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Title	Coexistence Scenarios for FDD-FDD, TDD-TDD and FDD-TDD Systems
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Re:	Call for contributions on coexistence, posted on 802.16 web site April 1999. Specifically, this contribution addresses the request for input on “the means by which TDD/FDD coexistence will be specified”
Abstract	Following the group consensus at the May meeting in Boulder to consider frequency and distance separation to coordinate systems, this contribution quantitatively examines the use of these parameters in the coordination of FDD-FDD systems, TDD-TDD systems, and FDD-TDD systems. The analysis methodology follows the framework for coexistence analysis, presented in 80216cc-99/02. It is shown that the most difficult cases to mitigate arise when at least one of the systems uses TDD. Hub-to-hub interference concerns dominate in these cases. The conclusion is that a harmonized up/down band plan and the use of FDD systems is highly desirable.
Purpose	It is proposed that 802.16 consider development of harmonized FDD up/down band plans for various allocations available. Further, it is proposed that FDD be adopted for the PHY layer of the 802.16 interoperability standard.
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Coexistence Scenarios for FDD-FDD, TDD-TDD and FDD-TDD Systems

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Introduction

This contribution is a response to the April 1999 call for contributions on “the means by which TDD/FDD coexistence will be specified”. The consensus from the May meeting of 802.16 was to consider frequency and spatial separation parameters in coordination of systems. This contribution provides rough quantitative estimates of the required separation distances for successful coordination between FDD and FDD BWA systems, TDD and TDD BWA systems, and FDD and TDD BWA systems. The intent is not to provide the definitive separation guidelines at this point. It is to demonstrate the need for a harmonized FDD band plan to mitigate interference, and to highlight the coexistence advantages of FDD for BWA systems, so as to encourage 802.16 to adopt FDD for the PHY layer of the interoperability standard.

This analysis makes use of the general framework for coexistence analysis presented in contribution 802.16cc-99/02.

Hardware Parameters

We adopt a received power spectral density of –144 dBW/MHz as our criterion of tolerable interference. As shown in 802.16cc-99/02, this results in a 1 dB degradation of a typical link budget.

Some examples of relevant typical hardware parameters may be taken from a Radio Advisory Board of Canada document on cross-border LMDS/LMCS coordination.[1]

Hub transmitted power spectral density: -28 dBW/MHz (18 dBm spread over 40 MHz)

Hub antenna gain: 18 dBi (90 degree sector)

Thus, hub EIRP spectral density co-channel is –10 dBW/MHz.

Subscriber transmitted power spectral density: -22 dBW/MHz (18 dBm spread over 10 MHz)

Subscriber antenna gain: 36 dBi (2 degree beam)

Thus, subscriber EIRP spectral density co-channel is 14 dBW/MHz. In cases where a subscriber station transmits into clear sky, an upstream power control turn-down can be expected. A typical rain fade margin in ITU rain region K for a 4 km cell is about 20 dB, however, power is usually not controlled right down to threshold; therefore, the turn down will be assumed to be 15 dB.

For out-of-channel interference analysis, we need typical parameters for out-of-channel emissions of a BWA transmitter. A useful guideline is the ETSI type approval specification EN 301 213-2. This specifies out-of-channel emissions more than 2 channels away must be less than –30 dBm per 100 kHz at millimetric frequencies. Typical transmitters meet this specification with some margin, so we will assume typical emissions of –40 dBm/100 kHz or –60 dBW/MHz. This results in out-

[1] See draft on RABC website at: http://www.rabc.ottawa.on.ca/english/Files/x%5Fbordr4%2Edoc

of-channel EIRP power spectral densities of –42 dBW/MHz for a hub and –24 dBW/MHz for a subscriber station.

In some cases, interference scenarios involve radiation to or from the sidelobe of an antenna. Guidelines for the typical sidelobe suppression of antennas can be found in the ETSI type approval standard EN 301 215-2. For sectoral-coverage hub antennas, minimum sidelobe suppression varies from 12 to 35 dB, depending on angle. We will take 30 dB as a typical suppression to use for calculation. For directional subscriber antennas, EN 301 215-2 specifies minimum suppression which varies from 20 to 40 degrees, depending on angle. We will take 35 dB as the typical suppression to use for calculation.

Calculation Method

The received interference power spectral density is given by:

PSDr [dBW/MHz] = EIRP [dBW/MHz] + Gr [dBi]– FSL [dB]

where PSDr is received power spectral density, EIRP is transmitted power spectral density relative to isotropic, Gr is receiver antenna gain over isotropic, and FSL is free space loss. In cases with rain in the interference path, EIRP is decreased by a rain fade margin of 20 dB. In cases where radiation picked up by a sidelobe is mechanism of interference, Gr is reduced by the sidelobe suppression of the receive antenna.

Free space loss at 28 GHz as a function of range, ignoring gaseous losses, is given by:

FSL[dB] = 121.4 +20log(R [km])

The transmitted power spectral density EIRP is given by:

EIRP [dBW/MHz] = PSDt [dBW/MHz] + Gt [dBi]

where PSDt is the transmitted power spectral density (co-channel to the victim receiver) supplied to the transmit antenna and Gt is the transmit antenna gain relative to isotropic. When interference is radiated by a sidelobe, Gt is decreased by the sidelobe suppression of the transmitting antenna. In cases where a subscriber antenna transmits into clear sky, EIRP is decreased by a power control turn down of 15.

Since we are generally calculating the range at which PSDr is our threshold of –144 dBW/MHz, we rearrange the first equation to calculate FSL and then use the second equation to calculate R.

FSL [dB] = 144 + EIRP + Gr

R [km] = 10**((FSL-121.4)/20)

Interference Scenarios

Contribution 802.16cc-99/02 presented a simplified general model for interference cases where the victim receiver is a hub. It is reproduced below as Figure 1.

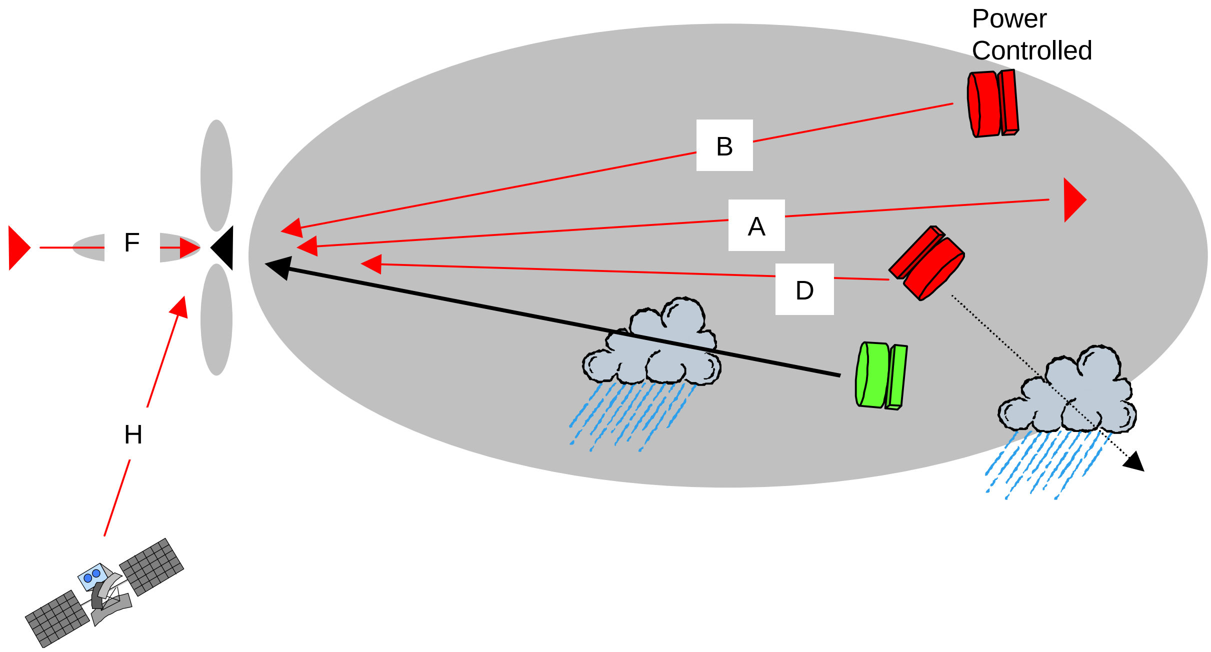

Figure 1: Simplified Model for Interference to a BWA Hub

The victim hub station is shown in black along with its radiation pattern in grey. The hub supplying the desired signal is shown in green and interferers in red.

Case H involves interference from a satellite and can be eliminated from consideration in this contribution, which deals only with BWA-BWA interference.

Case D involves interference radiated from the sidelobe of a subscriber antenna. If the subscriber station looks into rain, it may transmit at full power. However, note that sidelobe suppression of narrow-beam subscriber antennas is quite high. It needs to be so, otherwise Case D would become a significant source of intra-system interference in a multi-cell LMDS system in which the same channel is re-used in back-to-back sectors of adjacent cells. Thus, we can conclude that Case D will not be a dominant source of interference, even when co-channel to the victim hub's desired signal, as long as the interferer is beyond the nominal cell radius of the victim. The exception would be sidelobe radiation from a higher-powered point-to-point system, however, this contribution only considers BWA-BWA interference.

Removing Cases H and D, we can simplify the cases of concern where the victim is a hub receiver to those of Figure 2.

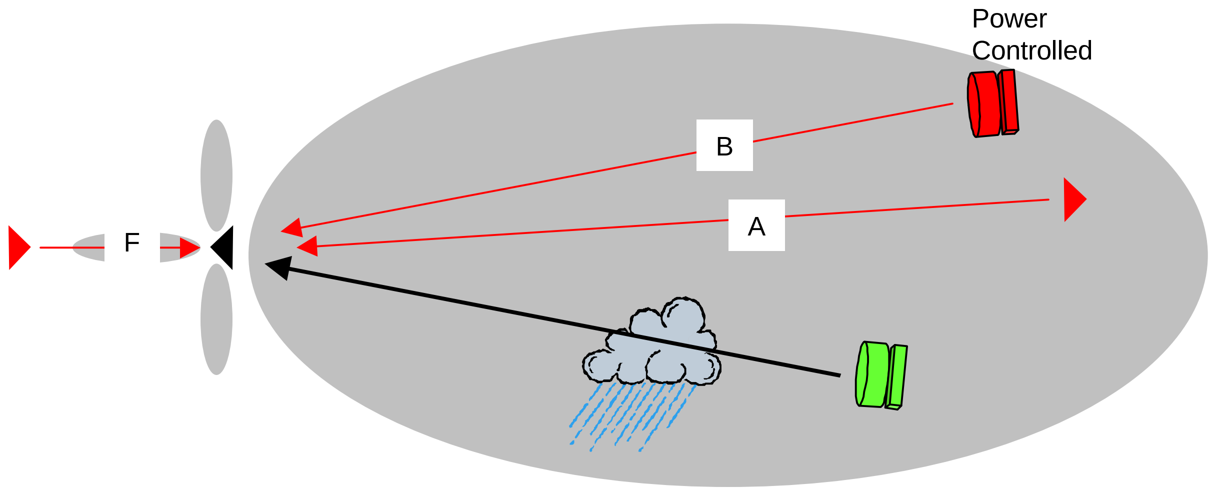

Figure 2: Further Simplified Model of BWA-BWA Interference to a Hub

Similarly, Figure 3 is the model of interference to a BWA subscriber station, reproduced from 802.16cc-99/02.

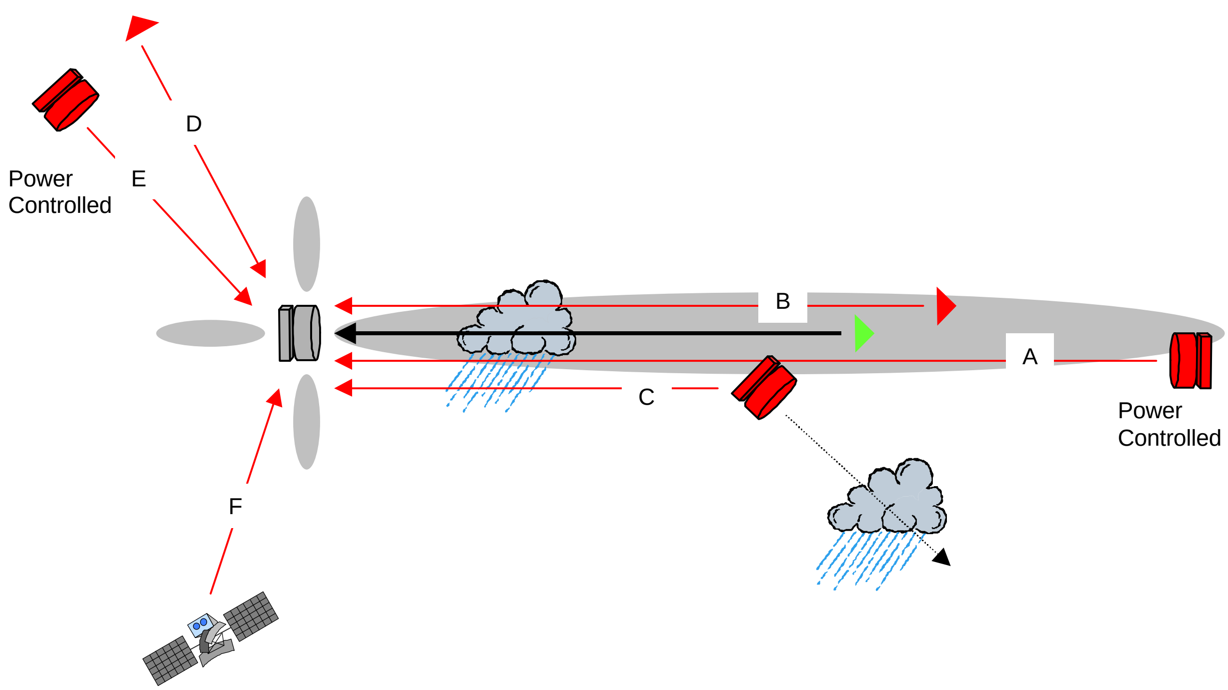

Figure 3: Interference to a BWA Subscriber Station

Following the above reasoning, we eliminate Cases F and D from further consideration here. Case F is not caused by a BWA system. Case D is no worse than the intra-system interference case with frequency re-use. Also, Cases C and E are equivalent, as they both involve subscriber-to-subscriber interference with one antenna's main lobe oriented towards the other's sidelobe. We therefore eliminate Case C. This leaves a further simplified model for BWA-BWA interference to a subscriber station in Figure 4.

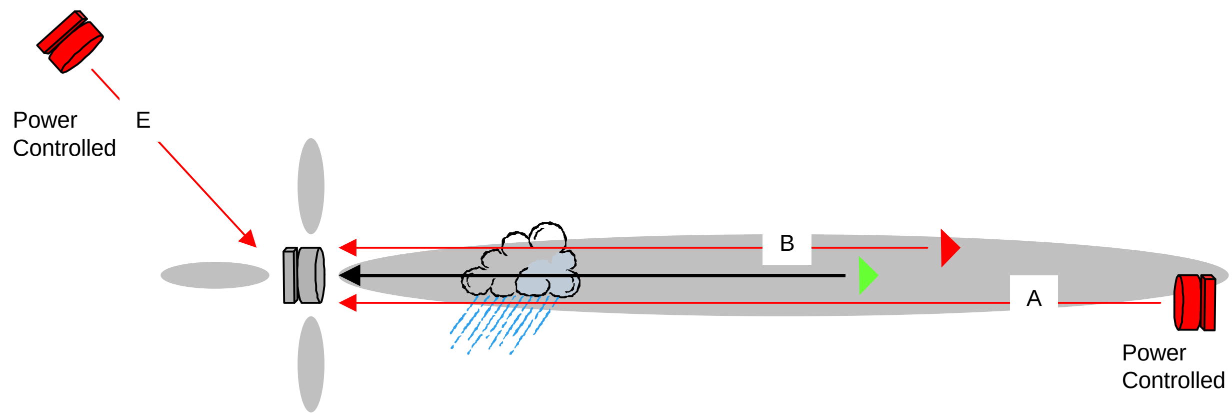

Figure 4: Further Simplified Model of BWA-BWA Interference to a Subscriber Station

FDD-FDD Interference

Co-channel Cross-boundary

When both systems use FDD according to the same band plan, such that there is a wide separation in up/down frequencies, the only scenarios are Case B of Figure 2 and Case B of Figure 4. These two cases have similar probability of occurrence, as they both involve the main lobe of a subscriber pattern oriented towards the main lobe of a hub sectoral pattern.

In Case B of Figure 2, the required free space loss for co-channel co-polar reuse using the hardware parameters above works out to 161 dB. This gives a required separation distance of 95 km for a single co-channel co-polar interferer. However, the earth's horizon is only about 35 km for 100 m hub elevation, and 25 km for 50 m subscriber elevation, so in practice, a separation distance of about 60 km is usually sufficient.

Case B of Figure 4 is similar, except the transmitted power spectral density is lower for the hub and there is no power control. There is, however, a rain fade in the path. In this case, we arrive at a separation distance of 27 km.

The implication of these results is that co-channel FDD systems within about 60 km of each other may need to be carefully deployed such that subscriber stations of one system do not directly face co-channel hubs of the other system. The fraction of problematic subscribers whose main lobes are seen by hubs of the other system 60 km away would only be about 0.5% per victim hub.

We do not consider cross-polarization isolation of the two systems as a generally available means of interference mitigation in point-to-multipoint systems for several reasons. First, many operators will prefer to deploy vertical polarization for all upstreams and all downstreams in order to achieve maximum range (horizontally polarized millimetre-wave radiation is more attenuated by rain than vertical). Second, some operators will choose to deploy alternating sectors with alternating horizontal and vertical polarized downstreams and upstreams in order to achieve a more aggressive intra-system frequency reuse pattern. This reduces the probability of interference by 50%, but does not decrease the separation distance when interference is present. Finally, since the hub radio is a shared resource, unlike point-to-point systems, it is not possible to flip polarizations of just one subscriber station and one hub radio to solve a particular interference problem; all users in that sector would have to change polarization.

Adjacent Block, Overlapping Deployment

We now consider the case where the two FDD systems are deployed in the same city in adjacent frequency blocks. In this case, the interferer's EIRP falling co-channel to the victim hub is greatly reduced, which results in much less required separation for both Case B of Figure 2 and Case B of Figure 4. In the worst case, which is Case B of Figure 2, the separation distance is 1.2 km. This is a reasonable result, as the interference situation is the same as the case of intra-system use of multiple carriers in the same sector. The implication is that for FDD systems deployed in a city in adjacent frequency blocks, there is generally no issue of subscriber stations of system A having to coordinate with hubs of system B. The only situation of concern would be a subscriber station of system A whose beam points at its own hub which is more distant than a hub of system B which is colinear with the subscriber station of system A and the hub of system A.

TDD-TDD Interference

Following the consensus of 802.16 at the May 1999 meeting to consider only frequency and spatial system separation, we assume here that the two TDD systems are not synchronized with respect to upstream and downstream transmissions.

Co-channel Cross-boundary

In addition to the cases analyzed for FDD-FDD, which are still present, there are additional interference mechanisms. In Figure 2, Case A becomes very significant.

Case A (hub-to-hub interference) is of great concern, as hub antennas typically cover a 90 degree sector. The probability of two hubs being in each other's main beams is very high. In addition, hub antennas tend to be elevated and hence there is a high probability of a line of sight path between them.

Using the typical hardware parameters we have adopted, the required separation distance from a victim hub to a single interfering co-channel co-polar hub is 34 km. As it is highly probable that a victim hub will see the main beam of several co-channel interfering hubs at such a distance, the required separation distance should be increased, so as to allow margin for multiple interferers. Allowing for 4 interfering hubs increases the separation distance to a horizon-limited 70 km (each hub elevated to 100 m).

As LMDS systems typically use intensive frequency re-use, of the order of one use of each possible frequency per cell, it will be almost impossible for unsynchronized TDD operators to coordinate frequencies so as to avoid this mechanism of interference, while making efficient, i.e. full, use of their spectrum allocations.

This result also has implications for synchronized TDD systems. If interference is significant out to 70 km hub separation, then it follows that synchronized TDD systems must allow enough guard time between transmit and receive time slots so that the last bit of interference generated by a synchronized hub at the end of the transmit slot, passes all hubs within 70 km before the receive time slot begins. This guard time is 230 microseconds. In order to keep the inefficiency of this guard time to less than 10%, the transmit/receive frame must be at least 4.6 ms, which may result in latency of MAC protocols.

Considering the subscriber station as victim, Cases E and A of Figure 4 become significant. Case A involves very high antenna gain at each end, so interference is clearly an issue up to horizon-limited distance of about 50 km (each subscriber antenna elevated to 50 m). However, this is a very low probability interference scenario as the beams of each antenna are narrow. Case E is of somewhat higher probability, as only one antenna must be pointing in a particular direction. Using our assumed hardware parameters, the required co-channel separation distance is 13 km. Although this is a low probability scenario, it could be problematic in that there could be many possible victims and many possible interferers; also, the locations of subscriber stations are more difficult to track, and change more often than hubs. In any case, the hub-to-hub problem dominates.

Adjacent Block, Overlapping Deployment

Using our assumed hardware parameters for Case A of Figure 2, the hub-to-hub required separation is 850 m. In a city where there are a limited number of choices for hub locations, and cells are of the order of 4 km in radius, this criterion will be difficult to ensure.

This result also has a profound implication for TDD systems which purport to be dynamically responsive to the mix of up/down data traffic. As the above analysis shows, there is an overriding need in a multi-cell system to maintain synchronization within an entire metropolitan area; otherwise severe base-to-base interference will result including intra-system. This means that the partitioning of the frame time between upstream and downstream must be the same for all cells.

Consequently, the partitioning must be based on the average upstream versus downstream demand for the entire metropolitan area and cannot be dynamically response to instantaneous data traffic demand in any particular sector.

For Case E of Figure 4, the required subscriber-to-subscriber separation is 180 m. This would generally not be a problem, except possible co-siting of two subscriber stations on the same or adjacent rooftops.

In many cities, a large number of radio hubs, even competing systems, share the same rooftop, as suitable hub sites are limited. In the case of very close separation, Case F of Figure 2 becomes a potential concern for unsynchronized TDD. Using our assumed hardware parameters, the required separation distance is 850 cm. This is feasible, but the calculation is critically dependent on maintaining 30 dB sidelobe suppression of each antenna. This may be problematic as near-field rooftop clutter may reduce the effective sidelobe suppression achievable in practical deployments. This result is also relevant to intra-system interference in a TDD system where the sectors are unsynchronized because each radio is dynamically varying the up/down time slotting to adapt to instantaneous traffic loads.

FDD-TDD Interference

Co-channel Cross-boundary

When the TDD system operates in both sub-bands used by FDD; i.e. full use of the same authorized block of spectrum, then all interference mechanisms present for FDD-FDD and TDD-TDD are present. The hub-to-hub interference problem dominates.

The other two possible scenarios involve TDD operating in less than the full spectrum, co-channel only to the upstream FDD sub-band or only to the downstream FDD sub-band. When the TDD system is co-channel to the upstream FDD sub-band, then the FDD system suffers mainly from hub-to-hub interference, whereas the TDD system suffers mainly from Case E of Figure 4 as for TDD-TDD, wherein subscriber stations must be 13 km from each other. Overall, the hub-to-hub separation distance of 70 km dominates. When the TDD system is co-channel to the downstream FDD sub-band, then the FDD system suffers mainly from Case E of Figure 4, which requires a subscriber-to-subscriber separation of 13 km. The TDD system suffers mainly from hub-to-hub interference from the FDD system. Overall, the hub-to-hub separation distance of 27 km dominates.

We therefore conclude that hub-to-hub interference will occur in FDD-TDD co-channel coexistence. By placing the TDD system in only one sub-band used by FDD, we can control which system is the victim, but the problem is not eliminated.

Adjacent Block, Overlapping Deployment

Similar to the above reasoning, the worst-case interference will be hub-to-hub interference, which requires hub separation of at least 850 m. By operating TDD adjacent to only one FDD sub-band, we can control which system is the victim, but the problem cannot be eliminated.

Conclusions

Table 1 summarizes the dominant interference mechanisms and required separations.

Table 1: Dominant Interference Mechanisms

Cases	Required Separation Distance	Comments
FDD-FDD		
Co-channel Subscriber to Hub	60 km	Cross-boundary issue. Low probability.
TDD-TDD		
Co-channel Hub to Hub	**70 km**	**Cross-boundary issue. High probability. Synchronization requires at least 230 microsecond guard time between transmit and receive.**
Co-channel Subscriber to Hub	60 km	Cross-boundary issue. Low probability.
Adjacent-block Hub to Hub	**850 m**	**High probability for two systems covering the same city. Difficult coordination**
Adjacent-block Hub to Hub (Co-sited)	850 cm	Feasible, but careful rooftop antenna deployment necessary to ensure two co-sited systems do not interfere
FDD-TDD		Same as TDD-TDD if TDD operates co-channel or adjacent to both FDD sub-bands. For TDD co-channel or adjacent to FDD upstream sub-band, FDD is victim of interference to hub scenarios. For TDD co-channel or adjacent to FDD downstream sub-band, TDD is victim of interference to hub scenarios.

FDD with a band plan that organizes all operators into the same up and down sub-bands which are suitably separated virtually eliminates adjacent-block issues of overlapping deployment in the same city. A cross-boundary issue remains, but the probability of interference is low, such that solutions might be found on a case-by-case basis.

TDD includes the FDD interference issue, but also suffers from an intractable hub-to-hub interference problem. Synchronization of co-channel TDD systems within 70 km of each other is an absolute requirement, and the guard time between transmit and receive bursts must be at least 230 microseconds. An implication of this is that it will not be feasible for a TDD system to dynamically partition the up/down timing split based on instantaneous traffic load as that represents unsychronization of sectors; any partitioning must be done synchronously on a metropolitan-wide basis, based on average traffic experienced by all TDD operators. Unsynchronized TDD is also problematic for overlapping deployment in two adjacent frequency blocks in the same city. It will be difficult to find hub sites with the required separation distance. Co-deployment of unsynchronized TDD systems on the same rooftop is feasible, but antenna deployment must be done carefully to maintain the required antenna-to-antenna isolation.

Interference between FDD and TDD systems is as problematic as TDD-TDD systems if the TDD system uses the same sub-bands as FDD or adjacent sub-bands. If TDD is only deployed in half the band, then the FDD system is the victim if TDD is deployed co-channel or adjacent to the FDD upstream band; otherwise the TDD system is the victim.

The author urges 802.16 to consider the implications of widespread TDD deployment in LMDS bands and proposes:

- 802.16 develop up/down FDD band plans for anticipated LMDS bands; and
- 802.16 resolve to use FDD for the PHY layer of the interoperability standard

END OF DOCUMENT