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Source(s)	Mariana Goldhamer Alvarion Tel Aviv, 21 HaBarzel Street Israel Voice: +972 3 6456241 Fax: +972 3 645 6204 mailto:mariana.goldhamer@alvarion.com
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Abstract	
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Proposal for an un-restricted contention-based protocol

Mariana Goldhamer
Alvarion

Introduction

This contribution enhances the 802.16h Coordinated Coexistence approach for the possibility that 802.11y will synchronize its frames such to avoid interference to systems based on the 802.16h coordinated approach.

We address:

- The procedures characteristic for an 802.11-based contention protocol.
- The minimum requirements for an 802.11-based contention protocol to avoid creating interference to the 802.16-based Coordinated Coexistence Protocol (CXP).
- Enhancements to the 802.16h coordinated approach (clause 15) to optimally share the spectrum with 802.11-based contention protocols suitable to operate as un-restricted contention-based protocols

FCC in the R&O 07-99 defines the Un-restricted Contention Based Protocols as follows:

§ 90.7 Definitions.
"*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."

More clarifications are given in the text referring to certification:

" § 90.203 Certification required.
(o) Equipment certification for transmitters in the 3650-3700 MHz band.
(1) **Applications for all transmitters must describe the methodology used to meet the requirement that each transmitter employ a contention based protocol and indicate whether it is capable of avoiding co-frequency interference with devices using all other types of contention-based protocols** (see § § 90.7, 90.1305 and 90.1321 of this part);"

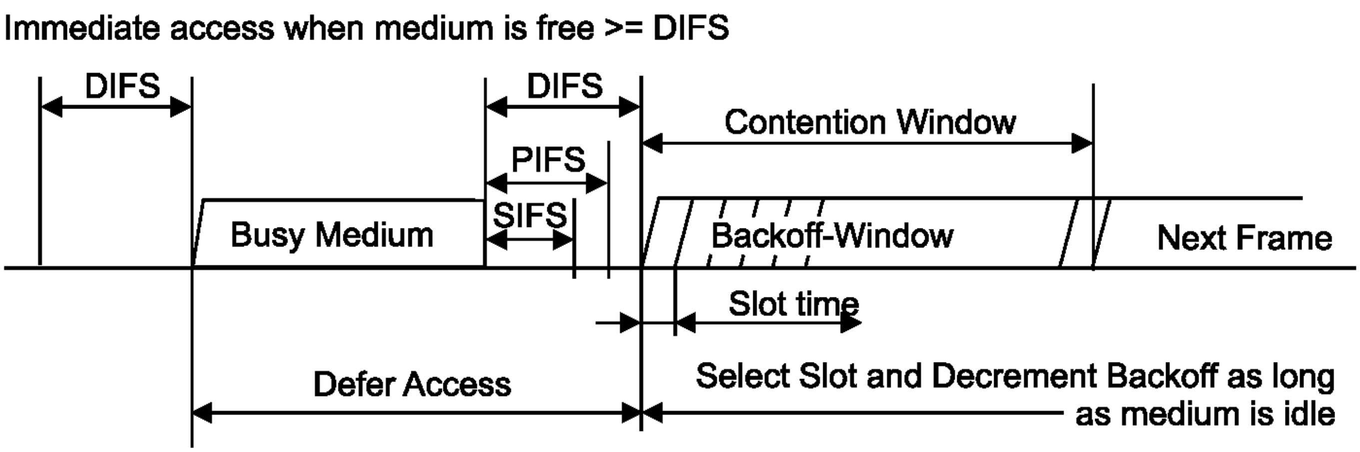
Procedures characteristic for an 802.11-based contention protocol

In this chapter we review the main elements of the Contention-based protocol, as described in the 802.11 standard and its amendments.

Contention-based medium access

9.1.1 DCF

"The fundamental access method of the IEEE 802.11 MAC is a DCF known as *carrier sense multiple access with collision avoidance* (CSMA/CA). The DCF shall be implemented in all STAs, for use within both IBSS and infrastructure network configurations.
For a STA to transmit, it shall sense the medium to determine if another STA is transmitting. If the medium is not determined to be busy (see 9.2.1), the transmission may proceed. The CSMA/CA distributed algorithm mandates that a gap of a minimum specified duration exist between contiguous frame sequences. A transmitting STA shall ensure that the medium is idle for this required duration before attempting to transmit.
If the medium is determined to be busy, the STA shall defer until the end of the current transmission. After deferral, or prior to attempting to transmit again immediately after a successful transmission, the STA shall select a random backoff interval and shall decrement the backoff interval counter while the medium is idle. "



9.1.3 Hybrid coordination function (HCF)

"The QoS facility includes an additional coordination function called HCF that is only usable in QoS network (QBSS) configurations. The HCF shall be implemented in all QSTAs. The HCF combines functions from the DCF and PCF with some enhanced, QoS-specific mechanisms and frame subtypes to allow a uniform set of frame exchange sequences to be used for QoS data transfers during both the CP and CFP. The HCF uses both a contention-based channel access method, called the enhanced distributed channel access (EDCA)."
"b)The minimum specified idle duration time is not the constant value (DIFS) as defined for DCF, but is a distinct value (contained in the MIB attribute table dot11QAPEDCATableAIFSN for a QAP, and in the MIB table dot11EDCATableAIFSN for a non-AP QSTA, see 9.9.1) assigned either by a management entity or by a QAP.
c) The contention window limits aCWmin and aCWmax, from which the random backoff is computed, are not fixed per PHY, as with DCF, but are variable, contained in the MIB attribute tables."

9.2.4 Random backoff time

“A STA desiring to initiate transfer of data MPDUs and/or MMPDUs shall invoke the CS mechanism (see 9.2.1) to determine the busy/idle state of the medium. If the medium is busy, the STA shall defer until the medium is determined to be idle without interruption for a period of time equal to DIFS when the last frame detected on the medium was received correctly, or after the medium is determined to be idle without interruption for a period of time equal to EIFS when the last frame detected on the medium was not received correctly. After this DIFS or EIFS medium idle time, the STA shall then generate a random backoff period for an additional deferral time before transmitting, unless the backoff timer already contains a nonzero value, in which case the selection of a random number is not needed and not performed. This process minimizes collisions during contention between multiple STAs that have been deferring to the same event.
Backoff Time = Random() $\times$ aSlotTime, where:
- Random() = Pseudo-random integer drawn from a uniform distribution over the interval [0,CW], where CW is an integer within the range of values of the PHY characteristics aCWmin and aCWmax, aCWmin $\leq$ CW $\leq$ aCWmax. It is important that designers recognize the need for statistical independence among the random number streams among STAs.
- aSlotTime = The value of the correspondingly named PHY characteristic.”

The slot time for the 802.11 OFDM PHY is as follows:

17.3.8.6 Slot time
“The slot time for the OFDM PHY shall be **9 μs**, which is the sum of the RX-to-TX turnaround time, MAC processing delay, and CCA detect time (< 4 μs). The propagation delay shall be regarded as being included in the CCA detect time.”

Listen Before Talk levels

The “Listen Before Talk” is defined in 802.11 for other systems, like 802.16, as “CCA-ED”, Clear Channel Assessment – Energy Detection. The draft 802.11y/D3 (June 2007) says:

“**I.2.4 CCA-ED Threshold**
For operation in the 3.65-3.7 GHz band, the optional CCA-ED thresholds shall be less than or equal to -72dBm for 20 MHz channel widths; -75 dBm for 10 MHz channel widths; and -78 dBm for 5 MHz channel widths (minimum sensitivity for BPSK, R=1/2 + 10 dB in Table 145).”

Fragmentation

9.1.5 Fragmentation / defragmentation overview

“The process of partitioning a MAC service data unit (MSDU) or a MAC management protocol data unit (MMPDU) into smaller MAC level frames, MAC protocol data units (MPDUs), is called fragmentation. Fragmentation creates MPDUs smaller than the original MSDU or MMPDU length to increase reliability, by increasing the probability of successful transmission of the MSDU or MMPDU in cases where channel characteristics limit reception reliability for longer frames.”

Minimum requirements for an 802.11-based contention protocol to avoid creating interference to the 802.16-based CX - Frame

The minimum requirements for allowing bursty technologies to avoid creating interference to 802.16h systems using the Coordinated Coexistence are:

- Synchronization with the start of the CX Frame
- Separation in time between the CX Frame sub-frames dedicated to scheduled protocols (802.16) and bursty protocols, according to the rules presented below.

Synchronization with the start of the CX-Frame

There is a multitude of ways to synchronize an 802.11 AP (access Point) with the start of the 802.16 CX-Frame:

- GPS synchronization, based on the absolute time
- Network Time synchronization, based on the absolute time
- Synchronization with the CX Control Channel, using simple cognitive radio procedures.

The 802.11 stations may be further synchronized to Access Points using regular 802.11 procedures.

Separation in time of the technologies

The clause 15.4.2.1.2 describes the separation in time between the scheduled and Bursty technologies.
The existing approach does not assume that 802.11y will synchronize its transmissions with the 802.16h CX Frame. The interference avoidance is based on the LBT procedures to be applied BEFORE the Bursty sub-frame start. In case of synchronized operation, should be NO energy before the start of the sub-frames allocated to Bursty systems.

We attempt to minimize the changes to be done by 802.11y and provide a simple approach, allowing the operation a mix of 802.16 and 802.11 systems in a frequency channel, by a simple separation of the technologies in time. 802.11y will not need to implement the CXCC functionality, but only the simple CX Frame synchronization.
An 802.16h system will detect the existence of 802.11y systems in the band based on measurements during the CXCC slots dedicated to assessment of interference created by non-802.16h systems.

Insert the following text at page 113, row 42

15.4.2.1.3 Scheduling of restricted transmission opportunities

In the clause 14.4.2.1.2 was described the CX-Frame such to accommodate one or two Bursty systems.

However the 802.16 transmissions during the Common sub-frames in fig. 48 may create interference to the Bursty systems. On the other hand the channel and the spectrum will not be used effectively if the 802.16 systems are not able to communicate during the Bursty zone.

In specific bands and regulatory domains, as 3.65-3.7GHz in US, FCC defines an un-restricted contention protocol as a protocol which avoids creating interference to devices using all other types of contention-based protocols. A Bursty system using such a protocol will have to synchronize with the CX Frame and use for its transmissions only the time intervals dedicated to Bursty systems.

The synchronized approach for interference avoidance is based on the CX Frame in fig. h49', where no more than two 802.16h systems can share a frequency channel in the case that a Bursty system is detected. An 802.16h system will detect the existence of 802.11y systems in the band based on measurements during the CXCC slots dedicated to assessment of interference created by non-802.16h systems.

The following occupancy rules for the Master and Shared sub-frames are defined:

- MAC Frames 4N and 4N+1 are reserved for scheduled operation; the created time interval is named CXSBI (Coordinated Coexistence Schedule-Based Interval);
- MAC Frames 4N+2 and 4N -1 are reserved for bursty operation; the created time interval is named CXCBI (Coordinated Coexistence Contention-Based Interval);
- The scheduled systems using the channel may use the MAC Frames reserved for Bursty operation in a coordinated coexistence contention-based protocol (CXCBP) mode, defined in continuation;
- If there are two Master scheduled systems, the bursty systems using the channel may use the MAC Frames allocated to scheduled systems according to Slave rules
- If there is only one Master system, the bursty system may use the Shared MAC frame if respects the rules for downlink / uplink synchronization.

The CX Frame structure is shown below:

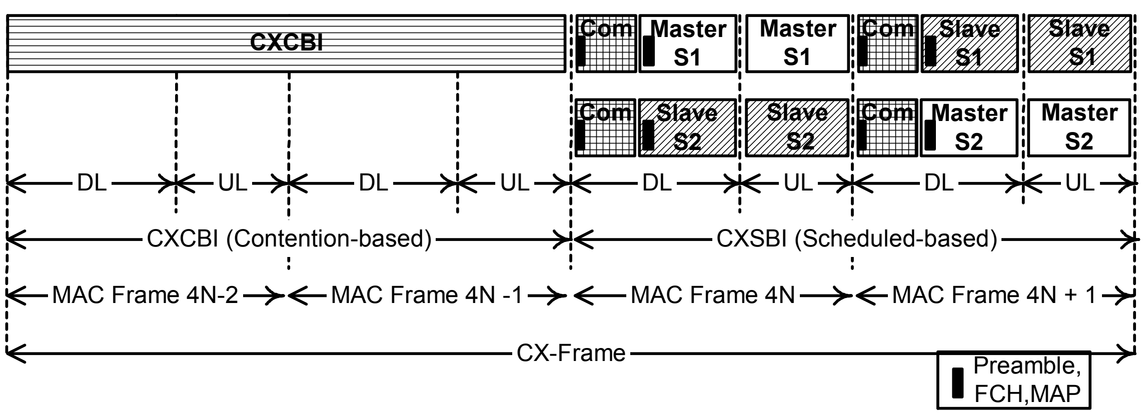


Figure h49' CX Frame structure for synchronized CXCBP

A. Rules for operation during CXSBI

An 802.11 system which does not create interference to an 802.16h system using the Coordinated Coexistence needs to respect the rules defined in clause 15, regarding:

- Downlink / Uplink synchronization
- Usage of CXCC
- Operational rules defined in clause 15.4.2.1.2.

B. Rules for operation during the CXCBI time interval

- Systems working during the CXCBI intervals will not create interference to 802.11 based systems. With this scope, it will be applied a special form of the contention-based protocol, named "Coordinated Coexistence Contention-Based Protocol" or CXCBP.

C. <u>Coordinated contention-based protocol</u>

The Coordinated Coexistence Contention-based Protocol (CXCBP) has the following basic elements:

- Frame structure derived from the CX Frame
- Detection of 802.11 systems
- Scheduled Listen-before-talk (SLBT)
- Contention window and quiet periods
- Logarithmic back-off
- Determination and scheduling of the transmit opportunities
- Longer slots as compared with 802.11.

<u>CXCBP: Frame Structure</u>
The Coexistence Frame will comprise two synchronized intervals:

- Contention-based interval (CXCBI)
- Scheduled-based interval (CXSBI)

This CX Frame structure is shown in fig. h49'. During CXCBI there are no Common sub-frames.

<u>CXCBP: Detection of Bursty systems</u>
The detection of Bursty (such as 802.11) systems takes place every CX Frame, at the beginning of the CXCBI sub-frames.
During a specified time, named CXBurstyDetectStart and defined as number of CX slots, no 802.16 activity will take place. This will allow the detection with high probability of the Bursty systems deployed in the area by either BS or SS/MS. The energy for detection of bursty systems is identical to the energy for detection in SLBT mode.
The MAC message (t.b.c.) will convey the information related to the 802.11 signal power from SS/MS to the BS. Based on this information, a BS will decide if there are or not Bursty systems deployed in the area. If no Bursty system activity is detected for T_Busrty_Detect by a system, that system may switch to the CX Frame structure described in clause 15.4.2.1.2.

CXBurstyDetectStart is defined as:

CXBurstyDetectStart = 2* CXSlotTime (for the OFDMA PHY)
CXBurstyDetectStart = 4* CXSlotTime (for the OFDM PHY).

CXBurstyDetectStart includes the RTG interval before a downlink transmission.

The CXSlotTime is equivalent with one OFDM/OFDMA symbol time + the cyclic prefix. This time includes medium sensing, Tx/Rx turn-around time, propagation delay and processing delay.

<u>CXCBP: Scheduled "Listen before Talk" (SLBT)</u>
Before any transmission, an 802.16 device (BS or SS/MS) will check if the medium is free.
The following rules will apply:

- If the medium is free for at least CX_LBT_Time [50us], before the scheduled transmission time of an 802.16 device, the 802.16-based system will start its transmission at the scheduled time;

- If the medium is busy, the transmission will be deferred until the next scheduled transmission opportunity;
- The SLBT threshold as received power detection level is [-85dBm] for every MHz of channel width.

CXCBP: Transmission scheduling

- The duration of the allocated interval for transmission, using either the DL MAP or UL MAP allocations shall be suitable to DL/UL sub-frame synchronization. This condition ensures compatibility with 802.16 MAC and better coexistence between 802.16h systems in case of adjacent areas using CX Frames according to fig. h46 or according to fig. h49'.
- For scheduling the traffic in MAC Frames which are beyond the scope of the basic MAC frames, either as relevance or as conditional transmissions, will be used the CX-DL-MAP and CX-UL-MAP messages, having an enlarged scope and allowing the support of MAC Frames using SLBT.

In fig. h49'' is given an example of scheduling for DL Scheduled Listen Before Talk opportunities inside the CXCW. It is shown the extended MAP relevance for covering the whole duration of the contention window.

In fig. h49''' is given an example of scheduling for UL Scheduled Listen Before Talk opportunities inside the CXCW. It was preferred to reduce the relevance of the MAP such to better adapt the transmission opportunities to the actual UL traffic.

<u>CXCBP: Contention window</u>

The contention window mechanism enables multiple devices to access the medium, while reducing the collisions.

In figures h49'' and h49''' is shown the random number of slots before the scheduled conditional transmission.

The contention windows will start after the expiration of the CXBurstyDetectStart interval. The duration of the contention window for a particular 802.16 transmitter is:

$$CXCWmin = 7 * CXSlotTime$$

$$CXCWmin < CXCW < CXCWmax.$$

CXCWmax is a system parameter having the CXSlotTime as unit and which is calculated separately for DL and for UL. CXCWmax cannot cover more than 2 CXCBI concatenated intervals.

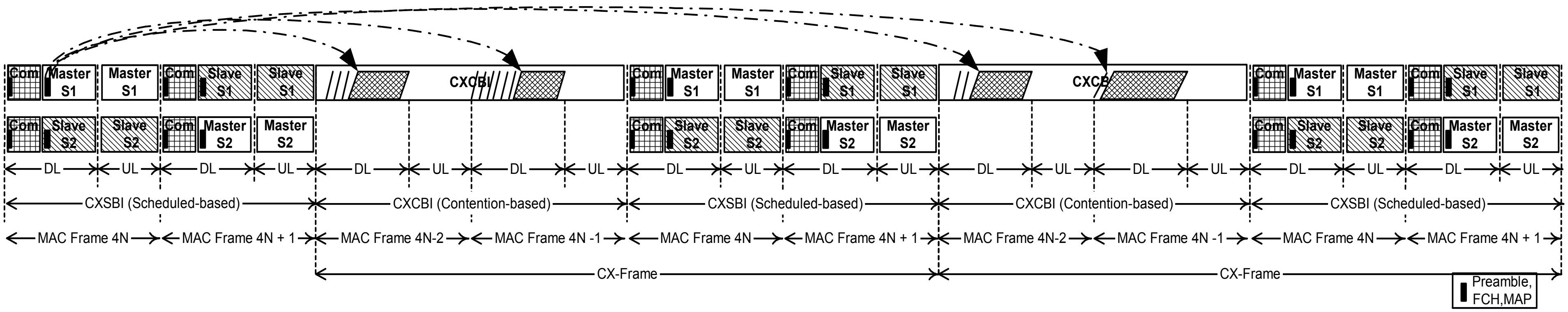


Fig h49’’ Example of DL Scheduled Listen Before Talk opportunities inside the CXCW

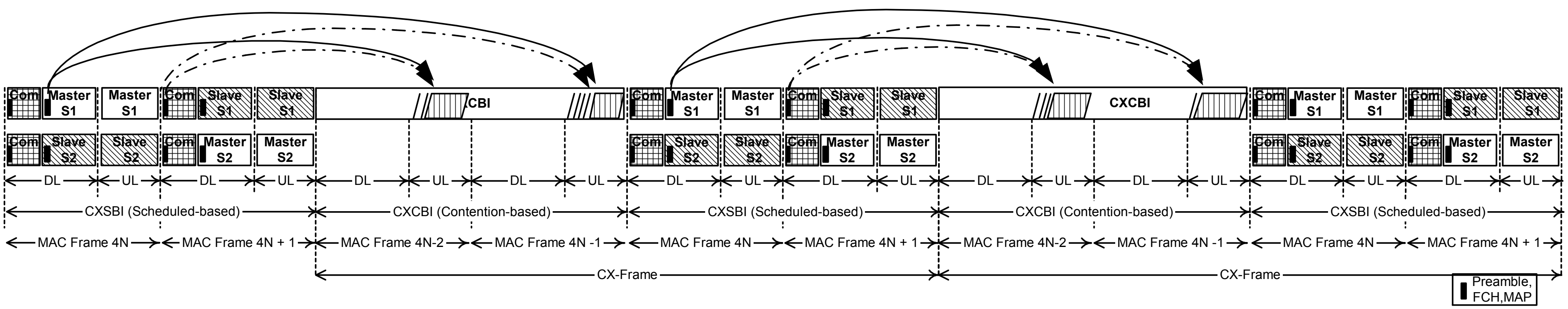


Fig h49’’’ Example of UL Scheduled Listen Before Talk opportunities inside the CXCW

The conditional transmission opportunity is scheduled during a random slot chosen within the CW. The transmitter will assess before the scheduled transmission time if the medium is free, based on SLBT procedures. The figure h49" shows the DL scheduling of conditional transmission opportunities inside the CXCW. The IE which actually schedule conditional transmission opportunities during the CXCBI can be inserted in DL or UL MAPs transmitted during any of the Common, Master or Slave sub-frames.

CXCBP: Back-off mechanisms

We define a number of back-off mechanisms, in case of un-successful reception:

- Logarithmic back-off mechanism based on the exponential increase of the CXCW size;
- Additional back-off mechanism inserting Quiet Periods.

CXCBP: Exponential CXCW and Quiet periods

In the case of failed receptions, the Base Station will increase the CW for DL or UL traffic according to the rule:

$$CXCW\_New = 2*CXCW\_Old + 1,$$

where CXCW_New is the number of slots in the CW after back-off and CXCW_Old is the number of slots in the CW before back-off.

$$CXCWNew < CXCWmax.$$

The conditional transmission opportunities which do not fall in intervals suitable to DL for BS and UL for SS/MS are escaped.

In case of a successful reception, the CXCW to be used in the next scheduling of the transmissions will be CXCWmin.

In the case that more than one CXZ is scheduled during a DL or UL sub-frame, the two zones will be separated by a CXCW.

If the CW has reached its maximum value and the last transmission was not successfully received, those conditioned transmission opportunities scheduled within first CXCBI will be skipped and a Quiet Period will be inserted during this interval.

If the next transmission will be also un-successful, the next two CXCBI intervals will be considered as Quiet Periods and the next transmission will be scheduled using the maximum contention window only.

The following tables illustrate the DL process of CXCW logarithmic back-off, for a 5ms OFDMA Frame with 47symbols, 60% DL, 40% UL including 28symbols in DL and 19symbols in UL.

For simplicity, lets suppose that the conditional transmission interval is scheduled as CXZ, with a minimum duration of 10symbols.

Table hxx Example of DL valid symbols for operation of a 802.16 system

	MAC Frame A	MAC Frame B	MAC Frame C	MAC Frame D
CXCBI visibility	1	1	2	2
Symbol (slot) number	3…28	48…75	96…121	141..168
Reserved slots for minimum CXZ	17…28	66…75	112…121	159…168

Table hyy Example of DL scheduling of conditional transmission opportunities and Quiet Periods

Case number	Duration of CXCW	Range for start of conditional transmission of CXZ (slot number)	CXZ duration
1	7	3...9, 11…17, 48…54, 56…62, 96…102, 104…110, 141...1147, 149…155	26…20, 18…10
2	15	1…15, 48…62, 96…110, 141…155	28...14
3	31	((3…17)U (48...63)), ((96...112)U(141...159))	26...12
4	63	((3…17) U (48...66)U(96...112)U(141...158))	26...10
5	63	(96...112)U(141...158)	26...10
6	63	N.A.	0
7	63	((3…17) U (48...66)U(96...112)U(141...158))	26...10

Determination and scheduling of the conditional transmission opportunities

The scheduling of a CXZ during CXCBI needs to follow the following rules:

- M (Mdefault = 4) next CXCBI intervals are concatenated
- Concatenation should take into consideration the DL and UL intervals synchronization; only the transmission opportunities for BS or MS/SS consistent with DL or UL will be used.
- The symbols intended for CXBurstyDetectStart at the beginning of each CXCBI are skipped.
- The OFDM/OFDMA symbols in the concatenated CXCBI intervals are numbered, according to the rules used in 802.16 (excluding the TTG and RTG intervals).

End insertion

MAC changes in support of CXCBP

Insert in the appropriate place and up-date the list of new MAC Messages

6.3.2.3.82 CX-DL-MAP (CX DL MAP) message

The CX-DL-MAP message defines the access to the DL information and has an extended scope and flexibility in comparison with the DL-MAP Message. If the length of the CX-DL-MAP message is a non-integral number of bytes, the LEN field in the MAC header is rounded up to the next integral number of bytes. The message shall be padded to match this length, but the SS shall disregard the 4 pad bits.

A BS shall generate CX-DL-MAP messages in the format shown in Table 40, including all of the following parameters:

PHY Synchronization

The PHY synchronization field is dependent on the PHY specification used. The encoding of this field is given in each PHY specification separately.

DCD Count

Matches the value of the configuration change count of the DCD, which describes the DL burst profiles that apply to this map.

Base Station ID

The Base Station ID is a 48-bit long field identifying the BS. The Base Station ID shall be programmable. The 24 MSBs shall be used as the operator ID. This is a network management hook that can be sent with the DCD message for handling edge-of-sector and edge-of-cell situations.

DL MAC IE relevance

This parameter indicates the virtual shift to be added to the MAC Frame number appearing in the subsequent DL-MAP Information Elements. In this way the relevance of the allocations in the succeeding DL-MAP Information Elements can be extended to future MAC frames.

Conditional DL transmission type

This parameter indicates the type of the condition to be checked in order to enable the scheduled transmissions in the following DL MAP. The possible values are:

0 – No condition
1 – Radio power at the receiver
2-15 – Reserved.

Max Power Level

This negative parameter indicates the max. power level (in dB) at which a transmission cannot be enabled.

The encoding of the remaining portions of the CX-DL-MAP message is PHY-specification dependent and may be absent. Refer to the appropriate PHY specification.

The DL-MAP IEs in the CX-DL-MAP shall be ordered in the increasing order of the transmission start time of the relevant PHY burst. The transmission start time is conveyed by the contents of the DL_MAP IE in a manner that is PHY dependant.

Multiple CX-DL-MAP Messages may be transmitted and every CX-DL-MAP Message may use a different DIUC.

Table 108xx—CX-DL-MAP message format

Syntax	Size (bit)	Notes
CX-DL-MAP_Message_Format() {	—	—
Management Message Type = 82	8	—
PHY Synchronization Field	*variable*	See appropriate PHY specification; may include MAC Frame Number.
if (WirelessMAN-CX) {		
No. OFDMA symbols		
}		
DCD Count	8	—
Base Station ID	48	—
Begin PHY-specific section {	—	See applicable PHY subclause.
if (WirelessMAN-OFDMA) {	—	—
No. OFDMA symbols	8	Number of OFDMA symbols in the DL
}	—	subframe including all AAS/
for (*i=1; i <= m; i++*) {		
for (*j* = 1; *i <= n*; *j*++) {	—	permutation zone.
DL MAC IE relevance	4	
Conditional DL transmission type	4	0 – no condition 1 – max. detected power level 2..15 - Reserved
if (Conditional DL transmission type = 1) {		-
Max power level	8	Negative value, in dBm

}		
DL-MAP_IE()	*variable*	—
}		For each DL-MAP element 1 to *n*
}	—	For each DL-MAP element 1 to *m*.
}	—	See corresponding PHY specification.
if !(byte boundary) {	—	—
Padding Nibble	4	—
}	—	—
}	—	Padding to reach byte boundary.

The logical order in which MPDUs are mapped to the PHY bursts in the DL is defined as the order of DL-MAP IEs in the DL-MAP message.

6.3.2.3.83 CX-UL-MAP (CX UL MAP) message

The CX-UL-MAP message defines the access to the UL channel and has an extended scope and flexibility in comparison with the UL-MAP Message. The CX-UL-MAP message shall be as shown in Table 108yy.

Table 108yy—CX-UL-MAP message format

Syntax	Size (bit)	Notes
CX-UL-MAP_Message_Format() {	—	—
Management Message Type = 83	8	—
Reserved	8	Shall be set to zero.
UCD Count	8	—
Begin PHY-specific section {	—	See applicable PHY subclause.
if (WirelessMAN-OFDMA) {	—	—
No. OFDMA symbols	8	Number of OFDMA symbols in the UL
}	—	subframe
for (*i=1; i <= m; i++*) {		
for (*j* = 1; *i* <= *n*; *j*++) {	—	permutation zone.
Allocation Start Time	32	—
Conditional UL transmission type	4	0 – no condition 1 – max. detected power level 2..15 - reserved
if (Conditional UL transmission type = 001) {		-
Max power level	8	Negative value, in dBm
}		
UL-MAP_IE()	*variable*	—
}		For each UL-MAP element 1 to *n*
}	—	For each UL-MAP element 1 to *m*.
}	—	See corresponding PHY specification.
if !(byte boundary) {	—	—
Padding Nibble	4	—
}	—	Padding to reach byte boundary.
}	—	—

The BS shall generate the CX-UL-MAP with the following parameters:

UCD Count

Matches the value of the Configuration Change Count of the UCD, which describes the UL burst profiles that apply to this map.

Allocation Start Time

Effective start time of the UL allocation defined by the UL-MAP (units are PHY-specific, see 10.3). The Allocation Start Time may indicate allocations in subsequent MAC frames.

Map IEs

The contents of a UL-MAP IE is PHY-specification dependent.

Conditional UL transmission type

This parameter indicates the type of the condition to be checked in order to enable the scheduled transmissions in the following UL MAP. The possible values are:

0 – No condition
1 – Radio power at the receiver
2..15 - Reserved.

Max Power Level

This negative parameter indicates the max. power level (in dB) at which a transmission cannot be enabled.

IEs define UL bandwidth allocations. Each UL-MAP message (except when the PHY is an OFDMA PHY) shall contain at least one information element (IE) that marks the end of the last allocated burst. Ordering of IEs carried by the UL-MAP is PHY-specific.

The CID represents the assignment of the IE to either an unicast, multicast, or broadcast address. When specifically addressed to allocate a bandwidth grant, the CID shall be the Basic CID of the SS. A UIUC shall be used to define the type of UL access and the UL burst profile associated with that access. An Uplink_Burst_Profile shall be included in the UCD for each UIUC to be used in the UL-MAP.

The logical order in which MPDUs are mapped to the PHY bursts in the UL is defined as the order of UL-MAP IEs in the UL-MAP message.

End insertion

Conclusions

The CXCBP, while behaving as a contention-based protocol, using listen-before-talk and back-off procedures, still has the robustness and the coexistence properties of the 802.16 scheduled approach.
The CXCBP has a number of advantages:

- The FCC requirements for an un-restricted protocol are respected.
- Creates a common coexistence frame with 802.11.
- Respect the rules of the contention-based medium access.
- Priority is given to the 802.11-based systems, due to the initial delay and larger slot times.
- Keeps the 802.16 scheduled approach and the associated robustness of UL/DL receive process
- The medium may be used in a flexible sharing mode.