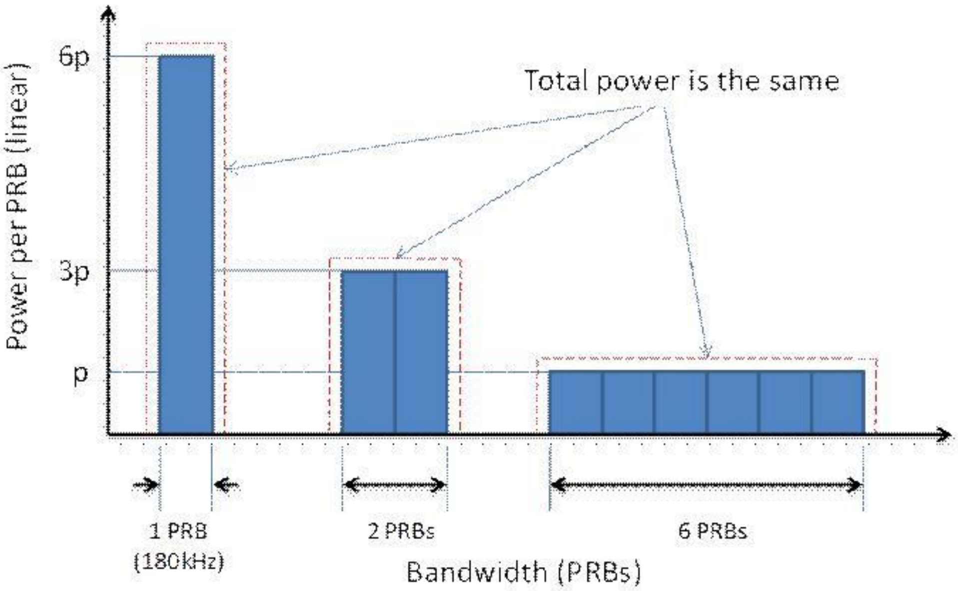
Dynamics of 3GPP LTE uplink: 800 MHz DTT and LTE coexistence



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Real Wireless is a leading independent wireless consultancy, based in the U.K. and working internationally for enterprises, vendors, operators and regulators – indeed any organization which is serious about getting the best from wireless to the benefit of their business.

We seek to demystify wireless and help our customers get the best from it, by understanding their business needs and using our deep knowledge of wireless to create an effective wireless strategy, implementation plan and management process.

We are experts in radio propagation, international spectrum regulation, wireless infrastructures, and much more besides. We have experience working at senior levels in vendors, operators, regulators and academia.

We have specific experience in LTE, UMTS, HSPA, Wi-Fi, WiMAX, DAB, DTT, GSM, TETRA – and many more.

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Executive summary

This report summarises a study conducted by Real Wireless on behalf of Ofcom, to investigate the potential interference impact from LTE uplink user devices operating at the frequency band of 832-862 MHz to Digital Terrestrial Television (DTT) receivers operating below 790 MHz. The main aim of this study is to seek a better understanding of technical issues that could potentially lead to significant interference to wanted DTT signals. The study leads to the following findings:

- Protection ratio tests on DTT receivers are often performed using signal sources with continuous power. Whilst this may be appropriate to emulate the effects of noise-like WDCMA transmissions, our analysis of LTE uplink shows that there are likely to be significant and rapid variations in the interference power towards DTT. It is therefore recommended that DTT protection should be evaluated with time varying signals representative of the LTE uplink, in addition to continuous power sources.
- Temporal variations in DTT interference arise from the LTE uplink power control mechanism which compensates for path loss variations on the UE (user equipment) to base station link. Since that fading is independent of those on the interference path from UE to DTT receiver, the interference power will have wider variations than the fast fading itself.
- Another source of variation results from LTE's ability to schedule UE transmissions in a subset of frequencies within the overall channel bandwidth. It is shown that out of band spectral emissions can vary significantly depending on the number and position of spectral resources on which the UE is assigned to transmit. Furthermore, the uplink control channel is found to hop between positions at the lower and upper channel edge every millisecond. This confirms that rapid changes in LTE out of band emissions are likely to occur frequently in practice.
- An analysis of coupling loss between an LTE UE and a DTT receiver's antenna provides the carrier-to-interference ratio (C/I) as a function of separation distance. This is performed for set top and rooftop DTT antenna scenarios, and for DTT signal powers representative of weak, medium and strong reception areas. These are then combined with 'conductive' (cabled) measurements of protection ratios for a number of DTT receiver types, to predict the DTT-LTE UE separation that would be needed in practice to prevent excessive degradation to the TV picture.
- 'Can' receiver types are found to co-exist in close proximity of an LTE UE transmitting on the uplink, even in weak DTT signal areas. A worst case of 2.5m UE-DTT receiver separation is needed for the set top case in a weak DTT signal area. For other scenarios, separations of less than 1m are found to be acceptable.
- 'Silicon' receiver types generally require greater separations from LTE UEs, which are greater than 10m in the weak DTT signal areas.
- 'Conducted' tests using discontinuous transmission of LTE UE interference require higher protection ratios and hence a higher minimum separation distance than those with continuous power. For both continuous and discontinuous LTE interference transmission, DTT receivers with set top antennas required greater separation from LTE UEs than DTT receivers with roof top antennas.
- Finally, the predicted distances are compared with results from 'radiated' measurements, where LTE UEs are moved towards DTT receivers until the TV picture quality is no longer acceptable. In general we find that distances measured in radiated tests are higher than that predicted by combining conducted protection ratio

measurements with the minimum coupling loss analysis. This is because we the predicted distances are based on a conservative view of the separations needed. A worst case is assumed where the path of LTE interference is not obstructed. In practice walls and other obstructions would help reduce interference. In such cases, LTE UEs will be able to coexist in closer proximity to DTT than the predicted distances might suggest.

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1. Introduction

Ofcom intends to free up 60MHz of spectrum, currently used by analogue terrestrial TV transmission, by switching to digital terrestrial TV (DTT) transmission. This will allow these frequencies to be made available for mobile broadband communications using LTE technologies. Ofcom has previously conducted studies related to the impact of LTE downlink transmission operating at 791 MHz and above, on DTT reception operating on frequencies below 790 MHz [1]. The aim of this project is to research into the interference effects of LTE uplink transmissions from mobile devices on DTT receiver performance. This has been achieved by means of analyses of existing studies of LTE uplink interference to DTT receivers, and consideration of measurement data such as those in [2].

1.1 Problem statement

The purpose of the study is to address the following question:

1) Is there potentially a significant interference issue between LTE UE transmission and DTT reception in 800 MHz?

Subsidiary questions in answering (1) are:

> (1a) Is the protection ratio significantly impacted by the time and frequency structure of the LTE UE transmissions relative to the same average power from a base station transmission?
>
> and
>
> (1b) Is there enough measurement data under credible conditions to answer (1)?
>
> (1c) If not, what should be done to obtain appropriate measurement data?
>
> (1d) Given an understanding of the required protection ratios, do these lead to concern under a plausible range of operating scenarios (e.g. UE-TV separations, DTT and mobile network topologies etc.)?

To address these questions, the study is structured as follows:

a) Considering the question of how LTE terminals behave in the context of time-discontinuity
b) Considering the question of how measured protection ratios (PR) should be used in analysis (e.g. minimum coupling loss analysis) in the context of LTE terminals with discontinuous transmission
c) Comparison of theoretical analysis with protection-ratio measurements
d) A survey of any other studies which may have been performed

1.2 Real Wireless' view on the LTE uplink and interference to DTT

The list below summarises key aspects of LTE uplink transmissions which distinguish it from downlink transmissions

- The entire transmit power allowance (23dBm) may be concentrated into a single 180 kHz resource block for cell edge UEs, resulting in high power spectral density.
- The uplink is power controlled, resulting in significant and rapid variations in device transmit power. The range may be tens of decibels, and adjustments are roughly every millisecond, with the actual rate and dynamic range depending on the channel conditions, and
- All of the above depends on the actual data the mobile has to transmit and the way the base station chooses to schedule the transmission of that data across time and frequency.

2. Dynamics of LTE Uplink Signals Impact Protection Ratios

The DTT receiver may experience interference signals with rapid temporal variations from one or more LTE UEs. There are several aspects of interfering signals that could potentially lead to higher protection ratio requirements for DTT receivers, as described in the following sections.

2.1 Link budget:

Figure 1 shows potential interference scenarios for LTE UEs into DTT receivers. UEs can be placed very near to DTT antennas or receivers and so minimum coupling loss is much lower than from LTE DL interference coming from base stations. Depending upon the DTT receiver types used, this requires different minimum separation between the receiver and LTE UE to ensure protection.

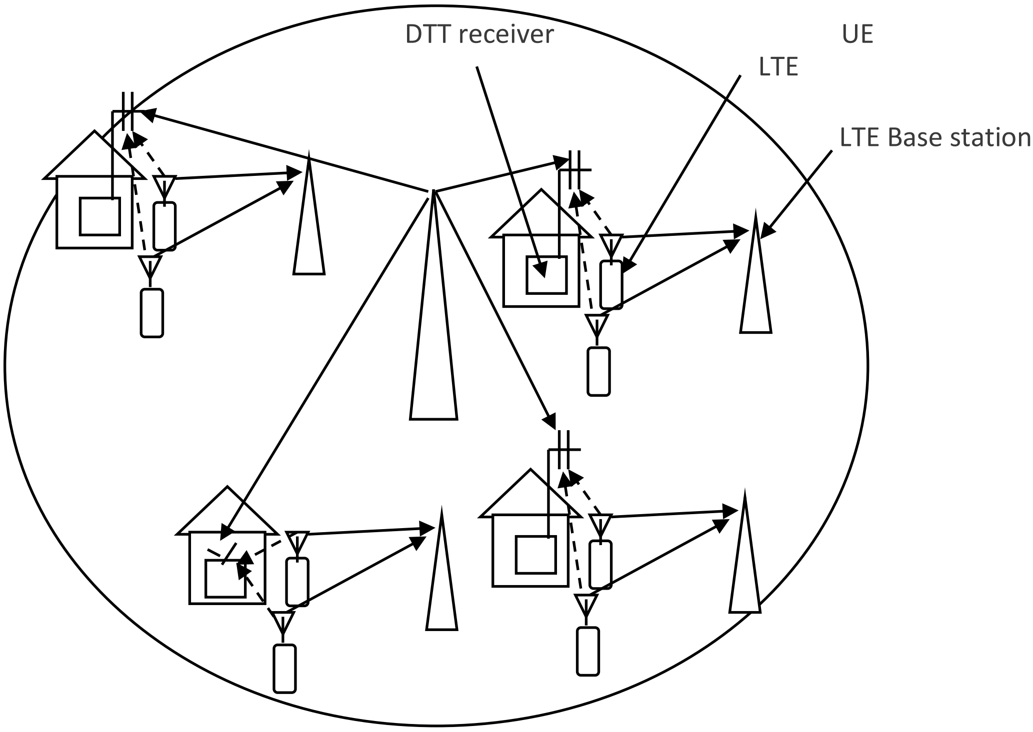

Figure 1: A scenario of LTE uplink UE interference to DTT

2.2 The dynamic range of each user's signal can vary significantly:

In the case of interfering signals travelling in a non-line-of-sight environment, the signals typically follow the Rayleigh amplitude distribution due to the effect of multipath. This leads to a fading problem, whereby there is an occasional power increase of the received signal by a factor of some 5-10 dB compared with the mean power[3].

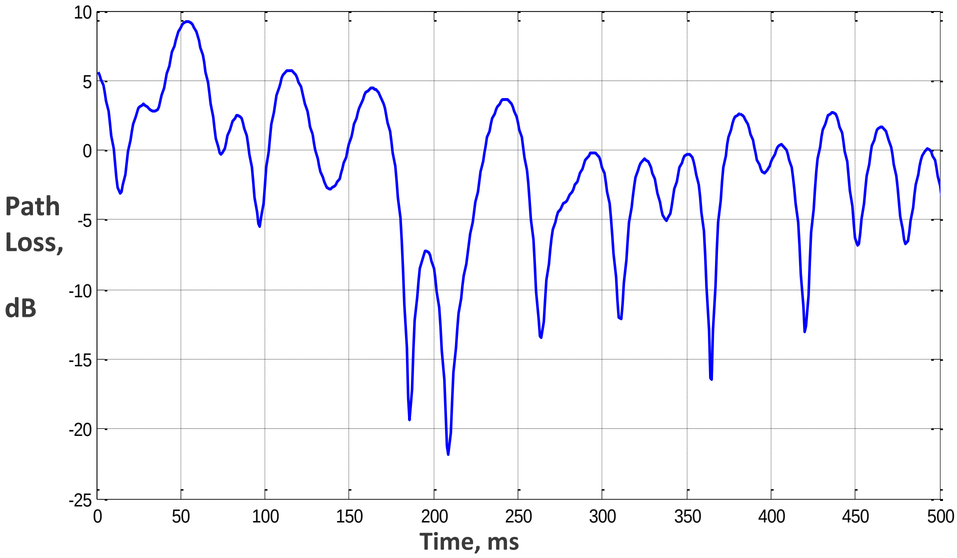

Figure 2: Example of time domain multipath fading channel profile of a UE, 800 MHz, 10km/h. Source: Real Wireless

An example of time domain variation of the UE received signal $r(t)$ is shown in Figure 2. The dynamic range DR, of a received signal can be expressed as:

$$DR = max\{r(t)\} - min\{r(t)\}$$

Figure 2 shows as an example that dynamic range of the path loss can vary by around 30-35dB. There are many instances where the power increases to around 5-10 dB above the mean power. This implies that an additional protection ratio of 5-10 dB may be needed, compared with a 'static' Gaussian-only channel environment. This variation of power is usually applied when transmit and receive devices are not within line–of-sight (i.e. there is no dominant 'direct path' component), so that the channel becomes Rayleigh faded. In such cases, when two devices are more than half the wavelength $\lambda/2$ apart, for their amplitudes to become fully uncorrelated [3], where λ is about 0.37 m for 800 MHz.

When there is a dominant multipath component (normally a Line-of-Sight or LOS), we can have Rician fading, which is less severe than Rayleigh, depending on how dominant the LOS component actually is. Thus Rayleigh can be considered as one extreme case of Rician, where the dominant component has become vanishingly small. So, in application to this situation: Where interfering UL UEs have a LOS to the DTT receiver (in the set top antenna case), up fades are likely to be smaller than the 5-10dB previously suggested. In the roof top case, there is less likely to be an LOS path from UE to DTT antenna, so Rayleigh upfades are more likely.

2.3 The whole of the 23 dBm max power could be transmitted in a single 180 kHz block:

In the uplink of LTE, UE devices can be allocated different amounts of bandwidth for the same maximum EIRP. When a UE device is near the cell edge, it may be scheduled to use all the available power over the minimum bandwidth, so as to maximise the link performance. When nearer the base station, the total UE power can be distributed over a wider bandwidth as shown in Figure 3.

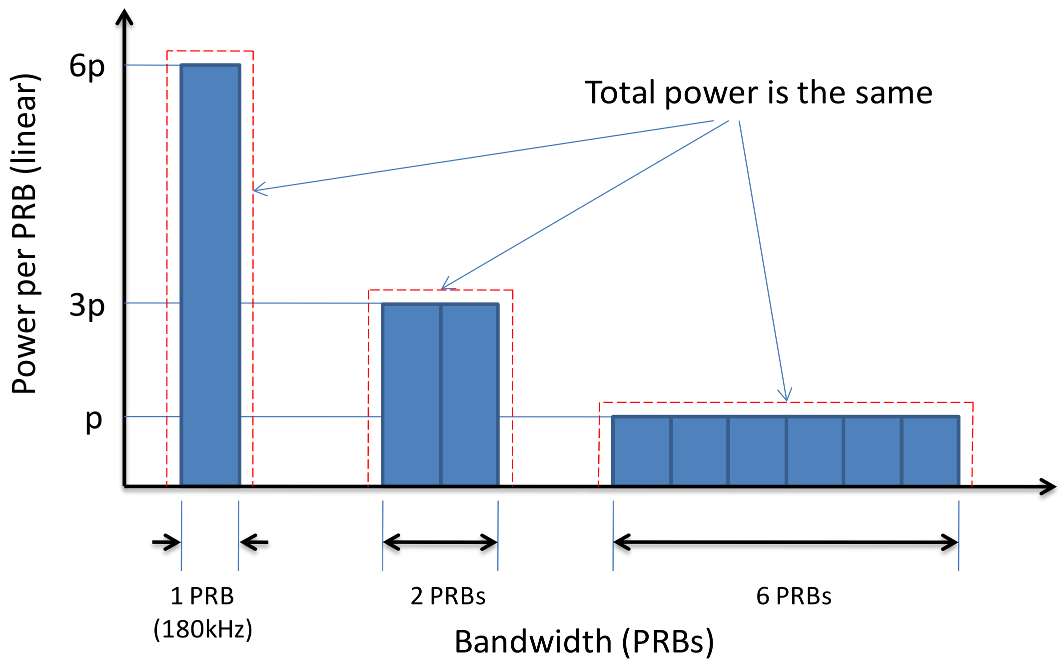

Figure 3: Power spectral density variation of LTE UE, Source: Real Wireless

Figure 4 extracted from [4] shows spectral emissions for different resource allocations for a UE transmitting 24dBm (slightly higher than the 23dBm specified in the 3GPP standard). We see in general that the full 25RB (Resource Block) allocation is the worst case. However the 1RB allocation does create an emissions spike which at one point exceeds the 25RB allocation case. An overlay of the (then) proposed LTE Spectral Emissions Mask (SEM) that the spike is beyond the acceptable level. [4] proposed that exceptions to the mask could be allowed for bandwidth less than 2-3 RBs.

These plots show that changing the position and amount of RBs allocated to a UE could result in significant variations in the emissions into adjacent bands. Such changes are a likely result of dynamic scheduling between multiple users.

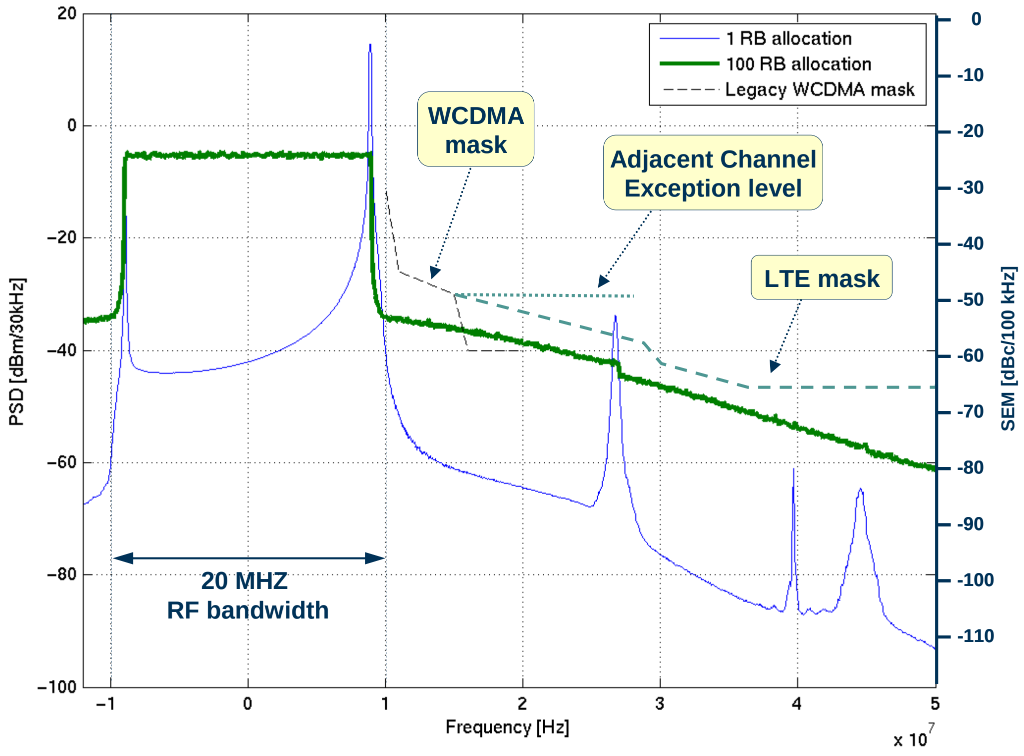

Figure 4: Emission mask of LTE UE (20 MHz bandwidth) Source: Ericsson [**Error! Bookmark not defined.**]

2.4 Control channels are frequently transmitted and alternate between the top and bottom of the channel bandwidth:

Connected (Active mode) UEs need to continuously feedback control information to the base station over the physical uplink control channel (PUCCH). When there is no uplink data transmission scheduled, the PUCCH is transmitted on alternate 0.5ms slots at the upper and lower extremities of the channel bandwidth, as illustrated in Figure 5. These are similar to the 1RB allocations at the band edge illustrated in Figure 4. When there is uplink data to transmit, the control information is piggybacked on to the transmission. This rapid frequency hopping behaviour may result in rapid variations in interference power seen by the DTT receiver in an adjacent band.

Figure 5 shows a resource grid in the uplink of LTE where PUCCH transmission alternates between the top and bottom frequencies. So even when UE has no data to transmit, the UEs will be transmitting the control signals such as ACK/NACK, CQI and rank over the PUCCH [4].

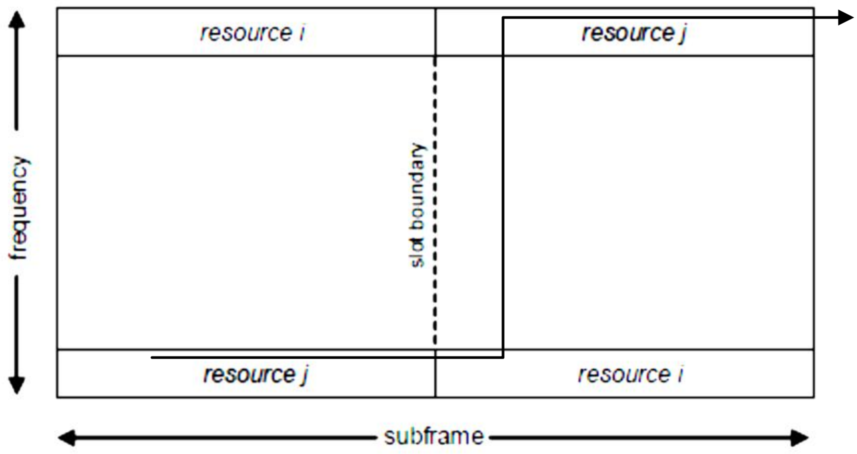

Figure 5: Resource blocks structure of LTE uplink. Source: Freescale[[5]

2.5 Uplink power control can result in significant variations in interference power to DTT:

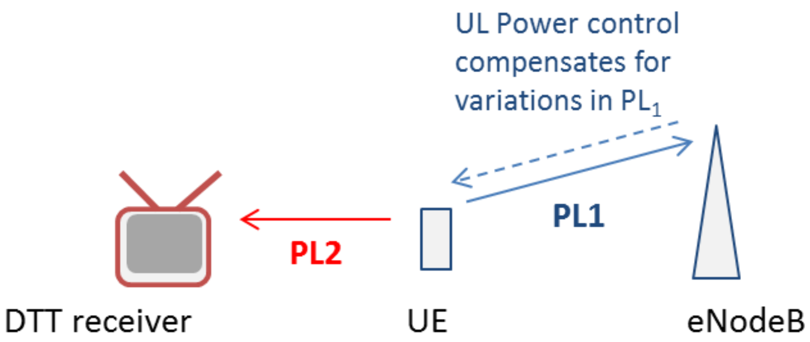

Figure 6: Impact of uplink power control on interference scenario

Figure 6: Impact of uplink power control on interference scenario

6 illustrates a typical uplink interference scenario. The uplink of LTE requires UE devices to monitor path loss (PL1) continuously and update this information via control channels. The base station then controls the UE's transmit power to mitigate any fading on the channel. The power transmitted by the UE is effectively the inverse of the path loss PL1, as illustrated in Figure 7. The UE power therefore varies significantly when there is fading on PL1. Since multipath fading on PL1 and PL2 are independent, the power received at the DTT receiver may experience very wide variations: The combination of a down fade on PL1 and an upfade on PL2 could result in a high level of interference power to the DTT receiver. This may require a much higher protection ratio for DTT receivers. However, 3GPP specifications for uplink power control do not allow the UE device to transmit more than 23 dBm, so truncation of transmission power occurs when the device is experiencing extreme fading [6].

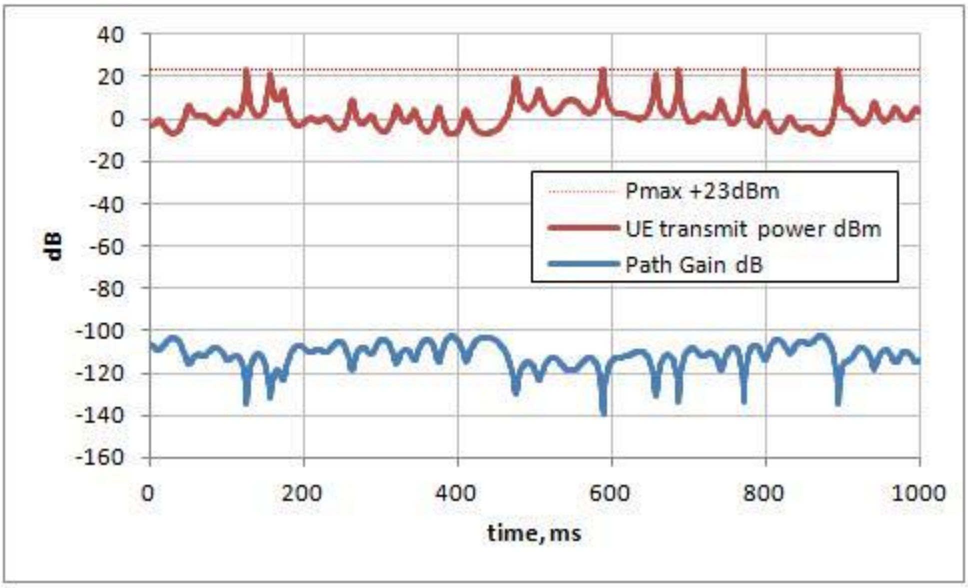

Figure 7: Transmitted power from LTE UE devices against channel fading

2.6 Time and frequency domain dynamics due to scheduling of LTE UEs' transmissions:

Depending on the link quality and interference experienced for each LTE UE, the base-station allocates resources for each UE by hopping from one frequency to another. This is done to minimize the impact of narrowband interferers and to improve the link throughput as shown in Figure 8. This dynamic nature of uplink LTE UEs can potentially affect DTT receivers in two ways:

- **Time domain:** The aggregation of interference power from multiple LTE UEs could impact the frontend of the DTT receiver.
- **Frequency domain:** The spectral emission of non-contiguous transmission of resource blocks from LTE UE devices may lead to greater range of spurious emission.

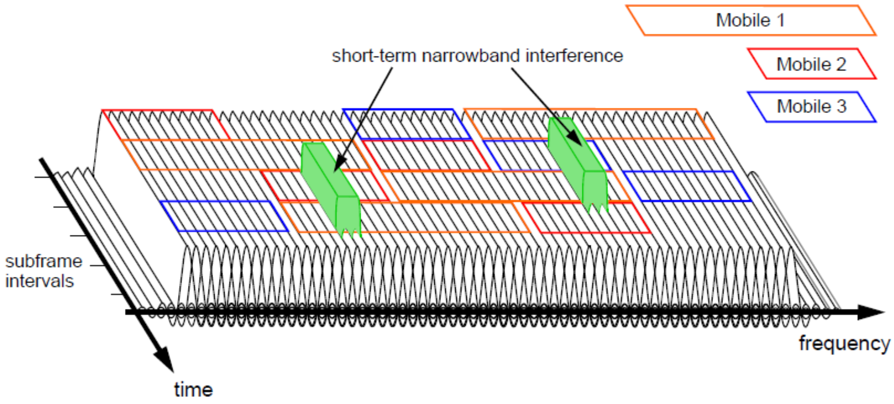

Figure 8: Time and frequency domain scheduling of resources for UEs in LTE uplink [7]

2.7 Summary of Dynamics

Several mechanisms have been identified which show that interference from LTE uplink transmissions incident to the DTT receiver may have significant and rapid power variations.

In the MCL analysis in the following section, we assume a worst case LTE UL allocation with all UE power concentrated into a single 180kHz resource block at the channel edge. We assume a free space propagation model, and so do not consider the impact of power control and independent fading on the interference path.

Signal dynamics may in addition have more subtle impacts to the DTT receiver, such as confusing an AGC (Automatic Gain Control). It is therefore recommended to supplement the protection ratio analysis with measured results.

3. Minimum coupling loss analysis

Here we consider protection ratio (dB) vs. protection distance (m). The following parameters are used in the analysis:

- DTT antenna locations:
  - a) fixed roof-top DTT antenna(at a 10m height),
  - b) set-top DTT antenna.
- DTT coverage: good, medium, poor (wanted DTT power at aerial output of -70, -50, -20 dBm).
- DTT roof-top aerial horizontally polarised, 9.15 dBi gain, with angular discrimination according to the ITU reference pattern.
- DTT set-top aerial, 2.15 dBi gain

The two scenarios of LTE uplink interference to fixed rooftop and set top DTT receivers are shown in Figure 9 and 10 respectively. We evaluate the LTE UL interference power as a function of horizontal separation between the DTT antenna and LTE UE. We then use this to plot the C/I vs separation that would be achieved in poor, medium and good DTT coverage areas. For the purpose of this analysis we assume a worst case path loss model to give the highest possible level of interference, and a conservative C/I estimate. Free space path loss is assumed, and there is assumed to be no additional loss for walls or other path obstructions. In practice, additional loss on the interfering link would improve C/I for the DTT signal. Link budget calculations along with a list of parameters and assumptions used for the MCL analysis are shown in Table 1. The table outputs achievable protection ratio for the given input of distance separation between DTT receiver and LTE UE interferer for various parameter settings.

The height of the UE is assumed 1.5 m, and the roof top antenna is at 10m height. Figure 11 shows the elevation pattern for the rooftop antenna, which is taken from the ITU[**Error! Bookmark not defined.**]. As a worst case, the interfering LTE UE is assumed to be on the boresight of the DTT antenna in the azimuth plane, and thus the gain for the wanted DTT signal and for the LTE interference is the same. In practice, the LTE would often be off boresight, providing additional angular discrimination and therefore improved C/I for DTT.

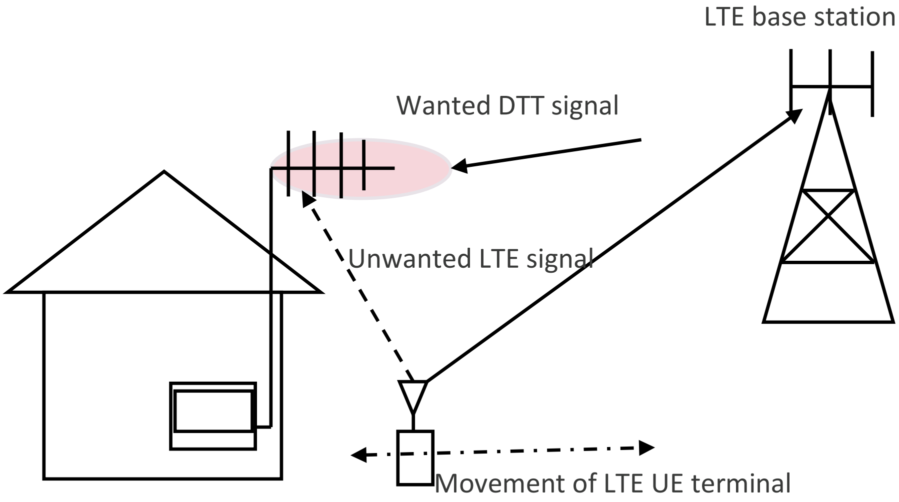

Figure 9: LTE uplink interference scenario for fixed roof top DTT reception

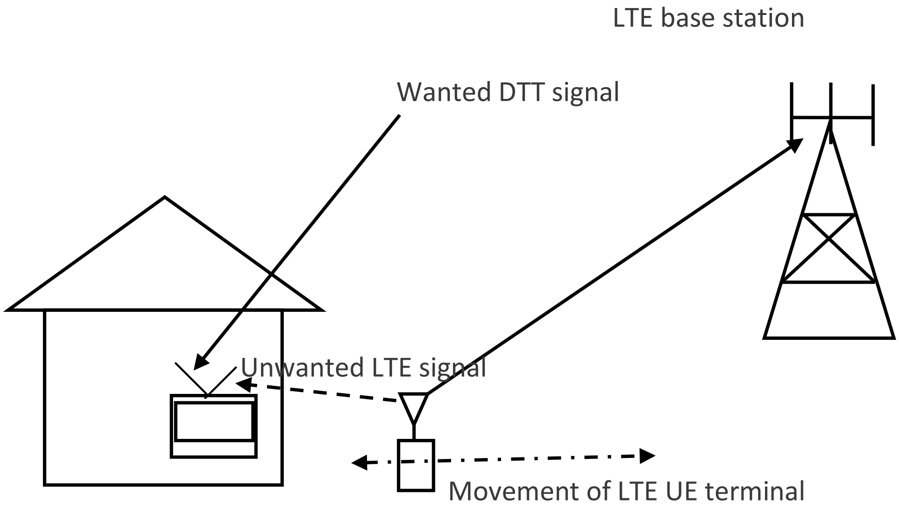

Figure 10: LTE uplink interference scenario for set top DTT reception, (DTT receiver antenna gain=2.15 dBi in all direction is assumed)

For the case of set top DTT receivers, we assume an omnidirectional antenna with 2.15 dBi gain. This again can be considered as a worst case, as a directional (or 'smart') antenna may be able to discriminate against the interfering signal (in angle) and so improve C/I. However, the indoor scenario is not likely to have a dominant angle of arrival for the DTT signal, and so an omnidirectional antenna is not considered to be overly conservative.

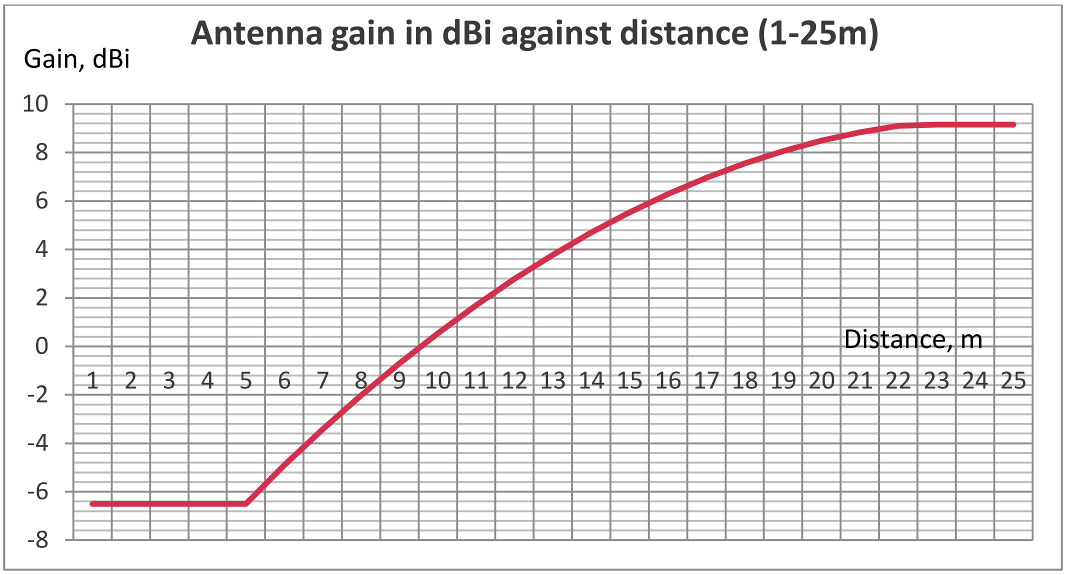

Figure 11: DTT receiver rooftop antenna (ITU-R Rec. 419-3) gain against distance

Table 1: Link budget calculation example

Link parameter	Symbol	Unit	Value	Comment
Wanted DTT signal power	P_w	dBm	-70	Input
Wanted DTT signal frequency	f_w	MHz	786	Input (Channel 60)
Roof top antenna height	h_r	m	10	Fixed roof top antennas
Horizontal Distance between the DTT receiver and LTE UE interferer	d	m	10	Varies from 1 to 100m
Interfering LTE UE EIRP	P_i	dBm	23	
Interferer signal frequency	f_i	MHz	837	LTE uplink Channel A
Antenna gain on the vertical plane	G_v	dBi	0.5	According to ITU-R Rec. 419-3
Antenna gain on the horizontal plane	G_h	dBi	0	According to ITU-R Rec. 419-3
Body loss of UE transmission	L_b	dB	6	
Free space path loss	L_{fr}	dB	50.9	$L_{fr}=20\log_{10}(4\pi d/\lambda)$
Received interferer's power	P_{ir}	dBm	-33.4	$P_{ir}=P_i+(G_h+G_v)-L_{fr}$
Protection ratio achieved	PR	dB	-36.6	P_w-P_{ir}

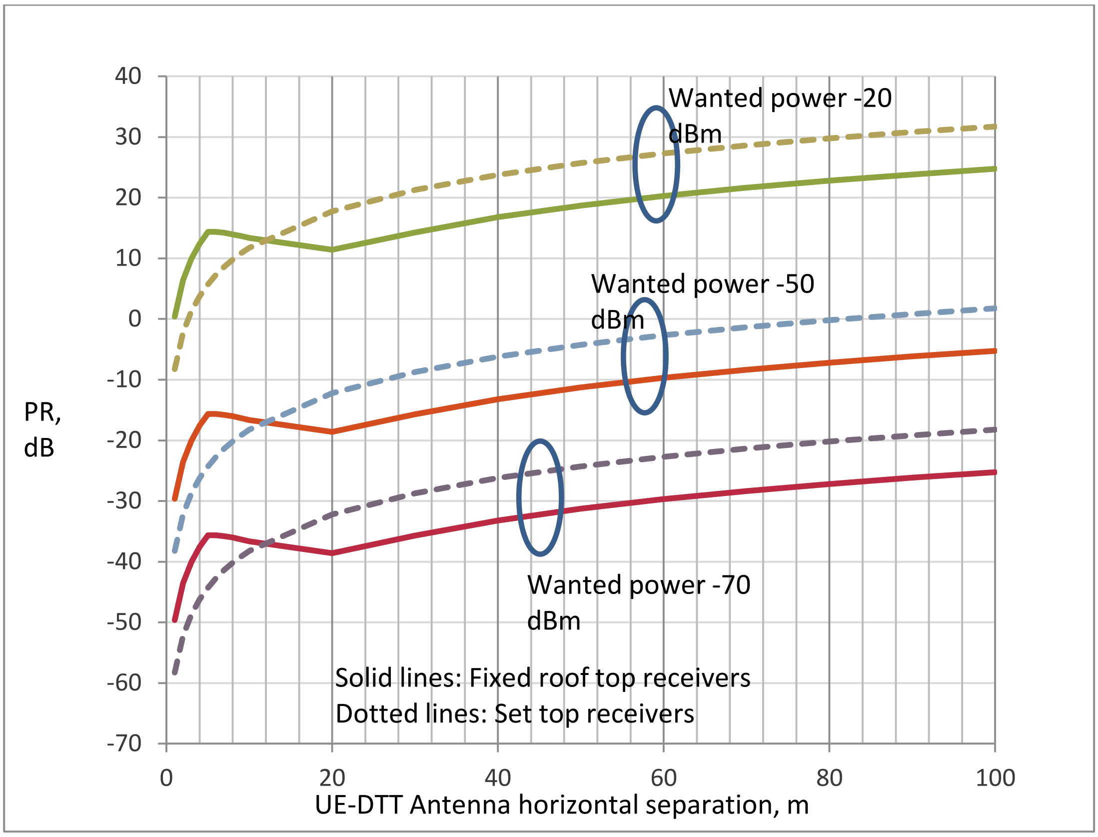

Figure 12: Achieved Protection ratio vs. protection distance for different wanted signal power

The protection ratio (C/I) achieved for different protection distances are shown in Figure 12. It can be seen from the figure that for the case of DTT receivers with fixed roof top antennas, the protection ratio is affected by the combination of the antenna's elevation pattern and the free space path loss due to the UE-DTT antenna separation. Up to a distance of 5m, protection increases and then it decreases up to 22 m. Beyond that, the PR increases steadily with increased distance.

4. Survey of protection ratio measurements

There have been number of conductive measurements performed in Europe on protection ratios for DTT receivers with interference from LTE transmission both in the uplink and downlink e.g. [8] [9] [10] [11] [12] [13]. In this section, these measurements are compared with the results from the MCL analysis in section 3. Specifically, the measured protection ratios are combined with the graph of protection ratio vs protection distance to estimate the minimum separation needed between an LTE UE and a given DTT receiver type.

4.1 'Conducted' Protection Ratio Measurements from [8]

The study in [8] has conducted a range of measurements on the impact of LTE interference to DTT reception in both time continuous and discontinuous transmission of the interference signals and required protection ratio to maintain satisfactory reception quality.

Definitions

Channel edge separation: The channel edge separation is defined as difference in frequency between two systems e.g. a DTT channel's upper edge and LTE channel's lower edge.

Frequency Offset: The frequency separation between each consecutive DVB-T channel from edge to edge is 7 or 8MHz; this separation is referred to as channel frequency offset later in the document.

LTE UE channel bandwidth: The channel bandwidth of LTE UE device varies from 1.5 MHz to 20 MHz.

Continuous and Discontinuous Transmission: The PR analysis for continuous transmission refers to the case where LTE is transmitting signals all of the time on all available resource blocks. The discontinuous transmission mode refers to the case where transmission occurs for only a fraction of the time e.g. 10 %.

Conducted and radiated measurements: Conducted measurements have a prototype LTE UE device connected by cable to a DVB-T receiver via an attenuator which emulates propagation losses in the radio channel. Radiated measurements are performed over the air.

[8] provides measured protection ratios for different channel edge separation frequencies and three types of receivers: Can STB/iDTV, Silicon STB/iDTV and Silicon USB. An LTE channel bandwidth of 5 MHz is used. Results are summarised in Table 2. The ranges of PR values for each receiver type against the frequency separation are due to the use of different transmission patterns by the LTE UE interferer. For the purpose of analysis and calculation of minimum separation distances, the worst case PR value for a given range is assumed. [8] notes that these figures were measured at high DTT signal powers and that "At wanted signal level close to receiver sensitivity, noise should be taken into account, e.g. at 3 dB above the receiver sensitivity level threshold, 3 dB should be added to the PR. ".

Table 2: DVB-T PR values in the presence of a LTE-UE interfering signal without TPC in a Gaussian channel environment at the 10th, 50th and 90th percentile: comparison between can-tuners and silicon-tuners [8]

DVB-T PR for 64-QAM 2/3 DVB-T signal (LTE UE TPC off)									
Channel edge separation (MHz)	PR (dB)								
	10th			50th			90th		
	Can STB/iDTV	Silicon STB/iDTV	Silicon USB	Can STB/iDTV	Silicon STB/iDTV	Silicon USB	Can STB/iDTV	Silicon STB/iDTV	Silicon USB
41.5	-79 … -63	-61 … -52	-49	-73 … -56	-53 … -45	-40	-66 … -49	-45 … -38	-31
49.5	-76 … -66	-60 … -56	-49	-74 … -57	-56 … -48	-40	-71 … -47	-51 … -40	-30
57.5	-77 … -66	-62 … -55	-49	-78 … -59	-55 … -46	-40	-70 … -52	-48 … -37	-30
65.5	-63 … -54	-63 … -52	-47	-50 … -44	-55 … -45	-40	-38 … -33	-47 … -37	-32

Figure 12a shows how separation distance is calculated by combining the measured protection ratio with the MCL analysis from the previous section. The graph is obtained by overlaying the PR values of three receiver types from Table 2 for the 90th percentile column with the PR vs separation results from Figure 12 to give protection distances required for the frequency separation of 41.5 MHz. The blue lines represent required distance vs. achieved protection ratio. The points on the x-axis are the PR values of the three receivers at the 90th percentile. The points where the vertical lines cross the blue lines represent the required protection distances for these receivers.

Note that as the protection ratio increases there are instances where there is sudden increase in distance required. This can be explained from Figure 12, where the same protection ratio can be achieved at two distances and the higher distance of the two has been used in Figure 14 to account for the worst case situation. Note that no transmit power control (TPC) is used in the LTE terminal for the PRs measurements. As described earlier, the interference dynamics caused by TPC may upset the DTT receiver and therefore require a higher protection ratio than that for a non varying interference signal. However, full EIRP from the LTE UE is a reasonable worst case. The Can receiver type seems to require lower protection ratio compared with Silicon types of receivers.

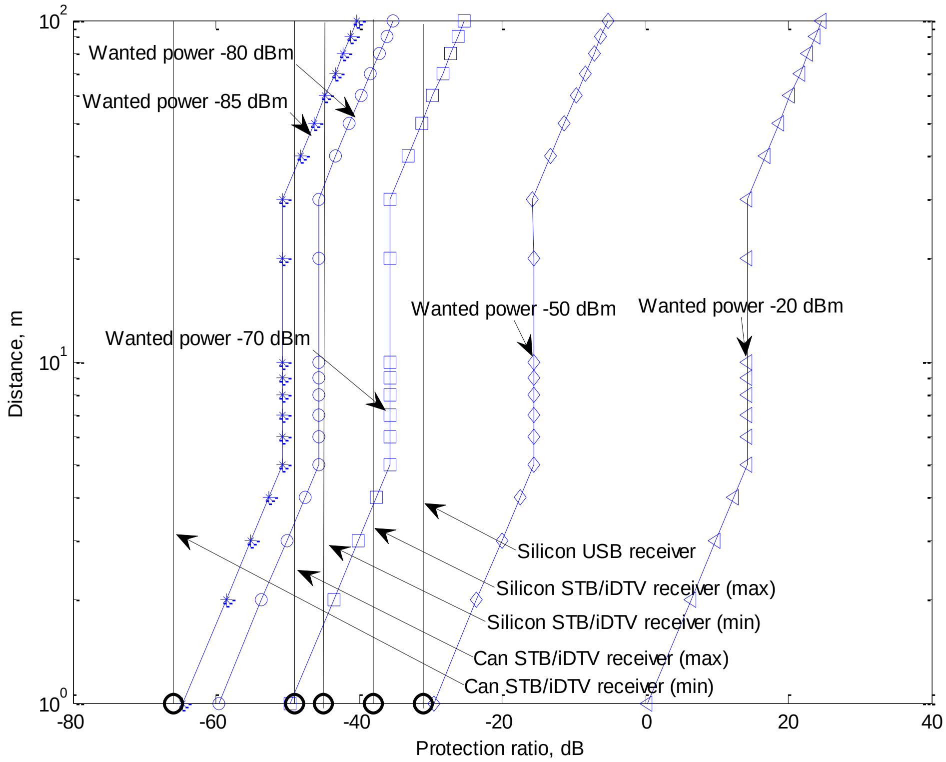

Figure 12a: 90 percentile protection ratios for different receivers using roof top antennas tested in Germany for channel edge separation frequency of 41.5 MHz from LTE UE signals in Gaussian channel (time varying pulsed transmission), ACLR=70dB [8]

Table 3 shows the minimum separation distances required at different wanted signal levels for different DTT receivers for both fixed roof top and set top locations. It can be seen that the required separation distance increases as the wanted signal power decreases. The set top receivers in general require greater separation distances compared with roof top DTT receivers.

Table 3: Minimum separation distance required vs measured protection ratios for DTT receivers for a channel edge separation frequency of 41.5 MHz from LTE UE signals in a Gaussian channel (time varying pulsed transmission), ACLR=70dB [8]

			Minimum Separation distance, m					
Receiver Type	Required Protection Ratio, dB	Source	Rooftop			Set top		
	(worst case)		P_w= -30dBm	P_w= -50dBm	P_w = -70dBm	P_w = -30dBm	P_w = -50dBm	Pw = -70dBm
Can (90 percentile) *	-49	[8]	<1	<1	1	<1	<1	2.5
Silicon STB (90 percentile) *	-38	[8]	<1	<1	4	<1	1.5	10
Silicon USB (90 percentile) *	-31	[8]	<1 [1]	<1 [1]	< 5 [1]	<1	2.5	15

* ACLR=70 dB is used in some of the above PR measurements [8]

Figure 13 shows comparison of minimum separation distances according to the MCL analysis for the three receivers used in [8]. The 'Can' tuner can co-exist in close proximity with an LTE UE transmitting on the uplink even in weak DTT signal areas. A worst case of 2.5m UE-DTT receiver separation is needed for the set top case in a weak DTT signal area. The silicon tuners generally require greater separations, which are greater than 10m in the weak DTT signal areas.

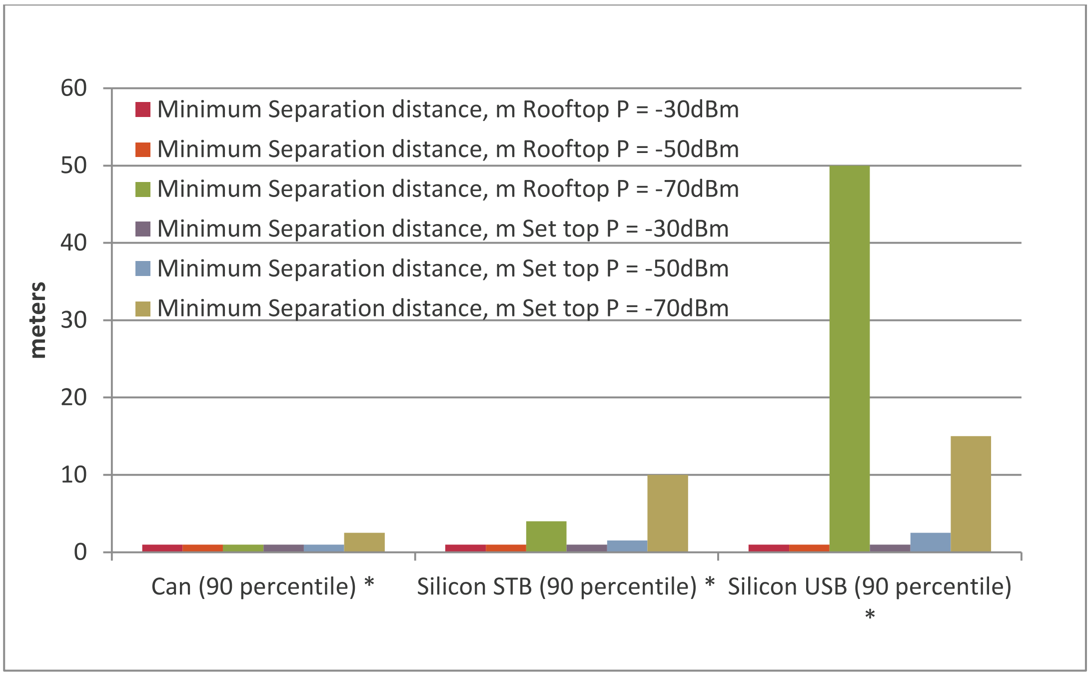

Figure 13: Comparison of minimum separation distances for different receivers in [8].

[1] The combination of USB receiver and roof top antenna is an unlikely scenario, but is included for completeness

4.2 'Conducted' Protection Ratio Measurements from [10-13]

Further studies on protection ratio measurements of LTE uplink interference to DTT receivers are conducted in [10-13]. These provide 'conducted' measurement of protection ratio for a number of receiver types at various frequency separations, and for continuous and discontinuous sources of emulated LTE interference. Table 4 shows DTT protection ratios needed with a continuous power interference source, and table 5 shows those needed with a discontinuous interference source. The discontinuous source uses a short duration pulse for 10% of the time.

Table 4: LTE UE interference to DTT receiver at different frequency offsets, 100% interference activity, wanted signal level =-70 dBm, centre frequency 786 MHz(channel 60)[12]

	Receiver types													
	1	2	3	4	5	6	7	8	9	10		11	12	13
Interferer Offset N	**Si Tuner E**	**Si Tuner A**	**Si Tuner F**	**Si Tuner B**	**Can Tuner A**	**Can Tuner D**	**Can Tuner E**	**Can Tuner F**	**Can Tuner G**	**Can Tuner B**		**Can Tuner H 7MHz**	**Can Tuner J 7MHz**	**Can Tuner L 7MHz**
5	-57	-56	-51	-52	-67	-63	-69	-66	-68	-61		-68	-45	-43
6	-59	-57	-51	-51	-69	-66	-70	-68	-69	-67		-74	-58	-66
7	-60	-58	-53	-52	-71	-75	-75	-70	-72	-75		-75	-61	-68
8	-61	-59	-53	-54	-71	-70	-75	-71	-70	-73		-77	-68	-70

Table 5: LTE UE interference to DTT receiver at different frequency offset, 10% interference activity, wanted signal level =-70 dBm, DTT centre frequency 786 MHz (channel 60) [12]

	Receiver types													
	1	2	3	4	5	6	7	8	9	10		11	12	13
Interferer Offset N	**Si Tuner E**	**Si Tuner A**	**Si Tuner F**	**Si Tuner B**	**Can Tuner A**	**Can Tuner D**	**Can Tuner E**	**Can Tuner F**	**Can Tuner G**	**Can Tuner B**		**Can Tuner H 7MHz**	**Can Tuner J 7MHz**	**Can Tuner L 7MHz**
5	-41	-51	-35	-49	-67	-63	-67	-61	-68	-61		-68	-45	-44
6	-43	-51	-36	-51	-69	-66	-70	-67	-66	-65		-74	-57	-65
7	-45	-53	-37	-51	-71	-75	-74	-69	-72	-70		-75	-61	-68
8	-48	-55	-39	-52	-71	-70	-73	-70	-70	-68		-76	-66	-70

We see from the tables that in general, the highest protection ratios are needed for frequency offsets of 5 channels (the highlighted rows in Table 4 and Table 5). DTT channels are 8MHz wide, so N=5 corresponds to a 40MHz offset from 786MHz or an LTE Centre Frequency at 826 MHz.

Table 6: Minimum separation distance required due to LTE UE interference to DTT receiver at the frequency offset of 5 channels, 100% interference activity, wanted signal level P_w=-30, -50 and -70 dBm, DTT centre frequency 786 MHz (channel 60)[12]

			Minimum Separation distance, m					
Receiver Type	Required Protection Ratio, dB (worst case)	Source	Rooftop			Set top		
			P_w = -30dBm	P_w = -50dBm	P_w = -70dBm	P_w = -30dBm	P_w = -50dBm	P_w = -70dBm
Si Tuner E	-34	[12]	<1	<1	< 1	<1	<1	<1
Si Tuner A	-40	[12]	<1	<1	<1	<1	<1	1.5
Si Tuner F	-27	[12]	<1	<1	<1	<1	<1	2.5
Si Tuner B	-40	[12]	<1	<1	<1	<1	<1	2.5
Can Tuner A	-31	[12]	<1	<1	<1	<1	<1	<1
Can Tuner D	-40	[12]	<1	<1	<1	<1	<1	<1
Can Tuner E	-36	[12]	<1	<1	<1	<1	<1	<1
Can Tuner F	-36	[12]	<1	<1	<1	<1	<1	<1
Can Tuner G	-33	[12]	<1	<1	<1	<1	<1	<1
Can Tuner B	-33	[12]	<1	<1	<1	<1	<1	<1
Can Tuner H 7MHz	-36	[12]	<1	<1	<1	<1	<1	<1
Can Tuner J 7MHz	-23	[12]	<1	1.5	2	<1	4.5	5
Can Tuner L 7MHz	-19	[12]	<1	2.5	2	1	6.5	6

Table 6 shows the minimum required separation distance for the different DTT receivers when there is continuous (100%) transmission from LTE UE interferers (All 10 blocks used) at frequency offset of 5 channels between the DTT receiver and LTE interferer. Note that 5 channel offset corresponds to 40 MHz for DTT receivers using 8 MHz channels and 35 MHz for DTT receivers using 7 MHz channels (i.e. Can tuners H, J, L). The minimum separation distances calculated in Table 6 are for the worst case protection ratio required for different wanted signal levels of -30, -50 and -70 dBm.

Table 7: Minimum separation distance required due to LTE UE interference to DTT receiver at the frequency offset of 5 channels, 10% interference activity, wanted signal level =-70 dBm, DTT centre frequency 786 MHz (channel 60)[12]

Receiver Type	Required Protection Ratio, dB (worst case)	Source	Minimum Separation distance, m					
			Rooftop			Set top		
			P_w = -30dBm	P_w = -50dBm	P_w = -70dBm	P_w = -30dBm	P_w = -50dBm	P_w = -70dBm
Si Tuner E	-32	[12]	<1	< 1	3	<1	<1	7
Si Tuner A	-32	[12]	<1	<1	1	<1	1.5	2.5
Si Tuner F	-11	[12]	<1	4	30	3	10	15
Si Tuner B	-37	[12]	<1	<1	1	<1	<1	3
Can Tuner A	-31	[12]	<1	<1	<1	<1	<1	<1
Can Tuner D	-40	[12]	<1	<1	<1	<1	<1	<1
Can Tuner E	-34	[12]	<1	<1	<1	<1	<1	<1
Can Tuner F	-34	[12]	<1	<1	<1	<1	<1	<1
Can Tuner G	-38	[12]	<1	<1	<1	<1	<1	<1
Can Tuner B	-33	[12]	<1	<1	<1	<1	<1	<1
Can Tuner H 7MHz	-36	[12]	<1	<1	<1	<1	<1	<1
Can Tuner J 7MHz	-22	[12]	<1	1.5	2	<1	4	4.5
Can Tuner L 7MHz	-21	[12]	<1	1.5	2	<1	5	4

Table 7 shows the minimum required separation distance for the different DTT receivers when there is discontinuous transmission i.e. repeating pulses 1 every 10 blocks (10%) from LTE UE interferers at frequency offset of 5 channels between the DTT receiver and LTE interferer.

From the Tables 6 and 7, it can be observed that in the case of the LTE interferer transmitting discontinuously, the required protection ratios are generally higher than the case of continuous interference from the LTE transmission. Hence the minimum separation distances are higher in the case of discontinuous transmission. Note that the type of discontinuous transmission in these tests (a pulse for 1ms out of every 10) is simplistic and does not necessarily replicate the full range of variations identified earlier (power control and variable resource allocations).

Figure 14: Comparison of minimum separation distances required for different receivers in [12]

Figure 14 shows a comparison of minimum separation distances required from the MCL analysis for the receivers types measured in [12]. This shows that minimum distances for the higher wanted signal power of -50 and -30 dBm are 1 m or less. For the wanted signal power of -70 dBm, Silicon types of receivers require higher separation distances of 2-3 m. Some of the ‘Can’ tuners in the 7 MHz category require separation distances up to 6.5 m.

5. Comparison with radiated measurements

The purpose of this section is to compare theoretical separation distances (obtained by combining the measured protection ratios with the MCL analysis) with separation distances measured in radiated tests. These were commissioned by Ofcom to understand how the minimum separation distances compare to each other.

In June 2010, Ofcom commissioned Cobham Technical Services/ERA Technology RF and EMC Group to carry out measurements of radiated interference of LTE interference to DTT reception [14]. For the case of LTE mobile interference, the following interference scenarios were considered as shown in Figure 15 and 16 for the cases of iDTV and STB receivers, respectively. The purpose of the experiments was to assess the impact of LTE interference at various locations within a single building, when DTT receiver is connected to a roof top Yagi antenna. Five different locations within the building were tested including the same room as the DTT receiver.

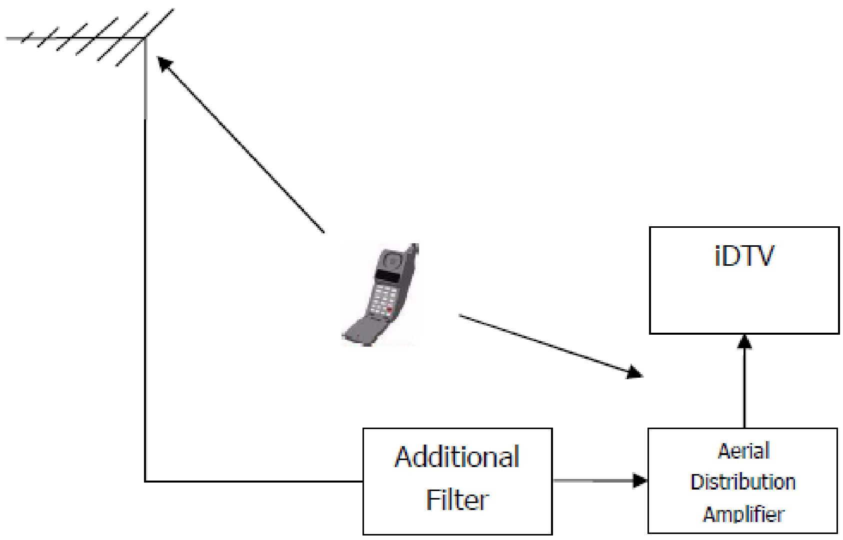

Figure 15: Radiated measurements of LTE interference on the DTT reception using iDTV receivers and fixed roof top antennas [14]

During the course of measurement, an additional filter was activated when the interference impact on the DTT receiver started to degrade the broadcast video quality. Also an attenuator was used to control the transmit power of LTE UE interferer to increase or decrease the EIRP.

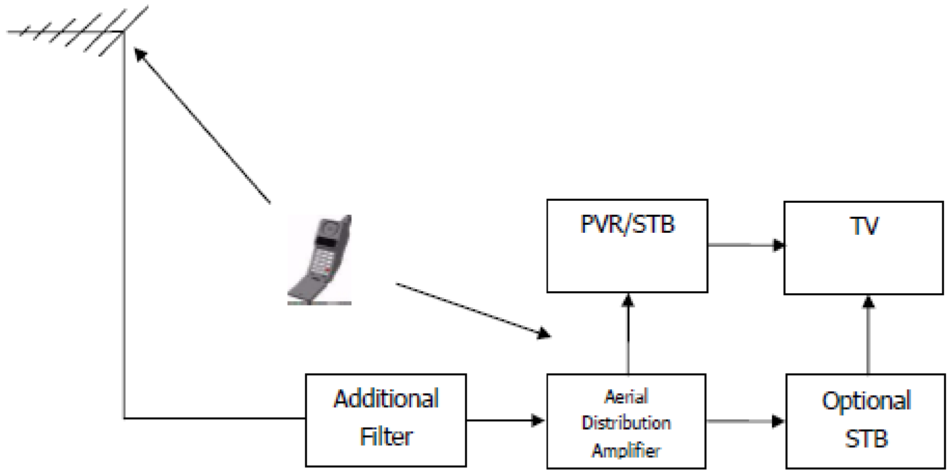

Figure 16: Radiated measurements of LTE interference on the DTT reception using STB receivers and fixed roof top antennas [14]

The measurement of protection ratio from the radiated signals was carried out for DTT reception at the frequency of 778 MHz (channel 59) with wanted signal levels of -70, -50, -30, -20 and -12 dBm and LTE interference signals of different powers at a centre frequency of 849 MHz. It was noted that when the DTT receiver is using the fixed roof top antenna and LTE UE interferer transmitting at 849 MHz (1 MHz below the N+9 image channel of DTT receiver) is indoor, the only case of interference was observed when the LTE UE device was in the same room as the DTT receiver. This was observed when the LTE UE power was increased from 23 dBm to 28 dBm.

A comparison of protection ratio vs. protection distance between the radiated measurements and those obtained from the MCL analysis in section 3 is shown in Table 8 below. This assumes a wanted DTT signal power of -70 dBm (weak reception area), an LTE UE interferer transmitting at 28 dBm, and a DTT antenna located on the roof top.

For set top DTT antennas, the experiments used a fixed UE-DTT separation of 2.5 metres, and the EIRP of the LTE UE was reduced until degradation of DTT reception disappeared. Results for this scenario are not presented as they are not comparable with the MCL based analysis.

Table 8: Comparison of theoretical and radiated results of protection distances for DTT receivers with fixed roof top and set top antennas, wanted signal power = -70 dBm

LTE UE EIRP = 28 dBm		
Receiver Type	**Minimum separation distance, m**	
	Roof top	
	Measured	**Theoretical**
iDTV	1.4	3
iDTV silicon tuner 1	0.35	1.8
iDTV silicon tuner 2	0.25	1.4
PVR	0.08	0.7
STB	0.33	1.6
STB via PVR	0.68	1.6

Table 8 shows that the protection distances from the MCL analysis are higher than those from radiated measurements in all cases. This is to be expected as the MCL analysis assumed a worst case unobstructed interference path from LTE UE to rooftop antenna. In the radiated measurements, the walls and floor would reduce the interference and increase the minimum required separation.

Note that all the radiated measurements used static LTE UE interferers with full resource block usage. It was noted in section 4 that time discontinuous transmission of LTE UE signals may lead to increases in the required protection ratio and thus separation distances. Power control dynamics of LTE UEs interferers have not been considered in the measurements and might result in further increases in separation distance. However since measurements assumed a worst case interference scenario of the LTE UE at full power, power dynamics should not significantly change the results.

6. Conclusions

DTT protection ratios obtained from a survey of conducted measurement campaigns are combined with a Minimum Coupling Loss analysis to estimate separation distances needed to protect a number of different DTT receivers from interference from LTE UE uplink transmissions. A range of experimental data obtained from both laboratory based conducted measurements and field based radiated measurements carried out in Europe and in the UK, have been used. Two types of LTE interference activity are considered: continuous, where the LTE UE transmits signals all the time, and discontinuous, where the LTE UE transmits in short bursts lasting 10 % of the time.

In the 'conducted' (cabled) measurements, various DTT receivers are connected by cable to a DTT signal source and to an LTE UE interferer via attenuators to emulate path loss in the radio channel. The protection ratio for different receiver types and for different frequency separations is then obtained by setting different wanted DTT signal power and then varying the interferer's power until video quality of DTT receivers stated to degrade at significantly perceivable level. Radiated measurements use a more realistic but less controlled over the air indoor scenario. The DTT antenna is either a rooftop or set top type and the LTE interferer is placed at various distances from the receiver or in different rooms.

For the case of continuous LTE UE interference transmission and a weak DTT signal of -70dBm, the minimum protection distance varied from 0.9 meters for the best receiver type to tens of meters for the worst performing receiver. For a stronger DTT signal of -50dBm, the analysis shows that most DTT receivers can operate within 1m of an interfering LTE UE. Some of the receiver types needed more separation, with the worst case receiver requiring a 6.5m separation. With a strong DTT signal of -30dBm, all but one of the receivers (the Can tuner 7 MHz) could operate within 1m of the LTE UE. For both continuous and discontinuous LTE interference transmission, DTT receivers with set top antennas required greater separation from LTE UEs than DTT receivers with roof top antennas. The MCL analysis shows that this is due to the elevation pattern of the DTT antenna, although in practice the walls of the building and height difference would help isolate the DTT antenna from UE interference. Since we assume a worst case of free space path loss and no obstructions for the interfering path, we can expect that roof top DTT receivers may still work well at smaller separation distances than those shown in this report. In this case, the dominant source of LTE interference may be from an alternate leakage between the indoor components, e.g., via the fly lead of the DTT. Such forms of interference have not been considered in this study.

An analysis of LTE uplink transmission mechanisms found that there are likely to be significant and rapid variations in the emitted interference which might cause problems with dynamic aspects of the DTT receiver. Conducted measurements showed that time discontinuous transmission of LTE UE interference did indeed increase the required protection ratio compared with continuous transmission as can be seen from Table 6 and 7. The comparisons of distances in the two cases show that in general the discontinuous LTE UE transmission required higher minimum separation distances. For example, 16 dB higher protection ratio was required for the case of Silicon Tuner E with the LTE UE pulsing for 10% of the time [12].

A survey of separation distances obtained from radiated measurements with a rooftop configuration generally gave more optimistic results (shorter separation distances) than that suggested by the theoretical analysis. This may be due to the worst case assumptions in the theoretical analysis of MCL. The analysis assumed that the LTE UE interferer and the DTT receiver were in line of sight and propagation between them was free space with no building penetration losses. The radiated measurements were carried out in a real in-building environment with walls and roofs isolating the LTE interference activity to some extent.

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