “B” and sinking “B” at the same time. Consequently, the TDD carrier will have to support the throughput equal to 2B. Similarly, where the average subscriber traffic is described as “S” this means that the subscriber is sourcing “S” and sinking “S” at the same time.

4.2.2 Application of Methodology

The following table illustrates the amount of spectrum requirement of a mesh network for a number of assumed parameter values.

Calculation of Number of Carriers Required		
Parameter	Assumed Value(s)	
ACR, Adjacent Channel Rejection	30 (14.8)	Factor (dB)
CIR, Carrier-to-Interference Ratio	40 (16.0)	Factor (dB)
V, Node valency	4	
kV, Average used valency (No of active links per node)	3	
s, Total no of time slot-pairs (channels) per carrier	8	
m, Mean no of time slot-pairs (channels) used per link	2	
θ, Antenna beamwidth to –20 dB	0.23562	Radians
No of Carriers = 1 + (1 + 2/ACR)*(CIR * kV * (m/s) * $(\theta/\pi)^2$ * (1/d))		
d (km) Mean distance between nodes (subscriber+seed+interconnection)	No of Carriers Required	
≥ 0.5	1.36 ≈ 2	
0.2	1.90 ≈2	
0.1	2.80 ≈ 3	
Calculation of Carrier Bandwidth		
Parameter	Assumed Value(s)	
S, Average subscriber traffic (Mbps)	1.3 Mbps	
Total throughput of a node= 2B = 2 * s * S / (0.3 * m)		
Total throughput of a node (Mbps)	34.66	
Calculation of Total Bandwidth		
Parameter	Assumed Value(s)	
Modulation Scheme (bps/Hz)	1.3 bps/Hz (QPSK)	
d (km) Mean distance between nodes (subscriber+seed+interconnection)	***Total Bandwidth Required (MHz)***	
≥ 0.5	***53***	
0.2	***53***	
0.1	***80***	

Table 4-4: Mesh Spectrum Requirement

For the assumed parameter values, the results indicate that the mesh network spectrum requirement is within 53-80 MHz depending on the assumed mean distance between the radio nodes.

It is important to note that the calculated spectrum requirement values are derived from algorithms taking account of the mesh network internal traffic. The number of mesh trunk network interface points also plays a significant role in determining the minimum number of carriers required. Mesh proponents expect a large number of interface points and the links to these interface points can be accommodated using the same carriers as used within the mesh. However, if there are fewer interface points than anticipated, the minimum number of carriers could increase because the concentration of traffic at these points will require a wider total bandwidth (i.e. more carriers). The determination of the number of required interface points is explained in the following section.

It is possible that second order effects will become apparent as the subscriber density increases. It might be suggested that as the subscriber density goes up the transmitter power levels will go down correspondingly and received interference levels will therefore be independent of subscriber density. However, the way in which a mesh is configured does not lead to the mean link length decreasing directly with subscriber density. This means that the general C/I levels in the network will get worse with a consequent requirement for an increased amount of spectrum.

4.3 Comparison

Any comparison of the spectrum efficiency of PMP and mesh systems has to have some regard to the economic and practical realities of the systems[4]. In particular this is because the PMP cell size argument taken to its extreme can indicate whatever spectral efficiency is required. Making the cell size smaller and smaller, while at the same time assuming a frequency re-use factor of 1, increases the spectral efficiency accordingly. However, there comes a point at which it is not practical to have base stations very close together and other solutions might be more economically attractive. Taken to the limit, a PMP network would eventually decompose into a network that looks similar to a mesh network.

Comparison of the calculated spectrum requirement figures indicates that, for a mean subscriber distance of 0.1 km, both mesh and PMP networks would require the same amount of spectrum if the PMP cell radius is reduced to approximately 0.3 km.

PMP calculations show that, for a cell radius of 0.3 km, the total bandwidth of 72 MHz per base station would be required to accommodate 36 subscribers (where each subscriber requires 1 MHz bandwidth in both directions). This, in turn, implies a total PMP backhaul requirement of 72 MHz per base station.

In the mesh case, using the same subscriber density and total bandwidth requirement, it can be shown that every 20 subscribers (i.e. mesh nodes) would require a trunk network interface point. This figure suggests that

- for the subscriber traffic demand of 1 MHz in both directions, mesh interconnection point would require 40 MHz backhaul capacity which compares directly with a PMP base station backhaul requirement of 72 MHz,
- for the assumed mean subscriber distance of 0.1 km and the PMP cell radius of 0.3 km, 1000 subscribers would require 28 base stations (each with a 72 MHz backhaul requirement) or 50 mesh trunk network interface points (each with a 40 MHz backhaul requirement).

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[4] However it should be noted that the business case associated with these systems was outside the scope of the study and therefore has not been addressed here.

The fundamental differences that influence the spectral efficiency can be summarised as follows:

PMP - For a given sector there is no frequency reuse within that sector (not withstanding the possibility of polarisation reuse[5]). The number of carriers required is determined by the number of subscribers in that sector, their traffic requirements and the capacity of a carrier. The driving factor in determining the spectral requirement is therefore the aggregation of subscriber traffic within the sector area.

An important characteristic of a PMP network is its inherent concentration of traffic (at a base station) which is necessary if there is a requirement to interface to a trunk network. Arguably it is this concentration of traffic that leads to the aggregate spectral requirement referred to above. It should be remembered that a similar functionality also has to be provided by a mesh network.

Mesh - The number of carriers required is determined by the beamwidth of the antennas. The size of the carriers is determined by a number of factors including the traffic attributable to a single subscriber, how the nodes are connected, and blocking considerations.

As in the case of PMP networks, aggregation of subscriber traffic plays a significant role in determining the total mesh spectrum requirement. Mesh network traffic is interfaced to the infrastructure network through a number of trunk network interface points. Within the number of carriers available it will be possible to transmit the aggregated traffic from a limited number of nodes to the same trunk network interface point. This means that, either there have to be a significant and dispersed number of trunk network interface points in order to make efficient use of the carriers available, or there have to be a far larger number of carriers available in order to serve fewer network interface points. In the case of the latter situation, the spectrum requirement starts to increase as the concentrating behaviour of the network interface point approaches the behaviour of a base station in a PMP network.

It can be seen therefore that the spectral efficiency of a mesh network not only depends on the frequency reuse obtained by the use of directional antennas at both ends of the link, but also by the dispersed nature of the interfacing to the trunk network.

5 SHARING WITH OTHER SERVICES

Any detailed sharing study involving terrestrial radio systems needs to take account of propagation and terrain effects, transmitter EIRP levels, transmitter and receiver antenna characteristics and receiver noise characteristics.

In this section, the implications of these parameters will be summarised by considering characteristics of broadband wireless system architectures.

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[5] For the sake of the argument this has been ignored here as it can also be used in mesh networks.

5.1 Current Allocations

The Radio Regulations (RRS5, Volume 1e, Geneva 1998) state that the 40.5-43.5 GHz frequency band is allocated to the following services.

Frequency Band	Region 1	Region 2	Region 3
40.5-42.5	FIXED BROADCASTING BROADCASTING SATELLITE Mobile *S5.551B, S5.551D*	FIXED FIXED SATELLITE (space-to-Earth) *S5.551B, S5.551E* BROADCASTING BROADCASTING SATELLITE Mobile *S5.551C, S5.551F*	
42.5-43.5	FIXED FIXED SATELLITE (Earth-to-space) *S5.552* MOBILE except aeronautical mobile RADIO ASTRONOMY *S5.149*		

Table 4-5: Frequency Allocation

S5.149 "… administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service".

S5.551B The use of the band 41.5-42.5 GHz by the fixed-satellite service (space-to-Earth) is subject to Resolution 128 (WRC-97). (WRC-97)

S5.551C Alternative allocation: in the French overseas territories in Regions 2 and 3, the Republic of Korea and India, the band 40.5-42.5 GHz is allocated to the broadcasting, broadcasting-satellite and fixed services on a primary basis. (WRC-97)

S5.551D Additional allocation: in Algeria, Saudi Arabia, Bahrain, Benin, Cameroon, Egypt, United Arab Emirates, Israel, Jordan, Kuwait, Lebanon, Libya, Mali, Morocco, Mauritania, Nigeria, Oman, Qatar, Syria, Tunisia and Yemen, the band 40.5-42.5 GHz is also allocated to the fixed-satellite service (space-to-Earth) on a primary basis. The use of this band by the fixed-satellite service shall be in accordance with Resolution 134 (WRC-97). (WRC-97)

S5.551E Use of the band 40.5-42.5 GHz by the fixed-satellite service shall be in accordance with Resolution 134 (WRC-97). (WRC-97)

S5.551F Different category of service: in Japan, the allocation of the band 41.5-42.5 GHz to the mobile service is on a primary basis (see No. S5.33). (WRC-97)

S5.552 The allocation of the spectrum for the fixed-satellite service in the bands 42.5-43.5 GHz and 47.2-50.2 GHz for Earth-to-space transmission is greater than that in the band 37.5-39.5 GHz for space-to-Earth transmission in order to accommodate feeder links to broadcasting satellites. Administrations are urged to take all practicable steps to reserve the band 47.2-49.2 GHz for feeder links for the broadcasting-satellite service operating in the band 40.5-42.5 GHz.

As can be seen, sharing with both terrestrial and space systems are required in the designated 40.5-43.5 frequency band.

5.2 Interference from MWS

The broadband PMP systems use highly elevated base station antennas (≈ 30m a.g.l.) with relatively wide horizontal beamwidths (≈ 60-90 degrees). These characteristics imply that interference from base station transmitter antennas to terrestrial stations operating in other Services might be significant as the impact of local clutter surrounding base station is minimal. The wider beamwidth also implies that the probability of a victim receiver being within the base station mean beam is relatively high.

Mesh systems do not employ base stations. Instead, multiple narrow beam antennas (for example, 4 antennas with 9 degrees beamwidth) are employed to provide network interconnectivity. These antennas do not have to be as high as base station antennas. Therefore, shielding provided by local clutter might be beneficial and the amount of interference into other terrestrial stations will be reduced. The use of narrow beam antennas might bring additional benefits since the probability of a victim receiver being at the mesh radio node boresight is smaller. However, this probability might increase as the density of mesh radio node increases.

As far as interference into space stations is concerned, power aggregation needs to be considered. Assuming similar PMP and Mesh subscriber densities, aggregate interference from PMP networks is likely to be greater. This is due to the fact that PMP subscriber transmitters might be required to transmit higher power as wanted path to the base station might be greater (≈ 5 km) than the average hop length of the mesh network (≈1 km). In addition, high power transmission might also be desired as the base station receiver antennas are not as highly directional as mesh radio node receiver antennas.

With regard to protection of Radioastronomy Service, a study of "Co-ordination between BFWA systems in the 28 & 42 GHz frequency band" undertaken by Aegis on behalf of RA (October'99) concluded that the separation distances of 29-60 km would be required from base station transmitters using an eirp of 0.5 dBW/1MHz. These separation distances were based on a smooth-Earth assumption and a propagation time percentage of 50% (i.e. the calculated distances ensure that the minimum required loss is exceeded for 50%). In the case of a 10% propagation time percentage (i.e. when the minimum required loss is exceeded for 90%), the calculated separation distances were within the range of 32-88 km.

The PMP system characteristics table (Section 2) shows that the PMP subscriber terminal transmit eirp is 17.5 dBW/1MHz, some 17 dB higher than the base station eirp. Therefore, in the event of an on-beam interference entry from a PMP subscriber terminal, even larger separation distances would be required.

5.3 Interference into MWS

Both mesh nodes and PMP subscribers might benefit from the shielding provided by local clutter. The impact of interference into PMP base station receivers, on the other hand, might be more problematic due to their height and wider beamwidth.

Another important aspect is the probability of an interfering station being at the boresight of MWS receivers. The PMP subscriber and mesh radio node antennas are narrow beam antennas and, therefore, the probability of on-beam interference hit will be lower. However, this probability increases as the subscriber density becomes higher.

6 CONCLUSIONS

From the discussions held with potential operators and equipment manufacturers, and from the high level analysis presented in this report, it is possible to draw the following conclusions:

1) **Spectral efficiency.**

The high level analysis presented in this document suggests that the spectral efficiency of a PMP network is largely determined by the cell radius. When a cell radius is reduced the spectrum efficiency increases. However, this could imply an increased number of base stations and, therefore, an increased cost per user.

The use of directional antennas at both ends of a link enables mesh networks to re-use available frequencies. Under certain circumstances (i.e. when compared with large PMP cell sizes), a mesh network can be more spectrum efficient than a PMP network. However, this can be offset by reducing the PMP base station cell size.

For the particular situation modelled, it has been shown that a PMP network would require fewer base stations each requiring a large backhaul capacity while a mesh network would need a large number of trunk network interface points each requiring less backhaul capacity. This suggests that the benefits of a mesh deployment can only be sustained where the interfacing of mesh traffic to the trunk network is frequent and well dispersed.

If this proves impractical then fewer trunk interfacing points will give rise to a larger spectrum requirement. In such circumstances, the spectral efficiency of a mesh network could likely to become comparable to that of a PMP network using a relatively large cell radius.

Because the mesh spectrum requirement analysis has had to be carried out at a high level it should be noted that it has been indirectly related to more detailed simulations that have been undertaken by other parties (e.g. what is a reasonable loading before blocking occurs in a mesh network). For complete confidence in the results it would be necessary to examine the simulations in detail.

Of course there can be arguments not only about the parameter values selected but also about other effects that have not been included (for example, exact modelling of traffic behaviour and the implications of the use of different duplexing and multiple access techniques). However, it is considered that the analysis contained in this document identifies the fundamental drivers that determine the spectrum requirement for each type of network.

An absolute measure of spectrum efficiency requires detailed simulation modelling involving accurate system characteristics and representation of actual traffic behaviour. However, having identified the fundamental drivers through the work reported in this document, it would be possible to go one step further and arrive at a more substantiated conclusion by introducing the economic aspect into the modelling presented in this report. High level modelling together with economic considerations could provide a better idea regarding to likely system sizing and, therefore, enable a more accurate comparison between mesh and PMP architectures to be made.

2) **Backhaul.**

If a given amount of subscriber traffic has to be interfaced to a trunk network a certain amount of traffic concentration has to take place. The concentrated traffic then has to be transferred by one means or another (i.e. radio or fibre) to a suitable point for injection into[6] the trunk network.

For the purposes of comparing a mesh network with an equivalent PMP network it is important to distinguish between what is and what is not backhaul.

In the case of a PMP network it is fairly clear. A base station implicitly concentrates the traffic from subscribers. If that traffic is to be connected to the trunk network, depending on the convenience of the connection point, it will have to be transferred by fibre or radio to the connection point. This transfer is the backhaul.

In the case of a mesh network the distinction is more diffuse. A certain amount of concentration takes place within the mesh network itself. The amount of concentration that can take place towards a single trunk network connection point will be determined by the number of carriers available and the frequency reuse that can be achieved with those carriers. If the carriers that support the general mesh interconnectivity are used for this purpose it is likely that the concentration will be limited and that as a consequence there will be a significant number of trunk network interconnection points. In the event that these trunk network interconnection points are not located conveniently relative to the trunk network then backhaul links will be required.

Both systems therefore have a requirement for backhaul depending on the relative locations of the trunk network to which they are connecting and the locations of the traffic concentrating points (base stations in the PMP case and interconnection points in the case of the mesh network). It is likely that PMP backhaul will require fewer but larger connections whereas the mesh network will require more but smaller connections.

3) **PMP coverage.**

From discussions held with potential operators and equipment manufacturers there appears to be considerable differences of opinion concerning the degree of coverage provided by a base station but also about the degree of frequency reuse that can be achieved. Furthermore, under the frequency / polarisation plans being proposed (e.g. 4 sector = 2 frequencies and 2 polarisations) it appears that the C/I ratios achieved will not enable higher order modulation schemes to be used. Some doubt has also been expressed as to whether the proposed frequency reuse plans will work when taking account of the rain fading that is expected at these high frequencies.

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[6] It is of course a two way process so there is also the case of the trunk network injecting traffic into the radio network for distribution.

For the spectral efficiency comparison purposes of this study it has been assumed that a frequency reuse of 1 can be achieved - this is optimistic but at least does not disadvantage PMP systems.

4) **Traffic / service assumptions.**

It should be noted that nature of the traffic to be supported by a network will have significant bearing on whether a network is seen to use the spectrum efficiently. It is clear from the discussions that the intended service offerings, target markets etc are all very different. This of course does not help a general analysis of the situation and indeed it is clear that the individual system architectures have been tailored to the service being offered and in some cases have also been influenced by the heritage from which the systems derive. For example, where it is felt that the future is going to be based on large quantities of identical information being sent to all users, with a limited requirement for user interaction, a PMP broadcast architecture is being proposed using FDD. This is a sensible choice based on a particular view of the traffic pattern of the future. While a mesh network might be able to cope with such a demand, it would not be the most efficient way of approaching this particular traffic pattern.

In general it is expected that businesses will be targeted first, mainly because of the expected cost. However there are clear ambitions that in the longer term the mass residential market will be targeted once the cost of technology comes down.

5) **Technology.**

One of the key aspects regarding the technology involved concerns the capability of the transmitter. It is widely recognised that achieving high levels of transmitter power at the frequencies under consideration here, is difficult and expensive, and likely to remain so in the near term. There are two implications arising from this situation:

- The cost of equipment may be relatively high in the near term and is therefore more likely to be aimed initially at the business market (as noted above).
- The shorter links of a mesh network (with cascaded links providing coverage) and the directional antennas at each end of the mesh network links will require a lower transmitter power and will therefore not be as constrained as the PMP case.