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Title	**Uncoordinated Coexistence Protocol (UCP) Coexistence Assurance statement for the 3.65GHz band in US and Canada**
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Abstract	This document provides a Coexistence Assurance analysis for the UCP (Uncoordinated Coexistence Protocol). Analysis focuses on the 3.65GHz band in the US and Canada aiming to address the requirements of the CBP (Contention Based Protocol) as defined by the FCC. Supporting simulation results are provided.
Purpose	Provide an analysis to show that the UCP (Uncoordinated Coexistence Protocol) provides fair channel sharing with other IEEE802 wireless technologies in 3.65GHz band; and meet the requirements for operation as specified by the FCC.
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Uncoordinated Coexistence Protocol (UCP) Coexistence Assurance statement for the 3.65GHz band in US and Canada

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1. Introduction

This document provides a Coexistence Assurance analysis for the UCP (Uncoordinated Coexistence Protocol). Analysis focuses on the 3.65GHz band in the US and Canada aiming to address the requirements of the CBP (Contention Based Protocol) as defined by the FCC. Supporting simulation results are provided.

2. Statement of compliance

Of coexistence this document makes the following claims:

1. The Uncoordinated Coexistence Protocol (UCP) of subclause 6.4.2 [1] provides coexistence with 802.11 systems as amended by 802.11y [4].
2. The Uncoordinated Coexistence Protocol (UCP) of subclause 6.4.2 [1] provides coexistence for 802.11 systems as amended by 802.11y [4] without any modifications required to 802.11y systems.
3. The Uncoordinated Coexistence Protocol (UCP) of subclause 6.4.2 [1] provides a medium access capability that meets the requirements of the *Unrestricted CBP* as defined by the FCC [5] as amended by [10] and [11].
4. In this way the Uncoordinated Coexistence Protocol (UCP) of subclause 6.4.2 [1] provides a *fair sharing* of the medium between 802.16h and 802.11y systems in the 3.65GHz band. This *fair sharing* is embodied in features supporting the requirements of the FCC [5] as amended by [10] and [11] that define:
    - The graceful handling of events where devices attempt to simultaneously access the same medium.
    - Rules by which a device provides reasonable opportunities for other transmitters to operate.
    - Maintenance a minimal Frame Error Rate and minimal delay.
    - Enhancements to mitigate the hidden node problem.

3. Scope

The scope of this document is to present a Coexistence Assurance (CA) statement by means of analysis and simulation. The statement will be centered on considering coexistence between systems based on amendments to the 802.16 and 802.11 wireless standards in the 3.65GHz band in the US & Canada. Specifically the 802.16-based system will support the Uncoordinated Coexistence Protocol (UCP) feature as set out in the 802.16h amendment to 802.16 [1], with 802.11-based systems using the 802.11y amendment [4].

4. Aims

This document aims to:

- Overview the purpose of a CA document and how this can be used to provide support for this work.
- Provide an overview of the regulatory requirements for operation in the 3.65-3.7GHz band.
- Provide an overview and detail of the features described in [1] which are designed to meet the requirements of the FCC CBP.
- Provide a description of the simulation by which CA is investigated and measured. This will draw heavily from [3] as defined in the *802.19 Coexistence Technical Advisory Group* (TAG)
- Provide substantive simulation results to verify that the specific cited features from [1] provide suitable coexistence, equitable channel sharing, and operational performance.
- Conclusions for CA from the features and results presented.

5. The regulatory landscape

This section provides some background from the regulatory perspective on the usage and restrictions of the 3.65-3.7GHz band. An explanation is also provided that imparts some information on the design decisions in order to meet the *Unrestricted CBP* as defined by the FCC.

5.1. Regulatory requirements for the 3.65-3.7GHz band

The FCC rules for the band are documented in 47 CFR 90, Subpart Z – Wireless Broadband Services in the 3650-3700 MHz Band [5] and as amended by [10] and [11].

The current rule making proposes a Non-Exclusive Registration Use licensing mechanism for the entire 3650 – 3700 MHz band. Licensees are required to registers their base stations and fixed stations online via the FCC's Universal Licensing System (ULS) and must delete the registrations for unused stations. License terms are for 10 years. Interference among base stations of different service providers are expected to be resolved among the providers themselves by 'mutually satisfactory arrangements'.

The following technical requirements appear in [5]:

1. 25 Watt EIRP maximum power in 25MHz bandwidth for registered Base and Fixed stations
2. 1 Watt EIRP maximum power in 25MHz bandwidth for Mobile and Portable stations
3. 1W / MHz EIRP maximum PSD for Base and Fixed stations
4. 40mW / MHz EIRP maximum PSD for Mobile and Portable stations
5. Sectorized antenna permitted only if each sector transmits different information
6. Beamforming is subject to the 25 Watt EIRP requirement
7. 43 + 10 Log(P) OOBE, with the 1% rule included
8. Mobile stations may only transmit if they can decode an enabling signal from a base station

9. Mobile stations may transmit to one another directly only if they can decode an enabling signal from a base station
10. Airborne operation prohibited
11. 150 km exclusion zone around FSS stations – unless agreed with the FSS licensee
12. 80 km exclusion zones around following federal radiolocation stations
    a. St. Inigoes, MD 38° 10' 0" N , 76° 23' 0" W
    b. Pascagoula, MS 30° 22' 0" N , 88° 29' 0" W
    c. Pensacola, FL 30° 21' 28" N , 87° 16' 26" W
13. Fixed devices must be at least 8 / 56 km away from international borders if the antenna looks within 160° / 200° sector toward the border – unless coordinated with Mexico or Canada.

5.2. A Contention Based Protocol (CBP)

Paragraph 90.7 of [5] and [11] provides the following defintion:

> Contention-based protocol *A protocol that allows multiple users to share the same spectrum by defining the events that must occur when two or more transmitters* ***attempt to simultaneously access the same channel*** *and establishing rules by which a transmitter* ***provides reasonable opportunities for other transmitters to operate****. Such a protocol may consist of procedures for initiating new transmissions, procedures for determining the state of the channel (available or unavailable), and procedures for managing retransmissions in the event of a busy channel. 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.*

Paragraph 90.1319 of [5] provides the following policies governing the use of the 3.65-3.6GHz band.

> *(a) Channels in this band are available on a shared basis only and will not be assigned for the exclusive use of any licensee*
>
> *(b) Any base, fixed, or mobile station operating in the band must employ a contention-based protocol.*
>
> *(c) Equipment incorporating an unrestricted contention-based protocol (i.e. one capable of avoiding cofrequency interference with devices using all other types of contention-based protocols) may operate throughout the 50 megahertz of this frequency band. Equipment incorporating a restricted contention based protocol (i.e. one that does not qualify as unrestricted) may operate in, and shall only tune over, the lower 25 megahertz of this frequency*

band.

(d) All applicants and licensees shall cooperate in the selection and use of frequencies in the 3650-3700 MHz band in order to minimize the potential for interference and make the most effective use of the authorized facilities. A database identifying the locations of registered stations will be available at http://wireless.fcc.gov/uls. Licensees should examine this database before seeking station authorization, and make every effort to ensure that their fixed and base stations operate at a location, and with technical parameters, that will minimize the potential to cause and receive interference. Licensees of stations suffering or causing harmful interference are expected to cooperate and resolve this problem by mutually satisfactory arrangements.

The design of the UCP feature set is driven by the two highlighted aspects of the CBP defintion:

- *Attempt to simultaneously access the same channel*: UCP provides a Listen Before Talk (LBT) style of operation to mitigate a situation where two devices are attempting to access the wireless medium at a given time interval.
- *Provides reasonable opportunities for other transmitters to operate*: UCP provides *quiet times* to ensure other systems have a clear chance to access the channel. These opportunities are driven by an ongoing measure of channel utilization maintained by the *802.16h* system.

The UCP feature set is designed to meet the requirements of the *Unrestricted CBP* drawing on the design goal of providing co-channel coexistence and exemplified in the analysis that follows where coexistence with *802.11y* systems is demonstrated.

More information on UCP and the features that underpin coexistence are given in the following clause.

6. The UCP (Uncoordinated Coexistence Protocol) feature

UCP (Uncoordinated Coexistence Protocol) is an umbrella term for a family of features designed to meet the requirements of the *Unrestricted CBP* as specified by the FCC [5]. As a consequence UCP provides *passive cognitive radio* coexistence with asynchronous systems, such as 802.11, also targeted for the band and expected to meet the requirements of the CBP. Within [1] UCP is band non-specific but is made band specific with an appropriate choice of operational parameters. The focus of this document considers UCP for operation in the 3.65GHz and therefore targeting coexistence with *802.11y* systems with appropriate parameters.

UCP is described in subclause 6.4.2.3 of [1] are draws upon two features further described. These features are:

- DCS (Dynamic Channel Selection) subclause 6.4.2.3.2 of [1]
- LBT (Listen-Before-Talk) subclause 6.4.2.3.7 of [1]

DCS provide the ability to select a quiet channel for operation. LBT provides mitigation for cases where two devices are attempting to access the medium at the same time and to provide opportunities for other devices to transmit – both required to met the requirements of the CBP. More detail of features is given in the following subclauses.

6.1. DCS (Dynamic Channel Selection)

DCS (Dynamic Channel Selection) is described in subclause 6.4.2.3.2 of [1] as an *uncoordinated* coexistence mechanism (where system attempts to achieve coexistence without exchanging messages) and provides the ability for a system to switch to different physical frequency channel, based on channel conditions, and thereby avoiding interference in non-exclusively assigned and non-exclusively licensed bands. DCS can be used as a means of finding a least interfered channel at system startup or can be used during normal system operation to provide constant interference monitoring capabilities and, with the ability to monitor other channels, provide a list of backup channels for informed switchover to a different, less interfered, channel.

DCS is distinct from DFS (Dynamic Frequency Selection) in that DCS is not used for interference avoidance for regulatory protected devices, such as radar systems, but to other non-exclusively licensed users in the band. Within the 802.16 standard DFS has a specific meaning and refers to a mechanism whereby a channel is monitored and vacated when certain protected devices are present.

6.2. LBT (Listen-Before-Talk)

LBT (Listen-Before Talk) is described in subclause 6.4.2.3.7 of [1]. The feature itself comprises a number of elements that form LBT operation. These elements are discussed in turn in the following subclauses.

6.2.1. Frame structure and frame allocation methodology

LBT is designed to work with any deterministic and slowly time varying frame allocation mechanism. To facilitate coexistence *802.16h Systems* (an *802.16h* BS and its associated SS) operating in the same geographical area use different frames to provide interference avoidance in time. The premise dictates that a System *targets* the use of a particular known frame in a known repetition cycle. The word *target* is used here to mean that an attempt to use a particular frame is made, but based on the prevailing activity of 802.11y systems in reality the frame may not be available. A priori knowledge for all *802.16h* Systems in the locality dictates the frame available to a particular System. Frame allocation can be achieved in a number of ways in including the use of a discovery protocol.

Figure 1 provides a representation of a possible frame structure for LBT operation. In this example 3 802.16 systems share frames allocated in a round robin manner. The rules to define which system has which frame may be determined by administrative means based on the fact that within the 3.65-3.7GHz band base and fixed stations will need to register their location. This registration process means that information is available to determine which Systems are in a given area and which need to coordinate their frame usage in time. This is a subset of the full behaviors defined in [1]. Figure 2 presents a frame allocation format as defined in [1].

In both Figure 1 and Figure 2 each frame comprises a DL, an UL, and a DMA (Dynamic Medium Acquisition) region. The DL and UL subframes are identical to that defined in the 802.16 standard [12]. The DMA region is an area at the end of the frame for the *System* occupying the following frame to determine if the medium can be used. The DMA region, as the name suggests, is logical and dynamic (in duration) and extends from the end of the frame towards the start of the frame; the duration is defined by current utilization.

When adopting the Mobile WiMAX System Profile parameters [6] and assuming a *Timing Advance* of 0µs (a notionally small cell) then the 47 OFDM symbols in a 5ms frame occupy 4841µs (assuming a Symbol is 103µs in duration – the actual value is 102.86µs but is rounded to 103µs since the simulation has a 1µs resolution). This leaves 159µs to accommodate the TTG, RTG, Timing Advance requirements and the DMA region. The simulation results will investigate the validity of this assumption and compare against different parameter assumptions for 802.11y with the goal of determining if fair channel sharing is achieved.

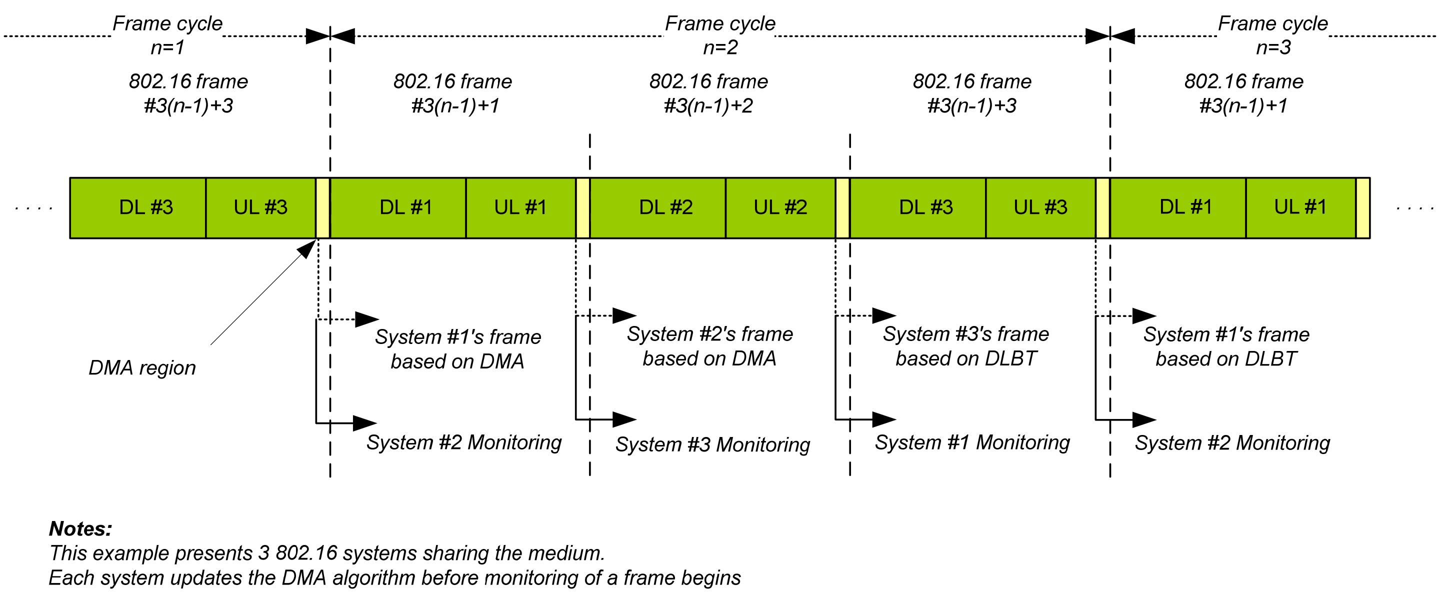

Figure 1 *An example frame allocation format with the DMA (Dynamic Medium Access) region.*

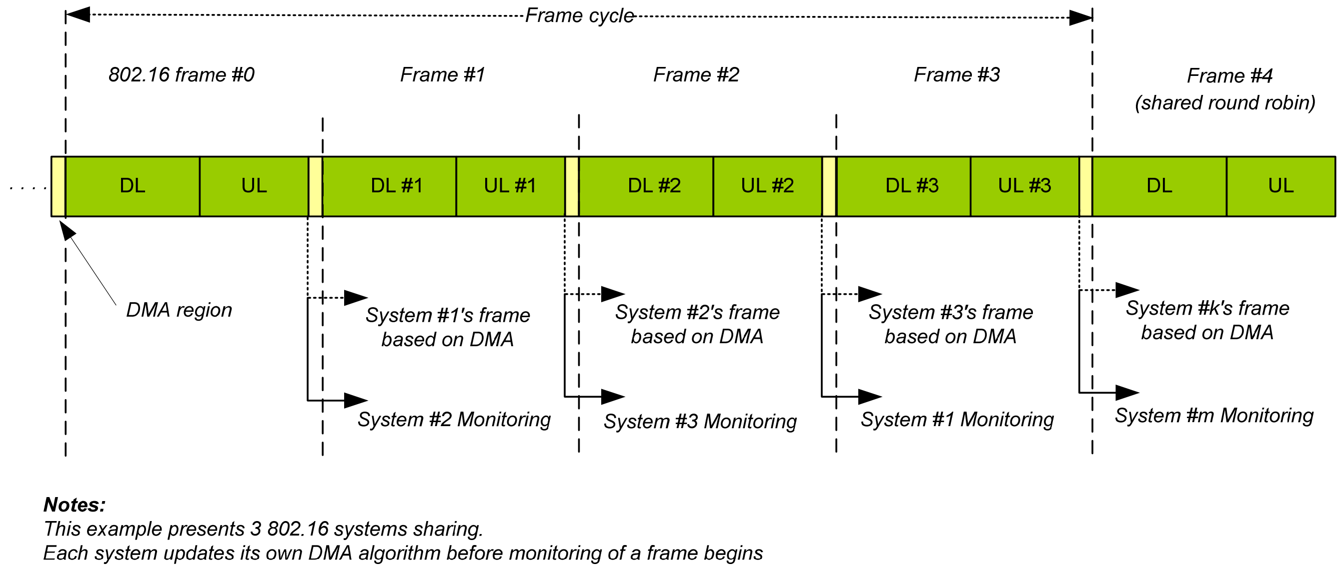

Figure 2 *An example frame allocation format as defined in [1] with the DMA (Dynamic Medium Access) region.*

6.2.2. Frame timings

The DMA region of Figure 1 is shown in more detail in Figure 3. The DMA region's right most extent is fixed and located at the end of the frame; the right most boundary is termed *FRSTn* variable and depends on the current channel utilization for a given 802.16 system. The adjustment of the DMA right boundary, based on *FRSTn*, defines a logical time when a system can possibly claim the medium for use in the next frame. The timing parameters are defined accordingly:

FRSTn - Frame Reservation Start Time: A timer updated over a sliding window and based on the current and past utilization of the channel for a particular system.

MAXFRST - The maximum value of *FRST*

MINFRST - the minimum value of *FRST*. $MINFRST = T_{CMA} + T_{FRAME\_END\_OFFSET}$

$T_{FRAME\_END\_OFFSET}$ - minimum time to switch Rx/Tx and claim the medium.

T_{CMA} – Clear Medium Assessment time. The time for 802.16 to determine the medium is clear for transmission.

The parameters in the DMA algorithm are maintained by each system and are likely to be different based on 802.11 activity.

Figure 3 depicts two cases:

$T_{medium\_quiet} > FRSTn$

In this case the medium becomes quiet (either due to 802.11 or 802.16 transmissions) after *FRSTn*. In this case it is necessary to wait until the medium is quiet which will occur when time is greater than T_{medium_quiet}. At this point can a medium assessment begin in which 802.16 may claim the channel for use in the following frame.

$T_{medium\_quiet} < FRSTn$

In this case the medium becomes quiet (either due to 802.11 or 802.16 transmissions) before *FRSTn*. In this case a medium assessment can begin as soon as *FRSTn* is reached since the medium is sensed to be quiet.

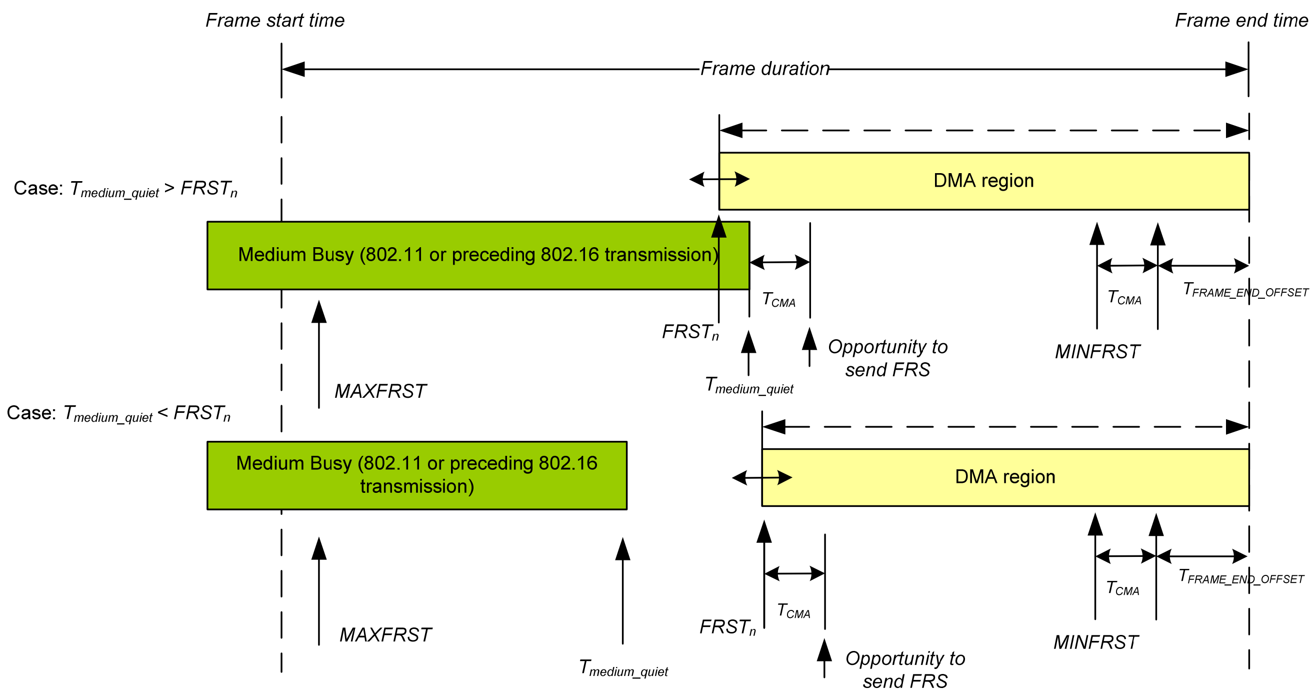

Figure 3 *DMA (Dynamic Medium Access) region detailing specific parameters.*

6.2.3. Utilization

FRSTn is modified according to the following algorithm. The *Utilization_Goal* is the “fair” channel occupancy for this system and based on the number of systems operational in a given area. For example a *Utilization_Goal* of 33% would be prescribed for the case where there were 2 802.16 and 1 802.11 systems present. *Current_Utilization* is the current achieved channel occupancy for a given 802.16 system and is the ratio of *Claimed_Frames* to *Total_Frames*. *Total_Frames* is not incremented when an 802.16h System (BS or any SSs) has no traffic present to transmit. In this way when 802.16 is working with 802.11 systems, where the 802.16 has a low load and the 802.11 a high load then 802.16 does not strive to obtain 50% of the frames to the unnecessary detriment of 802.11. The *Utilization_Ratio* is the metric indicating the level to which the *Utilization_Goal* has been achieved. *K* is a term which defines the *reactive* behavior of a system in achieving the *Utilization_Goal*.

$$FRST_n = MIN(MAX\_FRST, (MAX(Utilization\_Ratio \times FRST_{n-1}, MIN\_FRST)) \qquad [1]$$

$$Utilization\_Ratio = \left(\frac{Utilization\_Goal}{Current\_Utilization} \right)^{K} \qquad [2]$$

$$Current\_Utilization = \frac{Claimed\_Frames}{Total\_Frames} \qquad [3]$$

6.2.4. Frame Reservation Signal (FRS)

When using any carrier sense protocol, such as LBT, in a wireless environment the hidden node problem cannot be 100% avoided. It can only be mitigated. Additionally, in bands such as 3.65 GHz in the US, there is an aggravated hidden node problem due to the distinctly lower transmit power allowed for mobile devices compared to fixed, registered devices. The mobiles are more often geographically disadvantaged due to this transmit power disparity. Fixed, registered client devices can also be geographically disadvantaged (the classical hidden node problem), although not as often. To remedy this the BS transmits a Frame Reservation Signal (FRS) at the end of the downlink subframe to reserve the subsequent uplink subframe (or used portion, thereof) for the subscriber stations. The BS also transmits an FRS in the DMA region at the time a decision is made to claim the medium. The form of the FRS is band dependent and should be structured to be receivable by other technologies that may be co-channel. For instance, in bands where 802.11 would be a typical co-channel asynchronous system, the 802.11 CTS transmitted using the appropriate 802.11 burst structure would suffice. The reservation of the downlink and uplink subframe by the BTS precludes the need for the SS to also perform LBT. The use of the FRS to protect the uplink, and its realization in the simulation, is shown in Figure 4. The use of the FRS to protect the downlink following transmission in the DMA region, and its realization in the simulation, is shown in Figure 5.

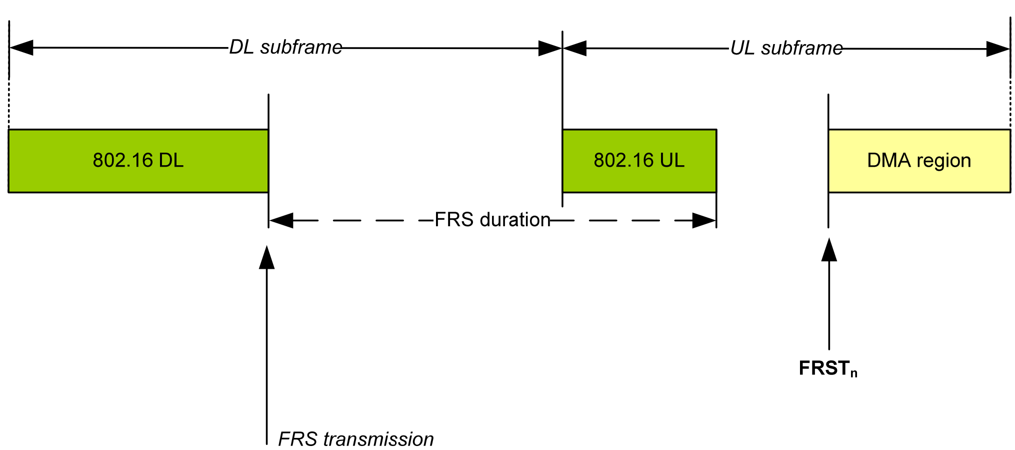

Figure 4 *FRS transmission in the DL subframe protecting the UL subframe (DL FRS)*

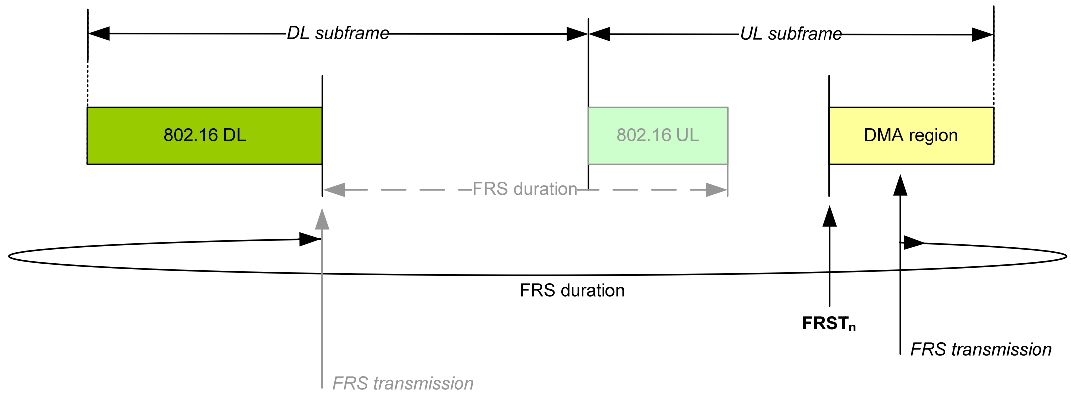

Figure 5 *FRS transmission in the UL subframe protecting the following DL subframe as claimed in the DMA region (UL FRS)*

7. Simulation Environment

The clause provides detail of a simulation environment used to analysis coexistence between *802.16h*-based and *802.11y*-based systems. The aspect of coexistence has been widely discussed in [3], a work item studied at length in 802.19 Coexistence TAG (http://www.ieee802.org/19/) and entitled *Parameters for simulation of Wireless Coexistence in the US 3.65GHz band*. This document focuses on providing details of the parameters used to align simulation; this section describes the specifics of the simulation itself not prescribed in [3].

7.1. Details of the simulation environment

This section provides more detail on specific aspects of the simulation pertinent to the simulation results presented later in the results section. Focus is placed on the following areas:

- Some high-level assumptions
- Device placement, topology description
- Specifics of the link budget assessment
- MCS selection algorithm
- DCS algorithm
- Long-term fading power control algorithm
- Interference calculation
- Traffic modeling and buffering assumptions
- 802.11 model
- Fairness metric calculation.

7.1.1. Some high-level assumptions

This subclause provides a brief overview of the simulation environment. Salient points are:

- The simulation has a 1µs resolution.
- Given the fine resolution the simulation provides for compensation for *time of flight* in assessment of interference.
- The simulation provides both a spatial and temporal element. A simulation space is defined with devices placed within this space. The simulation then provides a time domain analysis when considering the coexistence between devices.

7.1.2. Device placement, topology description

Device placement is a configurable element to the input configuration of the simulation. An illustrative example is given in Figure 6. Here *n 802.11y* APs (blue) are placed with *m* 802.16 BSs (green). A maximum of 4 subscribers are associated to each AP/BS. AP/BSs are assigned on a random basic with subscribers associated to AP/BS on minimum pathloss basis. As Figure 6 depicts not all subscribers are associated in a given simulation run. More specific examples, with tighter constraints, are presented later in this document.

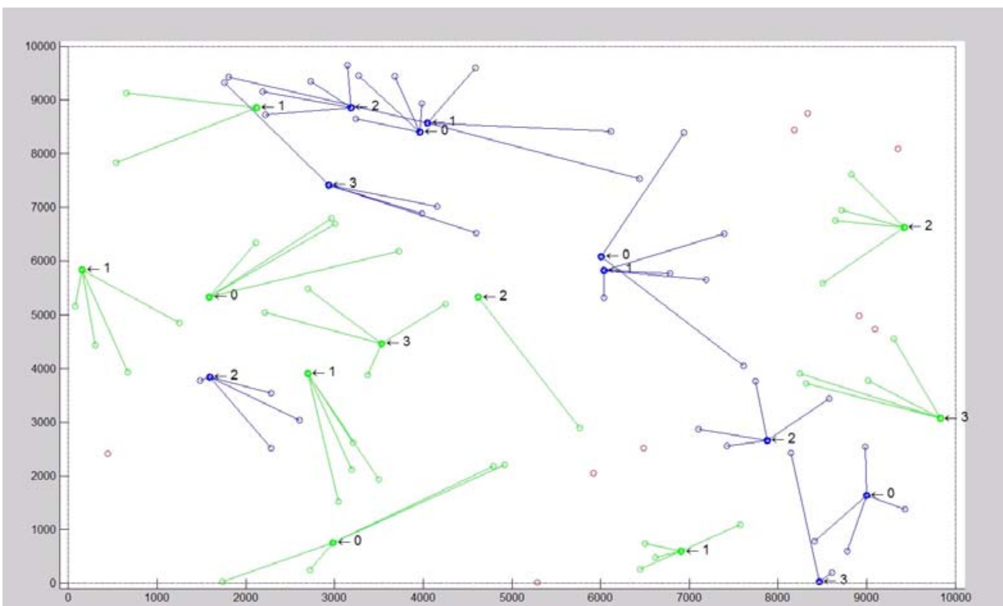

Figure 6 *An example distribution of devices in a simulation space of size 10km x 10km.*

7.1.3. Specifics of the link budget assessment

The simulation uses the SUI (Stanford University Interim) [7] to model large-scale fading. Figure 7 provides an illustration of the differences in pathloss for the different terrain types defined, and also the reference case of Free Space Pathloss. Terrain is defined thus:

– Terrain A - associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities.
– Terrain B - characterized with either mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities.
– Terrain C - associated with minimum path loss and applies to flat terrain with light tree densities.

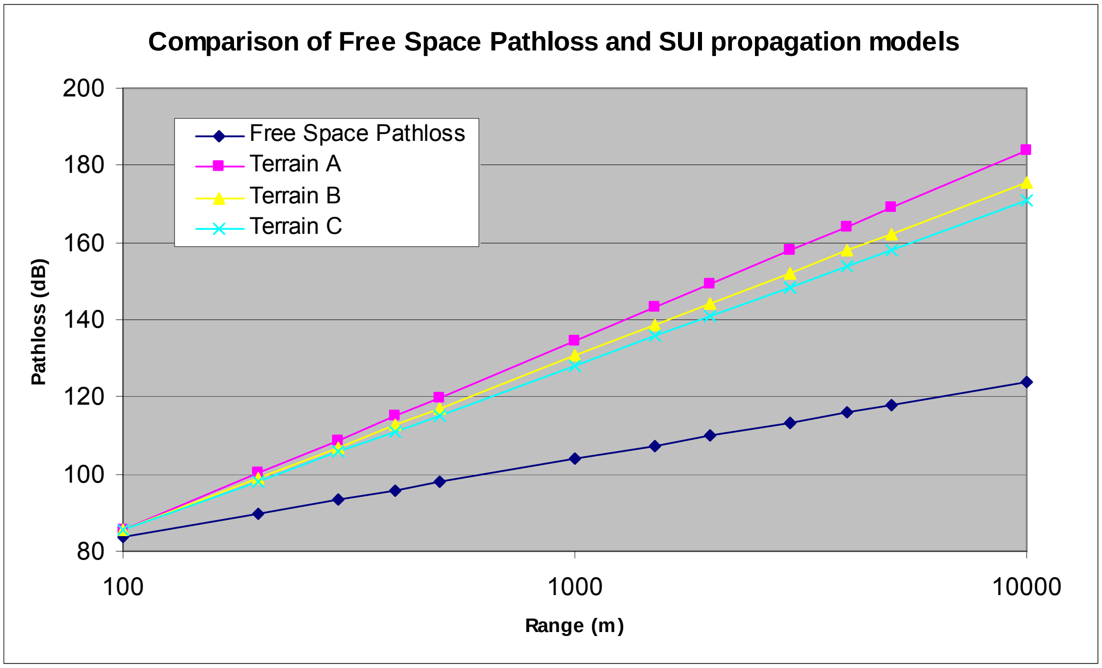

Figure 7 Pathloss against range for the SUI [7] *@3.65GHz, Base station height = 25m, Subscriber station height = 2m.*

The simulation considers both the downlink and uplink in determining if a link can be supported. Link limitation is determined and therefore the limiting link *System Gain* is used.

7.1.4. MCS selection algorithm

Based on the limiting link *System Gain* the highest order MCS is allocated to a specific link.

7.1.5. DCS (Dynamic Channel Selection) algorithm

The DCS algorithm used in the simulation is represented thus:

– Determine the number of channels available.
– Set zero output powers for all devices.
– For the next BS/AP device select the least interfered channel. Once a channel is selected set the output power for that device (BS/AP and subscribers) to maximum.

- Repeat previous step for all BS/AP devices selecting the channel with the least interference power each time.

7.1.6. Long-term fading power control algorithm

Link output powers are set based on the minimum transmit power to meet the pathloss for a given link and the MCS selected for a given link.

7.1.7. Interference calculation

A representation of the mechanism for interference calculation is given in Figure 8.

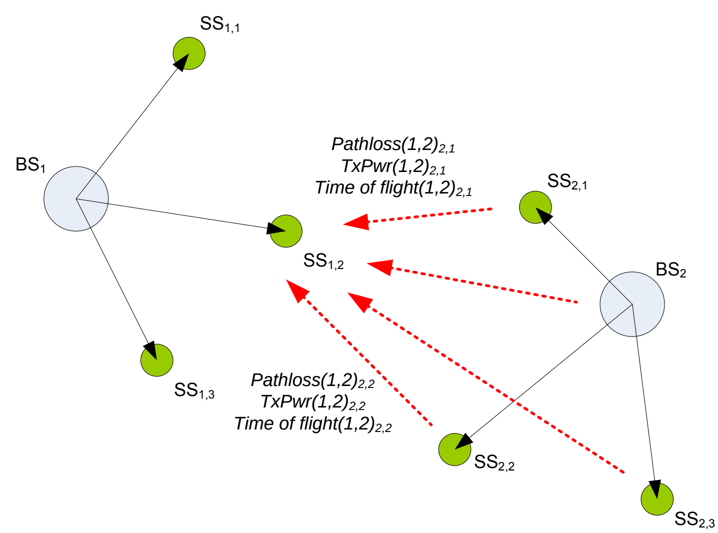

Figure 8 *A representation of the interference geometry calculation.*

In calculating interference the following analysis is applied:

- All devices are considered (excluding any BS/SSs associated with the focus device).
- Time of flight is taken into account based on the distance from all devices to the focus device.
- Link budget parameters are considered, e.g. transmit power.
- Antenna off bore sight contribution is considered (where applicable).
- Instantaneous interference power contributions are aggregated to provide an interference contribution at the focus node.

7.1.8. Traffic modeling and buffering simulation assumptions

Figure 9 provides a representation of the mechanism by which the simulation traffic handling, the buffering of the traffic and the scheduling on a frame by frame basis. A representation of this scheduled traffic on the air interface is given in Figure 10.

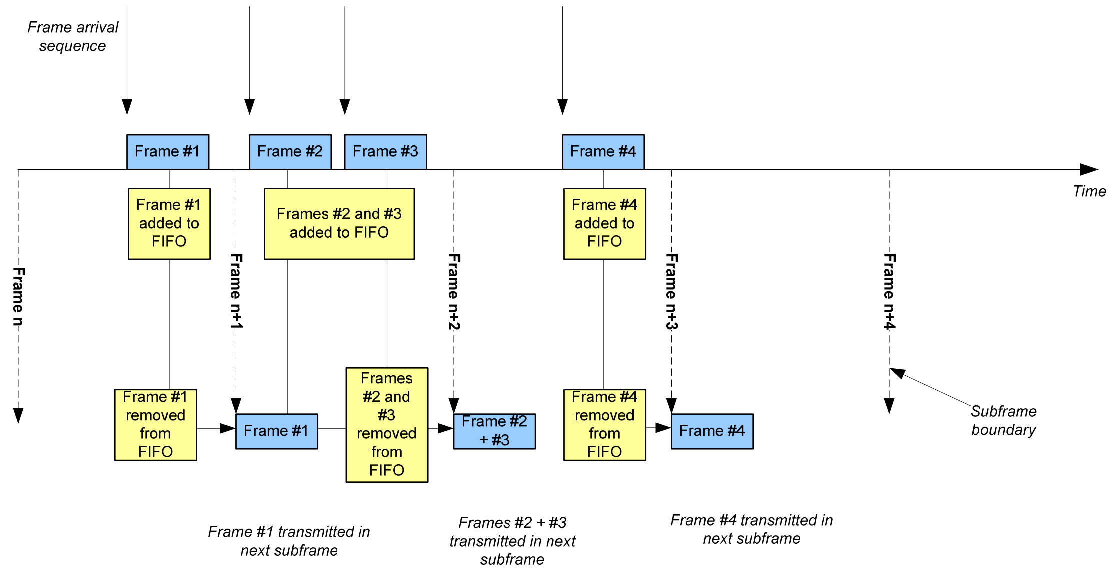

Figure 9 *A representation of the simulation's traffic handling, buffering, and scheduling.*

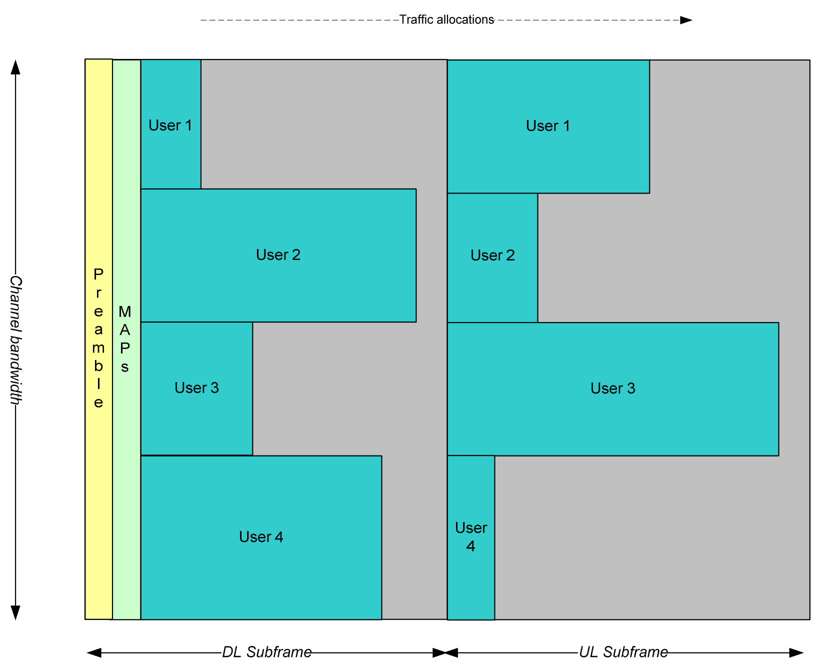

Figure 10 *A representation of the simulation's method of scheduling user traffic on to the air interface.*

7.1.9. 802.11y model

The 802.11y model used in the simulation is based on the 802.11 [8] which contains the former P802.11e amendment providing QoS support. HCF (Hybrid Coordination Function) is specified in the 802.11e amendment. HCF consists of EDCA (Enhanced Distributed Channel Access, distribution function) and HCCA (HCF Controlled Channel Access, centralized function). WMM (Wi-Fi Multimedia) certifies the EDCA and TXOP (Transmit Opportunity) features. EDCA and TXOP features enhance the QoS support in 802.11. EDCA introduces 4 AC (Access Categories) that prioritizes traffic class access to the air interface. TXOPs are used to provide a station with a time period in which to transmit in a non-contended manner.

	AC_VO	AC_VI	AC_BE	AC_BK	High (AC H)	Medium (AC M)	Low (AC L)
AIFSN:	2	2	3	7	2	4	7
CWmin:	3	7	15	15	7	10	15
CWmax:	7	15	1023	1023	7	31	255

Figure 11 *Values for EDCA 4 AC parameters [9].*

These changes based on 802.11e are reflected in the state flow given in Figure 12.

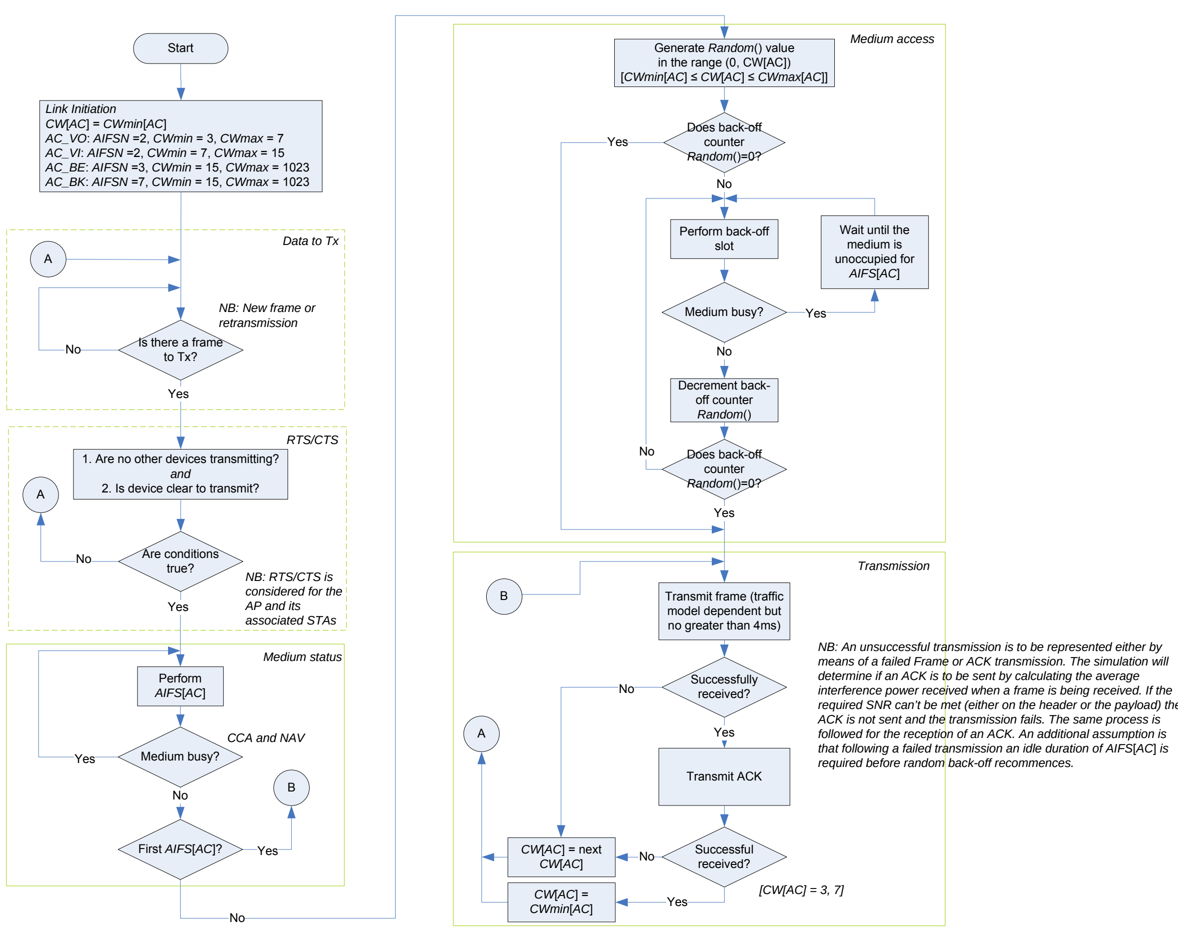

Figure 12 *802.11y model for medium access control.*

7.1.10. Fairness metric calculation

Why is *channel occupancy* a good metric for analysis?

MAC level fairness: At THE MAC level, the amount of time that a system is radiating energy on the channel, including overhead, ACKs, CTS, whatever, is assumed to be "good use of the channel". Systems shouldn't be penalized because they are inherently more "good" in their use of the channel. For instance, if the MAC level simulation shows equal opportunity to transmit, yet one system gets higher throughput and better access latency, that's just because that particular system is inherently more efficient.

7.2. Deviation and clarification of simulations based on 802.19 simulation parameters document [3]

There are some aspects of simulation configuration that are different from the simulation parameters document. These changes are summarized thus:

- To retain some simplification in the simulation scenarios and accentuate the demonstration of interference pathologies Omni antennas are used for both base station and subscriber station entities.
- 10MHz channels are assumed.
- Perfect RTS/CTS is assumed between 802.11 devices. For example if the simulation contains 2 802.11 APs and their respective STAs then no errors will be caused by lost or failed reception of 802.11 RTS/CTS transmissions. The motivation for the choice of this configuration provided, again, some simplification to the results by ruling out a known source of FER increase.
- In order to not exceed the maximum EIRP of a *802.16h* BS the per subscriber output power is reduced accordingly:

$$Max\_16h\_DL\_EIRP\_per\_SS = Max\_16h\_BS\_EIRP - 10\log(Num\_SS) \qquad [4]$$

$$Max\_16h\_UL\_EIRP = Max\_16h\_SS\_EIRP \qquad [5]$$

In this way DL allocated power for a particular SS is provided for the duration of the simulation. This is a fixed allocation regardless of the number of SS transmitting in a Symbol or frame – i.e. dynamic power allocation is not supported. This situation does not exist for the case of 802.11y. Since DL transmission is undertaken serially the expression is simplified thus:

$$Max\_11y\_DL\_EIRP\_per\_SS = Max\_11y\_BS\_EIRP \qquad [6]$$

$$Max\_11y\_UL\_EIRP = Max\_11y\_SS\_EIRP \qquad [7]$$

It is important to recognize regulatory limitations on PSD (Power Spectral Density) as described in 5.1.

At maximum power then *subchannelization gain* can not be applied for 802.16h systems given that the maximum PSD will be violated.

8. Simulation results and analysis

This section presents a range of simulation results with accompanying discussion. The results are divided into three main areas:

- Collocated simulation results
- Spatially distributed simulation results
- Optimization studies

8.1. Collocated simulation results

8.1.1. The simulation configuration and motivation

Figure 13 presents an illustration of a simplified simulation scenario used to prove some preliminary results and demonstrate aspects of coexistence. The figure presents a simplified scenario where the pathloss values between all devices is set to a nominal 1dB. The power control algorithm is disabled, meaning that the device output powers would be set to a value significantly higher than that which would normally be set for such low pathlosses. The configuration ensures that all devices can receive from all other devices and that interference, when apparent, is at a high level.

The motivation for this configuration provides an environment in which variability is reduced and fundamental conclusions about coexistence can be drawn. Results in this section cover:

- Validation of simulation environment, line rates, 802.16h and 802.11y individual behaviors.
- Demonstrate effective sharing for simple collocated topologies.
- Look at average and distributed results from the simulation. For example *average delay* is important but also the importance of calculating variance, or standard deviation, to get an idea of jitter behavior.
- Describe the ‘trumpet’ curves as a realization of fair sharing occupancy.

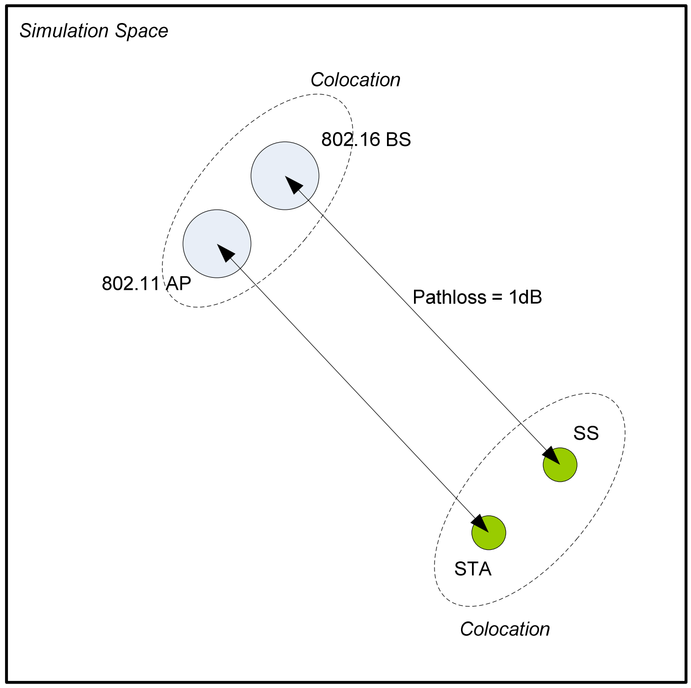

Figure 13 *Collocated simulation configuration.*

Results are based on parameters defined in [3]. Each BS/AP has a single associated SS/STA associated.

One 802.16 system (10MHz channel) with full access to the channel sees a maximum throughput rate:

– DL = ~17.8Mbps: UL = ~9.1Mbps

One 802.11 system (10MHz channel) with full access to the channel sees a maximum throughput rate:

– DL = ~13.5Mbps: UL = ~13.5Mbps

Two 802.16 system (10MHz channel) with full access to the channel sees a maximum throughput rate:

– DL = ~8.9Mbps: UL = ~4.5Mbps

Two 802.11 system (10MHz channel) with full access to the channel sees a maximum throughput rate:

– DL = ~6.6Mbps: UL = ~6.6Mbps

8.1.2. 802.16h and 802.11y coexistence

This subclause presents simulation results for a varying numbers of collocated 802.11 and 802.16 systems.

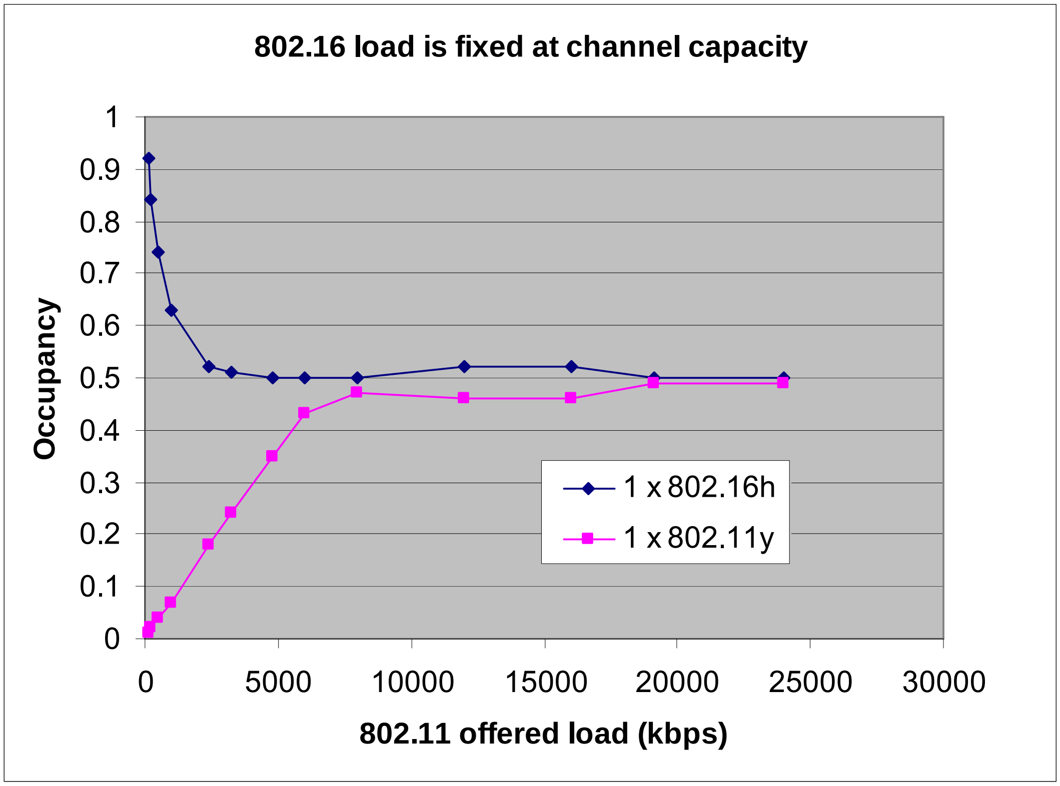

Figure 14 *Channel occupancy results for a collocated device scenario.*

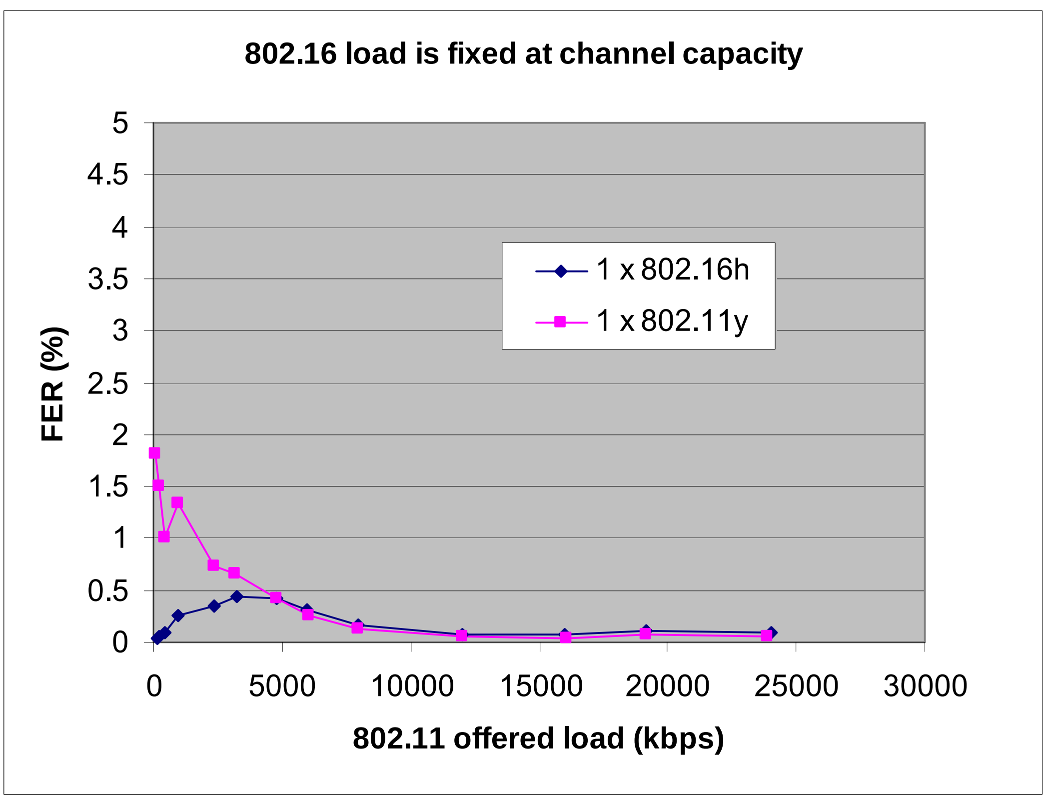

Figure 15 *FER results for a collocated device scenario.*

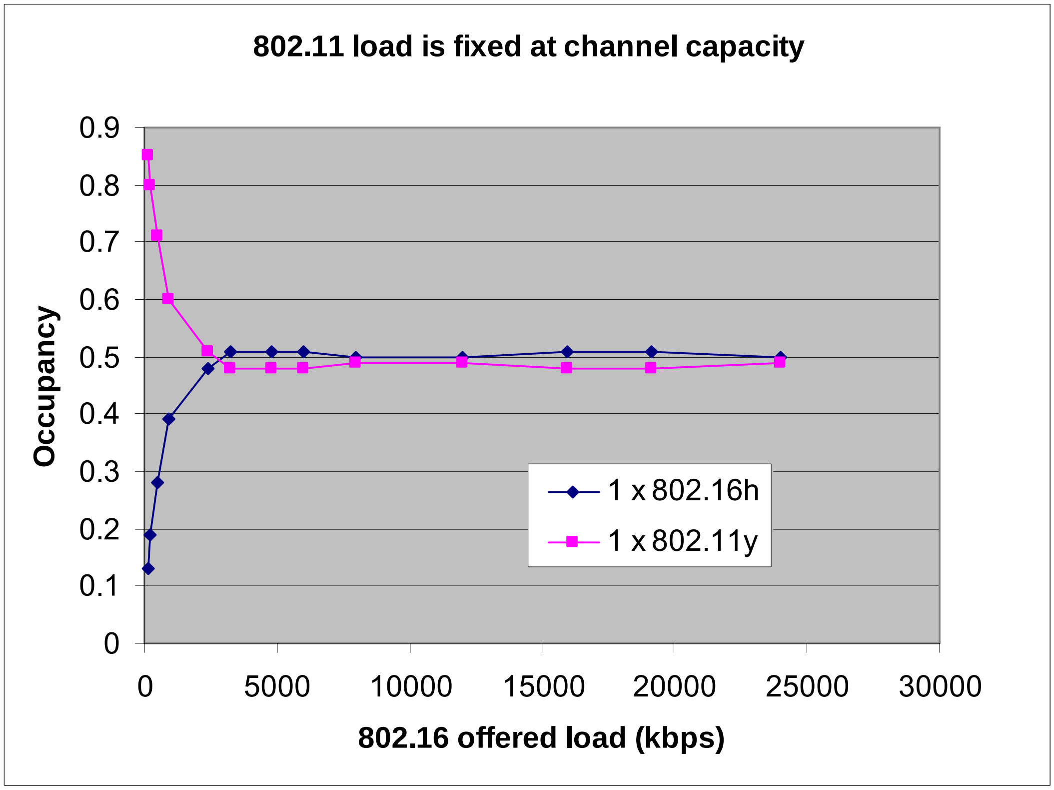

Figure 16 *Channel occupancy results for a collocated device scenario.*

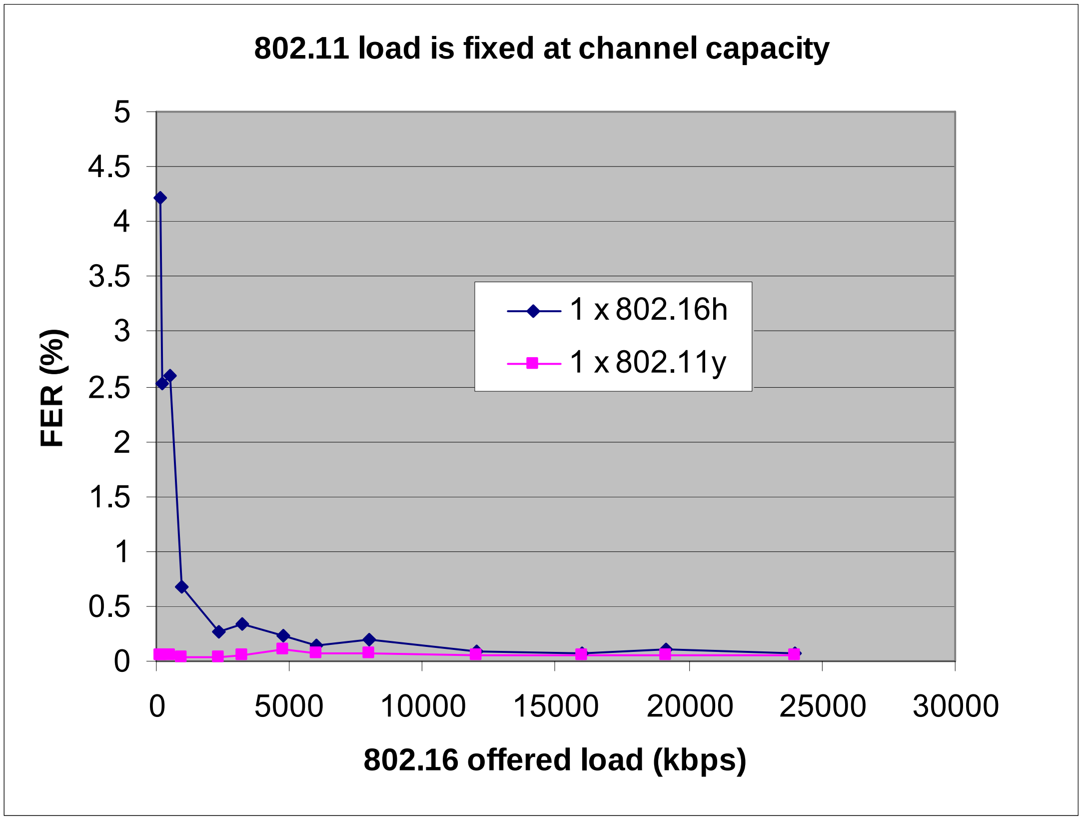

Figure 17 *FER results for a collocated device scenario.*

Findings:

- The DMA algorithm provides fair sharing of the medium for the case where 802.11 and 802.16 individually have offered loads at the channel occupancy. The interesting and important point to note is that when 802.11 loading is high and 802.16 loading is low then 802.16 does not demand 50% of the channel but recognizes that 802.11 has an appreciably higher offered load requirement.
- Results show that FER levels peak under conditions of low loading but then quickly reduce to residually low levels. This behavior is due to the fact that under low loading conditions there is increased uncertainty our medium access. Under low loading 802.16 frames are not allows full and the *FRSTn* location will be towards the end of the frame; in this case there is no defined end of transmission in which the following frame is claimed without ambiguity. However as the loading increases then this ambiguity reduces and the FER falls.

8.2. Spatially distributed simulation results

8.2.1. The simulation configuration and motivation

Figure 18 presents a representation of a spatially distributed scenario. In this case all BS/AP and associated subscribers are randomly located within a defined simulation space. The parameters defined in [3] are used to model the pathloss between randomly located devices. MCS selection and power control algorithms are applied as defined. In all simulation configurations there are up to 4 SS/STAs associated to a BS/AP.

Moving to a spatially distributed scenario beyond a scenario in which all devices are collocated requires some analysis of problems of *hidden nodes*. FRS transmission and CTS reception, from the point of view of 802.16h, is considered and simulation results presented.

FRS transmissions are 802.11 CTS messages which are configured as *CTS-to-self* transmissions. These are transmitted by an 802.16 BS and detectable by an 802.11y device operating in the band. CTS reception is the capability of an *802.16h* device to receive (and obey) CTS transmissions from 802.11 devices. It should be noted that FRS transmissions are not specifically *CTS-to-self* transmissions but in the context of this analysis for coexistence with 802.11-based devices in the 3.65-3.7GHz band then this is indeed the case.

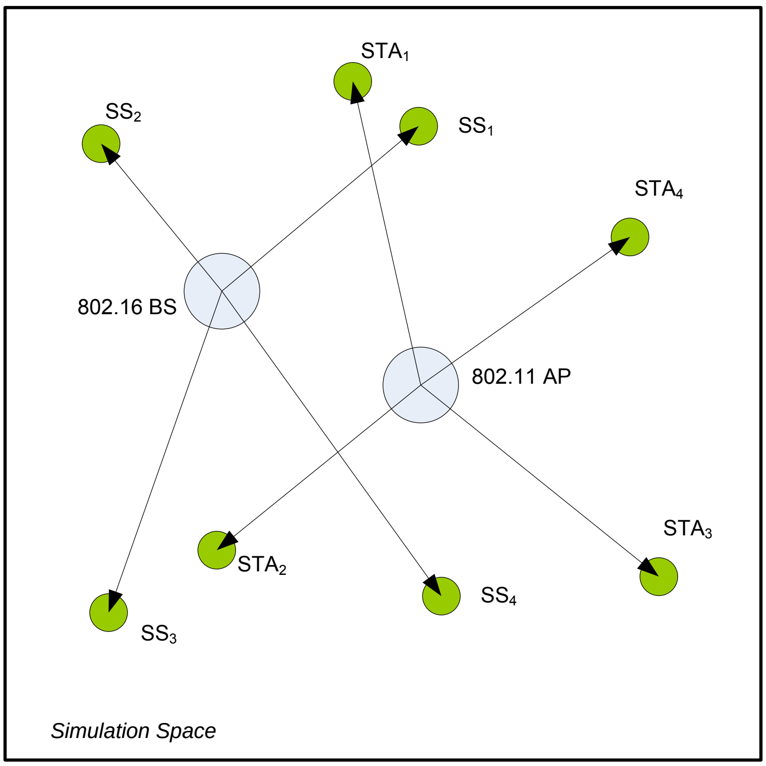

Figure 18 *Spatially distributed simulation configuration. In all simulation configurations there are up to 4 SS/STAs associated to a BS/AP.*

8.2.2. 802.16h and 802.11y coexistence in spatially distributed scenarios with FRS/CTS

The results presented in this subclause present an analysis of FRS and CTS. The simulation explicitly calculates whether a FRS or CTS transmission can be received by a particular device. This is based on the pathloss between devices and the related link budget parameters. In this way it is possible for a FRS or CTS to fail to be received by a corresponding device and subsequent collisions to occur.

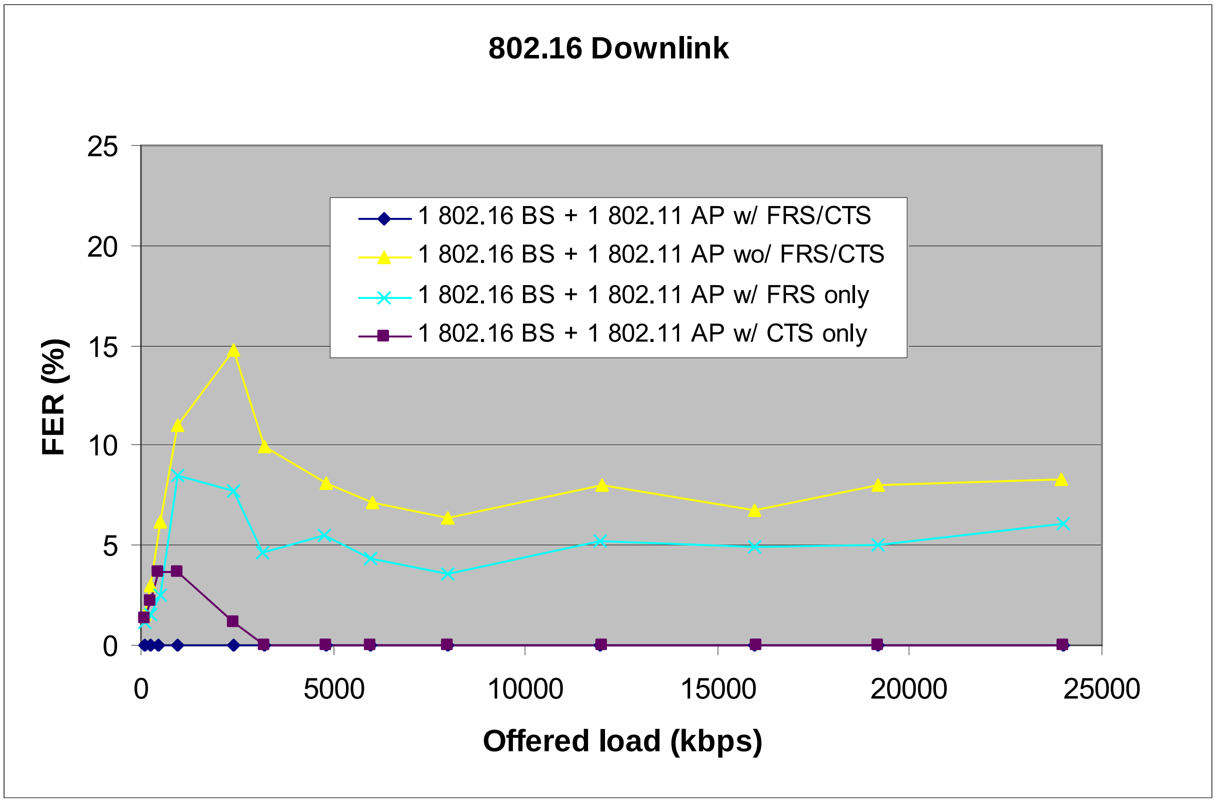

Figure 19 *FER results for a spatially distributed device scenario.*

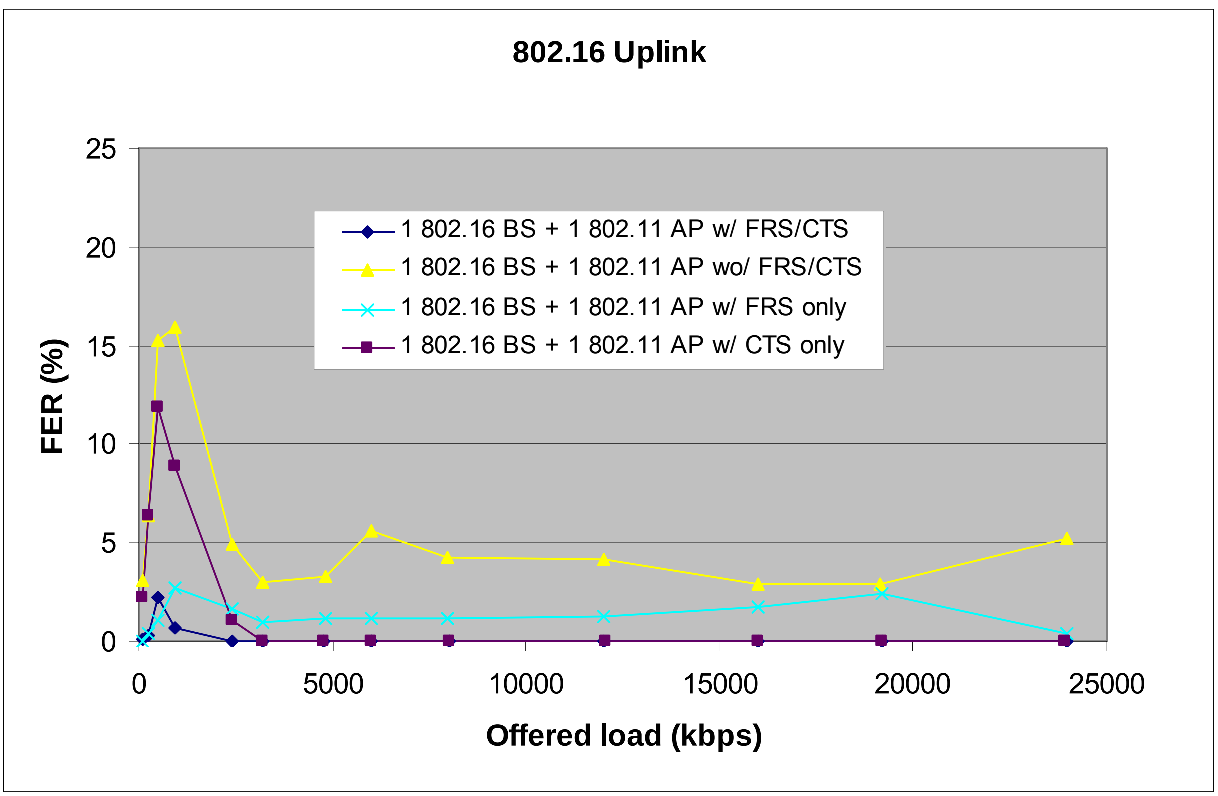

Figure 20 *FER results for a spatially distributed device scenario.*

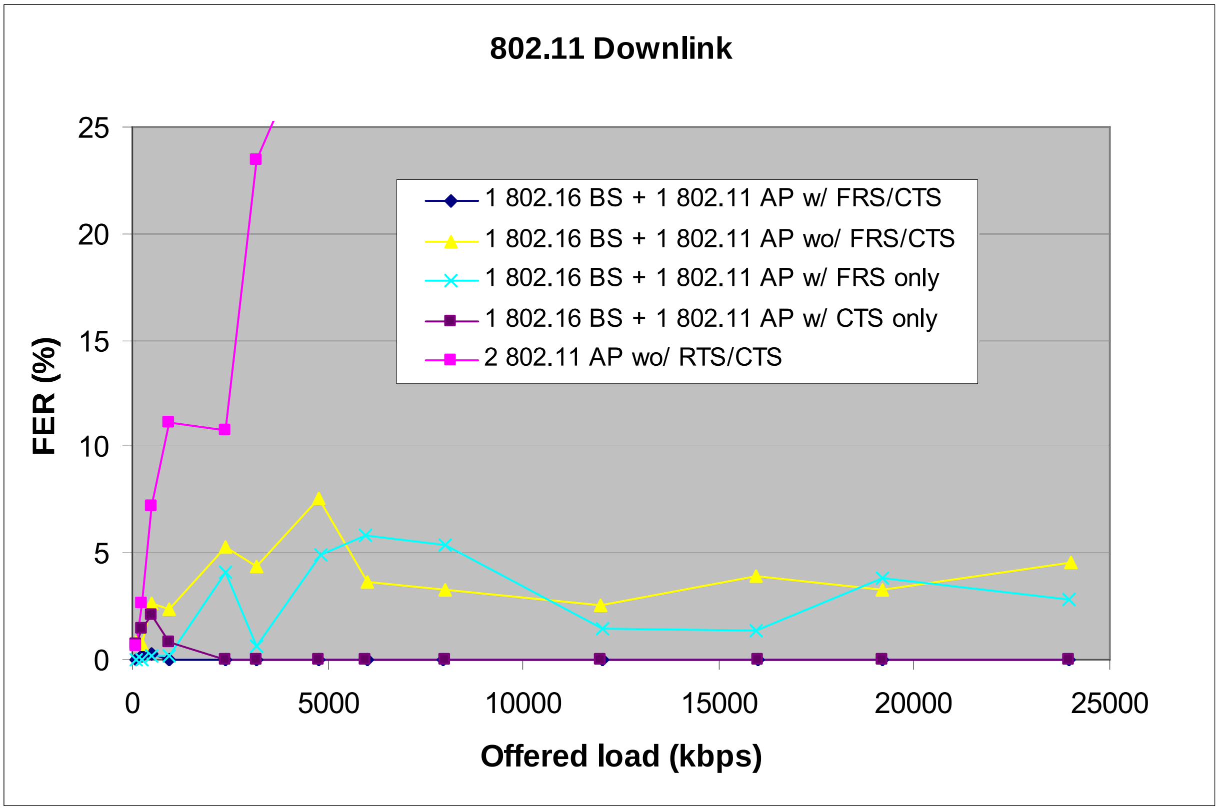

Figure 21 *FER results for a spatially distributed device scenario.*

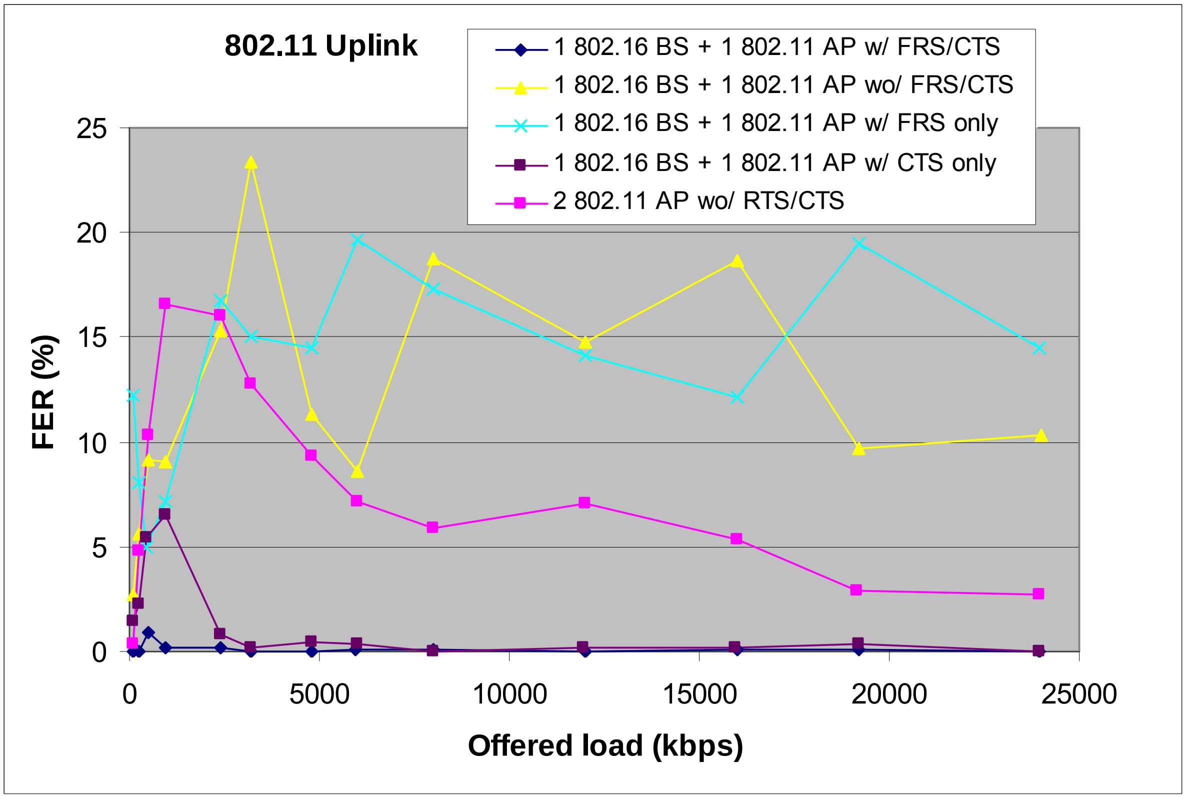

Figure 22 *FER results for a spatially distributed device scenario.*

8.3. Optimization studies

This section considers optimization studies related to specific aspects of the DMA algorithm. Areas of investigation cover:

- Sensitivity analysis for variations in 802.11y *aPropagationTime*, EDCA parameters, and the size of the DMA region
- Requirements for EQP (Extended Quiet Period) frame
- MAXFRST
- *K* term
- FRS/CTS optimization

8.3.1. Sensitivity analysis for variations in 802.11y *aPropagationTime*, EDCA parameters, and the size of the DMA region

An investigation is conducted that looks at the sensitivity of the 802.11 parameter *aPropagationTime* and EDCA parameters, and the allocated size of the DMA region.

To paraphrase [3] range dependency on propagation time is considered in subclause 7.3.2.9 '*Country information element*' of [8] and states:

> *The Country information element contains the information required to allow a station to identify the regulatory domain in which the station is located and to configure its PHY for operation in that regulatory domain.*

> *The Coverage Class field of the regulatory triplet specifies the aAirPropagationTime characteristic used in basic service set (BSS) operation, as shown in Table 27. The characteristic aAirPropagationTime describes variations in actual propagation time that are accounted for in a BSS and, together with maximum transmit power level, allow control of BSS diameter.*

From Table 27 [8]:

Coverage class value = 0 for *aAirPropagationTime* ≤1µs

Coverage class value = 1 for *aAirPropagationTime* 3µs

Coverage class value = 2 for *aAirPropagationTime* 6µs

…

Coverage class value = 31 for *aAirPropagationTime* 93µs

Subclause 9.8.4 of [4] states:

> *Radio waves propagate at 300 m/µs in free space, and, for example, 3 µs would be the ceiling for BSS maximum one way distance of ~450 m (~900m round trip).*

For the outdoor case: ***Coverage class value* = 6**, (18µs), giving a **cell radius of 2600m**, round trip 5400m. The maximum cell radius as calculated in Annex 1 clause 12.

For the indoor case: ***Coverage class value* = 0**, (≤1µs), giving a **cell radius of 150m**, round trip 300m.

Referencing to 9.2.10 *DCF timing relations* in [8]:

(*Legend 20MHz/10MHz/5MHz*)

SIFS = 16/32/64 µs

AIFS[AC] = SIFS + AIFSN[AC].aSlotTime

From Figure 170 [8]

aSlotTime = aCCATime + aRTTXTurnaroundTime + aAirPropagationTime + aMACProcessingTime

aCCATime (CCA) = 4/8/16 μs

aMACProcessingDelay (M2) = 2/2/2 μs

aRXTXTurnaroundTime (Rx/Tx) = 2/2/2 μs

aAirPropagationTime (D2) = 18μs (*bandwidth independent*) for the outdoor case.

aAirPropagationTime (D2) = 1μs (*bandwidths independent*) for the indoor case.

Four configurations with corresponding aSlotTime and AIFS[AC] Medium Access parameters are given in Figure 23.

	AC_VO AIFSN[AC_VO] = 2 [Contention Window = 3, 7]	AC_BE AIFSN[AC_BE] = 3 [Contention Window = 15, 1023]
Outdoor environment	aSlotTime = 26/30/38μs AIFS[AC_VO] = 68/92/140μs	aSlotTime = 26/30/38μs AIFS[AC_BE] = 94/122/178μs
Indoor environment	aSlotTime = 9/13/21μs AIFS[AC_VO] = 34/58/106μs	aSlotTime = 9/13/21μs AIFS[AC_BE] = 43/71/127μs

Figure 23 *aSlotTime and AIFS[AC] durations based on AC and deployment assumptions.*

The DMA region varies in size but is bounded by the frame duration, which itself is defined by the number of OFDM symbols contained within a frame. Section 6.2.1 introduces the size of the DMA region based on Mobile WiMAX System Profile parameters [6].

<*Results to be added.*>

Figure 24 Sensitivity analysis for variations in 802.11y aPropagationTime, EDCA parameters, and the size of the DMA region.

8.3.2. Analysis of EQP frame requirements

This analysis investigates the need for EQP frames in addition to the DMA algorithm

<Results to be added.>

Figure 25 *Analysis of EQP frame requirements.*

8.3.3. Analysis of the maximum duration of FRSTn (MAXFRST)

This analysis investigates the maximum duration of *FRSTn* (*MAXFRST*) as specified in the DMA algorithm.

<Results to be added.>

Figure 26 *Analysis of the maximum duration of FRSTn (MAXFRST).*

8.3.4. Analysis of sensitivities to the *K* term

This analysis investigates the impact of the *K* term as specified in the DMA algorithm.

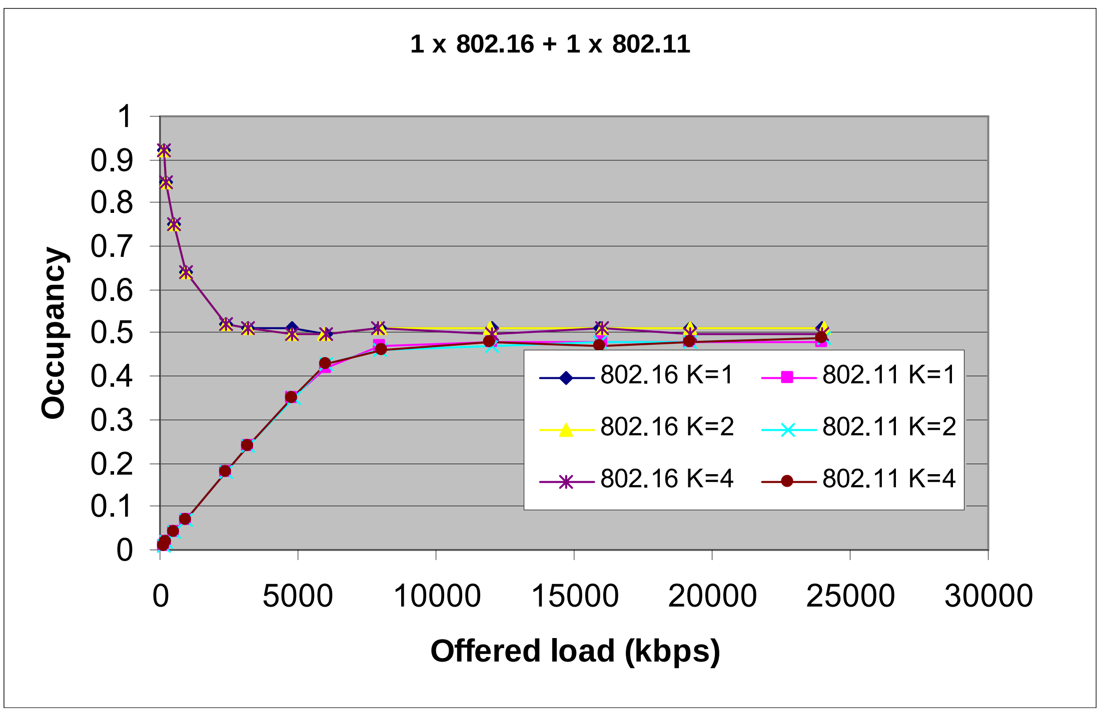

Figure 27 *Channel occupancy results for a collocated device scenario.*

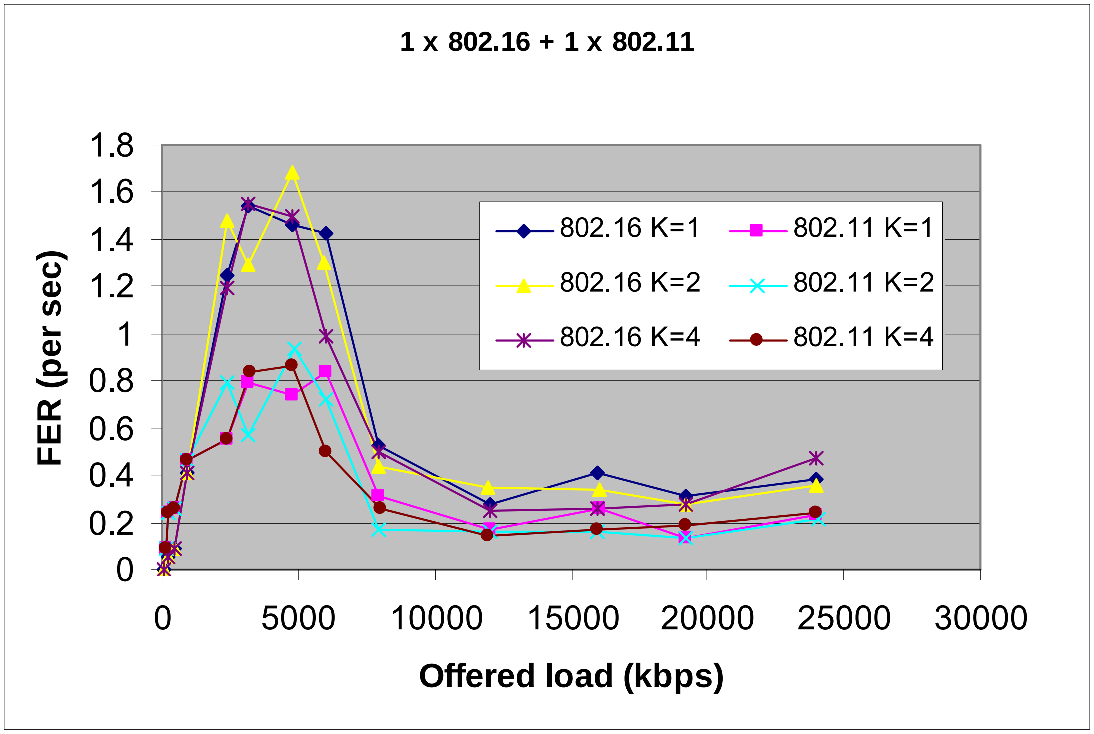

Figure 28 *FER results for a collocated device scenario.*

Findings:

- The *K* term appears to demonstrate a low sensitivity.

8.3.5. Analysis of FRS/CTS optimization

This analysis investigates the impact of FRS and CTS optimization.

<Results to be added.>

Figure 29 *Results.*

Findings:

- FRS/CTS reduces FER but also throughput
- Need both an FRS in the DL and UL – implementation dependant.
- CTS-Rx is more influential than FRS-Tx.
- So in summary there is a trade off:
  - o FRS-Tx/CTS-Rx disabled: EQP helps *802.11y*, but not *802.16h* (due to the increased probability

of collision).

  - FRS-Tx/CTS-Rx enabled: Error rates are low and EQP provides no discernable advantage but demonstrates a reduced line rate for *802.16h*.

- How loud to transmit these signals. Too loud and the throughput supported by both systems is reduced unnecessarily; too quite and the FER increases. This is really an issue for coexistence.
- The results were as expected: no FRS-Tx/CTS-Rx and the FER is high. FER is very low when using the assumption of perfect FRS/CTS reception/transmission. With an FER in the middle ground representing the assessment of whether or not an FRS/CTS can be heard or not based on link budget analysis.

Problems occur when the distribution of collocated system is over an appreciably large area that the CTS/FRS transmissions can not be heard by other systems' network elements – i.e. the hidden node problem becomes apparent. This is primarily demonstrated with high FER for *802.16h* DL and high FER for *802.11y* UL. This is a situation where a *802.11y* STA's CTS is not heard by 16BS, and is due to lower output powers of the *802.11y* STA.

For certain cell sizes all the device can be heard and the error rate is zero. As the cell size increases FER peaks and falls away again as the number of links supported reduces to zero given that the link budget can not be met in the simulation area considered and as a result very few links are supported for the sparse density.

For a mobile SS the maximum EIRP is 26dBm. This is some 14dB below that permitted for the BS. Fixed SS are permitted to transmit at 40dBm EIRP. There is however a 10dB gain in FRS/CTS reception based on the CCA-CS threshold compared with the CCA-ED threshold. However this is not sufficient.

A way of effectively boasting the *802.11y* STA output power helps.

Possible solutions:

- Limit BS output powers – not an appealing prospect.
- Increase mobile Max. EIRP – requires regulatory approval.
- Limit cell sizes to ensure CTS transmissions can be heard – again not a great prospect from the perspective of coverage.
- Suggest a lower CCA-CS threshold. -95dBm [instead of -85dBm] (10MHz). This effectively gives a further 10dB boost to the CTS transmissions from the *802.11y* STAs. This seems to work well – with low FERs for all cell sizes. However what about the prob. of false detection? There are also good results if the CCA-CS increased sensitivity is applied _only_ to the *802.16h* equipment. In this way this becomes our propriety enhancement without impacting the default numbers in the *802.11y* standard.
- Live with it. This simulation scenario is the worst case situation: systems are overlapping, and omni antennas are used. The real situation will probably be better than this pessimistic analysis.

9. References

[1] IEEE P802.16h/D3: *Air Interface for Fixed Broadband Wireless Access Systems Improved Coexistence Mechanisms for License-Exempt Operation*, Draft Standard.

[2] Paul Piggin, Ken Stanwood, Yair Bourlas, Kathy Sohrabi, *Enhancements to UCP LBT,* IEEE 802.16-07/078, September 2007.

[3] Paul Piggin, *Parameters for simulation of Wireless Coexistence in the US 3.65GHz band,* IEEE 802.19-07/11, October 2007.

[4] IEEE P802.11y/D5.0: 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.

[5] Title 47 – Telecommunication, Part 90 – Private Land Mobile Radio Services: Subpart Z - Wireless Broadband Services in the 3650-3700 MHz Band, Part 90.1301 - 90.1337, Federal Communications Commission.

[6] WiMAX Forum Mobile System Profile Release 1.0 Approved Specification (Revision 1.2.2: 2006-11-17).

[7] IEEE 802.16.3c-01/29r4: Channel Models for Fixed Wireless Applications, Erceg et al., IEEE 802.16 Broadband Wireless Access Working Group, January 2001.

[8] 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.

[9] Analysis of IEEE 802.11e for QoS Support in Wireless LANs, Mangold, Choi, Hiertz, Klein, Walke, IEEE Wireless Communications, December 2003.

[10] Report and Order and Memorandum Opinion and Order in the Matter of Wireless Operation in the 3560-3700MHz band, FCC 05-56, Federal Communications Commission.

[11] Memorandum Opinion and Order in the Matter of Wireless Operation in the 3560-3700MHz band, FCC 07-99, Federal Communications Commission.

[12] IEEE Standard for Local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems.

10. Abbreviations and definitions

802.11y A term used to describe systems employing features from the 802.11y amendment [4] to the 802.11 standard [8].

802.16h A term used to describe systems employing features from the 802.16h amendment [1] to the 802.16 standard [12].

AC Access Category

aEQP Adaptive Extended Quite Period

AIFS Arbitration Inter-Frame Space

AIFSN Arbitration Inter-Frame Space Number

AP	Access Point (An 802.11 term for a Base Station)
BS	Base Station (An 802.16 term)
CA	Coexistence Assurance
CCA	Clear Channel Assessment
CCA-CS	Clear Channel Assessment Carrier Sense
CCA-ED	Clear Channel Assessment Energy Detect
CBP	Contention Based Protocol
CMA	Clear Medium Assessment
CTS	Clear To Send
DCS	Dynamic Channel Selection
DFS	Dynamic Frequency Selection
DL	Downlink
DMA	Dynamic Medium Acquisition
EDCA	Enhanced Distributed Channel Access
EIRP	Effective Isotropic Radiated Power
EQP	Extended Quiet Period
FCC	Federal Communications Commission
FER	Frame Error Rate
FRS	Frame Reservation Signal
FRST	Frame Reservation Start Time
HCCA	HCF Controlled Channel Access
HCF	Hybrid Coordination Function
LBT	Listen Before Talk
PSD	Power Spectral Density
RTG	Receive Transition Gap
RTS	Ready To Send
SIFS	Short Inter-Frame Space
SS	Subscriber Station (An 802.16 term)
STA	STAtion (An 802.11 term for a subscriber station)
SUI	Stanford University Interim
TAG	Technical Advisory Group
TTG	Transmit Transition Gap
TXOP	Transmit OPportunity
UCP	Uncoordinated Coexistence Protocol

UL Uplink

ULS Universal Licensing System

WMM Wi-Fi MultiMedia

11. Table of contents

12. Annex 1 - *802.11y uplink budget evaluation*

802.11y uplink budget evaluation for aPropagationTime calculation

This analysis is used to calculate the maximum range of an 802.11y cell in the 3.65GHz band. This maximum range is used to calculate the maximum round trip time used in turn to evaluate 802.11y medium access parameters.

Assumptions

- Fixed subscriber (max. output power 5W (37dBm))
- Subscriber cabling/connector loss = 0.5dB
- Base Station antennas gain = 18dBi (Sectorized)
- Excluding: MIMO, diversity gains, HARQ,

Max STA EIRP	5	W	5MHz channel		
	37	dBm			
STA connector loss	0.5	dB			
BS cabling loss	1	dB			
BS antenna gain	18	dBi			
Imp. Loss	0	dB			
Rx sens.	-88	dBm	1.5Mbps	BPSK 1/2	
System Gain	**141.5**	**dB**			
			SUI parameters	Terrain B (suburban)	
			AP height	25	m

			STA height	10	m
SUI Pathloss	**141.5**	**dB**	Frequency	3675	MHz
			Cell range	**2600**	**m**