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Title	**Coordinated coexistence between wireless networks deployed in adjacent frequency allocations**
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Re:	16m Call for Contributions on Interference Mitigation
Abstract	
Purpose	Actions: 1. Modification of ToC 2. Capture of the text in the SDD
Notice	
Release	
Patent Policy	

Coordinated coexistence between wireless networks deployed in adjacent frequency allocations

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Introduction

The 802.16m SRD in its clause 8.3 defines the coexistence scenarios for a high variety of situations and technologies. Are included the sharing of the same-licensed band and coexistence with devices operating in adjacent license-exempt bands. The sharing of the same licensed band may include difficult problems, as FDD (Frequency Division Duplex) – TDD (Time Division Duplex) and un-synchronized TDD coexistence. Note that most of the FDD radios and, of course, many devices operating in LE (License Exempt) bands are not synchronized.

We present here an approach for improved coexistence between wireless networks deployed in adjacent frequency channels or frequency bands, synchronized and un-synchronized, intended to give a response to the above requirements, which combines:

- Procedures for the creation of an 802.16m Coordinated Coexistence Frame (CXCF), including:
  - A. protected intervals for the operation of the wireless networks affected by harmful interference
  - B. un-protected intervals.
- Synchronization of initially un-sync networks and their scheduling for reduced interference
  - Usage of cognitive radio properties for protected intervals
    - Cognitive properties may be dependent of the actual technologies to be used in a given band, in the adjacent bands and at a given location.

The harmful interference includes in its ITU-R definition [4]:

1.169 *harmful interference: Interference* which …… seriously degrades, obstructs, or repeatedly interrupts a *radiocommunication service* operating in accordance with Radio Regulations.

In this document we consider the “receiver blocking” as the most problematic harmful interference problem. The situations of “receiver blocking” appear between the devices located in the proximity of each-other and are created generally by a Subscriber Station working in the proximity of other SS, BS or Relay. The SS can work in the proximity of a BS or Relay in fento-cell deployments.

802.16m Coordinated Coexistence Frame (CXCF)

The 802.16m Coordinated Coexistence Frame period is based on its superframe structure, further including frames and sub-frames. The CXCF duration and structure depends on the technologies deployed in adjacent channels and adjacent bands.

Duration of CXCF

For resolving most of the coexistence problems in licensed operation, the CXF duration could be 20ms or a multiple of it. For resolving problems of LE operation deployed in adjacent bands to the licensed operation, including 802.11 (uses now as default a frame of 100ms) and Bluetooth (15ms frame), the CXCF duration could be 60ms or 120ms.

Structure of CXCF

The CXCF structure will include two different types of allocations (in time domain) as follows:

A. Protected allocations, having as scope to protect the receive operation of SS, BS, RS or a combination of them;

- **Silence intervals,** during which there are no transmissions, such to make possible the implementation of the protected allocations.

-B. Un-protected allocations, during which the interference is not mitigated.

The CXF structure depends on the scenarios considered in the protection target. In general, the scenarios can include:

1. **SS to SS interference**.
   Most problematic case: Small separation distance between SSs, because the RF filters may be inefficient or inexistent for SSs operating in adjacent frequency channels or frequency bands.
2. **SS to BS/Relay interference.**
   Most problematic case: Small cell deployments, where the distance between a foreign SS and a BS might be small.
3. **BS/Relay to BS/Relay interference.**
   Most problematic case: Co-located TDD-FDD wireless networks (WCDMA and 802.16m or LTE and 802.16) or un-sync TDD (LTE and 802.16m).
4. **BS/Relay to SS interference.**
   Most problematic case: in small cell deployments, where the distance between a foreign SS and a BS might be small.

The harmful interference created by the Subscriber Station (SS) to another SS in situations of the "receiver blocking" is generally reciprocal, meaning that a receiver which suffers from blocking will also create, when transmits, harmful interference to other devices. In order to avoid the SS receiver blocking is necessary to provide each network with its protected allocations. All the CXCF examples proposed below will also resolve the SS-SS interference, because due to the high level of the 1st adjacent channel, 2nd adjacent channel and out-of-band emissions this scenario has a big frequency of apparition and cannot be resolved by RF filters.

The CXCF structure shall be designed such to accommodate the technologies used by the co-located networks.

The protected allocations will include a number of time slots in which will be scheduled activities as follows:

- Time slots reserved for operation without harmful interference in receive state of a BS, SS or Relay station (RS); in general these time slots will also include the reception of the control information
- Time slots for scheduling the transmissions which may create harmful interference.

Taking into consideration the separate transmissions and receptions of the BS, Relay and SS, we may end with at least 3 different protected allocations, each being composed of a pattern of sub-frames, as follows:

- BS protected Rx allocation;
- Relay protected Rx allocation;
- SS protected Rx allocation.

A simplification of this approach is provided if instead of allocating a complicated pattern of sub-frames, which may change from operator to operator and it will be highly dependent of the traffic, we will allocate, when possible, time-slots having longer duration (approximately one 802.16m frame).

The protected allocations for a specific location and frequency assignment shall be defined while taking into account all the co-located networks and eventually each specific frequency channel. When we speak about FDD-TDD interference, the TDD channels situated next to an FDD receiver may create strong interference only to this specific receiver. For example, if TDD is deployed inside the duplex gap of the FDD allocations and the FDD Subscriber Station (SS) is transmitting within the lower frequency band, the FDD SS may interfere the receive activity of the TDD BS and TDD SS. The TDD BS probably will not interfere with the receive activity of the FDD SS, which located far enough in the frequency domain.

The general rule for defining the protected allocations is to create time zones in which each specific receiver (SS, Relay or BS) is not affected by the transmissions of the co-located networks. A good way of doing this is stopping, from time to time, the transmissions creating interference. The created silence intervals will give a possibility to the affected receiver of working without interference.

Examples of the CXCF protected allocations for FDD/TDD coexistence

The following examples show how can be achieved improved coexistence between FDD and TDD systems. The examples assume synchronized FDD LTE. According to [1], the FDD operation uses the subframes as follows:

Start quote (not for SDD)

Each radio frame is $T_f = 307200 \cdot T_s = 10\,\text{ms}$ long and consists of 20 slots of length $T_{slot} = 15360 \cdot T_s = 0.5\,\text{ms}$, numbered from 0 to 19. A subframe is defined as two consecutive slots where subframe i consists of slots $2i$ and $2i+1$. For FDD, 10 subframes are available for downlink transmission and 10 subframes are available for uplink transmissions in each 10 ms interval. Uplink and downlink transmissions are separated in the frequency domain. In half-duplex FDD operation, the UE cannot transmit and receive at the same time while there are no such restrictions in full-duplex FDD.

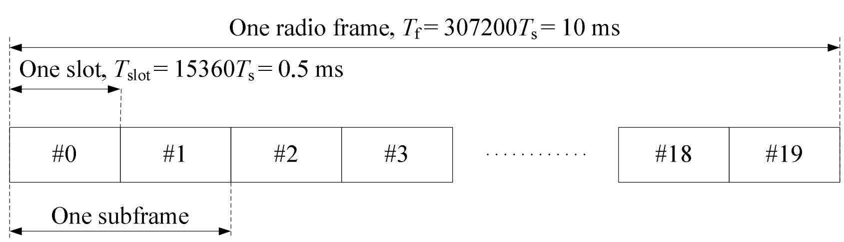

Figure 1 LTE Frame structure type 1

End quote

Fig 2 resolves all the coexistence scenarios and has low delay (10ms), with the penalty of reducing the operation

time of each network to 50%.
This figure uses as example two networks, one based on LTE FDD (two upper rows) and one based on 802.16 TDD (two lower rows). On 2nd row are shown the protected allocations of the TDD system and on 3rd row the protected allocations of the FDD system.

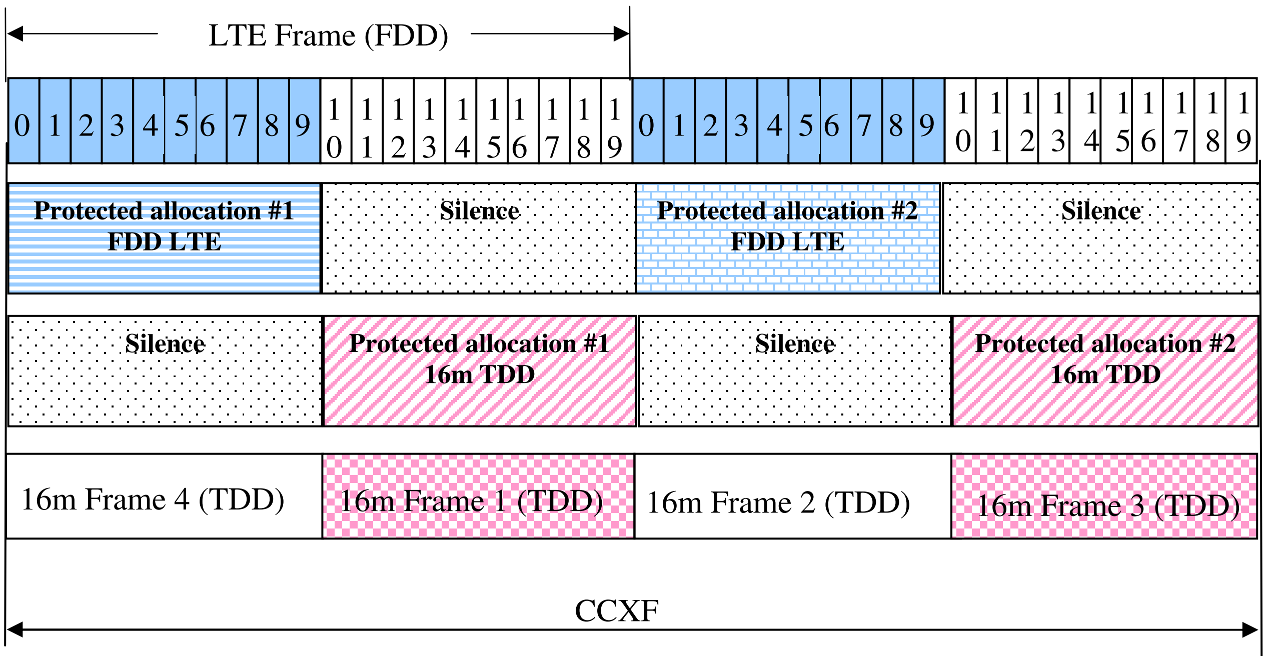

Fig. 2 Example of FDD/TDD protected allocations resolving all scenarios, 50% medium usage

Fig. 3 shows a CXCF structure which improves the operational time of each network to 75%, with the penalty of increased delay for those network elements creating reciprocal interference.

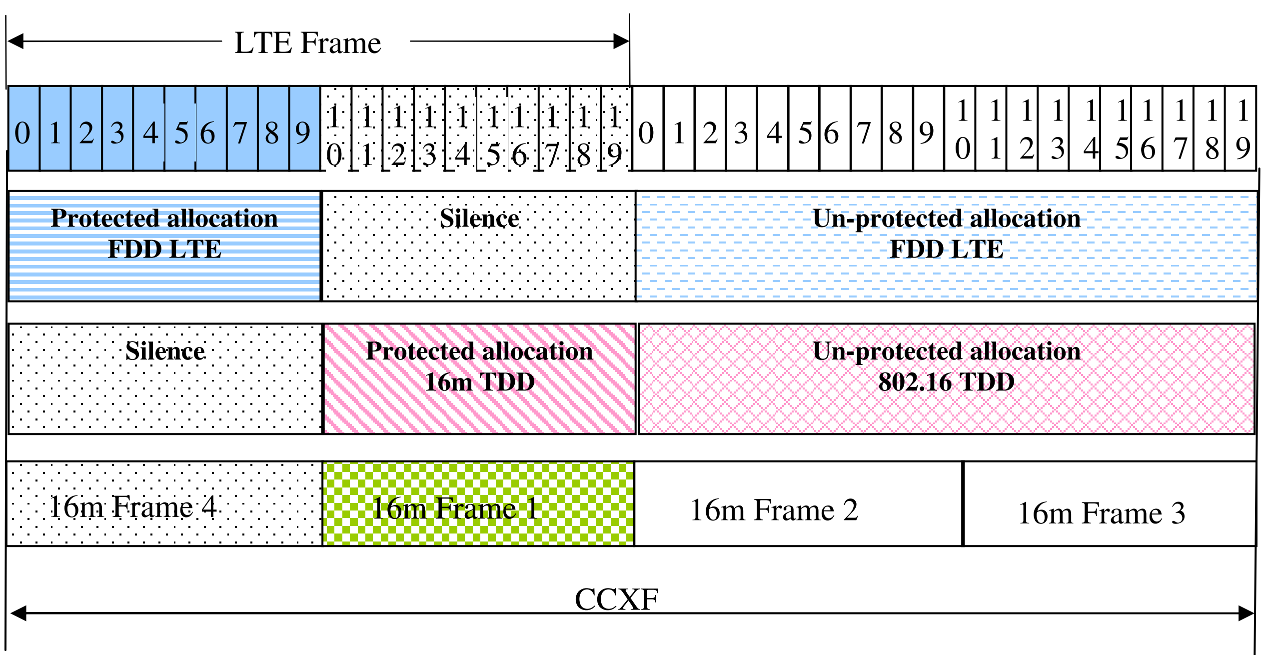

Fig. 3 Example of FDD/TDD protected allocations resolving all scenarios, 75% medium usage

In this case the scheduling entity will schedule the operation affected by interference during the protected allocations.

The medium occupancy can be further improved if we reduce the targets to SS-SS and BS-BS, which are also achieved if the co-located systems are both FDD-based or are TDD systems with synchronized transmit and receive intervals.

In Fig. 4 the medium occupancy is 80% for the FDD BS, 70% for the FDD SS and 100% for TDD. The interval between the protected allocations is reduced to 10ms.

The principles for allocating the protected intervals are based on synchronization between:

1. FDD SS and TDD SS reception
2. FDD BS and TDD BS reception.
3. Silence intervals were introduced to avoid transmissions creating interference.

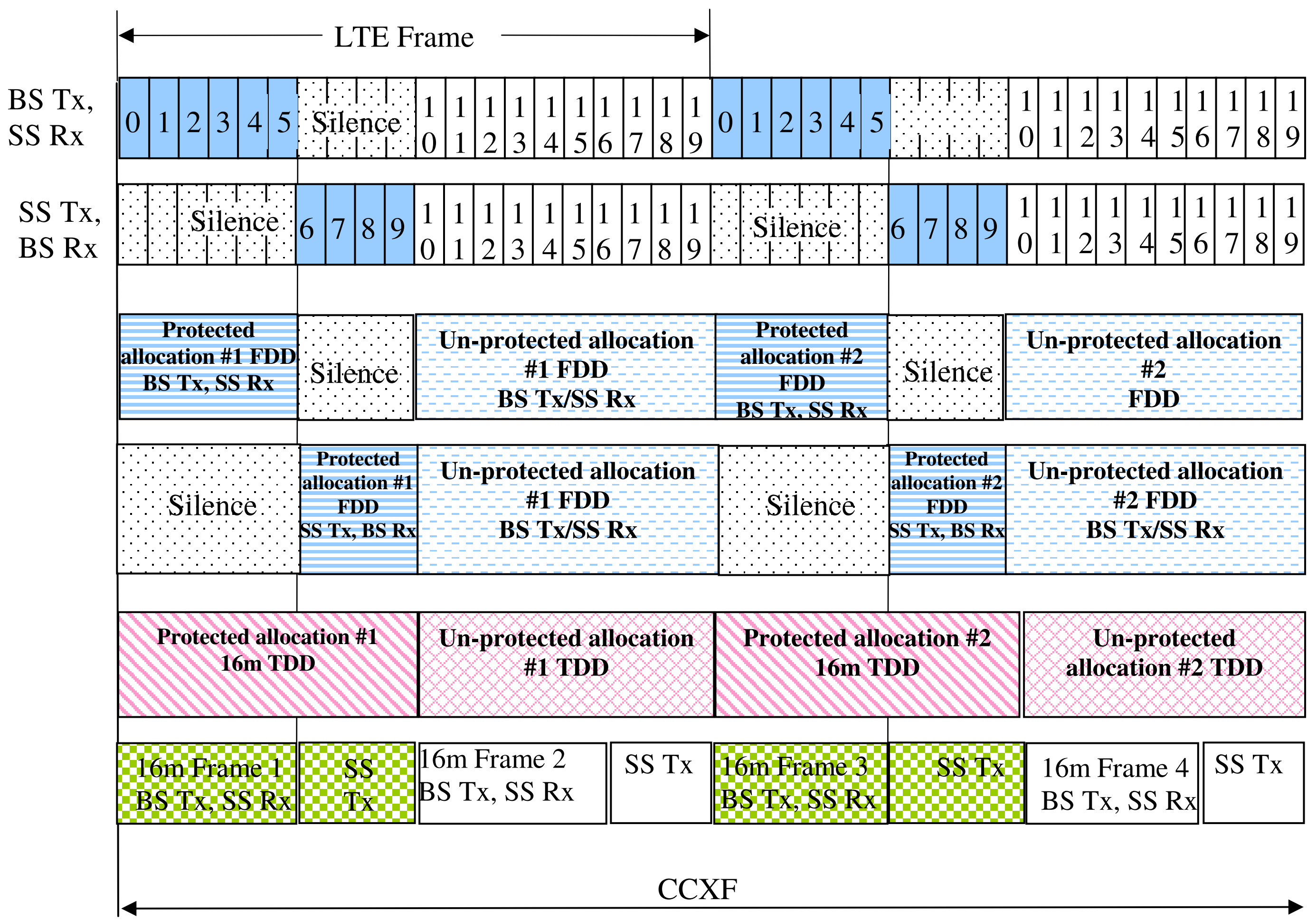

Fig. 4 Example of FDD/TDD protected allocations resolving BS-BS and SS-SS interference

The medium occupancy can be increased to 90% for the FDD BS and to 87% to the FDD SS, if the un-protected allocations during the 2nd LTE frame are extended over the entire frame.

Fig. 5 shows an example of FDD/TDD coexistence which targets only the SS-SS coexistence. It was assumed that the BS allocation filters are sufficient for resolving the BS-BS interference.
We chose to synchronize the SS receiving intervals, as in this way we achieve maximum media occupancy and lowest delay.

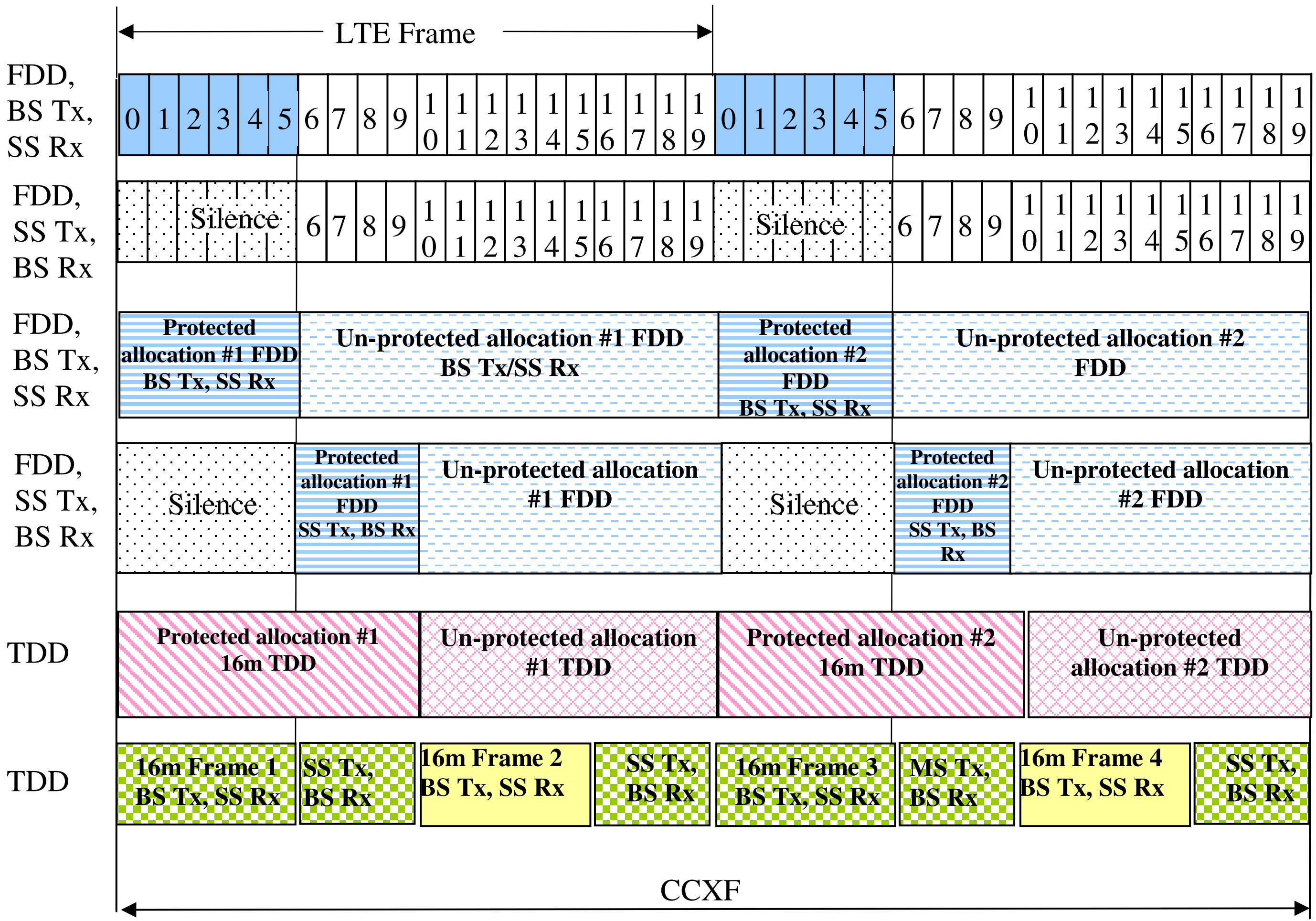

Fig. 5 Example of FDD/TDD protected allocations resolving SS-SS interference

Incase of 802.16 FDD and 802.16 TDD networks, the solution is similar with the LTE case, where the LTE frame is replaced with two 802.16 frames. An example is given in fig. 6:

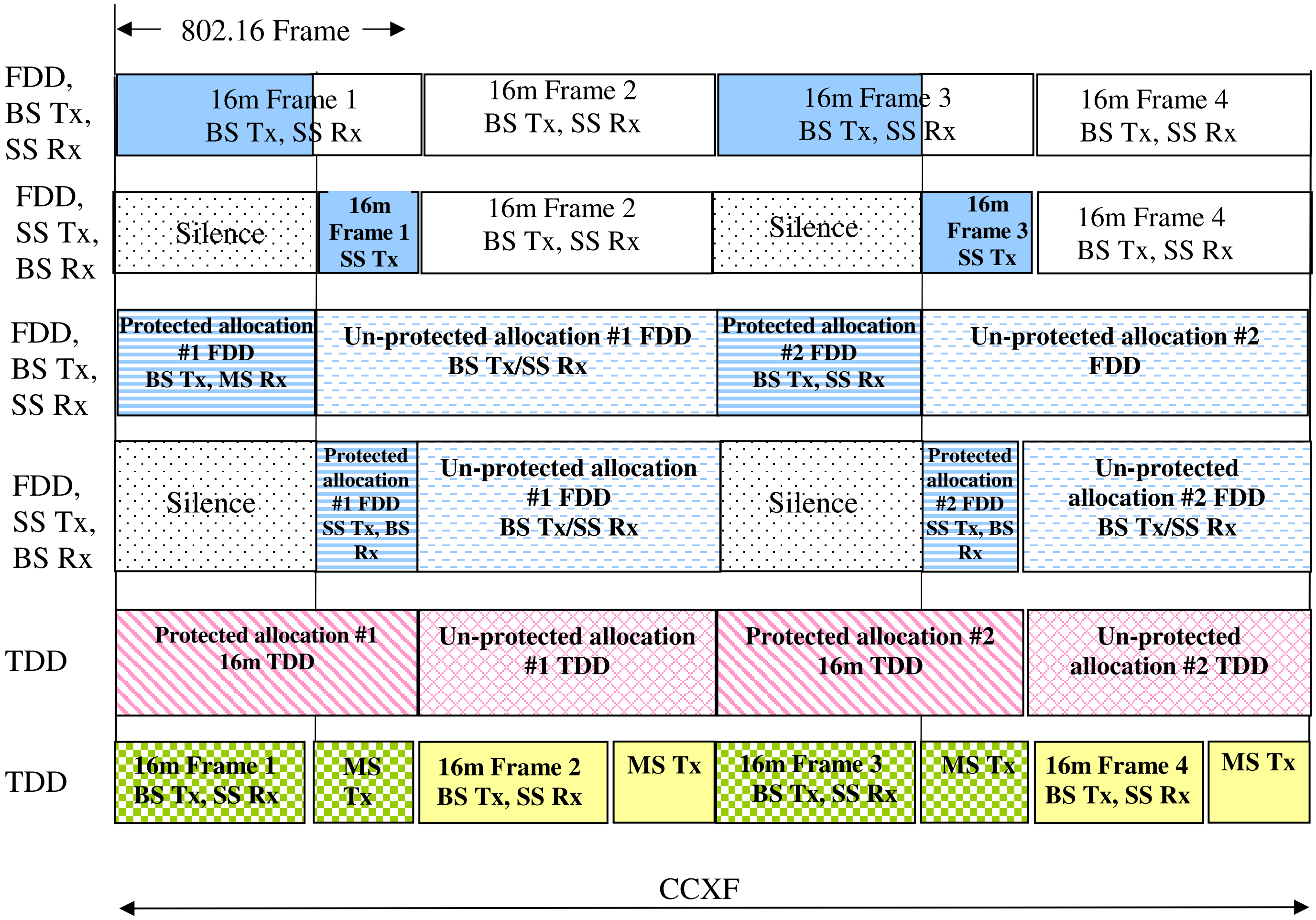

Fig. 6 Example of FDD/TDD 802.16 protected allocations resolving SS-SS interference

Examples of TDD/TDD improved coexistence

There is always the possibility to synchronize all the Tx/Rx intervals for addressing the general SS-SS and BS-BS coexistence scenarios between TDD networks operating in adjacent frequency channels. This approach resolve the coexistence issues with the penalty that both TDD operators have the same Tx/Rx splitting, which might not be suitable to the deployed services. For example, an operator deploying IP broadcast/multicast services will need a different DL (downlink) - UL(up-link) as compared with an operator deploying symmetrical services.

We will provide here an example based on two TDD systems: 802.16m and LTE.

The TDD Frame of the LTE system is, according to [1], of the following form:

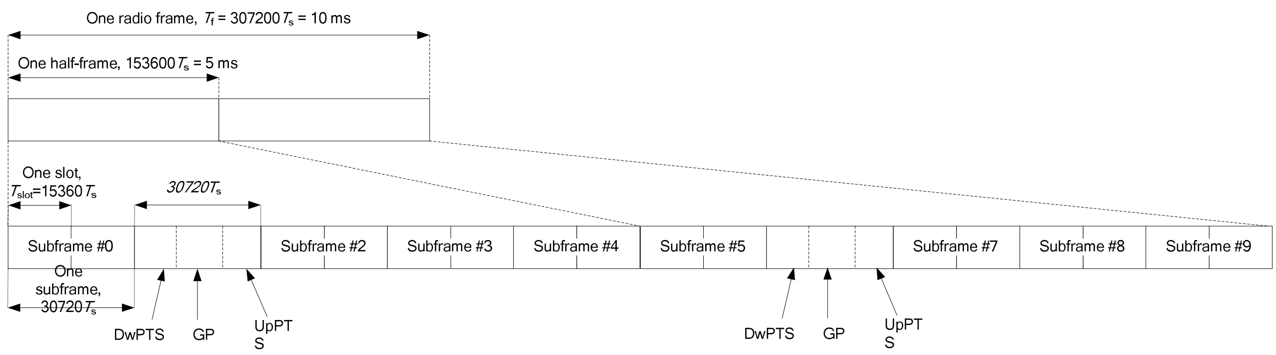

Fig. 7 TDD Frame of the LTE system

where “GP” stands for guard-period, “DwPTS” is sent in DL and “UpPTS” is sent in up-link.

The LTE TDD sub-frames can be configured according to the following table:

Configuration	Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	10 ms	D	S	U	U	U	D	S	U	U	D

We will consider the 10ms switch-point periodicity, LTE TDD configuration 4, which has a down-link traffic aprox. 75% of time, while for 802.16m will be chosen the 5ms frame, using 4 sub-frames (36 symbols or 2.47ms) DL and 4 sub-frames UL (see [3]). These systems are totally different; however it is still possible to obtain the SS-SS coexistence, as shown in fig. 8.

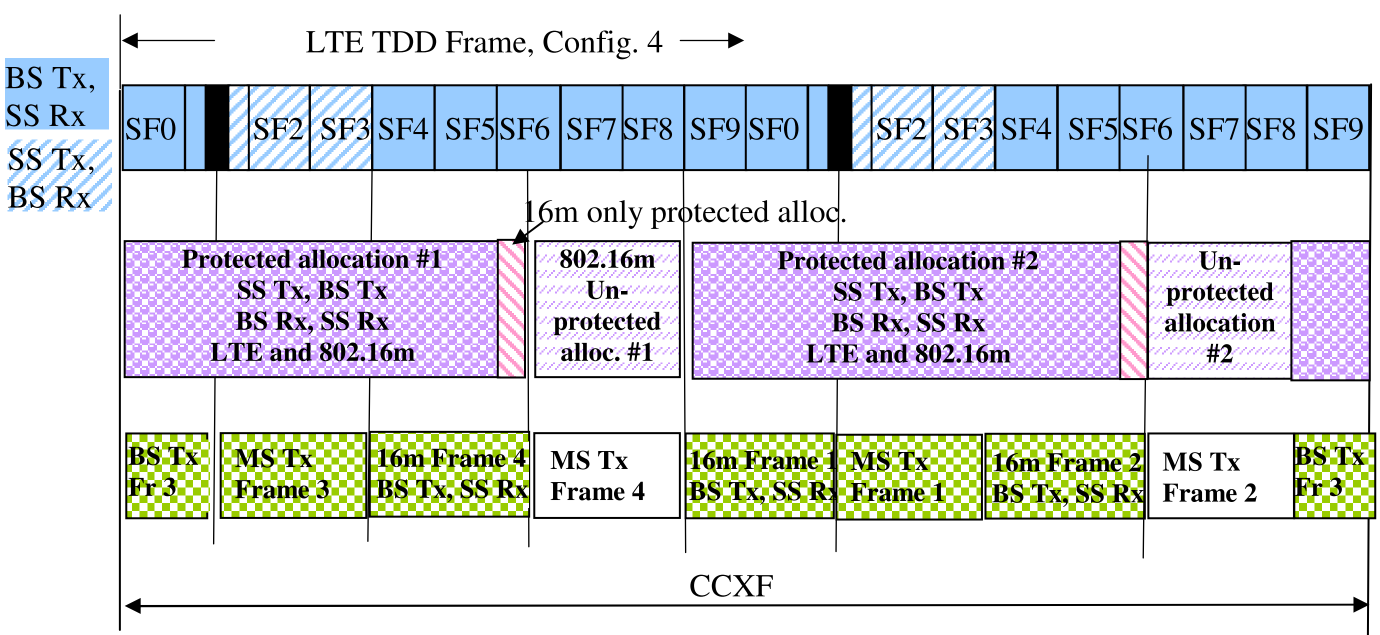

Fig. 8 Example of TDD/TDD 802.16 protected allocations for LTE/802.16

In Fig.8 we see that both networks operate 100% of time, however there are un-protected intervals (25% of time in 802.16m and 30% of time in LTE) in each network. The traffic affected by interference shall be scheduled in the protected allocations. Another possibility is to extend the 802.16m DL Frame such to take advantage of coexistence.

Each network operators has made concessions, as:

1. LTE has some DL un-protected transmissions
2. 802.16m has some UL un-protected transmissions and its frame split is 50%/50% instead of 5/3.

The 802.16m advantage is 100% DL protected operation, the LTE advantage is the usage of the desired DL/UL configuration.

Similar examples can be shown also for other TDD technologies, as UTRA TDD and TD-SCDMA (UTRA LCR-TDD).

Operation of un-synchronized networks

An un-synchronized system will not be able to take advantage of CCXF protection.

The un-synchronized networks will be able to detect some of the transmissions of the synchronized networks and the intervals with minimum interference. Based on the a priori knowledge of the pattern and durations of the time intervals reserved for the protected operation, these networks may be able to map the time graph of the detected harmful interference to the protected intervals used by synchronized networks.

A BS or Relay of an un-synchronized system will experience harmful interference mainly during the time-intervals reserved for the un-protected operation of other networks.
The best way to detect the network synchronization may be the time-shift of the FDD frame start until the reported interference will be minimal.

Cognitive information related to CCXF

CCXF has elements of cognitive information. In this example, these elements are:

- periodicity of the CCXF: 20ms
- duration and position of the intervals allocated for the TDD protected operation (relative to CCXF start)
- DL/UL split (if it is permanent, can be known).

An un-synchronized system can use the cognitive information related to the CCXF structure at its location for achieving synchronization.
TDD system are the best positioned to use the cognitive properties of the CXCF, due to the reciprocity the medium: for example, if and SS creates interference to another SS, it will also be an interference victim.

To better understand how it works for FDD networks, let's suppose that the FDD system is not synchronized with CCXF. In fig.9 LTE SS may experience the harmful interference produced by the transmissions of a TDD SS.

Fig. 9 shows that a BS can assess the harmful interference during these slots, based on the individual SS reports.

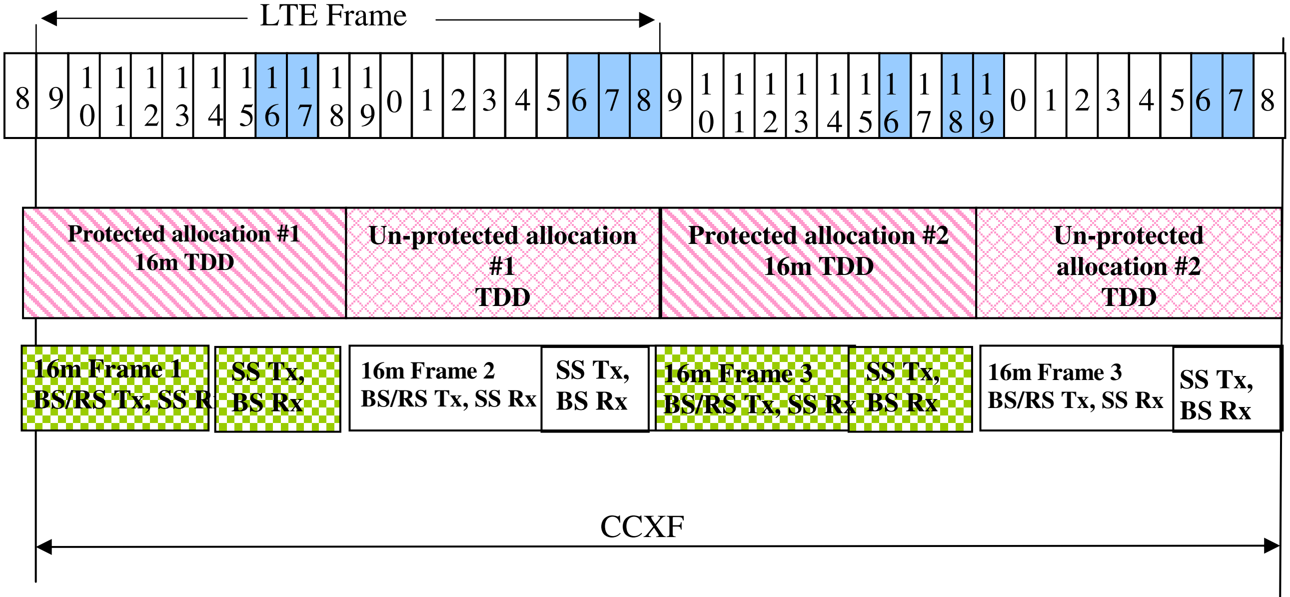

Fig. 9 – Harmful TDD interference experienced by SS within un-synchronized FDD network

The probability of detection of SS transmissions is increased if the intra-system power control is done in frequency (OFDMA) domain, because in this way are not created power patterns which may complicate the detection of SS transmission intervals. Note that SSs are good indicators, because their distribution on the field. However different implementations can develop specific detection methods of the CXCF elements.

WiFi synchronization with the CCXF based on cognitive CXCF information

An un-synchronized BS, once has established the timing of one CCXF protected allocation, will be able to synchronize its operation with CXCF. An unsynchronized BS can also use a time-shift of its protected scheduling in order to find the best match.

A special case is represented by the radio devices providing simultaneous services using adjacent frequency bands (co-located radio coexistence). Such a device may be connected to a synchronized BS which is aware of the CXCF structure at that specific location. If we suppose that in an adjacent frequency band operates a WiFi AP (Access Point) to which is connected the dual-mode device, this device can inform the AP about the timing of the CXCF and the timing of the protected allocations for WiFi operation.

WiFi can also detect the periodicity of the harmful interference. If a well defined CXCF are defined for the bands adjacent to the WiFi operation, it will be possible that new WiFi devices will not create harmful interference to devices using license-bands and situated in WiFi proximity. The operation in special licensed bands, as 3.65GHz, can also benefit from the cognitive characteristics of the coordinated coexistence frame.

Text for SDD

Insert:

11.4.8 Coexistence support within 802.16m superframe

This clause is dedicated to coexistence between wireless networks deployed in adjacent frequency allocations.

The approach for improved coexistence between wireless networks deployed in adjacent frequency channels or frequency bands, synchronized and un-synchronized, combines:

- Procedures for the creation of an 802.16m Coordinated Coexistence Frame (CXCF), including:
  - A. protected intervals for the operation of the wireless networks affected by harmful interference
  - B. un-protected intervals
- Synchronization of initially un-sync networks and their scheduling for reduced interference by:
  - Shifting the un-sync CXCF until experiencing minimum interference
  - Usage of cognitive radio properties for protected intervals
    - Cognitive properties may be dependent of the actual technologies to be used in a given band, in the adjacent bands and at a given location.

The harmful interference includes in its ITU-R definition [4]:

1.169 *harmful interference: Interference* which …… seriously degrades, obstructs, or repeatedly interrupts a *radiocommunication service* operating in accordance with Radio Regulations.

802.16m Coordinated Coexistence Frame (CXCF)

The 802.16m Coordinated Coexistence Frame period is based on its superframe structure, further including frames and sub-frames. The CXCF duration and structure depends on the technologies deployed in adjacent channels and adjacent bands.

Duration of CXCF

For resolving most of the coexistence problems in licensed operation, the CXF duration could be 20ms or a multiple of it. For resolving problems of LE operation deployed in adjacent bands to the licensed operation, including 802.11 (uses now as default a frame of 100ms) and Bluetooth (15ms frame), the CXCF duration could be 60ms or 120ms.

Structure of CXCF

The CXCF structure will include two different types of allocations (in time domain) as follows:

A. **Protected allocations**, having as scope to protect the receive operation of SS, BS, RS or a combination of them;

- **Silence intervals,** during which there are no transmissions, such to make possible the implementation of the protected allocations.

-B. Un-protected allocations, during which the interference is not mitigated. The existing licensed operation is based on this approach.

Fig. xx presents an example for improved coexistence between LTE (FDD) and 802.16m (TDD), resolving the SS-SS interference:

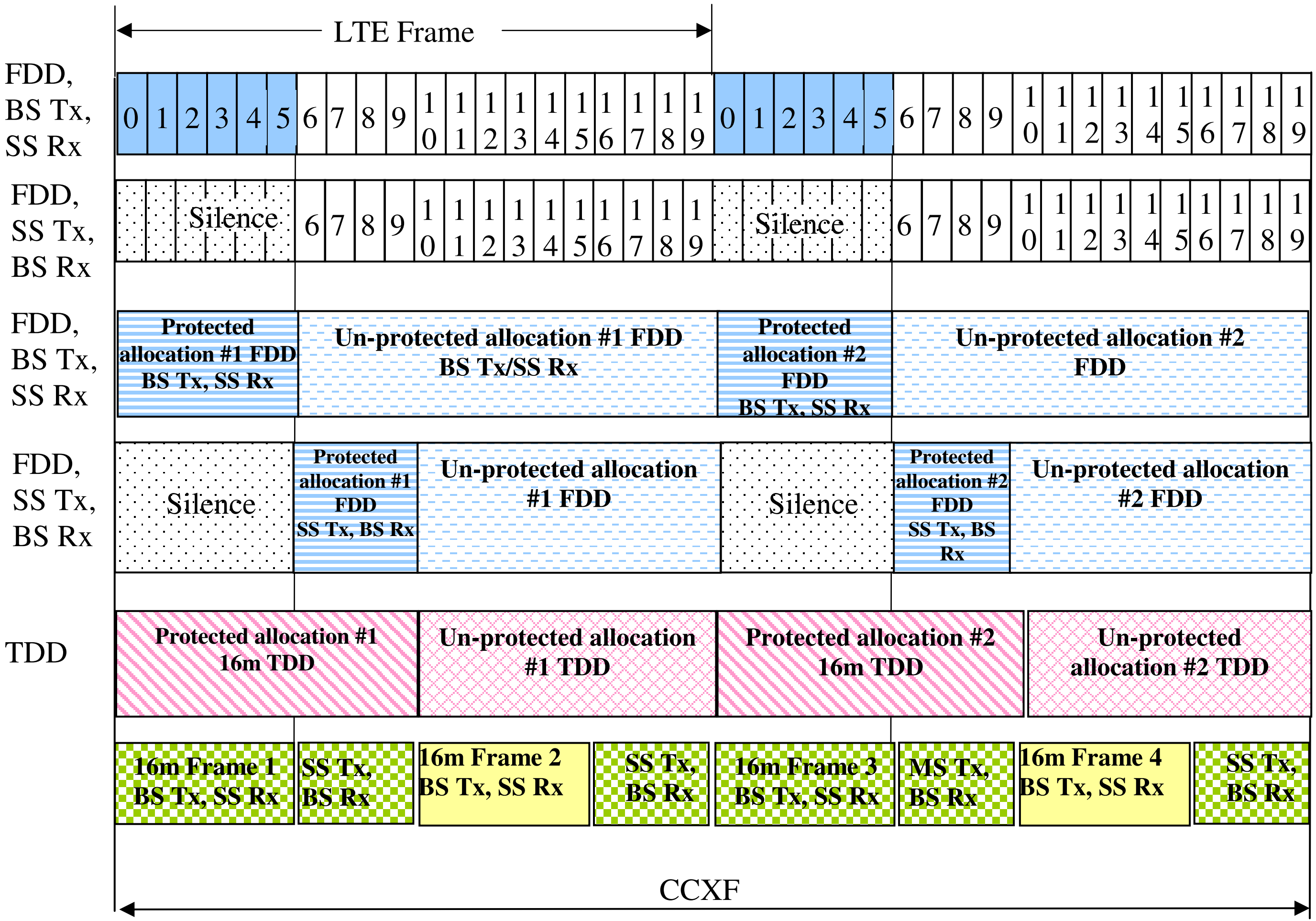

Fig. xx Example of FDD/TDD protected allocations resolving SS-SS interference

Fig. yy presents an example for improved coexistence between LTE (FDD) and 802.16m (TDD), resolving the SS-SS and the BS-BS interference:

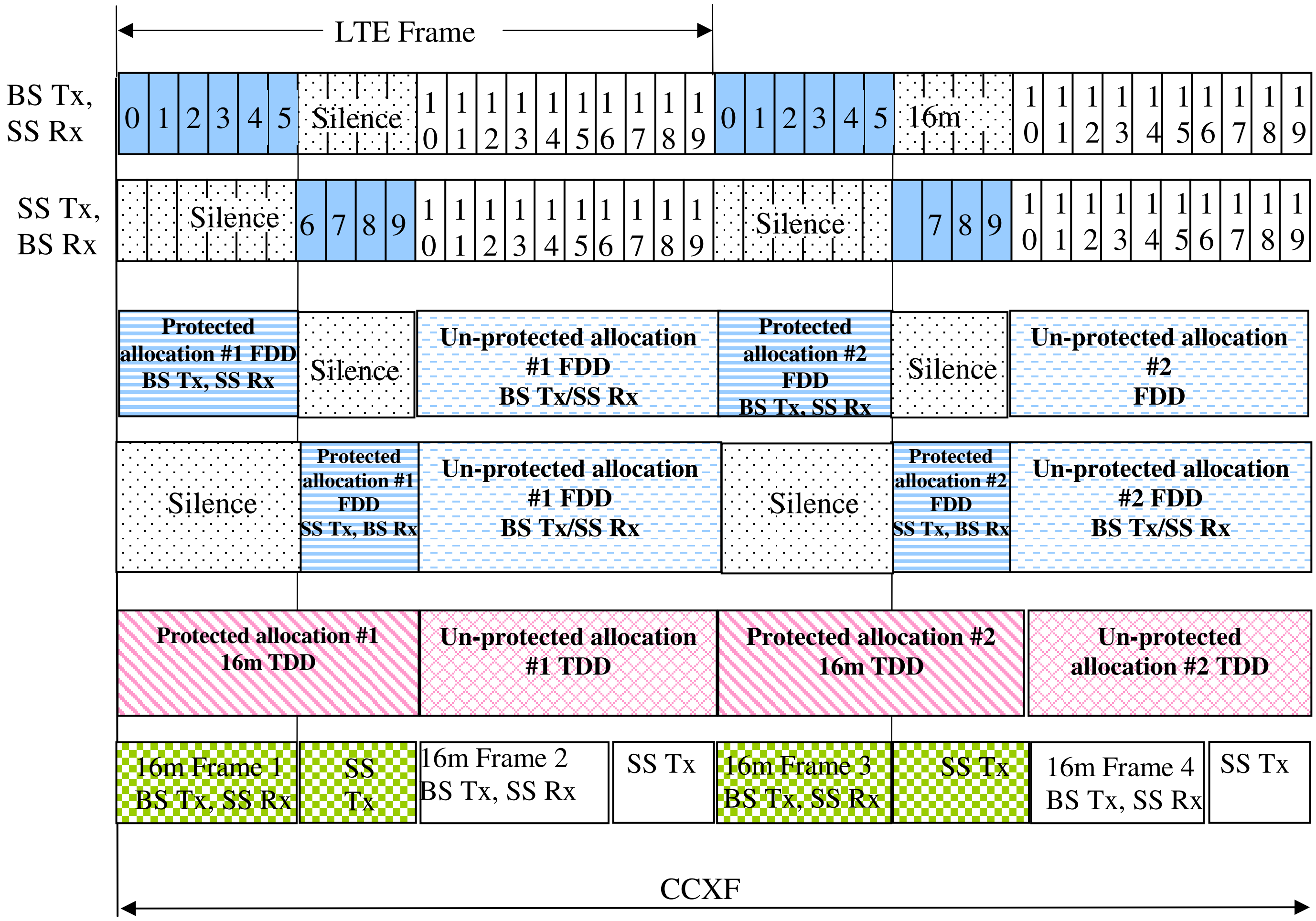

Fig. yy Example of FDD/TDD protected allocations resolving SS-SS and BS-BS interference

One of the most challenging coexistence case is the TDD-TDD coexistence when the co-located systems use different time durations.

Fig. zz presents the CXCC structure for TDD LTE with 10ms switching points and TDD 802.16m:

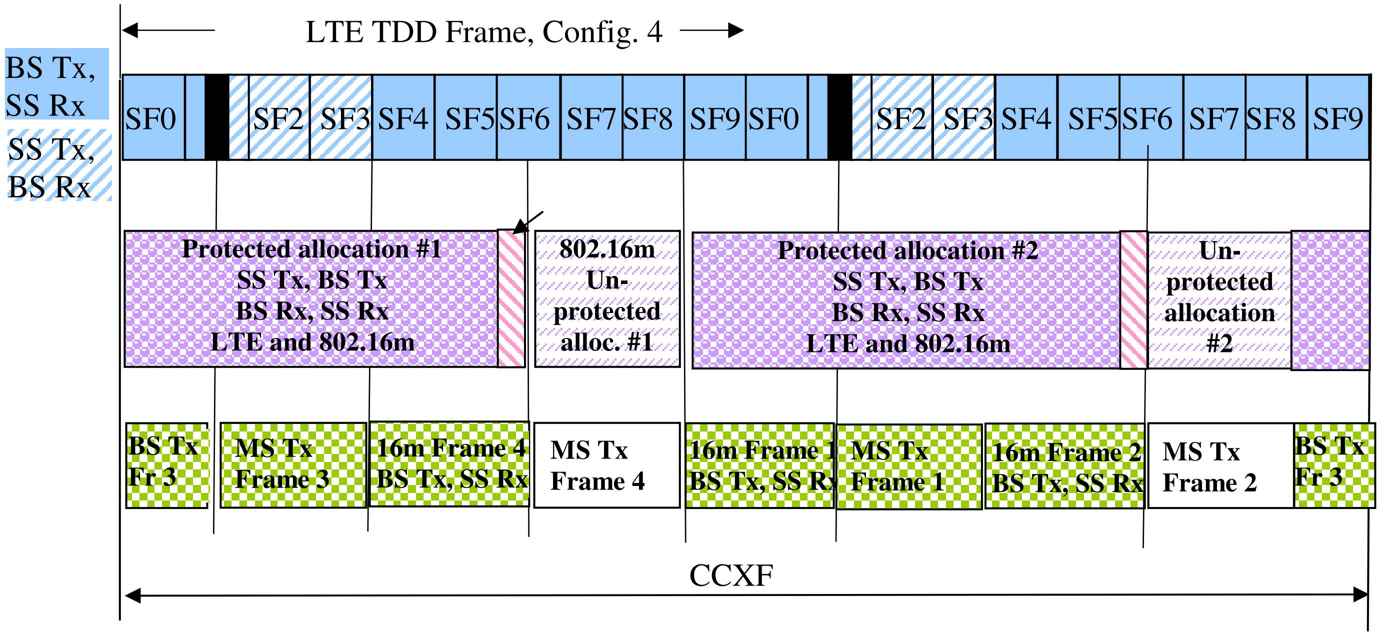

Fig. zz Example of TDD/TDD 802.16 protected allocations for LTE/802.16

Coexistence with 802.11 operating in adjacent frequency bands

A special case is represented by the radio devices providing simultaneous services using adjacent frequency bands (co-located radio coexistence). Such a device may be connected to a synchronized BS which is aware of the CXCF structure at that specific location. If we suppose that in an adjacent frequency band operates a WiFi AP (Access Point) to which is connected the dual-mode device, this device can inform the AP about the timing of the CXCF and the timing of the protected allocations for WiFi operation.

WiFi can also detect the periodicity of the harmful interference. If a well defined CXCF are defined for the bands adjacent to the WiFi operation, it will be possible that new WiFi devices will not create harmful interference to devices using license-bands and situated in WiFi proximity. The operation in special licensed bands, as 3.65GHz, can also benefit from the cognitive characteristics of the coordinated coexistence frame.

End Text for SDD

References

[1] 3GPP TS 36.211V8.2.0 (2008-03) 3GPP; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation; (Release 8)
[2] 3GPP TS 25.211 V7.3.0 (2007-09) 3GPP; Technical Specification Group Radio Access Network; Physical channels and mapping of transport channels onto physical channels (FDD) (Release 7)
[3] IEEE 802.16m-08/003r3, Shkumbin Hamiti: The Draft IEEE 802.16m System Description Document
[4] ITU; Radio Regulations; Edition 2004