



# **A Technical Evaluation of the Effect of UWB on Broadband Fixed Wireless Access in the 3.4 GHz Band**

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August 2005

Note that this report has been commissioned by Ofcom to provide an independent analysis into the deployment of new technology in the United Kingdom, in order to assist Ofcom in its development of policy in this area. The assumptions, conclusions and recommendations expressed in this report are entirely those of the contractors and should not be attributed to Ofcom.



## CONTENTS

1	Approach to Modelling the Impact of UWB Interference .....	2
1.1	Introduction .....	2
1.2	UWB interference .....	3
1.3	Impact on BFWA reception.....	5
1.4	Impact on BFWA systems .....	7
1.5	Modelling network performance .....	8
1.6	Correlation effects .....	10
2	Results of UWB Interference Modelling.....	12
2.1	Minimum coupling loss analysis .....	12
2.2	Network simulation without UWB interference .....	14
2.3	Network simulation with UWB interference .....	16
2.4	Conclusions from UWB interference modelling.....	17
3	Potential mitigation measures.....	18
3.1	UWB power control.....	18
3.2	Switching off UWB devices close to the primary PC .....	19
3.3	Capping the duty cycle .....	21
3.4	Switching UWB devices to higher frequencies .....	22
3.5	Conclusion on mitigation methods .....	25



# 1 Approach to Modelling the Impact of UWB Interference

## 1.1 Introduction

With the recent deployment of IPWireless UTRA TDD technology by UK Broadband, and the imminent arrival of WiMAX certified products, we can expect these two standards to be representative of the technology for any on-going BFWA business at 3.5 GHz. These modern broadband fixed wireless access systems use sophisticated air interface protocols designed to optimise the system's capability to carry a wide variety of traffic. In particular the protocols are able to respond rapidly to changes in radio channel conditions, transmitting data more slowly but more robustly in poor conditions and more rapidly but less robustly in good conditions. Interference that results in slower transmission will therefore have the effect of reducing system capacity for the duration of the interference. There is, however, a limit to the level of interference that can be mitigated in this way and higher levels will prevent reception of the wanted signal altogether for the duration of the interference. Thus, in considering the impact of UWB interference on BFWA systems it is necessary to consider both the resultant reduction in system capacity and the proportion of traffic which is blocked by interference (hereafter referred to as outage).

UWB devices are expected to be deployed extensively in a wide range of electronic products found in both home and office environments. Although the level of emissions will be very low, the interference suffered by a BFWA terminal can be large enough to affect the reception of weak signals when the terminal is in close proximity to a transmitting UWB device. However, the location of UWB and BFWA devices will be highly variable from one office (or home) to another. Furthermore the wireless activity of both UWB devices and BFWA terminals will typically be bursty in nature with little or no correlation between the two. Any estimation of the impact of UWB interference has, therefore, to take into account the statistical nature of their interaction, and this is done through the use of Monte Carlo simulation. The process can be conveniently considered in three steps.

1. The first step establishes the probability that a given level of UWB signal will be present at the antenna of the BFWA terminal.
2. The second step is to consider the impact of UWB interference on reception of BFWA signals, and the response of the BFWA system.
3. The final step is to evaluate the overall impact on BFWA system performance, in terms of capacity reduction and outage.

Modelling inevitably involves a number of simplifying assumptions. The three key assumptions made were:

1. The rapid pulse like nature of UWB emissions affects the BFWA receiver as if it were a single continuous transmission
2. Any UWB transmission which overlaps with the reception of a BFWA signal is treated as though it was present at the same level for the duration of the BFWA signal – thus overstating the impact of interference
3. The BFWA terminal is able to respond immediately and correctly to the start and cessation of interference – thus understating the impact of interference.

These were selected to be as reasonable as possible but with an overall bias towards conservatism so that any consequential bias would tend to overstate the impact of



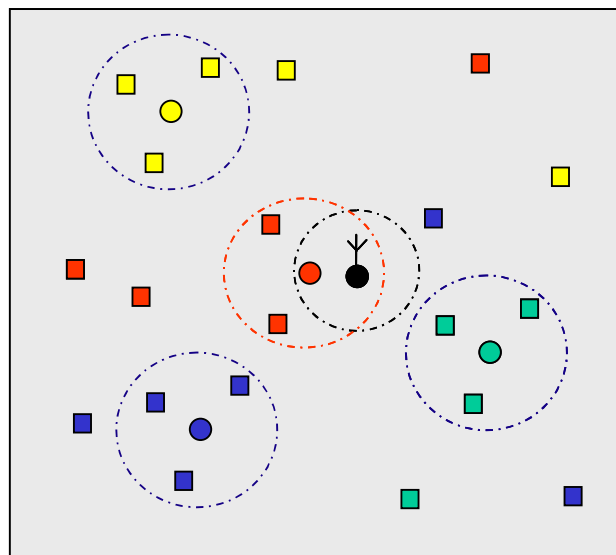
interference on the BFWA system. These and the other assumptions are described further in the following sections.

## 1.2 UWB interference

The level of interference at a particular instant in time is determined by placing the BFWA antenna and UWB devices at various locations within the office or home environments, selecting which UWB device is transmitting, and computing the resultant interfering signal strength at the BFWA antenna.

The number of UWB devices in typical home and office room is taken from Mason's forecasts<sup>1</sup> which include an uplift to take account of clustering, as specified using a "probability of presence" parameter. A typical layout of devices within a room is illustrated in Figure 1.1. Where there is more than one PC within the room<sup>2</sup> one "primary" PC is associated with the BFWA terminal. This PC is placed at a random location within 1.5m of the BFWA antenna<sup>3</sup> which is assumed to be at the centre of the room. Peripherals which are closely associated with the PC and contain UWB devices, such as keyboards or wireless monitors, are placed at random within 2m of the PC. Other peripherals associated with the PC, such as printers or mass storage products, are randomly placed within 15m of the PC. The other PCs are then placed at random within the room, but at least 1.5m away from the BFWA antenna, and their associated peripherals are placed in the same way as for the primary PC. Other products, using UWB devices but not associated with PC applications (such as mobile to PDA links) are placed at random within the room (see Figure 1.1).

**Figure 1.1 This illustration shows how some UWB devices are clumped around PCs with others more widely distributed, with one PC close to the BFWA terminal and its antenna.**



<sup>1</sup> "Value of UWB personal area networking services to the United Kingdom", Mason and Dotecon, November 2004

<sup>2</sup> For offices the number of PCs is derived from Mason's forecasts, homes are assumed to have only one in the same room as the BFWA terminal.

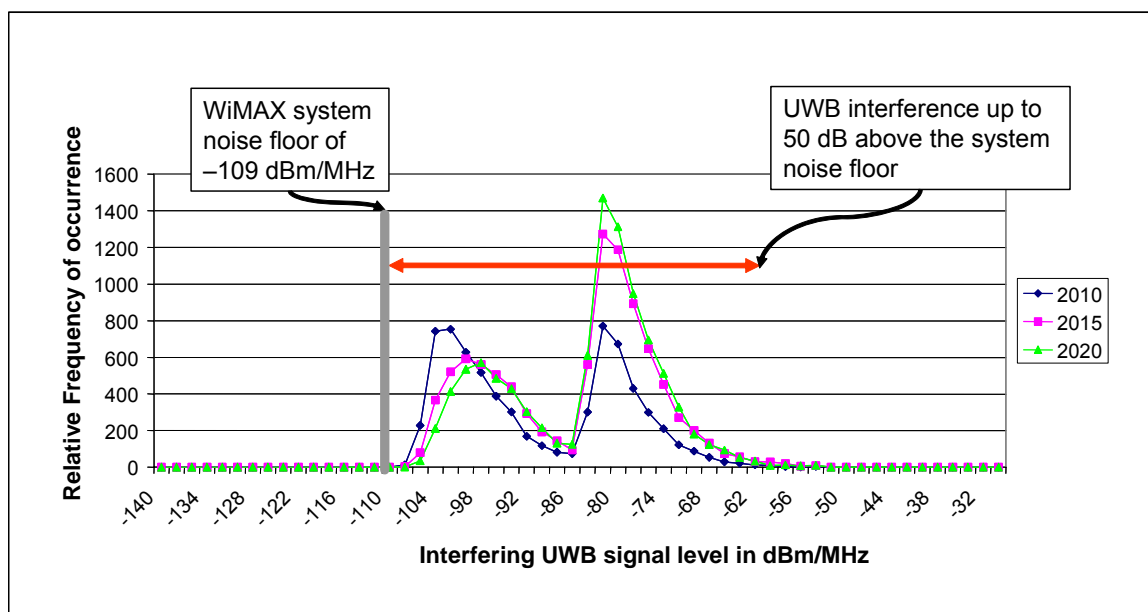
<sup>3</sup> We have assumed that indoor BFWA antennas will be attached to the main PC by a 1.5m lead.



The Monte Carlo simulation uses the UWB Activity Factors to determine which of the UWB devices are active at a particular instant. Where more than one device is determined to be active, the one closest to the BFWA antenna and producing the largest interfering signal is taken to be transmitting. In practice, where more than one UWB device is active at one time, the piconet controller will allocate time between the competing devices so that only one device transmits at a time. This part of the model therefore over-estimates the level of interference.

The level of the interfering signal at the BFWA antenna is calculated using free space path loss (i.e. assuming line of sight propagation) with a minimum coupling loss of 12dB. In practice average path losses are somewhat greater than line of sight in an indoor environment, again leading to an over-estimate of the level of interference. The UWB devices are assumed to always transmit at their maximum possible bit rate and at a maximum permissible power of -41.3dBm per MHz. Figure 1.2 shows an example of the relative frequency of interference levels determined in this way.

**Figure 1.2: The relative frequency of occurrence is shown as a function the interfering signal level experienced at the BFWA antenna. Results for the office environment are illustrated for each of the three years, 2010, 2015 and 2020.**



The results in Figure 1.2 show the interference to be centred around two peaks, one at -78dBm and the other at -96dBm. The first reflects the UWB devices closely associated with the primary PC which are closer to the BFWA antenna while the second results from the remaining UWB devices which are more widely distributed across the room. This is typical of results for both the office and home environments.

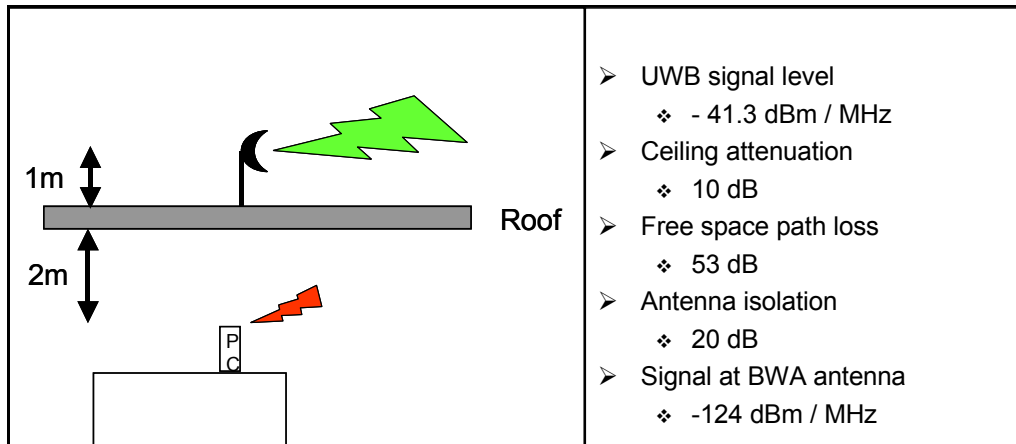
Also shown here is the system noise floor of a WiMAX system. The extent to which the UWB interference extends into the operating range of the system is clear with interference reaching more than 50 dB above the minimum operating level of the system. Although final conclusions have to be based on overall impact at the network level, these results show that UWB interference has the potential to affect BFWA system operation.



### 1.2.1 External antennas

External (directional) BFWA antenna may be deployed by BFWA operators and are allowed for in the network model. Typically, as shown in **Figure 1.3**, they will point away from the office and the equipment inside, and the intervening wall or ceiling will attenuate UWB signals.

**Figure 1.3: Representative external directional antenna configuration and path loss between UWB and BFWA antenna.**



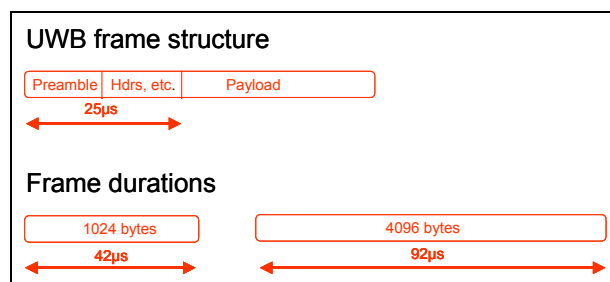
The estimate of the level of the interfering UWB signal at the BFWA antenna is some 15 dB below the WiMAX noise floor and we have therefore assumed that, with external antennas, BFWA receivers suffer no interference.

### 1.3 Impact on BFWA reception

DS-UWB devices generate a chip code sequence from sub-nanosecond pulses (3 cycles of RF centred on 4 GHz in the lower band) and convolve it with the data sequence to produce a spread spectrum signal with a bandwidth of around 1.5 GHz. MB-OFDM devices transmit a 500 MHz wide OFDM signal in 3 bands below 5 GHz but switch between bands every 312ns. Thus, on the sub-microsecond time scale, UWB radio signals consist of a series of ultra short bursts of RF.

UWB devices package data into frames for transmission. Each frame contains overhead in the form of preamble sequences, header information and FEC, and up to 4096 bytes of application payload. The preamble and header are transmitted at a relatively low rate (53.3 Mbits/s in the case of MB-OFDM) to ensure robust reception but the payload will normally be transmitted at higher rates depending upon the path length and the application. The frame structure and example frame durations are illustrated in Figure 1.4.

**Figure 1.4: Sample timings for UWB frames are shown, based upon the MB-OFDM proposals.**



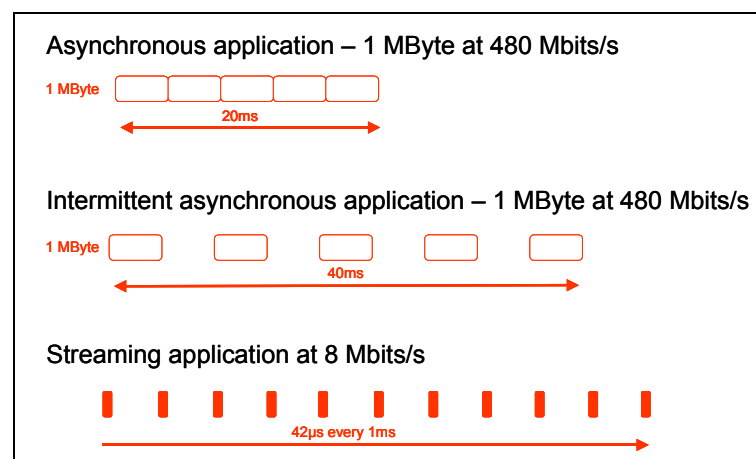


UWB devices will transmit data at very high data rates (typically 200 Mbit/s and above) whereas many applications will require lower data rates. UWB devices may therefore transmit for only a proportion of the time for which the application itself is actively generating data for transmission.

- For asynchronous applications (i.e. those that transfer discrete blocks of data such as file transfer) the UWB application will attempt to send the data file at the fastest possible speed using consecutive frames.
- Intermittent asynchronous applications – some applications may not be able to generate and buffer data rapidly enough to support the higher bit rates. These applications would therefore transmit a buffer full of data and then pause to fill the buffer before sending the next transmission.
- For streaming applications (audio and video transmissions that are intended to be experienced in real time by the user) the application will make regular transmissions having the overall throughput demanded by the application. Each burst of transmission will go at the highest rate available for the link.

Examples of corresponding transmissions are given in Figure 1.5.

**Figure 1.5: Examples of UWB transmissions for asynchronous and streaming applications.**



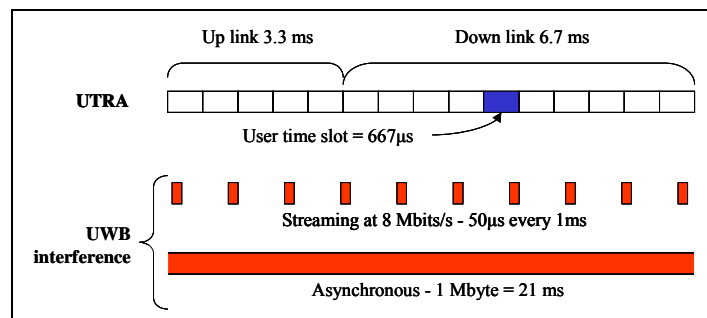
In UTRA TDD systems, the channel is divided into timeslots each of 667µs duration. Each subscriber station will be allocated capacity on downlink and uplink slots as appropriate to the service being received.

In the case of WiMAX, data is transmitted in frames with each frame carrying data for a number of terminals using TDM/TDMA. Each downlink frame consists of a preamble and header information followed by user data. Frame lengths vary between 2.5 and 20ms, and each subscriber station needs to successfully receive both the header information and its own burst of data.

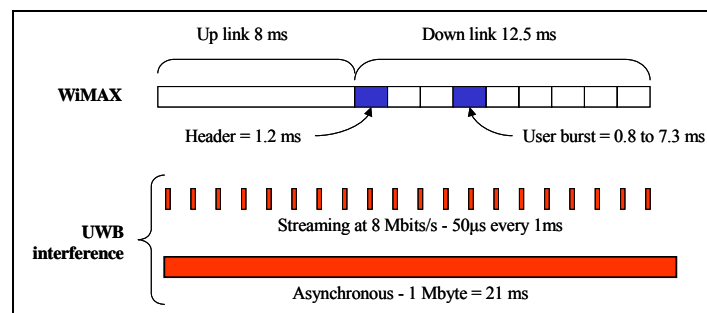
Figure 1.6 and Figure 1.7 compare UTRA TDD and WiMAX transmissions with potential UWB transmissions. For the cases illustrated the probability that the UWB and BFWA signals overlap is large, 100% in the case of the asynchronous UWB application and ~67% or greater in the case of the streaming application. Of course the probability will be less for applications sending less data or streaming at lower bit rates. However, UWB is expected to support many applications requiring significant amounts of data transfer or reasonably fast data rates. We

have therefore assumed that whenever a UWB device and a BFWA terminal are in “session” their signals will overlap. Thus the activity factors that are used to determine the probability of interference are the periods over which the application is actively in communication even though the corresponding transmissions may be discontinuous.

**Figure 1.6: This figure illustrates the high probability of UWB signals overlapping with the signal transmitted to a single UTRA TDD terminal.**



**Figure 1.7: This figure illustrates the high probability of UWB signals overlapping with the signal transmitted to a single WiMAX terminal.**



## 1.4 Impact on BFWA systems

Both UTRA TDD and WiMAX systems will respond to interference by using a more robust transmission mode. In the case of UTRA TDD, the system can both increase the power allocated to the affected transmissions and, with HSDPA, switch to a more robust modulation and coding scheme. In the case of WiMAX, the response is likely to be limited to switching to a more robust modulation and coding scheme. In both cases, the effect is to reduce system capacity as the affected transmissions occupy more power and/or time in the case of UTRA or more time in the case of WiMAX. Precisely how any system responds to interference is vendor specific but, for the purposes of modelling, we make the following assumptions:

- The system responds immediately and correctly to interference, and also responds immediately and correctly when the interference ceases (thus minimising the reduction in system capacity);
- The effect of the UWB interference is as if it were present for the duration of the BFWA signal regardless of its actual duration (thus tending to overstate the impact of UWB signals).



Our approach to quantifying the impact of UWB interference is to determine the cost of additional infrastructure (i.e. more base stations) required to recover the loss of capacity such that the BFWA subscribers receive the same quality of service as they would have done had there been no deployment of UWB devices. However, UWB signal levels can be large enough to overcome even the most robust BFWA transmission modes and in this case the BFWA signal will be blocked. Our results therefore also include the probability that BFWA signals will be blocked causing outage. The effect of outage on the end user will depend upon the type of activity they are engaged in, and we have therefore classified it into three levels.

1. In the case of real time applications (for example a streaming service using UDP) the data will be lost or not be received quickly enough and the application will suffer some form of disruption such as distortion to the audio or video, or a temporary interruption to the service. We have classified this effect as “disruptive”. We have assumed that traffic disrupted in this way is not re-offered to the BFWA network.
2. In the case of interactive applications such as surfing in which the user expects a response within a few seconds, outage can be less disruptive. Where the interference is brief (say a few hundred milliseconds) any corrupted data may be repeated (either by the radio interface protocol or by the TCP protocol) without impact on the user. Longer interruptions and greater loss of data will, however, result in the TCP backing off leading to a noticeable degradation of the response time. Interruptions which last several seconds will not only be noticeable to the user but may also cause either the application or the radio interface protocol to stop the session. We have therefore classified this effect as “annoying”. Since these applications are not real-time we have assumed that this traffic is re-offered to the BFWA network.
3. Some applications, such as downloading files, will often not be time critical from the user’s perspective and delays caused by interference may well go un-noticed. Longer delays, when they occurred, might stop a session and this would be annoying to the user. Where blockage occurs to such applications, we have classified the outage as “occasionally annoying”. We have assumed that this traffic is re-offered to the BFWA network.

## 1.5 Modelling network performance

The performance of both UTRA TDD and WiMAX based networks are modelled using a Monte Carlo simulation. The density of BFWA subscribers is determined from the relevant market forecasts, and their terminals are evenly distributed across the service area. For each snapshot, terminals are selected as active with probability proportional to their activity factors. For each active terminal the model then determines the capacity required to serve that terminal (i.e. its load on the system) as a proportion of the total capacity available in a cell (where a cell is served by one or more carriers from a single antenna). Both path loss and the class of traffic in use are taken into account. With multiple snapshots the average load (as a proportion of the total capacity available per cell) can be determined. This process is repeated for different cell sizes to obtain the average demanded load as a function of cell range (i.e. distance from the base station to the most distant user). The actual coverage area of the cell that would be supportable in a fully loaded network is then just the area for which the average load gives the required quality of service. In common with dimensioning practice on the internet, we have considered an average busy period load of 40% as providing an adequate quality of service, and determined through simulation the grade of service to which this relates.



The simulation is then repeated but with UWB devices now deployed for a subset of the BFWA subscribers (selected with probability proportional to the same “probability of presence” used to cluster UWB devices within homes and offices). The UWB applications are selected as active within each of these subscriber premises with probability proportional to their activity factors. The response of the BFWA network to UWB interference is modelled as described above, and the capacity required to support each terminal recalculated. The coverage area of the cell is then determined using the same dimensioning criteria as before. Terminals that are blocked by UWB interference are counted and classified as described earlier. Hence the failure statistics only describe the outage experienced by BFWA subscribers who also have UWB devices on the premises.

The network model has been designed to be as realistic as possible without undertaking detailed radio network planning. As such it uses average path loss values with distance rather than taking account of detailed terrain and clutter. Key aspects of the model include:

- Path loss is calculated using the Erceg<sup>4</sup> model as submitted to the IEEE 802.16 working group, with allowances made for in-building attenuation (a mean of 10dB);
- Inter-cell interference from surrounding sites is a significant contributor to the noise level in dense networks and varies with cell size. It has been included in the modelling.
  - *In the case of the 3.6-4.2GHz:*
- WiMAX technology will be deployed;
- 2 x 84 MHz of spectrum is available but only the lower band will be used for customer connections;
- 3.5 and 7 MHz RF carriers are deployed in a four sectored site arrangement with six 3.5 MHz carriers per sector. TDD operation is assumed with a DL/UL ratio of 2:1;
- Initially, roof mounted outdoor directional antennas are deployed for SMEs;
- From 2008, a number of SMEs adopt indoor antennas, in dense urban environments only. These auto-select the best signal from four 90° sectors;
- The maximum base station EIRP is 59.5 dBm (including the beamforming gain from the use of antenna arrays);
- The service offering is based on a minimum bit rate of 1 Mbits/s at the cell boundary;
- WiMAX parameters are based on IEEE 802.16-2004 (which incorporates 802.16-REVd) and the modulation / coding schemes used are as tabulated below.

**Table 1.1: Modulation and coding schemes for WiMAX. Note that the user rate is the combined user data rate on the carrier in the downlink after asymmetry and transmission overheads have been taken into account.**

Modulation	Coding	User rate (Mbit/s)*		Minimum CIR (dB)
		3.5 MHz	7 MHz	
	Carriers			
BPSK	1/2	1.1	2.3	1.8

<sup>4</sup> V. Erceg et al., “An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments”, *IEEE Journal on Selected Areas in Communication*, vol. 17, pp. 1205-1211, July 1999.



QPSK	1/2	2.2	4.4	4.9
QPSK	3/4	3.3	6.6	7.4
16QAM	1/2	4.4	8.7	10.5
16QAM	3/4	6.5	13.1	13.8
64QAM	2/3	8.7	17.4	16.8
64QAM	3/4	9.8	19.7	19.5

- *In the case of the 3.4-3.6GHz*

- UTRA TDD based technology is deployed with an DL/UL ratio of 2:1;
- 2 x 20 MHz of spectrum is available and 10 MHz carriers are deployed;
- 6 sector sites are used in dense urban areas, and tri-sectored sites elsewhere. Each sector has an average of 1.33 carriers;
- Multiple user detection is assumed to provide 75% suppression of intra-cell interference;
- The maximum base station EIRP is 45.5 dBm;
- The service offering is based on a minimum bit rate of 2 Mbits/s at the cell boundary;
- The following modulation and coding schemes - termed Transport Format Resource Combinations (TFRC) - are used based on the HSDPA parameters from 3GPP Release 5.

**Table 1.2: TFRCs for UTRA TDD.**

<b>Modulation</b>	<b>Coding</b>	<b>User rate (Mbit/s)</b>	<b>CIR (dB)</b>
QPSK	1/4	1.8	-14
QPSK	2/4	3.6	-10
QPSK	3/4	5.4	-7
16QAM	2/4	7.2	-5
16QAM	3/4	10.7	-1
16QAM	4/4	14.4	0

## **1.6 Correlation effects**

The impact of UWB interference on BFWA would be greater if there were a propensity for any UWB transmissions to take place at the same time as data was being received at the BFWA terminal. We therefore examined the 22 UWB applications and the typical applications within the five BFWA traffic classes. In most cases there is little reason to expect any correlation but where correlation was likely we classified it into two groups. Where a UWB application was likely to be used at the same time as most if not all applications within a BFWA traffic class the correlation was set at 100%. Where only some of the applications within a BFWA traffic



class would be correlated with UWB, the correlation was set at 50%. Table 1.3 shows the applications for which correlation is considered likely.

**Table 1.3: Correlation identified between UWB applications and BFWA traffic classes.**

<i>BFWA traffic classes</i>	<b>Surfing, etc.</b>	<b>Timely download</b>	<b>Non- critical download</b>	<b>Audio</b>	<b>Video</b>
<b>UWB applications</b>					
- <i>Office</i>					
PCs and keyboards / mice	100%	-	-	-	-
PCs and speakers	-	-	-	100%	100%
PCs and microphones	-	-	-	50%	50%
PCs and wireless monitor (with compression)	100%	-	-	-	100%
- <i>Home</i>					
PCs and TVs / projectors (for home theatre)	-	-	-	-	50%

To incorporate the effect of correlation within the model, each time a BFWA traffic class was selected as active, the activity factor of the UWB application was set to 50% or 100% if it appeared in the table (or whichever is highest if there is more than one BFWA traffic class active). Thus if an audio application was in progress over the BFWA system, the “PC and speakers” UWB application was always assumed to be active (on the basis that the subscriber would be always be listening) and the “PC and microphone” application was assumed to active 50% of the time (on the basis that some audio applications but not all would include two way speech).



## 2 Results of UWB Interference Modelling

### 2.1 Minimum coupling loss analysis

To aid understanding of the simulation results it is worthwhile to consider the minimum coupling loss between the two systems. The maximum power from a UWB device at 3.4 GHz is -41.3 dBm/MHz as defined by the emission mask. Assuming a minimum coupling loss between UWB and BFWA antennas of 12 dB at close proximity, this results in a maximum level of -53.3 dBm at the BFWA receiver antenna.

Where cells are smaller, then received signal levels at the cell boundary will be higher and outage can be expected to occur less frequently. The parameters and calculations in Table 2.1 establish the smallest cell size at which outage might be observed. Note that calculations are not shown for WiMAX in urban and suburban areas since the network is not expected to be planned for the use of indoor terminals in these areas.

The calculations in the table establish the values of the four main components of noise in the terminal: thermal noise, intercell interference, intracell interference (for CDMA based systems only) and UWB interference. These are added linearly to determine the effective noise floor. The wanted signal necessary to maintain adequate carrier to interference ratio is calculated for the most robust modulation and coding scheme. Since the table shows the conditions expected during network simulation, the cell range calculation uses the mean in-building attenuation of 10dB rather than a worst case attenuation that would typically be used for range limit calculations.

From Table 2.1, we can see that the effects of UWB will be observed where cell ranges are greater than 116 metres for UTRA TDD and 122 metres for WiMAX. However, in some circumstances effects might also be noticeable at closer distances where the instantaneous BFWA traffic demands a higher data rate than that provided by the most robust channel.



**Table 2.1 Minimum coupling loss parameters**

	UTRA TDD		WiMAX
	Dense urban	Urban & suburban	Dense urban
<b><i>Wanted channel characteristics</i></b>			
Maximum wanted channel power	31 dBm		28 dBm
TX feeder losses	2.5 dB		2.5 dB
TX antenna gain	18 dBi		16 dBi
TX beamforming gain			18 dB
TX channel EIRP	46.5 dBm		59.5 dBm
<b><i>Thermal noise</i></b>			
Bandwidth	10 MHz		7 MHz
Thermal noise (using NF = 5dB & T = 290°K)	-99.0 dBm		-100.5 dBm
<b><i>UWB Interference</i></b>			
Receiver antenna gain	5.0 dBi		6.0 dBi
Other receiver losses	2.0 dB		.0 dB
Max received UWB power	-40.3 dBm		-38.8 dBm
<b><i>Intracell interference</i></b>			
Maximum downlink power	43 dBm		
Intracell IF suppression	75%		
Intracell interference relative to wanted channel	+5.7 dB		
<b><i>Intercell interference</i></b>			
Mean downlink power	39 dBm (at 40% load)		28 dBm
Intercell interference relative to wanted channel (see note 1)	3.3 dB	-0.7 dB	-11.1 dB
<b><i>Required received level</i></b>			
C/I ratio required for most robust channel	-14 dB		0.8 dB
Received signal required	-53.1 dBm	-53.4 dBm	-38.0 dBm
Total system gain (TX/RX antenna gains, cable and connector losses etc)	18.5 dB		37.5 dB
Max path loss for no outage	102.6 dB	102.9 dB	103.5 dB
Max distance for no outage (see note 2)	*116 metres	*118 metres	*122 metres
Note 1: For UTRA TDD based on 40% load in neighbour cells. For WiMAX does not include beamforming gain for intercell interference.			
Note 2: Includes a 10dB allowance for mean in-building attenuation			

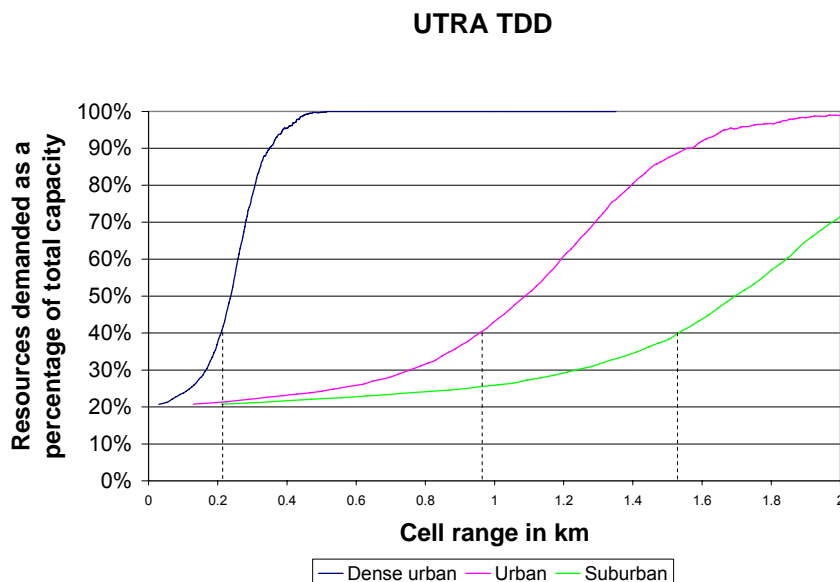


To completely overcome such interference would require a network to be designed according to these small cell ranges. However to have a more balanced view of the impact of UWB we need to understand how often this condition is likely to occur in practice given that much of the time UWB devices will not be transmitting or their signals will be received at lower levels.

## 2.2 Network simulation without UWB interference

Network simulation was performed on the basis of BFWA market forecasts for dense urban, urban and suburban environments in the years 2010, 2015 and 2020. Cell sizes were based on capacity limits in most of these scenarios using the cell range at which the mean busy hour load was 40%. Typical network capacities demanded as a function of cell range are shown in Figure 2.1 for the UTRA TDD system and Figure 2.2 for the WiMAX system.

**Figure 2.1 Plot of demanded capacity versus cell range in 2010 using the high BFWA forecast and UTRA TDD technology.**



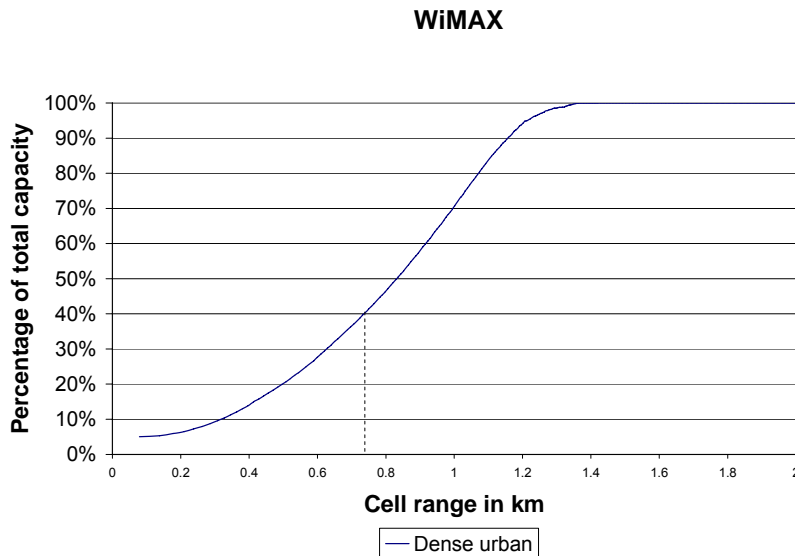
The difference between these curves is due to differing subscriber densities, and therefore the traffic demanded, in each environment. For the suburban environment in Figure 2.1, the forecast of subscriber density is such that the network would encounter range limitations first. Our link budget assumptions result in a maximum range for the UTRA TDD system of 1.2 km in these environments<sup>5</sup>. Therefore any UWB interference related range degradation must be compared to this figure rather than that indicated purely by capacity.

The equivalent range limitation for WiMAX (using indoor antennas) is slightly longer, at 1.4 km. Although the WiMAX system assumed here operates at a lower overall power for equivalent throughput, it benefits from the use of adaptive antenna arrays at the base station and directional antennas at the subscriber terminal.

<sup>5</sup> Maximum range calculations for network planning purposes usually include margins to ensure that typically 90% of subscribers can be provided with service within the planned area. Therefore, these ranges take account of additional assumptions of 10dB for shadow fade margin and 18dB in building penetration loss. For UTRA TDD operation at 50% of the maximum load was assumed (where the maximum load is that which results in a mean 40% of total power being used)..

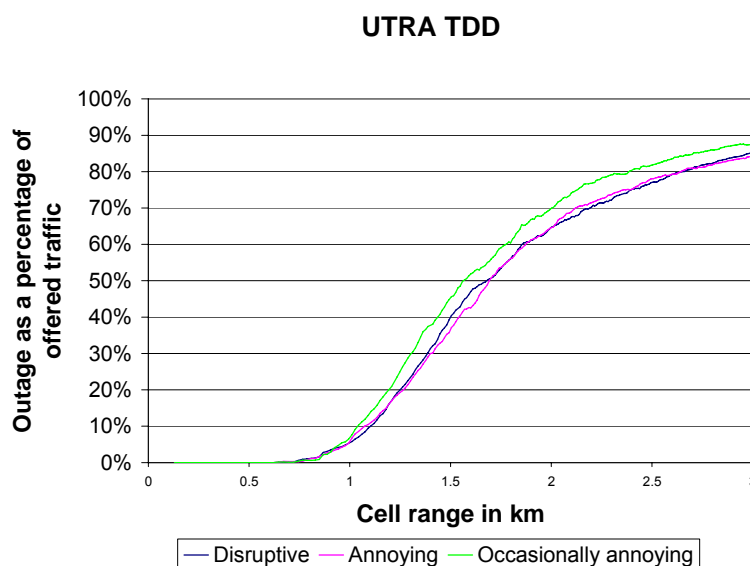


**Figure 2.2 Plot of demanded capacity versus cell range in 2010 using the high BFWA forecast and WiMAX technology.**



It can be seen that with higher BFWA subscriber density (in dense urban areas) the capacity demanded is higher and hence the range is shorter. However, the power is only one of the constraints on the network; the number of codes and timeslots available also limits capacity. Where the instantaneous data volume exceeds the available resources, the admission control function within the network must disallow customer connections. The simulation assumed that delay tolerant applications would be blocked first (occasionally annoying), followed by delay sensitive data (annoying), then finally real-time applications (disruptive). Typical outage is shown in Figure 2.3 without the presence of UWB interference.

**Figure 2.3 Plot of outage experienced by all users versus cell range for the urban environment in 2010, using the high BFWA forecast and UTRA TDD.**



It can be seen from this that outage occurs at a level of around 5% at the cell range corresponding to the 40% network dimensioning rule (i.e. 0.98km). In all our simulations for



the residential subscribers assumed for the UK Broadband network without the presence of UWB interference, we found a similar relationship between the capacity limited cell range and the corresponding levels of outage. For SME subscribers assumed for the Pipex network, we have forecast a lower level of video streaming and this coupled with the higher capacity per cell results in lower levels of outage at the 40% limit. The 5% level of outage for SMEs occurs at a loading of around 92%. In all our results, we have taken the point at which a 5% level of disruptive or annoying outage occurs (whichever is worst).

This level of outage is critical to the performance of a BFWA network. It competes in the broadband market with fixed connections using DSL technology with inherently high reliability and low levels of outage. Furthermore, since the configuration of BFWA connections tend to be slowly changing, outage will tend to be experienced by the same subscribers consistently rather than distributed across the entire subscriber base, as is the case in mobile networks.

We have chosen a 5% limit in outage as an explicit dimensioning guideline for the purposes of comparing maximum cell sizes with and without UWB interference. This has the benefit of being more readily identifiable given the shape of the outage curves. However, we acknowledge that a lower level of outage is likely to be necessary in real networks for customer acceptability.

### **2.3 Network simulation with UWB interference**

In the presence of UWB interference we can expect a number of effects to occur:

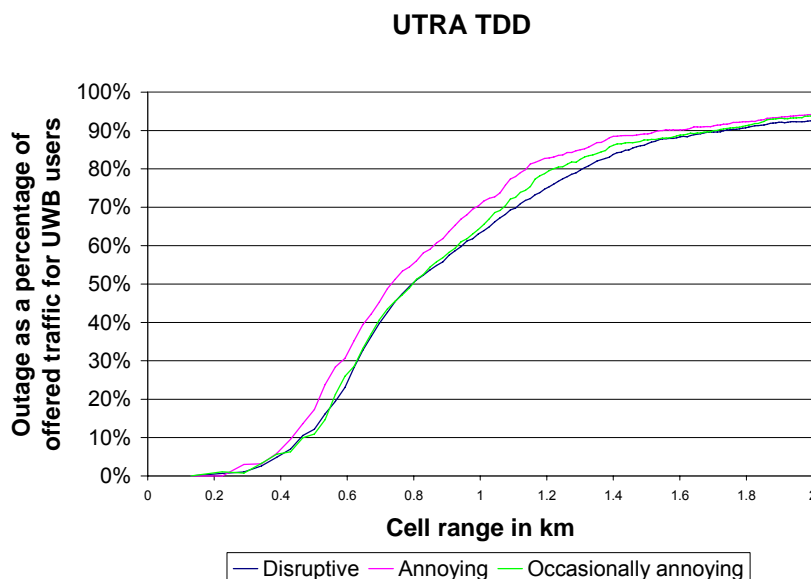
- The additional interference will require UTRA TDD systems to increase power and/or change modulation and coding to maintain the link. This will result in *more* capacity resources being demanded;
- The additional interference will require WiMAX systems to change modulation and coding to maintain the link. This will result in *more* capacity resources being demanded;
- If the modulation and coding scheme required to support the subscriber's instantaneous data rate cannot be supported, then transactions will be blocked and the system will require *less* capacity. However, the levels of outage will increase.

Which of these effects occur depends upon the severity of UWB interference at that instant, therefore the results of the simulation need to show both the total capacity demanded and the levels of outage. The most constraining of these two criteria were taken as the effective maximum cell range in the presence of UWB interference.

In all cases simulated we found that the levels of outage were as shown in Figure 2.4.



**Figure 2.4 Plot of outage experienced by UWB users versus cell range for the urban environment in 2010, using the high BFWA forecast and UTRA TDD (based on the UWB central case).**



In the example shown, the outage statistics are derived for the UWB users only<sup>6</sup>. The remaining BFWA subscribers experience similar performance to the “No UWB” case.

Figure 2.4 shows that the smallest cell range at which outage appears is consistent with the minimum coupling loss analysis. However, Figure 2.4 also shows that the levels of outage rise rapidly from this level as the cell range is increased.

In determining the cell ranges under UWB interference conditions we have used the more constraining of “Disruptive” or “Annoying” outage as the criteria for determining the cell range; with the actual cell range being that where the limit of 5% is not exceeded.

## **2.4 Conclusions from UWB interference modelling**

Our conclusions on UWB interference modelling can be summarised as follows:

- UWB interference is substantial compared to the received signal powers associated with BFWA access systems. Without mitigation, it renders BFWA signals unusable for those subscribers that are also UWB users;
- The primary impact on BFWA networks is not on the capacity required, but rather on the outage experienced by BFWA subscribers;
- The impact on a BFWA network is most pronounced when a network is lightly loaded (either in early years of network operation or in the more lightly loaded urban and suburban areas). In congested areas the cell ranges are naturally shorter due to higher capacity demands.

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<sup>6</sup> The simulation assumed that the call admission algorithm would tend to block users having the highest power requirements, hence the statistics tend to show the outage being absorbed by UWB users. In practice, if the communications link to the UWB users is established first then it may result in a subsequent non-UWB user being blocked. Monte Carlo simulation does not provide information on the time sequencing of events therefore we do not know the extent of this impact. However, internalising the impact to UWB users provides the most intuitive view of performance.

### 3 Potential technical mitigation measures

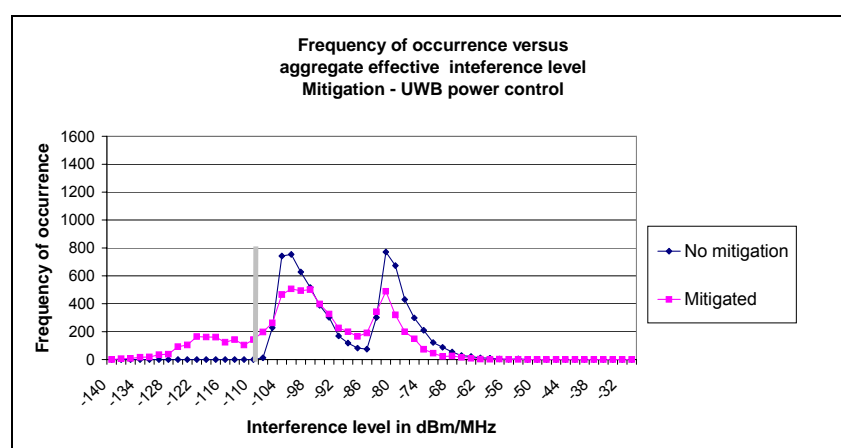
It is clearly of interest to determine if any mitigation measures would be capable of overcoming or at least significantly reducing the impact of UWB interference. The distribution of UWB signals (discussed in section 1.2) provides a useful way of visualising the impact of mitigation measures, and showed that UWB interference levels would need to be reduced by up to 50dB to ensure that the impact was minimal. This clearly rules out a reduction in the permitted level of UWB emissions but other measures can go a good way in this direction. The measures we have considered are

- UWB power control
- Switching off UWB devices close to the primary PC
- Capping the duty cycle of UWB devices
- Switching UWB devices to higher frequencies.

#### 3.1 UWB power control

The UWB protocol allows for control of the transmitted power level. The essence of the UWB protocol, however, is to transmit at its maximum rate wherever possible. The radiated power level will therefore only be reduced in those instances where two UWB devices are in close proximity, of the order of 3m or less. Since UWB devices will often be further apart than this, and anyway may be closer to the BFWA terminal, the effect on interference levels at the BFWA antenna is small. This small impact was born out in simulation, where the implementation of power control was found to have very little impact on the outage levels. This is illustrated in Figure 3.1.

**Figure 3.1: The reduction in UWB interference levels with UWB power control. The example shown is for the Office environment in 2010. The vertical line is the WiMAX system noise floor of -109 dBm/MHz.**



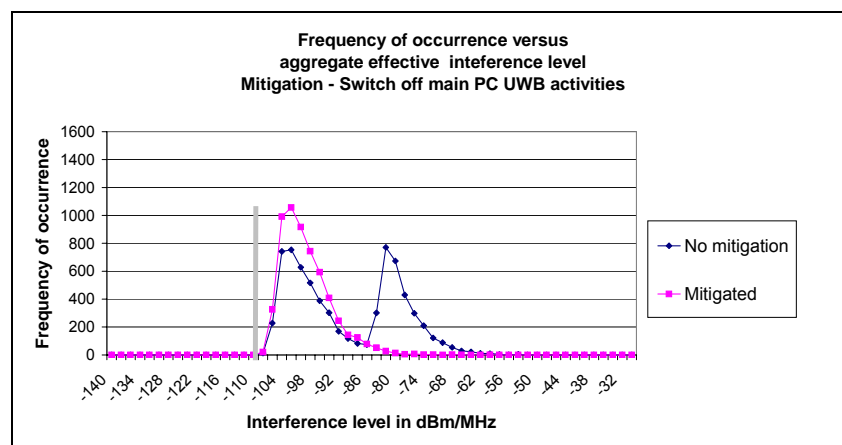


### 3.2 Switching off UWB devices close to the primary PC

Certain PC peripherals will be associated with the primary PC (keyboards, mice and wireless monitors in particular) and therefore potentially close to the BFWA antenna. We therefore examined the interference levels on the assumption that UWB transmissions between the primary PC and these peripherals could be avoided whenever a BFWA signal was being received (either through the PC automatically restricting communication to periods when it was not receiving over the BFWA link, or by simply not using UWB devices with these peripherals).

As shown in Figure 3.2, this provides a greater reduction in noise levels and reduces the number of interfering events, with the first interference peak almost disappearing. However, it still leaves interference up to 20 dB above the system noise floor and could still cause significant interference to some subscribers.

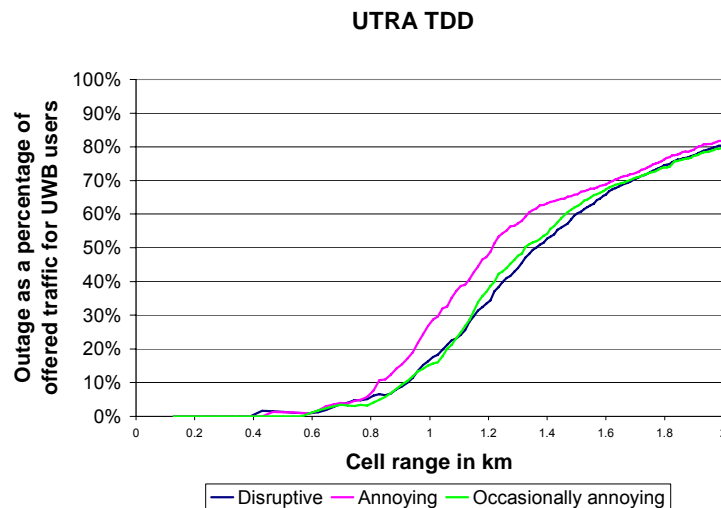
**Figure 3.2: Switching off UWB peripherals closely associated with the PC results in the first peak of interference being removed, but interference levels still extend up to 20 dB above the system noise floor.**



The overall impact on the level of outage is shown in Figure 3.3.



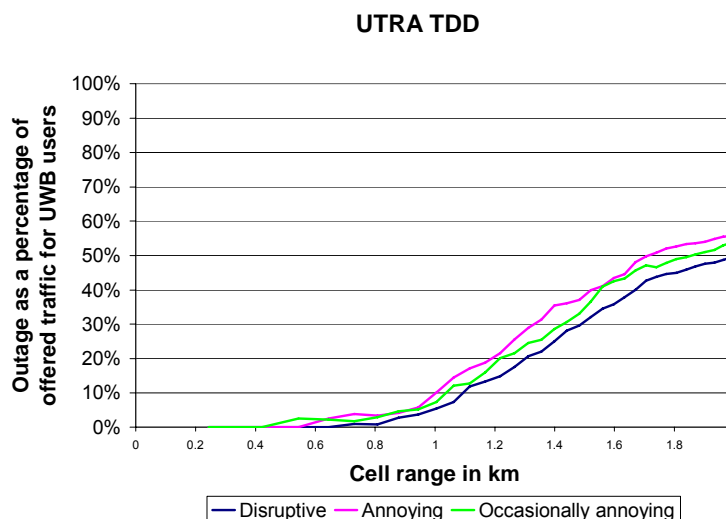
**Figure 3.3: The outage resulting from switching off those UWB peripherals closely associated with the primary PC (based on urban environment in 2010, high BFWA market forecast and central UWB market forecast).**



The outage indicated in Figure 3.3 shows a great improvement in performance compared to the unmitigated UWB interference (see Figure 2.4). It shows a cell range of 0.64 km compared to the 0.34 km achievable without mitigation. However, it is still well short of the 0.98 km range without UWB interference.

Using the moderate BFWA forecast the impact on outage is as shown in Figure 3.4.

**Figure 3.4: The outage resulting from switching off those UWB peripherals closely associated with the primary PC (based on urban environment in 2010, moderate BFWA market forecast and central UWB market forecast).**



In this case the technique is slightly more successful, achieving a cell range of 0.88 km (compared to 1.2 km without UWB interference). Similar simulations were performed using the UWB high case which showed that under the high BFWA market forecast a cell range of 0.39 km could be achieved, and under the moderate BFWA market forecast a cell range of



0.54 km. Clearly, the technique will not provide complete protection for BFWA networks under all market scenarios. Nevertheless, the analysis does show that it has some potential, perhaps in combination with other mitigation techniques.

Although the majority of damaging interference is reduced using this technique there are still a significant number of occasions when the outage occurs even with small cell ranges. This is due to the remaining UWB devices not associated with the primary PC occasionally coming close to the BFWA antenna.

Extending this measure to all peripherals which communicate via UWB with a PC would reduce the level of interference to negligible proportions (though not shown here the second peak is reduced to a few events centred on  $-100$  dBm/MHz). Whilst this measure would be effective, it would need a universal and reliable means of turning UWB devices off whenever the BFWA terminal was active. This is discussed later, see section 3.4. However, it would also negate many of the expected uses of UWB and reduce the associated benefits.

### 3.3 Capping the duty cycle

It has been suggested that capping the duty cycle of individual UWB devices would reduce the likelihood that a UWB transmission overlaps with BFWA signal reception. This is similar to putting a cap on the maximum rate<sup>7</sup> at which data could be transferred over a UWB link (but still allowing individual UWB frames to be transmitted at the maximum rate).

Simply capping the duty cycle at, say 5%, would not be an adequate measure. The example in Figure 1.6 shows how a brief but rapidly repeated UWB signal will have a high probability of overlapping with a BFWA signal, indeed the probability of the two overlapping in this case is dominated by the proportion of the BFWA frame occupied by the wanted BFWA signal. Noting that a BFWA subscriber towards the edge of a cell and requiring a higher bandwidth service would occupy a significant proportion of a BFWA frame, it is clear that the UWB transmissions would need to be spaced several BFWA frames apart. And, in order to give the BFWA system the maximum chance to recover from any frame outage, it would be necessary to limit the duration of any contiguous UWB transmission to less than the duration of a BFWA frame.

Frame durations with UTRA TDD are 10ms, and are variable between 2.5 and 20ms in the case of WiMAX. This suggests that to reduce the probability of overlapping signals by a factor of 20 the repetition rate for UWB should be limited to about once every 200ms, and the duration of each transmission capped at a few milliseconds, say 5ms. The impact on UWB would be significant, reducing the maximum throughput by a factor of 40. In the case of MB-OFDM, this would limit throughput to around 10 Mbits/s and impose latencies of the order of 200ms.

Furthermore, although the probability of overlap in any one BFWA frame is reduced, the UWB transmissions are spread out over commensurately longer time to transfer the required data volume. As a result the overall probability of a collision with a BFWA signal is little changed over a period of time.

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<sup>7</sup> Another suggestion is that video transmissions only be permitted if compressed video is used. This is similar to restricting the maximum throughput but is harder to enforce.

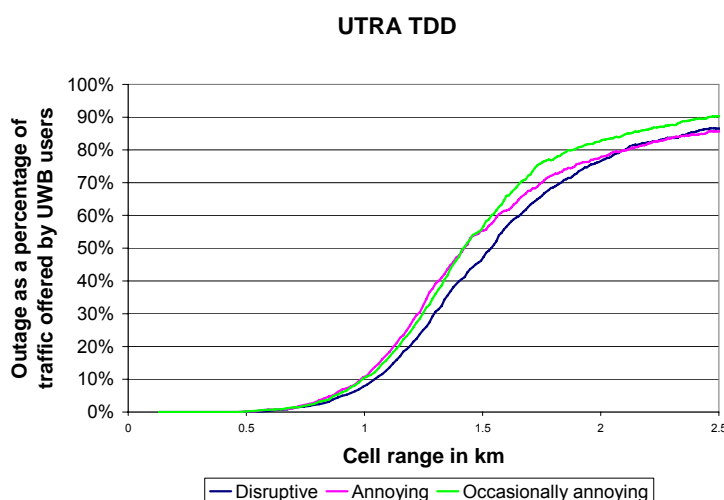
### 3.4 Switching UWB devices to higher frequencies

In its response to Ofcom's recent consultation on UWB, Intel suggested that UWB devices could detect BFWA activity. When a nearby terminal was determined to be active, the UWB device would for a period of time place a notch in its transmission band to protect the BFWA frequencies in use. It has also been suggested that an MB-OFDM device could alternatively restrict its transmissions to its Band 3 (4.2 to 4.7 GHz). DS-UWB can also insert small notches into its spectrum but we are not aware of any formal comment on this proposition by the DS-UWB proponents. Should notching be impractical, DS-UWB would need to switch its transmissions to the band above 6 GHz or simply postpone transmissions until BFWA activity was determined to have ceased.

Assuming for the moment that BFWA activity could be reliably detected, UWB devices would switch out of the bands occupied by UK Broadband and Pipex when a nearby BFWA terminal was active but their out of band emissions would still be received by the BFWA terminal. In the case of MB-OFDM the level of attenuation within a 50 MHz wide notch would be ~20dB<sup>8</sup>, and out of band emissions from devices operating in Band 3 would be expected to be at a similar level. If DS-UWB devices have to switch to the band above 6 GHz their out of band emissions would be expected to be attenuated by 30dB+. We have also considered a case where additional filtering is introduced to achieve 40dB of attenuation.

The reduction in outage that can be expected with 20dB, 30dB and 40dB of attenuation to UWB interference is illustrated in Figure 3.5, Figure 3.6 and Figure 3.7 respectively.

**Figure 3.5: A representative example of the reduction in outage when UWB interference is reduced by 20dB (based on UTRA TDD in the urban environment in 2010, for the high BFWA forecast and UWB central case).**



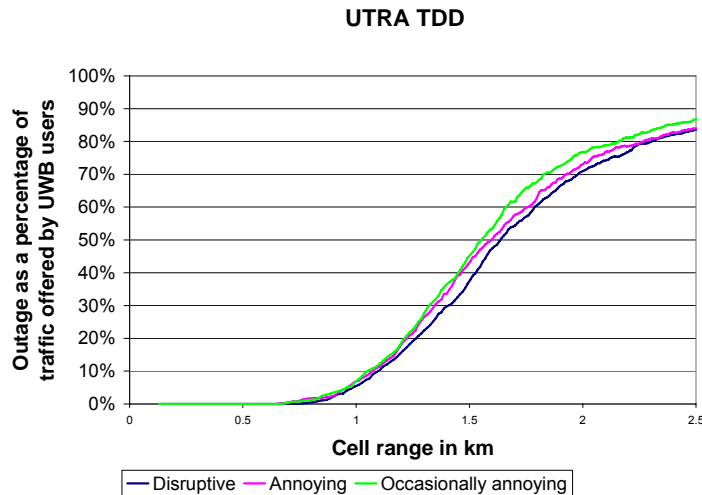
Comparing the range indicated in Figure 3.5 at 0.85 km with the 0.34 km achievable with the unmitigated levels of UWB interference, we can see that performance is much improved.

<sup>8</sup> Intel response to Ofcom UWB consultation, Annex 1, March 2005.



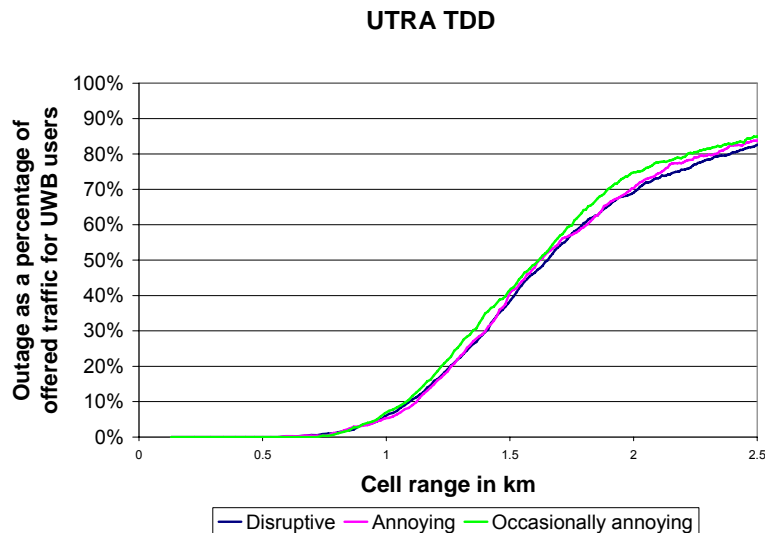
However it still results in a reduction in cell range of 13% (from 0.98 km), which translates to roughly 32% extra sites to cover the same area in this example.

**Figure 3.6: A representative example of the reduction in outage when UWB interference is reduced by 30dB (based on UTRA TDD in the urban environment in 2010, for the high BFWA forecast and UWB central case).**



Increasing the effective attenuation to 30dB improves the situation further to a cell range of 0.96 km which is a 2% reduction in range. This will result in around 4% extra sites to cover the same area in this example.

**Figure 3.7: A representative example of the reduction in outage when UWB interference is reduced by 40dB (based on UTRA TDD in the urban environment in 2010, for the high BFWA forecast and UWB central case).**

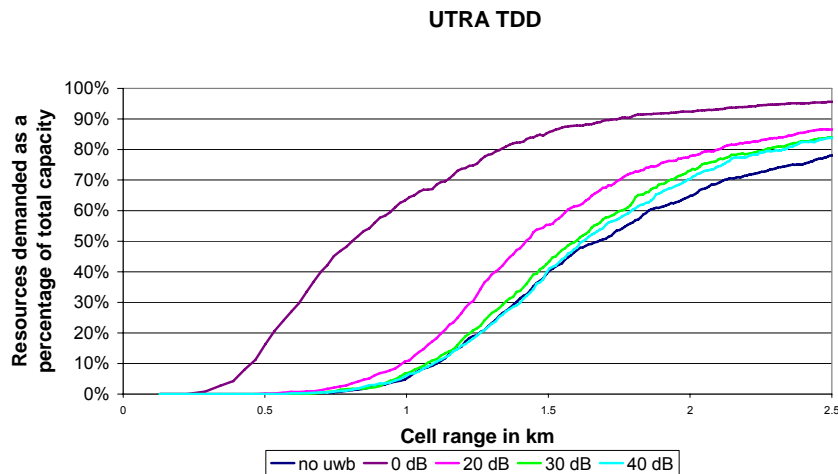


Increasing the effective attenuation to 40 dB increases the cell range to 0.98 km which is the same as the case with no UWB interference. No extra sites would be required in this example.



To aid comparison the above examples are also shown on the same chart where the outage is taken as the worst level of either the disruptive or annoying degradation. This is shown in Figure 3.8.

**Figure 3.8: A representative example of the reduction in outage resulting from various reductions in UWB interference (based on UTRA TDD in the urban environment in 2010, for the high BFWA forecast and UWB central case).**



The above figures show that there is benefit from applying attenuation to the emission mask, but that it is difficult to fully mitigate the UWB interference. Although in the example above 40dB was sufficient to reduce the outage to levels comparable to the no UWB interference case, in other environments and reference years there was still a residual impact on network cost. The analysis suggests that applying a 40dB attenuation to the emission mask would result in UWB interference having a residual impact of around 4% of sites cost for the high BFWA forecast and 1% for the moderate BFWA forecast.

Of course, the effectiveness of this mitigation measure is dependent on the ability of UWB devices to avoid transmitting when the nearby BFWA terminal is active. In this regard the following points may be noted:

- It is proposed<sup>9</sup> that a UWB device could detect signal levels as low as  $-74\text{dBm}$  with reliability of 99%;
- Since it is the uplink BFWA transmissions that would be detected, lack of a signal would not guarantee that the terminal was not in fact receiving a signal (in the case of TDD the terminal will never be receiving when its own transmissions are detected);
- Due to the random nature of BFWA traffic, a BFWA down link signal could commence immediately after a UWB device had determined that there was no current activity. Thus it will be necessary for the UWB device to check for BFWA activity frequently once it has commenced a transmission;
- It will be necessary to carefully select and test the mitigation rules, and to ensure that they are workable with a range of technologies, both FDD and TDD. Issues such as the hidden terminal problem will need to be considered.

<sup>9</sup> Philips International response to Ofcom UWB consultation, March 2005.



Clearly, the mitigation rules will not be foolproof, and for this reason the improvement in outage shown in Figure 3.5 to Figure 3.8 will be overstated to some extent.

There would also be dis-benefits to UWB. Firstly, there would be some additional complexity and cost to UWB devices. In addition, notching out part of the band and especially restricting transmissions to greater than 4.2 GHz would reduce the throughput achievable during periods when there was local BFWA activity. Commercial UWB products operating above 6 GHz are expected to be some years behind devices in the lower band. Thus, if adequate notching was not practical with DS-UWB, these devices would have to cease transmission for the duration of BFWA activity, effectively resulting in reduced overall throughput.

### **3.5 Conclusion on mitigation methods**

Our conclusions on mitigation methods can be summarised as follows:

- The use of power control and capping of duty cycles are not effective means of mitigating UWB interference;
- Inhibiting UWB applications that are associated with the primary PC has potential to substantially reduce the levels of UWB interference however, there is still a significant residual impact on BFWA performance. This option relies on an effective means of detecting BFWA activity;
- Switching UWB devices to higher frequency bands either as a complete regulatory measure or in response to detection of BFWA activity has potential to reduce the outage substantially. However, a reduction by the readily achievable 20 or 30dB still results in a significant residual interference impact on BFWA networks.
- The simulation shows that by attenuating UWB emissions by 40dB, the interference impact can be reduced to around 4% of network site costs for the high BFWA market forecast and around 1% of network site costs for the moderate BFWA market forecast. Attenuation by 50dB appears to remove all effects of UWB interference.