IEEE P802.19
Wireless Coexistence

Simulation of WirelessMAN-UCP coexistence with 802.11y in the 3.65GHz band

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Author(s):

Name	Company	Address	Phone	email
Paul Piggin	NextWave Wireless	NextWave Wireless Unit 7 Greenways Business Park Bellinger Close Chippenham, Wiltshire SN15 1BN, UK.	44 1249 800 100	ppiggin @ nextwave.com

Abstract

This document provides analysis, description and simulation results for IEEE802.16 WirelessMAN-UCP coexistence with IEEE802.11y systems in the 3.65-3.7GHz band in the US.

1 Table of contents

2 Introduction

This document presents initial analysis and simulation results for discussion at the IEEE 802 Plenary Denver, CO. July 2008. The work analyses coexistence in the 3.65-3.7GHz band in line with FCC regulation set out in [1] and modified by [2]. Simulation results report the coexistence behavior of WirelessMAN-UCP, as described in [3] (and summarised in [4]), in the presence of 802.11y [5].

The study of coexistence in the 3.65-3.7GHz band within the 802.19 Working Group is supported by two documents: a Simulation Parameters document [4] and a Coexistence Metrics document [6]. The Simulation Parameters document provides simulation scenarios and parameters, therefore providing detailed specification for simplified comparison of simulation results from different sources. Coexistence Metrics define how simulation results are to be presented and help in the assessment of whether or not coexistence is achieved.

The remainder of this document is divided into the following sections:

- An overview of the WirelessMAN-UCP feature set and how the feature aims to achieve coexistence.
- An overview of the simulation assumptions and the expected impact of these assumptions on the simulation results.
- Simulation results – detailing *collocated* and *spatially distributed* scenarios. The *collocated* scenario offers a simplified analysis to demonstrate the behaviour of the feature for fair sharing of the medium; the *spatially distributed* scenarios builds on this to provide a thorough analysis and addresses such issues as hidden and exposed node behavior.
- Discussion of simulation results.
- Conclusions.

3 The WirelessMAN-UCP designation in 802.16

3.1 Overview

This section provides an overview of the WirelessMAN-UCP (Wireless Metropolitan Area Network - Uncoordinated Coexistence Protocol) designation in the 802.16h amendment [3] to the 802.16 standard [7]. The WirelessMAN-UCP designation is used in the 802.16h amendment as a label or handle for the purpose of identifying a feature set to solely address 802.16 coexistence in the 3.65GHz band. The 802.16h amendment under the WirelessMAN-UCP designation has extended the specification of features in the base standard [7] used to protect radar systems (often termed DFS – Dynamic Frequency Selection) to covers specification of avoiding co-channel users not protected by regulation. This is described as Dynamic Channel Selection (DCS) in the 802.16h amendment. This mechanism essentially provides a mechanism to select a clear channel, a channel without interference, for operation. Further specification provides a mechanism for co-channel coexistence for other 802.16h systems and also 802.11y. Co-existence with co-channel systems is specified under the notation UCP and provides options for frame sharing and a LBT (Listen Before Talk) mechanism, similar to that used by 802.11. This facilitates a suitable co-channel coexistence mechanism that is designed to meet the requirements laid down by the FCC for operation in the band. The implementation of the 802.11 medium access protocol and fair sharing of the medium is encompassed within the DMA (Dynamic Medium Access) algorithm described in the amendment.

In order to expedite deployment in the band, the FCC introduced the concept of *Restricted* and *Unrestricted CBPs* in June 2007 [2]. Equipment incorporating an *Unrestricted CBP* is permitted to operate over the whole 50MHz of the band. Equipment incorporating a *Restricted CBP* may operate in the lower 25MHz of the band only. This modification added the following clause to the original CBP definition:

> *"Contention-based protocols shall fall into one of two categories:*
> *(1) An unrestricted contention-based protocol is one which can avoid co-frequency interference with devices using all other types of contention-based protocols.*
> *(2) A restricted contention-based protocol is one that does not qualify as unrestricted."*

WirelessMAN-UCP is designed to meet the requirements of an *Unrestricted CBP*.

The structure of the WirelessMAN-UCP designation and the features supporting the designation within the 802.16h amendment [3] are shown in Figure 1 below.

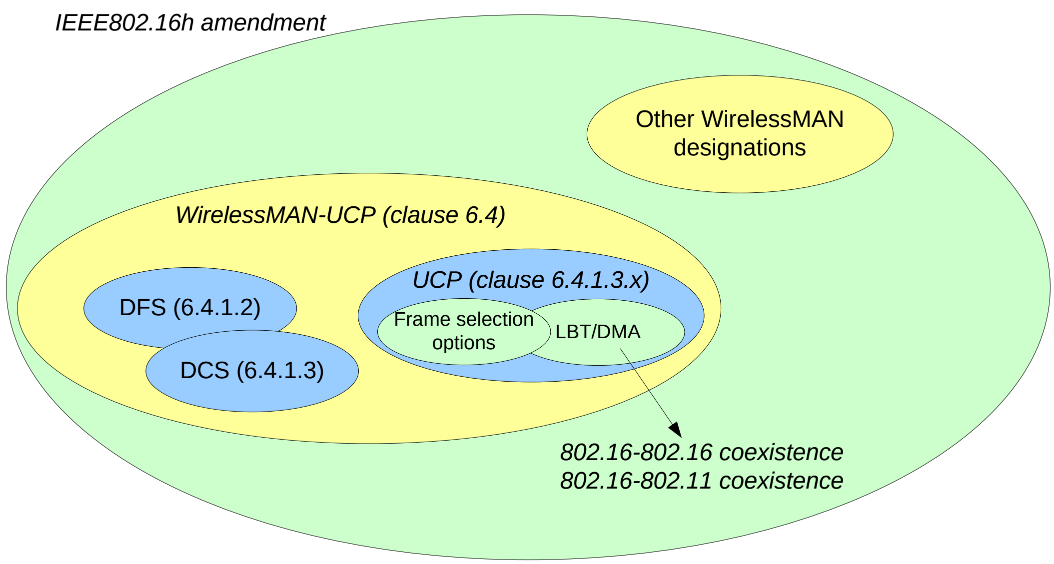

Figure 1 A diagrammatic representation of the WirelessMAN-UCP designation's structure in the 802.16h amendment [3]. The focus of this document details 802.16-802.16 and 802.16-802.11 coexistence using *DMA* (6.4.1.3.4.1) and the *DMA Discovery Protocol* (6.4.1.3.4.2).

3.2 Details of UCP and the DMA algorithm

A medium sensing scheme is employed by 802.16, in a similar way to that of 802.11, to determine when the medium is quiet and can be claimed for use. The channel sensing interval is placed at the end of an 802.16 frame thus utilizing the RTG (Receive Transition Gap). Since the *Mobile WiMAX System Profile* [8] dimensions the number of OFDM symbols per 5ms frame for macro cellular deployments then for LE band, where cell sizes are likely to be smaller, the RTG (the Receive Transition Gap) at the end of the frame offers an opportunity for other co-channel systems to claim the medium. Given the WiMAX Forum numerology then there is an opportunity to share the medium every 5ms. Furthermore, OFDM symbols can be removed from the uplink subframe to accommodate a longer measurement period. The mechanism for reclaiming the medium acts as the interface between the synchronous behavior of 802.16 systems and the asynchronous behavior of 802.11.

The unique requirements of the 3.65GHz band means that since an operator is required to register the location of all fixed stations then it is possible for operators to determine, to a certain accuracy, how many systems are operational in a given area. This knowledge allows 802.16 to set a utilization goal (for example 33% if there is one 802.16 system and two 802.11 systems in the area) to ensure fair sharing of the medium for the deployed systems. An assessment of how much of the 33% is successfully being claimed can be used to modify a Dynamic Medium Acquisition (DMA) algorithm. The DMA algorithm sets intervals when an 802.16 system can begin monitoring and subsequently claim the medium. This interval is based on the past utilization and the *Utilization Goal*. As the *Utilization Goal* is achieved the opportunities to claim the medium are reduced. 802.16 claims unused frames whenever possible as a means of maximizing the retention of frames for synchronization. Figure 2 presents the usage of the DMA algorithm.

To reduce the uncertainty between 802.11 and 802.16 in claiming the medium, 802.16 claims the medium over an observation period and transmits 802.11 control frames. An 802.11 CTS (Clear-To-Send), specifically a *CTS-to-self*, signal (called an FRS (Frame Reservation Signal)) is transmitted by 802.16 to ensure that the TTG (Transmit Transition Gap), RTG (Receive Transition Gap), and frame transmissions are protected from interference by 802.11. CTS transmissions from 802.11 are also detected and obeyed by 802.16 systems. In this way the Frame Error Rate for both systems are much reduced. Details of FRS transmissions are shown in Figure 3 and Figure 4 for the downlink and uplink respectively.

Figure 2 shows an example frame allocation where priori knowledge of which frames are allocated to which 802.16 systems is assumed. The example also shows how 802.16 systems surrender frames due to presence of other systems and how the medium can be subsequently reclaimed by 802.16. The *DMA Region* is shown in details for *System 2* in Figure 2 and appears at the end of the 802.16 frame. The dynamic boundary is termed the *FRSTn* (Frame Reservation Start Time). This boundary depends on the current channel utilization for a given 802.16 system and defines a logical time when a system can possibly claim the medium for use in the following frame. The values are updated based on the current and past utilization of the channel. *MAXFRST* is the absolute leftmost extreme of the *DMA Region* and is the maximum value (earliest time) of *FRST*. *MINFRST* is the minimum value of *FRST*. *MINFRST* is calculated from the end of the frame and comprises the minimum time for 802.16 to determine the medium is clear and therefore claim the medium.

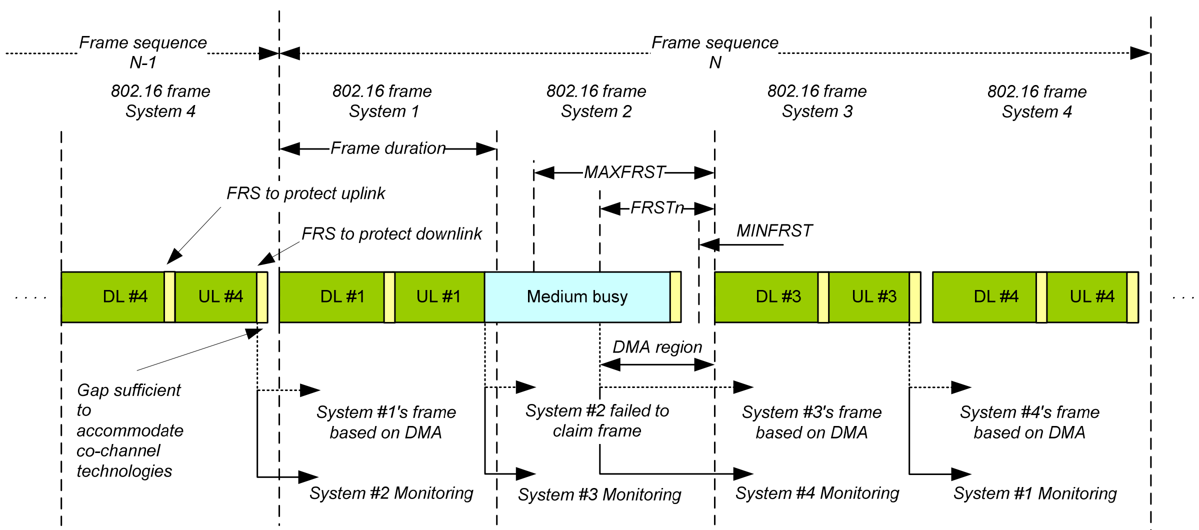

Figure 2 An illustration of the operation of the DMA algorithm and sharing with 802.11. The example shows 4 802.16 systems sharing the medium. *System 2* is unable to use its frame allocation due to a busy medium.

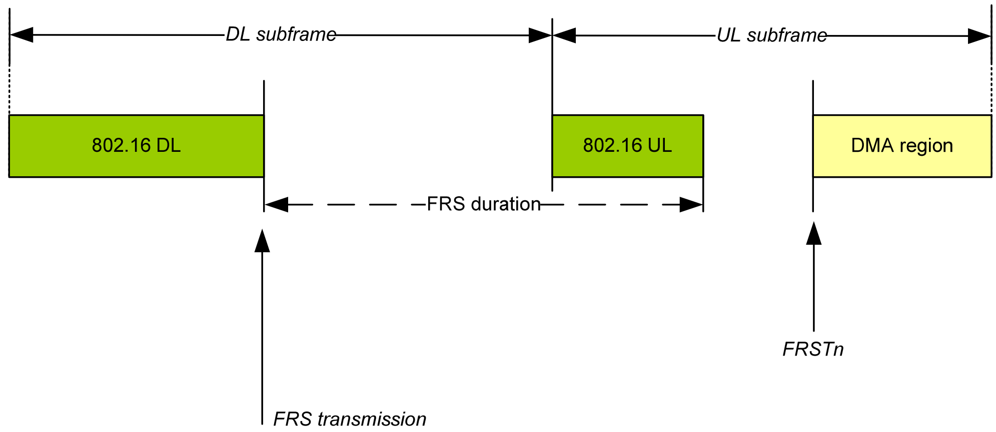

Figure 3 Details of FRS transmission in the downlink.

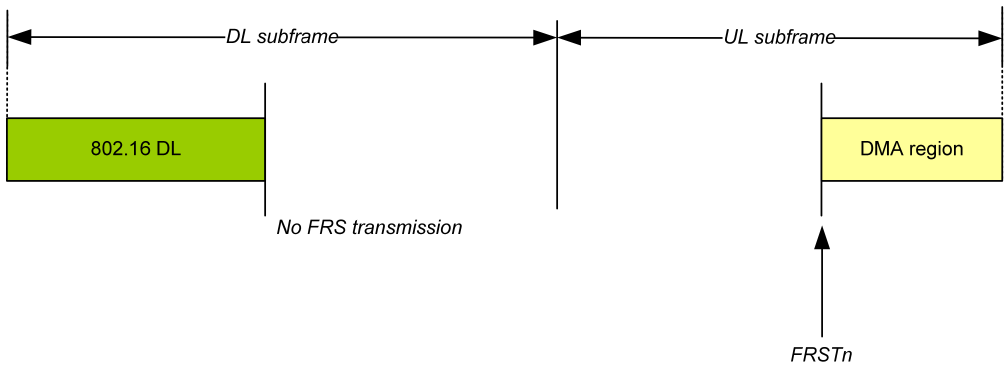

Figure 4 Details of FRS transmission in the uplink.

The DMA algorithm in extended in subclause 6.4.1.3.4.2 [3] providing a *discovery protocol* for coexistence with 802.16-based systems in addition to coexistence with asynchronous non-802.16 systems. DMA as a discovery protocol for coexistence with 802.16-based systems uses the existing DMA algorithm described in [3] but may use different default configuration parameters. In addition the BS uses the 802.11 Medium Acquisition (MA) algorithm [9] as a means of accessing the medium, and as a means of providing fair sharing of 802.16 frames between 802.16 and 802.11 Systems. In a similar way to that described previously the MA procedure is triggered once *FRSTn* has been exceeded in a given frame. An example of this operation is provided in Figure 5.

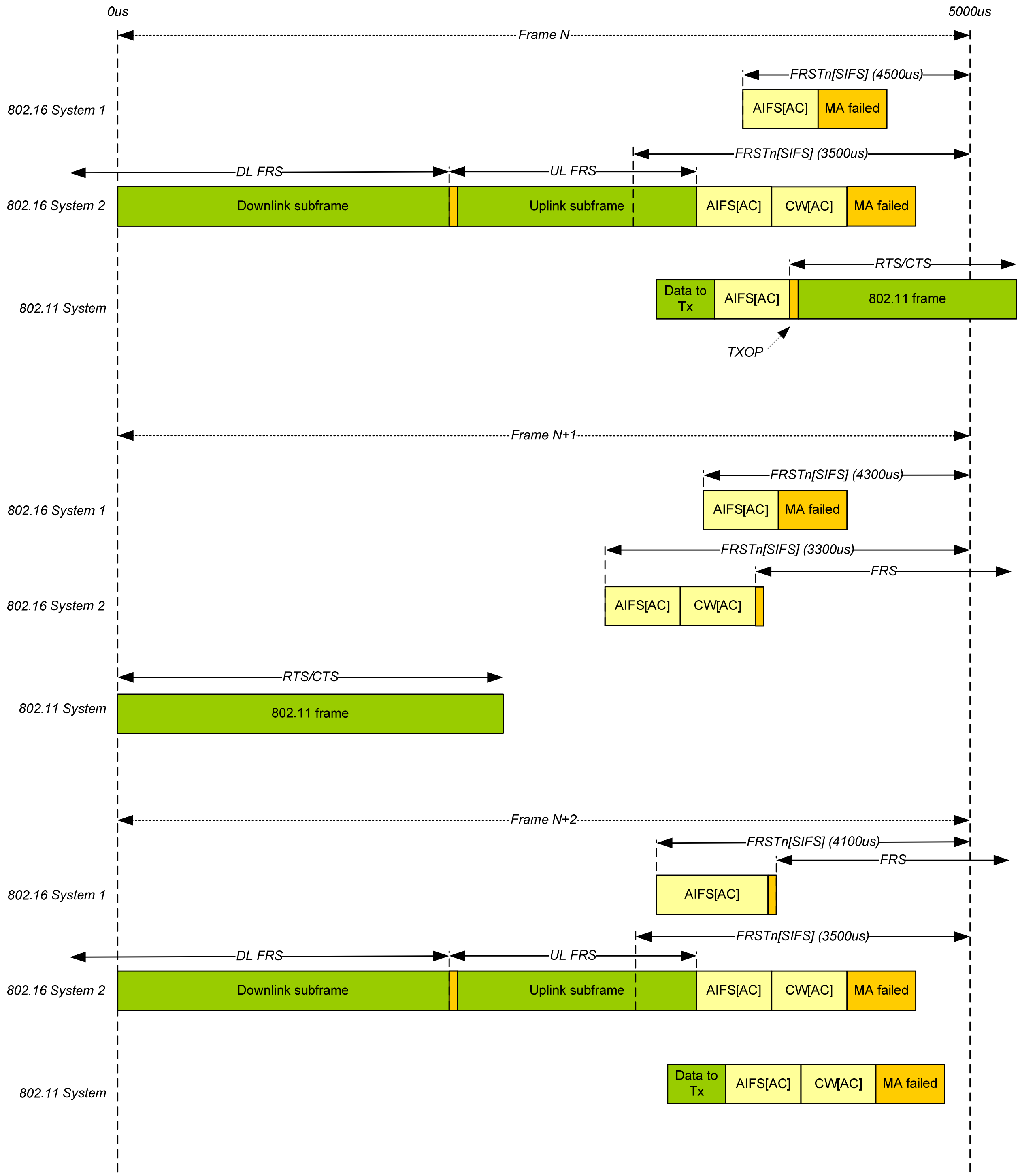

Figure 5 A detailed example of two 802.16 and one 802.11 systems sharing the medium over three frame intervals. 802.16 System 2 has Frame *N*, 802.11 uses Frame *N*+1, and 802.16 System 2 claims Frame *N*+2. 802.16 System 1 claims Frame *N*+3.

4 Simulation assumptions

A framework of simulation parameters relating to this study are described in [4]. There are a number of simulation assumptions used to generate the simulation results which are not defined in this document. These assumptions are listed below:

- Perfect RTS/CTS/FRS transmission and reception. Loss of control frames is not modelled.
- The RTS/CTS/FRS frames are transmitted at powers as indicated. The powers are either at the maximum EIRP (23dBm) or typical EIRP (17dBm) [4].
- DCS is not implemented since all simulations are assumed co-channel.
- *Utilization Goal* is set to represent the number of active systems.
- 802.11 uses Best Effort Access Category – aligned with the traffic model.
- DMA uses Voice Only Access Category.
- Downlink symbols: 28; Uplink symbols: 17; Total number of symbols per frame: 45.
- TTG = 50µs. Therefore *MINFRST* needs to be accommodated in 315µs.

$$MINFRST = AIFS[AC] + CW[AC]*aSlotTime + T_{FRAME\_END\_OFFSET} \quad [1]$$

Parameter	**Values**
AC (Access Category)	AC_VO (Voice Only)
Channel bandwidth	5MHz
Cell radius	1.4km
SIFS	64µs
AIFSN[*AC*]	2
aSlotTime	32µs
$AIFS[AC] = SIFS + AIFSN[AC].aSlotTime$	128µs
$CW_{min}[AC]$	3
$T_{FRAME\_END\_OFFSET}$	50µs
MINFRST	**274µs**

Figure 6 Details of parameters used for calculation of *MINFRST* where DMA is used as a Discovery Protocol.

It should be noted that *MINFRST* needs to be set accordingly since if an 802.16 single system is operating 274µs is required to transmit on seceding frames.

4.1 Worst case analysis

The analysis required by the simulation parameters can be regarded as a worse case analysis. This is for the following reasons:

- The specification of base station antennas requires no antenna down tilt.
- Large standard deviations values are applied in the calculation of shadow margin. This results in significant variability in pathloss calculation for subscribers and uncertainty at cell edges and for adjacent and overlapping cells.
- Using high traffic loading results in a worst case analysis.
- The assumption that subscriber devices are in a building and the resulting application of 12dB of Building Penetration Loss means a higher FER for the uplink case. Is this realistic for all cases?
- For a mobile scenario (scenario C in [4]) the disparity between base and subscriber transmission power means a higher uplink FER. This is a regulatory requirement.

5 Simulation results

5.1 Introduction

The simulation results presented in this section are divided into two distinct areas, namely *collocated* and *spatially distributed* cases. The following sections describe these scenarios and present simulation results accordingly.

5.2 Collocated cases

The *collocated case* provides a 'proof-of-concept' simulation configuration; and provides a time domain assessment of coexistence capabilities. In this configuration many of the variables of a spatially distribution simulation are fixed or removed and so within a well controlled environment provides the ability to analyze the sensitivity of a number of elements and external influences to the DMA scheme. Figure 7 presents an illustration of the collocated simulation configuration. Important simulation values, other than those presented in [4], and unless otherwise stated, are:

- Number of subscribers per base station is one.
- Pathloss between devices is an arbitrary 1dB.
- *Cell extent* is an arbitrary 1m.
- Traffic load increases from 120kbps to 24Mbps.
- Fixed traffic load is at 9.6Mbps for both 802.16 and 802.11.
- In the limit 802.16 supports 4.3Mbps downlink and 1.9Mbps uplink, 802.11 supports 3.1Mbps downlink and 3.1Mbps uplink.

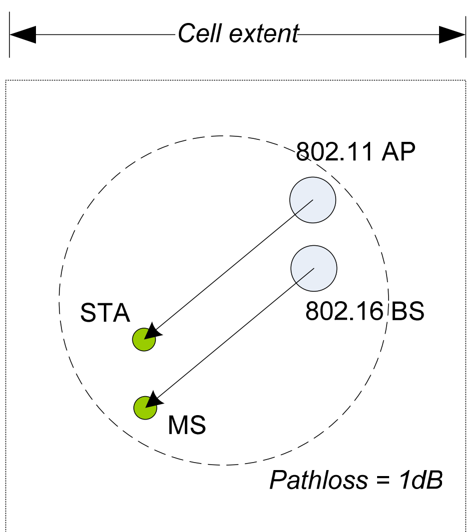

Figure 7 *Collocated* simulation configuration.

Simulation results are presented to demonstrate the fair sharing between 802.16h and 802.11y Systems. Fair sharing is demonstrated by using *Channel Occupancy*. *Channel Occupancy* is defined as when 802.16 claims a frame, and when 802.11 is transmitting at a given instant.

5.2.1 802.16 and 802.11 traffic load increasing

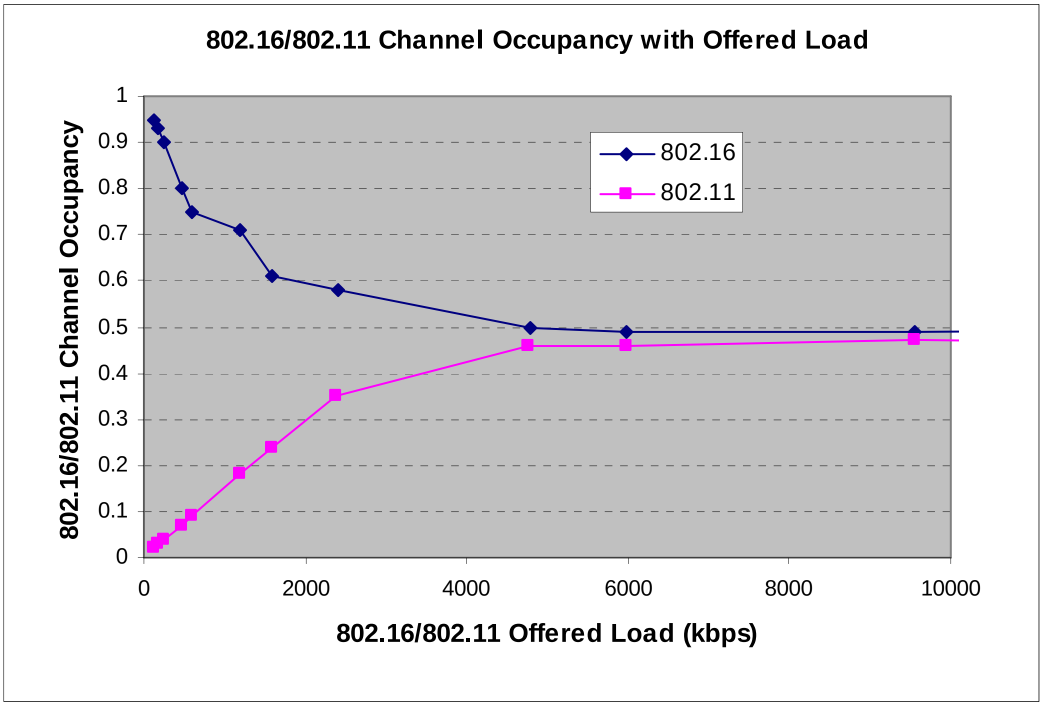

Figure 8 802.16 and 802.11 traffic levels increase from 120kbps to 24Mbps. 802.16 supports up to 4.3Mbps downlink and 1.9Mbps uplink. 802.11 supports up to 3.1Mbps downlink and 3.1Mbps uplink.

5.2.2 802.16 traffic load increasing with 802.11 traffic load fixed

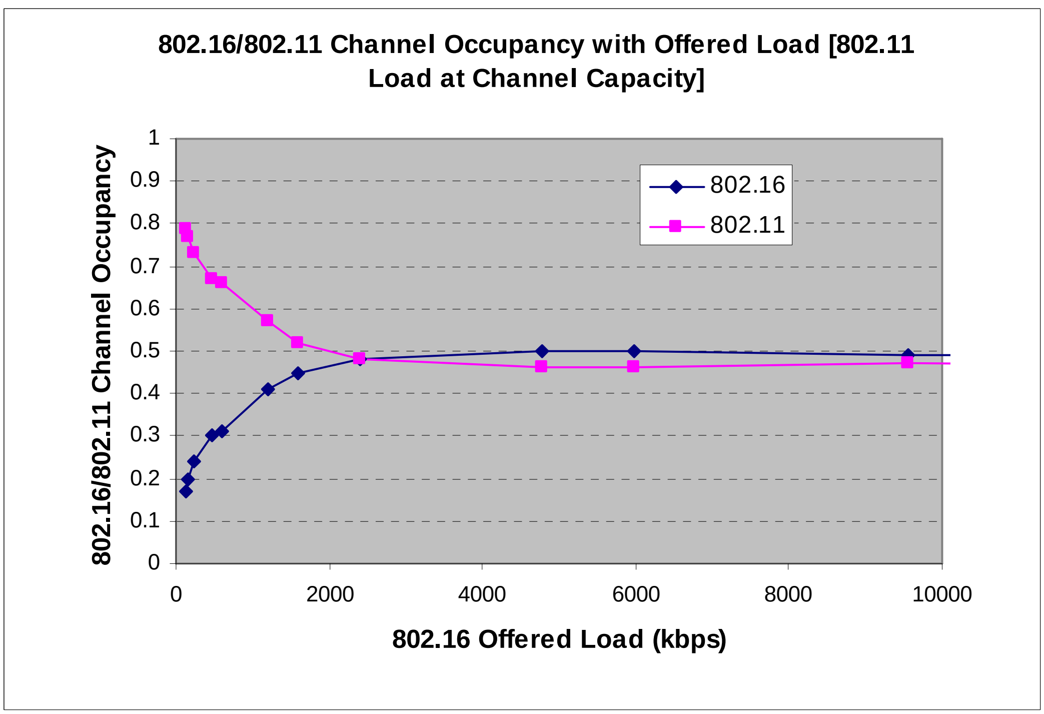

Figure 9 802.16 traffic levels increase from 120kbps to 24Mbps. 802.11 has an offered load of 9.6Mbps. 802.16 supports up to 4.3Mbps downlink and 1.9Mbps uplink. 802.11 traffic levels decrease from 5.6Mbps to 3.1Mbps downlink and uplink.

5.2.3 802.11 traffic load increasing with 802.16 traffic load fixed

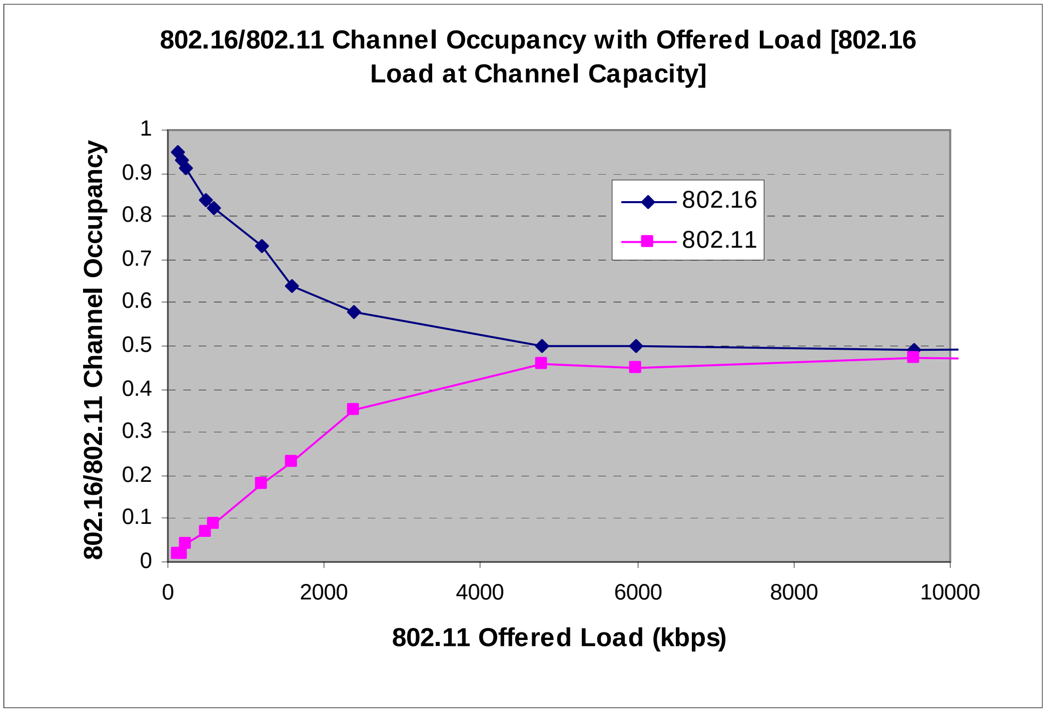

Figure 10 802.11 traffic levels increase from 120kbps to 24Mbps. 802.16 has an offered load of 9.6Mbps. 802.11 supports up to 3.1Mbps downlink and uplink. 802.16 traffic levels decrease from 8.5Mbps to 4.3Mbps downlink, and 3.8Mbps to 1.9Mbps uplink.

5.3 Spatial distributed cases

Spatially distributed cases extend the limited configuration of the *collocated case*. This case allows the exploration of the behavior of the DMA solution to cases where a more realistic case of a distributed network is considered. The simulation consideration also allows the investigation of FRS transmissions and the impact of hidden and exposed nodes for both 802.16 and 802.11. Important simulation values, other than those presented in [4], and unless otherwise stated, are:

- Number of subscribers per base station is four.
- *Cell extent* is dependent on the technology and configuration [4].
- *Simulation extent* is 30km.
- Offered traffic load is 9.6Mbps per link.
- Using *Scenario C* for the *Mobile* case as indicated [4].

Figure 11 presents an illustration of the spatially distributed simulation configuration representing one 802.16 System and one 802.11 System.

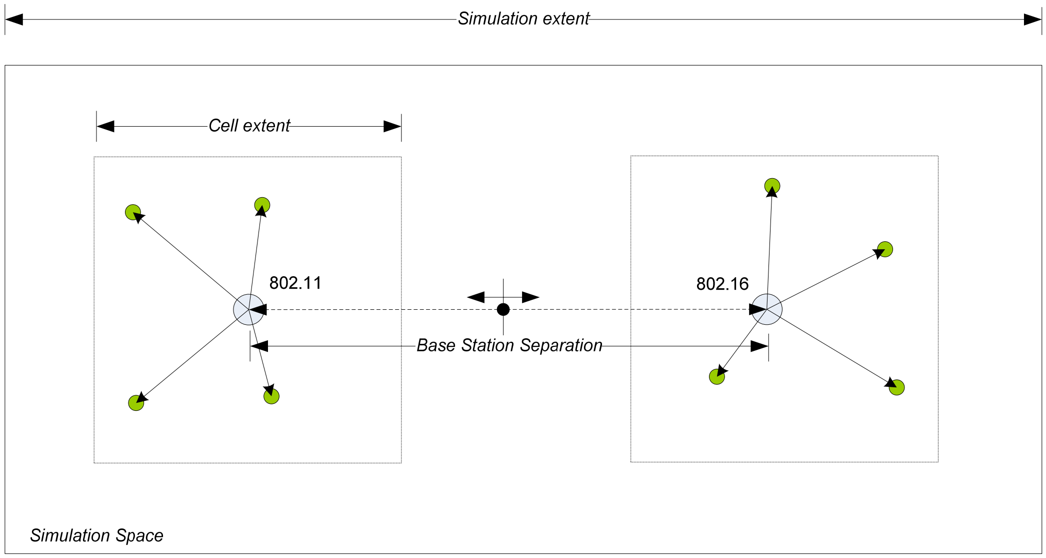

Figure 11 Spatially distributed simulation configuration: one 802.16 System and one 802.11 System.

Simulation results are presented to demonstrate the following:

- FER (Frame Error Rate) as a function of BS/AP separation. Considering 802.11y Systems alone, 802.16h Systems alone, and a combination of the two Systems.
- Specific behavior of *Scenario C* [4].
- Illustration of spectral reuse with BS/AP separation.

5.3.1 Spatial scenario with a mix of 802.16 and 802.11 systems

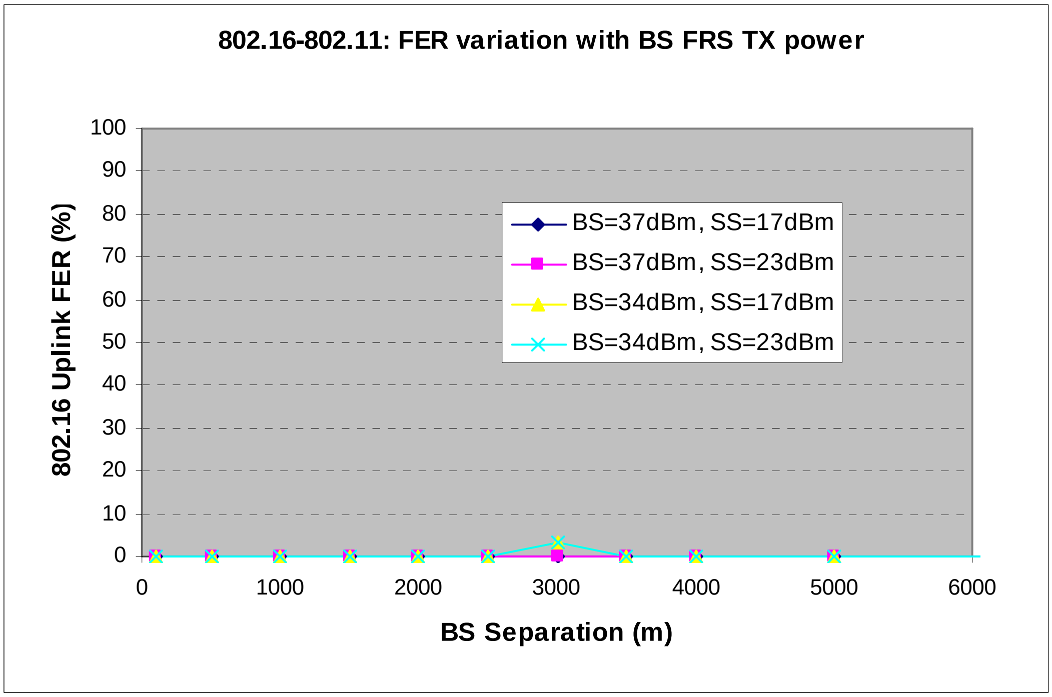

Figure 12 802.16 uplink FER against FRS transmit power for a spatially distributed simulation configuration with one 802.16 system and one 802.11 system. The downlink FER is zero for all BS separations.

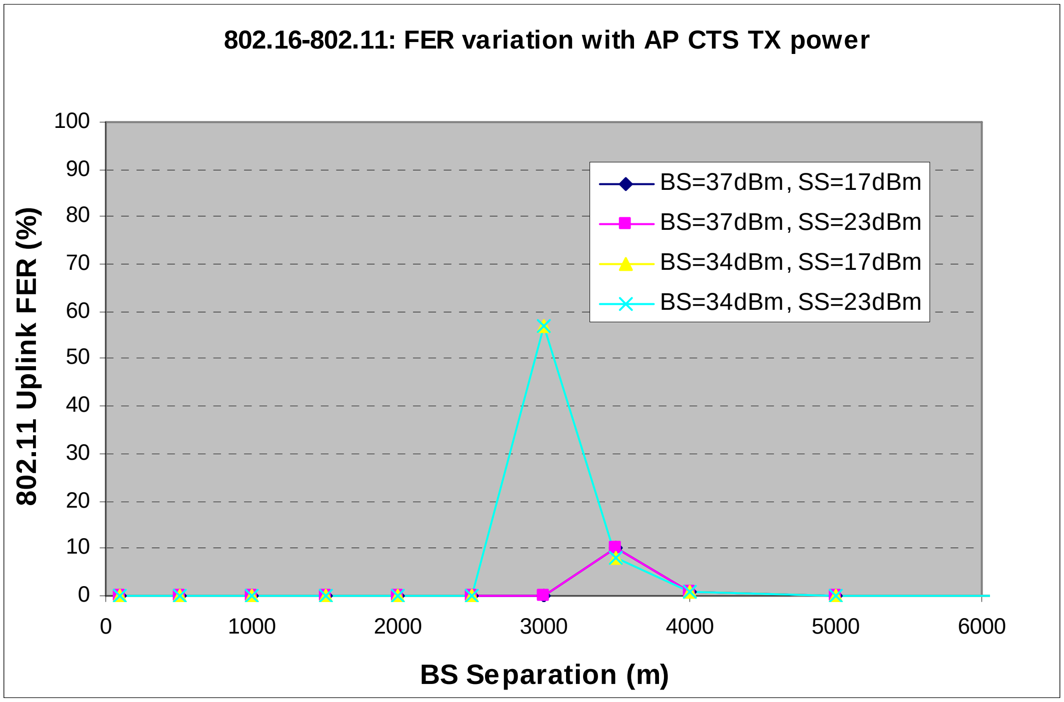

Figure 13 802.11 uplink FER against RTS/CTS transmit power for a spatially distributed simulation configuration with one 802.16 system and one 802.11 system. The downlink FER is zero for all BS separations.

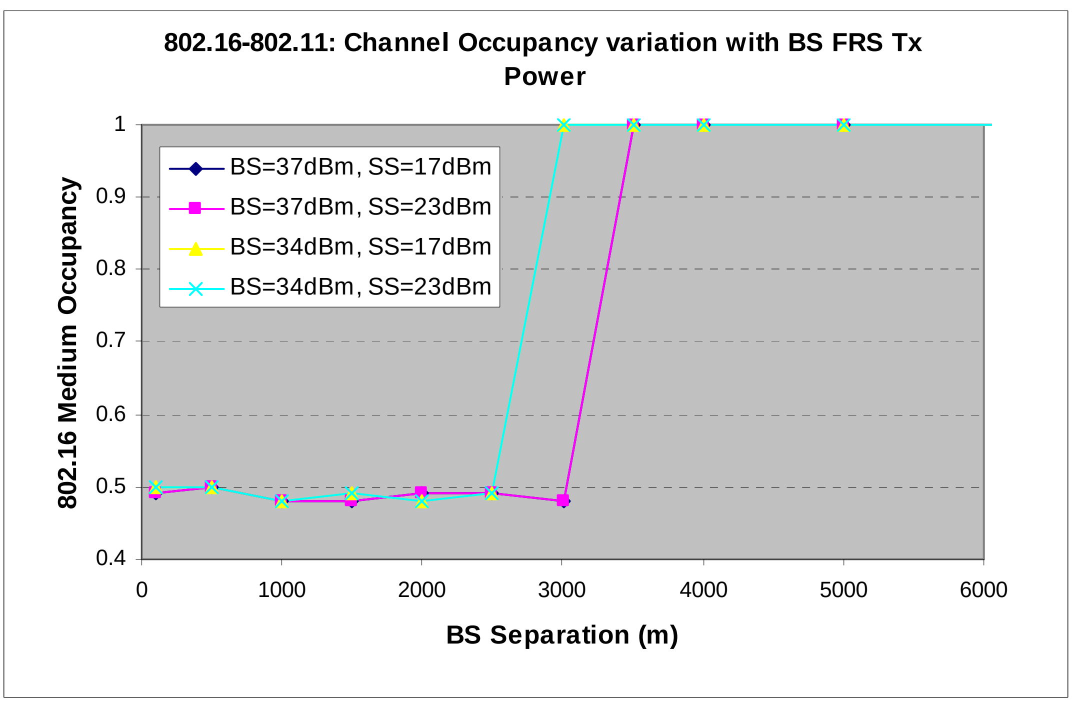

Figure 14 802.16 Medium Occupancy against FRS transmit power for a spatially distributed simulation configuration with one 802.16 system and one 802.11 system.

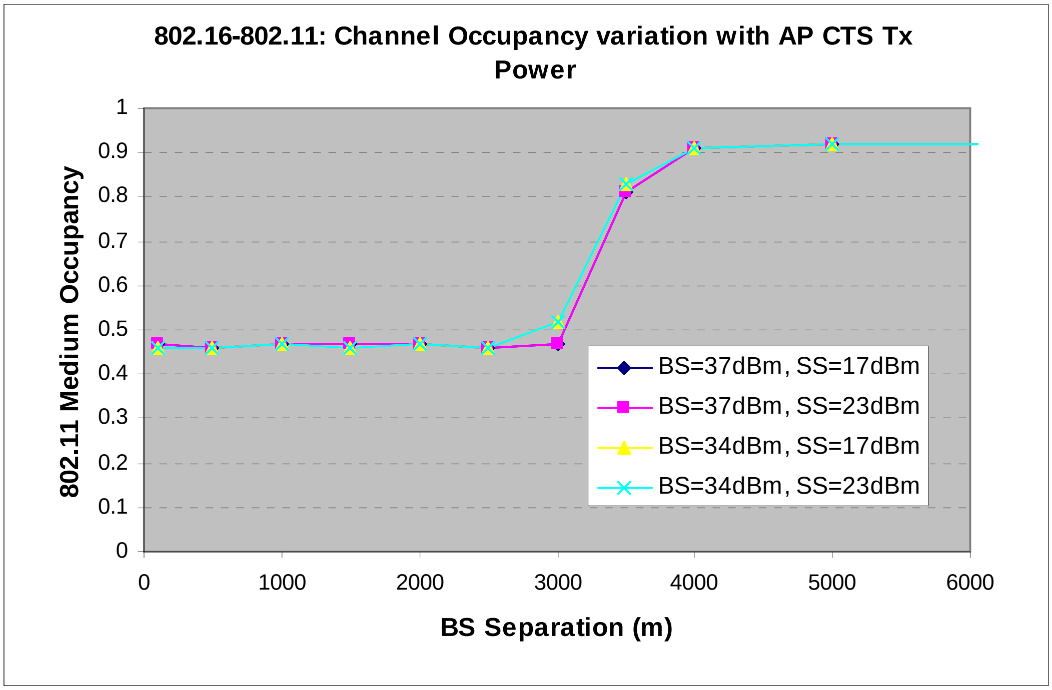

Figure 15 802.11 Medium Occupancy against RTS/CTS transmit power for a spatially distributed simulation configuration with one 802.16 system and one 802.11 system.

General observations

There is a limiting impact of BS/AP sending RTS/CTS/FRS given the near free space propagation between BSs and SS/STAs being shielded from the macrocellular layer by 12dB of Building Penetration Loss. So for the SS/STA to contribute then the transmit power needs to be 12dB higher plus the gain of the propagation model for BS-SS over free space. Hence there is no impact from the SS/STA gain in the transmit power ranges that are used.

When the RTS/CTS/FRS frames can no longer be received the Medium Occupancy metric approaches one per System. 802.16 systems exhibit a value at 1.0 due to the way that occupancy is measured in the simulation (total number of 5ms frames occupied divided by the total number of frames during simulation). 802.11 has a value of approximately 0.92. This is due to the fact the 802.11 Medium Occupancy is calculated based on the percentage of time a transmitter is operational. This value is less than unity due to the Medium Access procedure used by 802.11.

Downlink

No FERs – the RTS/CTS/FRS is sufficient to protect the downlink.

Uplink

FER is higher for 802.11 seen in the area of adjacent System deployments. 802.16 is protected by the fact 802.11 senses at the AP and STA. The reason for a worse FER for 802.11 in the uplink is because 802.11 may not sense when 802.16 (BS or SS) is transmitting. When 802.11 decides to transmit – 802.16 may be doing so at the same time and can have a higher likelihood of FERs for 802.11.

Increasing the transmit power and reducing the building penetration loss has an impact of reducing FER for 802.11 uplink. The problem is caused partly by the low powers at the subscriber side – as dictated by regulation for these simulation assumptions.

5.3.2 Spatial scenario with 802.16 systems only

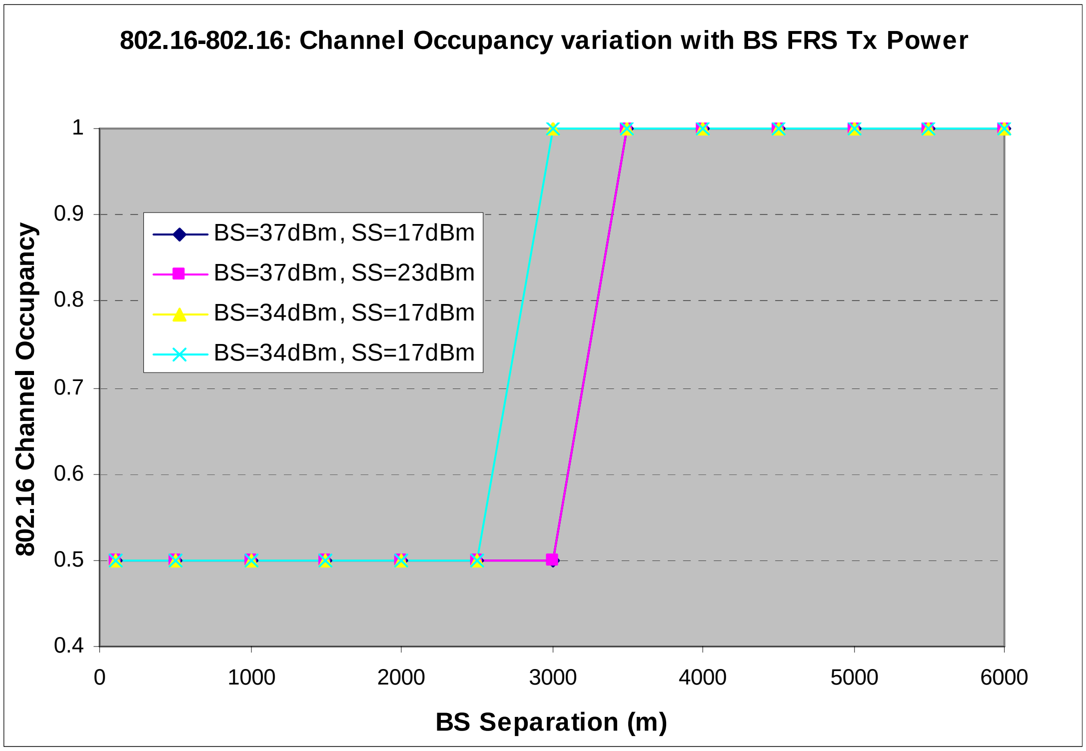

Figure 16 802.16 Medium Occupancy against FRS transmit power for a spatially distributed simulation configuration with two 802.16 systems. The downlink and uplink FER are zero for all BS separations.

General observations
Sensing is only undertaken at the BS.

Downlink
The FER is zero for all BS separations. The FRS transmission is sufficient to protect the downlink and Line of Sight propagation between BS means there is a large separation between BS until the Systems are independent and the Channel Occupancy approaches one.

Uplink
The FER is zero for all BS separations. This is because the frame alignment means there is no uplink interference from downlink transmissions in the neighbouring System. This is akin to an FDD interference scenario i.e. synchronous TDD.

5.3.3 Spatial scenario with 802.11 systems only

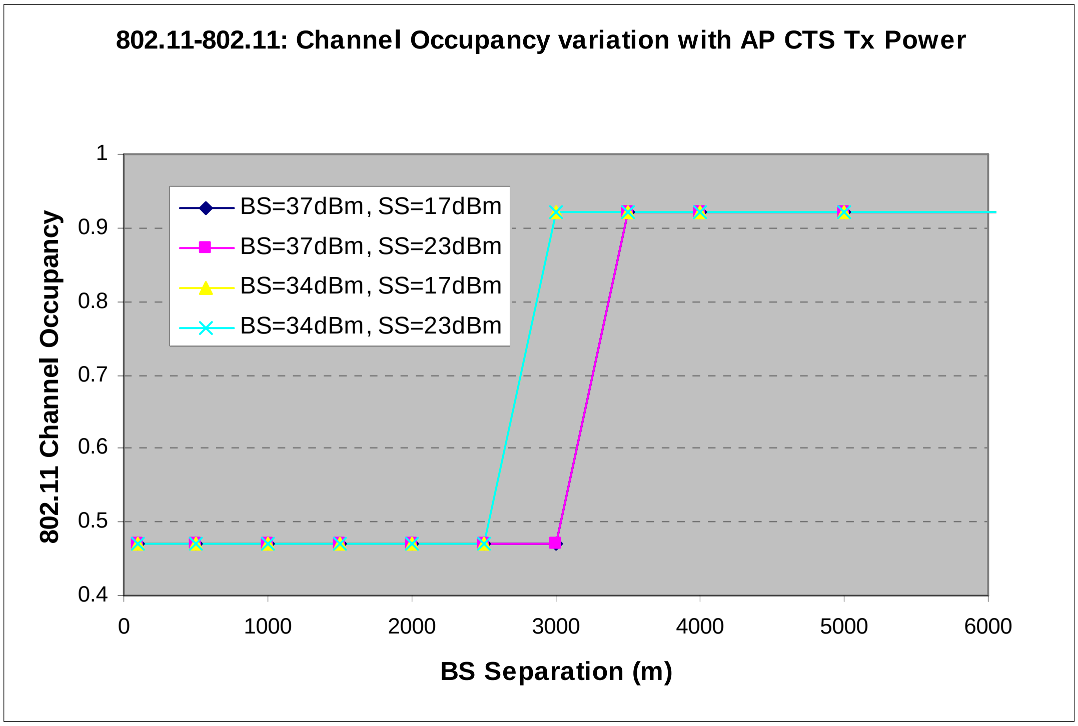

Figure 17 802.11 Medium Occupancy against RTS/CTS transmit power for a spatially distributed simulation configuration with two 802.11 systems. The downlink and uplink FER are zero for all AP separations.

General observations
With sensing at the AP and STA provides lower FER compared with other scenarios.

Downlink
The FER is zero for all AP separations. The RTS/CTS transmissions are sufficient to protect the downlink.

Uplink
Removing Building Penetration Loss and increasing the transmit power of the subscriber reduces the FER; however the exposed node problem is exacerbated.

5.3.4 Study into varying control frame transmit power

This sections looks at a *spatially distributed* scenario and the sensitivity of varying the power of the RTS/CTS/FRS control frames.

Reducing the RTS/CTS/FRS transmission power reduces the coupling and exposed node effect between Systems and the separation between Systems which see the Medium Occupancy approaching one. However reducing this power results in a higher FER since variability in pathloss introduced by the Shadow Margin creates hidden nodes.

Results showing this behaviour for 802.11 are presented in Figure 18, Figure 19, and Figure 20. Results for 802.11 are presented in Figure 21, Figure 22, and Figure 23.

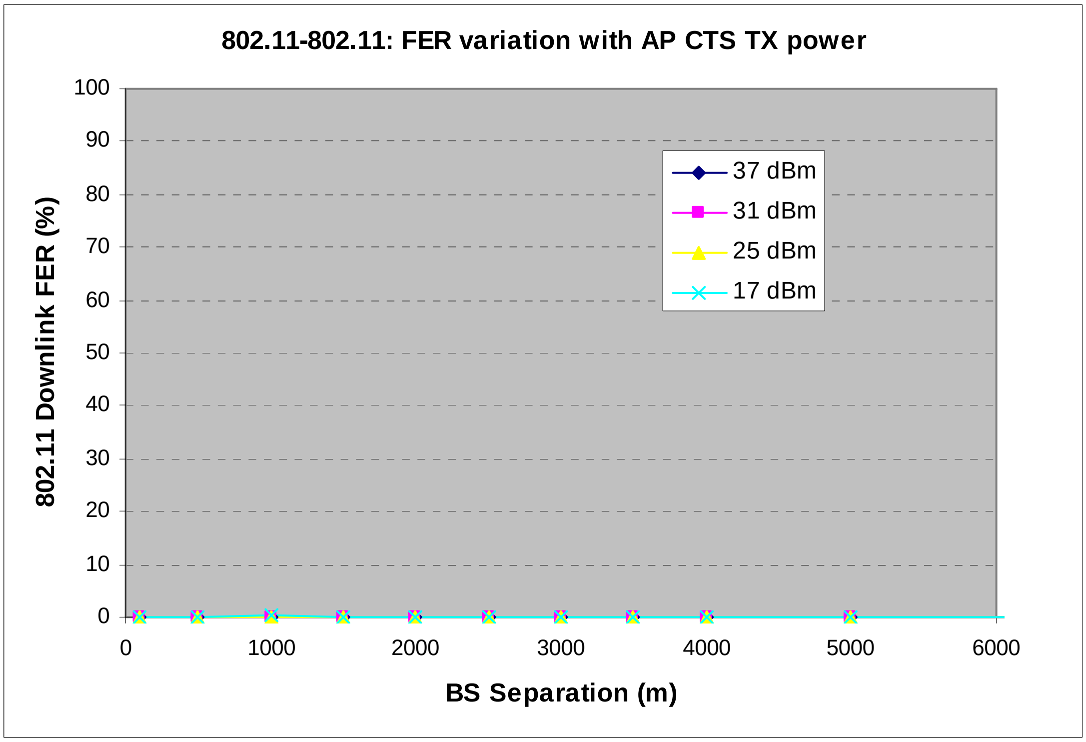

Figure 18 802.11 downlink FER for two 802.11 systems against AP separation and RTS/CTS transmit power. STA RTS/CTS transmit power is 17dBm.

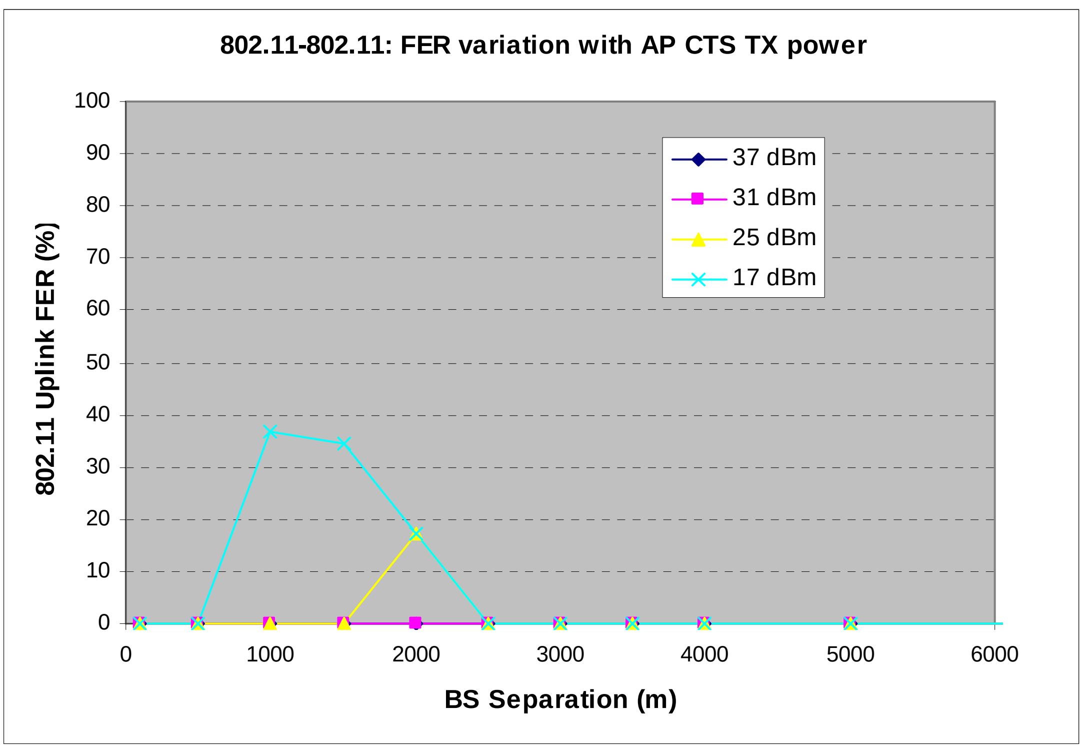

Figure 19 802.11 uplink FER for two 802.11 systems against AP separation and RTS/CTS transmit power. STA RTS/CTS transmit power is 17dBm.

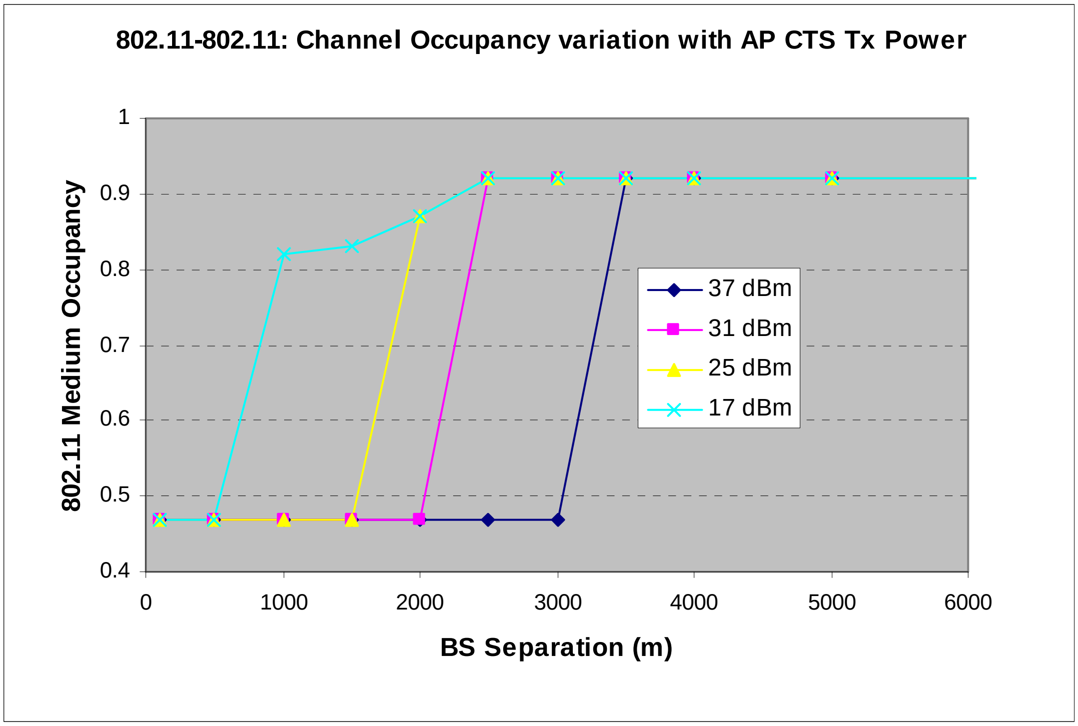

Figure 20 802.11 Medium Occupancy for two 802.11 systems against AP separation and RTS/CTS transmit power. STA RTS/CTS transmit power is 17dBm.

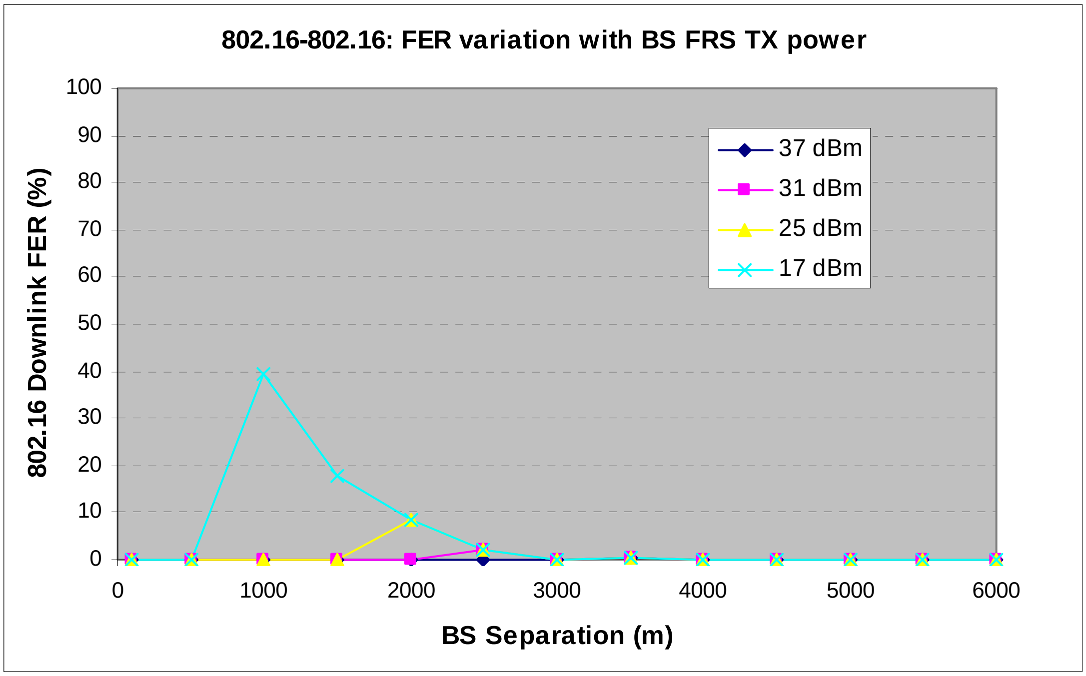

Figure 21 802.16 downlink FER for two 802.16 systems against BS separation and FRS transmit power.

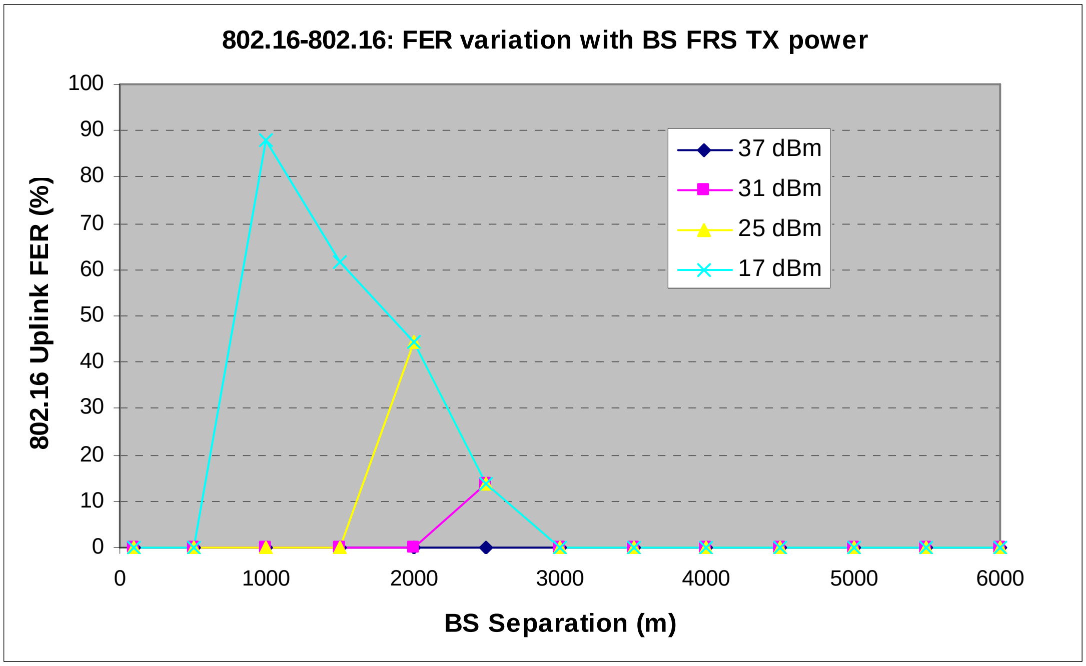

Figure 22 802.16 uplink FER for two 802.16 systems against BS separation and FRS transmit power.

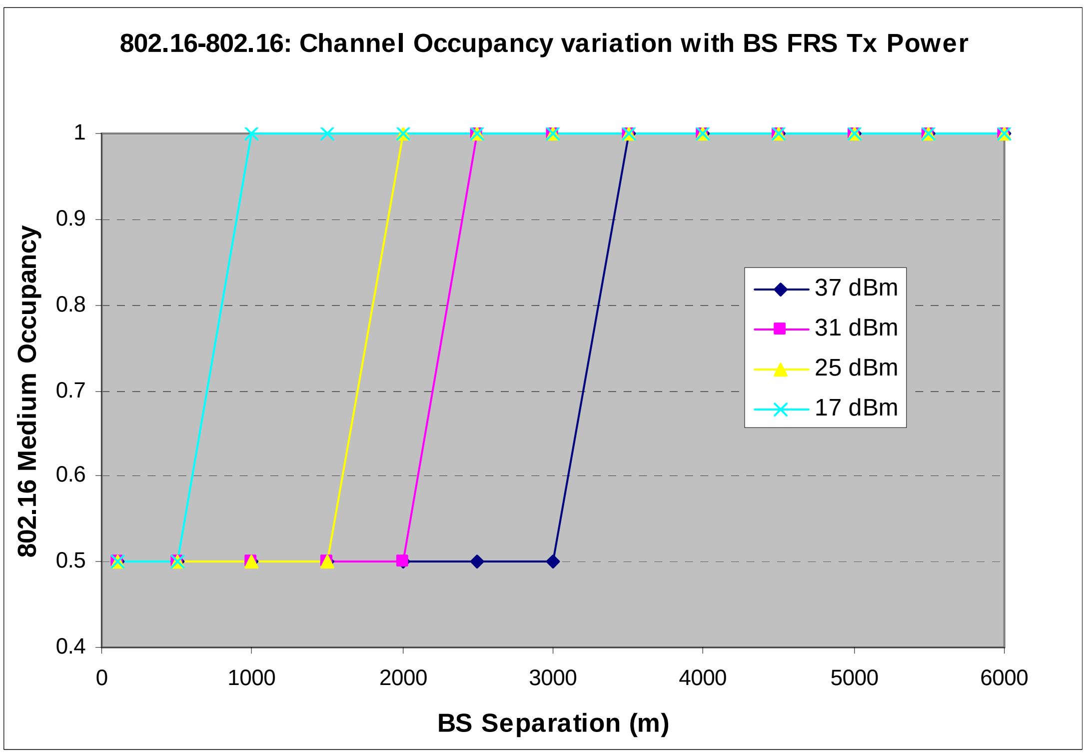

Figure 23 802.16 Medium Occupancy for two 802.16 systems against BS separation and FRS transmit power.

6 Conclusions

The following conclusions can be drawn from the simulation results presented in this document:

- Simulation assumptions create sensitivities in the simulation results.
- FER increases for partial overlapping and adjacent cells. This situation is directly impacted by: the Transmit power of control frames (base and subscriber), Shadow Margin, the propagation model (base station-base station, base station-subscriber, subscriber-subscriber), and In-building Penetration. The simulation results present an indication of the sensitivity of these parameters to coexistence.
- 802.11-802.11 simulation results show low FERs in both the downlink and uplink given the sensing capabilities at the AP and STA.
- 802.16-802.16 simulation results show that the interference environment is synchronous TDD (base station – subscriber, subscriber – base station). Due to the simulation assumptions and LOS between BSs then FERs are low.
- 802.16-802.11 simulation results show an elevated FER for the uplink as a result of the hidden node problem and simulation assumptions. This is specifically the case due to building penetration loss and low transmit power regulated for mobile subscriber devices.
- RTS/CTS/FRS transmission power dictates the effective spectral reuse for Systems based on exposed nodes (5.3.4).
- Under appropriate deployment conditions WirelessMAN-UCP meets the requirements of the band as an *Unrestricted CBP* based on the FCC definition.

7 Abbreviations

AC	Access Categories
AP	Access point
BPL	Building Penetration Loss
BS	Base Station
CBP	Contention Based Protocol
CCA-CS	Clear Channel Assessment – Carrier Sense
CCA-ED	Clear Channel Assessment – Energy Detect
DCS	Dynamic Channel Selection
DFS	Dynamic Frequency Selection
DMA	Dynamic Medium Acquisition
EIRP	Effective Isotopic Radiated Power
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FER	Frame Error Rate
LBT	Listen Before Talk
MA	Medium Acquisition
MAN	Metropolitan Area Network
MCS	Modulation and Coding Schemes
OFDMA	Orthogonal Frequency Division Multiple Access
PDU	Protocol Data Unit
RTG	Receive Transition Gap
SDU	Service Data Unit
SS	Subscriber Station
STA	Subscriber STAtion
TDD	Time Division Duplex
TTG	Transmit Transition Gap

TXOP	Transmit OPportunity
UCP	Uncoordinated Coexistence Protocol

8 Definition

Base Station	A general term referring to both an 802.11 AP and 802.18 BS.
Subscriber Station	A general term referring to both an 802.11 STA and 802.18 SS.
System	A base station and its associated subscribers. This can be either related to 802.16h and 802.11y.

9 References

[1] FCC Memorandum, 031505 3650-3700MHz R&O MO&O, FCC 05-56, March 16, 2005.
[2] FCC Memorandum, 060707 3650-3700MHz MO&O, FCC 07-99, June 7, 2007.
[3] IEEE P802.16h: Air Interface for Fixed Broadband Wireless Access Systems Improved Coexistence Mechanisms for License-Exempt Operation, Draft Standard.
[4] IEEE 802.19-07/11 *Parameters for simulation of Wireless Coexistence in the US 3.65GHz band* 802.19 Working Group.
[5] IEEE P802.11y: Draft STANDARD for Information Technology — Telecommunications and information exchange between systems— Local and metropolitan area networks- Specific requirements— Part 11:Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: 3650-3700 MHz Operation in USA.
[6] IEEE 802.19-07/20 *Coexistence Metrics for the 3650MHz Band* 802.19 Working Group.
[7] IEEE Standard for Local and metropolitan area networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems. IEEE Std 802.16-2004; October 2004.
[8] WiMAX Forum Mobile System Profile Release 1.0 Approved Specification.
[9] IEEE Std 802.11: Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.