Considerations on Connection Based Over-the-air Inter Base Station Communications: Logical Control Connection and its Application to Credit Token Based Coexistence Protocol

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  Considerations on connection based over the air BS to BS communications

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Introduction

• Over the air BS to BS communication principle and mechanisms are under discussion in both IEEE 802.22 WG and 802.16h TG

• Purpose of this contribution is to:
  – Present principles of possible other approaches for over the air BS to BS communication as complementary approaches currently followed in IEEE 802.16h TG
  – Provide some more material on this topic to further progress in IEEE 802.16h TG

• Content of this contribution is two-fold:
  – Present Logical Control Connection (LCC) principles for inter BS communications over the air
  – Present joint usage of LCC and credit token based co-existence protocol (CRCP).
Connection Based Inter-BS Communications

- Connection identifier (CID) specified as a key component
- Define a mapping between transmission-reception processes for deterministic communication scheduling
- Enable communication prioritization and reliability guarantee
- Enable secure inter-BS communications (with security association between coexisting BSs via bridging CPEs)
- Complementary to the contention based inter-BS communications method
Logical Control Connections (LCC)

- Connection based inter-system communications
  - Reliable, efficient
- Enable the feasibility and overall efficiency of the collaborative coexistence mechanism (e.g. to support the credit token based co-existence protocol (CTCP))
- Very low communications overhead
  - Spectrum bandwidth, Messaging latency, Hardware/software complexities
Logical Control Connection:
The Principle
Bridge CPE

- Located in the overlapping area of two cells
- Associated with one BS (service BS) through service connections;
- Associated with another BS (coexistence BS) through coexistence connections
  - Coexistence communications only
Co-existence Connections

• Regular connections
  – Carry co-existence communications only

• Established and maintained
  – Between a bridge CPE and the coexistence BS (C-BS) on request by the service BS (S-BS)
  – Between two BSs
    • if S-BS is within the arrange of C-BS
    • S-BS behaves as a CPE of C-BS in such case)
  – On channels occupied by the coexistence BS
Co-existence Connections

• Establishment/maintenance performed along with service data transmission
  – Ranging, connection acquisition
  – Controlled by S-BS and shall be guaranteed that they are not co-scheduled with service communications
LCC Between Two Base Stations
Over-the-Air Co-existence Communications

• **S-BS communicates with C-BS for co-existence via B-CPE as a relay**
  – Communications via Service connection + coexistence connection
  – S-BS controls the coexistence operations between B-CPE and C-BS

• **Coexistence communications**
  – Messaging for spectrum contention/negotiation,
  – Sensing measurement sharing,
  – Operation parameter (transmission power, channel in-use, etc.) announcement
Coexistence Communications Control for LCC

- S-BS (Service BS) controls the coexistence communications between B-CPE and C-BS (Coexist BS)
Logical Control Connection:
Coexistence Communications Scheduling
Basic Scenarios and Conditions

- Two basic scenarios
  - Two/Multiple WirelessMAN-CXs sharing a single channel, which can only be occupied by one WirelessMAN-CX
  - Two/Multiple WirelessMAN-CXs sharing two/multiple channels or sub-channels of the same channel simultaneously

- Basic conditions
  - WirelessMAN-CXs synchronize MAC frames by sharing a common clock.
    - UTC stamps WirelessMAN-CX synchronization
    - Or, GPS
  - Self Coexistence Window (SCW) ~ CMI/CSI
  - Offeror Slots (OS) available for dedicated radio resource announcement, discovery and negotiation.
MAC Frame Structure

- **OS**: Offeror Slot, dedicated to announcing, discovering and negotiating the available radio resource.

- **SCW**: Self Coexistence Window, a contention window shared by all systems for transmitting/receiving coexistence messages.
Communications between Two WirelessMAN-CXs on a Single Channel: Scenario I
Scenario I – Announcement and Discovery

- C-BS announces its existence through Self Coexistence Window (SCW) or offeror slots (OS).
- B-CPE captures C-BS’s announcements and reports to S-BS.
- S-BS instructs B-CPE to notify S-BS’s existence to C-BS through SCW.
- S-BS and C-BS use the OS to enable offeror and renter BSs to communicate for CTCP (discovery, negotiation)
Scenario I – Initial Coexistence Resolution

- C-BS sends coexistence messages in SCW.
- S-BS responds to C-BS’s requests via B-CPE in SCW.
- If C-BS acquires partial of the channel, follow the procedure for scenario II.
- Else if C-BS fails to acquire the channel, go back to step 1 to repeat the coexistence resolution process.
- Else if C-BS acquires the whole channel
  - S-BS instructs B-CPE to setup Coexistence Connections with C-BS after the channel is released.
  - S-BS instructs B-CPE to request “Reserved Time Slots” (RTS) for B-CPE to S-BS communications on the channel after the channel is release.
  - S-BS provides B-CPE parameters (e.g. credit tokens) and strategies for coexisting with C-BS.
  - S-BS releases the channel at the time both S-BS and C-BS agree upon.
Scenario I – Coexistence Connection Establishment and Maintenance

- B-CPE, as instructed by S-BS, sets up coexistence connections with C-BS.
- B-CPE requests for “Reserved Time Slots” (RTS) for B-CPE to S-BS communications in the channel.
  - RTS: interference free time slots for S-BS to B-CPE communications on the coexistence channel.

C-BS has acquired Channel A from S-BS
Scenario I – Inter-BS Communications
(C-BS occupies the channel)
Scenario I – Inter-BS Communications (C-BS occupies the channel)

- Periodic RTS monitoring (performed by S-BS)
- B-CPE to C-BS communications
- Coexistence bandwidth allocation (performed by C-BS)
  - RTS (Reserved Time Slots)
- Feedback of coexistence bandwidth allocation (by B-CPE)
- B-CPE to S-BS communications using the granted RTS
- B-CPE to C-BS communications
Scenario I - Coexistence Resolution

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- Coexistence bandwidth allocation (performed by S-BS)
  - RTS (Reserved Time Slots)
- Feedback of coexistence bandwidth allocation (by B-CPE)
- B-CPE to C-BS communications using the granted RTS
- B-CPE to S-BS communications
Communications between Two WirelessMAN-CXs on Two Channel (Scenario II)
Scenario II – Announcement and Discovery

- S-BS and C-BS announce their existence in self coexistence window (SCW).
  - If SCW is used, announcements can be done by base stations themselves or via bridge CPEs.

- S-BS and C-BS use the offeror slots (OS) to enable offeror and renter BSs to communicate for CTRP (discovery, negotiation)

- S-BS and C-BS capture the existences and channel usages/sharing information of each other.
Scenario II - Coexistence Connection Establishment and Maintenance

- S-BS instructs B-CPE to establish and maintain coexistence connections with C-BS in channel B.
- Similarly, C-BS could instruct CPE1 to establish and maintain coexistence connections with S-BS in channel A.
Scenario II - Inter Base Station Communications

- **C-BS**: MAP
- **B-CPE**: MAP
- **S-BS**: MAP

- **Polling Slots**: Arrows indicating communication between C-BS and B-CPE.
- **B-CPE ↔ C-BS Communications**: Horizontal bars indicating data exchange.
- **Polling Slot**: Arrows indicating communication between S-BS and B-CPE.
- **B-CPE ↔ S-BS Communications**: Horizontal bars indicating data exchange.

- **Operations on Channel A**
- **Operations on Channel B**
- **Coexistence Messages**: Colored bars indicating message exchange.
Scenario II - Inter Base Station Communications

• Periodic Coexistence Polling Slots (CPS)
  – After coexistence connections has been established with B-CPE, C-BS periodically schedules Coexistence Polling Slots for asynchronized B-CPE to C-BS communications.
  – S-BS also schedules periodic CPS to reestablish communications with B-CPE after coexistence communications between B-CPE and C-BS has completed.
  – CPS could be used for coexistence message transmissions
Scenario II - Inter Base Station Communications

- B-CPE to C-BS Communications
  - S-BS schedules B-CPE to communicate with C-BS through the coexistence connections for a Coexistence Operation Period (e.g. 2-frame duration)
    - B-CPE switches to channel B and decodes the MAP of C-BS;
    - B-CPE sends BW requests (could be w/ coexist messages) via the scheduled CPS;
    - C-BS grants BW to B-CPE for communicating with B-CPE.
    - C-BS and B-CPE communicate with each other using the allocated BW.
  - During B-CPE to C-BS communication period, S-BS does not schedule CPS for B-CPE.
  - C-BS resumes CPS scheduling for B-CPE after the communications with B-CPE is completed.
Scenario II - Inter Base Station Communications

• **B-CPE to S-BS Communications**
  – After the Coexistence Operation Period, S-BS periodically schedules Coexistence Polling Slots for asynchronizaed B-CPE to S-BS communications, until B-CPE to S-BS communications are reestablished.

  – After B-CPE to C-BS communications, B-CPE switches back to channel A, and decodes the MAP of S-BS, in search of CPS of the S-BS.

  – B-CPE sends BW requests (could be w/ coexist messages) to S-BS via the scheduled CPS.

  – S-BS grants BW to B-CPE for communicating with B-CPE.

  – C-BS and B-CPE communicate with each other using the allocated BW.
Joint LCC and Credit Token based Co-existence Protocol (CTTCP) Usage

- **CTTCP** between BSs enables a dynamic cooperative and fair radio resources sharing between offeror BS (O-BS) and renter BSs (R-BS).
- This protocol requires real time messages exchange between the O-BS and R-BSs.
- **Over the air** messages between the O-BS and R-BSs is needed to support the radio resources sharing opportunities advertisement discovery and negotiation phases between the WirelssMAN-CXs.
- The over the air discovery procedures consists (by broadcasting) in the discovery of O-BS’s radio resources sharing offers by the neighbouring R-BSs.
- The over the air negotiation phase consists in the different sequences of the CTTCP between O-BS and R-BSs. The negotiation requires dedicated O-BS <-> R-BS communications.
- The messages between O-BS and R-BSs are conveyed by the CPEs that act as RF bridges between the O-BS and R-BSs.
- **CTTCP** can use specific time intervals to convey these messages with the support of the LCC establishment and maintenance procedures.
Rental Protocol Frame Structure (1/3)

OS: Offeror Slot
CPS: Coexistence polling slots
Rental Protocol Frame Structure (2/3)

- Frame structure is designed to enable real time renting while supporting several parallel rentings originated from several O-BSs:
  - Each RPP is composed of N frames (i.e. N renting processes initiated by N different O-BSs can be handed in parallel).
  - In each frame, a DL OS (DL Offeror Slot) is located in the DL subframe.

- The DL OS is used by the LCC procedure to enable the DL operations between the B_{offeror}-CPE (belonging to the O-BS) and the R-BSs.

- In each frame, CPS is located in the UL subframe. The CPS can be allocated anywhere in the UL subframe and is not necessary contiguous.

- The CPS is used by the LCC procedure to enable the UL operations respectively between the B_{offeror}-CPE and the O-BS, and between the B_{offeror}-CPE and the R-BS.
Rental Protocol Frame Structure (3/3)

- Any new O-BS is assigned with a free DL OS (not already used by another O-BS) in the RPP for its own renting operations with the R-BSs. This O-BS is using the CPS corresponding to the frame this DL OS belongs to.
- Once this O-BS is assigned with a DL OS, this O-BS always uses the same frame in each RPP to communicate with the R-BSs (via LCC) until the CTCP between the O-BS and R-BSs is complete. During all this time, this DL OS is dedicated to this O-BS.
- During each frame of the RPP, the O-BS assigned to this frame can establish parallel connections with several R-BSs. There is a $B_{\text{offeror}}$-CPE for each O-BS <-> R-BS connection:
  - The OS DL is dedicated for all the DL connections with the $B_{\text{offeror}}$-CPEs,
  - There are as many CPSs as $B_{\text{offeror}}$-CPEs.
Discovery Phase

- O-BS broadcasts periodically its offer (e.g. starting time of the renting period $T_{start}$, ending time of the renting period $T_{End}$, reserve price auction RPA, etc) in a DL-OS he is assigned within RPP.
- Detection and identification of the O-BS’s offer by the renter $B_{renting}$-CPEs (discovery by $B_{renting}$-CPEs).
- $B_{renting}$-CPEs report this message information to their own BS (R-BS) in a regular fashion.
- The reporting from the $B_{renting}$-CPEs towards the R-BS is policy ruled by the R-BS to avoid unnecessary bandwidth use. Policy is aligned with the R-BS’s renting strategy (dynamic).
- Also, the policy regulates the number of reportings while ensuring information reliability and security check in the reporting.
When the R-BS decided to come into negotiation with the O-BS, the O-BS <-> R-BS connection is established using LCC. The LCC includes respectively the $B_{\text{offeror}}$-CPE <-> R-BS and $B_{\text{offeror}}$-CPE <-> O-BS communications.

With respect to LCC terminology:
- $B$-CPE ($B_{\text{offeror}}$-CPE) belongs to O-BS
- $S$-BS = O-BS
- $C$-BS = R-BS
Negotiation Phase (2/3)

Inter Rental Protocol Period (T_{IRPP})

Rental Protocol Period (T_{RPP})

OS: Offeror Slot

CPS: Coexistence polling slots

O-BS: Offeror BS
R-BS: Renter BS
B-CPE: Bridge CPE (belongs to O-BS)

LCC procedures

Negotiation Phase (3/3)

Inter Rental Protocol Period (T_{IRPP})

Rental Protocol Period (T_{RPP})

R-BS: Renter BS

B-CPE: Bridge CPE (belongs to O-BS)

O-BS: Offeror BS

OS: Offeror Slot

CPS: Coexistence polling slots
Reliability Enhancement for Logical Control Connection
Reliable Inter-Bs Communication

- **Timeout and retransmission is used for**
  - handling message loss
- **Sequence number is used to make sure**
  - a response is for a appropriate request
  - duplicated messages are ignored by the receiver
- **To make sure that timeout mechanism works properly, a retransmission timeout (RTO) estimation algorithm is proposed**
Timeout and retransmission

Service BS  \rightarrow Bridge CPE  \rightarrow Coexist BS

Service Connections  \rightarrow Coexist Connections

Request Msg  \rightarrow Request Msg  \rightarrow Request Msg

Response Msg  \rightarrow Response Msg  \rightarrow Response Msg

Timer times out

Reset Timer
Sequence Number Maintenance

- 8 bits sequence number is used, the initial value is set to 0.

- The service BS maintains its sequence number
  - Each time a service BS sends a request message out, it increases sequence number.

- The coexist BS maintains one sequence number for each service BS which maintains a coexist relationship with it
  - If a request message with newer sequence number is received, the coexist BS shall send a response message out.
  - Otherwise the received request message is deleted without response message being sent out.
Retransmission Timeout Estimation

\[ \text{delta} = \text{measuredRT} - \text{srtt} \]

\[ \text{srtt} = \text{srtt} + g \times \text{delta} \]

\[ \text{rtt var} = \text{rtt var} + h \times (|\text{delta}| - \text{rtt var}) \]

\[ \text{RTO} = \text{srtt} + 4 \times \text{rtt var} \]

srtt: smoothed RTT.
rtt var: smoothed mean deviation estimator.
RTO: retransmission timeout.
h, g: value which are smaller than 1.
Thank you!