TDD and FDD Wireless Access Systems

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Coexistence of TDD and FDD
Wireless Access Systems
In the 3.5GHz Band

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Several million lines of proprietary Wireless Local Loop (WLL) systems are in service around the world. The outstanding sub-10GHz licensed band for WLL deployment is the 3.4GHz-3.6GHz band commonly referred to as the 3.5GHz band. In most countries that follow the ETSI recommendations, the licensing regime and therefore the systems deployments in this band have followed the Frequency Division Duplex (FDD) method.

With the arrival of the IEEE 802.16 standard, wireless access is a more credible technology then ever before for bringing, in an economically viable manner, both fixed and mobile broadband solutions to millions of customers all over the world. The WiMAX Forum has defined 'Fixed' WiMAX profiles with both FDD and Time Division Duplex (TDD); whereas the currently defined 'Mobile' WiMAX profiles are in TDD only.

It is well known that introducing TDD systems into the same spectral and geographic space as FDD systems can be problematic and requires careful RF engineering. Therefore, Airspan has undertaken an extensive study in order to establish the boundaries of the TDD / FDD coexistence issues in the 3.5GHz band, the results of which are summarised in this white paper.

Please consult the Airspan Web-site (www.airspan.com) for further details about Airspan's WiMAX products and solutions.

Introduction

During the last decade several million lines of proprietary Wireless Local Loop (WLL) products have been deployed around the world to provide customers with telephony, data and Internet access services. With the arrival in 2004 of the IEEE 802.16 standard for wide area wireless access, interest in wireless access is keener than ever before. WiMAX, championed by the WiMAX Forum to promote conformance and interoperability of the IEEE 802.16 standard, has revolutionised the wide area broadband wireless communications. The latest version of the standard, IEEE 802.16e-2005, extents the earlier specifications in order to address the requirements of both mobile and fixed WiMAX deployments.

Wireless access systems are deployed in both licensed and unlicensed bands. Operators prefer to deploy in licensed bands in order to deliver better quality services without suffering from arbitrary interference problems that may be experienced in unlicensed bands. Of all the sub-10GHz bands used for wireless access, by far the most popular is the 3.5GHz band, which covers from 3.4GHz to 3.6GHz. It is a licensed band and in most ETSI countries it is licensed for Frequency Division Duplexing (FDD) operation. There are exceptions to this; in some countries it is permissible to deploy Time Division Duplexing (TDD) systems in the 3.5GHz band.

For many years FDD and TDD have been the two methods of choice for handling uplink (UL) and downlink (DL) transmissions in wireless systems. FDD uses two different frequencies for the UL and DL thereby separating them in frequency whereas TDD utilises a single frequency for both UL and DL signals and separates them in time.

In 2004 WiMAX Forum, in consultation with operators and vendors, defined a number of profiles in the 3.5GHz band that specify both FDD and TDD duplexing methods, examples of which are 3.5F1 and 3.5T1 profiles. The first profiles defined for 'Mobile' WiMAX support only TDD which means that in the future we will see an increasing number of TDD systems deployed in the 3.5GHz band as well as in other bands.

As we will explain later on in this paper, the FDD and TDD systems operate in different ways, as a result of which coexistence of FDD and TDD systems in the same spectral and/or geographic space could cause interference problems between systems, which need to be carefully managed. Interference is caused by one system transmitting whilst the other system is receiving in an adjacent band. Base stations are particularly susceptible to interference from other base stations but interference can also be caused by a mobile station belonging to one system interfering with the base station of another system.

In this paper we explore the issues arising from introducing TDD systems into environments where there are already established networks of pre-WiMAX or WiMAX equipment based on FDD, and offer some guidance and solutions.

Frequency Division Duplexing (FDD) System

In FDD systems UL and DL transmissions are allocated separate frequency bands. The UL and DL channels are grouped into contiguous blocks of paired channels as shown in Figure 1. The paired UL and DL channels are typically separated by 100MHz. Thanks to the guard band between UL and DL, the interference of one FDD system with another is minimised.

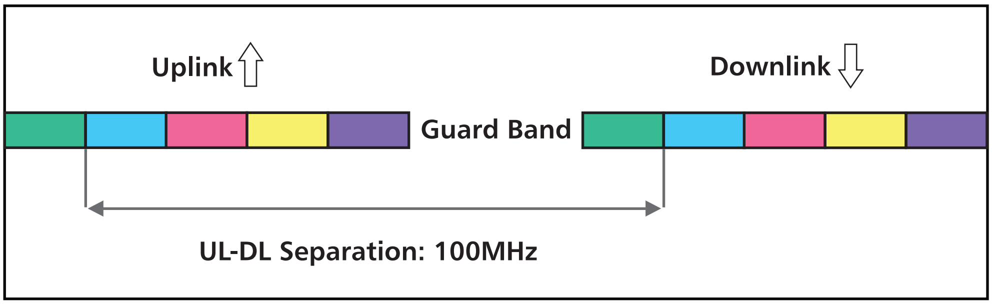

Figure 1 – Spectrum allocation in FDD systems

Advantages of FDD Systems

Simultaneous and continuous UL and DL transmission

FDD systems provide full duplex operation making them ideal for applications such as voice, where the UL and DL traffic requirements are more or less symmetrical. Moreover, continuous transmissions help reduce layer 2 (MAC) delays by enabling immediate feedback to be provided about channel conditions.

Immunity to system interference

Thanks to a large separation between UL and DL, Base Station (BS) to BS and Subscriber Station (SS) to SS interferences are minimised and are negligibly small.

Ease of network planning

Since the BS-BS interference is kept to a minimum, network radio planning is easier for FDD systems.

Disadvantages of FDD Systems

Fixed channel allocation

In FDD the UL and DL channel allocations are fixed. Whilst this provides benefits for symmetric traffic, it can result in wasted bandwidth when the applications are asymmetric. As data traffic and Internet access become the dominant users of bandwidth the need for flexible channel utilisation becomes more important.

Guard Band

FDD requires a guard band to separate the UL and DL channels.

Higher hardware costs

FDD requires a transmitter, a separate receiver and a diplexer. Furthermore, sharp RF filters are required to isolate the UL and DL. These higher costs can be justified at the base stations but at the subscriber stations often half duplex FDD (H-FDD) solutions are used in order to keep the costs low.

Time Division Duplex Systems

A TDD system does not require paired frequency channels for UL and DL nor does it require a guard band. Instead TDD systems use the same channel for UL and DL transmission separating them in the time domain. Each channel consists of one DL and one UL sub-frame as illustrated in Figure 2. TDD systems use guard intervals between the transition from DL to UL and from UL to DL. These guard intervals are called Transmit/receive Transition Gap (TTG) and Receive/transmit Transition Gap (RTG). Generally TTG is larger than RTG in order to allow time for the round-trip delay of the signals from the edge of the sector.

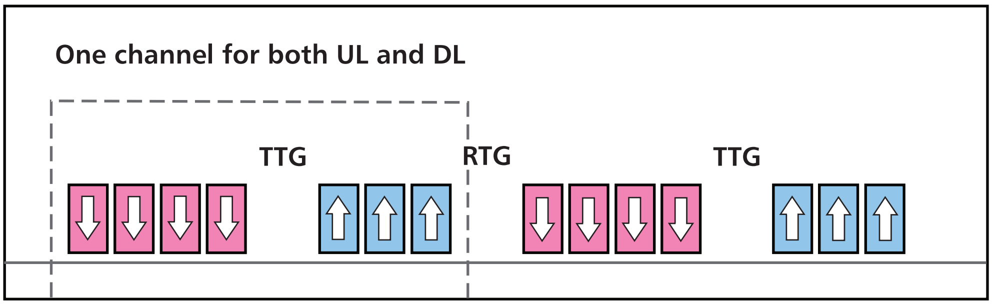

Figure 2 – TDD structure

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Advantages of TDD Systems

Flexible bandwidth allocation for UL and DL

TDD systems can flexibly allocate bandwidth to UL or DL simply by altering their sub-frame duration. In future systems variation in traffic symmetry is expected to be large, making flexible allocation of bandwidth an important feature.

Channel reciprocity leads to better use of multiple antenna systems

Since in TDD systems both the UL and the DL use the same channel, their channel responses are said to be reciprocal. Therefore the station is better able to optimise the transmit parameters used in multiple antenna systems such as MIMO or beamforming.

Lower hardware costs

The hardware costs of a TDD system could be lower than an FDD system because the same oscillator and filters are shared for both UL and DL and there is no need for a diplexer.

Disadvantages of TDD Systems

Interference problems

In TDD systems interference arises when neighbouring base stations do not synchronise their frames and have different UL and DL symmetries. BS-BS interference is more severe than SS-BS interference because LOS may exist between base stations.

Inter-operator interference

When more than one operator is present in a geographic area it is possible that the cells of different operators using adjacent channels will overlap and cause adjacent channel interference (ACI). The operators need to cooperate in order to minimise ACI (for example put a large physical separation between BSs using adjacent channels), however, in reality this does not happen and the one practical solution is to leave a large guard band between the bands used by different operators.

Guard intervals

TDD systems require guard intervals between UL and DL transitions, called TTG and RTG. The TTG interval needs to be larger than the round-trip delay. Therefore, for large cells the overhead of TTG relative to the TDD frame could be significant, thus reducing the efficiency of the system by about 2%.

Airspan Study into Co-existence of TDD and FDD systems

Since 1992 Airspan has been a leading provider of wireless access solutions. Today Airspan has more than 400 customers in over 100 countries and has shipped more than 1 million lines of wireless access. In 2005 Airspan started shipping its Fixed WiMAX solutions as well as its widely used proprietary solutions. Today Airspan has WiMAX commercial deployments and trials with more than 80 customers. As we prepare to bring to market our TDD based IEEE 802.16e-2005 solutions it is important that we fully understand the co-existence issues between proprietary and WiMAX products and between TDD and FDD, so that we can plan network solutions in a professional way.

For these reasons Airspan has undertaken an extensive study of the following co-existence scenarios:

1 Interference Analysis between Base Stations

a) Mobile WiMAX TDD BS and Proprietary FDD BS
b) Mobile WiMAX TDD BS and Fixed WiMAX FDD BS

2 Interference Analysis between Subscriber/Mobile Stations

a) Mobile WiMAX TDD Mobile Station (MS) and Proprietary FDD Subscriber Station (SS)
b) Mobile WiMAX TDD MS and Fixed WiMAX FDD SS

We did not study the interference scenarios between two TDD base stations or between two FDD base stations because the solutions to these are well understood. For completeness these are summarised below:

The interference between two TDD base stations can arise due to two main reasons: cross-slot co-channel interference and interoperator adjacent channel interference (ACI). Cross-slot co-channel interference can be solved by synchronising the base stations and by the careful use of sectorised antennas. However, synchronisation is not seen as a practical way of managing interoperator ACI. Instead, ACI can be reduced by using very sharp RF filters, which is expensive, or a more practical approach is to assign large guard bands between the bands used by different operators.

The interference between two FDD base stations can be managed relatively easily thanks to the large separation between the UL and DL channels of FDD systems.

Methodology for BS-BS Interference analysis

The methodology we have used to study the interference scenarios mentioned above is summarised here.

First we established the system characteristics for the base stations we want to study. We defined the system characteristics for Mobile WiMAX TDD BS, for the Fixed WiMAX FDD BS and for the Proprietary FDD BS based on the system parameters of our products.

We then developed co-existence scenarios to calculate interference levels as a function of interferer/victim separation distances. Scenarios considered include:

- Interference from a Mobile WiMAX TDD BS into a Proprietary FDD BS
- Interference from a Mobile WiMAX TDD BS into a Fixed WiMAX FDD BS
- Interference from a Proprietary FDD BS into a Mobile WiMAX TDD BS
- Interference from a Fixed WiMAX FDD BS into a Mobile WiMAX TDD BS

We studied the implications of the interfering and victim BSs operating on the same tower and on opposite towers. The analysis consisted of two steps, the derivation of the Net Filter Discrimination (NFD) and the analysis of the impact of Receiver Blocking.

The first step of the analysis is the derivation of the Net Filter Discrimination (NFD), which specifies the amount of suppression available as a function of frequency offset between the interferer and victim receiver. The NFD calculation is based on series of calculations using interferer emission and victim receiver selectivity masks. The NFD method is fully detailed in Reference 1. In our study, the method was applied by sliding the interferer emission mask across the victim receiver selectivity mask step by step. The NFD level at each step is then calculated using the amount of overlap between the masks.

For the scenarios where the interfering and victim BS antennas are assumed to be operating on the same tower, the additional suppression required to bring the interference to an acceptable level is calculated using the interfering BS transmit power, the maximum achievable isolation between the antennas and the victim BS interference criterion. The additional suppression is then compared against the NFD levels. The frequency offset at which the calculated additional suppression is equal to the NFD level is the required guard band.

For the scenarios where the interfering and victim BS antennas are assumed to be operating on opposite towers, the additional suppression required to bring the interference to an acceptable level is calculated using the interfering BS transmit power, the interfering and victim BS antenna gains, the path loss corresponding to the distance between the interfering and victim BS and the victim BS interference criterion. The additional suppression is then compared against the NFD levels. The frequency offset at which the calculated additional suppression is equal to the NFD level is the required guard band.

The second step of the analysis examines the impact of receiver blocking using same-tower and opposite-towers scenarios. In the case of a same-tower scenario, the additional suppression required to prevent front-end saturation is calculated from the interfering BS transmit power and the victim BS receiver blocking level. The calculated additional suppression is then compared against the maximum achievable isolation between the interfering and victim antennas to identify if the co existence on the same tower is possible without the risk of the victim BS being blocked.

In the case of an opposite-towers scenario, the required isolation is calculated from the interfering BS transmit power, the interfering and victim BS antenna gains and the victim BS receiver blocking level. The calculated isolation is then translated into a minimum separation distance between the interfering BS and the victim BS. This is the minimum distance at which the interference power is less than the victim BS receiver blocking level. In all opposite-tower scenarios, the free-space model is used to calculate interference path losses.

For a particular scenario to be feasible both the NFD analysis and the Receiver Blocking analysis must be feasible.

In this white paper we do not intend to present and discuss each and every result of the extensive study but we will give an example, generalise the findings and draw conclusions.

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Example: Interference from Mobile WiMAX TDD (5MHz) BS into a Proprietary FDD BS

NFD Analysis

The NFD graph shown in Figure 3 is derived with respect to the frequency separation between carrier centre frequencies using the TDD Mobile WiMAX BS (5 MHz) emission mask and the FDD Proprietary WLL BS receiver selectivity mask.

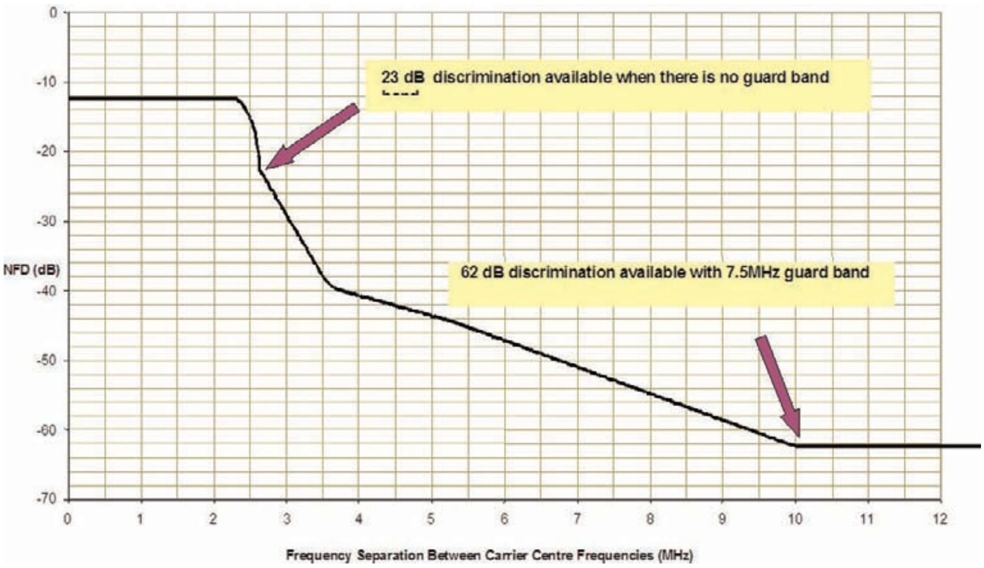

Figure 3 – NFD Graph

The separation between the Mobile WiMAX TDD BS and Proprietary FDD BS carrier centre frequencies is:

Mobile WiMAX TDD Channel Bandwidth of 5 MHz / 2 +
Proprietary FDD Channel Bandwidth of 0.3072 / 2 = 2.6536 MHz

Identifying this value on the NFD graph shows the discrimination that is achieved when there is no guard band, which is approximately 23 dB.

Using the NFD graph we can draw conclusions about the separation and suppression requirements for same tower or opposite tower operation. Considering same tower operation for example, the maximum suppression available in the NFD graph is 62.45 dB, which corresponds to the carrier centre frequency separation of 10.14 MHz, hence a guard band of approximately 7.5 MHz.

Assuming that the interfering and victim antennas are on opposite towers and pointing away from each other (i.e. backlobe-to-backlobe alignment) the guard band values shown in Figure 4 are calculated as a function of the distance between interfering and victim BSs.

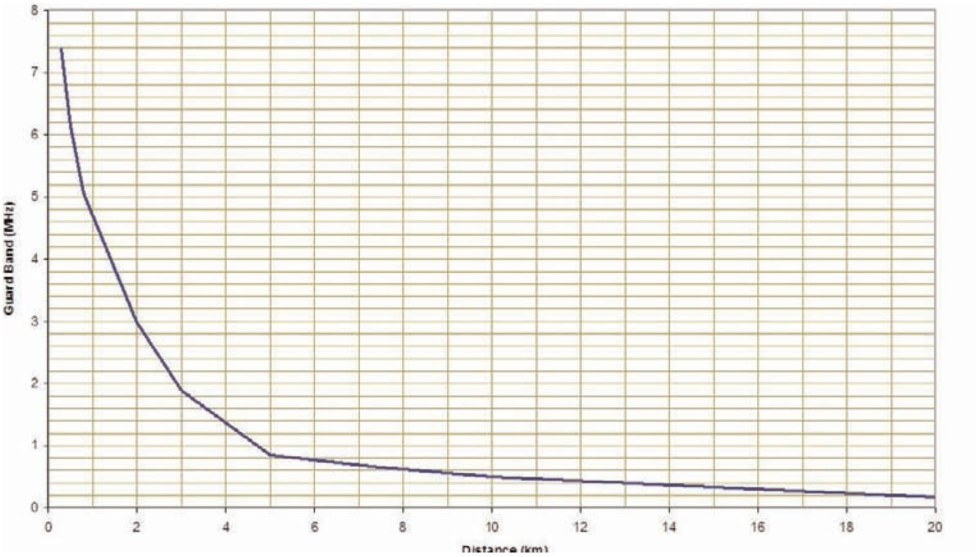

Figure 4 – Guard Band vs Distance (Boresight-to-Boresight)

As shown in the figure above, a minimum distance of 300 m and a guard band of 7.5 MHz are required when antenna gains are 0 dBi at interfering and victim antennas. Any distance less than 300 m results in an additional suppression requirement that is in excess of the maximum discrimination provided by the NFD (which is 62.45 dB).

Receiver Blocking Level Analysis

The same tower and opposite tower operation analysis is also performed using the Receiver Blocking level.

For an assumed receiver blocking level of –24 dBm (which corresponds to 3 dB reduction in sensitivity) and an emission level of 35 dBm, same-tower co existence requires an isolation of 59 dB. Providing that the maximum achievable antenna isolation is 60 dB the interfering and victim antennas may just operate on the same tower without saturating the receive antenna front end.

Assuming that interfering and victim antennas are on opposite towers and directly pointing at each other (i.e. boresight-to-boresight alignment), the minimum required separation distance to prevent front-end saturation is approximately 315 m. This is reduced to well below 100 m if the antennas point away from each other and backlobe-to-backlobe alignment is achieved.

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The receiver blocking level analysis results suggest that blocking requirements are significantly less stringent than those obtained from the analysis with the emission and receiver selectivity masks. However, for a particular co-existence scenario to be successful both requirements must be met.

The Impact of Additional RF filtering

We repeated the above analysis assuming that the system is now implemented using additional RF filtering in the Mobile TDD system. Figure 5 shows the NFD graphs with and without transmit RF filters.

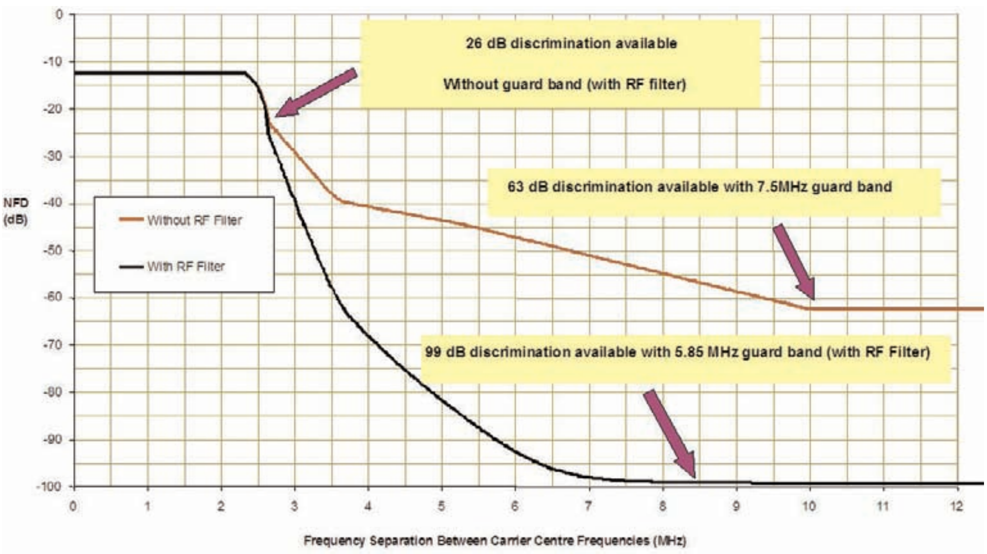

Figure 5 – NFD graphs with and without RF filters

The NFD plots show that when the transmitter RF filter is used the available discrimination is increased from 23 dB to 26 dB for the scenario where transmit and receive carriers are next to each other with no guard band in between. In addition, with the transmit RF filter, the maximum available discrimination is 99.15 dB corresponding to a guard band of 5.85 MHz, instead of the 7.5MHz without the RF filter.

The use of transmit RF filtering also improves the Guard band vs distance graph as shown in Figure 6.

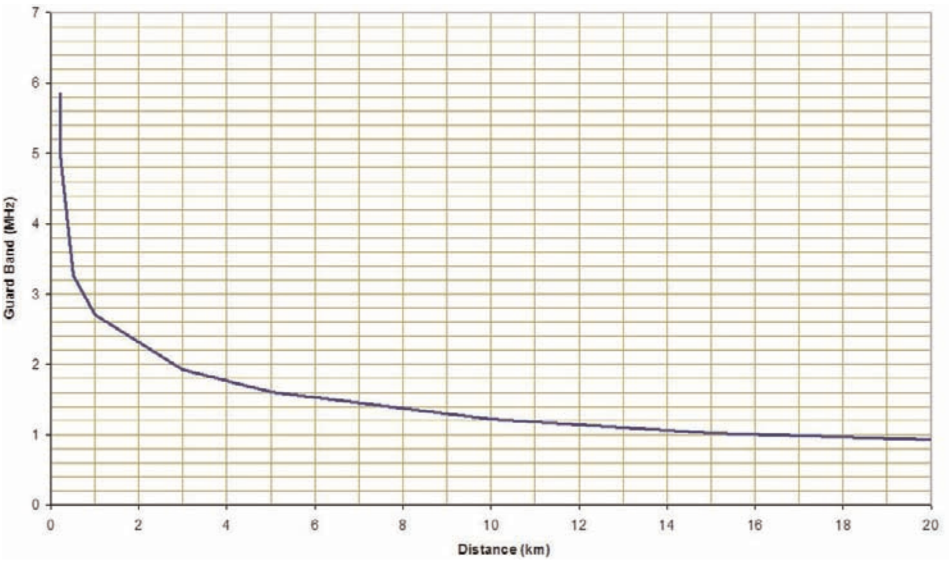

Figure 6 – Guard band vs. Distance (Boresight-to-Boresight)

The plot shows that when the transmit RF filtering is used a minimum separation of 210 metres and a guard band of 5.85 MHz meet the interference criterion in the presence of interference from a single carrier. A one-channel guard band (i.e. 5 MHz) ensures that the minimum separation requirement is 220 metres.

Methodology for MS/SS-SS Interference analysis

We have also studied the impact of interference between subscriber stations. A Monte Carlo simulator was developed to model interference between subscriber stations. The simulator aggregates emissions from randomly located interferers at a randomly located victim receiver. Results are presented in the form of 'percentage of locations for which a given level of C/(N+I) is exceeded'. Simulations were created for cases where the base stations are co-located and where they are separated.

Example – Interference from TDD Mobile WiMAX SS into FDD Proprietary WLL SS

The following figure illustrates an example set of SS locations considered in the first scenario where the victim and interfering link BSs are assumed to be co located.

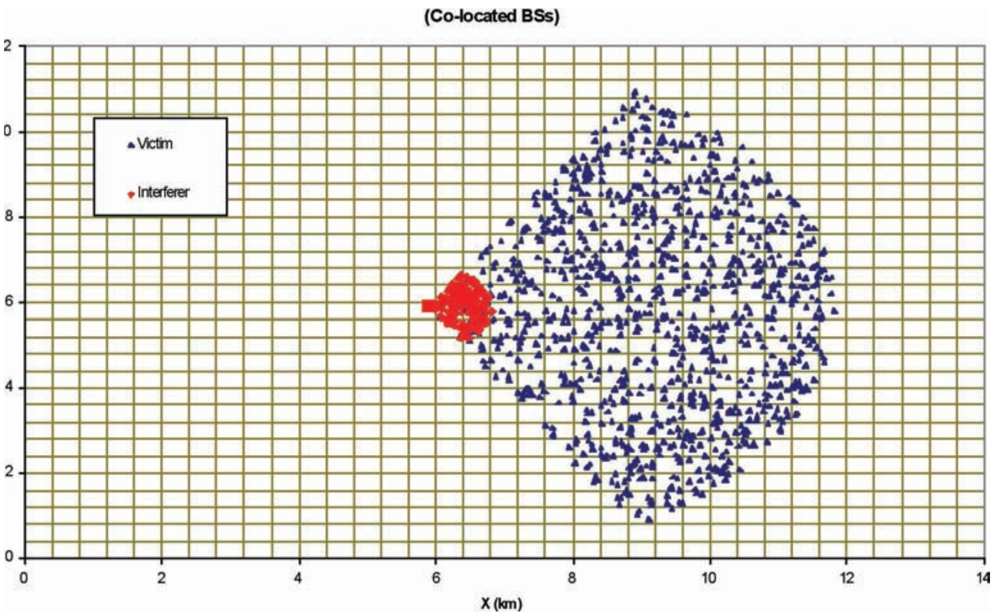

Figure 7 – Sample SS locations (co-located BSs)

In each trial, interference is aggregated from two interferers operating in first two adjacent channels (i.e. interference contributions from further channels are assumed to be negligible). It is assumed that interferers are equally likely to be indoors or outdoors while the victim SS is outdoors. The following plots show the C/N, C/(N+I) variations together with the victim receiver target C/(N+I).

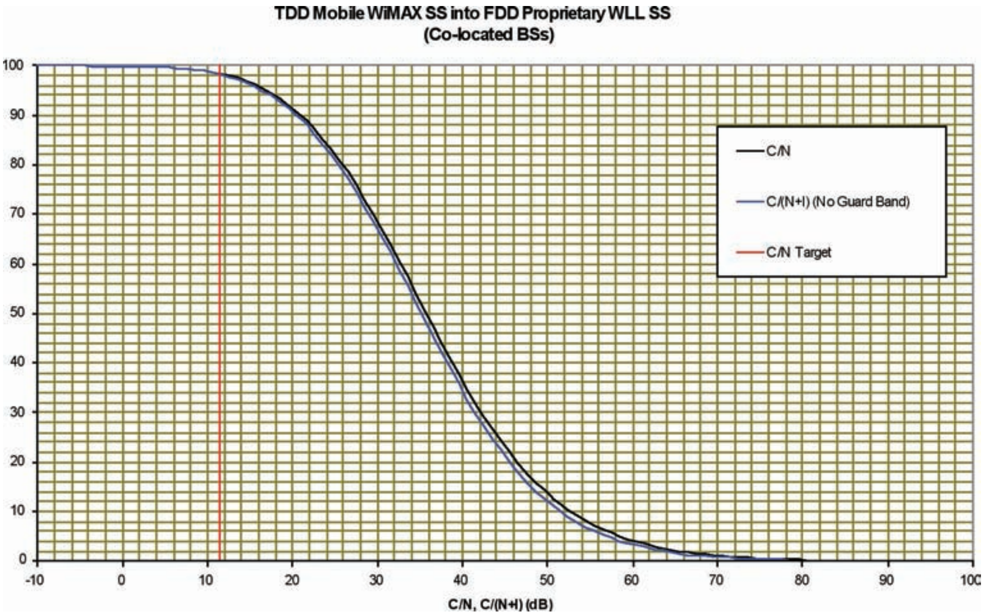

Figure 8 - C/(N+I) (Co-located BSs)

Detailed results suggest that the target C/(N+I) is exceeded at 98.44% of locations when there is no interferer and 98.29% of locations when two interferers operate in adjacent bands with no guard band. Therefore, the percentage of receivers affected by interference is 0.15%. It should be noted that when there is no guard band present, the NFD levels are 23 dB and 53.6 dB for the first and second interfering adjacent channels, respectively.

When the same analysis is carried out for separated interferer and victim link base stations the results are very similar.

Conclusions of the study

The analysis of adjacent band interference between base stations of systems using TDD and FDD has shown that the co-existence in the same geographic area requires the use of additional front-end RF filtering as well as substantial guard bands between the FDD and TDD systems.

FDD System	Guard Band	TDD System	Guard Band	FDD System

Figure 9 – Guard Bands between FDD and TDD systems

When there is a boresight-to-boresight alignment between the victim and interfering antennas separation distances can be in the order of kilometres (for a guard band of 5 MHz) unless front-end RF filters are used to reduce separation distances to few hundred metres for the same guard band. In addition, these measures also make same tower operation possible.

The analysis of adjacent band interference between subscriber stations of systems using TDD and FDD has shown that the co-existence requirements are not nearly as stringent as those calculated for base stations. In most scenarios, potential receiver locations affected by adjacent band interference remain below 0.5% with no guard band between the victim and interfering subscriber terminals.

Utilising the Guard Band

As shown in Figure 9 above, having adequate guard bands between FDD and TDD systems is a must in order to control interferences between the systems. However, wireless spectrum is a precious commodity and wasting spectrum should be avoided if at all possible.

FDD System	HFDD System	TDD System	HFDD System	FDD System

Figure 10 – Hybrid FDD deployment in the guard bands

Airspan's HiperMAX base station family addresses and solves this issue by providing a Hybrid FDD (HFDD) solution, which can be deployed in the guard bands, as shown in Figure 10.

HiperMAX HFDD solution co-exists with both the TDD and the FDD systems that operate in either side of it. This is achieved by synchronising its UL and DL transmissions with the TDD system. Since it uses separate channels for UL and DL transmissions in the same way as an FDD system, interference with other co-located FDD systems are also eliminated.

For more information about the HiperMAX base stations please visit Airspan's web site (www.airspan.com).

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Summary

Over the past decade millions of lines of wireless access systems using the FDD duplexing method have been deployed around the world. With the imminent arrival of the TDD based Mobile WiMAX systems it is more important than ever before to understand the co-existence issues between FDD and TDD systems.

To this end Airspan has undertaken an in-depth study to fully understand the co-existence issues between TDD based Mobile WiMAX systems and FDD based Fixed WiMAX and proprietary systems. The knowledge gained from the study has complemented years of experience gained from deploying FDD and TDD systems around the world and has enabled Airspan to pinpoint and solve such co-existence issues in its customers' networks.

Airspan's HiperMAX base station family offers a solution to the 'wasted' guard band spectrum by implementing a Hybrid FDD solution that utilises the guard bands between the TDD and FDD systems, thus ensuring optimum utilisation of this precious resource.

References:

1 ETSI Technical Report ETSI TR 101 854 [2]

2 ETSI EN 301 021 V1.6.1: Fixed Radio Systems; Point-to-multipoint Equipment; Time Division Multiple Access; Point-to-multipoint Digital Radio Systems in Frequency Bands in the Range 3 – 11 GHz

3 ETSI TR 101 854 V1.3.1: Fixed Radio Systems; Point-to-point Equipment; Derivation of Receiver Interference Parameters Useful for Planning Fixed Service Point-to-point Systems Operating Different Equipment Classes and/or Capacities

Airspan