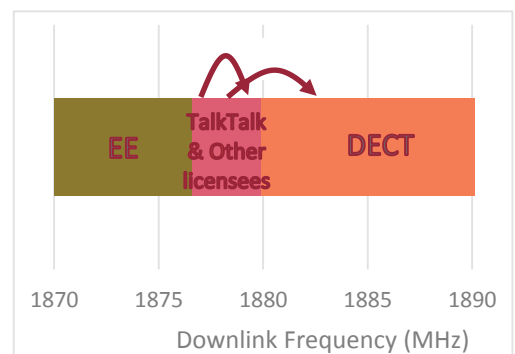
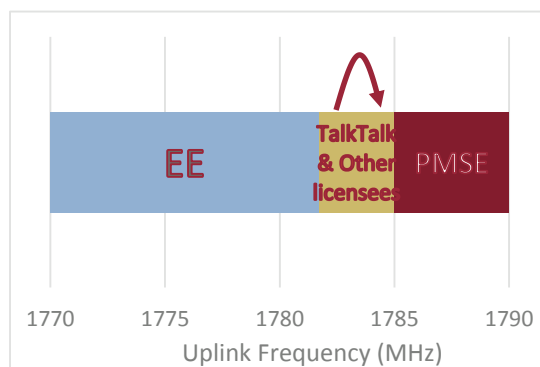


RF co-existence analysis of (DECT) guard-band LTE to DECT and GSM

A Real Wireless report for TalkTalk



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Executive summary

This study has been commissioned by TalkTalk for Real Wireless to investigate the potential impact of deploying LTE in the frequency bands 1781.7-1785 MHz paired with 1876.7-1880 MHz.

In November 2005, Ofcom recommended [i] that the frequency bands 1781.7-1785 MHz paired with 1876.7-1880 MHz (the Digital Enhanced Codeless Telecommunications (DECT) Guard bands) be released for use of low power concurrent shared access (CSA), subject to limits on the in-band and out of band power spectral densities and other technical licence conditions. This decision took into consideration responses from a consultation and a technical analysis on the interference that would be caused to adjacent bands by allowing operation in these bands [ii]. This technical analysis determined that it was possible to deploy “both narrowband (e.g. low power GSM) and wideband (e.g. low power cdma2000x1)” systems, but noted that in-band sharing would likely need co-ordination between the shared users of the band. Protection of adjacent bands required a power limit which was modified to a power spectral density to facilitate more flexible use of the spectrum.

Since 2005, mobile technology has evolved from 2G to advanced 4G systems, with typical expected spectral efficiencies in an urban environment rising from 0.04bps/Hz for GSM to 1.3 for LTE R8 and 2.6 for LTE R10 [iii], and vastly improved ability to support high rate data services expected by consumers. Despite having slightly higher Out of Band emissions than legacy technology, the advantages of using more advanced technology in 1800MHz spectrum was recognised by Ofcom [iv] when in 2012 they granted EE’s request to vary their licence in order to be able to additionally deploy other technologies in their 1800MHz spectrum.

In March 2014 Ofcom initiated a consultation on relaxing these licence conditions further [v] in order to increase the maximum EIRP that can be used by MNOs in E-UTRA band 3 by 3dB in the downlink (base transmit) direction. Ofcom’s corresponding statement [vi] agreed to the request to increase the maximum BS transmit power on the basis that “there is unlikely to be a significant change in the existing interference environment experienced by current radio services operating in the same band or adjacent to the 1800 MHz licensees if we allow a 3 dB power increase” and “that granting the requested variations has the potential to provide benefits for consumers through improved mobile coverage and/or capacity, deeper in-building penetration and greater network engineering flexibility”.

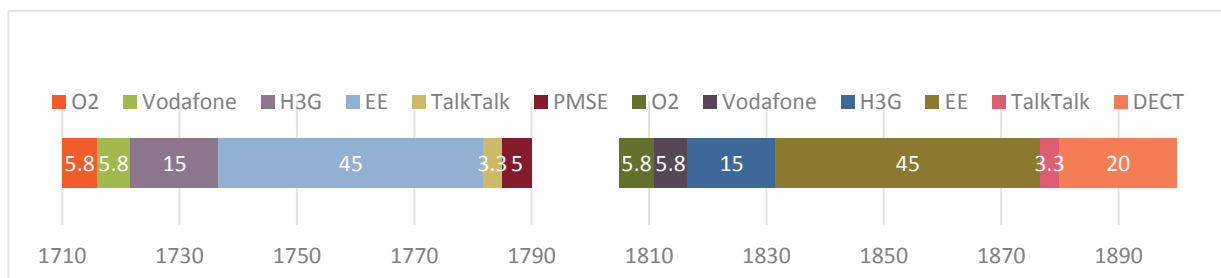


Figure 1: The 1800MHz band showing the frequency allocations to mobile operators, TalkTalk (and other CSA licensees) and adjacent use of PMSE and DECT technologies.

TalkTalk have a licence to operate [vii] low power transmitters in the CSA band (1781.7-1785 MHz paired with 1876.7-1880 MHz). This frequency range is at the upper edge of the harmonised E-UTRA (commonly referred to as LTE) band 3 [viii], and represents spectrum that has equipment readily available for use in this band and is shown in Figure 1.

TalkTalk previously asked Real Wireless to quantify the additional interference that could be caused to licenced users of adjacent spectrum [ix] if LTE equipment using the more relaxed Out of Band emission limits if Commercially Off The Shelf (i.e. without any additional filtering than standard) LTE equipment was to be used rather than legacy GSM equipment. This found that the impact on an adjacent LTE mobile operator would be small (increase in ACI by small fractions of a dB), and that this would be insensitive to the coupling loss values assumed.

Ofcom has reviewed these results and asked for more detailed calculations to be provided that can inform what impact may occur on adjacent channel DECT systems and co-channel users of the CSA band, and for measurements to be made of the impact of any LTE interference on DECT systems compared to that caused by a GSM picocell [x]. The findings are summarised below.

The measurement campaign:

- Interference from a 20dBm LTE home eNodeB does not:
 - Reduce voice quality of a DECT system compared to a GSM picocell.
 - Reduce dropped call performance of a DECT system, compared to a GSM picocell.
 - Reduce baby monitor performance compared to a GSM picocell
- Spectrum Emission measurements show that:
 - Spectrum emissions from the eNodeBs tested (from Arcadyan and Huawei) meet the proposed licence limits although they do not comply with the existing licence limits.

We have performed an assessment of the impact on co-channel and adjacent channel uses, using a methodology based upon a previous study of this band by Ofcom. Three different environments were considered for the co-channel case, and one of these was used to assess the adjacent channel case. We have found:

Analysis of co-channel uses of the CSA band:

- Whereas GSM use of the CSA band allows frequency re-use to avoid interference, the impact of co-channel interference can prevent call success. LTE throughput will tend to reduce – in effect there is a more gradual degradation when LTE is subject to interference.
- When GSM is co-located with LTE, the protection requirements of GSM dictate the required isolation.
- In general, the protection distance to protect GSM from LTE is approximately ½ that required to protect GSM from a co-channel GSM interferer
- LTE can co-exist with other LTE systems: In general two floors or two houses separation is required to achieve >10Mbps; reduced separation distances reduce the achievable throughput, but link performance is maintained in the cases considered.

- More detailed separation distances are presented in Table 13, Table 15 and Table 16.

Analysis of adjacent channel case:

- In an adjacent dwelling, GSM does not impact DECT on channels 0 to 7. More remote dwellings suffer less impact.
- In an adjacent dwelling a high power 34.3dBm LTE HeNB causes some interference impact to all DECT channels. In DECT channels 0-5 100% call success probability is possible in more than half of the victim-aggressor geometries assessed. It is highly likely that interference impact free locations can be found to locate any DECT receivers that may suffer interference from LTE. The capacity available for these lightly impacted channels would be sufficient to support traffic demand in high density user environments.
- Though the potential for interference is low, the fact that LTE has a potential impact on all DECT channels raises the potential concern that any interfered DECT system may not be able to find a spare free DECT channel for use. The measurements performed in a related study suggest that this is not the case, even with more severe (i.e. worse) interference geometries than those used in the analysis in this report.

Taken together, the analysis and measurement campaigns demonstrate that:

- Any additional interference caused by relaxing the OoB emissions by adopting the proposed licence limits would not cause any operational impairment to neighbouring adjacent channel use (DECT or LTE licensed by MNOs)
- In order to protect existing GSM use in the CSA bands, LTE deployment will need a separation distance approximately ½ of the separation distance required between co-channel GSM users, though alternative frequencies cannot be used.
- Since it is understood that existing use of the CSA band is limited, these separation constraints should not impose a significant barrier to LTE deployment in the CSA band.

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Contents

1.	Introduction.....	1
2.	Previous co-existence studies.....	3
3.	Licence limits and out of band emissions.....	4
4.	Interference scenarios of interest in this study	7
4.1	Co-channel interference	7
4.1.1	Desired and interference communication links	7
4.1.2	Co-channel interference assessment methodology.....	8
4.1.3	GSM ACS in presence of a co-channel wideband interferer	11
4.1.4	Parameters used in co-channel case	13
4.2	Adjacent channel interference to neighbouring DECT band.....	15
4.2.1	Desired and interference communication links	15
4.2.2	Background on DECT systems	16
4.2.3	DECT system response to interference from GSM and LTE	16
4.2.4	Adjacent channel interference assessment methodology.....	19
4.2.5	Parameters for adjacent channel case	19
5.	Interference assessment results	22
5.1	Co-channel interference assessment	22
5.1.1	Multi-storey office environment	23
5.1.2	High density residential environment (terraced houses).....	27
5.1.3	Campus environment with an outdoor interfering microcell	30
5.2	Adjacent channel interference assessment	34
6.	Summary and findings	37

Tables

Table 1: The existing licence limits for the downlink frequency band 1876.7-1880 MHz, for both in-band and out-of-band emission limits.....	5
Table 2: LTE UE (aggressor) Tx parameters	13
Table 3: GSM MS (aggressor) Tx parameters	14
Table 4: Equipment parameters – LTE victim UE receiver.....	14
Table 5: Equipment parameters – GSM victim MS receiver.....	15
Table 6: DECT ACS values for an interference from other DECT channels	17
Table 7: ACS for different DECT channels to the nearest GSM interferer able to transmit at 23dBm. 18	
Table 8: ACS of different DECT channels to a 3MHz wideband LTE interferer in the CSA band. 19	
Table 9: List of HeNB (aggressor) transmitter parameters.....	20
Table 10: Equipment parameters – DECT victim Fixed/Portable Part.....	21

Table 11: Environment parameters.....	22
Table 12: Technology interactions for different scenario identities	22
Table 13: Multi-storey environment: Summary separation metric to protect different combinations of technology mix for multi-storey case	27
Table 14: Probability of call success for scenario 1, high density residential environment using GSM victim and receiver EIRPs of 0dBm or 23dBm, 3 house separation.	28
Table 15: High density residential environment: Summary separation metric to protect different combinations of technology mix	30
Table 16: Campus environment with an outdoor interfering microcell: Summary separation metric to protect different combinations of technology mix.....	33
Table 17: Technology interactions for different scenario identities	34
Table 18: DECT channel 6	35

Figures

Figure 1: The 1800MHz band showing the frequency allocations to mobile operators, TalkTalk (and other CSA licensees) and adjacent use of PMSE and DECT technologies.	5
Figure 2: The 1800MHz band showing the frequency allocations to mobile operators, TalkTalk (and other CSA licensees) and adjacent use of PMSE and DECT technologies.	2
Figure 3: In-band and Out of Band limits of existing CSA licence, previously proposed licence limits and the limits of different base stations.	6
Figure 4: Interference paths of relevance when considering interference between different low power licensees of the CSA band.....	7
Figure 5: Assumed downlink user data throughput available per LTE resource block (i.e. available to user after consideration of guard band, signalling and reference symbol overheads) for a lightly loaded network using 2x2 MIMO (based upon []).	10
Figure 6: ACLR for a 23dBm 1800MHz basestation, from []	10
Figure 7: ACS values for GSM as a function of the offset from the GSM channel []	12
Figure 8: Illustration of GSM as a co-channel victim in the presence of a wideband interferer	12
Figure 9: Adjacent channel interference contribution in to the in-band	13
Figure 10: Interference paths of relevance when considering interference to DECT.	16
Figure 11: DECT carrier arrangement in proximity to GSM carrier that would cause most interference.	17
Figure 12: DECT carrier arrangement in proximity to a 3MHz LTE in the CSA band. Overlapping with the LTE carrier are the positions of hypothetical DECT carriers if the DECT sequence were to be extended.	18
Figure 13: Multi-storey environment: Probability of call success on different floors at different distances from serving picocell, for scenario 1 and 10. This is the 23dBm GSM transceiver case.	23
Figure 14: Multi-storey environment: Throughput available for scenario 4 at different separations from the serving cell on different floor separations.....	24
Figure 15: Multi-storey environment: Mean throughput available for different floor separations, for DL (Scenario 4) and UL (Scenario 8). Desired transmitter sources are a low power (20dBm, scenario 4) HeNB and a 23dBm UE (scenario 8), in the presence of 23dBm GSM aggressor transceivers.	24

Figure 16: Multi-storey environment: Mean call success rate available for different floor separations, for DL (Scenarios 2 and 3) and UL (Scenario 7). Interference sources are a higher power (34.3dBm, scenario 2) and lower power (20dBm, scenario 3) HeNBs and a 23dBm UE (scenario 7).	25
Figure 17: Multi-storey environment: Mean throughput available for different floor separations, for DL (Scenarios 5 and 6) and UL (Scenario 9). Interference sources are a higher power (34.3dBm, scenario 5) and lower power (20dBm, scenario 6) HeNBs and a 23dBm UE (scenario 9).	26
Figure 18: High density residential environment: Mean call success rate available for different terraced house separations, for DL (Scenarios 2 and 3) and UL (Scenario 7). Interference sources are a higher power (34.3dBm, scenario 2) and lower power (20dBm, scenario 3) HeNBs and a 23dBm UE (scenario 7).	28
Figure 19: High density residential environment: Mean throughput available for different terraced house separations, for DL (Scenario 4) and UL (Scenario 8). Desired transmitter sources are a low power (20dBm, scenario 4) HeNB and a 23dBm UE (scenario 8), in the presence of 23dBm GSM aggressor transceivers.	29
Figure 20: High density residential environment: Mean throughput available for different terraced house separations, for DL (Scenarios 5 and 6) and UL (Scenario 9). Interference sources are a higher power (34.3dBm, scenario 5) and lower power (20dBm, scenario 6) HeNBs and a 23dBm UE (scenario 9).	30
Figure 21: Line of Sight campus environment: Probability of call success for scenario 1, with an indoor GSM victim MS (served by a 23dBm indoor microcell) subject to interference from a 23dBm outdoor GSM microcell.....	31
Figure 22: Line of Sight campus environment: Mean call success rate available versus separation distance, for DL (Scenarios 2 and 3) and UL (Scenario 7). Interference sources are a higher power (34.3dBm, scenario 2) and lower power (20dBm, scenario 3) HeNBs and a 23dBm UE (scenario 7).....	32
Figure 23: Line of Sight campus environment: Mean throughput available versus separation distance, for DL (Scenario 4) and UL (Scenario 8). Desired transmitter sources are a low power (20dBm, scenario 4) HeNB and a 23dBm UE (scenario 8), in the presence of 23dBm GSM aggressor transceivers.	32
Figure 24: Line of Sight campus environment: Mean throughput available for different separation distances, for DL (Scenarios 5 and 6) and UL (Scenario 9). Interference sources are a higher power (34.3dBm, scenario 5) and lower power (20dBm, scenario 6) HeNBs and a 23dBm UE (scenario 9).....	33
Figure 25: High density residential scenario: Average probability of DECT call success on different DECT channels and housing separations, with a 23dBm GSM BS transmitting in GSM ARFCN 884.....	34
Figure 26: High density residential scenario: Average probability of DECT call success on different DECT channels and housing separations, with a 34.3dBm LTE (high power) HeNB.	35

1. Introduction

This study has been commissioned by TalkTalk for Real Wireless to investigate the potential impact of deploying LTE in the frequency bands 1781.7-1785 MHz paired with 1876.7-1880 MHz.

In November 2005, Ofcom recommended [11] that the frequency bands 1781.7-1785 MHz paired with 1876.7-1880 MHz (the Digital Enhanced Cordless Telecommunications (DECT) Guard bands) be released for low power concurrent shared access use (CSA), subject to limits on the in-band and out of band power spectral densities and other technical licence conditions.

This decision took into consideration responses from a consultation and a technical analysis on the interference that would be caused to adjacent bands by allowing operation in these bands [12]. This technical analysis determined that it was possible to deploy “both narrowband (e.g. low power GSM) and wideband (e.g. low power cdma2000x1)” systems, but noted that in-band sharing would likely need co-ordination between the shared users of the band. Protection of adjacent bands required a power limit which was modified to a power spectral density to facilitate more flexible use of the spectrum.

Since 2005, mobile technology has evolved from 2G to advanced 4G systems, with typical expected spectral efficiencies in an urban environment rising from 0.04bps/Hz for GSM to 1.3 for LTE R8 and 2.6 for LTE R10 [13], and vastly improved ability to support high rate data services expected by consumers. Despite having slightly higher Out of Band emissions than legacy technology, the advantages of using more advanced technology in 1800MHz spectrum was recognised by Ofcom [14] when in 2012 they granted EE’s request to vary their licence in order to be able to additionally deploy other technologies in their 1800MHz spectrum.

In March 2014 Ofcom initiated a consultation on relaxing these licence conditions further [15] in order to increase the maximum EIRP that can be used by MNOs in E-UTRA band 3 by 3dB in the downlink (base transmit) direction. Ofcom’s corresponding statement [16] agreed to the request to increase the maximum BS transmit power on the basis that “there is unlikely to be a significant change in the existing interference environment experienced by current radio services operating in the same band or adjacent to the 1800 MHz licensees if we allow a 3 dB power increase” and “that granting the requested variations has the potential to provide benefits for consumers through improved mobile coverage and/or capacity, deeper in-building penetration and greater network engineering flexibility”

TalkTalk have a licence to operate [17] low power transmitters in the CSA band (1781.7-1785 MHz paired with 1876.7-1880 MHz). This frequency range is at the upper edge of the harmonised E-UTRA (commonly referred to as LTE) band 3 [18], and represents spectrum that has equipment readily available for use in this band and is shown in Figure 2. Mobile downlink is supported in the upper duplex band. Being able to use this CSA band to support LTE would permit operation of equipment with higher spectrum efficiency than the existing licenced use, and TalkTalk have previously asked Real Wireless to quantify the additional interference that could be caused to licenced users of adjacent spectrum [19] if LTE equipment using the more relaxed Out of Band emission limits if Commercially Off The Shelf (i.e. without any additional filtering than standard) LTE equipment was to be used rather than legacy GSM equipment.

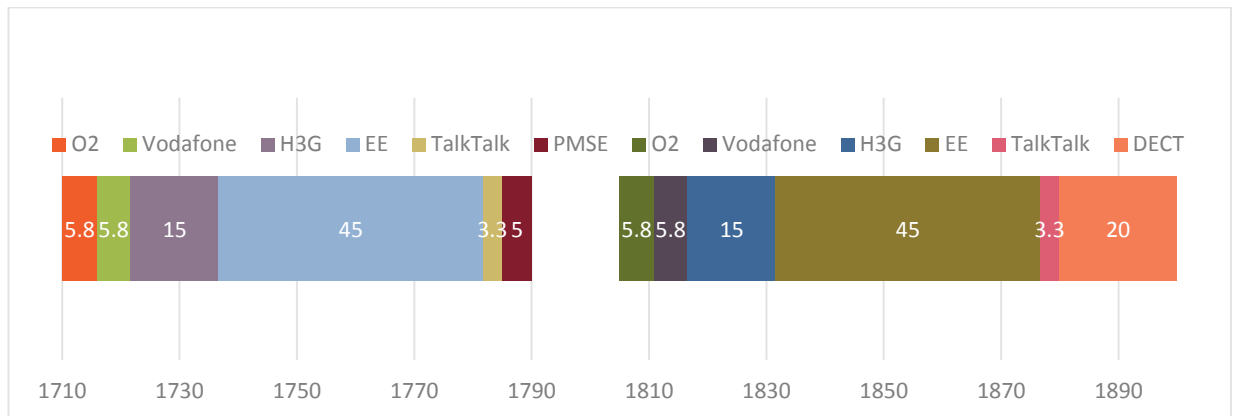


Figure 2: The 1800MHz band showing the frequency allocations to mobile operators, TalkTalk (and other CSA licensees) and adjacent use of PMSE and DECT technologies.

The above study looked in particular to the interference that exists at the adjacent LTE mobile operator (EE) to compare existing and proposed out of band limits were used, and found:

- Changing from existing to proposed limits increases the ACI by small fractions of a dB, e.g. ranging from 0.02dB to 0.09dB depending to the proximity to the band edge.
- The ACI is dominated by the ACS of the victim's receiver, since LTE ACS is less than the ACLR, the increased Out of Band (OoB) emission limits of the proposed licence have little impact.
- The difference between existing and proposed limits is insensitive to the coupling loss values assumed.

These results were shared with Ofcom in order to support a request made by TalkTalk to vary the CSA licence conditions to conform to the more relaxed OoB limits found in COTS LTE equipment, but conforming to the existing in-band power flux density limits.

Ofcom has reviewed these results and asked for more detailed calculations to be provided that can inform what impact may occur on adjacent channel DECT systems and co-channel users of the CSA band, and for measurements to be made of the impact of any LTE interference on DECT systems compared to that caused by a GSM picocell [20].

This measurement report was conducted in the presence of an operational LTE and GSM networks and consisted of the following test scenarios.

1. Spectrum emission test
2. DECT interference test (voice quality tests on DECT and other Key Performance Indicators (KPI)s such as dropped call rate and call hold times for DECT)
3. Baby monitor interference test

These measurements found that:

- Interference from a 20dBm LTE home eNodeB does not:
 - Reduce voice quality of a DECT system compared to a GSM picocell.

- Reduce dropped call performance of a DECT system, compared to a GSM picocell.
- Reduce baby monitor performance compared to a GSM picocell
- Spectrum Emission measurements show that:
 - spectrum emissions from the eNodeBs tested (from Arcadyan and Huawei) meet the proposed licence limits although they do not comply with the existing licence limits.

This report presents the results of a co-existence assessment of co-channel (LTE and GSM) and adjacent channel (DECT) interference should LTE be deployed in the CSA band, one of whose licensees is TalkTalk.

This report is structured as follows:

- Section 2 reviews previous findings on co-existence studies or relevance.
- Section 3 presents the licence limits (proposed and existing) and the Out of Band emissions of GSM and LTE
- Section 4 Identifies the interference scenarios of interest and the methodology used in the interference assessment. This section also identifies the parameters used or derives suitable parameters for use to assess the interference.
- Section 5 presents the results
- Section 6 summarises the findings.

2. Previous co-existence studies

As part of the analysis to determine viability of using LTE or WiMax in E-UTRA band 3 (1800 MHz band) instead of GSM, CEPT has published 2 key documents of particular relevance to this study:

- CEPT Report 40 [21]: This report is concerned with interference between technologies in the same band (including LTE interference into GSM)
- CEPT Report 41 [22]: This report is concerned with interference between technologies in the 1800MHz band to adjacent bands (including LTE interference to DECT).

Particular interference combinations of relevance to this study considered in the above reports are:

- Interference in adjacent channels: LTE HeNB interfering with DECT PP or DECT FP. This is covered in section 8 of CEPT Report 41, which finds:

“It can be concluded that the interference created by the LTE/WiMAX1800 system would be similar to the interference created by GSM1800.”

“No guard band is therefore required between LTE/WiMAX1800 and DECT allocations, provided that DECT is able to properly detect interference on closest DECT carriers F9-F7 and escape to more distant carriers F6-F0 within 1880 - 1900 MHz”

“When pico-cellular LTE/WiMAX1800 BS is deployed inside of the building in co-existence with DECT FP and PP deployed in the same building indoor area, some potential interference is likely to exist from indoor pico-cellular LTE/WiMAX1800 BS to DECT if they are placed too close and they are operating in the adjacent channel at 1880 MHz”

- In-band interference: LTE HeNB interfering with devices in an adjacent band or channels¹ (either GSM MSs or LTE UEs). This is covered in CEPT Report 40, which finds:

“1) A frequency separation of 200 kHz or more [is required] between LTE channel edge and the GSM carrier’s channel edge between a neighbouring LTE network and a GSM network.

2) No frequency separation [is] required between LTE channel edge and the UMTS carrier’s channel edge between a neighbouring LTE network and a UMTS network

3) No frequency separation [is] required between LTE channel edges between two neighbouring LTE networks”

- Adjacent channel interference: LTE UEs interfering with low power GSM BS or LTE HeNB sharing access to the same or adjacent channel:
 - Though not directly equivalent, CEPT report 41 considers the potential interference of LTE UEs into adjacent channel METSAT Earth station receivers at the lower frequency end of Band 3. It notes that any interference from GSM MSs has not been evident and that *“It is believed that the interference from LTE/WiMAX UE to METSAT Earth Stations operating in adjacent frequency band is unlikely to be a problem.”* This indicates that CEPT do not expect interference caused to adjacent channel receivers to be any worse than the GSM case.

ERC Report 100 [23] is specifically concerned with an evaluation of compatibility between DECT and GSM 1800. In particular section 4.4.7 is concerned with interference from an indoor GSM 1800 micro BTS interfering with an indoor DECT system. This study assumed that the GSM micro BS would have a maximum power of 30-33dBm, and concluded that the indoor co-existence case ‘was not a critical scenario’ since DECT will always have carriers that are not interfered, assuming that DECT can detect the interference (and avoid it).

No previous work on co-channel interference between GSM and LTE has been found.

3. Licence limits and out of band emissions

In order to facilitate technology neutral licences, Ofcom defined the Out of Band limits for use in this band using a radiated power spectral density rather than a maximum EIRP. The value of the peak power spectral density is consistent with a GSM picocell radiating 23 dBm EIRP in a channel bandwidth of 200 kHz (i.e. 0dBm/kHz).

¹ The CEPT studies were primarily interested in interference between operators using non-overlapping spectrum. In this study we are also interested in the case of LTE HeNB interfering with GSM devices sharing access to the CSA band. This was not covered by CEPT, but will be addressed in this study.

The existing in-band and out of band licence limits [vii] for the base station transmit band are shown in Table 1. These limits are the same as the licence limit definition, but are presented here in one table to simplify the presentation.

Table 1: The existing licence limits for the downlink frequency band 1876.7-1880 MHz, for both in-band and out-of-band emission limits.

Δf - frequency offset from lower band edge (MHz)	Maximum EIRP power spectral density (dBm/kHz) (two values are given for in-band power spectral density (psd) – the higher only to be used with agreement and in exceptional conditions)	
-5.7 to -1.5	-74	
-1.5 to -0.9	-56	
-0.9 to -0.3	-53	
-0.3 to -0.1	$-49 + 20 * (\Delta f + 0.1)$	
-0.1 to 0	$-33.6 + 153.3 * \Delta f$	
0 to 0.05	$-33 + 153.3 * \Delta f$	$-33 + 153.3 * \Delta f$
0.05 to 0.1	$-26 + 60 * (\Delta f - 0.05)$	$-26 + 60 * (\Delta f - 0.05)$
0.1 to 0.2	$-23 + 230 * (\Delta f - 0.1)$	$-23 + 300 * (\Delta f - 0.1)$
0.2 to 3.2	0	7
3.2 to 3.3	$-23 + 230 * (3.3 - \Delta f)$	$-23 + 300 * (3.3 - \Delta f)$
3.3 to 3.35	$-23 - 60 * (\Delta f - 3.3)$	
3.35 to 3.5	$-26 - 153.3 * (\Delta f - 0.05 - 3.3)$	
3.5 to 3.7	$-49 - 20 * (\Delta f - 0.2 - 3.3)$	
3.7 to 4.3	-53	
4.3 to 4.9	-56	
4.9 to 9.1	-74	

The in-band and OoB limits of the existing licence conditions and for different classes of LTE base stations [18], a 23dBm GSM base station [26] and the previously proposed licence limits [19] are shown in Figure 3, where the in-band limits are truncated at the maximum 0dBm/kHz existing licence limit. As can be seen, the previously proposed licence limits are set at a power flux density which is the maximum of the existing licence limit or the 3GPP specification of the 24dBm EIRP local area BS in a 3MHz bandwidth.

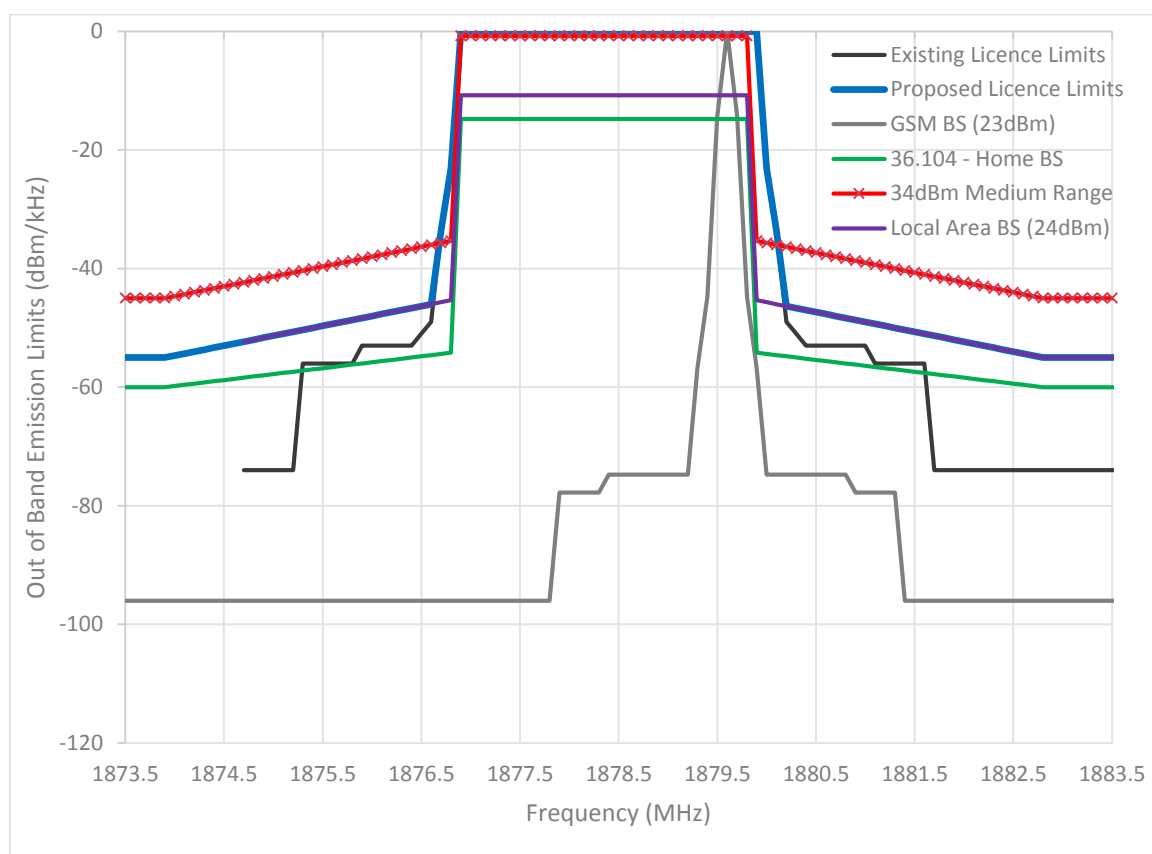


Figure 3: In-band and Out of Band limits of existing CSA licence, previously proposed licence limits and the limits of different base stations.

Currently, there is no restriction on co-siting multiple 23dBm GSM base stations operating across the CSA band – and this would correspond to a slightly higher power spectral density (psd) envelope than the previously proposed licence limits. Hence deployment of a system corresponding to the proposed licence limits should not be any worse than what can potentially be deployed today. These limits, though not written into the licence, were predicated on the use of GSM which can accommodate 14 channels of standard 23dBm EIRP and allow frequency co-ordination to avoid interference.

From examination of Figure 3, it is evident that:

- For adjacent channels systems:
 - The existing licence OoB limits are set at a level that is lower than is achievable by COTs LTE equipment with the same in-band transmit psd, and that the 20dBm Home base station would exceed the existing licence limits more than 2MHz from the channel edge. With the proposed licence limits, interference to a potential victim would reduce if the victim system ACS performance is less than the minimum 45dB ACLR performance of the proposed licence limits.
 - LTE equipment with a transmit power of less than 34dBm has less psd EIRP than the existing limit. With the proposed licence limits, interference to a potential victim would reduce if the victim system ACS performance is less than the minimum ACLR performance plus the in-band psd reduction of the potential LTE aggressor transmitter below licence limits.

- For co-channel systems (i.e. other CSA licensees):
 - The interference impact will be dominated by the ability to reuse spectrum by potential victims. In the case where the full bandwidth is used, the re-use distance will be the required separation distance – which will depend upon the potential aggressor transmit psd. This re-use distance may be less than that of existing GSM aggressors.

4. Interference scenarios of interest in this study

In this study we are interested in the interference that would be generated by use of the CSA band to neighbouring DECT systems or to other uses of the DECT guard band.

Hence, there are two key cases to analyse:

- Co-channel case: Interference to and from other potential users of the CSA band. We will consider both uplink and downlink for both GSM and LTE technologies.
- Adjacent channel case: Interference in the adjacent DECT channel (from any Out of Band emissions from the LTE HeNB and DECT sensitivity to adjacent channels).

4.1 Co-channel interference

4.1.1 Desired and interference communication links

The desired and interference paths between the transmitter and receivers of the CSA band are shown in Figure 4.

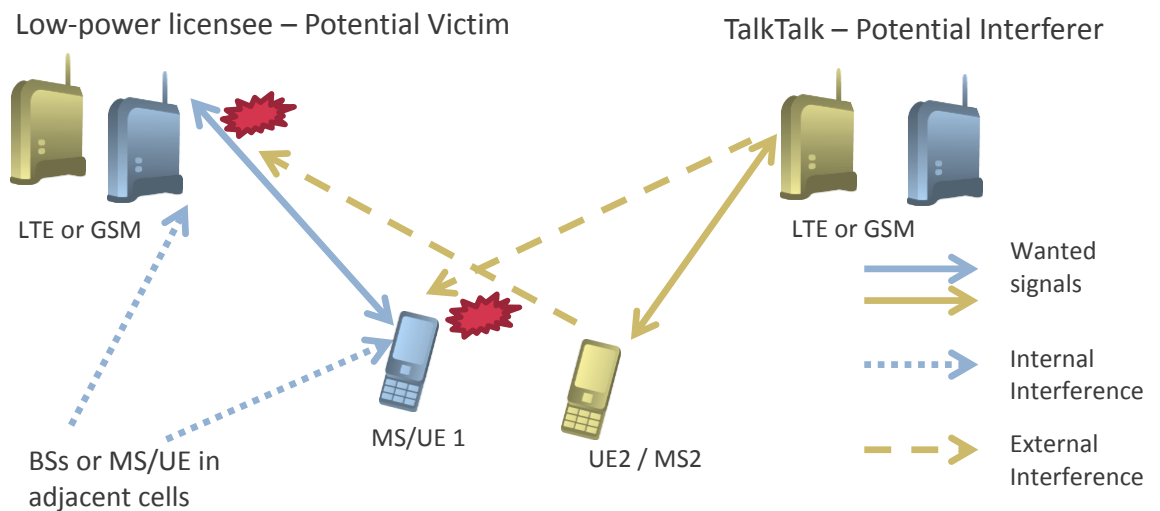


Figure 4: Interference paths of relevance when considering interference between different low power licensees of the CSA band.

Both the uplink and the downlink need to be considered, and the different candidate technologies of interest are GSM and LTE. This therefore results in the following 4 cases for both uplink and downlink directions.

- GSM-GSM case: Where a GSM system is deployed, what is the frequency re-use distance, and are there sufficient GSM channels available to allow a CSA operator to deploy to support adequate (voice) service, using other channels within the same frequency re-use distance?
- LTE-GSM case: Where an LTE system is deployed (occupying the whole band), what is the re-use distance for a potential victim GSM receiver to allow adequate voice quality.
- LTE-LTE case: Where an LTE system is deployed, what is the separation distance required, such that an acceptable degradation in throughput can be supported by the victim system.
- GSM-LTE case: For a given GSM carrier, what is the separation distance required to allow an acceptable degradation in throughput, given that the GSM interference will only impact a limited number of LTE RBs.

4.1.2 Co-channel interference assessment methodology

Ofcom's 2005 analysis to establish the viability of low power use of the CSA bands in the presence of in-band interference was based on identifying the achievable utility of low power GSM in the presence of narrowband GSM and broadband CDMA interference. A key difference is that GSM is based on narrowband frequency re-use, whereas LTE is designed to work with a re-use factor of 1. However GSM could utilise up to 14 channels in the CSA band, meaning that frequency co-ordination can adopt any available channels within the re-use distance of an interfered channel.

The Ofcom methodology is directly relevant to this case and will be summarised below before identifying the differences required to adapt for use with LTE.

Using the methodologies described, Ofcom considered the following environments² [24]:

- Multi-storey office environment: Ofcom identified the floor separation / separation distance to allow frequency re-use in a multi-storey office environment: Having assessed the number of cells required to support operation within each floor (based on range and capacity), the method calculated the interference to other users on different floors to work out the frequency re-use distance in terms of the number of floors for an adequate call success rate, given the probability of the received C/I being adequate given the propagation fading statistics. The environmental parameters (serving cell to victim, victim to aggressor geometry, path loss models, penetration losses and fading statistics) are described in detail in Annex A of [24].
- High density residential environment (terraced houses): Ofcom identified the separation distance to permit frequency reuse in a high density residential environment (terraced houses) and to achieve a call success rate of at least 97% based on adequate C/I and fading statistics. The environmental parameters

² Ofcom also considered the required separation distance between office buildings. This example has not been considered in this study.

- (serving cell to victim, victim to aggressor geometry, path loss models, penetration losses and fading statistics) are described in detail in Annex D of [24].
- Campus environment with an outdoor microcell: In this case an external microcell interferes with indoor users being served by an indoor microcell. Ofcom assessed the probability of call success for indoor users served by an indoor picocell in the presence of interference from an outdoor microcell at different separation distances and different obstructions and path loss models users as a function of the distance of users from their serving picocell. These overall call success probability was derived by weighting the individual call success probabilities for different desired path separation distances by the probability of users being at different distances from their serving picocell. The environmental parameters (serving cell to victim, victim to aggressor geometry, path loss models, penetration losses and fading statistics) are described in detail in Annex C of [24].

For this study we can adopt these 3 environments and other model parameters, replacing GSM parameters with suitable LTE parameters where appropriate, and establish separation distance metrics between victim and aggressor systems such that adequate performance can be achieved³.

For each environment of interest, the performance metrics are the separation such that degradation doesn't exceed acceptable limits. These are:

- Multi-storey office environment: The number of floors separating victim and aggressor
- High density residential environment (terraced houses): The number of houses separating victim and aggressor systems.
- Campus environment with an outdoor microcell: The separation distance of the outdoor microcell from the building such that indoor victim system performance is adequate.

The performance metric depends upon the victim system technology. For GSM, the key metric of interest is the ability to maintain connectivity to establish and maintain a phone call. For LTE, the packet-oriented communications link can be maintained over a wide range of SINR, with the throughput reducing with interference but being able to maintain connectivity at reduced throughput. This is particularly the case where GSM interference may only impact a limited number of LTE resource blocks. It is therefore of interest to consider the relationship between SINR and user throughput per resource block based upon [25] and depicted in Figure 5.

³ Note that since both GSM and LTE are FDD systems it is not appropriate to consider the mutual interactions between base stations or user terminals.

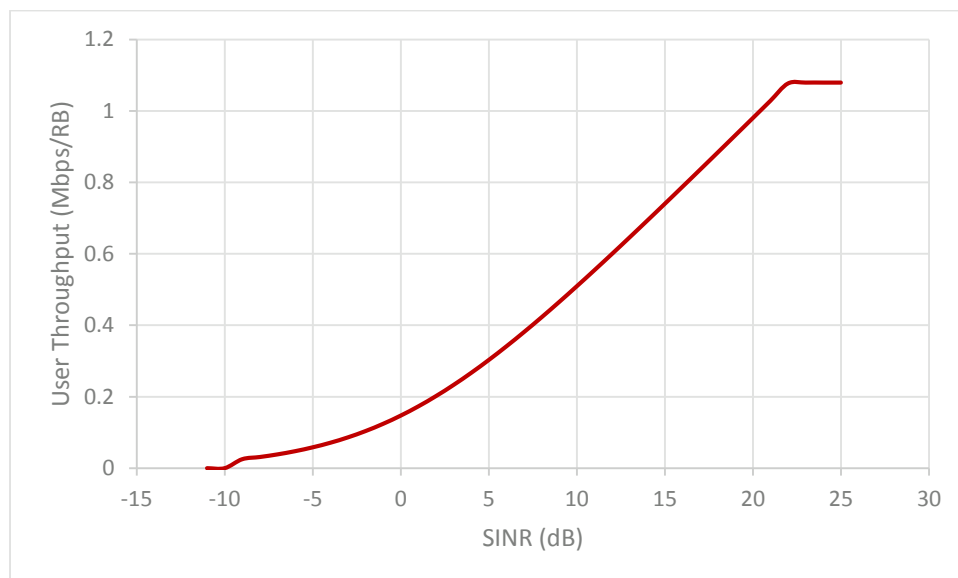


Figure 5: Assumed downlink user data throughput available per LTE resource block (i.e. available to user after consideration of guard band, signalling and reference symbol overheads) for a lightly loaded network using 2x2 MIMO (based upon [25]).

Above 22dB the spectrum efficiency cannot improve further and below -10dB demodulation is not possible. Based on this assumed performance curve, using all 15 resource blocks available in a 3MHz LTE carrier, a maximum user throughput of 16.2Mbps is available in the downlink direction. It is therefore of interest to consider the impairment likely to be caused by a GSM interferer.

Table 2 of Annex 2 of ERC report 100 [26] identifies the GSM 1800MHz OoB emissions. For a 23dBm EIRP basestation these can be translated into equivalent ACLR values as a function of GSM channel separation shown in Figure 6. At one channel offset the ACLR is at the baseline level of 45dB defined for LTE systems – and so it would be expected that at one channel offset the impact of a narrowband GSM carrier would be no worse than an LTE carrier with which the LTE system is designed to cope.

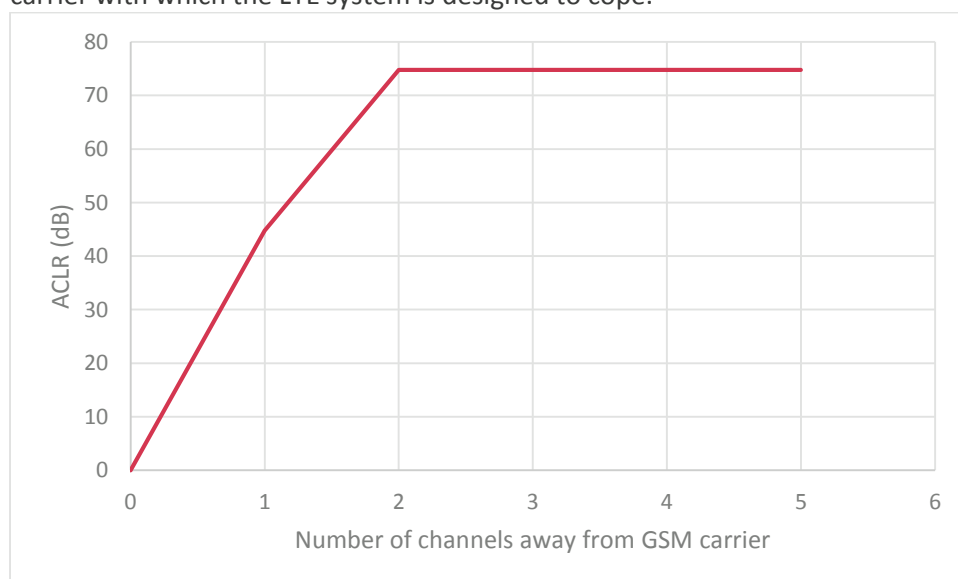


Figure 6: ACLR for a 23dBm 1800MHz basestation, from [26]

The 180 kHz resource block bandwidth is only slightly less than the nominal 200kHz GSM carrier bandwidth separation. Whilst it is possible that a GSM carrier could overlap with up to 3 resource blocks this would be unlikely to occur and the impact on the two edge resource blocks is likely to be small. It is therefore of interest to consider the more likely case that a GSM carrier may occur co-channel with 2 resource blocks. When the peak psd of each RB is at the same level as the GSM transmitter, protection of any victim co-channel RBs would require identical separation distances as the GSM case. In any event where the LTE psd is less, the separation distances would increase slightly since the victim LTE RB signal power would be less. The next adjacent resource blocks would be less impacted owing to the GSM ACLR – though not to the same extent as an adjacent LTE carrier if the LTE psd is less than the GSM carrier. In any event it is highly unlikely that a single GSM carrier would have any perceptible impact on more than 4 LTE RBs – corresponding to a maximum user throughput of 11.9Mbps (reduced from a maximum of 16.2Mbps).

Given this we can establish target performance metrics as:

- GSM as victim: Consistent with the Ofcom study, the distance is calculated as that which permits a C/I value so that 97% of the assumed normal fading distribution can achieve a minimum C/I of 9dB.
- LTE as victim: We can calculate the total user throughput available considering the overlap between the aggressor and the victim bandwidth. In the case that GSM is the aggressor the impact of the interference assuming the GSM carrier is in the middle of two Resource Blocks and apply the GSM ACLR response to adjacent RBs. In the case that LTE is the aggressor, it is assumed that all RBs are impacted equally. The aggressor signal is assumed to be increased owing to fading, but the victim throughput is calculated assuming no fading on the desired signal path (i.e. mean propagation conditions).

4.1.3 GSM ACS in presence of a co-channel wideband interferer

The ACS for an 1800MHz GSM MS of adjacent 200 kHz GSM channels, taken from [27], is as is shown in Figure 7. The in-channel and first adjacent 3 channels do not change between GSM systems at 900 or 1800MHz, and between MS or BS, though BSs do have better isolation away from these nearby channels.

We can use these values to determine the co-channel interference power accepted by a GSM victim in the presence of a wideband interferer.

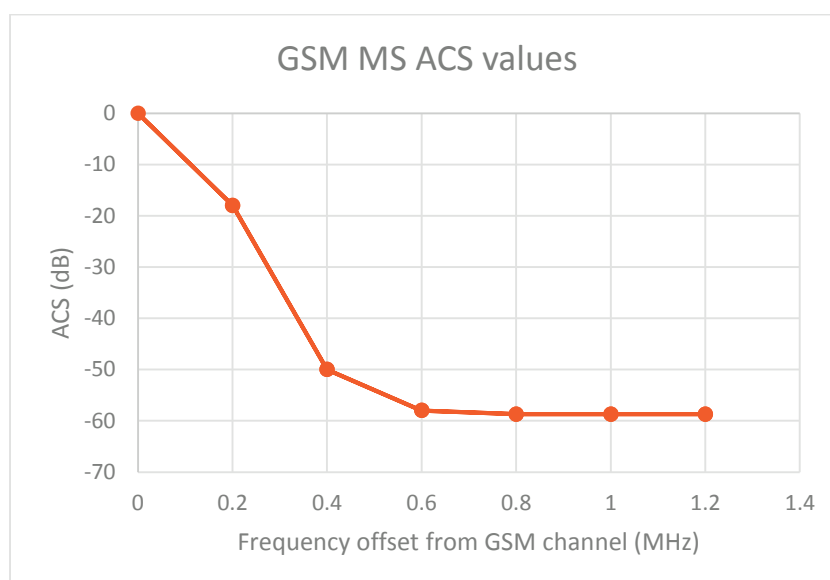


Figure 7: ACS values for GSM as a function of the offset from the GSM channel [23]

As shown in Figure 8, a narrowband co-channel victim will receive unsuppressed victim bandwidth interference power, together with suppressed energy from the wideband source that overlaps with adjacent narrowband victim channels.

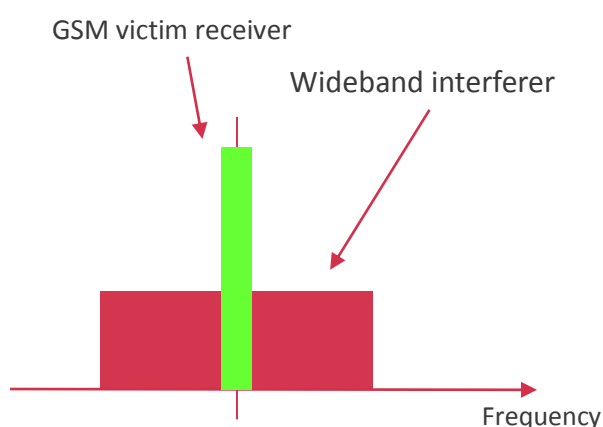


Figure 8: Illustration of GSM as a co-channel victim in the presence of a wideband interferer

Using the in-band interference power as a reference, Figure 9 shows the additional interference power as additional adjacent channel energy is captured by the receiver. It can be seen that by increasing the interference of additional adjacent channels has a marginally small increase in the total interference power captured by the GSM receiver, asymptoting at approximately 0.14dB. Since the ACS of GSM is identical for the first 3 adjacent channels for GSM BS and MS, we can use the value of 0.14dB for both MS and BS victims in this analysis.

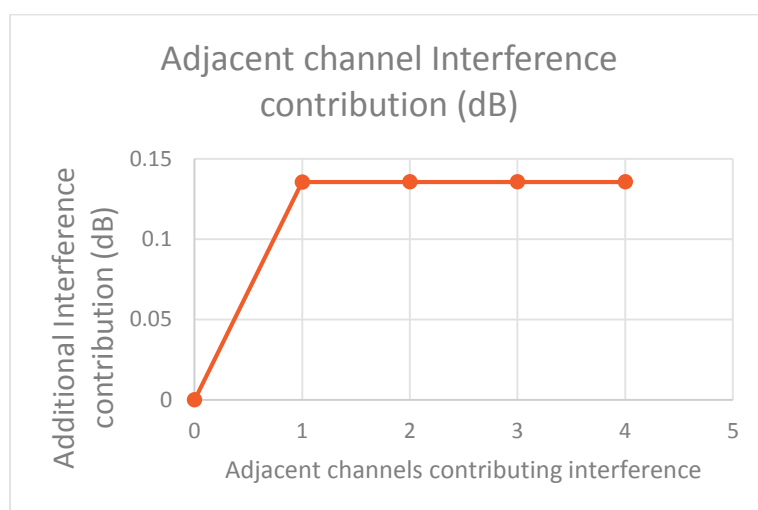


Figure 9: Adjacent channel interference contribution in to the in-band

4.1.4 Parameters used in co-channel case

Following tables show the parameters used in the case A:

- Table 2: LTE UE (aggressor) Tx parameters
- Table 3: GSM MS (aggressor) Tx parameters
- Table 4: Equipment parameters – LTE victim UE rx
- Table 5: Equipment parameters – GSM victim MS rx
- Environment parameters Table 11

Parameter	Value	Units	Comment
Maximum transmit power	23	dBm	3GPP TS 36.101 – Table 6.2.2-1: UE Power Class
Transmission BW	3	MHz	This is the BW that TT uses
ACLR	N/A	dB	N/A

Table 2: LTE UE (aggressor) Tx parameters

Parameter	Value	Units	source
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Maximum transmit power	Maximum mean EIRP density	dBm/kHz	Information Memorandum, Ofcom November 2005
Transmission BW	200	kHz	Technology specification, ETSI TS 145.005, Section 2
ACLR	Fn. Of frequency	dB	ECC Report 082, Compatibility study for UMTS operating within the GSM900 and GSM1800 frequency bands. May 2006 See figs 12 and 13

Table 3: GSM MS (aggressor) Tx parameters

Parameter	Value	Units	source
Channel bandwidth	50 (10 MHz) Adj-ch 18 (3.3 MHz) Co-ch	Resource blocks	3GPP 36.101 – table 5.6.1, for a 10MHz carrier bandwidth.
Antenna gain	0	dBi	3GPP 36.101 – S6.1
ACS	33 (BW≤10MHz) 30 (BW=15MHz) 27 (BW=20MHz)	dB	3GPP 36.101 - Table 7.5.1-1. Not needed for WPB
Noise Figure	9	dB	3GPP R4-092042. NB: TS36.101 has a reference sensitivity in Band 3 with a 10MHz channel bandwidth of -94dBm (corresponding to a noise figure of 10dB).

Table 4: Equipment parameters – LTE victim UE receiver

Parameter	Value	Units	Source
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Receiver bandwidth	200	kHz	Technology specification, ETSI TS 145.005, Section 2
Antenna gain / other losses	N/A	dBi	Use different coupling losses. Comparison is between the different OoB emission limits
Reference sensitivity	-102 (and a 8dB noise figure)	dBm	ETSI TS 145.005, Table 6.2-1a 3GPP TR45.050 for NF
ACS	68.7	dB	See the following documents for details. See Annex 3 and table 88 from: Compatibility study for LTE and WiMAX operating within the bands 880-915/92-960MHz and 1710-1785 / 1805-1880MHz (900/1800 MHz bands). November 2010. CEPT report 40: http://www.erodocdb.dk/docs/doc98/official/pdf/CEPTREP040.pdf NB these results are derived using a target C/I (co-channel) of 9dB – same as used by Ofcom for their low power analysis. Low Power concurrent use in the spectrum bands 1781.7 – 1785 MHz paired with 1876.7 – 1880MHz.

Table 5: Equipment parameters – GSM victim MS receiver

4.2 Adjacent channel interference to neighbouring DECT band

4.2.1 Desired and interference communication links

DECT systems use TDD to separate uplink and downlink communication. The Fixed Part (FP) and Portable Part (PP) have similar transmit and receive characteristics – and so we can simplify the analysis. Interference to the potential victim (either the FP or PP) come from the OoB emissions from the HeNB.

The desired and interference paths are shown in Figure 10.

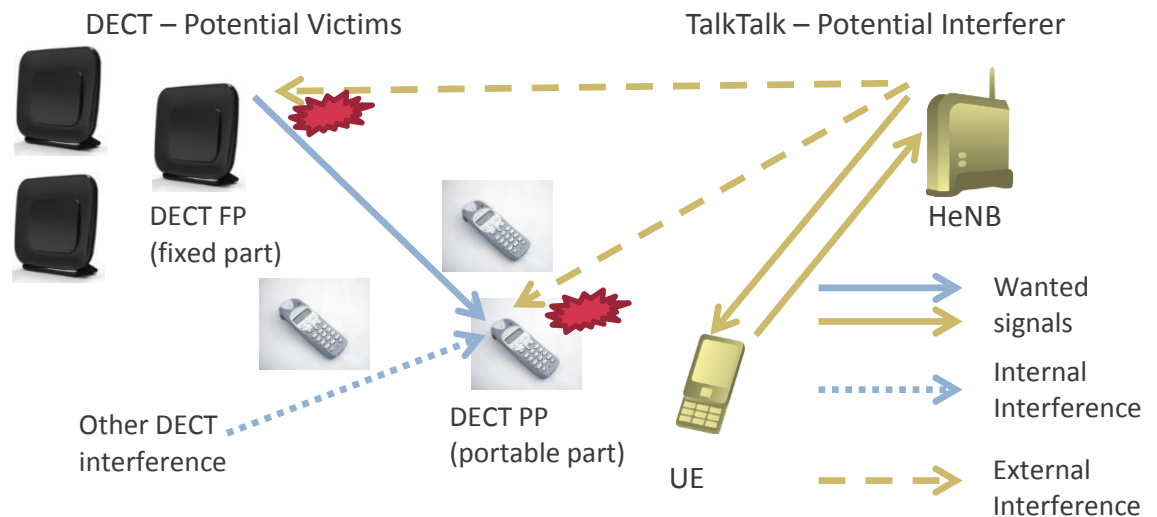


Figure 10: Interference paths of relevance when considering interference to DECT.

The key issue is to identify what DECT channels are able to support adequate voice quality when subject to interference from either GSM or LTE, and to assess if the number of acceptable DECT channels is sufficient to support DECT deployment.

4.2.2 Background on DECT systems

Within Europe DECT typically operates in the 20MHz between 1880 and 1900MHz [28], allowing use of 10 TDD carriers, each with a bandwidth of 1.152MHz, spaced 1.728MHz apart. Each carrier is able to support 12 different bi-directional communications links and each link can support a voice connections. Multiple communications links can be aggregated to support higher bandwidth links, but any applications which use this capability do not appear to be widespread, though market data on this has not been found. A FP terminal can support multiple links to each PP terminal meaning that multiple links need to be used to support intercom-type communication links. Using all carriers result in being able to support 120 bi-directional voice communications links. DECT operation in the USA [29] uses half the bandwidth of Europe (in the band 1920-1930MHz), and “[despite this allocation not being exclusive], it is generally sufficiently free of other users to achieve similar interference-free operation [to Europe]”.

To aid co-existence with other systems, DECT implements a ‘listen before transmit’ capability and is able to move from a ‘noisy’ carrier to a less noisy carrier in the presence of interference. Details of the DECT system properties relating to compatibility can be found in [28]. This coupled with the large number of potential communications links available, suggest that adequate DECT co-existence may be possible, even if DECT channels at the band edge received higher levels of interference than at present.

4.2.3 DECT system response to interference from GSM and LTE

The adjacent channel suppression of a DECT receiver to interference from DECT interference has been derived from minimum performance requirements in [28] to have the ACS values as shown in Table 6.

DECT channel separation	ACS (dB)
1 st adjacent	24
2 nd adjacent	45
3 rd adjacent	51
4 th adjacent	55
5 th adjacent or further	58

Table 6: DECT ACS values for an interference from other DECT channels

In practice DECT ACS is better than these minimum performance requirements and in a previous consideration of licence variation of the 1800MHz band by Ofcom [15], Ofcom noted that:

“We have used the improved blocking performance of 6 dB as compared to the value derived from ETSI standard and used in CEPT Report 41. This is based on the practical tests results in ERC Report 100 which indicated that measured DECT device has blocking performance 6 to 17 dB better than the values in the ETSI standard.”

We will therefore use the value of Table 6 plus 6dB, to estimate the effective ACS of a DECT receiver in the presence of interference from GSM or LTE carriers in the CSA band.

GSM case:

The closest class C carrier in the CSA band is located at ARFCN 884⁴ and we will consider this since it is a representative poor case that would have most impact on the DECT carriers. DECT carriers have a bandwidth of 1.152MHz and are separated by 1.728MHz (i.e. there is a centre carrier to centre carrier gap of 0.576MHz between the carrier edges). The GSM carrier with ARFCN 884 has a gap between the carrier edges of 1.516MHz – ie the GSM carrier is at the far end of the bandwidth that would be occupied by a DECT carrier following the same separation pattern. This is shown in Figure 11.

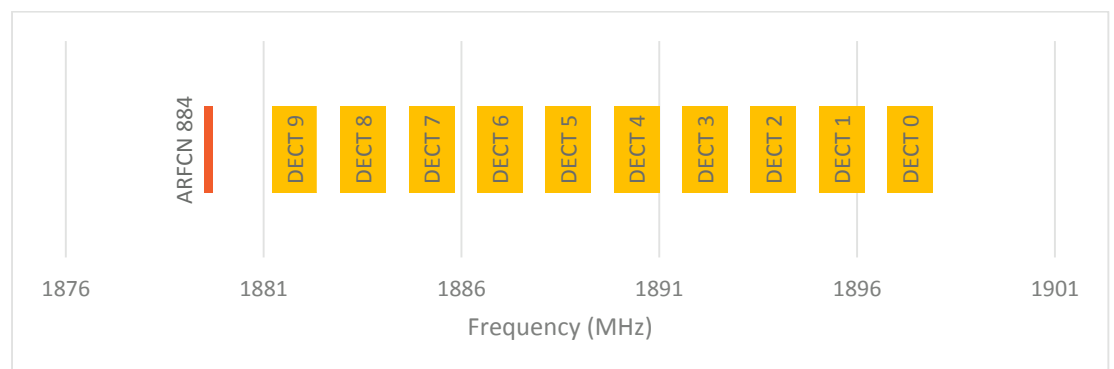


Figure 11: DECT carrier arrangement in proximity to GSM carrier that would cause most interference.

⁴ A lower power 3dBm EIRP carrier at ARFCN=885 is permitted according to the existing eCOP.

Since the GSM carrier is located where a DECT carrier would be (though at the 'remote edge of such a nominal carrier), then we can conservatively approximate that the GSM carrier is 1 DECT carrier separation from the DECT channels, and so the ACS of the different DECT carriers to the GSM interference would be the following.

DECT channel ID	ACS to the closest GSM interferer(dB)
Channel 9	30.0
Channel 8	51.0
Channel 7	57.0
Channel 6	61.0
Channels 0 to 5	64.0

Table 7: ACS for different DECT channels to the nearest GSM interferer able to transmit at 23dBm.

LTE Case:

The position of a 3MHz LTE carrier positioned in the CSA band, and the nearby DECT carriers is show in Figure 12. Also shown in Figure 12 are the positions of hypothetical DECT carriers had the same carrier separation to be extended to lower frequencies from the existing DECT allocation.

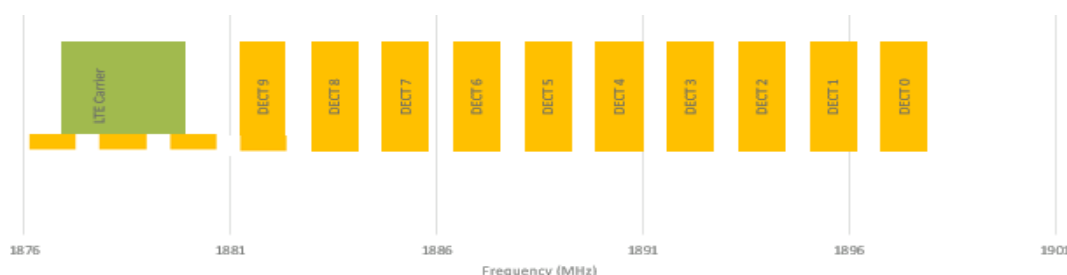


Figure 12: DECT carrier arrangement in proximity to a 3MHz LTE in the CSA band. Overlapping with the LTE carrier are the positions of hypothetical DECT carriers if the DECT sequence were to be extended.

It is clear from inspection of the figure that the ACS in DECT carrier 9 would have a contribution from interference separated in frequency equivalent to the 1st adjacent, the 2nd adjacent and 3rd adjacent channels. DECT carrier 8 would experience interference equivalent to energy from 2nd, 3rd and 4th adjacent carriers, etc.

In [28], the equivalent DECT ACS from an adjacent wideband carrier was based on a weighted average of equivalent DECT adjacent carriers, with the 'middle' carrier weighted by 0.5, and the edge carriers allotted 0.25. The total interference power over the LTE bandwidth being integrated into the victim DECT receiver should be used in conjunction with this estimated ACS.

Using this methodology, the following DECT ACS for each DECT channel to an LTE interferer located in the CSA band is shown in Table 8.

DECT channel ID	ACS to LTE interferer
Channel 9	35.9
Channel 8	55.0
Channel 7	60.0
Channel 6	63.0
Channels 0 to 5	64.0

Table 8: ACS of different DECT channels to a 3MHz wideband LTE interferer in the CSA band.

4.2.4 Adjacent channel interference assessment methodology

Since DECT is assumed to be able to move to interfered channels, in order to be conservative, it is useful to consider the impact on a densely deployed DECT environment where a large number of users may be using any available DECT capacity. For this reason we will consider a dense residential environment.

Ofcom's 2005 analysis [24] to establish the viability of low power use of the CSA bands in the presence of in-band interference was based on identifying the achievable utility of low power GSM in the presence of narrowband GSM and broadband CDMA interference. This methodology will be used in the co-channel case but the general approach and environment can be reused here, modified to consider adjacent channel interference.

In particular we will use:

- High density residential environment (terraced houses): Ofcom identified the separation distance required to support adequate call quality in a high density residential environment (terraced houses) and to achieve a call success rate of at least 99% based on adequate C/I and fading statistics⁵. The environmental parameters (serving cell to victim, victim to aggressor geometry, path loss models, penetration losses and fading statistics) are described in detail in Annex D of [24] and can be reused here.
- We will assess the call success probability on different DECT channels in the presence of GSM and LTE adjacent channel interference to identify the number of available DECT channels as a function of separation distance. The capacity available within this separation distance will be assessed to determine if DECT is unreasonably impacted.

4.2.5 Parameters for adjacent channel case

Following tables show the parameters used in the adjacent channel case:

- Table 9: HeNB transmitter which is modelled as the aggressor
- Table 10: DECT system (fixed and portable part) which is modelled as the victim

⁵ This 99% success rate is higher than Ofcom used for the GSM case – but a higher level of call success is required for DECT systems since they are used like 'fixed line' phones.

- Table 11: Environment related

Parameter	Value	Units	Source
LTE transmit power	High power 34.3 Low power 20dBm	dBm	<p>From 3GPP 36.101, table 5.6.1 there are 15 Resource Blocks for 3MHz channel.</p> <p>At 0dBm/kHz psd, this is a total power of 34.3dBm</p> <p>NB. Compare to 3GPP 36.104 (table 6.2-1 rated power for different base station classes)</p> <ul style="list-style-type: none"> • Wide area (no limit) • Medium range ($\leq 38\text{dBm}$) • Local Area ($\leq 24\text{dBm}$) • Home ($\leq 20\text{dBm}$ for one antenna port) <p>And 3GPP 36.104 table 6.4.2-1 on</p> <ul style="list-style-type: none"> - max. HeNB power to protect adjacent E-UTRA $\leq 10\text{dBm}$ <p>For examining the co-existence impact we will use Existing Licence Limits and compare to Proposed Licence Limits.</p>
Transmission BW	15	RB	See above
ACLR	Fn. Of frequency	dB	Use OoB emissions defined in TS36.104 (for LTE Spec limits) and Proposed licence limits

Table 9: List of HeNB (aggressor) transmitter parameters

Parameter	Value	Units	Source
Noise figure	10	dB	CEPT Report 41 [22].
Receiver bandwidth	1.152	MHz	CEPT Report 41 [22].

Carrier Separation	1.728	MHz	CEPT Report 41 [22].
Required C/I	10	dB	Table 3 (Appendix 1, pp27) of ERC Report 100 [23]
PP or FP Tx Power	24	dBm	Table 3 (Section 4, pp6), of ERC Report 100 [23]

Table 10: Equipment parameters – DECT victim Fixed/Portable Part

Parameter	Assumptions	Comment
Number of transmitters	Single interferer	Closest aggressor devices will dominate interference and improve transparency of the modelling
Aggressor situation	Indoor setting – assume aggressor is transmitting at full power to a UT at edge of coverage.	A pessimistic view of the potential interference between aggressor and victim
Victim situation	Indoor – victim DECT receiver at edge of DECT coverage, but ‘close’ to aggressor.	A pessimistic view of the potential interference between aggressor and victim
Path model	Enhanced minimum coupling loss model	Enables the translation of coupling loss values into free space distances
Fading/body loss/etc	At the edge of coverage including other losses	Simplifies scenario set up
Internal wall penetration loss	Using the general in building propagation loss formula: $L = 20 \log_{10} f + 30 \log_{10} d + 0.4d - 28$ Where L path loss f frequency 1880 MHz	Source: General in building loss formula from The propagation model was taken from Recommendation ITU-R P.1238-3. As used in Ofcom’s analysis on coexistence for low power shared access in the 1800 MHz band [30]

	d distance from transmitter varied based on noise rise	
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Table 11: Environment parameters

5. Interference assessment results

5.1 Co-channel interference assessment

The different victim-aggressor technology combinations interactions are designated scenario identities as depicted in Table 12. Results for example scenarios will be provided but the main results will be presented in a table format identifying the separation distances required to achieve target performance for different deployment configurations.

		Victim Systems			
		GSM MS	LTE UE	GSM picocell	LTE HeNB
Aggressor Systems	HeNB (home BS)	Scenario 3	Scenario 6	N/A	
	HeNB (high power)	Scenario 2	Scenario 5		
	GSM BS	Scenario 1	Scenario 4		
	LTE UE	N/A		Scenario 7	Scenario 9
	GSM MS			Scenario 10	Scenario 8

Table 12: Technology interactions for different scenario identities

The different deployment configurations of interest are these:

- GSM – GSM: This is the case that has already been studied by Ofcom. We will include here are a comparison
- LTE – LTE: This is the case for any LTE deployment that needs to consider co-channel interference with LTE deployment.
- GSM – LTE: This is the case for any LTE deployment that may seek to be deployed where a GSM deployment already exists. We will identify what is the limiting case to protect and required separation distances.

The different link scenarios identified in Table 12 will be assessed to identify the requirements to protect these practical deployment configurations.

5.1.1 Multi-storey office environment

GSM – GSM case:

Scenario 1 was the case considered by Ofcom and the probability of call success for different storeys of the multi-storey office environment is shown in Figure 13. This result replicates the Ofcom results and shows that the same GSM channels can be re-used every 7 floors and maintain a call success rate of 97% when the victim is at separation distances as far as 50m from the serving picocell. Since the same RF characteristics are used for the GSM picocell as the GSM MS, the same results apply to scenario 10 and each direction of the link is equally limited (i.e. it is not constrained more by the uplink than the downlink).

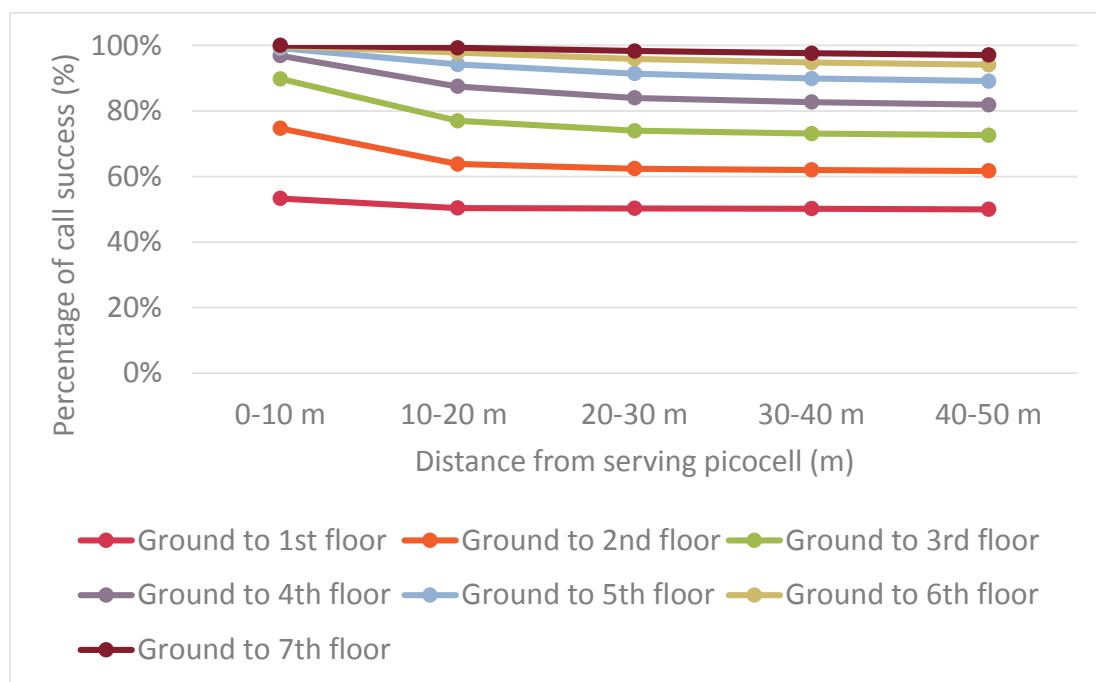


Figure 13: Multi-storey environment: Probability of call success on different floors at different distances from serving picocell, for scenario 1 and 10. This is the 23dBm GSM transceiver case.

GSM-LTE case and LTE-GSM case

Scenario 4 is concerned with the throughput to an LTE UE (i.e. the DL) from a low power (20dBm) HeNB, in the presence of interference from a GSM BS. The achievable throughput on different floors and distances from the serving picocell is shown in Figure 14.

Scenario 8 is concerned with the UL direction of this communications link. To compare UL and DL direction, we can show the mean throughput (averaged across the distance on each floor from the serving cell) for these two scenarios, as shown in Figure 15.

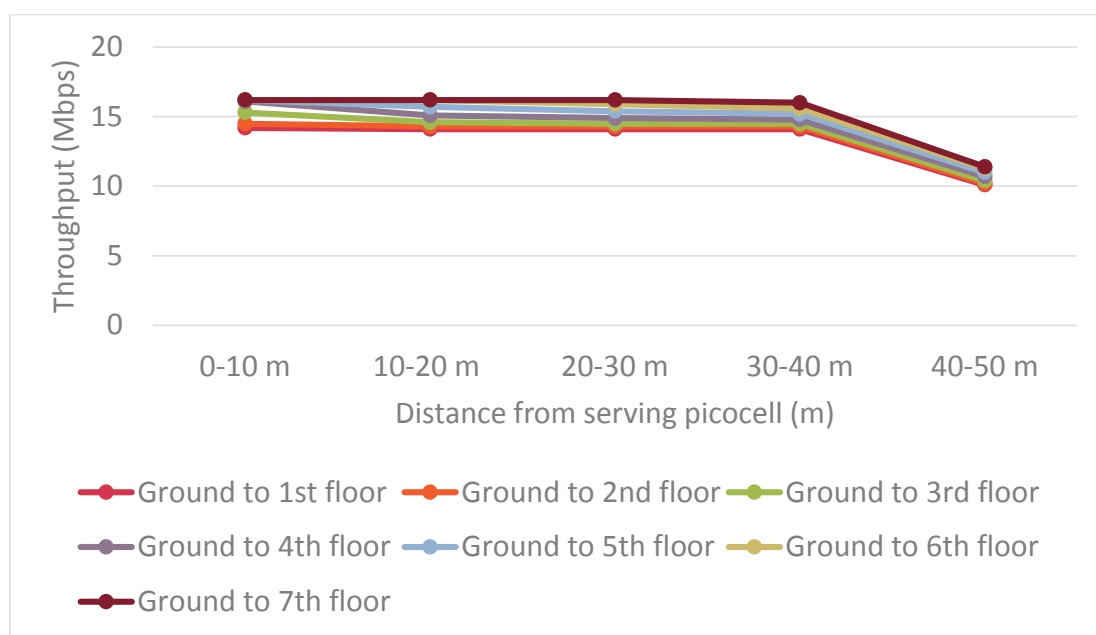


Figure 14: Multi-storey environment: Throughput available for scenario 4 at different separations from the serving cell on different floor separations.

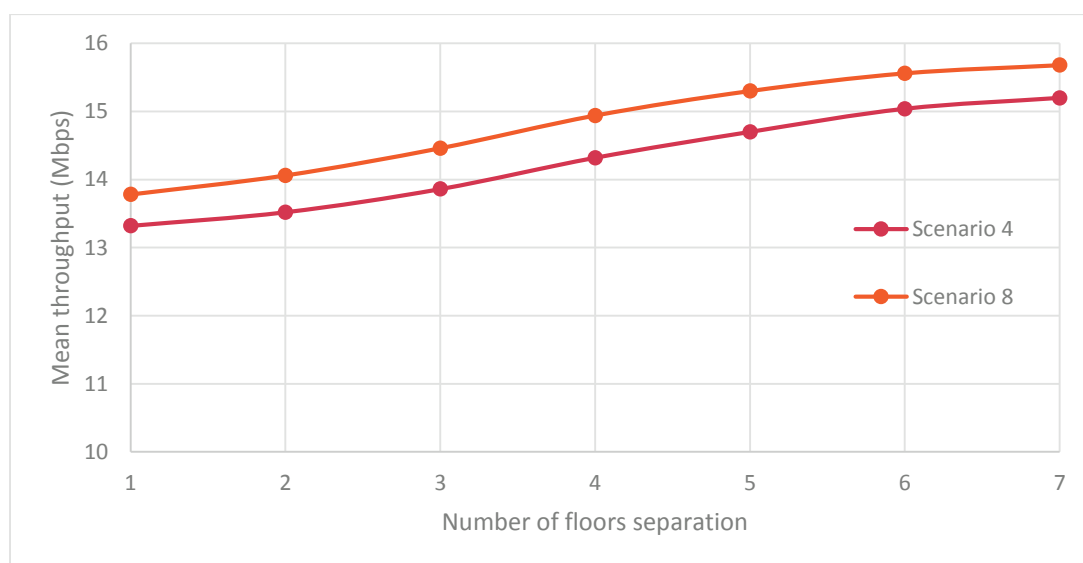


Figure 15: Multi-storey environment: Mean throughput available for different floor separations, for DL (Scenario 4) and UL (Scenario 8). Desired transmitter sources are a low power (20dBm, scenario 4) HeNB and a 23dBm UE (scenario 8), in the presence of 23dBm GSM aggressor transceivers.

The low power of the HeNB means that the throughput in the DL is less than the UL direction. However, more than 13Mbps is available on the floor adjacent to the GSM aggressor – as expected, LTE would appear to be resilient to this narrowband interference.

Since we are primarily interested in understanding the required floor separation distances, we can present the mean call success of the GSM system in the presence of interference from LTE in each direction by presenting the mean call success data for scenarios 2, 3 and 7 as shown in Figure 16.

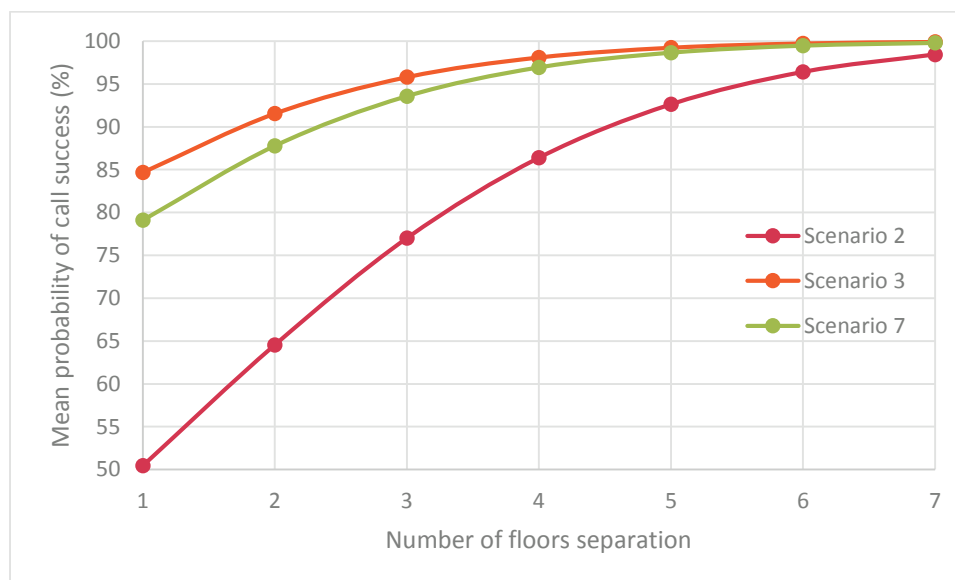


Figure 16: Multi-storey environment: Mean call success rate available for different floor separations, for DL (Scenarios 2 and 3) and UL (Scenario 7). Interference sources are a higher power (34.3dBm, scenario 2) and lower power (20dBm, scenario 3) HeNBs and a 23dBm UE (scenario 7).

The 34.3dBm HeNB (scenario 2) has the same psd as a GSM transmitter and causes similar levels of interference to the victim GSM system resulting in a similar separation distance of 7 floors. No CSA GSM systems could operate within this separation distance since no alternative interference-free CSA channels would exist.

Interference from the low power HeNB (scenario 3) results in the GSM victim being UL limited (i.e. more interference is caused by the LTE UE than by the low power Home BS). With a low (high) powered HeNB, the average victim GSM call success rate of $\geq 97\%$ is only achievable if the victim GSM system is separated by 4 (7) floors from the aggressor LTE system. In practice UE power control would reduce the interference in scenario 7, meaning that 95.8% mean call success would be available with a separation of 3 floors.

LTE-LTE case:

This case is considered in scenarios 5, 6 and 9 to investigate the separation requirements between different LTE systems. Scenario 5 and 6 are concerned with DL performance, scenario 9 with the UL. In scenario 5 both victim and aggressor systems use the higher power 34.3dBm HeNBs, in scenario 6 they both use 20dBm HeNBs.

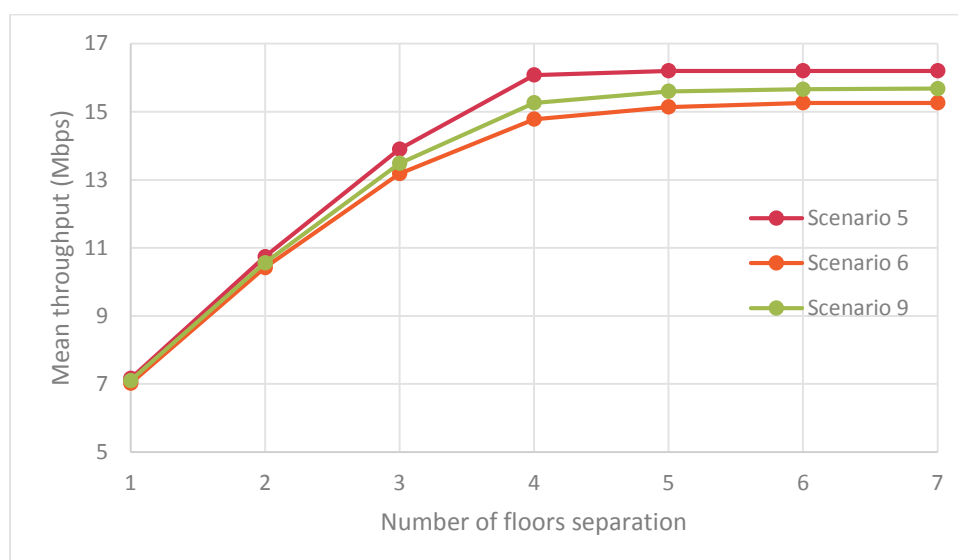


Figure 17: Multi-storey environment: Mean throughput available for different floor separations, for DL (Scenarios 5 and 6) and UL (Scenario 9). Interference sources are a higher power (34.3dBm, scenario 5) and lower power (20dBm, scenario 6) HeNBs and a 23dBm UE (scenario 9).

The lower power transceiver constrains throughput performance in all cases. So the communication link is constrained by the DL using the lower power HeNB, and by the UL using the higher power HeNB.

Use on adjacent floors is possible if throughput limited to 7Mbps are acceptable, and on alternate floors for throughputs above 10Mbps.

Summary:

Using performance targets of an LTE throughput of 10Mbps, and 97% call success for GSM, we can summarise the required separation distances and limiting technology interactions as shown in Table 13.

Technology Mix	Quality Metric	Limiting Link Type and direction	Separation Distance
GSM - GSM	97% call success	Equally constrained	7 floors
LTE - LTE	10 Mbps throughput	DL limited (for low power HeNB) UL limited (for high power HeNB)	2 floors (for either low or high power HeNB)
Mixed GSM – LTE	The lesser of 97% call success (GSM victim) or 10Mbps throughput (LTE victim)	GSM interference limited (UL or DL)	4 floors separation (with low power HeNB), or, 7 floors (high power HeNB)

Table 13: Multi-storey environment: Summary separation metric to protect different combinations of technology mix for multi-storey case

5.1.2 High density residential environment (terraced houses)

GSM – GSM case:

Ofcom performed the analysis for this scenario by splitting a house into 5 transmitting locations and 5 receiving positions and calculated the call success for the 25 combinations, for different house separations assuming a terrace. In some of the 25 possible combinations, the call success probability may be above or below the target rate; Ofcom took the average and deemed the house separation to allow frequency re-use when the average call success probability across the 25 combinations exceeded 97%.

”[For the third house, the] average probability of call success (...) is 98.6 %. We conclude that the frequency can be re-used every third house from the interferer”.

We have replicated Ofcom’s methodology and found the call success rate is identical call success rate whether the GSM picocell maximum EIRP is 23dBm or 0dBm, and is shown in Table 14.

Interferer distances	Distance from wanted cell 1.95 m	Distance from wanted cell 4.85m	Distance from wanted cell 7.75m	Distance from wanted cell 10.64m	Distance from wanted cell 13.54m
1.45m	100.0	99.9	99.6	98.7	97.1
4.35m	100.0	99.9	99.5	98.2	96.0
7.25m	100.0	99.9	99.5	97.9	95.0
10.14m	100.0	100.0	99.5	97.7	94.2
13.04m	100.0	100.0	99.6	97.8	93.8

Table 14: Probability of call success for scenario 1, high density residential environment using GSM victim and receiver EIRPs of 0dBm or 23dBm, 3 house separation.

GSM-LTE case and LTE-GSM case

In the multi-storey case the separation distance to protect GSM limited the minimum inter-system separation distance and so the results for 1, 2 and 3 house separation are of interest. The call success probability averaged across the 25 possible source-receiver positions for scenarios 2, 3 and 7 are shown in Figure 18

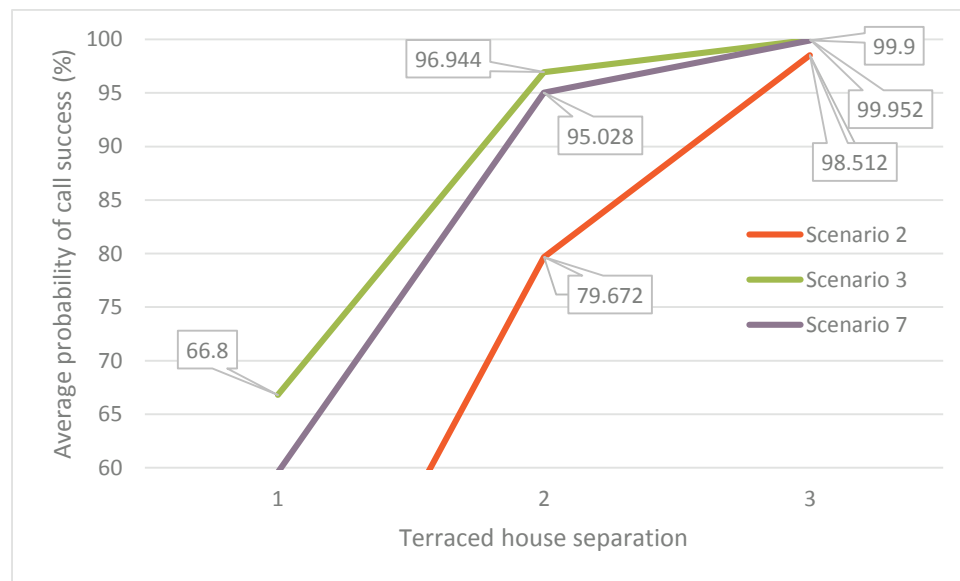


Figure 18: High density residential environment: Mean call success rate available for different terraced house separations, for DL (Scenarios 2 and 3) and UL (Scenario 7). Interference sources are a higher power (34.3dBm, scenario 2) and lower power (20dBm, scenario 3) HeNBs and a 23dBm UE (scenario 7).

These results suggest that low power LTE HeNB can marginally be deployed separated from a GSM system by 2 terraced houses – and either low or high power LTE HeNBs can be deployed separated by 3 terraced houses in order to provide adequate protection to an existing GSM picocell system.

When the performance of the LTE system is considered, it can be seen (Figure 19) that using the low power HeNB means that the DL performance is the limiting case, but that interference from GSM has a small impact on the achievable performance on either UL or DL even when located in the neighbouring terraced house.

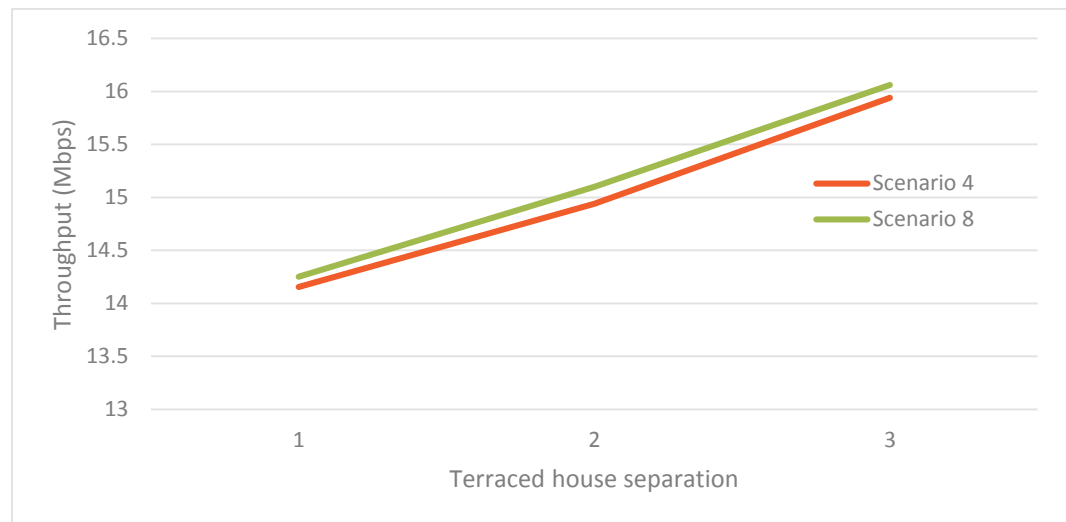


Figure 19: High density residential environment: Mean throughput available for different terraced house separations, for DL (Scenario 4) and UL (Scenario 8). Desired transmitter sources are a low power (20dBm, scenario 4) HeNB and a 23dBm UE (scenario 8), in the presence of 23dBm GSM aggressor transceivers.

LTE-LTE case:

This case is considered in scenarios 5, 6 and 9. This scenario is interference limited and any additional power of the desired transmitter is matched by the increased aggressor transmitter – for both UL and DL directions. The performance is identical in both link directions and for all scenarios. As shown in Figure 20.

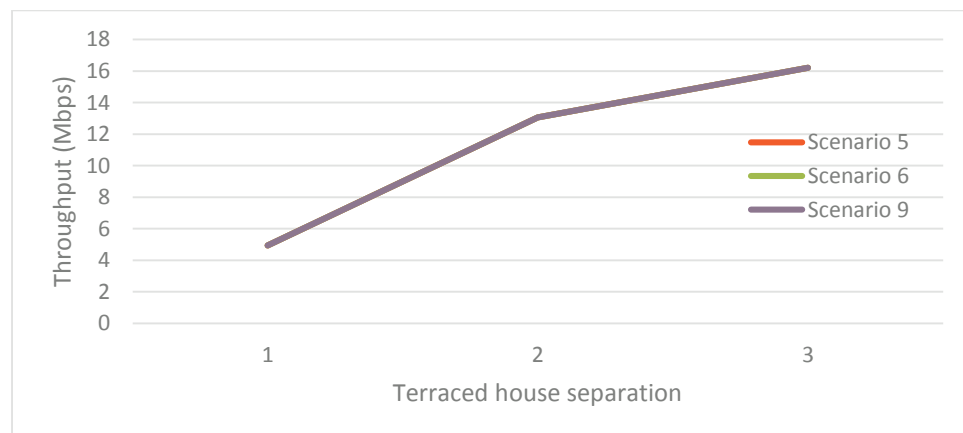


Figure 20: High density residential environment: Mean throughput available for different terraced house separations, for DL (Scenarios 5 and 6) and UL (Scenario 9). Interference sources are a higher power (34.3dBm, scenario 5) and lower power (20dBm, scenario 6) HeNBs and a 23dBm UE (scenario 9).

Two house separation is required to maintain the throughput above 10Mbps on average. In some of the 25 positions determined for the 1 house separation case very low throughputs (even 0Mbps) were determined, so adjacent house deployment would not be appropriate.

Summary:

Using performance targets of an LTE throughput of 10Mbps, and 97% call success for GSM, we can summarise the required separation distances and limiting technology interactions as shown in Table 15.

Technology Mix	Quality Metric	Limiting Link Type and direction	Separation Distance
GSM - GSM	97% call success	Equally constrained	3 terraced house separation
LTE - LTE	10 Mbps throughput	Equally constrained	2 terraced house separation
Mixed GSM – LTE	The lesser of 97% call success (GSM victim) or 10Mbps throughput (LTE victim)	GSM receiver (UL or DL)	With low power HeNB 2 terraced house separation is marginal. Lower and higher power can be deployed with 3 terraced house separation

Table 15: High density residential environment: Summary separation metric to protect different combinations of technology mix

5.1.3 Campus environment with an outdoor interfering microcell

The interest in this study is to determine the level of any impairment if LTE is used instead of GSM. We can therefore adopt the simple line of sight scenario of Ofcom's campus evaluation (Campus Scenario 1: Line of Sight Scenario). In this scenario the issue is to assess the interference caused to indoor small cells in the presence of outdoor cells intended to provide indoor and outdoor service in a campus environment.

We were not able to replicate the answers published in Ofcom's document unless the equation used to describe the inbuilding propagation model was modified by removing the '+4' dB term⁶. The results in this report have used this modification, consistent with the conditions used to match Ofcom's published data, for comparison. The results presented

⁶ See Linbuilding on pp38 of Technical Study 1 from [12].

below are a weighted average across the a set of potential user locations to determine a representative average probability of call success or throughput.

GSM – GSM case:

Consistent with the result presented by Ofcom, the required separation of low power (23dBm) outdoor GSM microcell needs to be as much as 10km to permit a 97% call success probability for an indoor user being served by, and less than 50m from, an indoor 23dBm picocell.

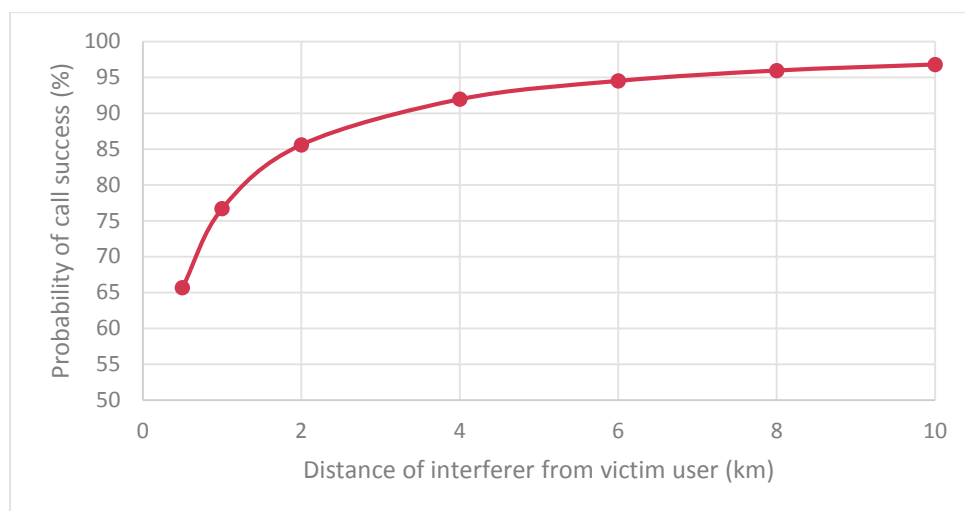


Figure 21: Line of Sight campus environment: Probability of call success for scenario 1, with an indoor GSM victim MS (served by a 23dBm indoor microcell) subject to interference from a 23dBm outdoor GSM microcell.

GSM-LTE case and LTE-GSM case

The call success probability for scenarios 2, 3 and 7 as the interference separation distance increases are shown in Figure 22.

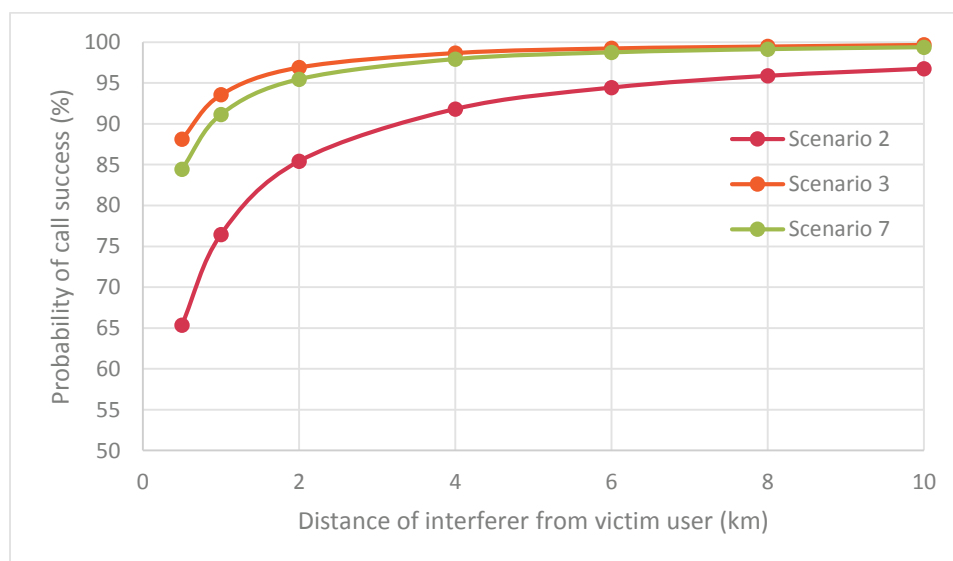


Figure 22: Line of Sight campus environment: Mean call success rate available versus separation distance, for DL (Scenarios 2 and 3) and UL (Scenario 7). Interference sources are a higher power (34.3dBm, scenario 2) and lower power (20dBm, scenario 3) HeNBs and a 23dBm UE (scenario 7).

As would be expected, the 34.3dBm HeNB (scenario 2) follows a very similar path the GSM-GSM case since the same transmit psd is used, and separation distances of 10km would be required to permit a 97% indoor GSM call success rate. The required separation reduces to 2km when a lower power (20dBm) HeNB is used. The case of the 23dBm LTE UE causing interference (scenario 7) is also shown and suggests that a large separation distance may be required to protect the indoor GSM microcell. In practice the UE power control, would restrict interference to the locality of the serving LTE outdoor small cell.

When the performance of the LTE system subject to interference from a GSM aggressor is considered, it can be seen (Figure 23) that, again, the low power HeNB means that the DL performance is the limiting case, but that interference from GSM has a small impact on the achievable performance on either UL or DL. The LTE system could be located close an interfering GSM system and not suffer a throughput drop below 10Mbps.

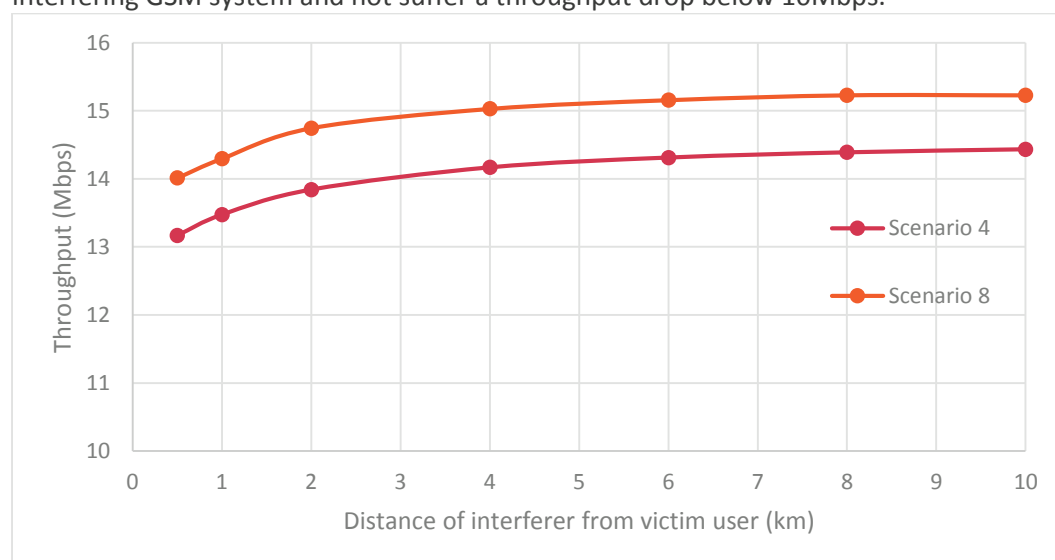


Figure 23: Line of Sight campus environment: Mean throughput available versus separation distance, for DL (Scenario 4) and UL (Scenario 8). Desired transmitter sources are a low power (20dBm, scenario 4) HeNB and a 23dBm UE (scenario 8), in the presence of 23dBm GSM aggressor transceivers.

LTE-LTE case:

This case is considered in scenarios 5, 6 and 9. In this case the additional transmit power of either the UE or the HeNB helps improve the link quality in the presence of interference from an aggressor with the same transmit power. Again, even at short distances, though the interference impairs the link throughput, this throughput is above 10 (14) Mbps when the aggressor is more than 0.5 (2.0) km from the victim.

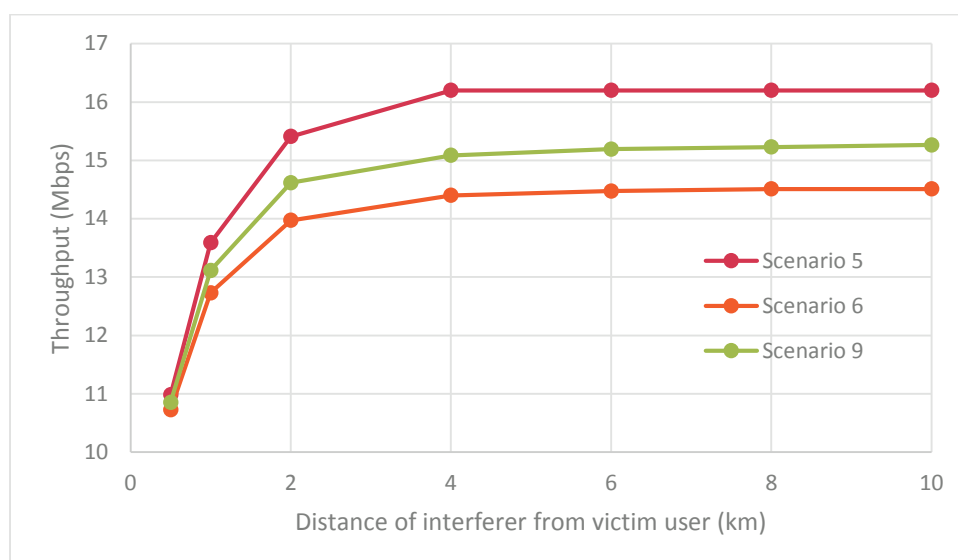


Figure 24: Line of Sight campus environment: Mean throughput available for different separation distances, for DL (Scenarios 5 and 6) and UL (Scenario 9). Interference sources are a higher power (34.3dBm, scenario 5) and lower power (20dBm, scenario 6) HeNBs and a 23dBm UE (scenario 9)

Summary:

Using performance targets of an LTE throughput of 10Mbps, and 97% call success for GSM, we can summarise the required separation distances and limiting technology interactions as shown in Table 15.

Technology Mix	Quality Metric	Limiting Link Type and direction	Separation Distance
GSM - GSM	97% call success	Equally constrained	>10km
LTE - LTE	10 Mbps throughput	UL limited (for low power HeNB) DL limited (for high power HeNB)	>0.5km
Mixed GSM – LTE	The lesser of 97% call success (GSM victim) or 10Mbps throughput (LTE victim)	GSM receiver (UL or DL)	>4km (<23dBm HeNB) >10km (34.3 dBm HeNB)

Table 16: Campus environment with an outdoor interfering microcell: Summary separation metric to protect different combinations of technology mix

5.2 Adjacent channel interference assessment

The different victim-aggressor technology combinations for the adjacent channel case can be presented analogously to the co-channel case. The victim of interest is DECT and the interference can be GSM (comparison case) or LTE. The scenarios of interest and the separation metric is shown in Table 17.

		Victim Systems
		DECT
Aggressor Systems	HeNB (high power)	High density house separation
	GSM BS	High density house separation

Table 17: Technology interactions for different scenario identities

We are concerned about the re-use distance of different DECT channels that will suffer sufficiently little interference to be able to support traffic. For this we can re-use the high residential environment and the methodology from the co-channel case considered previously to determine the call success rate in different DECT channels in the presence of interference from GSM and LTE.

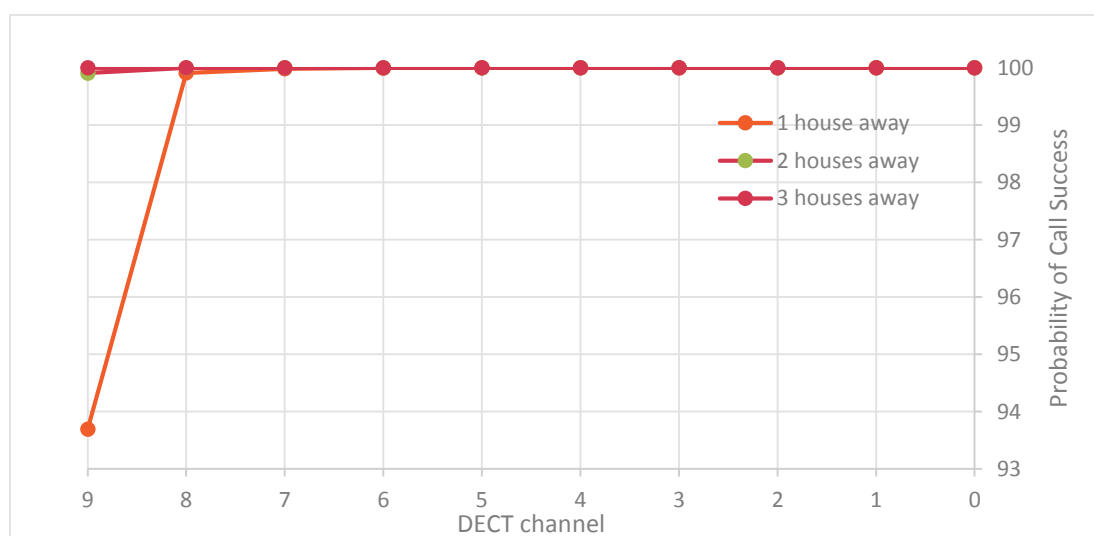


Figure 25: High density residential scenario: Average probability of DECT call success on different DECT channels and housing separations, with a 23dBm GSM BS transmitting in GSM ARFCN 884.

Analogous to the co-channel interference case presented for GSM-GSM interference, Figure 25 presents the results of the average probability (averaged across the 25 different victim-aggressor separations). It is clear that DECT channel 9 suffers interference in the adjacent house, but the call success rate approaches 100% for all other cases.

Similar results for the case of a 34.3dBm LTE HeNB interferer are shown in Figure 26. It is evident that all DECT channels experience some interference in the adjacent house, but that there is little impact on any DECT channels at greater separations – and channels 0 to 7 have call success rates of 100%.

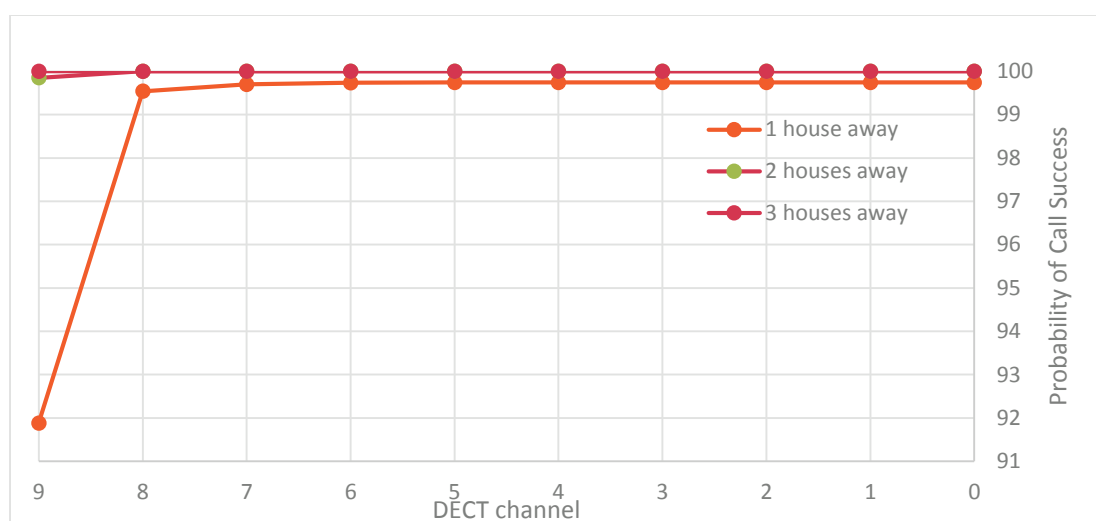


Figure 26: High density residential scenario: Average probability of DECT call success on different DECT channels and housing separations, with a 34.3dBm LTE (high power) HeNB.

It is therefore of interest to examine in more detail the geometries that reduce the call success in the adjacent house. Noting that CEPT reports noted degradation was possible in DECT channels 7-9, Table 18 shows the DECT call success rates at different separations from the serving cell in DECT channel 6. Clearly in the majority of geometries it is possible to achieve 100% call success based on a DECT BER of 0.001%. In the event that users experience interference, moving to a different location would reduce the impact of any interference. DECT channel 6 can achieve high (>99%) call success rates in an adjacent dwelling in channel 6. Channel 5 yields 100% call success rates in 13 of the 25 combinations of interferer-victim distances assessed.

Percentage of call success (%)					
Interferer distances (m)	Distance from serving cell				
	1.95 m	4.85 m	7.75 m	10.64 m	13.54 m
1.45	100.0	100.0	100.0	100.0	99.9
4.35	100.0	100.0	99.9	99.8	99.8
7.25	100.0	100.0	99.9	99.6	99.4
10.14	100.0	100.0	99.9	99.4	98.6
13.04	100.0	100.0	100.0	99.5	97.8

Table 18: DECT channel 6

If DECT use is restricted to only channel 0 to 5 in the adjacent dwelling (i.e. 6 channels available instead of 10), it is useful to consider if this will have any impact on DECT to support traffic demand. As noted earlier, each DECT channel can support 12 bi-directional communications links. Assuming each FP is paired with 3 PP, this means that 6 channels

could be support 24 installations. It is also noted that in the USA only 5 DECT channels are available for use.

6. Summary and findings

In this report we have performed an assessment of the impact on co-channel and adjacent channel uses, using a methodology based upon a previous study of this band by Ofcom. Three different environments were considered for the co-channel case, and one of these was used to assess the adjacent channel case.

We have found:

Co-channel case:

- Whereas GSM use of the CSA band allows frequency re-use to avoid interference, the impact of co-channel interference can prevent call success. LTE throughput will tend to reduce – in effect there is a more gradual degradation when LTE is subject to interference.
- When GSM is co-located with LTE, the protection requirements of GSM dictate the required isolation.
- In general, the protection distance to protect GSM from LTE is approximately $\frac{1}{2}$ that required to protect GSM from a co-channel GSM interferer.
- LTE can co-exist with other LTE systems: In general two floors or two houses separation is required to achieve >10Mbps; reduced separation distances reduce the achievable throughput, but link performance is maintained in the cases considered.
- More detailed separation distances are presented in Table 13, Table 15 and Table 16.

Adjacent channel case:

- In an adjacent dwelling, GSM does not impact DECT on channels 0 to 7. More remote dwellings suffer less impact.
- In an adjacent dwelling a high power 34.3dBm LTE HeNB causes some interference impact to all DECT channels. In DECT channels 0-5 100% call success probability is possible in more than $\frac{1}{2}$ of the victim-aggressor geometries assessed. It is highly likely that interference impact free locations can be found to locate any DECT receivers that may suffer interference from LTE. The capacity available for these lightly impacted channels would be sufficient to support traffic demand in high density user environments.
- Though the potential for interference is low, the fact that LTE has a potential impact on all DECT channels raises the potential concern that any interfered DECT system may not be able to find a spare free DECT channel for use. The measurements performed in a related study suggest that this is not the case, even with more severe (i.e. worse) interference geometries than those used in the analysis in this report.

Taken together, the analysis and measurement campaigns demonstrate that:

- Any additional interference caused by relaxing the OoB emissions by adopting the proposed licence limits would not cause any operational impairment to neighbouring adjacent channel use (DECT or LTE licensed by MNOs)

- In order to protect existing GSM use in the CSA bands, LTE deployment will need a separation distance approximately $\frac{1}{2}$ of the separation distance required between co-channel GSM users, though alternative frequencies cannot be used.
- Since it is understood that existing use of the CSA band is limited, these separation constraints should not impose a significant barrier to LTE deployment in the CSA band.

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