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Title: **Comparison of FDD and TDD for HIPERACCESS Including Cellular Aspects**

Agenda item: **HA PHY Duplex Scheme**

Document for:

Decision	
Discussion	X
Information	X

Decision/action requested

This contribution is intended as an input to assist the decision process at ETSI BRAN on the co-existence issue for HIPERACCESS systems.

Abstract

The duplex separation schemes FDD and TDD are compared in this paper. We consider both single-cell systems as well as multi-cellular deployments with certain configurations including adjacent cells and sectors, sectorized cells and overlapping cells. There are only small differences between FDD and TDD with regards to flexibility and spectral efficiency, however, a more detailed investigation covering many aspects of the physical layer and the multi-cellular interference scenario will clearly indicate that FDD is considerably more robust and offers more advantages than TDD in the context of a wireless access system.

1. Introduction

The duplex separation in wireless access systems could be performed by either Frequency Division Duplex (FDD) or Time Division Duplex (TDD). Several aspects of these techniques are discussed in [1]. We consider a cellular system, maybe extended to sectorized cells, where the frequency resource in a cell or sector is shared between many users. The transmission direction from Base Station (BS, or Access Point Transceiver APT) to the Terminal Stations (TS, or Access Terminal AT) is called downlink (DL) and the reverse direction is called uplink (UL).

In a single-cell system TDD and FDD each offer specific pros and cons, ranging from various aspects of the physical layer to service flexibility. In a multi-cellular system comprising of many adjacent or even overlapping cells of perhaps different network operators, however, the problem of interference from adjacent cells and/or adjacent frequencies is of major importance.

Two possible duplex schemes for wireless multiple access systems are outlined as follows:

- **Frequency Division Duplex (FDD)** requires two distinct paired *traffic frequency bands* for DL and UL. The two traffic bands are separated by a *guard frequency band* and the *duplex frequency* is the difference between DL and UL carriers. Both traffic frequency bands are typically of equal width, providing the best match to services with with symmetrical data rates for both directions.

The width of the traffic frequency bands is related to the sum of the individual data rates of all TS within the cell or sector, subsequently refered to as *sum data rate*. The flexible sharing of capacity between the many TSs is organized by the multiple access scheme. The *peak data rate* of a TS in DL or UL is bounded by the sum data rate (if the total capacity is allocated to a single TS) and by the maximum data processing capability of the TS.

- **Time Division Duplex (TDD)** requires only a single unpaired frequency band. According to a so-called *duplex frame* on the time-axis, the direction of transmission is switched alternately between DL and UL and vice versa, i.e. the separation is achieved in time instead of frequency. A *guard time* is required between alternates of the transmission direction. A multiple access system requires the synchronization of the duplex frames between all TSs within a cell or sector.

  For a cellular environment with several cells or sectors two possible deployments of TDD have to be distinguished: For **synchronous TDD (syncTDD)** the duplex frames of all BSs (and thus also of all TSs) in all cells or sectors are synchronized in time and length, whereas for **asynchronous TDD (asyncTTD)** the duplex frames of adjacent cells or sectors could have arbitrary positions and lengths.

  The width of the frequency band is related to the total sum of all individual data rates in DL and UL of all TSs within the cell or sector. The flexible sharing of the capacity between the many TSs as well as between DL and UL of a single TS is organized by the multiple access scheme. The peak data rate of a TS in DL or UL is bounded by the sum data rate (if the total capacity is allocated to a single TS for one direction) and by the maximum data processing capability of the TS.

2. Single-Cell Aspects

The following comparison between TDD and FDD (as summarized in Table 1) is restricted to single-cell aspects. The multi-cellular scenarios will be considered in section 3.

In some applications including internet access the average data rate in DL is much higher than in UL. TDD allows for asymmetrical sum data rates for DL and UL without any impact on the frequency allocation. Moreover, by a simple variation of the duplex frame a fast flexible sharing of transmission capacity between DL and UL is possible. However, such an adaptive mode is only reasonble for asyncTDD, since syncTDD requires a common and synchronized change of the duplex schemes of all cells. An independent sharing between DL and UL for each cell is not possible. It is quite unreasonable that different operators are willing to synchronize their duplex frames. In principle, syncTDD for a multi-cellular scenario will be restricted to a fixed sharing between DL and UL.

FDD allows only for symmetrical sum data rates in case of equal bandwidths for DL and UL. However, this could be reasonable even in cases with asymmetrical burst data transmission (e.g. ATM cells or IP), since short data bursts could be transmitted in UL with the same small delay than in DL. Hence the transmission in UL from a single TS to the BS will be of high burstiness for such applications. For DL, in contrast, a continuous data stream could be transmitted from BS to all TSs (e.g. a stream of ATM cells could be filled up with empty cells) whereas a specific TS extracts only the dedicated data bursts.

Criterium	**TDD**	**FDD**
Principle of duplex separation	by time, requires only a single unpaired frequency band	by frequency, requires paired frequency band allocations
Physical means for duplex separation	switch	diplexer (ie. filter)
Required overhead for duplex separation	guard time, depending on range and power ramping	guard frequency band (could be used otherwise)
Frequency allocation	1 wide band	2 narrow bands, separated by a guardband
Flexible sharing between sum DL data rate and sum UL data rate	yes (asyncTDD) no (syncTDD)	not possible
Flexible sharing of capacity between DL and UL for a single TS	yes	yes
Flexible sharing between TSs within DL	yes	yes
Flexible sharing between TSs within UL	yes	yes
Antenna in BS and TS	narrow-band compared to data rate (due to identical Tx/Rx band)	wide-band compared to data rate, but narrow-band compared to carrier frequency
Frequency-selective propagation	more critical due to doubled bandwidth	less critical
Synchronisation in Rx (tracking)	more challenging since Rx receives in burst-mode	more simple due to permanent received signal (in TS)
Sampling frequency for ADC and DAC	more than twice compared to FDD	only half of TDD

Table 1: Comparison of Duplex Schemes (Not Including Cellular Aspects)

Apart from considering the sum data rates, a flexible sharing of capacity between DL and UL for a single TS as well as a flexible sharing between TSs within DL or within UL is possible both with TDD and FDD.

As mentioned in section 1, TDD requires a guard time between transmitted and received signals which can not be used for data transmission, causing both delay problems as well as a certain loss in spectral efficiency. The guard time must be increased or the efficiency is reduced, if

- the length of duplex frame is reduced (maybe required to reduce delays)
- short data bursts have to be transmitted (the ratio between traffic data and guard time will be decreased)
- high-level modulation schemes are used (maybe required for better frequency efficiency, but causing short data bursts)
- the High Power Amplifier (HPA) is operated with power ramping.

The transmission of short data bursts is thus less efficient with TDD compared to FDD, but TDD offers lower delay due to the higher bandwidth. However, this is only a rule of thumb, since the exact figures are depending on the details of the multiple access scheme.

The width of the two FDD traffic frequency bands equals approximately half of the TDD bandwidth in case of equal data dates. Therefore, the sampling rates for Analogue-to-Digital Converters (ADC) and Digital-to-Analogue Converters (DAC) must be doubled for TDD compared to FDD. The doubling of sampling rates may be more costly and may has to be paid by a certain loss of ADC and DAC resolution implying a certain loss of dynamic.

For FDD, the separation between simultaneously transmitted and received signals is achieved with a diplexer (filter). Since the diplexer must guarantee a high stopband attenuation, the duplex frequency is typically larger than the width of the traffic bands but typically much smaller than the carrier frequency. The separation for TDD is achieved with a switch which must also ensure a high decoupling between transmitter (Tx) and receiver (Rx) path. For both duplex schemes, the implementation of the FDD diplexer or the TDD switch is more demanding for higher carrier frequencies and higher transmitted-to-received power ratios.

Transmitted and received frequencies are identical for TDD, but with appropriate techniques FDD requires only a single local oszillator too. A single antenna is sufficient not only for TDD but also for FDD, since the total bandwidth (lower traffic band + duplex band + upper traffic band) is much smaller than the carrier frequency. However, FDD allows for cross-polarization between DL and UL with separated antennas.

The transmission may suffer from frequency-selective effects due to multipath propagation, depending on the radio channel properties and the width of the traffic frequency band. It is expected that these effects are less severe with higher carrier frequency. TDD will be more affected than FDD due to the doubled bandwidth.

As mentioned above for FDD, a continuous data stream could be transmitted from BS to all TSs. A specific TS extracts only the dedicated data bursts after decoding, however, the front stages of the TS receiver could operate in continuous mode for an improved tracking of the synchronization circuits. This is not possible with TDD, so that transmitter and receiver of the TS have to maintain their tracking from the current DL part to the next DL part of the duplex frame.

3. Cellular Aspects: Interference from Adjacent Cells or Adjacent Frequencies

Various system configurations of multi-cellular HIPERACESS systems are imaginable but can be represented by only three major constellations as follows (see Figures 1, 2 and 3):

- Constellation 1: **Adjacent cells** are operated at the same carrier frequency or at adjacent carrier frequencies with omni-directional antennas at the BSs. In case of sectorized cells, the worst-case arises with two sectors oriented towards each other. The narrow-beam antennas of the TSs are oriented towards the BSs.
    - The case of equal frequencies is only possible due to the antenna beamforming at the TSs, but this is certainly a realistic assumption if only one frequency band (paired for FDD or unpaired for TDD) is allocated to a network operator.
    - The case of adjacent frequencies presupposes an allocation of several carrier frequencies to one network operator. Without the feature of antenna beamforming at the TSs this would correspond in principle to mobile radio systems like GSM.

- Constellation 2: **Sectors of one cell** are operated at the same carrier frequency. Adjacent sectors could be separated by cross-polarization. Thus two sectors with the same polarization are separated by another sector.

- Constellation 3: **Overlapping cells** are operated at adjacent carrier frequencies by different network operators without the restriction of a common coordinated cell planning. Hence the overlapping cell structures and the cell sizes are expected to be completely arbitrary.

The problem of mutual interference including co-channel and adjacent channel interference from adjacent cells or sectors is thus of major importance for the comparison of TDD and FDD.

Consider a transmitter A and a receiver B operating at adjacent frequencies f_A and f_B at the same time in the same area. Two effects are responsible for adjacent channel interferences:

- Due to non-perfect transmitter filtering (frequency mask), the transmitter A will cause out-of-band emissions into frequency f_B. For example, according to [2, 3] for FDMA point-to-multipoint systems, out-of-band emissions to adjacent frequency bands are specified with −25 dB to −33 dB below the desired band (depending on the modulation scheme).
- Due to non-perfect receiver filtering with limited stopband attenuation, the receiver B will receive not only the intended frequency f_B, but also attenuated signals from f_A.

The problem of adjacent channel interference is relaxed if the frequency distance between the two carriers is increased, since broader transitions bands allow for more stopband attenuation. Interferences from other radio systems outside of HIPERACCESS are excluded from the following discussion (implying also a restriction to licensed bands). Furthermore, interferences between links within a cell or sector are not considered because this has to be avoided in principle by an appropriate access scheme and an appropriate design of the physical layer.

The Figures 1, 2 and 3 represent the three cellular constellations as described above. The bold two-sided or one-sided arrow represents the link (both DL and UL) between BS and TS under consideration. The thin one-sided arrows represent the interference paths:

- In UL the BS receives not only the own TS (i.e. registered for this cell or sector) but also strange TSs (i.e. not registered for this cell or sector) and strange BSs (i.e. BSs of other cells).
- In DL the TS receives not only the own BS but also strange BSs and strange TSs.

The geographical positions of the TSs within the cellular coverage in the three Figures shall represent the worst-case conditions.

The labeling of every arrow from left to right refers to the three duplex schemes syncTDD, asyncTDD and FDD. The numbers from 1 to 4 are the most important quantities representing a rating of the adjacent cell interference scenario:

- 1 = does not appear
- 2 = not critical at all, no relevant degradations in any case
- 3 = may cause critical degradations, depending on the specific conditions
- 4 = critical degradations are very likely

Obviously, a rating as critical for the UL could imply a blocking of the complete cell or sector and must be avoided in principle by means of an appropriate duplex scheme and an appropriate cell planning. In contrast, a rating as critical for the DL implies only a blocking of a singular TS what might be resolved by a better placing of the antenna. In other words, blocking of some DLs is equivalent to a somewhat reduced coverage, whereas blocking of the UL causes total loss of all links within the cell or sector.

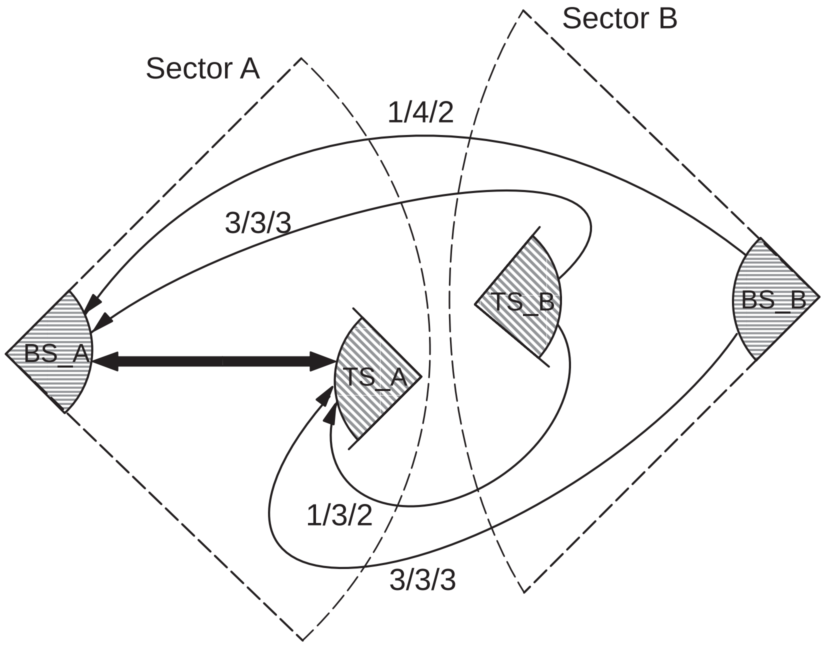

Figure 1: Sectors of Adjacent Cells (with Equal or Adjacent Frequencies)
(labeling of arrows: syncTDD / asyncTDD / FDD,
1=does not appear, 2=not critical, 3=maybe critical, 4=critical)

Remarks to Figure 1: Suppose at first equal carrier frequencies in cells A and B.
(i) Consider the UL: BS_A is not affected by BS_B in case of syncTDD. In case of asyncTDD critical interferences causing a total blocking of cell A are possible, especially for low received power levels of TS_A. Due to the large duplex frequency in case of FDD it is possible to suppress the impact of BS_B on BS_A completely. BS_A receives TS_B irrespectively of the duplex scheme, however, the result depends on the beamforming of the TS_B antenna and the TS_A antenna gain as well as of the ratio of the received power levels of both TSs.
(ii) Consider the DL: TS_A receives BS_B irrespectively of the duplex scheme, with a result depending on the beamforming of the TS_A antenna as well as of the ratio of the transmit power levels of both BSs. TS_A is not impacted by TS_B in case of syncTDD, however, the opposite is true in case of asyncTDD depending on the beamforming of both TS antennas and the ratio of the transmit power levels of BS_A and TS_B. The signal path from TS_B to TS_A is not critical in case of FDD due to the large duplex frequency.
(iii) In case of adjacent frequencies for cells A and B, all problems can be relaxed by appropriate receiver filtering. Especially the ratings for the UL can be reduced from 4 to 3 and from 3 to 2.

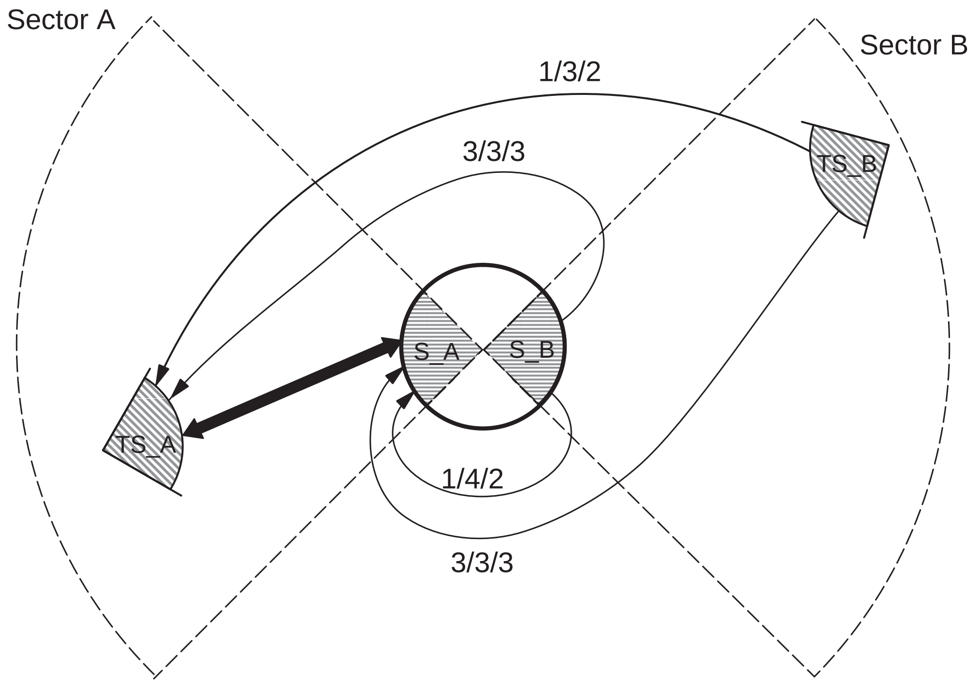

Figure 2: Sectorized Cell (with Equal Frequencies)
(labeling of arrows: syncTDD / asyncTDD / FDD,
1=does not appear, 2=not critical, 3=maybe critical, 4=critical)

Remarks to Figure 2: We assume that both sectors S_A and S_B are operated at the same carrier frequency and at the same polarization. Thus both sectors are not adjacent, since adjacent sectors are operated with cross-polarization.
(i) Consider the UL: S_A is not afffected by S_B in case of syncTDD. In case of asyncTDD critical interferences causing a total blocking of sector A are possible, especially for low received power levels of TS_A. Due to the large duplex frequency in case of FDD it is possible to suppress the impact of S_B on S_A completely. S_A receives TS_B irrespectively of the duplex scheme, however, the results depends on the beamforming of the S_A antenna as well as of the ratio of the received power levels of both TSs.
(ii) Consider the DL: TS_A receives S_B irrespectively of the duplex scheme, with a result depending on the transmit power levels of S_A and S_B. In case of syncTDD TS_A is not affected by TS_B, however, the oppposite is true in case of asyncTDD depending on the ratio of transmit power levels of S_A and TS_B. Due to the large duplex frequency in case of FDD, the signal path from TS_B to TS_A is not critical at all.

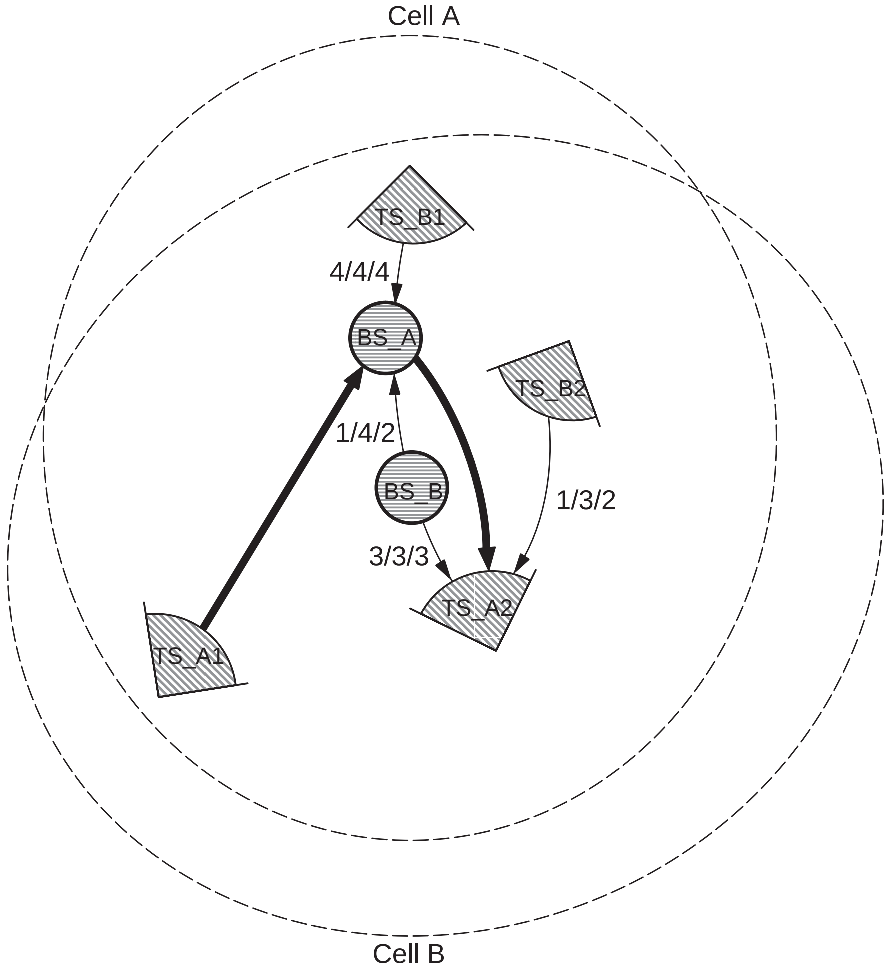

Figure 3: Overlapping Cells (with Adjacent Frequencies)
(labeling of arrows: syncTDD / asyncTDD / FDD,
1=does not appear, 2=not critical, 3=maybe critical, 4=critical)

Remarks to Figure 3: We assume two overlapping cells of different network operators operating at adjacent carrier frequencies.
(i) Consider the UL. The worst-case conditions are caused through a distance combination of a far TS_A1 and a near TS_B1. BS_A is not affected by BS_B in case of syncTDD. However, in case of asyncTDD, irrespectively of the different carrier frequencies, BS_A could receive the out-of-band emissions of BS_B with high power compared to the received signal of the far TS_A1. Hence all uplinks from far terminals like TS_A1 could fail, and thus the complete cell could be blocked. In contrast, FDD is not critical at all for this scenario due to the large duplex frequency. Furthermore, regardless of the different carrier frequencies, BS_A could also be considerably affected by the out-of-band emissions of a near TS_B1, which might be received with higher power level than TS_A1 in case of a large distance from TS_B1 to BS_B.
(ii) Consider the DL. The worst-case conditions are caused through combination of a small distance between BS_B and TS_A2 and an adjacent TS_B2. If TS_A2 is near to the strange BS_B and far to the own BS_A, then BS_B will domineer over BS_A causing a loss of the downlink to TS_A2. However, this is only rated with 3 instead of 4, since only a single terminal is affected. TS_A2 is not affected by TS_B2 in case of syncTDD, whereas the opposite is true for asyncTDD. This situation is not critical at all in case of FDD due to the large duplex frequency.

(iii) The critical interference relations are relaxed if the distance between the two carrier frequencies of the overlapping cells is increased.

The interference ratings from Figures 1, 2 and 3 are now summarized in Table 2.

Cellular constellation	**Duplex scheme**		
	syncTDD	**asyncTDD**	**FDD**
Case 1: Neighbour cells	**maybe critical / maybe critical**	**critical / maybe critical**	**maybe critical / maybe critical**
Case 2: Sectorized cell	**maybe critical / maybe critical**	**critical / maybe critical**	**maybe critical / maybe critical**
Case 3: Overlapping cells	**critical / maybe critical**	**critical / critical**	**critical / maybe critical**

Table 2: Summary of Interference Ratings for UL / DL

4. Summary

According to the typical conditions of HIPERACCESS systems, FDD seems to be the better choice if considering single-cell aspects. The spectral efficiency of FDD is approximately equal or slightly superior compared to TDD. There remains only one major advantage of TDD over FDD, namely the flexible sharing of capacity between downlink and uplink, yet this is only reasonable in case of asynchronous TDD.

The advantages of FDD are clearly obvious by drawing the main conclusions from the cellular scenario:

- Asynchrouous TDD might fail in a multi-cellular deployment, at least for the uplink, since base stations can transmit simultaneously on identical or adjacent frequencies causing a mutual blocking of entire cells.

- TDD is thus only reasonable in the synchronous mode, where showing similar interference ratings as FDD.

- Synchronous TDD implies a fixed sharing between downlink and uplink capacity. This is less attractive and offers no significant additional flexibility compared to FDD. Moreover, synchronous TDD implies an unacceptable required amount of coordination between different network operators.

- Overlapping cells in conjunction with worst-case distance relations between base and terminal stations require sufficient distances between the carrrier frequencies in order to achieve sufficient stopband attenuation by appropriate receiver filtering. This relates to the specification of frequency masks and carrier frequency allocation strategies irrespectively of the duplex scheme.

References

[1] A.Nascimbene, A.Bolle: Comparison between FDD and TDD. ETSI BRAN11, October 1998, Rennes (France). Document HA11ERI1a.

[2] ETSI Draft EN 301 080 V1.1.1 (1997-08) Transmission and Multiplexing (TM); Digital Radio Relay Systems (DRRS); Frequency Division Multiple Access (FDMA) point-to-multipoint DRRS in the band 3 GHz to 11 GHz.

[3] ETSI Draft EN 301 213 (1998-06) Transmission and Multiplexing (TM); Digital Radio Relay Systems (DRRS); Point-to-multipoint DRRS in frequency bands in the range 24,25 GHz to 29,5 GHz using different access methods. Part 1: Basic parameters. Part 2: Frequency Division Multiplexing (FDMA) methods.