3GPP TR 36.816 V11.2.0 (2011-12)

Technical Report

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Evolved Universal Terrestrial Radio Access (E-UTRA);
Study on signalling and procedure for interference avoidance for in-device coexistence
(Release 11)

Keywords

LTE

3GPP

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Contents

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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- x the first digit:
  - 1 presented to TSG for information;
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- y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.
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1 Scope

The present document is intended to capture the output of the study item on Signalling and procedure for interference avoidance for in-device coexistence, which was approved at TSG RAN#48.

The objective of the SI is to investigate suitable mechanisms for interference avoidance from signalling and procedure point of view to facilitate the coexistence scenario that LTE and GPS/ ISM radio within the same device working in adjacent frequencies or sub-harmonic frequencies. The work under this study should take the following steps:

（1） Evaluate whether existing RRM mechanisms could be utilized to effectively solve the coexistence problems that arise in supporting the scenarios abovementioned and guarantee the required QoS in LTE with proper GPS/ISM operation.

（2） If legacy signaling and procedure are not sufficient to ensure required performance in the interested coexistence scenario, study enhanced mechanisms to better avoid interference and mitigate the impact caused by ISM radio.

Impact on legacy LTE UEs should be minimized.

NOTE: The candidate solutions should be firstly considered in the non-CA (carrier aggregation) cases.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 36.101: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception".

[3] Current and Planned Global and Regional Navigation Satellite Systems and Satellite-based Augmentations Systems International Committee on Global Navigation Satellite Systems Provider’s Forum, United Nations, Office of outer space affairs.

[4] 3GPP TS 36.305: "Stage 2 functional specification of User Equipment (UE) positioning in E-UTRAN".

[5] 3GPP TR 23.861: "Multi access PDN connectivity and IP flow mobility".

[6] 3GPP TS 23.203: "Policy and charging control architecture".

[7] R4-102416: "In-device coexistence interference between LTE and ISM bands".

[8] R4-103306: "Some experimental results and suggestions for in-device coexistence".

[9] R4-103526: "Some experimental results for LTE and WLAN in-device coexistence".

[10] R4-103670: "In-device coexistence interference between LTE and ISM bands".

[11] R4-104334: "Analysis on LTE and ISM in-device coexistence interference".

[12] ACPF-7024: "ISM Bandpass filter data sheet"

[13] ACPF-7025: "WiMAX bandpass filter data sheet".

[14] 3GPP TS 36.321: "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification".

[15] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Layer Procedures ".

[16] R2-111390: "Autonomous gap patterns for BT conversational voice".

[17] R2-112325: "HARQ based gap patterns for coexistence of LTE TDD and Bluetooth".

[18] R2-114331: "Solutions for IDC interference in LTE + BT voice scenario".

[19] R2-114323: "Autonomous denials and WiFi beacon handling".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

example: text used to clarify abstract rules by applying them literally.

In-device Coexistence Interference: when transmitting in one frequency band interferes with receiving in another, within the same UE.

ISM Radio: the radio transceiver operating in ISM band

Unscheduled period: Period during which the LTE UE is not scheduled to transmit or receive, thereby allowing the ISM radio to operate without interference.

Scheduling period: Period during which the LTE UE may be scheduled to transmit or receive.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

<symbol> <Explanation>

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

ISM band	Industrial, scientific and medical band
GPS	Global Positioning System
BT	Bluetooth
GNSS	Global Navigation Satellite System
SCO	Synchronous connection oriented link
eSCO	Extended synchronous connection orientated
A2DP	Advanced audio data profile
ACL	Asynchronous connection-oriented link
DCF	Distributed Coordination Function

4 Scenarios

[Editor's note: This section covers the coexistence scenarios that the study work is focusing on]

In order to allow users to access various networks and services ubiquitously, an increasing number of UEs are equipped with multiple radio transceivers. For example, a UE may be equipped with LTE, WiFi, and Bluetooth transceivers, and GNSS receivers. One resulting challenge lies in trying to avoid coexistence interference between those collocated radio transceivers. Figure 4-1 shows an example of coexistence interference.

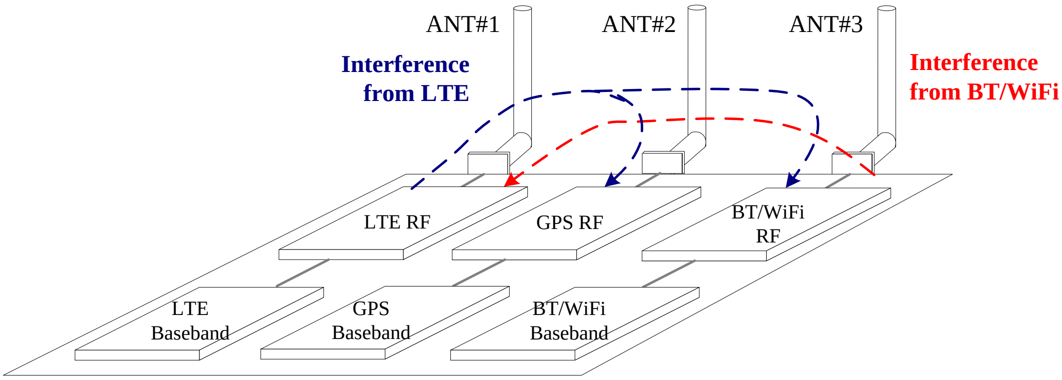

Figure 4-1: Coexistence interference within the same UE

Due to extreme proximity of multiple radio transceivers within the same UE, the transmit power of one transmitter may be much higher than the received power level of another receiver. By means of filter technologies and sufficient frequency separation, the transmit signal may not result in significant interference. But for some coexistence scenarios, e.g. different radio technologies within the same UE operating on adjacent frequencies, current state-of-the-art filter technology might not provide sufficient rejection. Therefore, solving the interference problem by single generic RF design may not always be possible and alternative methods needs to be considered. An illustration of such kind of problem is shown in Figure 4-2 and some RF analyses on in-device coexistence between LTE and ISM are given in Annex A.

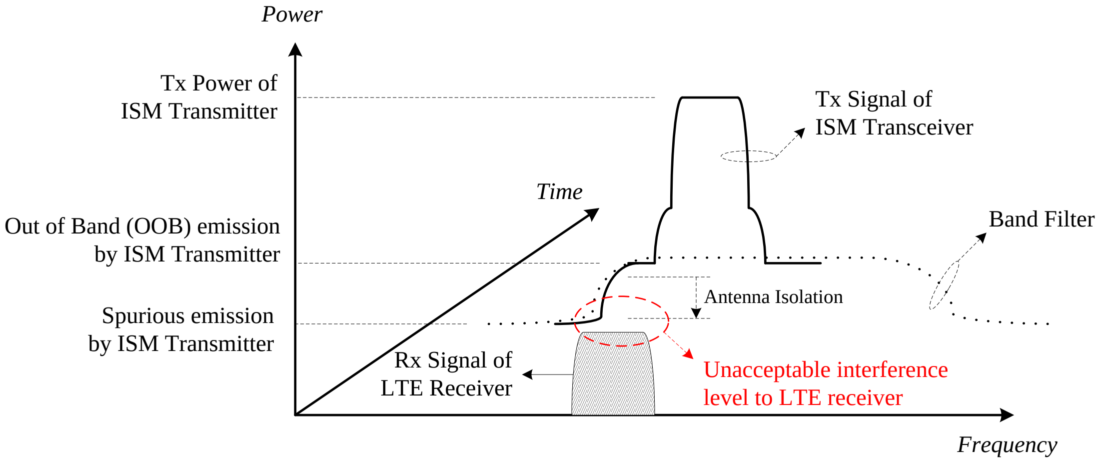

Figure 4-2: Example of coexistence interference from in-device ISM transmitter to E-UTRA receiver

4.1 Coexistence interference scenarios

In this subclause, the coexistence interference scenarios between LTE radio and other radio technologies are described. 3GPP frequency bands around 2.4GHz ISM band are illustrated in Figure 4.1-1 [2].

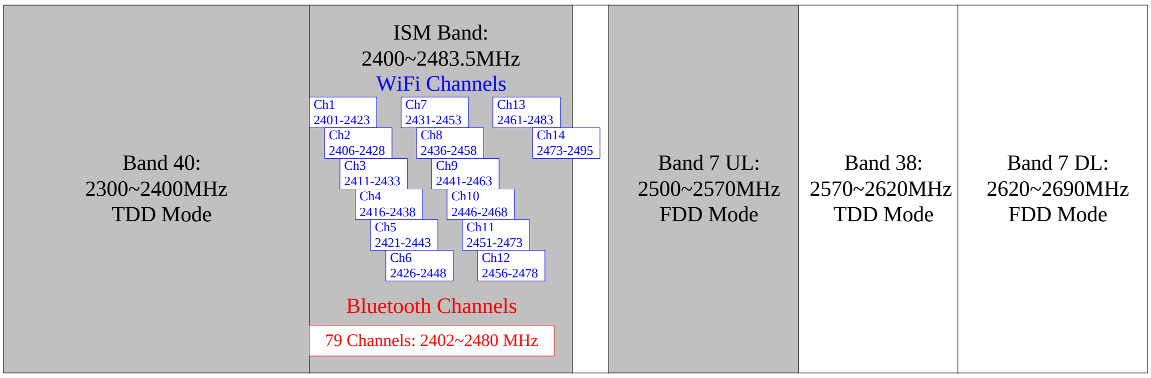

Figure 4.1-1: 3GPP frequency bands around ISM band

LTE coexisting with WiFi

There are 14 channels demarcated in ISM band for WiFi operation. Each channel has 5 MHz separation from other channel with an exception of channel number 14 where separation is 12 MHz. Channel 1 starts with 2401 MHz and channel 14 ends at 2495 MHz. Different countries have different policies for number of allowed channels of WiFi. Most of the countries allow only channel 1 to 13, while only in Japan the usage of channel number 14 is allowed for IEEE 802.11b. The transmitter of LTE band 40 will affect receiver of WiFi and vice-versa. Since band 7 is a FDD band so there is no impact on LTE receiver from WiFi transmitter but WiFi receiver will be affected by LTE UL transmitter.

LTE coexisting with Bluetooth

Bluetooth operates in 79 channels of 1 MHz each in ISM band. The first channel starts with 2402 MHz and the last channel ends at 2480 MHz. Similar as WiFi case, the activities of LTE band 40 and BT will disturb each other, and the transmission of LTE band 7 UL will affect BT reception as well.

LTE Coexisting with GNSS

Examples of GNSS include GPS, Modernized GPS, Galileo, GLONASS, Space Based Augmentation Systems (SBAS), and Quasi Zenith Satellite System (QZSS) [3], [4]. GNSS systems operate in various frequencies globally with country specific deviations:

- Frequencies of operation for GPS, Modernised GPS: L1 (1575.42 MHz), L2(1227.6 MHz), L1C (1575.42 MHz), L2C (1227.6MHz), L5(1176.45 MHz);
- Frequencies of operation for Galileo: E1(1575.42MHz), E5A(1176.45 MHz), ALTBOC(1191.795MHz), E5B (1207.14 MHz), E6(1278.75 MHz);
- Frequencies of operation for GLONASS: L1(1602.0 MHz), L2 (1246.0 MHz);
- Frequencies of operation for Compass: Same frequencies as Galileo;
- Frequencies of operation for QZSS and SBAS: Same frequencies as GPS.

Therefore, the problematic cases for collocated LTE and GNSS include:

- Band 13 (UL: 777-787 MHz) / 14 (UL: 788-798 MHz) can cause interference to L1/E1 frequency of GNSS (1575.42 MHz) as it is close to the second harmonics of band 13/14 (1554-1574 MHz for band 13, 1576-1596 MHz for band 14);
- Galileo is supporting proposal for new global allocation at 2.5 GHz for GNSS, which will be affected by band 7 LTE collocated operation [3];
- Indian Regional Navigation Satellite System uses IRNSS standard position and restricted services are transmitted on L5 (1164-1215 MHz) and S (2483.5-2500 MHz) bands [3], which will be affected by band 7 LTE collocated operation.

NOTE: In the last few years, there have been tremendous advancements in GPS receivers to reduce size, cost and improve accuracy. A near future possibility of advancement in GNSS receiver would be to build dual frequency GNSS receiver at low cost. It is possible to build dual frequency GNSS receiver using L1 and L5 in low cost, because L5 frequency is open for public use and it can be used for more precise positioning. This makes it an attractive possibility of integrating dual frequency GNSS receiver using L1 and L5 frequency. The issue with L5 now is that there are only few satellites transmitting L5 and they are focusing on North America only. All GPS satellites start transmitting L5 only by 2020. But a positive trend is that even Galileo is planning L5 and other systems developed by various countries are also planning L5. Hence, most probably L5 frequency will be available by 2014 globally. Another direction of GNSS receiver advancement is integration of motion sensors with GNSS receivers. With the help of motion sensors, the position can be predicted even if GNSS signal suddenly becomes week or unavailable.

Summary of in-device coexistence interference scenarios

Based on the above analysis, some examples of the problematic coexistence scenarios that need to be studied are:

- Case 1: LTE Band 40 radio Tx causing interference to ISM radio Rx;
- Case 2: ISM radio Tx causing interference to LTE Band 40 radio Rx;
- Case 3: LTE Band 7 radio Tx causing interference to ISM radio Rx;
- Case 4: LTE Band 7/13/14 radio Tx causing interference to GNSS radio Rx.

4.2 Usage scenarios

In order to facilitate the study, it is also important to identify the usage scenarios that need to be considered. This is because different usage scenarios will lead to different assumption on behaviours of LTE and other technologies radio, which in turn impact on the potential solutions.

1a) LTE + BT earphone (VoIP service)

In the scenario of LTE voice over IP, the voice traffic transmitted by BT is actually from/to LTE, where the traffic activities between LTE and BT will be very similar because of the end-to-end latency requirement.

The coexistence interference case 1-3 of section 4.1 may happen in this usage scenario.

1b) LTE + BT earphone (Multimedia service)

Another scenario is that multimedia (e.g. HD video) is downloaded by LTE and audio is routed to a BT headset, where the traffic activities between LTE and BT are correlated as well.

For the multimedia (HD video) scenario, in case a time domain solution is needed, the requirements for the scheduling/unscheduled periods for typical streaming applications can be obtained based on the requirements on the BT and LTE sides. Activity time on BT can be very dynamic for BT streaming. The BT audio stream typically uses the advanced audio data profile (A2DP) for Bluetooth and typically more than [60 ms] transmission latency can cause playback problems at the BT receiver. Hence, the scheduling period of LTE should not exceed this time.

The latency requirement is less stringent on the LTE side, depending on the QCI (e.g. 150ms for QCI 2 [6]). Hence, the maximum unscheduled period for LTE can be as much as 150 ms. However, in order to not limit LTE throughput, it is desirable to minimize the LTE unscheduled period and the smallest unscheduled period is determined by the on time needed by BT to sustain the data rate, depending on the link condition. This number typically ranges from [15] ms to [60] ms. Note that making the LTE unscheduled period much shorter can make it difficult for BT to utilize the available time given the BT framing structure.

Further, there are no benefits in this case to align the LTE unscheduled period to the BT timelines. In summary, under this scenario and the assumed BT profile, if a time domain solution is needed, it should meet the following guidelines:

- The LTE scheduling period is to be less than [60] msec
- The LTE unscheduled period is to be around [15-60] msec

The coexistence interference case 1-3 of section 4.1 may happen in this usage scenario.

2) LTE + WiFi portable router

In this scenario, LTE is considered as a backhaul link to access the Internet, and the connectivity is shared by other local users using WiFi. In this scenario, the WiFi transceiver is operated as an AP and has full control on frequency channel and transmitting power. Given the ability of the WiFi transceiver to select the frequency channel, it may be possible to avoid interference to/from WiFi by moving the WiFi signal away from the LTE band. If this is not sufficient, time domain solutions are applicable.

On the DL, the worst case latency will be for a packet arriving at the eNB at the beginning of the LTE unscheduled period, with the resulting latency being the sum of the LTE unscheduled period (waiting for LTE scheduling) and the LTE scheduling period (waiting for WiFi scheduling). Similar argument applies on the UL. Though the scheduling/unscheduled periods can be made as small as 1 ms to minimize latency, this is not desirable due to the impact on retransmissions and other timelines on both LTE and WiFi. Hence, somewhat larger periods should be used, keeping in mind a balance between the timeline requirements and the needs of the specific QCI.

In order to fulfil latency requirements of common services under this scenario, the scheduling periods and unscheduled periods should use the following guidelines

- Scheduling periods and unscheduled periods should be typically not more than [20-60] ms.
- The scheduling and unscheduled periods should be large enough for reasonable operation of the LTE and WiFi timelines. Corresponding numbers are FFS.
- Since LTE has typically lower data rate than the WiFi link, the LTE scheduling periods should be longer than the unscheduled periods in order to achieve roughly the same throughput on both links.

The coexistence interference case 1-3 of section 4.1 may happen in this usage scenario.

3) LTE + WiFi offload

In this scenario, an LTE UE can also connect to WiFi to offload traffic from LTE and the WiFi transceiver of the UE operates as a terminal (not AP) in infrastructure mode. It is difficult for the WiFi radio to change the configured frequency channel. In addition, the WiFi radio has to keep listening to the beacon signal transmitted from WiFi AP for maintaining connection. This usage scenario is getting studied in 3GPP [5].

For this scenario, in case a time domain solution is needed, the requirements for the scheduling period and unscheduled periods differ from the previous scenario in three ways:

One difference is about WiFi beacon reception by the UE in WiFi client mode. Proper reception of the beacon requires alignment of the LTE unscheduled period with the WiFi beacons. Also, the scheduling period of LTE should be no longer than 100ms in order to provide for beacon reception.

The second difference is that the packet traverses only one over-the-air link (WiFi for offload packets, and LTE for non-offload packets), hence somewhat larger (approximately double) scheduling periods and unscheduled periods can meet the same latency requirements.

The third difference is that the ratio of the scheduling and unscheduled periods should roughly correspond to the traffic volume of the non-offloaded and offloaded traffic.

As in the previous scenario, the guidelines depend on a balance between the latency requirements of the QCI, and the requirements of the acknowledgement/timeline of LTE and WiFi. In order to fulfil latency requirements of common services under this scenario, the scheduling periods and unscheduled periods should use these guidelines

- The scheduling and unscheduled periods should typically be not more than [40-100] ms.
- The scheduling and unscheduled periods should be large enough for reasonable operation of the LTE and WiFi timelines. Corresponding numbers are FFS.
- Aligning the LTE unscheduled period with WiFi beacons is important.
- The ratio of the scheduling and unscheduled periods should be aligned to the ratio of the volume of non-offloaded and offloaded traffic.

The coexistence interference case 1-3 of section 4.1 may happen in this usage scenario.

4) LTE + GNSS Receiver

This usage scenario considers that the LTE UE is also equipped with the GNSS (e.g. GPS) receiver to support location services. To be specific, the following three sub-scenarios represent sufficiently wide range of possibilities for use:

- Initial position fix (initial satellite search) in good signal conditions (e.g. outdoors). This sub-scenario is applicable for emergency calls, where the UE needs to locate itself using the A-GPS assistance information. It can be also applicable for navigation and other location based services (e.g. advertisements).
- Initial position fix in difficult signal conditions (e.g. urban canyon, or indoors). This sub-scenario is similar to the previous one, but with special consideration to the signal conditions.
- Successive position fixes during navigation. In this sub-scenario, the UE has already a good knowledge about the satellite signals, and is only making successive fixes. On the other hand, it can be expected that the LTE is serving voice and/or data, for example to download maps.

In all the sub-scenarios, it can be expected that LTE UL transmissions cause interference to the GNSS receiver.

The coexistence interference case 4 of section 4.1 may happen in this usage scenario.

5 Potential solutions for interference avoidance

[Editor's note: This section is intended to capture potential solutions to solve the in-device coexistence issues described in section 4. The effectiveness of existing solutions and envisioned enhancement will be analyzed and evaluated in this section.]

5.1 Introduction

The potential solutions for interference avoidance are mainly considered for the UE in CONNECTED mode. IDLE mode operation itself is not considered a problem, since the UE can just stop ISM transmissions at important LTE reception moments, e.g. when receiving LTE paging. It is FFS whether cell reselection enhancements need to be considered in order for the UE in IDLE mode to avoid problems at every subsequent transition to RRC_CONNECTED.

5.1.1 Modes of interference avoidance

5.1.1.1 Uncoordinated mode

In this mode, different technologies within the same UE operate independently without any internal coordination between each other, as illustrated in Figure 5.1.1.1-1.

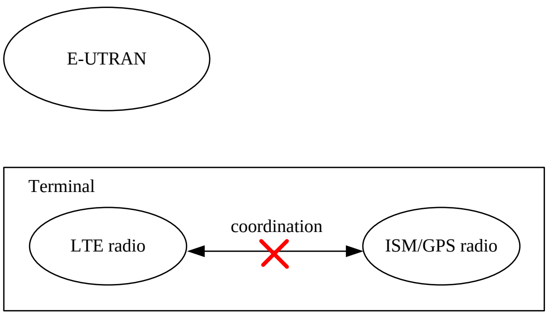

Figure 5.1.1.1-1: Uncoordinated mode

5.1.1.2 Coordinated within UE only

In this mode, there is an internal coordination between the different radio technologies within the same UE, which means that at least the activities of one radio is known by other radio. However, the network is not aware of the coexistence issue possibly experienced by the UE and is therefore not involved in the coordination.

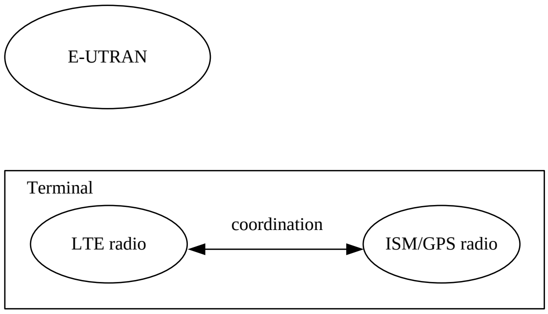

Figure 5.1.1.2-1: Coordinated within UE only

5.1.1.3 Coordinated within UE and with network

In this mode, different radio technologies within the UE are aware of possible coexistence problems and the UE can inform the network about such problems. It is then mainly up to the network to decide how to avoid coexistence interference.

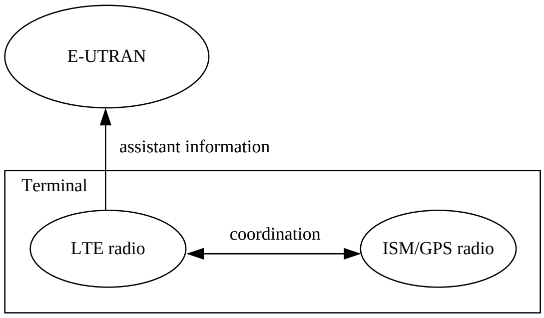

Figure 5.1.1.3-1: Coordinated with network level

5.1.2 Potential solution directions

5.1.2.1 Move LTE Signal away from ISM Band

The basic concept of this solution is illustrated on Figure 5.1.2.1-1, where LTE signal is led away from ISM band in frequency domain.

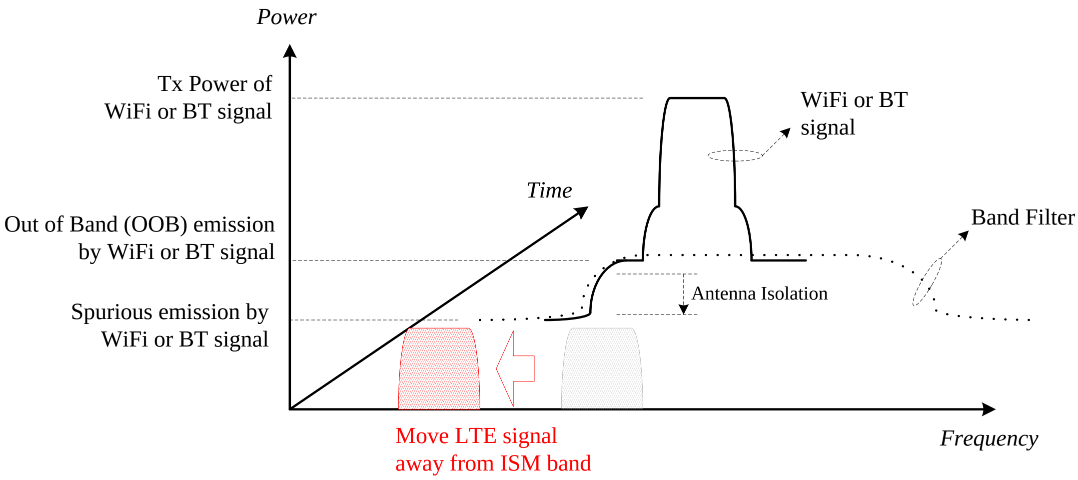

Figure 5.1.2.1-1: Potential solutions to move LTE signal away from ISM band

5.1.2.2 Move ISM Radio Signal away from LTE Frequency Band

The basic concept of this solution is illustrated on Figure 5.1.2.2-1, where ISM radio signal is led away from LTE frequency band in frequency domain. In order to help ISM radio complete the necessary procedure to enable this option, LTE may also need to avoid coexistence interference to ISM radio during the initial stage.

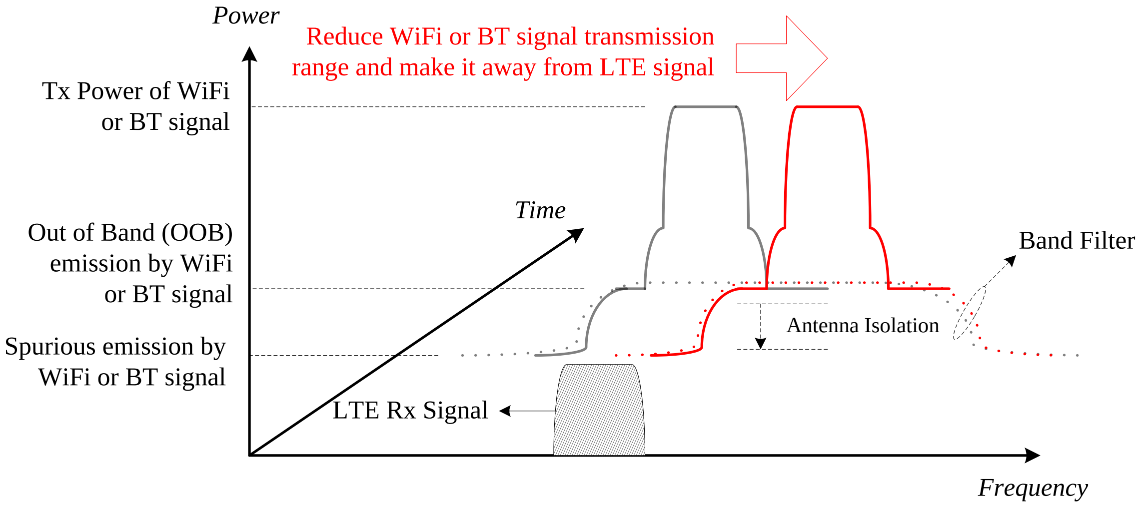

Figure 5.1.2.2-1: Move ISM radio signal away from LTE frequency band

5.1.2.3 Time Division Multiplexing (TDM)

The basic concept of this solution is illustrated on Figure 5.1.2.3-1. It consists in ensuring that transmission of a radio signal does not coincide with reception of another radio signal.

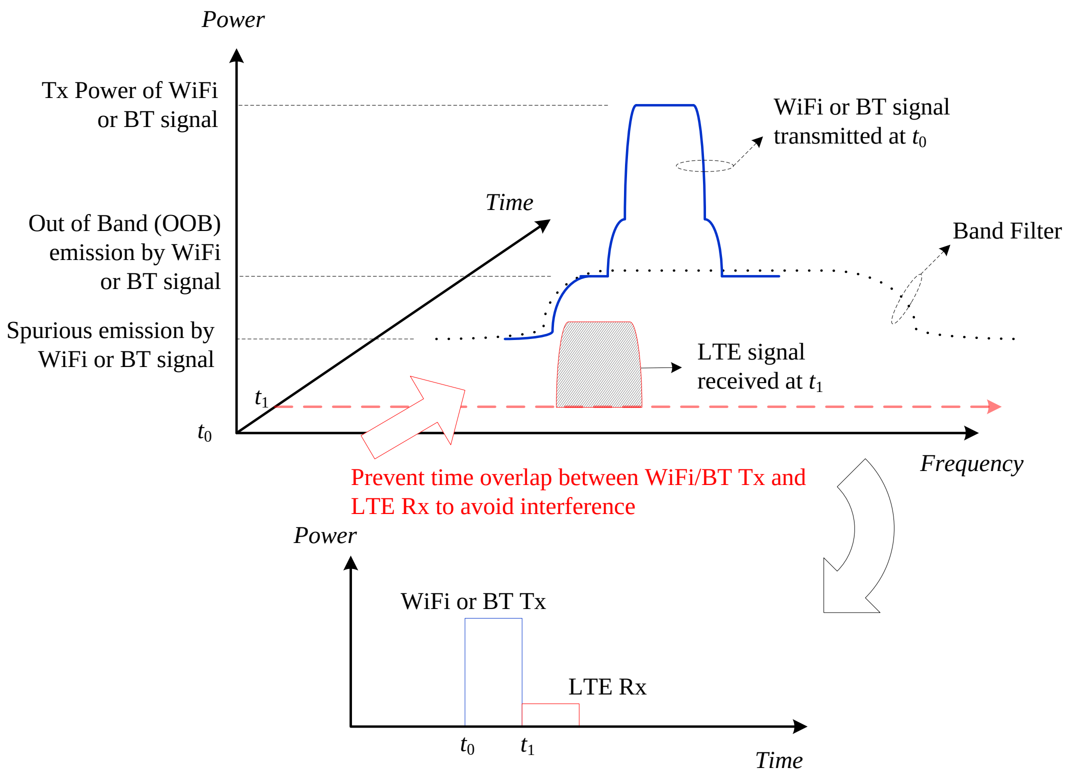

Figure 5.1.2.3-1: Time division multiplexing for coexistence interference avoidance

5.1.2.4 LTE Power Control (LTE PC)

The basic concept of this solution is illustrated on Figure 5.1.2.4-1. LTE transmission power is reduced to mitigate the interference to ISM/GNSS receiver.

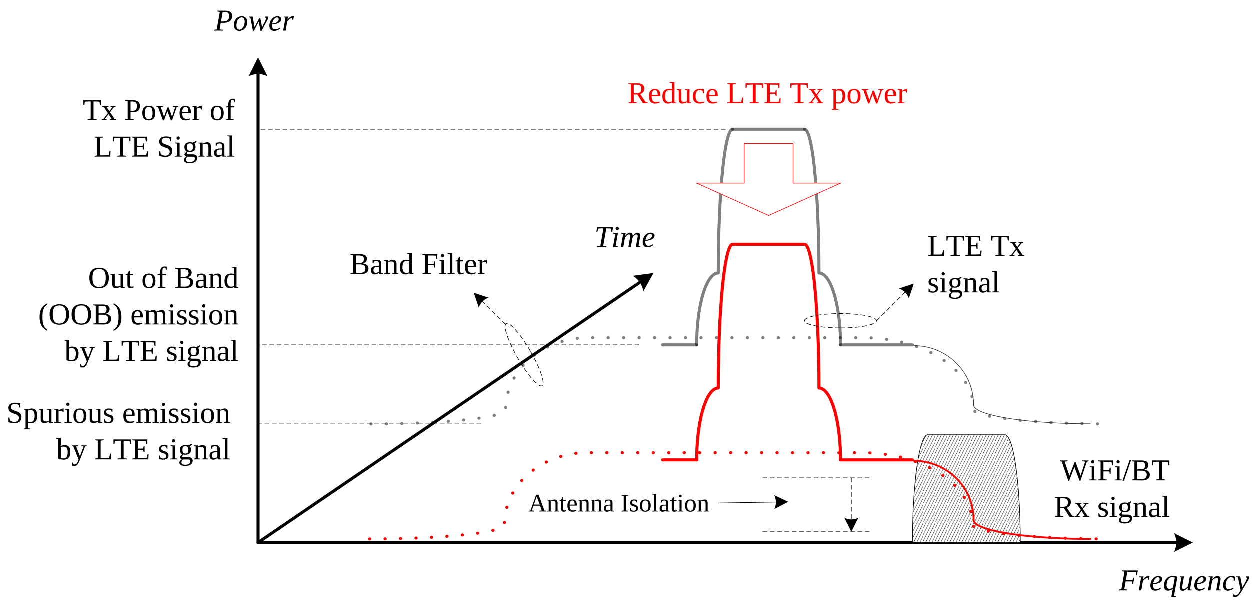

Figure 5.1.2.4-1: LTE power control for coexistence interference mitigation

5.1.2.5 ISM Power Control (ISM PC)

The basic concept of this solution is illustrated on Figure 5.1.2.5-1. ISM transmission power is reduced to mitigate the interference to LTE receiver.

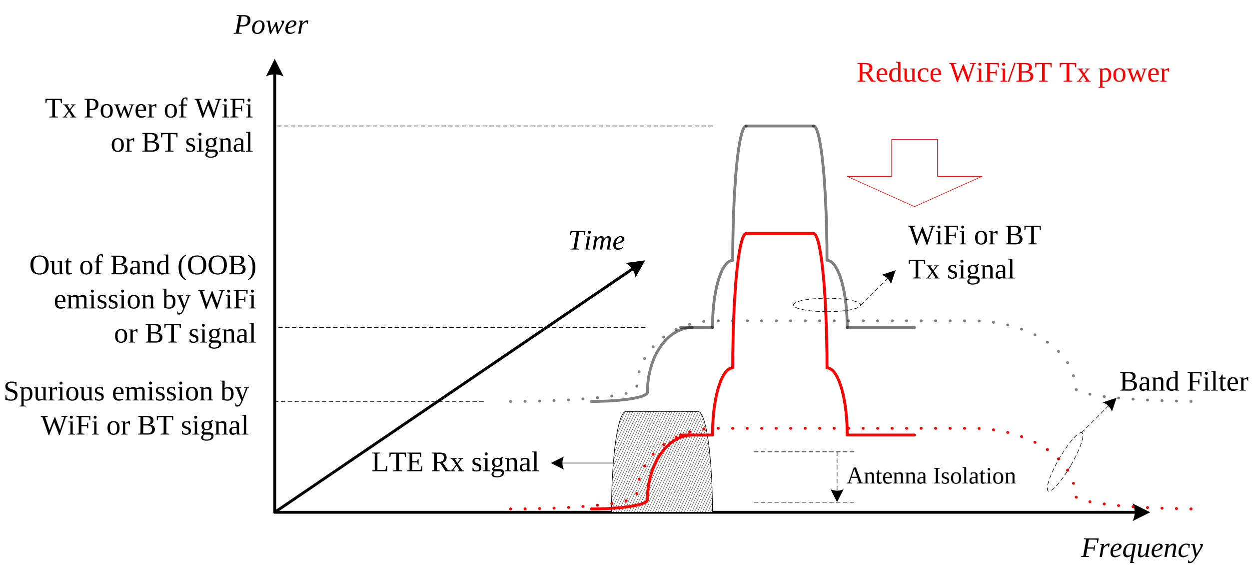

Figure 5.1.2.5-1: ISM power control for coexistence interference mitigation

5.2 Description of interference avoidance solutions

5.2.1 LTE network-controlled UE-assisted solutions

5.2.1.1A General

Depending on the conditions of in-device coexistence interference on the serving frequency and non-serving frequencies, there are four scenarios to be considered as listed in Table 5.2.1.1A-1.

Table 5.2.1.1A-1: Conditions of in-device coexistence interference

Scenario	Simple description for each scenario
1	On-going interference on the serving frequency
2	Potential interference (currently not on-going) on the serving frequency
3	On-going interference on non-serving frequencies
4	Potential interference (currently not on-going) on non-serving frequencies

At the initiation of LTE network-controlled UE-assisted solutions, the UE can send an indication to the network to report the coexistence problems. In case of scenario 1, indications can be sent by the UE whenever it has problem in ISM DL reception it cannot solve by itself. At the same time, indications can also be sent by the UE whenever it has problem in LTE DL reception it cannot solve by itself, and the eNB did not take action yet based on RRM measurements. Other triggers of indication could be summarized as the following three cases, which relate to scenario 2-4 in Table 5.2.1.1A-1 respectively:

1) the UE indicates the network that coexistence problems may become serious on the serving frequency due to e.g. increase of ISM traffic;

2) the UE indicates the network that certain of non-serving frequencies are experiencing serious coexistence problems (no serious coexistence problems on the serving frequency);

3) the UE indicates the network that coexistence problems may become serious on the non-serving frequencies (no serious coexistence problems on the serving frequency).

When LTE UL transmission interferes with ISM/GNSS DL reception, LTE measurements cannot be used to detect the problem and the details of the trigger(s) for the UE to report the problem will probably not be specified in 3GPP. When ISM UL transmission interferes with LTE DL reception, existing RRM measurement cannot guarantee timely trigger of indication. Triggers of indication in scenarios 2-4 are not limited to LTE DL measurements.

The triggers of indication should focus on scenarios 1 and 3 in Table 5.2.1.1A-1. If the interference situation changes significantly, the UE should send an indication to the network to report the updated interference situation. It is left to work item phase to discuss how to limit unnecessary triggers/trigger misuse e.g. by defining new measurements or new test cases.

In order to avoid ping-pong handover back to the problematic frequency, it would be valuable to make the target eNB be aware of the coexistence problem within the UE. The following two options have been identified to transport (part of) the information to a target eNB:

- The information is transferred from the source to the target eNB;

- The information is reported again by the UE to the target eNB

5.2.1.1 Frequency Division Multiplexing (FDM) solution

The UE informs the E-UTRAN when transmission/reception of LTE or other radio signal would benefit or no longer benefit from LTE not using certain carriers or frequency resources. UE judgement is taken as a baseline approach for the FDM solution, i.e. the UE will indicate which frequencies are unusable due to in-device coexistence.

It is FFS how this indication is transmitted (e.g. new report, CQI dummy values, dummy RSRP measurement, etc) and if additional information would be useful to report to enable different handover policies in the eNB based on the actual interferer.

The details of E-UTRAN actions upon reception of the assistant information are FFS.

5.2.1.2 TDM solutions

SCO, eSCO, A2DP and ACL protocols are assumed to be supported by in-device BT radio when analyzing the TDM solutions for LTE-BT coexistence. Beacon, power saving and DCF protocols are assumed to be supported by in-device WiFi radio when analyzing the TDM solutions for LTE-WiFi coexistence.

For TDM solutions, the UE can signal the necessary information, e.g. interferer type, mode, and possibly the appropriate offset in subframes to the eNB. The UE can also signal a suggested pattern to the eNB. Based on such information, the final TDM patterns (i.e. scheduling and unscheduled periods) are configured by the eNB.

5.2.1.2.1 DRX based solution

The UE provides the eNB with a desired TDM pattern. For example, the parameters related to the TDM pattern can consist of:

- Periodicity of the TDM pattern;
- Scheduling period (or unscheduled period).

One example of the desired TDM pattern is depicted in Figure 5.2.1.2.1-1

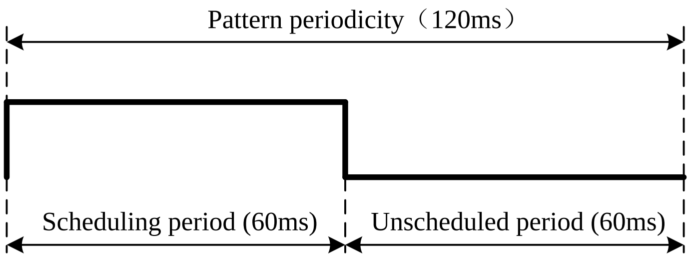

Figure 5.2.1.2.1-1: Example of UE suggested TDM pattern

It is up to the eNB to decide and signal the final DRX configuration to the UE based on UE suggested TDM pattern and other possible criteria e.g. traffic type. The scheduling period corresponds to the active time of DRX operation defined in section 5.7 [14], while unscheduled period corresponds to the inactive time. The eNB should try to guarantee the unscheduled period by existing mechanisms, e.g. appropriate UL/DL scheduling, SRS transmission configuration, DRX Command MAC control element usage, and etc. It means that flexibility principles from existing DRX mechanism will apply (i.e. variable scheduling/unscheduled period is possible) and no impact on UE HARQ operation is assumed so far. During inactive time UE is allowed to delay the initiation of dedicated scheduling request and/or RACH procedure. Figure 5.2.1.2.1-2 illustrates one example of eNB signalled DRX configuration based on UE suggested pattern depicted in Figure 5.2.1.2.1-1:

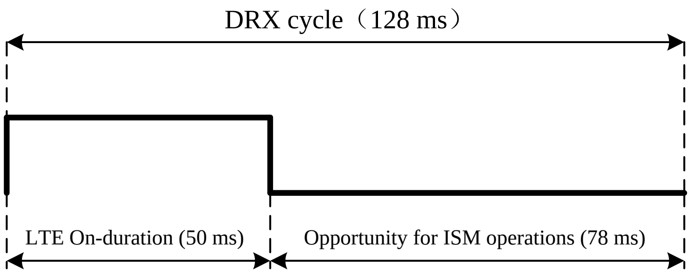

Figure 5.2.1.2.1-2: Example of DRX configured by eNB to enable TDM

It is FFS whether special handling for RRM/RLM/CSI measurement during unscheduled period (inactive time) would be required.

In the Rel-8/9 DRX mechanism, the UE needs to be active for potential uplink and downlink HARQ retransmissions:

- After the DL transmission, the UE waits for the HARQ RTT timer (e.g. 8 ms for FDD) and after that the UE is Active during the drx-RetransmissionTimer if the received transport block is not decoded correctly.

- After the UL transmission, the UE needs to monitor potential UL retransmission grants. These adaptive grants can occur every RTT (e.g. 8 ms for FDD) until the maximum number of UL HARQ transmissions is reached.

A typical value for drx-RetransmissionTimer is 16 PDCCH sub-frames. In case of FDD, this timer together with HARQ retransmission timer means that the UE can be active (even not continuously) 8 + 16 = 24 ms after the DL transmission. The time how long the UE needs to monitor adaptive retransmission grants depends on the configured value of the maximum HARQ transmissions. Configuring sufficiently large number of HARQ transmissions guarantees that packets are not lost at the HARQ level. With 4 possible retransmissions, for FDD the UE is Active (even not continuously) 8*4=32 ms after the initial grant. Taking the potential UL and DL retransmissions into account, with the values shown in Figure 5.2.1.2.1-2, an Active time limited to 50 ms can be reached only if the UE is scheduled during the first 18 ms of OnDurationTimer. If the UE can be scheduled for the initial HARQ transmissions only during the first 18 ms of each 128 ms period, the UE available data rate drops to 14%.

It is possible to optimize DRX and HARQ settings for IDC scenario in such away that the transition period from the LTE Active state to the state reserved for ISM operations is shorter. With this tuning time that can be used for LTE increases as well as the corresponding LTE throughput. Change of the parameter setting increases HARQ level data loss rate that is harmful especially for UM bearers. However, this can be compensated by more robust coding in a scheduler.

Modifications for Rel-8/9 DRX could be introduced to reduce the transition time from the Active state to the DRX state. For example, the eNB could send a specific MAC CE that enforces the UE to sleep and ignore potential HARQ retransmissions.

One example of the performance analysis of three scenarios discussed here is depicted in Table 5.2.1.2.1-1. When the performance obtained with the modified DRX mechanism is compared to the performance obtained with tuning of DRX parameters, from peak-rate point of view it is not obvious that enhancements to Rel-8/9 DRX are needed.

Table 5.2.1.2.1-1: Performance analysis of DRX solution in the example WiFi offload scenario

Case	UE available data rate (expressed as a ratio from maximum)	Data loss rate at HARQ level	Standardization impact on DRX and HARQ
Default DRX configuration	14%	Close to 0%	No
IDC tuned DRX configuration	33%	1% in UL and DL	No
IDC optimized DRX mechanism	39%	Depends on the solution and scenario	Yes

DRX solution could be used also for shorter interference patters. E.g. with BT voice, it is possible to configure DRX cycle to 10 ms or 5 ms and then achieve a desired gap pattern with appropriate setting on drx-OnDurationTimer, drx-InactivityTimer, drx-retransmissionTimer and DRX offset. In some cases, drx-retransmissionTimer of 0 ms needs to be introduced to avoid the UE to be DRX Active in the subframes that are reserved for ISM traffic. See more details of DRX solution in [18]. The performance of this solution is similar to the corresponding HARQ process reservation solution discussed in Subsection 5.2.1.2.2.

5.2.1.2.2 HARQ process reservation based solution

In this solution, e.g. a number of LTE HARQ processes or subframes are reserved for LTE operation, and the remaining subframes are used to accommodate ISM/GNSS traffic.

For example, for LTE TDD UL/DL Configuration 1, the solution is shown in Figure 5.2.1.2.2-1. For each radio frame, subframe #1, #2 #6 and #7 are reserved for LTE usage. Other subframes may be used for ISM/GNSS traffic, i.e. UE may not be required to receive PDCCH/PDSCH and/or transmit PUSCH/PUCCH in those subframes, depending on coexistence scenarios.

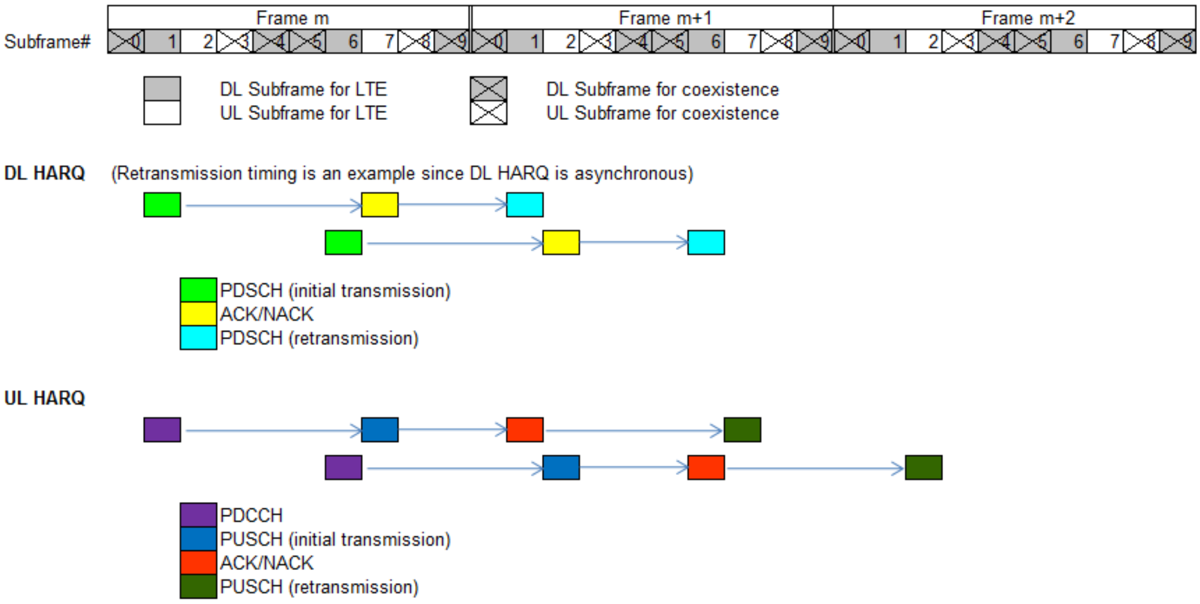

Figure 5.2.1.2.2-1: Example of HARQ process reservation solution

It is up to the eNB to decide and signal the final pattern, e.g. a bitmap (i.e. subframe reservation pattern) to the UE based on some assistance information reported by the UE. With respect to the assistant information, the UE can indicate either:

- Time offset between BT and LTE + BT configuration, or
- In-device coexistence interference pattern(s), or
- HARQ process reservation based pattern(s)

The information that UE provides should allow the network to ensure at least a pair of clean BT Tx/Rx instances in each BT interval, and as much as possible capacity to LTE. The reserved subframes should comply with LTE release 8/9 UL HARQ timing [15], and comply with LTE release 8/9 DL HARQ timing [15] as much as possible. It means that UE can assume that the eNB will restrict itself to DL allocation/UL grants inside this pattern. It is FFS whether the patterns are standardized in the specification, so that the eNB (or UE) can only signal an index of pattern (e.g. bitmap) to the UE (or eNB). It is FFS how frequent the assistant information should be sent from the UE.

Editor's note: The feasibility and usefulness of this solution need further study.

In Table 5.2.1.2.2-1 some HARQ compliant bitmaps having length of 10 ms are presented, whereas in Table 5.2.1.2.2-2 interference bitmaps having the length of 30 ms are presented. Note that the patterns are not necessarily optimised for max LTE subframe usage. From the tables it can be seen that by having a longer bitmap (30 ms), the maximum data rate achieved in the LTE side is higher than with a short bitmap (10 ms).

Table 5.2.1.2.2-1. Performance of HARQ compliant bitmaps (short bitmaps)

Case		DL data rate	UL data rate
TDD config 2, master	1111110100	5/8=63%	½=50%
TDD config 3, master	1111111101	6/7=86%	2/3=67%
TDD config 4, master	1111111001	6/8=75%	½=50%
TDD config 5, master	1111010010	5/9=56%	1/1=100%
TDD config 1, slave	0011011001	3/6=50%	2/4=50%

Table 5.2.1.2.2-2. Performance of non-HARQ compliant bitmaps (long bitmaps)

Case		DL data rate	UL data rate
TDD config 2, master	1111101111 1111111111 0111111111	22/24=92%	6/6=100%
TDD config 3, master	1111111101 1111111011 1111111011	18/21=86%	8/9=89%
TDD config 4, master	1111110111 1011110111 1111111011	20/24=83%	2/2=100%
TDD config 5, master	1111101011 1111101111 0111110111	19/24=79%	2/2=100%
TDD config 1, slave	1011110111 1011110111 1011110111	4/6=67%	¾=75%

5.2.1.2.3 Uplink scheduling restriction based solution

LTE uplink transmission causes interference to GNSS reception. In certain coexistence scenarios it would be helpful if the eNB scheduler restricts uplink scheduling for the UE to certain threshold. This solution is suitable for solving coexistence issue for those scenarios which needs LTE uplink transmission randomly distributed but restricted to certain threshold. The UE inform the interference situation to the eNB along with some assistant data e.g. uplink scheduling restriction threshold. The eNB scheduler tries to restrict uplink scheduling for the UE within the threshold.

For example, in GNSS each bit is DSSS spread over few tens of ms, i.e. 20ms bit period in case of GPS. GNSS requires some amount of interference free time every bit period depending upon GNSS receiver phase (i.e. acquisition, tracking phase). There may be no specific requirement that certain portion of bit period is more critical than other. If GNSS receiver can get sufficient percentage of interference free time out of every bit period then it can possibly recover the signal and solve the in-device co-existence issue.

Editor's note: The feasibility and usefulness of this solution need further study.

5.2.1.3 LTE power control solutions

To mitigate coexistence interference to ISM/GNSS DL reception, the UE can report the need for power reduction to the eNB.

For existing mechanism, the UE can adjust the power control parameters locally and report the change by existing mechanism (PHR, extended PHR). The eNB may not be aware of the reason, but it gets the idea that the UE demands power reduction through the report. This group of solutions can be implemented by Rel-8/9/10 UEs. It is FFS whether P-MPR can be used for this purpose.

If a new report is introduced, it is FFS how the report is transmitted (e.g. via RRC or MAC) and what information should be included (e.g. interference type, power reduction value, etc).

Upon reception of the report the eNB can adjust the UE transmission power through existing mechanism, e.g. PDCCH or RRC signalling.

5.2.2 UE autonomous solutions

5.2.2.1 TDM solutions

5.2.2.1.1 LTE denials for infrequent short-term events

UE can autonomously deny LTE resources due to some critical short-term events of ISM side, e.g. some events during BT/WiFi connection-setup or other important signalling. Otherwise, large delay or failure of connection-setup could happen if these events are not prioritized over LTE. This solution is assumed to be used for the event that rarely takes place. Potentially, requirements on the frequency and duration of denials would need to be defined if such a solution would be adopted.

The analysis indicates that autonomous LTE denial at the UE, i.e. UE occasionally skipping an LTE UL transmission without any limitation is not acceptable due to its impact on LTE performance, especially on PDCCH link adaptation accuracy and PDCCH capacity [19]. It is FFS whether autonomous LTE denial with further enhancement, e.g. the UE would have to provide additional assistant information to the network, is needed to handle rare periodic or non-periodic events.

Editor's note: The feasibility and usefulness of this solution need further study.

5.2.2.1.2 LTE denials for ISM data packets

During stable situation of ISM operation, some LTE resources can be denied by UE autonomously to protect ISM data packets, so e.g. the BT eSCO connection or WiFi connection with PS-Poll can be maintained. The UE can feedback the denial pattern to the eNB, or the eNB can learn the pattern used by the UE based on DTX and other implementation specific solutions. An example of this solution is shown in Figure 5.2.2.1.2-1.

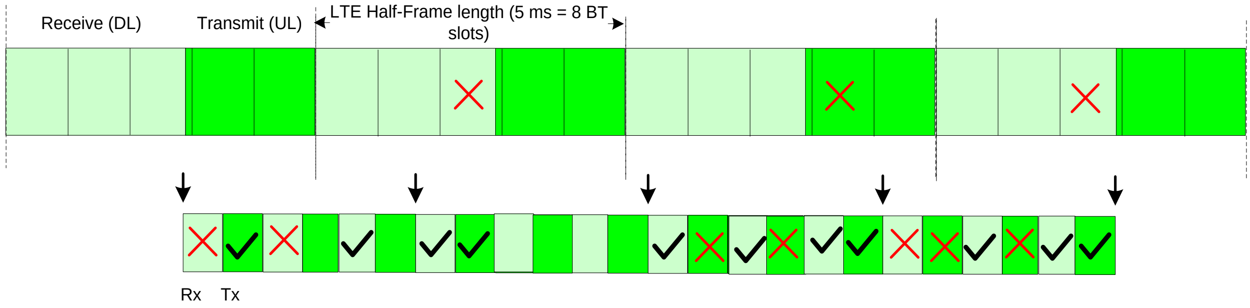

Figure 5.2.2.1.2-1: Example of LTE denials in case of LTE in Band40 coexisting with BT slave

The analysis indicates that without eNB knowing the denial resources, the UL throughput loss is up to 41.6% [16]. Therefore, autonomous LTE denials for ISM data packets seem not an acceptable solution for solving steady state situations e.g. voice call.

5.2.2.1.3 ISM denials for LTE important reception

UE can autonomously deny ISM transmissions to ensure successful reception of important LTE signalling, e.g. system information, paging, synchronization signal, critical dedicated signalling, etc. The details are up to UE implementation and will not be specified in 3GPP.

5.3 Applicability of interference avoidance solutions

The applicability of TDM solutions for each usage scenario is summarized in Table 5.3-1.

Table 5.3-1: Applicability of different TDM solutions

TDM solution	Usage scenario				
	LTE+BT earphone (VoIP service)	LTE+BT earphone (Multimedia service)	LTE+WiFi portable router	LTE+WiFi offload	LTE+GNSS Receiver
HARQ process reservation based solution	Applicable	Applicable for BT Master, but not applicable for BT Slave	FFS	FFS	Applicable
DRX based solution	Applicable	Applicable	Applicable	Applicable	Applicable
Uplink scheduling restriction based solution	Not applicable	Not applicable	Not applicable	Not applicable	Applicable
Autonomous denial solution	Complementary solution for receiving important signalling				

6 Conclusion

[Editor's note: This section captures the conclusion of the study. The section can be formulated in such way that the contents can be used as an input of further specification work.]

The following main conclusions were drawn during the study item phase:

1. Regarding the usage scenarios to be considered, the prime focus is to support data communication over one type of ISM radio when LTE is also active at the same time.

2. With respect to the modes of interference avoidance, at least an internal coordination between different radio technologies within the UE should be assumed when defining solutions.

3. FDM solution is believed to be a feasible solution to resolve the in-device coexistence issues.

4. DRX based TDM solution is believed to be a feasible solution to resolve the in-device coexistence issues.

5. At this stage, it seems impossible to come up with a unified TDM solution to solve coexistence issues of all the usage scenarios. The possibility of unified signalling approach could be investigated during work item phase.

6. It has been confirmed that any media sharing solution will come at a cost for LTE.

Annex A: Interference analysis on in-device coexistence between LTE and ISM

The RF analyses on in-device coexistence interference between ISM and LTE technologies have been studied. The analyses and measurements presented in [7], [8], [9], [10], and [11] indicate that for some in-device coexistence scenarios, significant degradation of both LTE and ISM systems can occur despite current state-of-the-art RF filtering technology. However, for other in-device coexistence scenarios, it is observed that frequency-domain solutions, e.g. moving to different frequencies and filtering can sufficiently suppress the coexistence interference [11]. The precise quantitative results differ from contribution to contribution due to different assumptions in the analyses or the measurement approaches. Nonetheless, the conclusions are consistent in that at least a significant fraction of spectrum is highly desensitized when the other technology is transmitting. For the remainder of this section, we will refer to the analysis provided in [7] as Analysis 1, the measurement and analysis in [8] and [9] as Analysis 2, the analysis in [10] as Analysis 3, and the analysis in [11] as Analysis 4, respectively. The approaches and assumptions for these four analyses are summarized in Table A-1.

Table A-1: Assumptions for the RF Analyses

Parameter	Analysis 1	Analysis 2	Analysis 3	Analysis 4
LTE Band	40 and 7	40 and 7	40	40 and 7
ISM technology considered	BT, WLAN	WLAN	WLAN	BT, WLAN
Interference directions considered for B40	LTE to BT/WLAN; BT/WLAN to LTE	LTE to WLAN; WLAN to LTE	LTE to WLAN only	LTE to BT/WLAN; BT/WLAN to LTE
Interference mechanisms considered	Spurious emission and blocking	Spurious emission and blocking	Spurious emission only	Spurious emission and blocking
Filter	FBAR	No filters external to test set-up	Commercially available filter (typical/minimum)	FBAR
Antenna Isolation	12 dB	15, 20, 25 dB	12 dB	12 dB
LTE Tx power	23 dBm	23 dBm	N/A	0, 15, 23 dBm
WLAN Tx power	20 dBm	20 dBm	20 dBm	20 dBm, 14.5 dBm
BT Tx power	10 dBm	N/A	N/A	4 dBm, 0 dBm
LTE RSSI (as victim)	-94 dBm	-70 dBm	-94 dBm	-94 dBm (Band 40) -92 dBm (Band 7)
WLAN RSSI	-79 dBm	-50 dBm	N/A	-89 dBm, -76 dBm
BT RSSI	-90 dBm	N/A	N/A	-70 dBm
LTE Bandwidth	20 MHz	25-100 RBs (over 20 MHz)	20 MHz	20 MHz
WLAN Bandwidth	22 MHz	22 MHz	22 MHz	22 MHz
BT Bandwidth	1 MHz	N/A	N/A	1 MHz
Performance measure	Desensitization (in dB)	EVM	Desensitization (in dB)	Desensitization (in dB)

Based on the RF analyses, the following observations are obtained:

- For some in-device coexistence scenarios, the interference can severely disrupt receive activities in the entire victim band. For these scenarios, frequency-domain solutions such as moving to different frequencies or filtering may not be feasible.

- For other in-device coexistence scenarios, frequency-domain solutions can sufficiently suppress the coexistence interference.

- LTE transmit power control (typically power level below the maximum 23dBm) can help mitigate/reduce the coexistence interference to ISM receptions.

A.1 Assumptions

A.1.1 Filtering assumptions

A critical parameter in quantifying the expected degradation in performance is the filtering assumptions used in the analysis. A transmit filter reduces the out-of-band spurious emissions falling into the receive band of the other technology; whereas a receive filter reduces the blocking effect due to the transmitter in the other technology. Each filter serves a different, but necessary purpose in mitigating interference and desensitization to the extent possible within the constraints of the design. For purposes of this coexistence study, the key constraint is the limited attenuation available over the transition band of the filter. In some cases, for example between LTE in Band 40 and ISM starting at 2400 MHz, there is no guard band available for the filter to transition over. Thus, the limited rejection of the filter over the transition band is the most detrimental when each technology is operating at the band edges. The problem is amplified when one takes into account the variation in filter response across manufacturing process and over the temperature range that the device must operate.

In Analysis 1, the best known simulated BAW (FBAR) filter performance for both ISM and LTE have been assumed. The analysis further accounts for filter response variations over process and temperature.

In Analysis 2, lab measurement results were provided to indicate the nature of interference and the performance degradation. In this case, lab bench test equipment was used to evaluate performance. The transmitted signals, both wanted and interfering, were produced by signal generators. The receiver was a vector signal analyzer measuring the error vector magnitude (EVM) of the received signal corrupted by interference. External filters were not employed in the test setup, so the Tx and Rx filtering function was provided by the inherent filtering in the signal generators and vector signal analyzer. The filtering function on the test equipment was not specified in the contribution.

In Analysis 3, a commercially available filter [12] has been assumed for ISM transmitter. Both the typical and the worst filter performance parameters are evaluated as indicated below.

- Typical attenuation filter value: 45dB for frequencies less than 2370 MHz and 37dB for frequencies between 2370 MHz and 2380 MHz

- Minimum attenuation filter value: 30dB for frequencies less than 2370 MHz and 22dB for frequencies between 2370 MHz and 2380 MHz

Since only the ISM Tx filter has been identified, the analysis considers the out-of-band spurious emissions from ISM into LTE, but the blocking aspect of the ISM transmitter has not been included.

Analysis 4 also assumes a commercially available FBAR filter [12] for the ISM Tx/Rx filter. For LTE Band 40 filter, transition and stop band responses are assumed to be similar to the ISM band filter, but shifted downward with a pass band in 2300~2400 MHz. The Band 7 transmit filter is assumed to have similar transition and stop band responses to the commercially available 2496–2690 MHz WiMax bandpass filter [13].

A.1.2 Antenna isolation

Another key parameter affecting in-device coexistence performance is the antenna isolation between the two systems. Analyses 1, 3, and 4 have assumed an antenna isolation of 12dB to be representative of typical applications and devices. Analysis 2 has investigated the impact of antenna isolations of 10, 15, and 20 dB.

A.1.3 Interference mechanisms

The interference mechanisms from one technology transmitting while the other one is receiving that have been considered are out-of-band spurious emissions and receiver blocking. The spurious emissions result from the ACLR sidebands from the transmitting waveform. The spurious emissions, attenuated by the Tx filter, can extend into the receive band of the other technology causing an effective increase in noise level, or desensitization, or a degradation in measured EVM. Receiver blocking is resulted from a large unwanted signal adjacent to or within close proximity in frequency to the desired signal. The blocking signal coupled with the non-linearity within the receiver generates an additional in-band noise component which can also increase EVM and degrade sensitivity of the impacted system.

In Analysis 1, both spurious emissions and blocking have been considered in the evaluation. Their cumulative effect on desensitization is reported. The ACLR of the transmitter and the linearity of the receiver are not specified.

In Analysis 2, since a lab measurement was performed, all aspects including spurious emissions and blocking are considered. However, because the receiver in this case is a vector signal analyzer, the linearity of this test equipment may not be representative of the linearity in an actual LTE or ISM device. However, the spurious emissions effect is modeled in this measurement as ACLR1 and ACLR2. The assumptions are as follows

- LTE ACLR1 = -32dB

- LTE ACLR2 = -50dB

- WLAN ACLR1 = -34dB

- WLAN ACLR2 = -51dB

In Analysis 3, the spurious emissions impact has been considered by using a measured PA output spectrum for WLAN 802.11g. The blocking effect has not been considered.

In Analysis 4, both spurious emissions and blocking have been considered in the evaluation. Their cumulative effect on desensitization is reported specifying the receiver compression point.

A.1.4 Signal Bandwidth

Signal bandwidth of the transmitting signal impacts the frequency extent of the spurious emissions – wider bandwidths generate spurious emissions which extend further in frequency. In all cases, the bandwidth of WLAN is fixed at 22

MHz and the Bluetooth bandwidth at 1 MHz not taking into consideration frequency hopping. The bandwidth of the LTE signal has been assumed to be 20 MHz for Analysis 1, Analysis 3, and Analysis 4. For Analysis 2, the channel bandwidth for LTE is assumed to be 20 MHz, but the uplink allocation and therefore the extent of spurious emissions is varied from 100RB's at full allocation to 50 RB's and 25 RB's.

A.1.5 Transmitter output power

Transmitter output power affects the blocking performance and the amplitude of spurious emissions. More interference is generated when the output power is higher. In Analysis 1-3, a high output power was assumed. The maximum output power for LTE was assumed at 23dBm, the output power for WLAN was assumed to be 20dBm, and the output power for Bluetooth was assumed to be 10dBm.

Analysis 4 investigates the coexistence interference level for various transmit powers of aggressors. Considering that LTE transmission with 23dBm transmit power are typically associated with cell-edge UEs with smaller resource allocations, practical resource allocation and/or resource allocation limitations (e.g., limiting the number of RBs and position away from ISM band-edge) can reduce the LTE interference primarily impacting channels in the ISM band-edge. Finally, Analysis 4 assumes Bluetooth power class 2, which allows the maximum transmit power of 4dBm.

A.1.6 Performance metrics

The impact on the affected system is characterized by degradation in performance. Desensitization is a common indicator. Indeed, desensitization is the metric used in Analyses 1 and 3 where the desensitization is relative to an assumed reference sensitivity value. The desensitization is approximated as $10\log_{10}(\alpha)$ in Analysis 1 and computed as $10\log_{10}(\alpha+1)$ in Analysis 3 and Analysis 4, where α is the ratio between the coexistence interference and the noise floor at sensitivity. The assumed reference sensitivity values in Analysis 1 are -94dBm for LTE in Band 40, -92dBm for LTE in Band 7, -90dBm for Bluetooth, and -79dBm for WLAN. Using desensitization as the performance measure gives an indication of the degradation that can be expected when the victim system is in its most vulnerable state at the edge of its coverage, so may be descriptive of a worst case scenario.

On the other hand, Analysis 2 uses a slightly different metric of EVM. EVM can also indicate potential degradation in receiver performance as signal with large EVM would likely be incorrectly decoded at the demodulator. Instead of considering reference sensitivity, Analysis 2 provides insight into performance at more nominal receive power levels that might be more typically observed in practice. For example, the received signal power for the LTE receiver is -70dBm, which is 24dB above reference sensitivity. The received signal power level for the WLAN receiver is -50dBm, which is 29dB above sensitivity as defined in Analyses 1 and 3. Analysis 2 uses a benchmark of 5.62% EVM to judge whether the LTE or WLAN system performance is acceptable or not.

A.2 Results

The results of the interference analyses are provided in this subclause.

A.2.1 Analysis 1 Results

A quick look into the results shows that LTE activities in the highest 30MHz of Band 40 can, in the worst case scenario, disrupt BT/WLAN activity over the entire ISM band. Moreover, LTE activity in any portion of Band 40 will have serious impact on the lowest 20MHz of the ISM band.[1]

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[1] While this may not be an issue for BT which employs adaptive frequency hopping (AFH) and can avoid transmission/reception in the first 20MHz, it is definitely an issue for WLAN channel 1 if it operates in the infra structure mode.

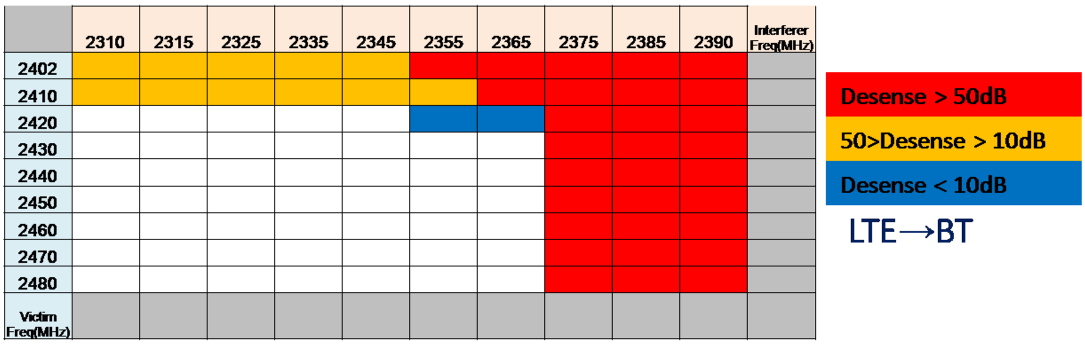

Figure A.2.1-1: Coexistence interference impact from LTE in B40 on BT

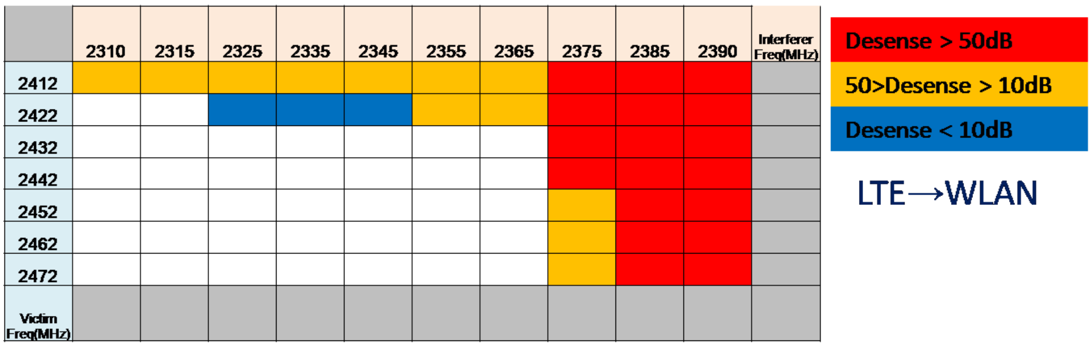

Figure A.2.1-2: Coexistence interference impact from LTE in B40 on WLAN

Figure A.2.1-3 and Figure A.2.1-4 show the coexistence interference impact on LTE from BT and WLAN respectively. As shown in the figures, any activity in the lowest 20MHz[2] of the ISM band can, in the worst case scenario, impact LTE activities across the entire Band 40. Also, BT/WLAN activity anywhere within the ISM band could impact the highest 20-30MHz of Band 40.

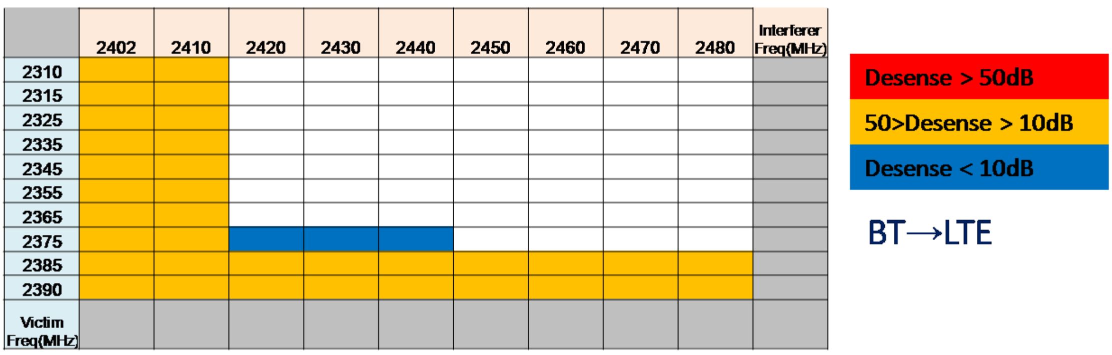

Figure A.2.1-3: Coexistence interference impact on LTE in B40 from BT

[2] Again, this frequency range can be avoided in BT by AFH

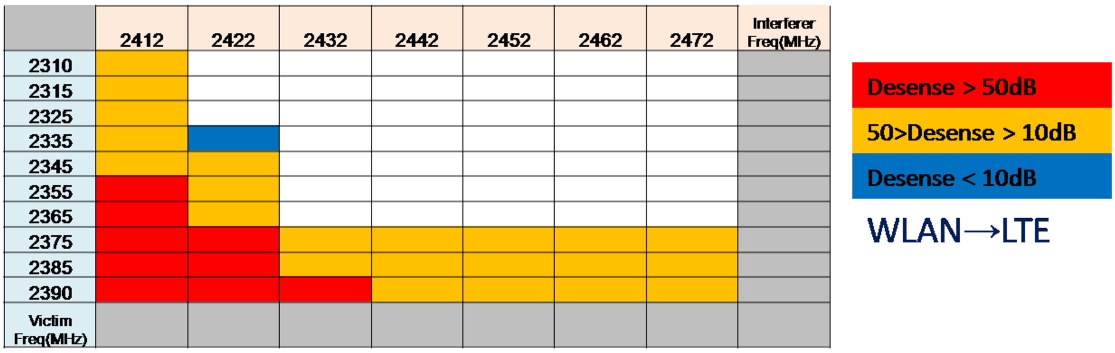

Figure A.2.1-4: Coexistence interference impact on LTE in B40 from WLAN

Figure A.2.1-5 and Figure A.2.1-6 show the coexistence interference impact from LTE in Band 7 on BT and WLAN respectively. As expected, in the worst case, LTE UL in the 2510MHz channel can desensitize the entire ISM band. For the remaining LTE channels, AFH on BT is required to limit operation to the first 40-60MHz of the ISM band.

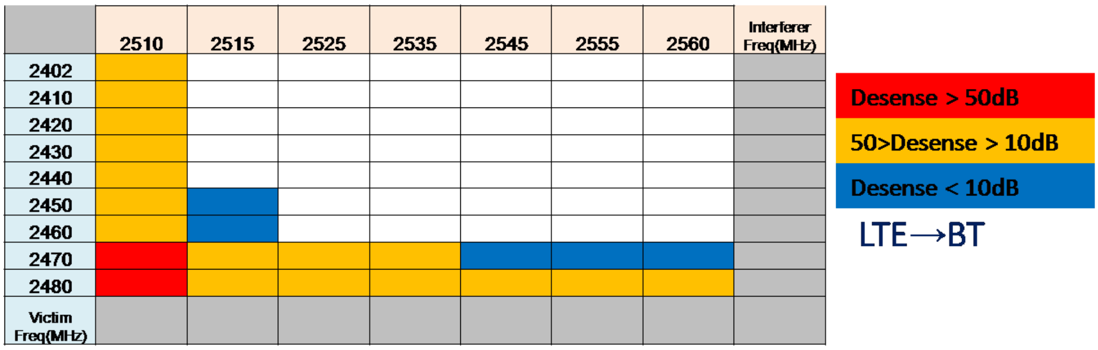

Figure A.2.1-5: Coexistence interference impact from LTE in B7 on BT

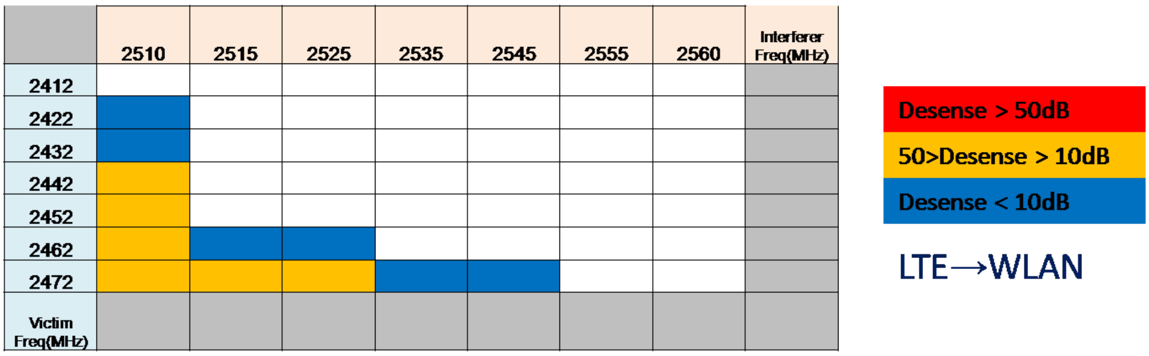

Figure A.2.1-6: Coexistence interference impact from LTE in B7 on WLAN

Note that Band 7 DL is far enough away from the ISM band to suffer interference. While there may be an interference mechanism here such that a simultaneous transmission of ISM and LTE UL mixes due to non-linearity and falls in LTE, we do not consider such mechanisms in this paper.

In conclusion, the presented analysis shows significant degradation in sensitivity due to LTE-ISM coexistence on the same device. While the analysis assumes worst case conditions in terms of aggressor transmit power, receiver RSSI and filter variations, we note that coexistence interference extends to a number of cases in nominal conditions. For instance, LTE transmit activities in 2380-2400MHz and/or ISM transmissions in 2400-2420MHz can severely disrupt receiving activities in the whole victim band. In addition, the FBAR filters used in the analysis come with additional cost compared to the typically used SAW and ceramic filters.

The analysis above clearly shows that in a number of LTE and ISM channel combinations, RF filtering is not enough to prevent significant desensitization.

A.2.2 Analysis 2 Results

Table A.2.2-1: Experimental results about Minimum Center Frequency Space

Aggressor	Victim	Minimum Center Frequency Space（MHz）		
		Antenna isolation		
		10dB	15dB	20dB
LTE band 40	WLAN	58MHz	52MHz	50MHz
WLAN	LTE band 40	56MHz	50MHz	46MHz
LTE band7	WLAN	60MHz	52MHz	50MHz

NOTE: The number of RB for band40 or band7 is 100RB and the moving step for LTE away from WLAN is 2MHz in above experiment.

From the above table we can conclude that:

- For band 40 or band 7, when LTE working at the center frequency f1 and WLAN working at the center frequency f2, the space of center frequency between LTE and WLAN need to meet:

$$|f1 - f2| \geq Minimum\ Center\ Frequency\ Space$$

- The antenna isolation is a great impact on the Minimum Center Frequency Space between LTE and WLAN, so we should try to increase the antenna isolation to decreasing Minimum Center Frequency Space.

- The band is divided into safety zone and danger zone by considering Minimum Center Frequency Space.

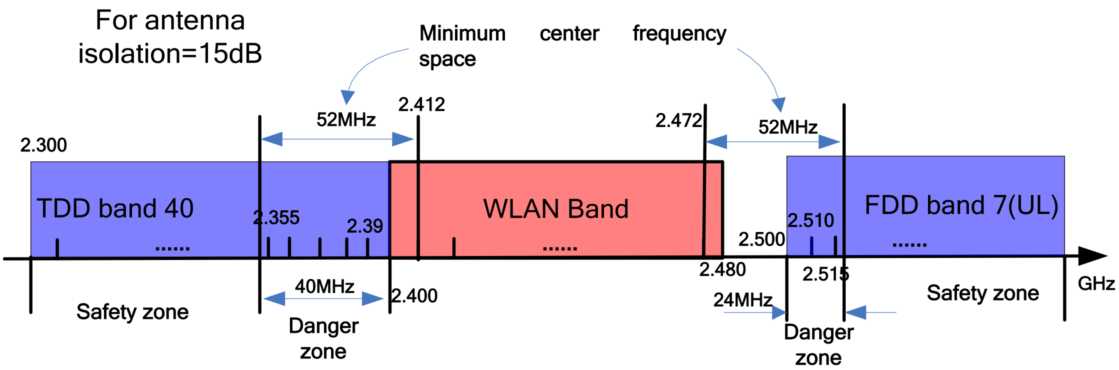

Figure A.2.2-1: Safety zone and danger zone

From the Figure A.2.2-1 we can see that the size of danger zone for band 7 is smaller than danger zone for band 40.For antenna isolation=15dB, the size of danger zone for band 40 is 40 MHz, but 24 MHz for band 7. There are only 2 center frequencies in the danger zone for band 7, but there are about 5 center frequencies for band 40, according to center frequency distribution of band 40 and band7 in [7].

Table A.2.2-2: Experimental results about Minimum Center Frequency Space

	Antenna isolation		
	10dB	15dB	20dB

Band7:2510MHz WLAN:2472MHz	100RB Start=0	fail	fail	fail
	50RB Start=50	fail	fail	ok
	25RB Start=75	ok	ok	ok
Band7:2515MHz WLAN:2472MHz	100RB Start=0	fail	fail	ok
	50RB Start=50	ok	ok	ok
	25RB Start=75	ok	ok	ok

NOTE: "Fail" is used to mark the situation of EVM> 5.62%, and "OK" is used to mark the situation of EVM<=5.62%.

A.2.3 Analysis 3 Results

Table A.2.3-1 shows the desensitization results when using typical attenuation filter values and Table A.2.3-2 shows the desensitization results when using minimum attenuation filter values.

Table A.2.3-1: Coexistence interference impact from WLAN to LTE in B40 –Typical attenuation filter values used

	2412	2422	2432	2442	2452	2462	2472	Interferer Freq. MHz
2310	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
2315	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
2325	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
2335	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
2345	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
2355	3.9	2.5	2.5	2.5	2.5	2.5	2.5	
2365	12.3	7.7	4.7	4.5	4.5	4.5	4.5	
2375	54	48	43	38	38	38	38	
2385	63	57	51	46	43	43	43	
2390	66	60	54	49	45	44	44	
Victim Freq. MHz								

Desensitization < 3dB
3dB < Desensitization < 10dB
10dB < Desensitization< 50dB
Desensitization > 50dB

Table A.2.3-2: Coexistence interference impact from WLAN to LTE in B40 – Minimum attenuation filter values used

	2412	2422	2432	2442	2452	2462	2472	Interferer Freq. MHz
2310	14	14	14	14	14	14	14	
2315	14	14	14	14	14	14	14	
2325	14	14	14	14	14	14	14	
2335	14	14	14	14	14	14	14	
2345	14	14	14	14	14	14	14	
2355	17	14	14	14	14	14	14	
2365	27	22	18	17	17	17	17	
2375	54	48	43	38	38	38	38	
2385	63	57	51	46	43	43	43	
2390	66	60	54	49	45	44	44	
Victim Freq.								

MHz								

Desensitization < 3dB
3dB <Desensitization< 10dB
10dB <Desensitization< 50dB
Desensitization > 50dB

From the results shown in the above tables we can note that although LTE sensitivity degradation is severe for very close interferer and victim spacing, the nominal filter response of the ISM band-pass filter used in this analysis effectively controls the interference in the lower half of Band 40. There is a sensitivity degradation of about at least 2.5 dB across the whole Band 40 due to the noise floor of the specific WLAN PA and the limited attenuation of the ISM filter mask. In reality, the ISM filter's response will not be flat across Band 40, and better performance is expected for at least some parts of the band. Assuming worst-case filter response, however, sensitivity degradation is severe across the whole band.

A.2.4 Analysis 4 Results

Table A.2.4-1 presents LTE blocking levels to WLAN/BT receivers for different LTE transmit powers and operating channel bands in LTE Band 40 and Band 7. As shown in Table A.2.4-1, a cell-edge UE transmitting with 23dBm maximum power in the uppermost 20MHz channel band of Band 40 can result in the maximum 7dBm out-of-band blocking interference at the WLAN/Bluetooth receiver. The LTE transmit power level needs to be limited for the simultaneous operation with ISM (reception) if the LTE transceiver is operated in upper 20MHz of Band 40. The maximum allowed LTE transmit power for the coexistence varies depending on the blocking characteristics of WLAN/BT receivers.

Table A.2.4-1: LTE blocking levels to Bluetooth/WLAN receivers for different LTE transmit powers and operating channel bands

LTE Tx Power (dBm)	Blocking with FBAR (dBm)				
	2300-2370 (MHz)	2360-2380 (MHz)	2380-2400 (MHz)	2500-2520 (MHz)	2520-2570 (MHz)
23	-34	-28	7	-37	-40
21	-36	-30	5	-39	-42
19	-38	-32	3	-41	-44
17	-40	-34	1	-43	-46
15	-42	-36	-1	-45	-48
13	-44	-38	-3	-47	-50
11	-46	-40	-5	-49	-52
9	-48	-42	-7	-51	-54
7	-50	-44	-9	-53	-56
5	-52	-46	-11	-55	-58
3	-54	-48	-13	-57	-60
1	-56	-50	-15	-59	-62
-1	-58	-52	-17	-61	-64
-3	-60	-54	-19	-63	-66
-5	-62	-56	-21	-65	-68
-7	-64	-58	-23	-67	-70
-9	-66	-60	-25	-69	-72

Figure A.2.4-1 presents desensitization levels in WLAN receivers due to LTE blocking and out-of-band/spurious emission for LTE transmission power levels of 23dBm, 15dBm, and 0dBm. In practice, when a strong blocking signal exists at the LNA input, the AGC algorithm reduces the receiver front end gain to avoid LNA saturation, which results in a noise floor increase at the receiver. In our analysis, we assume a noise floor increase of 4dB per 5 dBm of blocking above blocking requirements. Figure A.2.4-2 shows WLAN receiver desensitization levels when the LTE transceiver employs switching between two band pass filters, that is, pass bands of 2300-2400 MHz and 2300-2380 MHz. LTE transmission in 2300-2380 MHz results in negligible sensitivity degradation for all WLAN channels by using the alternative band pass filter of pass band 2300-2380MHz. However, the dual band pass filters solution may not be applicable for all deployment scenarios, e.g. the operator only has 20MHz spectrum at 2380-2400MHz.

	WLAN	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5-11
		2401-2423	2406-2428	2411-2433	2416-2438	2420-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	>16	>16	13	2	1
	2300-2360	>16	>16	13	2	1

(a) LTE Tx Power = 23 dBm

	WLAN	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5-11
		2401-2423	2406-2428	2411-2433	2416-2438	2420-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	>16	15	6	0	0
	2300-2360	>16	15	6	0	0

(b) LTE Tx Power = 15 dBm

	WLAN	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5-11
		2401-2423	2406-2428	2411-2433	2416-2438	2420-2480
LTE	2380-2400	>16	>16	15	12	9
	2360-2380	10	3	0	0	0
	2300-2360	10	3	0	0	0

(c) LTE Tx Power = 0 dBm

Figure A.2.4-1: WLAN receiver desensitization levels (dB) due to LTE transmission.

	WLAN	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5-11
		2401-2423	2406-2428	2411-2433	2416-2438	2420-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	1	1	1	1	1
	2300-2360	1	1	1	1	1

Figure A.2.4-2: WLAN receiver desensitization levels (dB) due to LTE transmission when switching between two LTE band pass filters. LTE Tx Power = 23 dBm.

Figure A.2.4-3 and Figure A.2.4-4 provide LTE receiver desensitization levels caused by simultaneous WLAN transmission. LTE in 2380-2400 MHz seems to be unusable due to severe sensitivity degradation if WLAN is transmitting in the 2.4GHz ISM band. WLAN in Channel 1-2 (2401-2428 MHz) transmitting with 20dBm transmit power causes 10dB or higher desensitization on the entire LTE Band 40 due to WLAN blocking to LTE. We can observe in Figure A.2.4-4 that switching between two LTE front-end filters results in manageable desensitization levels for LTE 2300-2380 MHz band irrespective of location of WLAN channel. However, the dual band pass filters solution may not be applicable for all deployment scenarios, e.g. the operator only has 20MHz spectrum at 2380-2400MHz.

	WLAN	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5-11
		2401-2423	2406-2428	2411-2433	2416-2438	2420-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	>16	16	8	5	5
	2300-2360	>16	13	5	2	2

(a) WLAN Tx Power = 20 dBm

	WLAN	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5-11
		2401-2423	2406-2428	2411-2433	2416-2438	2420-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	16	8	2	2	2
	2300-2360	15	7	1	1	1

(b) WLAN Tx Power = 14.5 dBm

Figure A.2.4-3: LTE receiver desensitization levels (dB) due to WLAN transmission.

	WLAN	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5-11
		2401-2423	2406-2428	2411-2433	2416-2438	2420-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	5	5	5	5	5
	2300-2360	2	2	2	2	2

Figure A.2.4-4: LTE receiver desensitization levels (dB) due to WLAN transmission when switching between two LTE band pass filters. WLAN Tx Power = 20 dBm.

Figure A.2.4-5 and Figure A.2.4-6 show BT receiver desensitization levels due to simultaneous LTE transmission. For LTE operated in 2380-2400 MHz with the maximum transmit power, the coexistence interference cannot be avoided by BT adaptive frequency hopping (AFH) due to high BT desensitization levels for all the BT channels. For LTE in 2300-2380 MHz, simultaneous operation of LTE and BT is feasible via BT AFH with BT avoiding Channels 1-15.

	BT	Channels 1-13	Channel 14-16	Channel 17	Channel 18-19	Channel 20-79
		2402-2414	2415-2417	2418	2419-2420	2421-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	>16	7	4	1	0
	2300-2360	>16	7	4	1	0

(a) LTE Tx Power = 23 dBm

	BT	Channels 1-13	Channel 14-16	Channel 17	Channel 18-19	Channel 20-79
		2402-2414	2415-2417	2418	2419-2420	2421-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	>16	2	1	0	0
	2300-2360	>16	2	1	0	0

(b) LTE Tx Power = 15 dBm

	BT	Channels 1-13	Channel 14-16	Channel 17	Channel 18-19	Channel 20-79
		2402-2414	2415-2417	2418	2419-2420	2421-2480
LTE	2380-2400	>16	>16	>16	12	9
	2360-2380	9	0	0	0	0
	2300-2360	9	0	0	0	0

(c) LTE Tx Power = 0 dBm

Figure A.2.4-5: BT receiver desensitization levels (dB) due to LTE transmission.

	BT	Channel 1-13	Channel 14-16	Channel 17	Channel 18-19	Channel 20-79
		2402-2414	2415-2417	2418	2419-2420	2421-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	0	0	0	0	0
	2300-2360	0	0	0	0	0

Figure A.2.4-6: BT receiver desensitization levels (dB) due to LTE transmission when switching between two LTE band pass filters. LTE Tx Power = 23 dBm.

Figure A.2.4-7 and Figure A.2.4-8 present LTE receiver desensitization levels from BT transmission.

	BT	Channels 1-13	Channel 14-16	Channel 17	Channel 18-19	Channel 20-79
		2402-2414	2415-2417	2418	2419-2420	2421-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	8	3	3	3	3
	2300-2360	6	1	1	1	1

(a) Bluetooth Tx Power = 4 dBm

	BT	Channels 1-13	Channel 14-16	Channel 17	Channel 18-19	Channel 20-79
		2402-2414	2415-2417	2418	2419-2420	2421-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	4	1	1	1	1
	2300-2360	3	0	0	0	0

(b) Bluetooth Tx Power = 0 dBm

Figure A.2.4-7: LTE receiver desensitization levels (dB) due to BT transmission.

	BT	Channels 1-13	Channel 14-16	Channel 17	Channel 18-19	Channel 20-79
		2402-2414	2415-2417	2418	2419-2420	2421-2480
LTE	2380-2400	>16	>16	>16	>16	>16
	2360-2380	3	3	3	3	3
	2300-2360	1	1	1	1	1

Figure A.2.4-8: LTE receiver desensitization levels (dB) due to BT transmission when switching between two LTE band pass filters. BT Tx power =4dBm.

The coexistence interference level and its impact on the receiver performance depends on transmit power and receiver blocking characteristic of each radio and physical characteristics of transceivers (e.g. filter responses, antenna isolation, etc.). The following conclusions can be drawn from the analyses:

- For most cases, we observe that frequency-domain solutions - moving to different frequencies and filtering can sufficiently suppress the coexistence interference.

- For the upper-most region of LTE Band 40, 2380-2400 MHz, LTE transmitting with the maximum power of 23dBm can block the WLAN/Bluetooth signal in the entire ISM band. Limiting the maximum LTE transmit power below 23dBm, moving LTE signal away from ISM, or time-division multiplexing need to be considered.

- For 2300-2380 MHz of LTE Band 40, WLAN/BT desensitization due to the LTE coexistence interference may be acceptable except for lower 20MHz of ISM band given current state-of-the art FBAR filters and that device out-of-band/spurious emission, sensitivity, and blocking performances of implementations are typically better than specification limits. Additionally, limitations on the resource allocation (e.g., limiting the number of RBs and position away from ISM band-edge) which directly impact the OOB emissions can help reduce dense to the lower 20MHz of ISM band.

- A dual filter (switch between two RF front-end filters) solution in LTE Band 40 is considered which can significantly reduce the BT/WLAN desensitization level for the lower 20MHz of ISM band. However, the dual band pass filters solution may not be applicable for all deployment scenarios, e.g. the operator only has 20MHz spectrum at 2380-2400MHz.
- LTE transmit power control (typically power level below the maximum 23 dBm) can further help mitigate/reduce the coexistence interference.
- Large dense to LTE 2380-2400 MHz due to WLAN/BT transmission in the ISM band may require either TDM between LTE operated in 2380-2400 MHz and BT/WLAN in the ISM band or moving an LTE frequency from the ISM band to be considered.
- Use of WLAN Channel 1-2 (WLAN STA) require either TDM or dual filter solutions to prevent blocking of LTE Band 40. The dual filter solution may enable LTE Band 40 and ISM simultaneous operation without compromising the system performance of both ISM and LTE, however with an increased cost for UE implementation and may have some limitations in specific deployment scenario.
- Coexistence interference in the ISM band is significantly reduced due to the presence of a 17MHz guard band between LTE Band 7 uplink and ISM band and by using current state-of-art filters. Practical resource allocation (LTE transmission with 23dBm transmit power are typically associated with cell-edge UEs with smaller resource allocations) and/or resource allocation limitations (e.g., limiting the number of RBs and position away from ISM band-edge) which directly impact the OOB emissions can further reduce the LTE interference primarily impacting the WLAN Channels 12-13 near the upper ISM band-edge.

Annex B: Timeline analysis of in-device coexistence between LTE and Bluetooth

B.1 Assumptions

B.1.1 Bluetooth

In this analysis, T_{eSCO} is assumed to be 6 slots for eSCO EV3. Bluetooth Tx/Rx duration is 0.42 ms and retransmission window W_{esco}=4. For Bluetooth polling rule, scenario A/B/C/F/G in Figure B.1.1-1 below are available Tx/Rx pairs if Bluetooth device is master. If Bluetooth device is slave, Tx label is replaced with a Rx label and vice-versa. It is also assumed that Bluetooth device can choose its frame timing relative to LTE if Bluetooth device is master. The following rules are used in the timeline analysis to select BT transmission instance within BT T_{eSCO} interval. Note that order A/B/C/F/G is used when select BT Tx/Rx pair in the guideline below.

For the analysis without BT retransmissions, the guideline to find a suitable BT Tx/Rx instance within a BT T_{eSCO} interval is described below.

- Try to use the first instance when there is no interference between BT and LTE.
  - If no such instance can be found, try to use the first instance when there is no interference from BT to LTE.
    - If no such instance can be found, use the first instance.

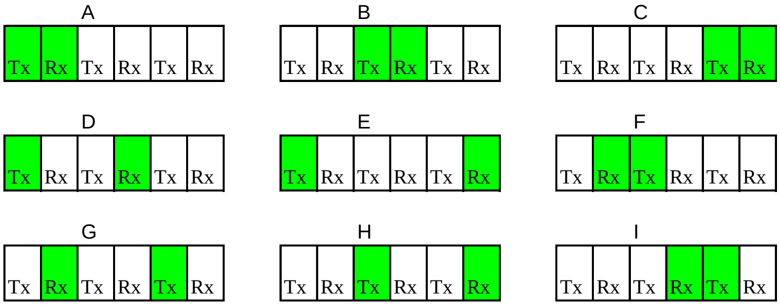

Figure B.1.1-1: BT Tx/Rx pairs

B.1.2 LTE

For LTE TDD, normal CP are used for both DL and UL, and special subframe configuration 4 is used. For bitmaps, bit=1 indicates that corresponding subframe is for LTE usage.

B.2 Results

For all the results, red bar indicates that there is interference at corresponding Rx side.

B.2.1A Coexistence between LTE and BT eSCO EV3 without TDM solutions for BT master

Considering Frequency Hopping (FH) operation of Bluetooth, two scenarios could be assumed based on the RF analysis result given by Figure A.2.1-1 of subclause A.2.1:

1) LTE central frequency (*fc*) is in the range of 2375 to 2390 MHz. In this scenario, all Bluetooth channels are desensitized.

2) LTE central frequency (*fc*) is in the range of 2310 to 2365 MHz. In this scenario, 2/9 of Bluetooth channels are desensitized. It should be noted that adaptive frequency hopping could further improve the situation for this scenario.

Bluetooth EV3 and LTE collision ratios for the above two scenarios are shown in Table B.2.1A-1. The results presented in this table are based on the assumptions and results from the case "Analysis 1" in Annex A. Note that for calculation of LTE collision ratio, it is assumed that the whole LTE subframe is impacted if it interfered by BT transmission.

Table B.2.1A-1: BT EV3 and LTE collision ratio

LTE TDD UL/DL Configuration	BT Collision ratio (Scenario 1)	BT Collision ratio (Scenario 2)	LTE Collision ratio (Scenario 1)	LTE Collision ratio (Scenario 2)
0	0%	0%	0%	0%
1	0%	0%	0%	0%
2	0%	0%	8.3%	1.9%
3	0%	0%	14.3%	3.2%
4	0%	0%	16.7%	3.7%
5	12.5%	2.8%	18.5%	4.1%
6	25%	5.6%	0%	0%

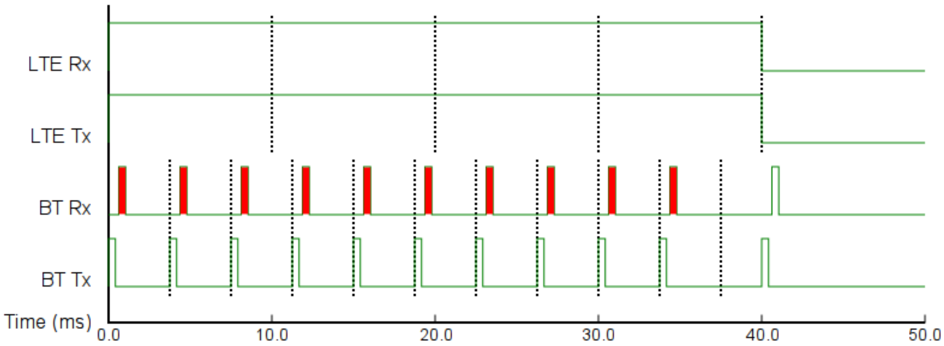

Figure B.2.1A-1: FDD and BT EV3 (Offset of BT relative to LTE frame: 0 ms)

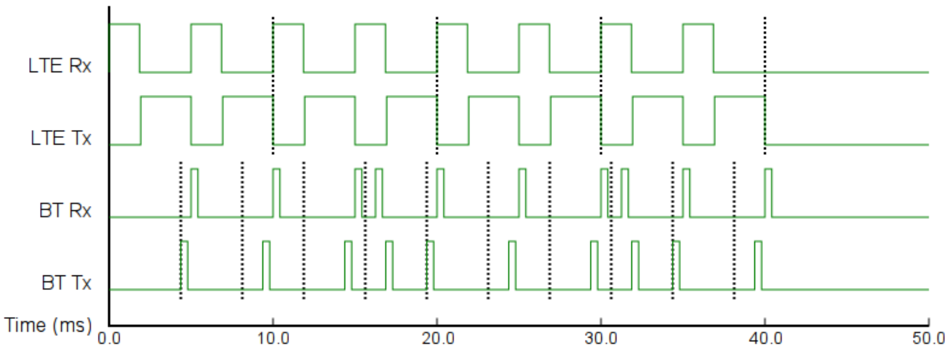

Figure B.2.1A-2: TDD Configuration 0 and BT EV3 (Offset of BT relative to LTE frame: 4.375 ms)

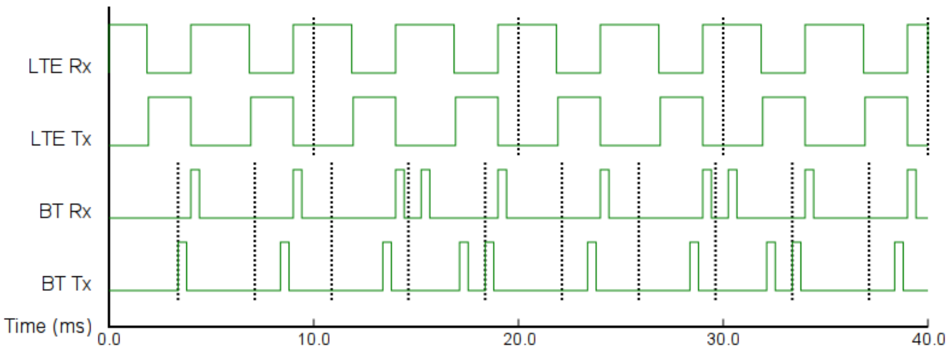

Figure B.2.1A-3: TDD Configuration 1 and BT EV3 (Offset of BT relative to LTE frame: 3.375 ms)

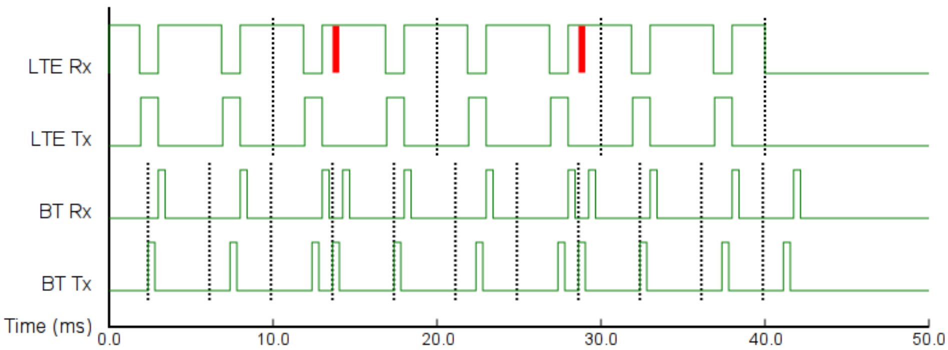

Figure B.2.1A-4: TDD Configuration 2 and BT EV3 (Offset of BT relative to LTE frame: 2.375 ms)

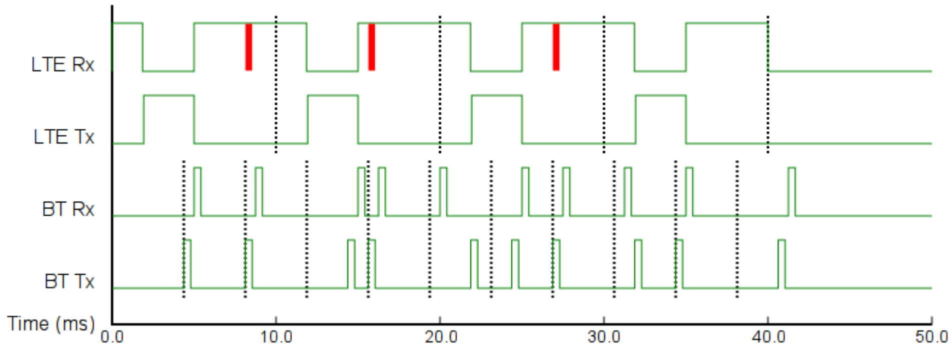

Figure B.2.1A-5: TDD Configuration 3 and BT EV3 (Offset of BT relative to LTE frame: 4.375 ms)

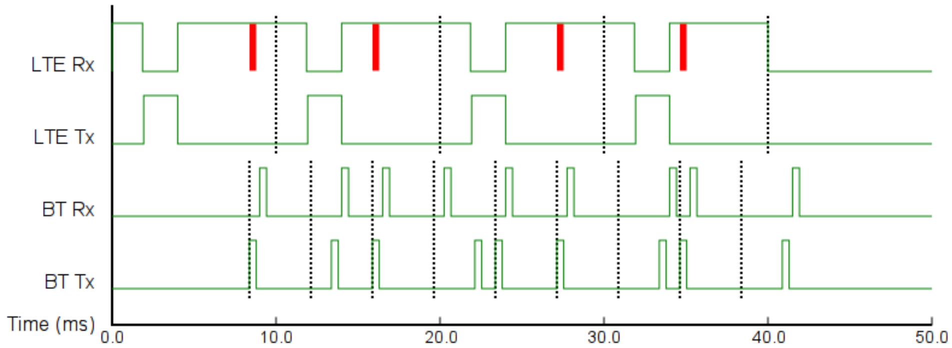

Figure B.2.1A-6: TDD Configuration 4 and BT EV3 (Offset of BT relative to LTE frame: 8.375 ms)

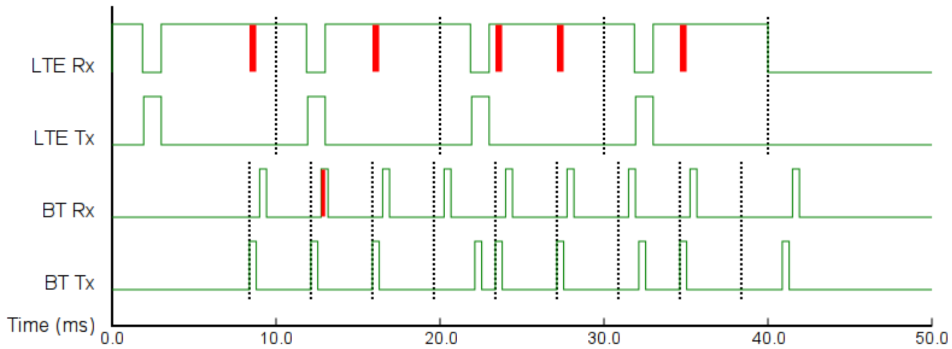

Figure B.2.1A-7: TDD Configuration 5 and BT EV3 (Offset of BT relative to LTE frame: 8.375 ms)

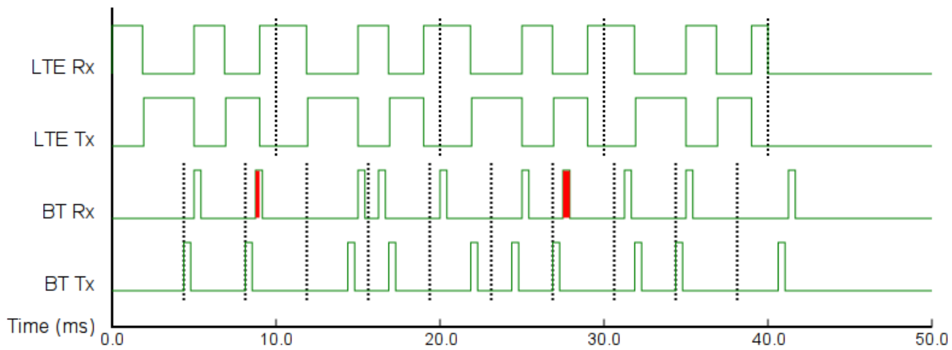

Figure B.2.1A-8: TDD Configuration 6 and BT EV3 (Offset of BT relative to LTE frame: 4.375 ms)

B.2.1 Void

B.2.2 Coexistence between LTE and BT eSCO EV3 with TDM solutions for BT master

In this subclause, bitmap based TDM solution is used to mask off a number of LTE HARQ processes to accommodate coexistence. In these examples, the length of bitmap is 8 for FDD, 10 for TDD UL/DL Configuration 3, and 60 for TDD UL/DL Configuration 6. For TDD UL/DL Configuration 2/4/5, two set of results are provided: in Figure B.2.2-2, B.2.2-5, and B.2.2-7, the length of bitmap is 10; in Figure B.2.2-3, B.2.2-6, and B.2.2-8, the length of bitmap is 30.

LTE FDD

For LTE FDD (Figure B.2.2-1), it can be seen that there is no interference.

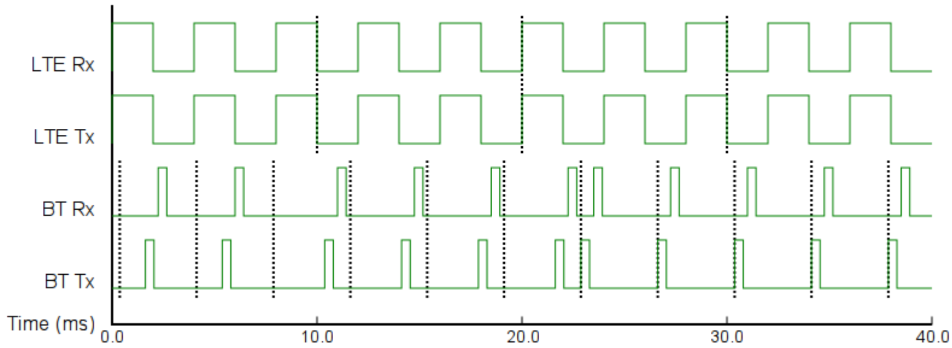

Figure B.2.2-1: LTE FDD and BT EV3 (Offset of BT relative to LTE frame: 1- 0.625 ms, bitmap 11001100)

LTE TDD

Bitmaps are selected for compatibility with HARQ processes and are used from Figure B.2.2-2 to Figure B.2.2-9 below. The results show that with proper time alignment between LTE and Bluetooth and adequate number of reserved HARQ processes in LTE side, there is no interference.

Note that the bitmaps shown in the results are fully HARQ compliant. Set of reserved subframes confirmed by eNB can also be partially HARQ compliant which means that all retransmissions of some UL HARQ processes may not be reserved for LTE.

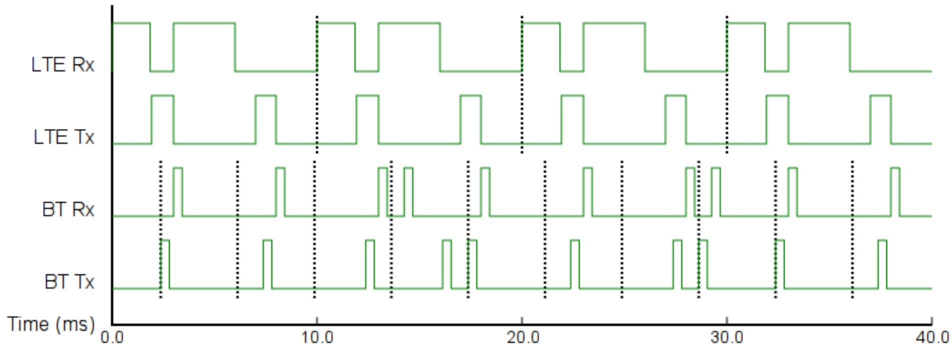

Figure B.2.2-2: TDD Configuration 2 and BT EV3 (Offset of BT relative to LTE frame: 2.375 ms, bitmap 1111110100)

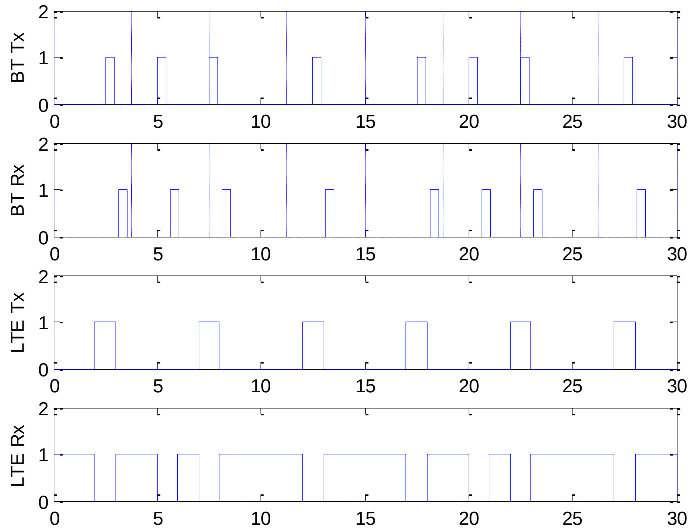

Figure B.2.2-3: TDD Configuration 2 and BT EV3 (Offset of BT relative to LTE frame: 0 ms, bitmap 1111101111 1111111111 0111111111)

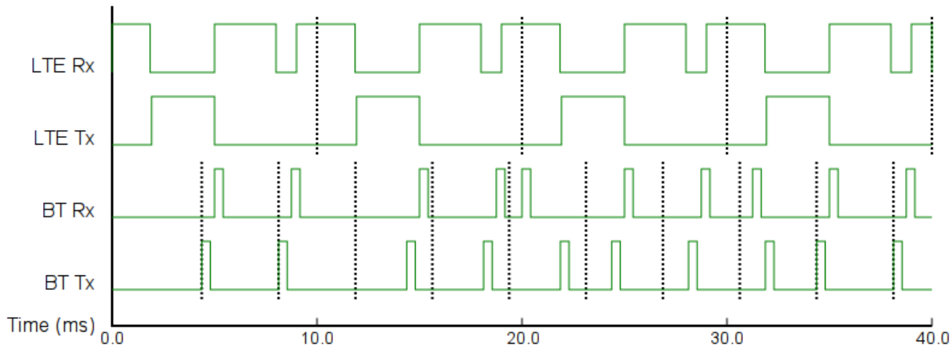

Figure B.2.2-4: TDD Configuration 3 and BT EV3 (Offset of BT relative to LTE frame: 4.375 ms, bitmap 1111111101)

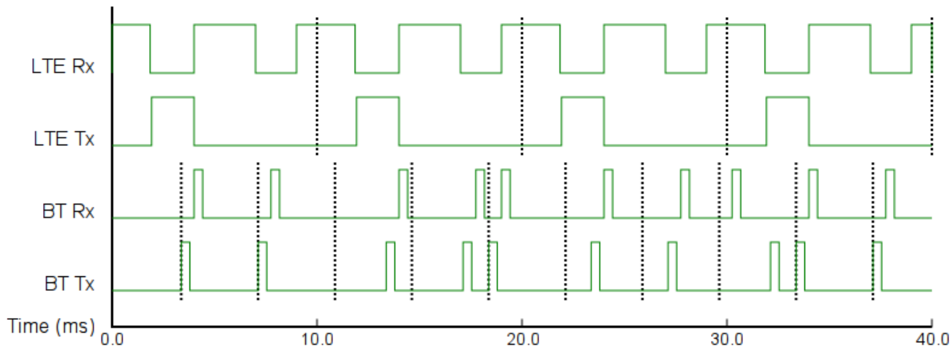

Figure B.2.2-5: TDD Configuration 4 and BT EV3 (Offset of BT relative to LTE frame: 3.375 ms, bitmap 1111111001)

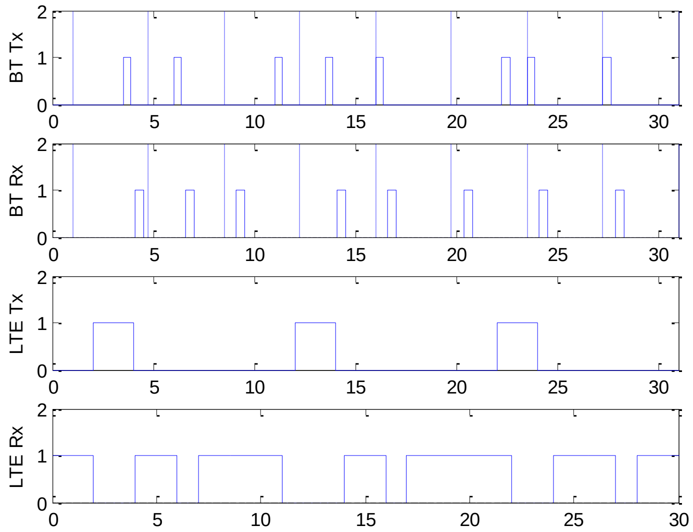

Figure B.2.2-6: TDD Configuration 4 and BT EV3 (Offset of BT relative to LTE frame: 1 ms, bitmap 1111110111 1011110111 1111111011)

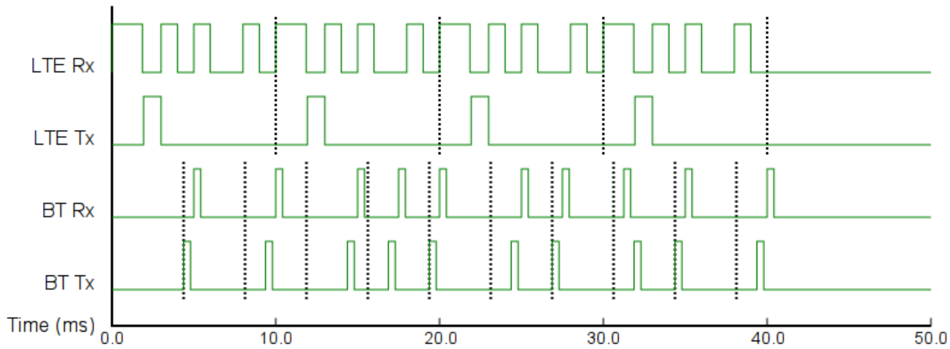

Figure B.2.2-7: TDD Configuration 5 and BT EV3 (Offset of BT relative to LTE frame: 4.375 ms, bitmap 1111010010)

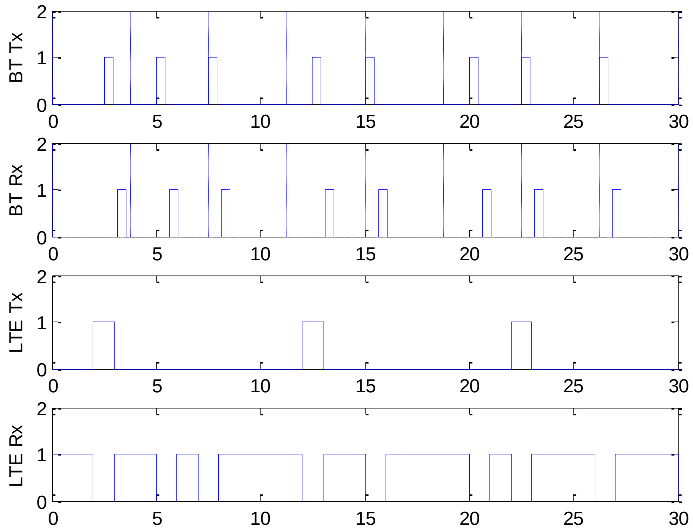

Figure B.2.2-8: TDD Configuration 5 and BT EV3 (Offset of BT relative to LTE frame: 0 ms, bitmap 1111101011 1111101111 0111110111)

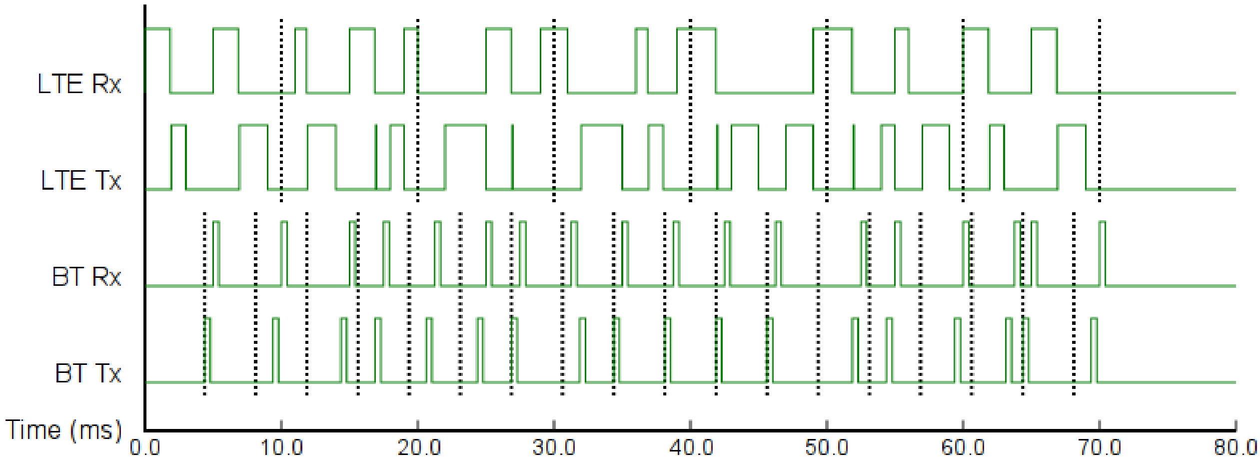

Figure B.2.2-9: TDD Configuration 6 and BT EV3 (Offset of BT relative to LTE frame: 4.375 ms, bitmap 1110011110 0111011011 0011111001 1011101101 1101100111 1100110110)

B.2.3 Coexistence between LTE and BT eSCO EV3 with TDM solutions for BT slave

Two example timelines of HARQ TDM solution for TDD UL/DL Configuration 1 and BT Slave EV3are provided in this section.

In the first example, a HARQ bitmap of 0011011001 is used which is guaranteed to work for all possible timing offsets between LTE and BT [17]. A representative example of two possible BT timing offsets 0.5ms and 2.5ms are considered to show that the same LTE HARQ pattern works for both. The patterns of used BT slot pairs depend on the offset and are also shown. The BT slot pairs are shown over an interval of 30ms since the pattern of overlap with LTE repeats after that.

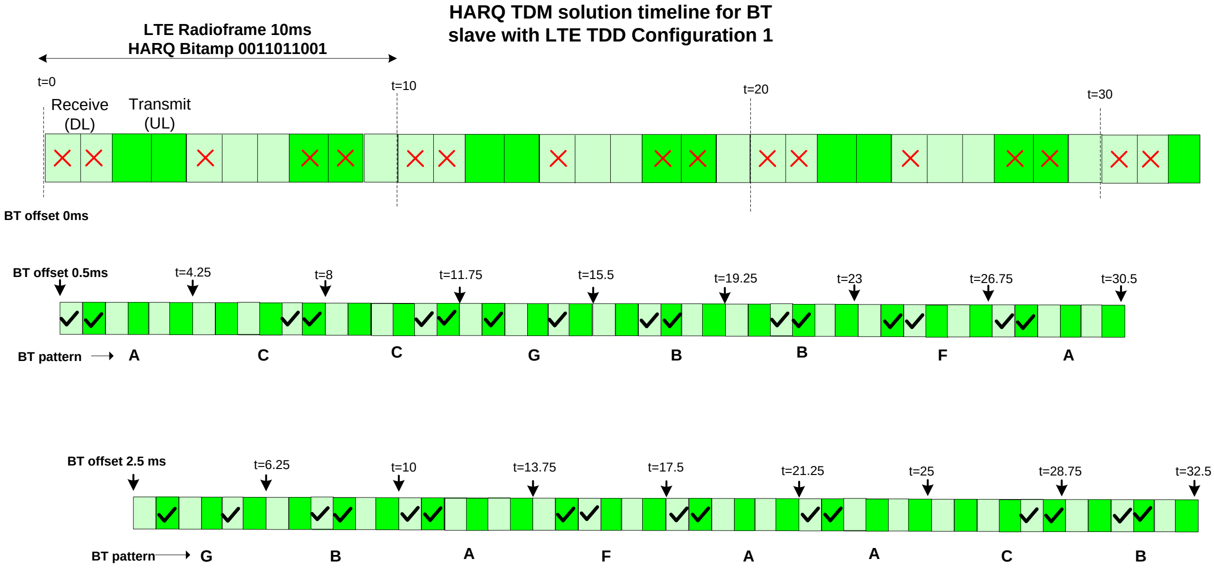

Figure B.2.3-1: Timeline analysis for BT slave

An explicit validation of the used pattern was carried out for all BT timing offsets in [17]. For LTE TDD Configuration 1, there are a maximum of two consecutive UL subframes and these are separated by three DL subframes. This ensures that one BT Rx slot is guaranteed to succeed in any eSCO interval. For three consecutive DL subframes as in this TDD Configuration, there can be a BT offset for which no Tx slot is available in an eSCO interval. With the above HARQ TDM pattern, there is also no occurrence of more than three consecutive DL subframes. So, we have at least one BT Tx slot in each eSCO interval that does not cause interference to LTE. For slave, this Tx slot is usable if it is a reserved slot. If it is not a reserved Tx slot, then the poll in the previous Rx slot is required to succeed. The above gap pattern ensures that in such situations, this previous Rx slot also always succeeds due to the additional LTE UL gaps.

Another timeline example is shown in Figure B.2.3-2 and Figure B.2.3-3 below. In this example, the timing offset is 0 ms between LTE and BT. Interference scenario is shown in Figure B.2.3-2, while Figure B.2.3-3 shows that improvement is possible when such timing offset knowledge is used to select the bitmap.

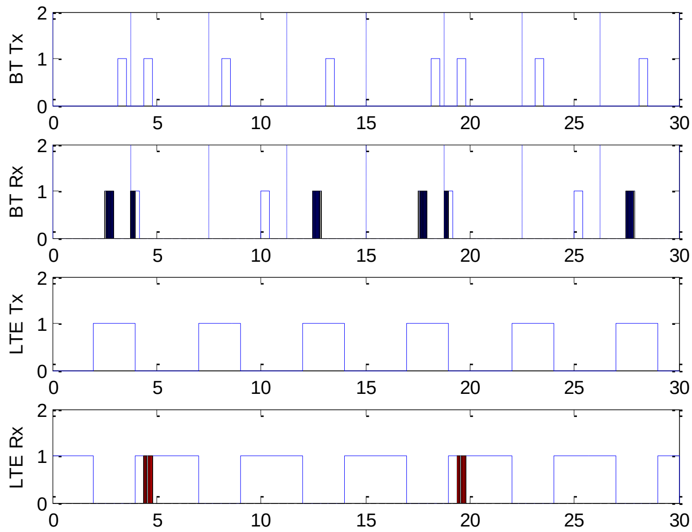

Figure B.2.3-2: Timeline analysis for BT slave (TDM solution not used)

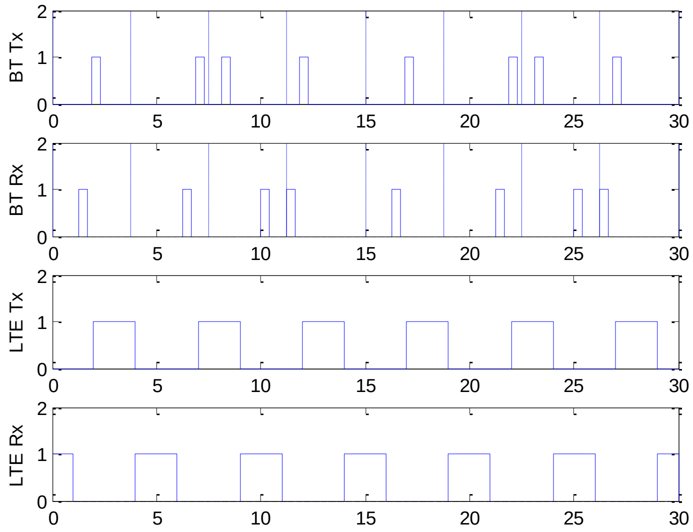

Figure B.2.3-3: Timeline analysis for BT slave (TDM solution used, bitmap 1011110111 1011110111 1011110111)

Annex C:
Change History

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2010-08	RAN2 #71	R2-104555	-	-	Agreed skeleton TR at RAN2 #71	-	0.1.0
2010-08	RAN2 #71	R2-105214			TR 36.816 v0.1.1 capturing agreements of RAN2 #71	0.1.0	0.1.1
2010-10	RAN2 #71bis	R2-105668			TR 36.816 v0.1.2 (revision of v0.1.1 after email discussion after RAN2 #71)	0.1.1	0.1.2
2010-10	RAN2 #71bis	R2-106004			Agreed version at RAN2 #71bis	0.1.2	0.2.0
2010-10	RAN2 #71bis	R2-106008			TR 36.816 v0.2.1 capturing agreements of RAN2#71bis and agreed TP from R2-106024	0.2.0	0.2.1
2010-10	RAN2 #71bis	R2-106034			RAN2 agreed TR v0.3.0 by email discussion after RAN2#71bis	0.2.1	0.3.0
2010-11	RAN2#72	R2-106925			TR 36.816 v0.3.1 capturing agreements of RAN2#72	0.3.0	0.3.1
2010-11	RAN2#72	R2-106971			RAN2 agreed TR v1.0.0 by email discussion after RAN2#72	0.3.1	1.0.0
2011-01	RAN2#72bis	R2-110676			TR 36.816 v1.0.1 capturing agreements of RAN2#72bis	1.0.0	1.0.1
2011-02	RAN2#72bis	R2-110703			RAN2 agreed TR v1.1.0 by email discussion after RAN2#72bis	1.0.1	1.1.0
2011-03	RAN2#73	R2-111693			TR 36.816 v1.1.1 capturing agreements of RAN2#73	1.1.0	1.1.1
2011-03	RAN2#73	R2-111759			RAN2 agreed TR v1.2.0 by email discussion after RAN2#73	1.1.1	1.2.0
2011-04	RAN2#73bis	R2-112582			TR 36.816 v1.2.1 capturing agreements of RAN2#73bis	1.2.0	1.2.1
2011-04	RAN2#73bis	R2-112648			RAN2 agreed TR v1.3.0 by email discussion after RAN2#73bis	1.2.1	1.3.0
2011-05	RAN2#74	R2-113571			TR 36.816 v1.3.1 capturing agreements of RAN2#74	1.3.0	1.3.1
2011-05	RAN2#74	R2-113686			RAN2 agreed TR v2.0.0 by email discussion after RAN2#74	1.3.1	2.0.0
2011-06	RP-52				TR 36.816 RP-110613 approved at RAN #52 as v11.0.0	2.0.0	11.0.0
2011-09	RP-53	RP-111299	0002	-	Analysis of DRX solution for IDC interference avoidance	11.0.0	11.1.0
	RP-53	RP-111299	0003	-	Solutions for IDC interference in LTE + BT voice scenario	11.0.0	11.1.0
	RP-53	RP-111299	0004	-	Corrections to timeline analysis	11.0.0	11.1.0
	RP-53	RP-111299	0008	-	Agreements on IDC interference avoidance (of RAN2 #75)	11.0.0	11.1.0
2011-12	RP-54	RP-111722	0009	-	CR to 36.816 on DRX based TDM solution	11.1.0	11.2.0