LTE User Equipment Coexistence with 862 - 870MHz

Research Document

Publication date: 11th September 2012

Contents

Section 1

Executive Summary

Previous studies undertaken by Ofcom[1] on the potential of 800 MHz LTE user equipment (UE) to cause interference to devices operating in the adjacent band (862 – 870 MHz) have used worst case assumptions about the use of transmit power and cell resources in those analyses of possible interference. It is important in understanding coexistence issues with future LTE deployments to characterise more likely emission characteristics of LTE user equipments and therefore how likely to occur these worst case scenarios in the previous studies are.

There is currently limited information available to us in advance of established LTE networks having been rolled out in the UK. However, we have undertaken a number of practical measurements on a live LTE network with the objective of better characterising typical UE emissions and behaviour.

The LTE network that we were able to study was operating in the middle of the 800 MHz band and therefore was not immediately adjacent to the 862 – 870 MHz band of interest. We therefore undertook a series of measurements in a lab environment using a commercial LTE base station and UEs from a number of different manufacturers in order to better understand how the measurements from the live network may be applied to future LTE deployments operating in the upper 10 MHz of the 800 MHz band (852 – 862 MHz paired with 811 – 821 MHz). In summary, we do demonstrate that measurement data from the middle block can be used to represent those from the upper (and adjacent) 10MHz block when taking account of appropriate offsets

Whilst, these measurements have been made using 800 MHz LTE equipment, and out of band (OOB) emissions examined in the adjacent band of 862 – 870 MHz, they are likely to read across to other mobile communications bands using LTE such as 2.6 GHz.

This report presents the results of those measurements and the conclusions we infer from them regarding LTE emissions. It also provides specific examples of out of band emissions at SRD frequencies in the 863 – 870 MHz band. Our high level conclusion regards LTE UE emission is that the level and likelihood of emissions falling at a particular frequency in the adjacent band is related to the uplink resource demand from the user; the scheduling algorithms of the LTE network; and the transmit power level of the UE. This is in line with what we have said in our previous studies (detailed above) when suggesting that we believe that the likelihood of those worst case scenarios occurring is low.

---

[1] ERA Technology: Investigation on the receiver characteristics of SRD equipment in the 863 – 870 MHz band (http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/SRD-Study.pdf), ERA Technology: "Investigation of LTE UE Interference into Social Alarms, http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/LTE_UE.pdf and Ofcom: "Potential for LTE interference to Wireless Audio, http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/Wireless_Audio_Testing.pdf

Specifically we conclude:

i) Typical application throughputs may be considerably less than the maximum data rate that the cell can support in the uplink;

ii) Due to additional band filtering, care should be taken when inferring emission levels for the closest LTE block from measurements of blocks that are further away from the adjacent band in question;

iii) For a given data rate the number of resource blocks (RB) that the network will schedule and consequently the number of time slots that a particular RB is in use will affect the likely interference risk;

iv) For a given data rate the number of RBs that are used and the pattern of hopping employed by the network will have an effect on the probability of OOB emissions falling on a particular frequency above 862MHz;

v) The OOB emissions in our measurements were, for the majority of time, between 20dB and 40dB lower than those from a device using all resources of the cell uplink; and

vi) The UE uses power control such that it's transmit power is optimised to ensure appropriate power levels arriving at the base station and maximise battery life. Therefore transmit power was distributed between the maximum of +23dBm and a minimum of around -45dBm.

We present results from measurements on a live LTE network showing the typical level of out-of-band emissions that are generated within the 862-870MHz band under certain uplink load conditions. We have also shown that for the majority of time across different uplink resource scenarios that the total LTE UE power is considerably less than 23dBm. Even in one extreme case, with high resource usage, the power was less than 13dBm for 50% of the time at our example location.

Section 2

Introduction

2.1 800MHz band for award

In July 2012, Ofcom published a statement setting out decisions for the award of spectrum in the 800 MHz and 2.6 GHz frequency bands[2]. The 800 MHz band will be used to deliver the next generation of mobile broadband services using 4G technologies such as LTE and WiMAX.

The harmonised frequency arrangement for the 800 MHz band in Commission Decision 2010/267/EU is 2 x 30 MHz with a duplex gap of 11 MHz, based on a block size of 5 MHz, paired and with a guard band at 790-791 MHz. The Frequency Division Duplex (FDD) downlink starts at 791 MHz and FDD uplink starts at 832 MHz. This is illustrated by Figure 1 below.

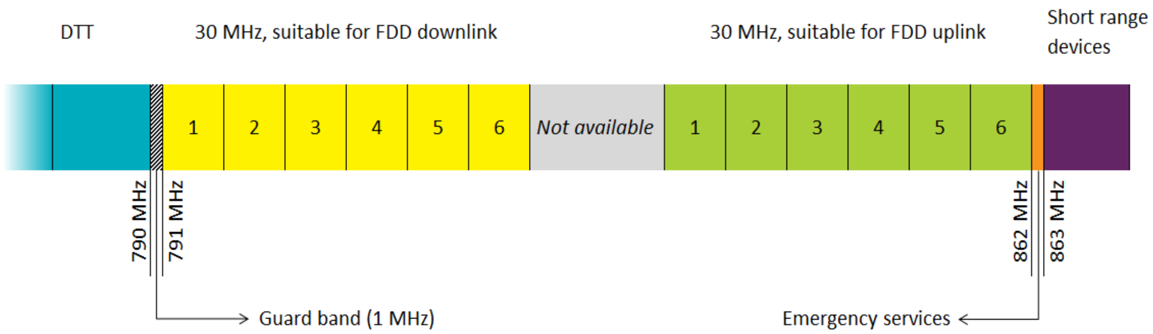


Figure 1: 800 MHz band plan

The total band allocated for LTE transmission has typically been allotted in three blocks of 10 MHz each in auctions in other countries, as shown in Figure 2. We have followed a similar approach for this study and they are referred to as Blocks “A”, “B”, and “C”, respectively. The frequency range of each block is given in Table 1.

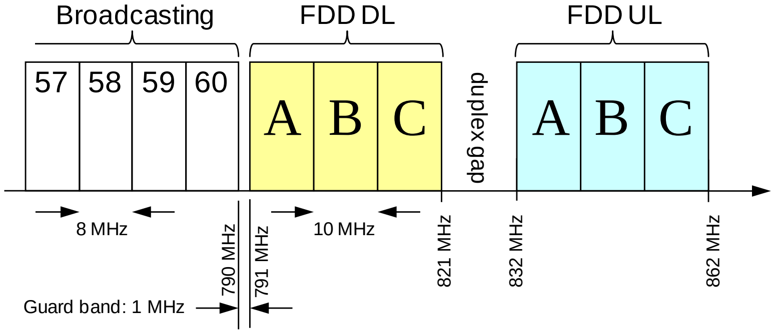


Figure 2: Frequency arrangement used in this study

[2]Statement on the award of 800 MHz and 2.6 GHz spectrum at http://stakeholders.ofcom.org.uk/consultations/award-800mhz-2.6ghz/statement/

Table 1: Spectrum Blocks Considered in our analysis

	Frequency Range	Centre Frequency
Block A	832-842 MHz	837MHz
Block B	842-852 MHz	847MHz
Block C	852-862 MHz	857MHz
Out-of-band (OOB)	>862 MHz	N/A

2.2 Adjacent band

The 862-863 MHz band is currently allocated for use by the emergency services, although as we describe in the Information Memorandum for the 800 MHz and 2.6GHz award, they are currently in the process of moving services from this band to alternatives.[3]

The 863-870MHz frequency band has been set by CEPT as a European harmonised band for licence – exempt operation of a wide range of specific and non-specific short range devices (SRDs). This includes device such as alarms, telemetry and telecommand devices, RFID and radio microphones, with maximum powers of up to 500mW. Different types of devices use (or could use) different parts of the SRD band:

i) The frequencies between 863 and 865 MHz are used mainly by audio devices including wireless headphones; assistive listening devices, such as amplified sound for the hard of hearing; and wireless microphones used in mainly non commercial situations such as schools and church halls (professional use of such equipment is usually licensed and deployed in other frequency bands).

ii) The frequencies between 865 and 868 MHz are used mainly by radio frequency identification (RFID) devices i.e. the tracking and monitoring of cargo or stock in manufacturing or distribution industries.

iii) The frequencies between 868 and 870 MHz are used mainly for telemetry devices (alarm and monitoring systems). These include commercial fire alarms, domestic intruder alarms, smart meters (for utilities), routine medical monitoring, and social alarms for the vulnerable.

2.3 Coexistence issues

As part of our June 2011 consultation on technical licence conditions, Ofcom published a detailed initial study of potential interference issues into the short range device (SRD) band[4].

The results of that study indicated that, under certain assumptions about LTE UE operation and wanted SRD signal level, there is the potential for interference into some types of SRD equipment if the UE is placed within a certain minimum distance of the receiving unit. Results suggest that the impact to devices operating in the emergency service (862 – 863MHz) and SRD (863 – 870MHz) bands is from out of block emissions from adjacent LTE services. This means that LTE handsets operating in the highest 10MHz allocation (Block C)

[3] Information Memorandum on the award of 800 MHz and 2.6 GHz spectrum at http://stakeholders.ofcom.org.uk/consultations/award-800mhz-2.6ghz/statement/

[4] ERA Technology: Investigation on the receiver characteristics of SRD equipment in the 863 – 870 MHz band (http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/SRD-Study.pdf)

will have the greatest potential impact. As part of additional work undertaken since the June 2011 consultation, Ofcom has published two additional studies looking at the potential for interference into the SRD band[5], however, these both take a pessimistic view by assuming that LTE signals transmitted by the user terminal (the dominant source of interference to the band above 862 MHz) are transmitted at full power using all of the resources blocks and thus all resources of the cell. We have previously suggested that this situation is unlikely and this study seeks to provide more realistic information on likely usage based on transmissions in live LTE networks.

An example measurement from an LTE user terminal which shows the OOB emissions is shown in Figure 3.

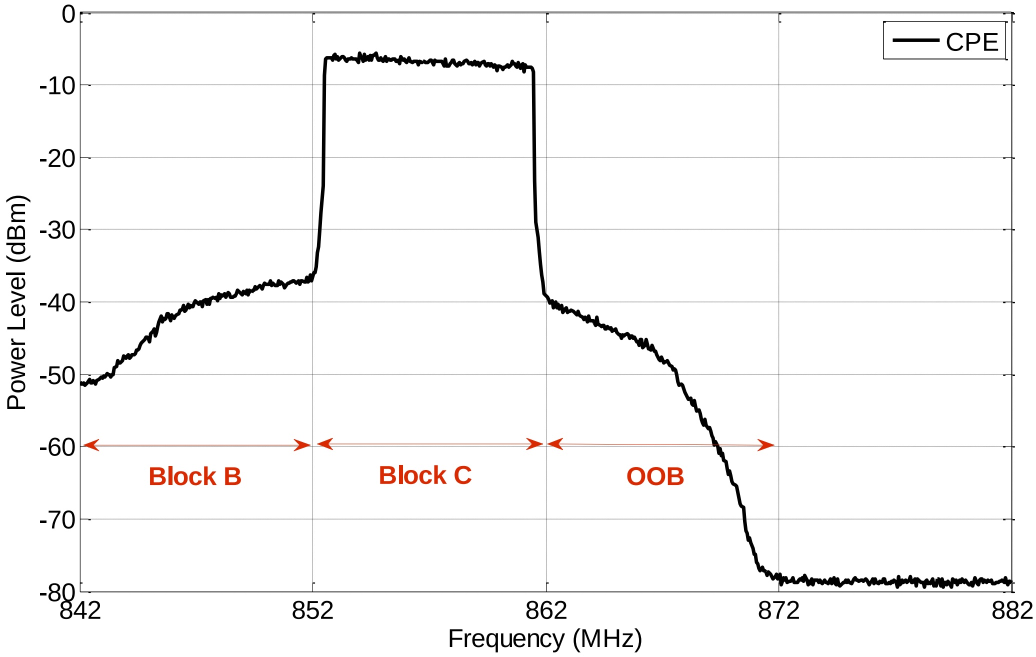


Figure 3: Measurement of an example LTE production UE showing in and out of band signal transmissions (Measurements taken with a 10 kHz resolution bandwidth)

2.4 Structure of this report

We might expect, for a number of reasons including network and battery management, that LTE devices will not be transmitting at the worst case of full power, using all resource blocks for long periods of time. Reasons include:

---

5 ERA Technology: "Investigation of LTE UE Interference into Social Alarms, http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/LTE_UE.pdf and Ofcom: "Potential for :LTE interference to Wireless Audio, http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/Wireless_Audio_Testing.pdf

i) Typical application throughputs may be considerably less than the maximum data rate that the cell can support in the uplink;

ii) For a given data rate the number of resource blocks that the network will schedule consequently the number of time slots that a particular RB is in use will affect the likely interference risk;

iii) For a given data rate the number of RBs that are used and the pattern of hopping employed by the network will have an effect on probability of OOB emissions falling on a particular frequency above 862MHz; and

iv) The UE will be use power control such that it’s transmit power is optimised to ensure appropriate power levels arriving at the base station and maximise battery life. Therefore transmit power will be distributed between the maximum of +23dBm and the minimum of -41dBm.

This study provides analysis of all four aspects highlighted in the above list with the latter three based on measurements taken from a live LTE network:

- Section 3 looks at typical user throughputs required for certain applications, setting the scene for the typical rates used during the measurements.

- The measurement methodology is summarised in Section 4 with additional detail provided in Annex 2.

- Section 5 presents measurement results taken in a lab environment in order to demonstrate that measurement data from Block B can be used to represent Block C and how the main user device used in our measurements of the live network compares with other devices that we had available.

- The results from our measurements on a live LTE network are presented in Section 6.

- We draw some conclusions in Section 7.

Section 3

Typical User Throughputs

One of the reasons that we have given above for suggesting that user terminals are unlikely to be transmitting using all resource blocks is that a user is unlikely to require sustained use of the full uplink capacity of a cell, which is able to support up to 43Mbps[6] for a 10MHz channel.[7] In this section we provide a little background to typical user rates that might be required for example file uploads.

Table 2 provides some example media streams and their typical sizes along with example file transfer times based on a 5 Mbps throughput channel. If these media streams were transmitted in real-time then the required average throughput required is likely to be lower than 5 Mbps. For example a 45-minute HDTV show in real time would need approximately 1 to 1.5 Mbps and it is considerably less for a standard definition TV show or movie. It should also be noted that these files would need to be transmitted from the user to the network for these rates to be applicable for the uplink. If they were downloads instead, then we suggested in the statement on the award of 800 MHz and 2.6GHz spectrum that the uplink would typically need to support about 4% of the downlink data rate in order to meet the requirements for data protocol acknowledgements[8].

Table 2: Typical media streams and durations[9]

Length and type of media	File Size	Rate (assume a 5 Mbps rate)
4-minute song	4 MB	4-5 seconds
5-minute video	30 MB	30-40 seconds
9-hour audio book	110 MB	2 minutes
45-minute TV show	200 MB	3-5 minutes
45-minute HDTV show	600 MB	10-15 minutes
2-hour movie	1.0-1.5 GB	18-24 minutes
2-hour HD movie	3.0-4.5 GB	54-72 minutes
iPod Game	10-60 MB	About 30-70 seconds

The values in Table 2 therefore demonstrate that it is possible to support multiple users in the uplink and still meet their service demands. Whilst we do not consider in this section how user demands are scheduled in the uplink and we recognise that a user could get all resources of the cell, to meet the 4% uplink requirements for a download this is unlikely except at the fringes of coverage. If a user was uploading large quantities of data then this might be possible but if all resources of the cell were used for any length of time this would only be because there were no other users on the cell at that time, which as networks mature is unlikely.

[6] H. Holma, A. Toskala, *LTE for UMTS 2nd Edition*, John Wiley & Sons, Ltd, Mar 2009, pp. 259

[7] Our practical testing presented in the following sections showed that we could achieve approximately 20Mbps with a UE that was not capable of using the highest modulation rates in the uplink, suggesting that there was also some error coding being employed.

[8] See Annex 8 and 10 of the Statement at http://stakeholders.ofcom.org.uk/consultations/award-800mhz-2.6ghz/statement/

[9] Taken from download times given on the iTunes website. http://support.apple.com/kb/HT1577

Section 4

Methodology

In our investigations we have relied upon uplink measurements that were undertaken by the Technical Division of Ofcom on an 800 MHz LTE network that was delivering services to a number of users. The results of which are presented in section 6. In order to support the validity and interpretation of these measurements we have also conducted measurements in a more controlled lab environment using transmissions in a range of frequencies within the 800 MHz band.

The live LTE network was supporting multiple users and resources were allocated to our test user device in a manner consistent with the rest of the users on the network. Whilst we acknowledge that the network had not reached a level of maturity and may not necessarily be representative of performance of LTE networks in the future, it provides the best information that we had available at the time.

The live network contained base station equipment from two different vendors, both of which were used to support our uplink requirements during our measurements. The lab based measurements were undertaken using equipment from a single base station vendor.

4.1 Uplink measurements

More detail on our methodology for both the live and lab-based LTE measurements is given in Annex 2. However we provide a brief summary of the key elements below.

i) Real-time RF recordings of uplink transmissions were made using equipment directly coupled to the antenna port of the LTE UE.

ii) Uplink data was generated across the LTE link using dedicated software running on a laptop connected to the UE and a server connected into the LTE core network. This allowed a range of rates to be tested[10].

iii) The LTE UE was connected "over the air" on the live network and connected directly to the base station via RF cable and attenuators in the lab environment.

iv) Recorded RF transmissions of around 5 minutes in duration were subsequently analysed to provide the results presented in the following sections.

Figure 4 provides an example snapshot of the post processed recordings over a 1ms sub-frame for the three uplink data rates of 12 kbps, 500 kbps and 2 Mbps that were measured on the live network. Resolution bandwidth has been adjusted to 180 kHz, commensurate with 12 x 15 kHz subcarriers making up a resource block.

[10] Rates of 12 kbps, 500 kbps and 2 Mbps only were used on the live LTE network so as not to place an excessive load on a network with other users. Additional rates of 10 Mbps and 20 Mbps were used during measurements in the lab environment.

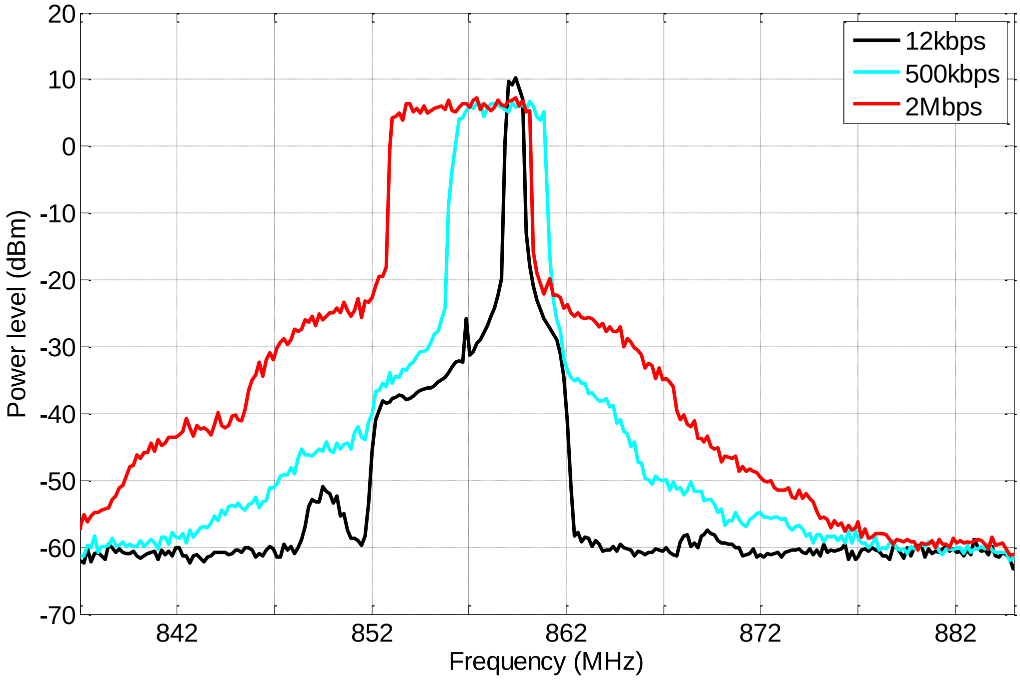


Figure 4: A snapshot of the in-band and out-of-band power level measured from a production LTE user device with various data rates (resolution bandwidth = 180 kHz)

Section 5

Lab-based Measurement Results

5.1 Performance of different UEs

As we mentioned above, we undertook measurements using different example user devices. One was a WiFi router with LTE backhaul (referred to as CPE in the following sections); the others were 4G USB modems (referred to as Dongles).

In the subsequent analysis, we have focussed predominantly on the use of the CPE for consistency. As well as practical reasons for its use, we show in the following paragraphs that we believe it to be a fair representation of the pool of devices that were available to us.

In order to understand the relative performance of the devices available to us, we commissioned some additional lab testing by RFI Global. RFI Global used a laboratory LTE test-set to establish an LTE radio link with the device under test and configure it to transmit in a number of different scenarios. Figure 5 shows the in-band and out-of-band power measured for each device when it was configured to transmit at full power (23dBm) on all 50 resource blocks within a 10MHz channel centred on 857MHz (Block C). The operating modulation scheme is fixed to 16QAM[11].

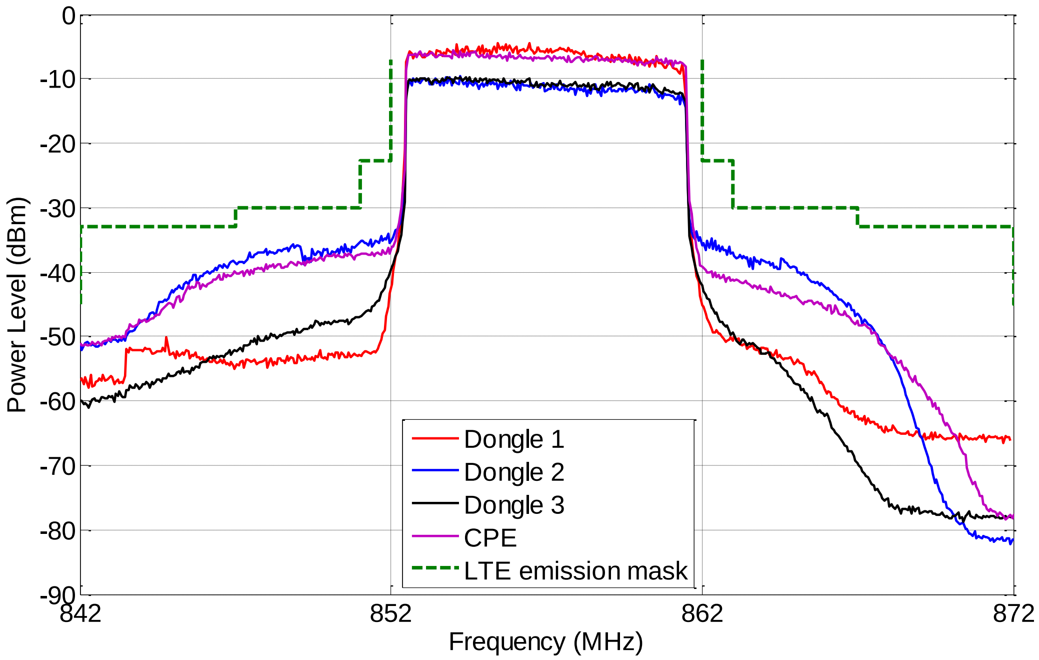


Figure 5: RMS signal measurements of four LTE devices transmitting full power in the uplink with all resource blocks in use (resolution bandwidth = 10 kHz)

It can be seen in Figure 5, that the level of OOB emissions is quite variable depending on the particular device, although we note that we only tested a single sample of each device.

[11] This was the maximum modulation scheme supported by all devices and we found similar results were achieved using a lower modulation scheme.

The plot suggests that Dongle 2 and Dongle 3 were not able to transmit the full 23dBm on one antenna port in the 10MHz channel; however the CPE and Dongle 3 were. The device with the worst performance depends on which part of the band is of interest; however we consider that the CPE shows relatively pessimistic performance over the entire SRD band (up to 870 MHz).

All of the subsequent results are presented for the CPE and are taken from our analysis of the CPE when directly connected to an LTE base station in a lab environment.

5.2 Performance of different LTE blocks

As we set out in section 2, the greatest risk of interference to devices operating in the 862 – 870 MHz SRD band is from LTE operating in Block C and therefore it is necessary for us to evaluate the performance of LTE devices operating in Block C. The live LTE network that we had access to was only operating in a 10MHz channel centred on 847MHz (Block B) and therefore OOB emissions in the 863 – 870MHz SRD band are low and may have little effect. It is therefore necessary for us to consider the effects from Block B shifted by 10MHz in our analysis as if they were from Block C.

Figure 5 shows that the LTE Dongles and CPE that we have tested in Block C exhibit lower OOB emissions on the upper side of the band suggesting that there is some additional filtering. In order to compare directly, we have considered the OOB emissions produced by a 20Mbps (all RB) for both Block B and C in a lab environment. Figure 6 shows the difference in OOB emissions between Block B shifted in frequency to represent those from Block C and those measured from Block C. The divergence of the two lines above 862 MHz shows the additional filtering applied and unless this additional filtering is taken into account, analysis based on Block B will overestimate the OOB emissions.

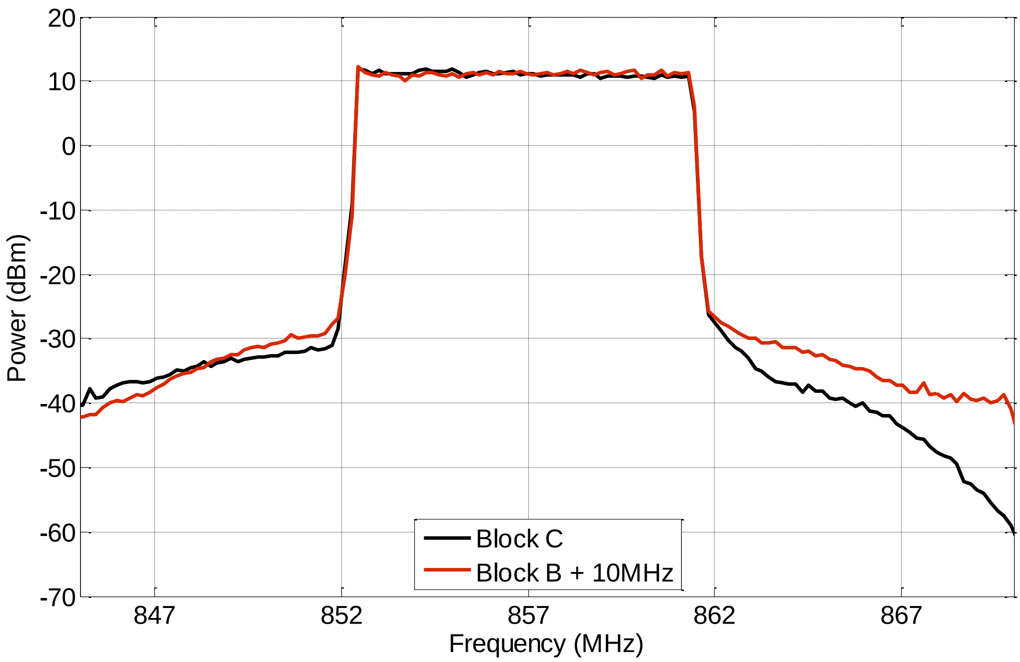


Figure 6: The max-hold power level plots showing the comparison between lab-based LTE uplink measurements in Block B and Block C (resolution bandwidth = 180 kHz)

The deltas calculated from two rates of 500kbps and 2Mbps show very similar results and are presented in Figure 7. We have listed offsets in Table 3 for some example frequencies used in our subsequent analysis[12]. In our analysis based on the live LTE network, we have applied a 10MHz frequency offset and reduced the OOB emission by the relevant amount in Table 3 in order to demonstrate the OOB that we expect if the network was operating on Block C.

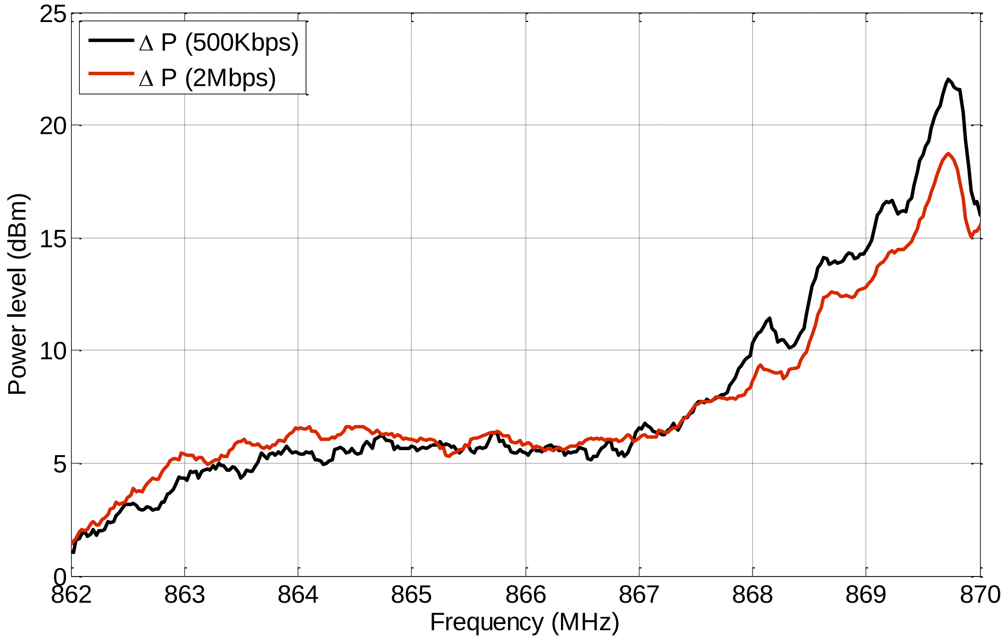


Figure 7: The difference in OOB level between Block B and Block C

Table 3: Block B and Block C offsets for OOB emission level

Short Range Device Operating Frequency	Bandwidth	Offset Loss (Block B OOB Level – Block C OOB Level)
862.9625 MHz	25KHz	5.3dB
864.85 MHz	25KHz	6.2 dB
864.85 MHz	200KHz	6.2 dB
868.0 MHz	25KHz	8.6 dB
869.5 MHz	25KHz	16.0 dB

5.3 Performance of different data rates

Whilst Figure 5 above shows the OOB emissions generated when all resource blocks are in use, Figure 8 demonstrates that for lower data rates, a lower number of RBs are typically used. The plot shows the cumulative distribution function based on the number of RBs that

[12] 864.85MHz is typically used for wireless audio devices and therefore a 200 kHz channel bandwidth is appropriate, however we have also provided results for a 25 kHz channel bandwidth at this frequency to allow direct comparison with our other example frequencies across the band which represent more generic SRDs operating in the band.

are used in each 1 ms sub-frame for different uplink data rates. It can be seen that lower data rates use a low number of resource blocks more often.

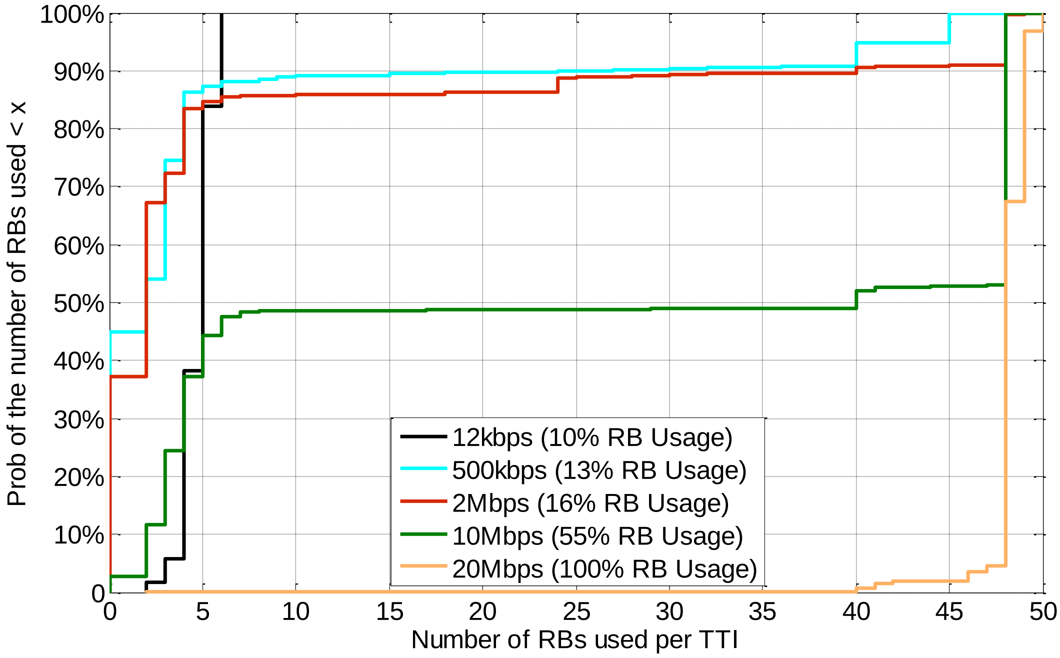


Figure 8: The CDF curves showing the distribution of number of RBs used per sub-frame with different rate targets

Given the overall maximum transmit power may not exceed 23dBm, then when a lower number of resource blocks are transmitted, the power allocated to each RB may be higher than when a larger number of RBs are used. Consequently instantaneously higher OOB emissions may be generated at certain frequencies depending on which RBs are in use at that instance. An LTE base station typically employs frequency hopping to mitigate propagation effects and thus, over time, all RBs are used with a corresponding increase in the OOB emissions compared with when a large number of RB are used. Figure 9 shows the comparison of these max-hold results for three low data rate services with the CPE curve from Figure 5.

Whilst the OOB emissions in Figure 9 for the lower rates are very slightly higher than when all RBs are used, an individual RB will be used for only a percentage of the total time. As the OOB emissions are related to the number and position of the RB in use then we show later how this affects the likelihood that OOB will be at a particular level for selected frequencies within the OOB frequencies.

The number of RBs that are required for a given data rate is related to the spectral efficiency achieved over a link, which in turn is related to the quality of that link. The greater the link quality[13] the less error coding is required and higher modulation schemes are used, thus more bits per RB can be transmitted and less RBs are required to achieve a given rate.

[13] This is measured as signal to interference plus noise ratio (SINR) in LTE systems.

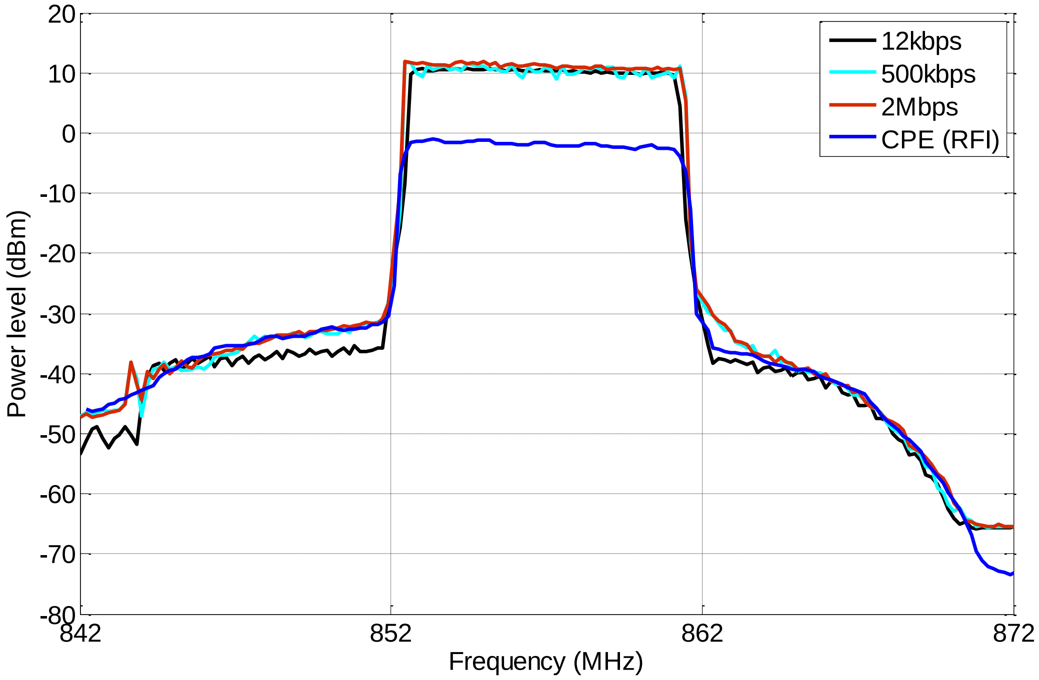


Figure 9: The max-hold plots of the emissions of LTE uplink measurements with different rate targets

While Figure 8 shows the number of RB in use as a function of time, Figure 10 shows the percentage of time that each individual RB is in use. We show rates of 12kbps to 20Mbps, but it can be seen that the usage of each RB is not entirely proportional to the required data rate.

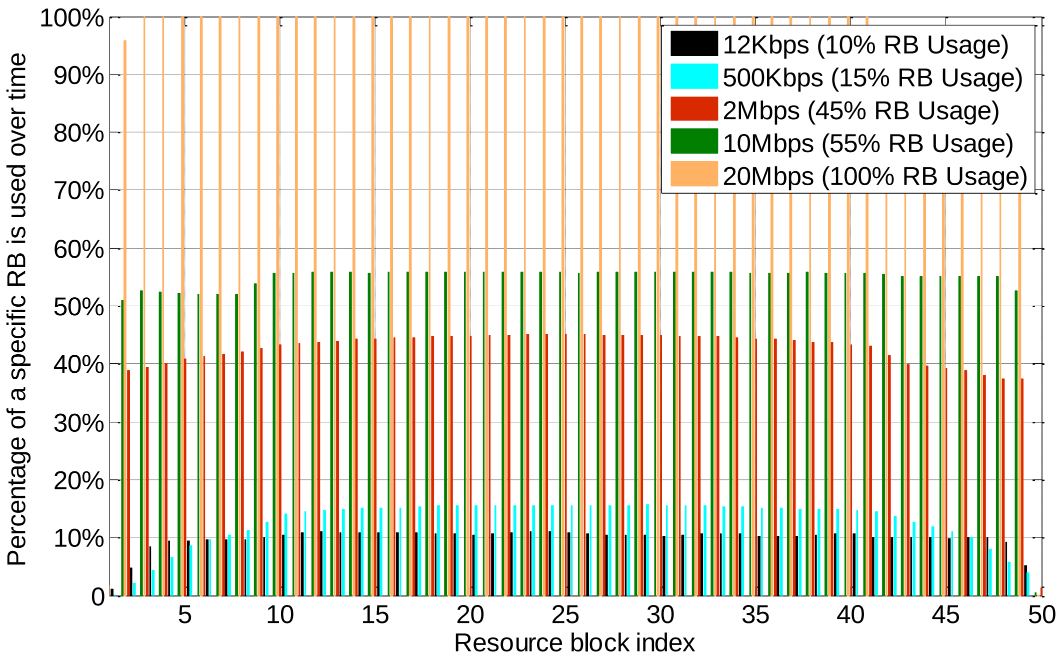


Figure 10: The RB usage in the uplink at a date rate of 12Kbps, 500Kbps, 2Mbps, 10Mbps and 20Mbps

In the lab environment there were no other base stations and therefore the signal quality was limited by noise rather than interference and thus a higher quality link represents a user that is closer to the base station and a lower quality one, a user that is further from the base station. When sufficient resources on the cell are available to meet the demands of the user, then not all the available uplink transmit power may be required from the UE and it will transmit a lower overall power with consequential reduction in the OOB emissions. This difference in signal power level can be observed in the max-hold plots presented in Figure 11. The near user has a better signal quality and therefore the UE transmit power has been reduced relative to that from the far user.

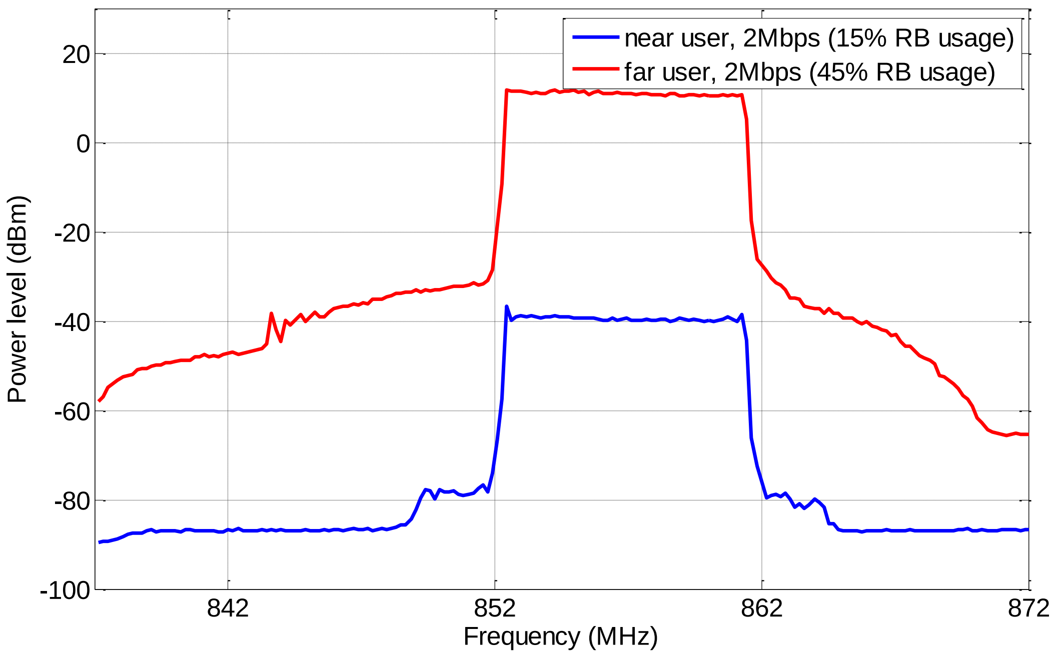


Figure 11: The max-hold plots showing the transmitted power level and OOB comparison between near and far users (resolution bandwidth = 180 kHz)

The effect on RB usage is shown in Figure 12, where in our example, a 2Mbps uplink requirement needs RBs to be used for approximately 15% of the time for a near user and 45% of the time for a user which is further away.

As a result of the different spectral efficiencies, the RB usage and thus OOB emissions are related not so much to data rates but rather the amount of time an RB is used. Table 4 shows some example RB usage for near and far users in our lab testing. We have therefore included the RB usage as well as originally demanded data rate in the relevant graphs of the following section.

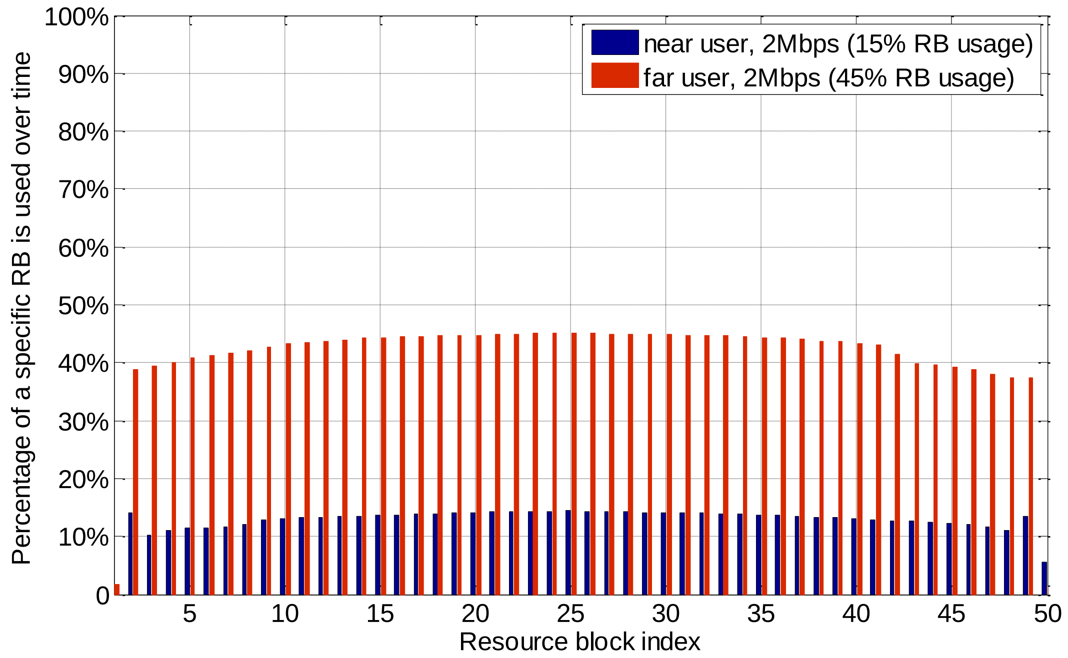


Figure 12: RB usage over for Block C at a date rate of 2Mbps for far and near user scenarios

Table 4: RB usage for different data rates scenarios

Data Rate	Near user	Far user
12Kbps		10%
500Kbps		15%,
2Mbps	15%	40%
10Mbps	55%	N/A
20Mbps	100%	N/A

The net effect of the values in Table 4 is that irrespective of other users on the cell, the full uplink throughput is not available to a user that is located towards the edge of the cell. This can be seen in Table 5, which shows the maximum achievable rates for a single user if they were allocated all resources in the cell. User scenarios A to D correspond to example users that are progressively further from the base station. Average throughputs are calculated by determining the upload time for a large file of 10, 25 or 50 MB in size. In some cases, particularly scenario C, throughputs were determined for several runs of the analysis and therefore an average of all results has been taken.

Table 5: Achievable throughputs in the uplink

User Scenario	System Loss to BS	Average Throughput
A	86 dB	19 Mbps
B	106 dB	19 Mbps
C	120 dB	8.4 Mbps
D	126 dB	2.6 Mbps

Section 6

Results From a Live Network

As described in section 4, the live network was provisioned with base stations from two different vendors; these are referred to as 'Vendor 1' or 'V1' and 'Vendor 2' or 'V2' in the analysis that follows.

6.2 RB allocation

The results in this section give an illustration of the usage distribution of different individual resource blocks. The RB usage for Vendor 1 transmission is presented in Figure 13. As the resource requirement increases, RBs are used for a larger percentage of the measurement time[14]. The graph shows that the individual RBs at the upper end of the 10 MHz channel are more heavily used for low resource requirements. As the resource requirements increase, the usage of RBs becomes more evenly distributed and the system slightly favours those around the central frequency at 40% resource requirement.

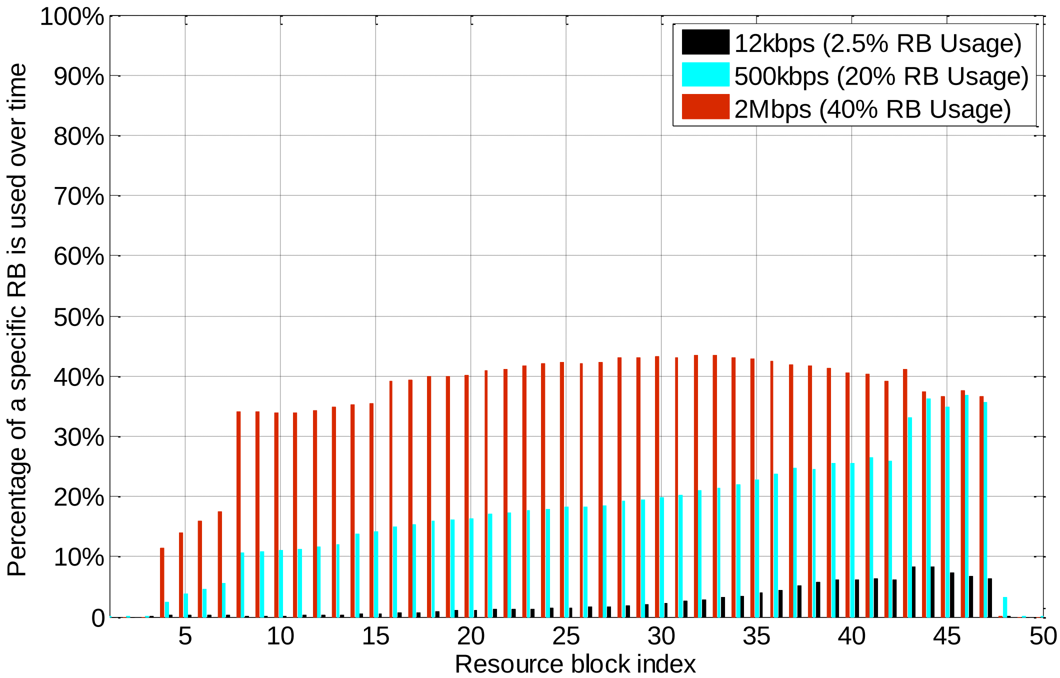


Figure 13: RB usage of Live LTE uplink measurements (Vendor 1)

The test locations used for Vendor 2 were closer to the base station and less spectrum resources were required for the desired data rates than with Vendor 1 as can be seen in Figure 14, therefore the two scenarios are not directly comparable. Compared to Vendor 1, the Vendor 2 base station is scheduling resources weighted more towards the middle of the channel. This may be as a result of different hopping sequences employed by the different vendors.

[14] Analysis is performed over approximately 5 minutes duration

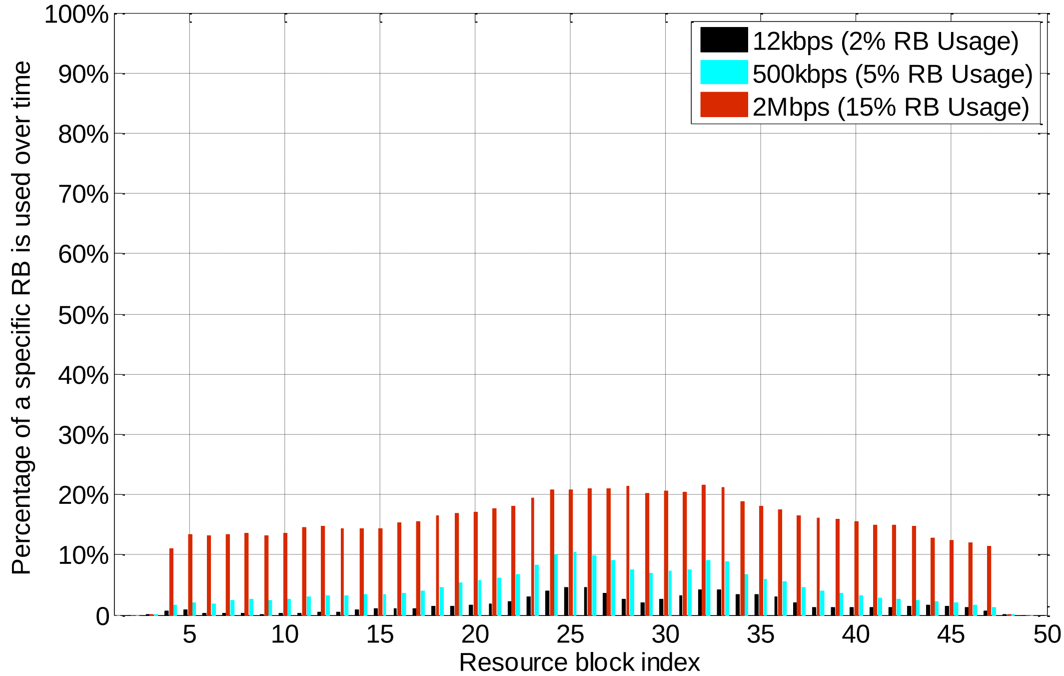


Figure 14: RB usage of Live LTE uplink measurements (Vendor 2)

Based on the results above, the average RB usage percentage for various data rates with Vendor 1 and 2 are presented in Table 6 and the cumulative distribution plots showing corresponding RB usage distribution can be found in Figure 15.

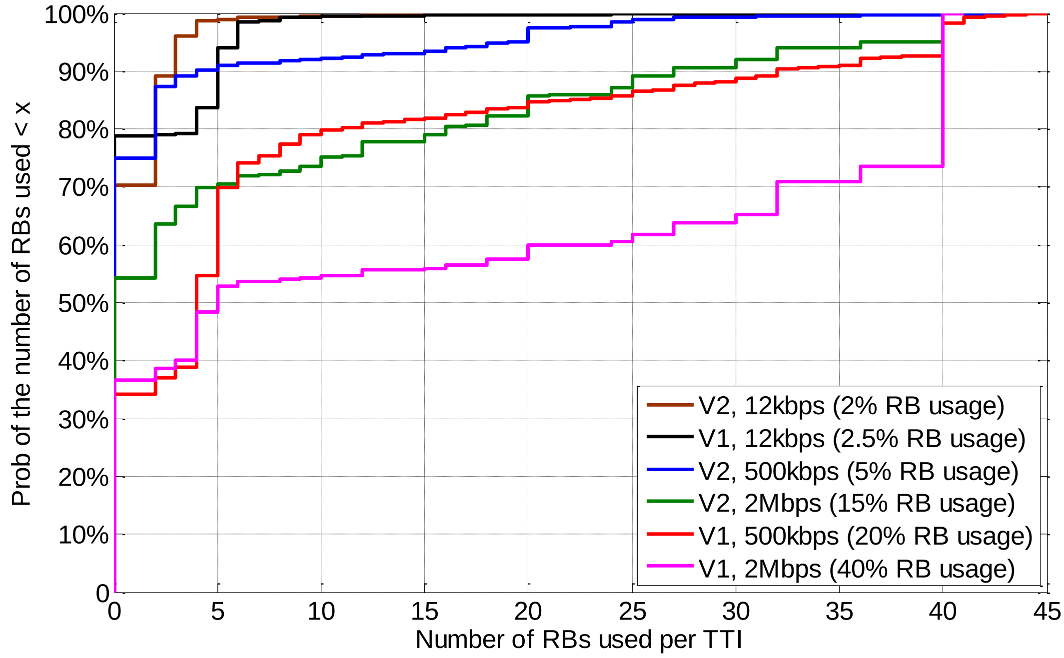


Figure 15: CDF curves showing the number of RBs used per sub-frame on the live network uplink for different target data rates

Table 6: Live base station measurement scenarios

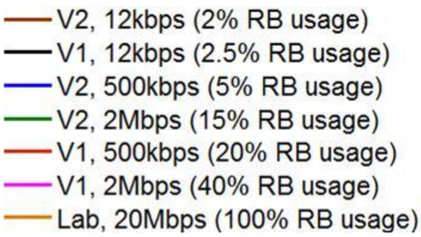
Scenario	Vendor	Data Rate	RB usage
1	Vendor 1	12 Kbps	2.5 %
2	Vendor 1	500 Kbps	20 %
3	Vendor 1	2 Mbps	40 %
4	Vendor 2	12 Kbps	2 %
5	Vendor 2	500 Kbps	5 %
6	Vendor 2	2 Mbps	15 %

6.3 Out-of-band emission analysis

As we saw above, the number of resource blocks used and the usage of an individual RB is related to the amount of resources required by the uplink data demand from the user. We show in the following figures, how the OOB emissions at particular frequencies in the 862 to 870 MHz band are affected by the six different scenarios of data requirement and RB usage given in Table 6.

All results are presented for the measurements taken on the live network and have been adjusted by 10MHz in frequency with the additional losses of Table 3 applied so as to be representative of emissions from an LTE system operating in Block C. For comparison, we have also presented the emission levels from a 20Mbps 100% RB usage measured in the lab environment.

Figure 16 to Figure 20 show cumulative distributions for the range of uplink resource usage from 2% to 100% in Table 6 based on LTE transmissions to base stations from the two vendors. We have provided curves based on a 25 kHz receiver bandwidth at our example frequencies of 862.9625, 864.85[15], 868.0 and 869.5 MHz. The following legend applies to Figure 16 to Figure 20



The graphs may be interpreted as follows, with reference to Figure 16. In our example with a 2Mbps demand (15% utilisation of RB) on a network using a Vendor 2 base station (green line) it can be seen that for 50% of the time the OOB emission are less than -75dBm at the output port of the UE. A separation distance of 5m equates to a 45dB loss in free space and therefore suggests that the OOB emission power received by an SRD receiver will be -120dBm and therefore unlikely to cause significant interference. Taking a 90% time value then the OOB emissions are approximately -50dBm and a received power of -95dBm is applicable at an SRD 5m away.

[15] 864.85 MHz is typically used for wireless audio where the channel bandwidth is typically 200 kHz therefore we have included results for both 25 and 200 kHz receiver bandwidths

Depending on the frequency and utilisation, it can be seen that the OOB emissions of our measurements were between 20 and 40 dB lower than those from a device that was using all resources of the cell and transferring 20 Mbps of data in a lab environment.

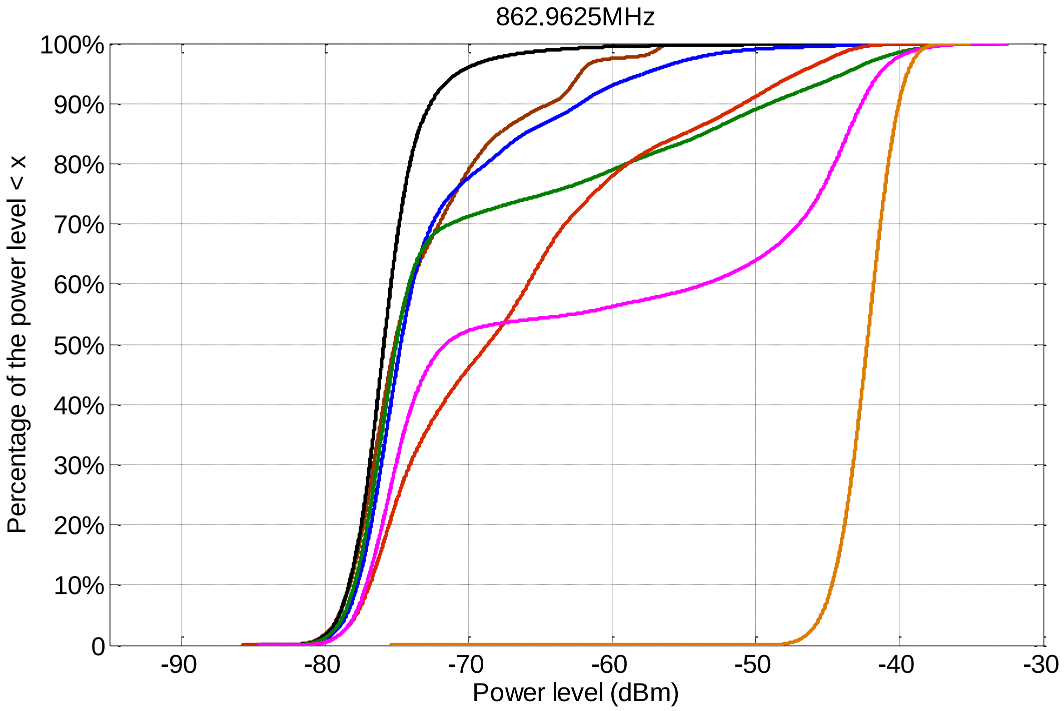


Figure 16: Probability of OOB at 862.9625 MHz (Block Edge + 0.9625 MHz, 25 kHz Bandwidth) at various rate targets

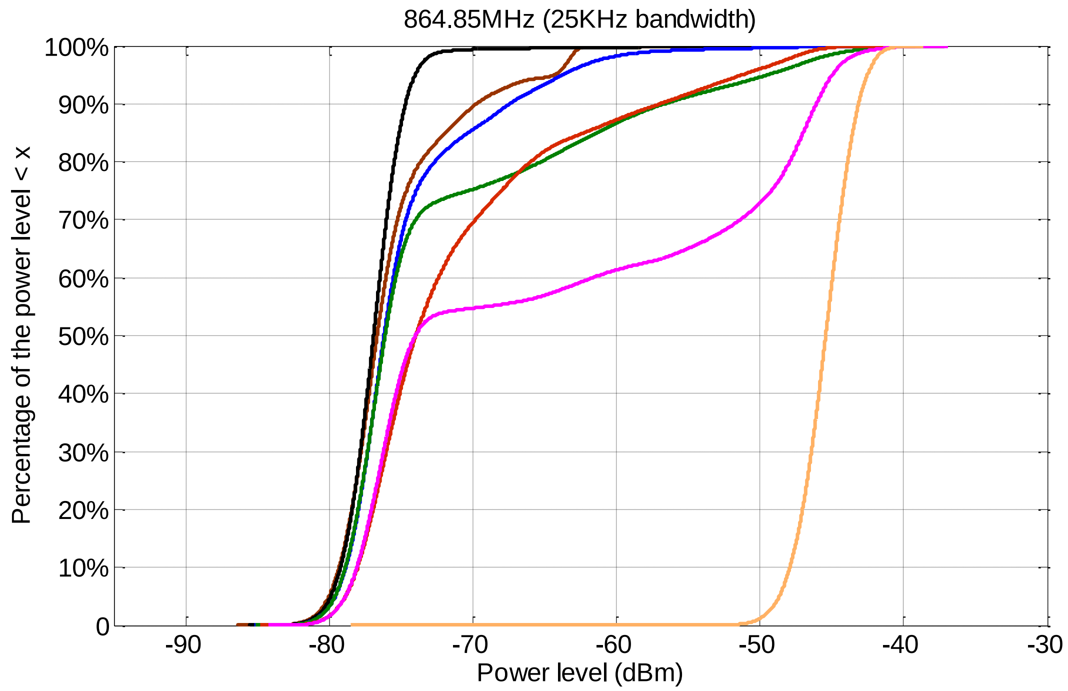


Figure 17: Probability of OOB at 864.85 MHz (Block Edge + 2.85 MHz, 25 kHz Bandwidth) at various rate targets

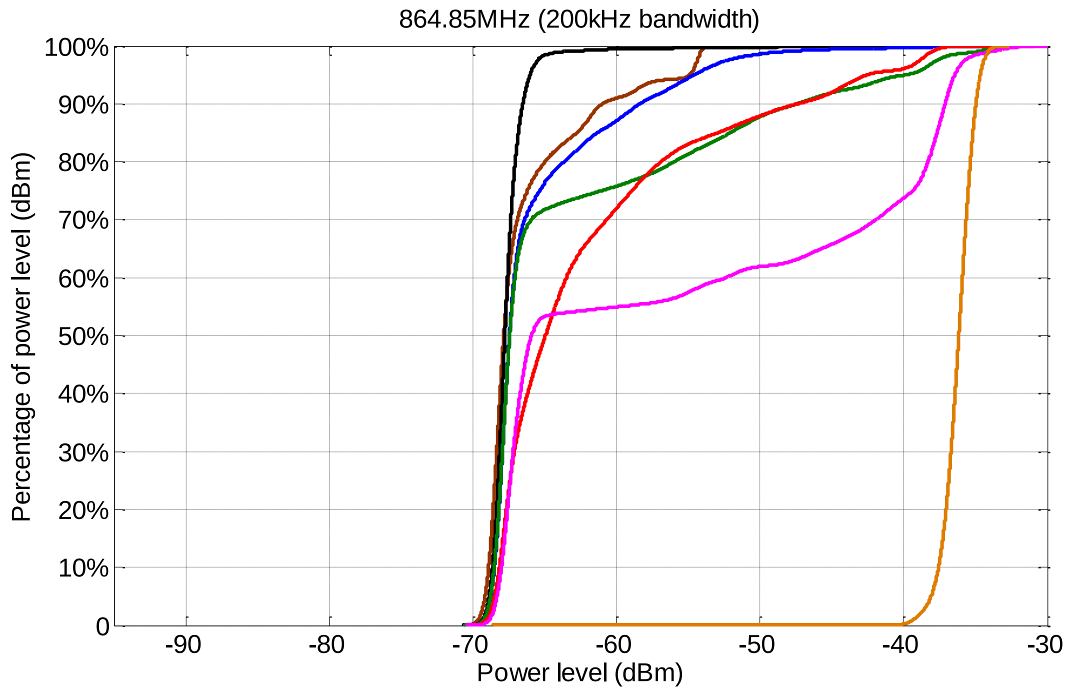


Figure 18: Probability of OOB at 864.85 MHz (Block Edge + 2.85 MHz, 200 kHz Bandwidth) at various rate targets

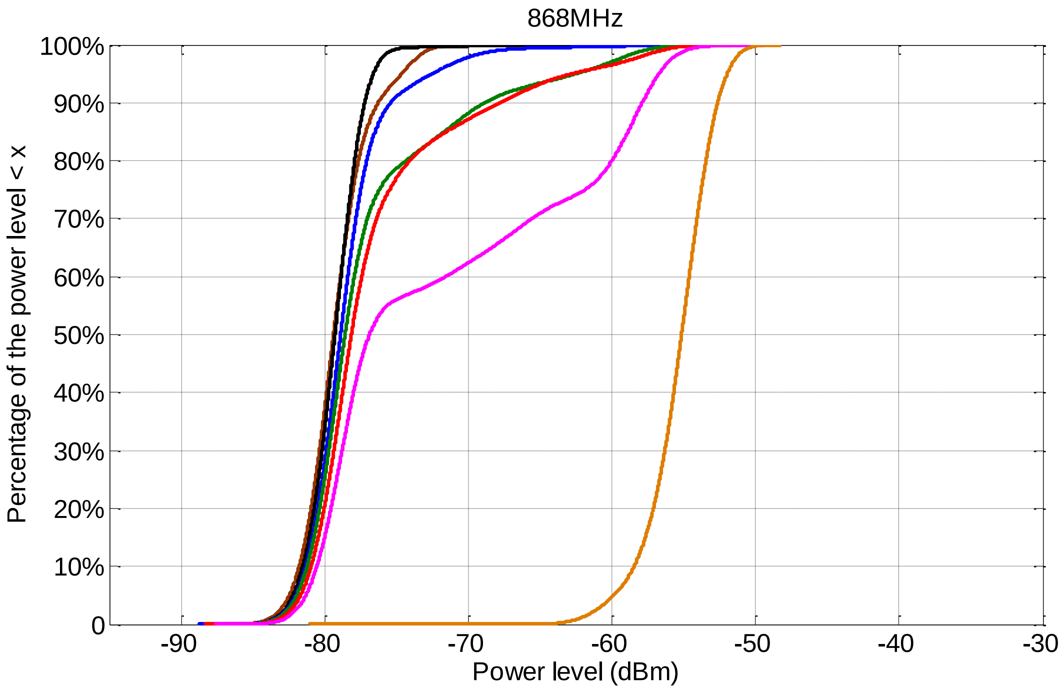


Figure 19: Probability of OOB at 868.0 MHz (Block Edge + 6.0 MHz, 25 kHz Bandwidth) at various rate targets

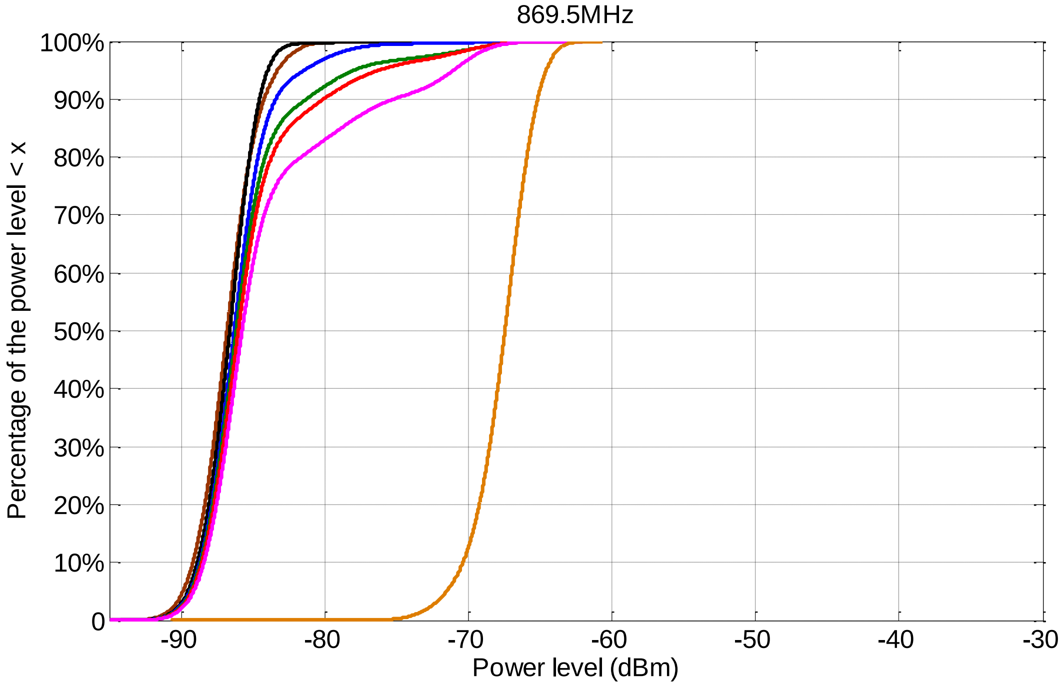


Figure 20: Probability of OOB at 869.5 MHz (Block Edge + 7.5 MHz, 25 kHz Bandwidth) at various rate targets

6.4 Power control

We have calculated the total power transmitted by the UE for each 1 ms subframe by summing the linear power from each of the 50 resource blocks in the 10 MHz channel. Curves of the cumulative distribution for two test locations with different data throughputs and resource usage are shown in Figure 21.

Figure 21 shows that the greater the amount of resources that are being used in the uplink, the greater the transmit power is. However, it also suggests that the available power is not kept constant and split entirely between the number of RBs in use and that the scheduling process is considerably more complicated with a balance being created between signal to interference and noise ratio in the uplink and therefore spectral efficiency and overall loading requirements on the cell. We do not know the overall loading requested in the cell uplink from all users but the curves suggest that this might also play a part in the number of RBs that are required.

It is clear however that even with 40% of RBs being used, the total power is less than approximately 13dBm for 50% of the time and less than 20dBm for approximately 66% of the time.

It should be noted however that the effects of this power variability are already taken into account in the resultant OOB emissions presented in Figure 16 to Figure 20.

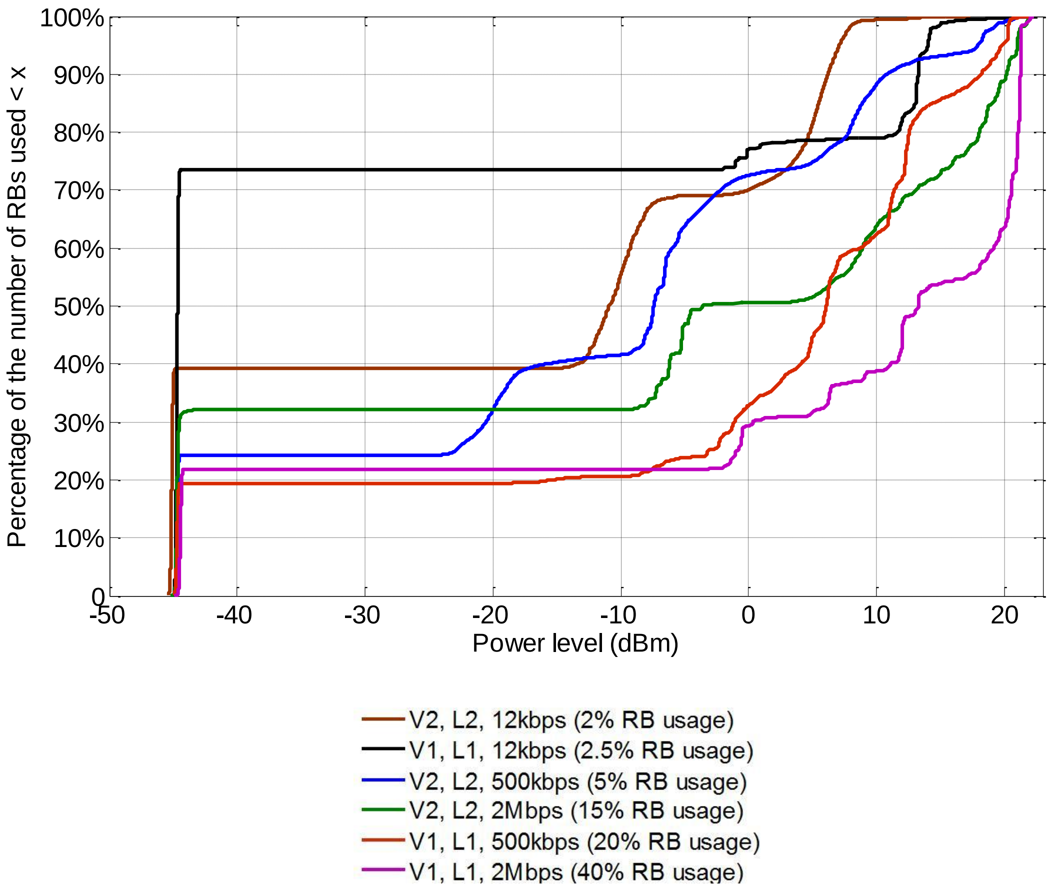


Figure 21: Probability of in-band LTE signal power level at various rate targets and scenarios

Section 7

Conclusions

We have shown in this study that the uplink data rate required for certain applications and uploads are considerably below both; the 43Mbps peak rate supported in the standard for LTE operating in a 10MHz channel; and the maximum of 20Mbps that we found using the example LTE device used in our testing therefore suggesting that the full resources of the cell are unlikely to be allocated to a single user. However, we note that as the path loss between the user and the base station increases the overall uplink throughput available decreased and the user will require more resources of the cell for a given data rate requirement. Therefore the out of band (OOB) emissions are dependent on the cell resources required rather than the absolute uplink data rate requested.

We have undertaken a series of measurements on a live LTE network operating in the middle of the 800 MHz band and used these in conjunction with some lab-based testing to present the out-of-band emissions that might be typical for a system operating in the top 10MHz of the 800 MHz band. We found that additional filtering at the upper edge of the 800 MHz band needed to be taken into account as well as the 10MHz frequency offset in this translation.

We selected a small pool of production standard user equipment and have shown that some of these have lower OOB emissions than the unit that we have primarily used for our testing. We have provided graphs of the OOB emissions that are detectable at frequencies of 862.9625, 864.85, 868.0 and 869.5MHz under various uplink loading rates. The graphs show that for the majority of time the OOB emissions from our measurements were at least 20dB and as much as 40dB lower than those from a device using all the resources of the cell.

It is hoped that these graphs will provide a valuable reference to manufacturers and stakeholders in the 862 – 870 MHz band in helping them understand and mange the potential risk for interference to their systems.

We have also shown for some example locations within a live LTE network that the power level transmitted by the UE is considerably less than 23dBm for the majority of time. The power level is throughput and resource usage dependent as would be expected but even in the highest usage example of 40% of resource blocks, the power was less than approximately 13dBm for 50% of the time.

In summary we conclude that LTE out of band emissions falling at a particular frequency in the adjacent band is considerably lower in our live network examples than for a device using all resources of the cell and transmitting at maximum power. Our key conclusions are therefore:

i) Typical application throughputs may be considerably less than the maximum data rate that the cell can support in the uplink;

ii) Due to additional band filtering, care should be taken when inferring emission levels for the closest LTE block from measurements of blocks that are further away from the adjacent band in question;

iii) For a given data rate the number of resource blocks that the network will schedule and consequently the number of time slots that a particular RB is in use will affect the likely interference risk;

iv) For a given data rate the number of RBs that are used and the pattern of hopping employed by the network will have an effect on the probability of OOB emissions falling on a particular frequency above 862MHz;

v) The OOB emissions in our measurements were, for the majority of time, between 20dB and 40dB lower than those from a device using all resources of the cell uplink; and

vi) The UE uses power control such that it's transmit power is optimised to ensure appropriate power levels arriving at the base station and maximise battery life. Therefore transmit power will be distributed between the maximum of +23dBm and a minimum of around -45dBm.

Annex 1

Glossary

LTE	Long Term Evolution, a 4G technology
OOB	Out of Block
MIMO	Multiple Input Multiple Output
RB	Resource Block
RF	Radio Frequency
RFID	Radio Frequency Identification
SIMO	Single Input Single Output
SINR	Signal To Interference plus Noise Ratio
SRD	Short Range Device
SC-FDMA	Single Carrier – Frequency Division Multiple Access
TCP	Transmission Control Protocol
UE	User Equipment
WiMAX	Worldwide Interoperability for Microwave Access, a 4G technology

Annex 2

Detailed Measurement Methodology

2.1 Uplink measurements on a live network

An overview of the measurement setup is shown in Figure 22. Uplink throughput was driven across the LTE network in a controlled manner using Jperf throughput analysis software[16] based on a client laptop at the user end with a corresponding server located within the core of the LTE network. A number of different TCP packet layer throughput rates[17] were used in order to gain an understanding of the performance of the uplink.

In order to maximise efficiency of our testing, approximately 5 minutes of real-time recording of the RF transmissions were made and analysis was then performed in post processing in non-real-time. In order to capture all of the transmissions, we configured the UEs to work with a single antenna port (SIMO configuration) and connected an RF power divider directly to the port. This allowed the antenna to be connected to one branch and our recording and monitoring hardware to be connected to the other.

Figure 23 provides an example snapshot of the recordings over a 1ms sub-frame for the three uplink data rates of 12 kbps, 500 kbps and 2 Mbps that were measured. Resolution bandwidth has been adjusted to 180 KHz, commensurate with 12 x 15 kHz subcarriers making up a resource block.

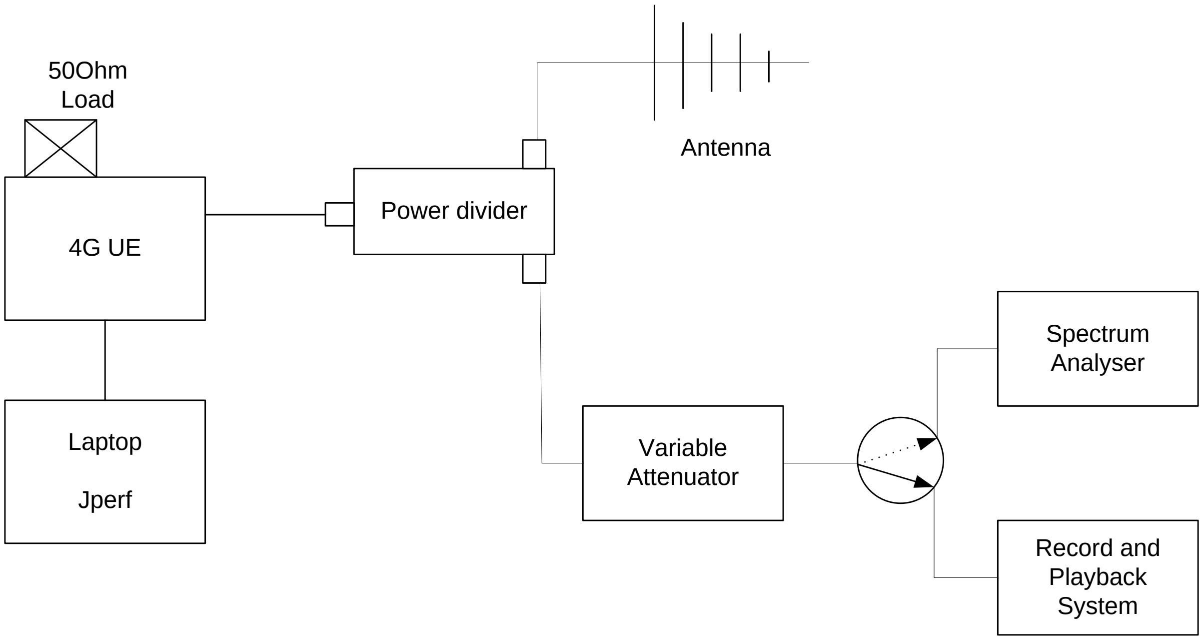


Figure 22: Block diagram of LTE Network Measurement Setup

16 http://sourceforge.net/projects/jperf/

17 Rates of 12 Kbps, 500 kbps and 2 Mbps only were used so as not to place an excessive load on a network with other users

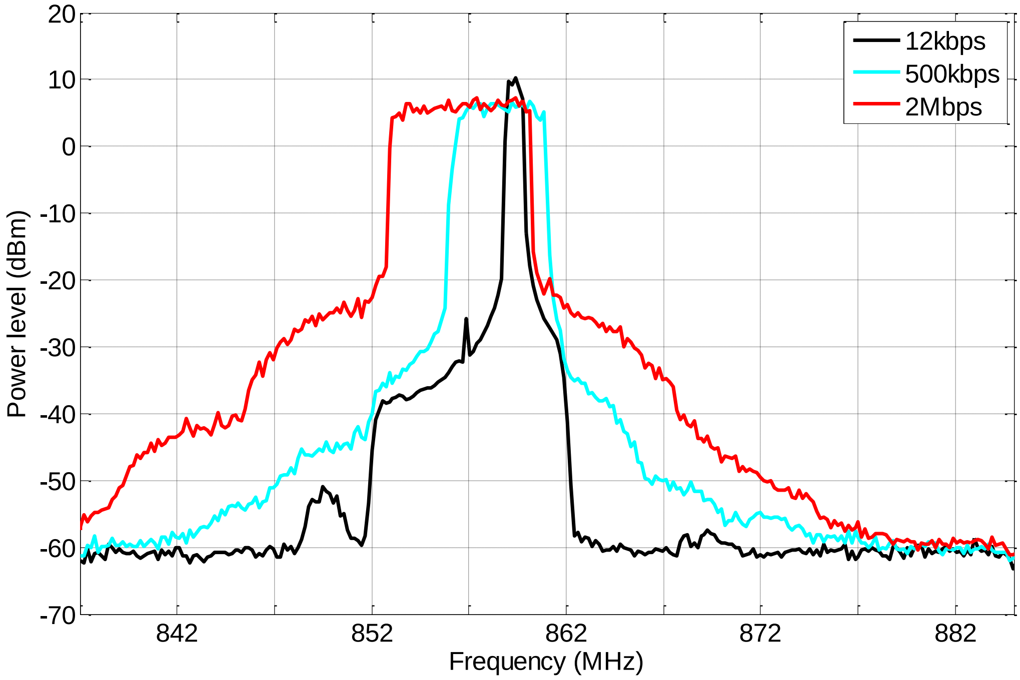


Figure 23: A snapshot of the in-band and out-of-band power level measured from a production LTE user device with various data rates

2.2 Uplink Measurements in a Lab Environment

We also carried out a series of measurements of the uplink emissions from several different user devices in a lab environment. An overview of the measurement setup is presented in Figure 24. In this case we used a single conducted path between the base station and the user device and did not evaluate any benefits of multiple data streams (MIMO). The base station was connected to a core network but our test device was the only user connected to the base station at any time.

As in the measurements made using a live network, uplink throughput was driven across the LTE radio link in a controlled manner using a combination of Jperf throughput analysis software for the lower data rates and an FTP server and client for the higher data rates (up to 20 Mbps), both used a laptop connected to the LTE UE and a server located within the LTE core network.

Once again, we monitored and recorded the uplink transmissions in real-time for subsequent post processing, using a single antenna port on the user equipment. We tested with several different user devices. In one case we could not select the UE to use only one antenna port so we coupled the two ports together using an RF power combiner.

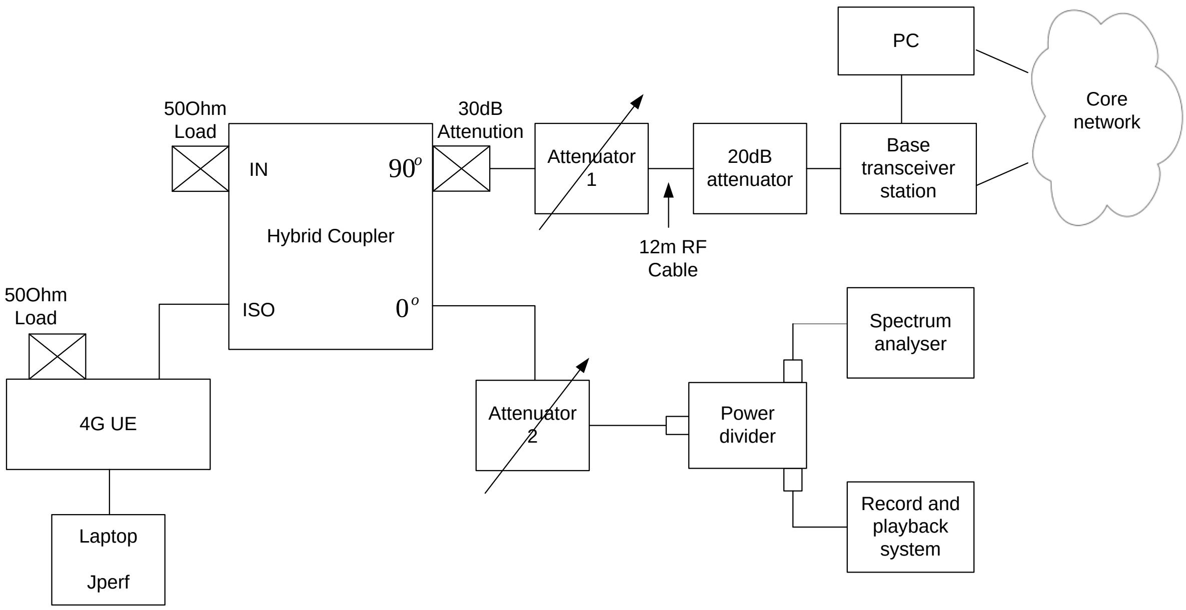


Figure 24: Block diagram of Lab Measurement Setup

The use of a single uplink stream provides a worse case interference risk. If two or more streams are transmitted from a device then the total power is divided equally between them. The transmissions may not necessarily add together coherently and therefore the overall OOB emissions may be reduced slightly.

2.3 Analysis Methodology

LTE is specified based on timeslots of 0.5ms duration containing 7 symbols and resource blocks of 180 kHz made up of 12 subcarriers of 15 kHz each. The specification only allows resources to be allocated on the basis of a 1ms sub-frame and a contiguous set of resource blocks in the uplink. The total uplink power of 23dBm may be allocated to the number of resource blocks that are actually in use within a particular 1ms sub-frame.

The data files created by recording the real-time power measurements are then post processed to convert these back into a frequency domain (as shown in Figure 3) and then further processed to allow analysis at a resource block level. The detailed procedures of processing the measurement file involve: converting to the frequency domain and applying offset to account for cable and attenuation losses; data is then combined into a per RB basis and subsequent analysis undertaken.

The frequency resolution of the analysis is set to 1 kHz. The transmission parameters of the LTE user equipment (UE) are presented in Table 7. Our recordings generally covered a 50 MHz bandwidth to ensure the wanted and OOB emissions were covered.

Table 7: Measured UE Signal Parameters

Parameter	Value
Maximum Output Power	23dBm
Multiple Access Method	SC-FDMA
Block Bandwidth	10MHz
Time Transmission Interval (TTI)	1ms
Time frame	10ms
Allocated resource blocks	Varies between 0 – 50
resource block spacing	180kHz
Number of occupied sub-carriers	600
sub-carrier spacing	15kHz
Number of sub-carrier per resource block	12