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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Purpose:

Considerations on connection based over the air BS to BS communications

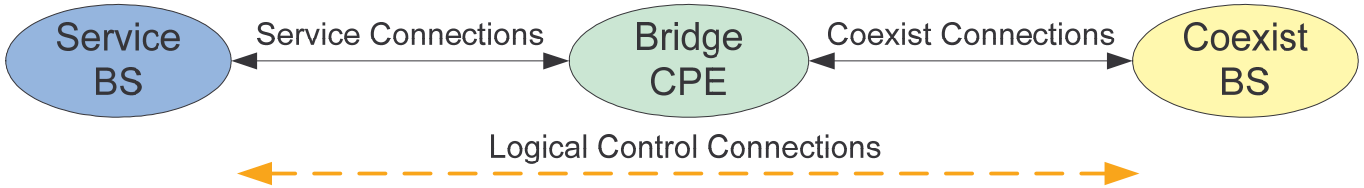
Introduction

- **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 approches 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)

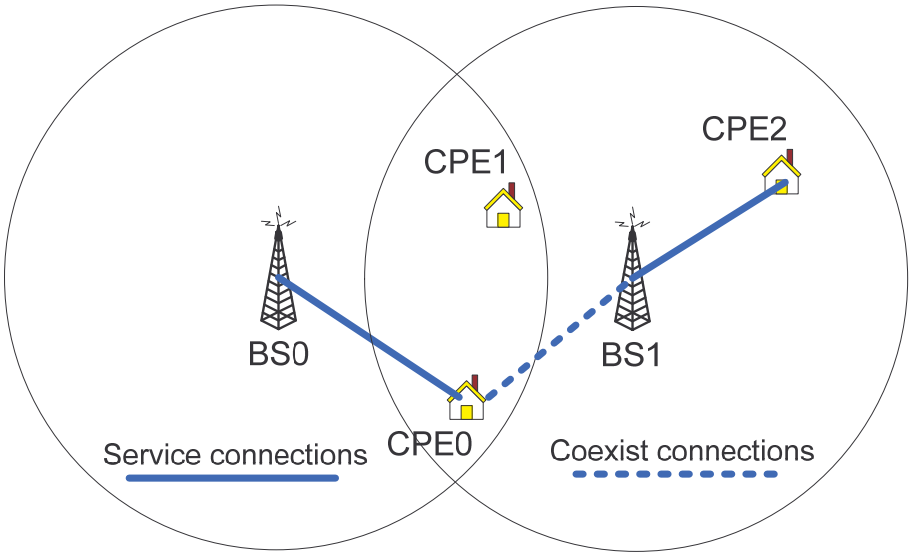


- Connection based inter-system communications
  - Reliable, efficient
- Enable the feasibility and overall efficiency of the collaborative coexistence mechanism (e.g. to support the credit token based co-existence protocol (CTCP))
- Very low communications overhead
  - Spectrum bandwidth, Messaging 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



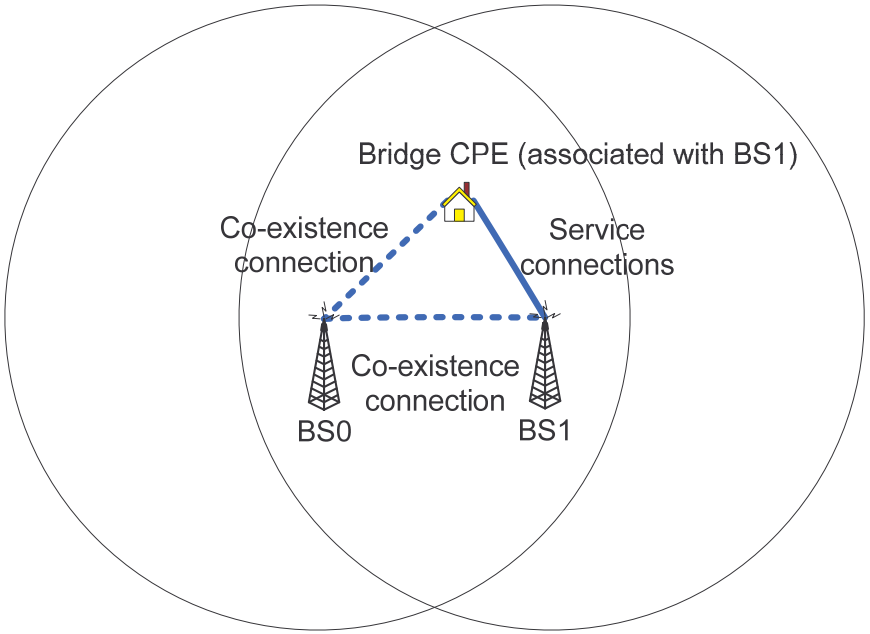
Co-existence Connections

- 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

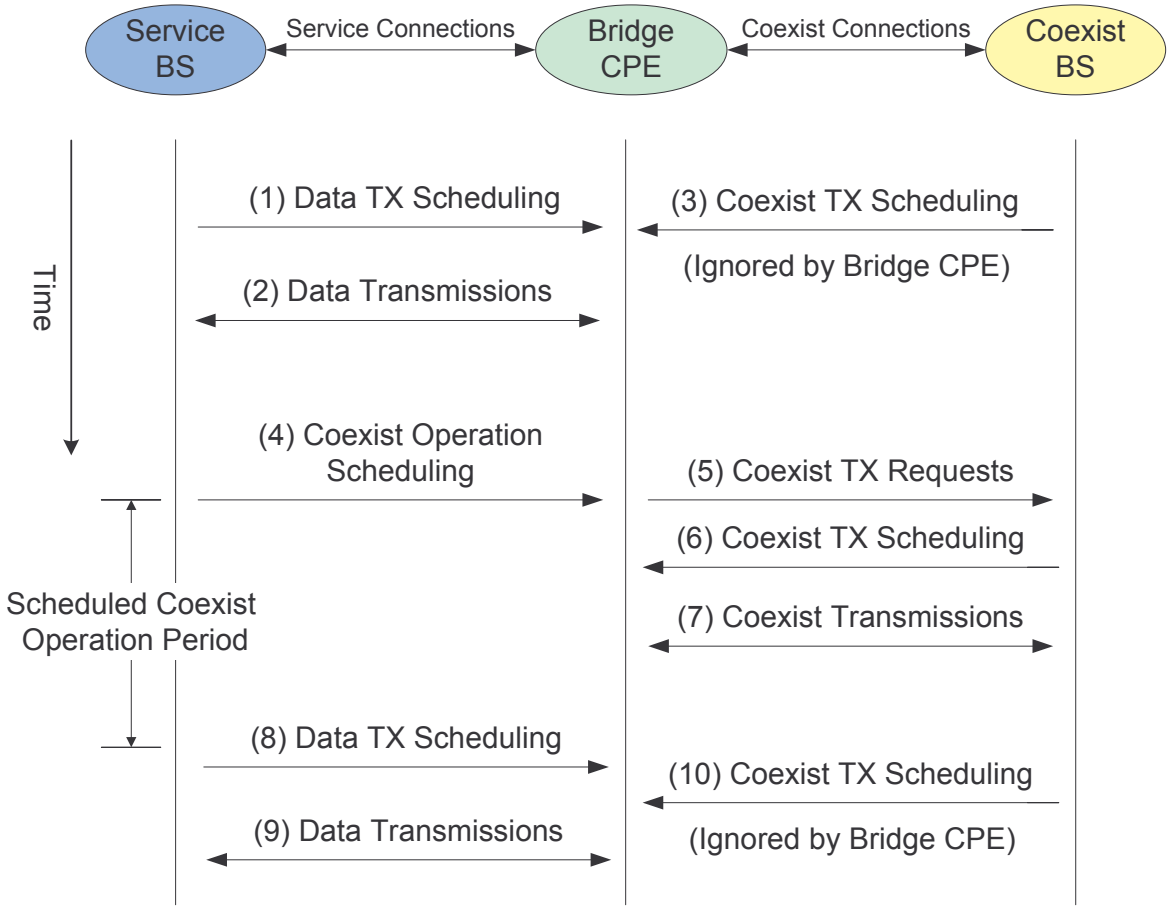


Over-the-Air Co-existence Communications

- **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)



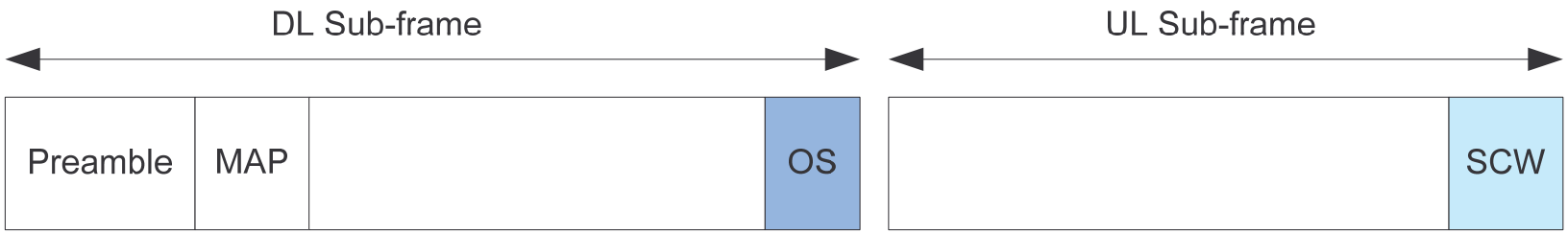
Logical Control Connection: Coexistence Communications Scheduling

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.

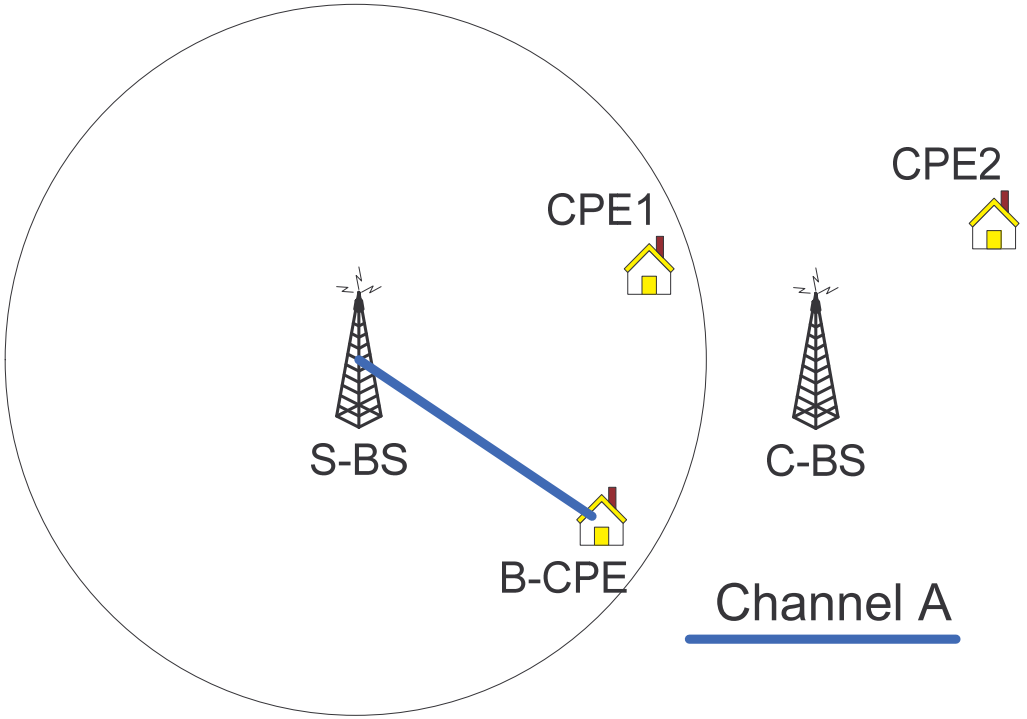
MAC Frame Structure



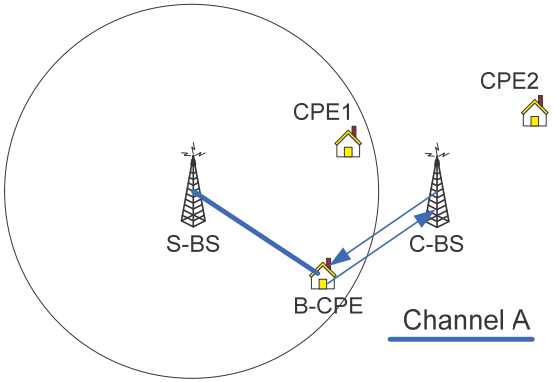
- OS: Offeror Slot, dedicated to a Offering WirelessMAN-CX system for announcing, discovering and negotiations the available radio resource

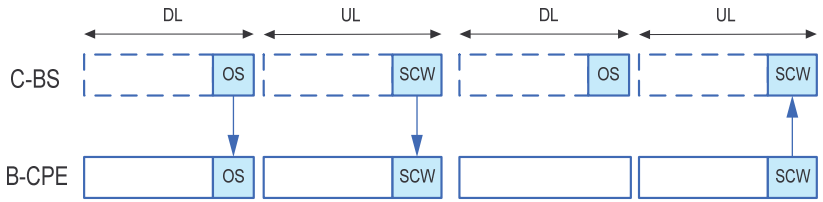
- SCW: Self Coexistence Window, a contention window shared by all systems for transmitting/receiving coexistence messages

Communications between Two WirelessMAN-CXs on a Single Channel: Scenario I



Scenario I – Announcement and Discovery



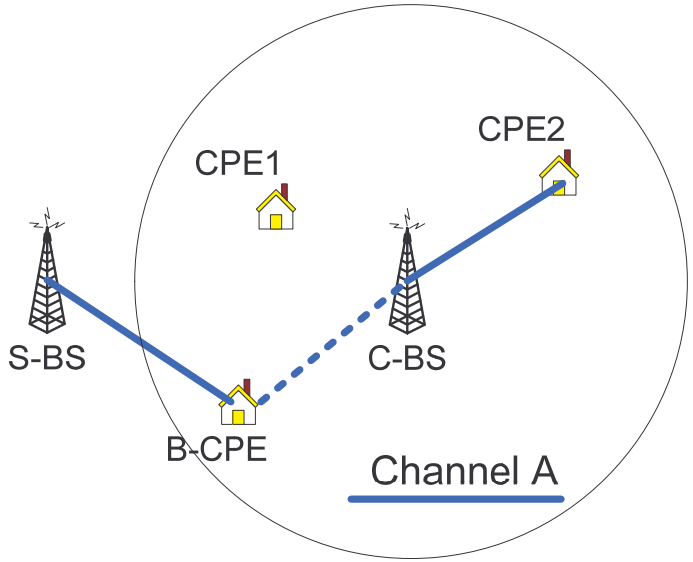


- C-BS announces its existence through Self Coexistence Window (SCW) or offeror slots (OS).
- B-CPE captures C-BS's announcements and reports to S-BS.
- S-BS instructs B-CPE to notify S-BS's existence to C-BS through SCW.
- S-BS and C-BS use the OS to enable offeror and renter BSs to communicate for 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.

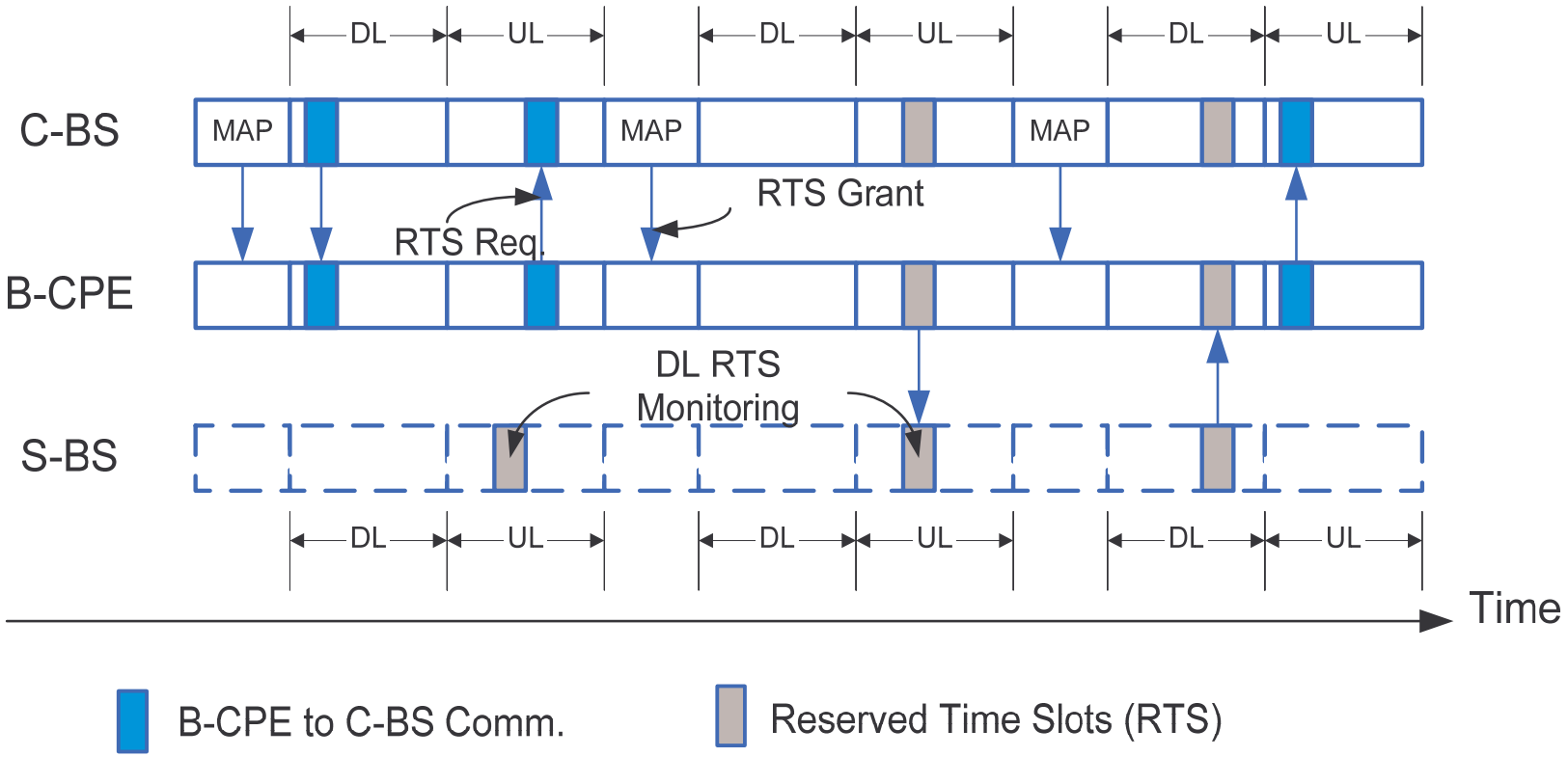
Scenario I – Coexistence Connection Establishment and Maintenance



C-BS has acquired Channel A from S-BS

- 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

Scenario I – Inter-BS Communications (C-BS occupies the channel)

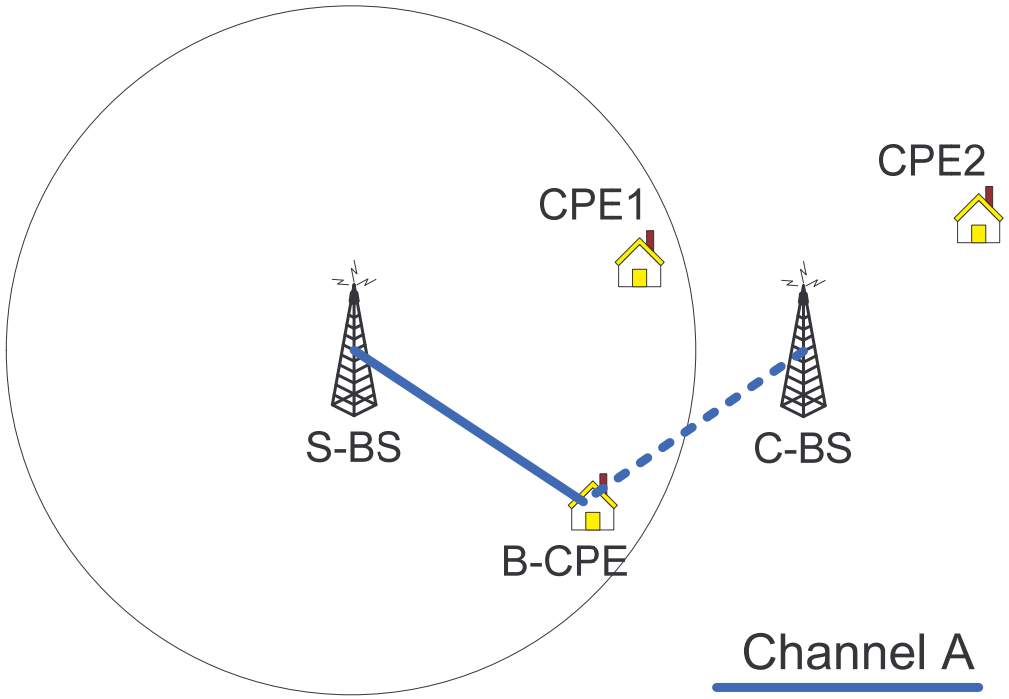


Scenario I – Inter-BS Communications (C-BS occupies the channel)

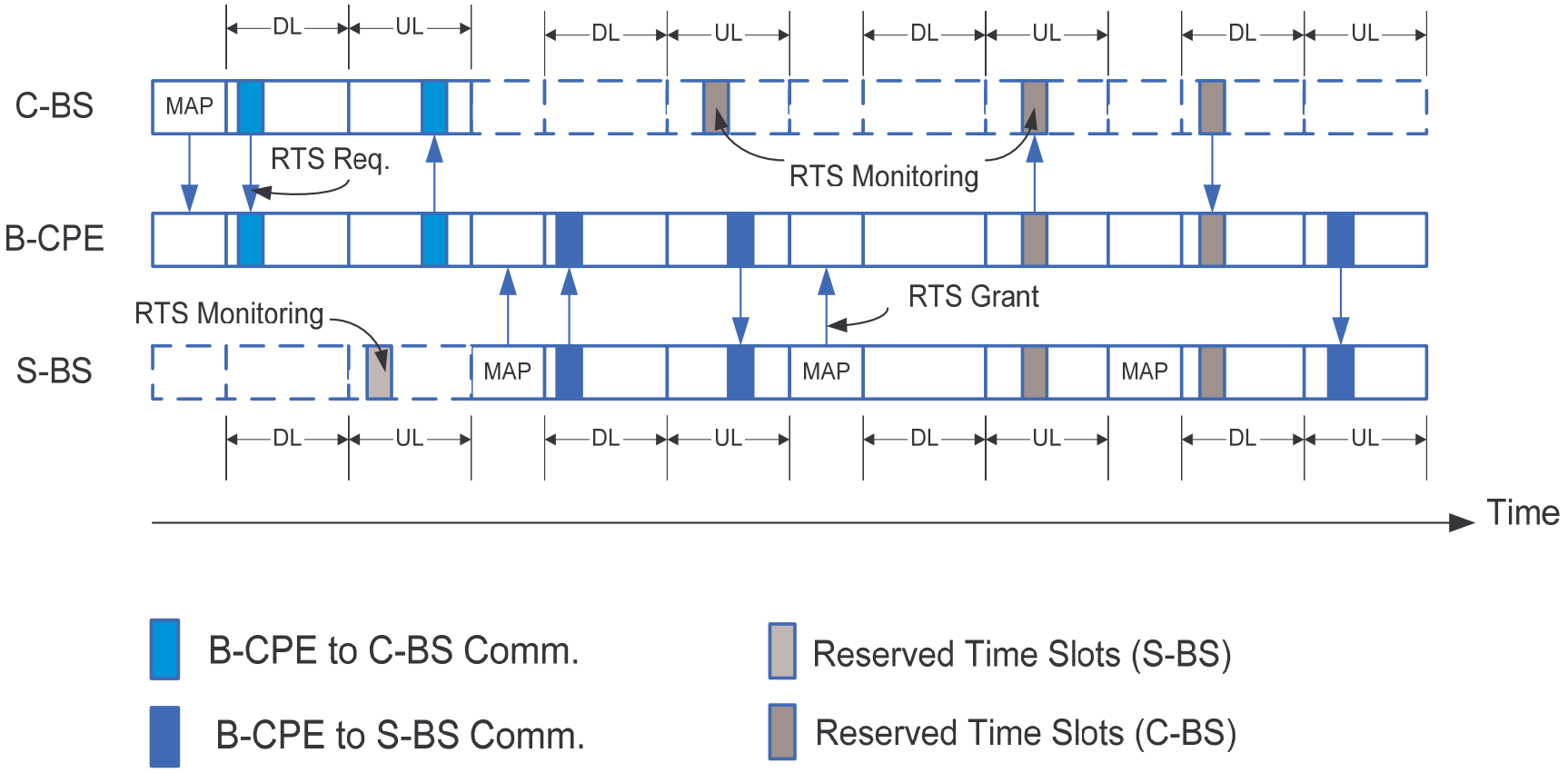
- Periodic RTS monitoring (performed by S-BS)
- B-CPE to C-BS communications
- Coexistence bandwidth allocation (performed by C-BS)
  - RTS (Reserved Time Slots)
- Feedback of coexistence bandwidth allocation (by B-CPE)
- B-CPE to S-BS communications using the granted RTS
- B-CPE to C-BS communications

Scenario I - Coexistence Resolution

S-BS has acquired Channel A from C-BS



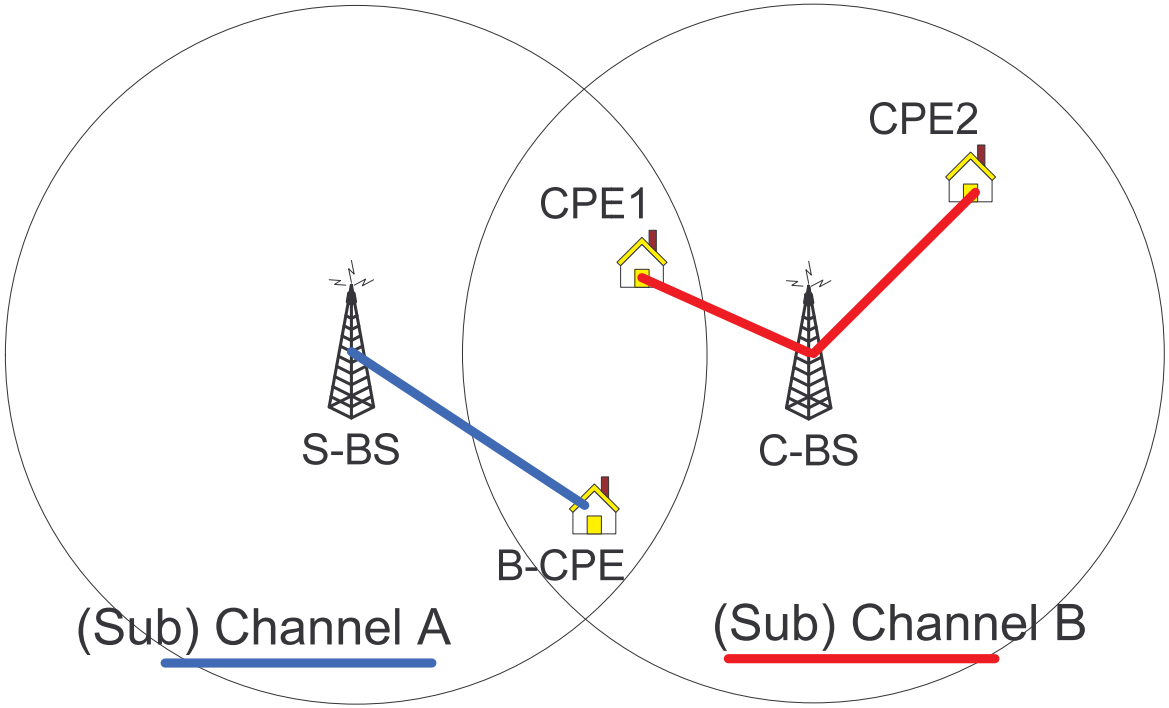
Scenario I – Inter-BS Communications (S-BS occupies the channel)



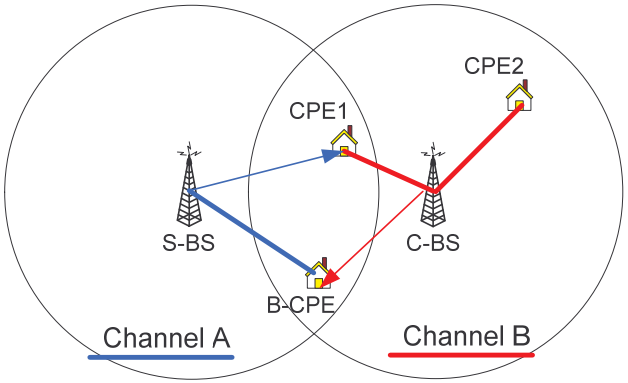
Scenario I – Inter-BS Communications (S-BS occupies the channel)

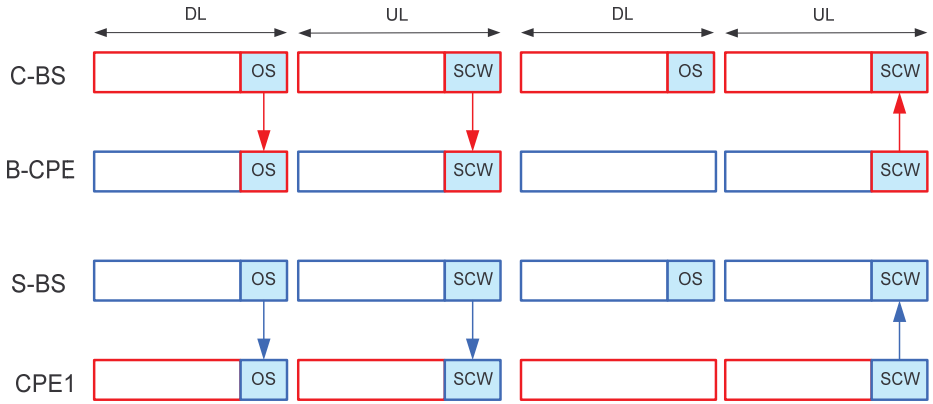
- Periodic RTS monitoring (performed by C-BS)
- B-CPE to S-BS communications
- Coexistence bandwidth allocation (performed by S-BS)
  - RTS (Reserved Time Slots)
- Feedback of coexistence bandwidth allocation (by B-CPE)
- B-CPE to C-BS communications using the granted RTS
- B-CPE to S-BS communications

Communications between Two WirelessMAN-CXs on Two Channel (Scenario II)



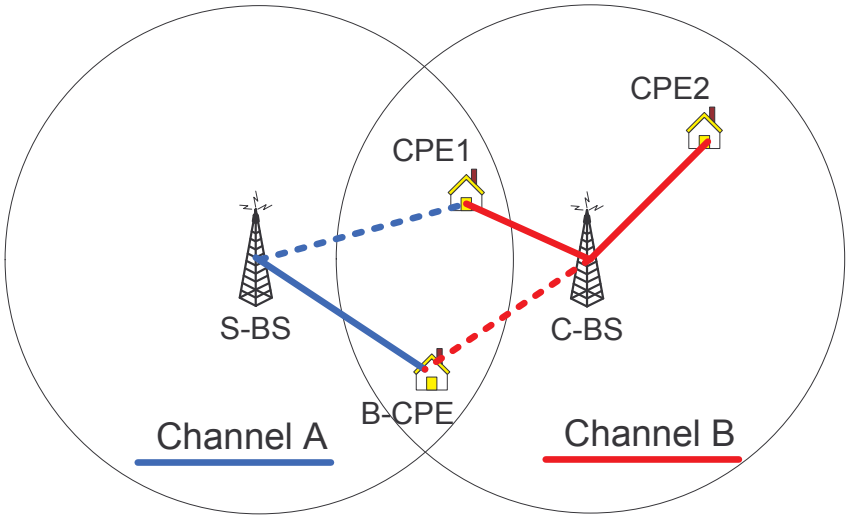
Scenario II – Announcement and Discovery





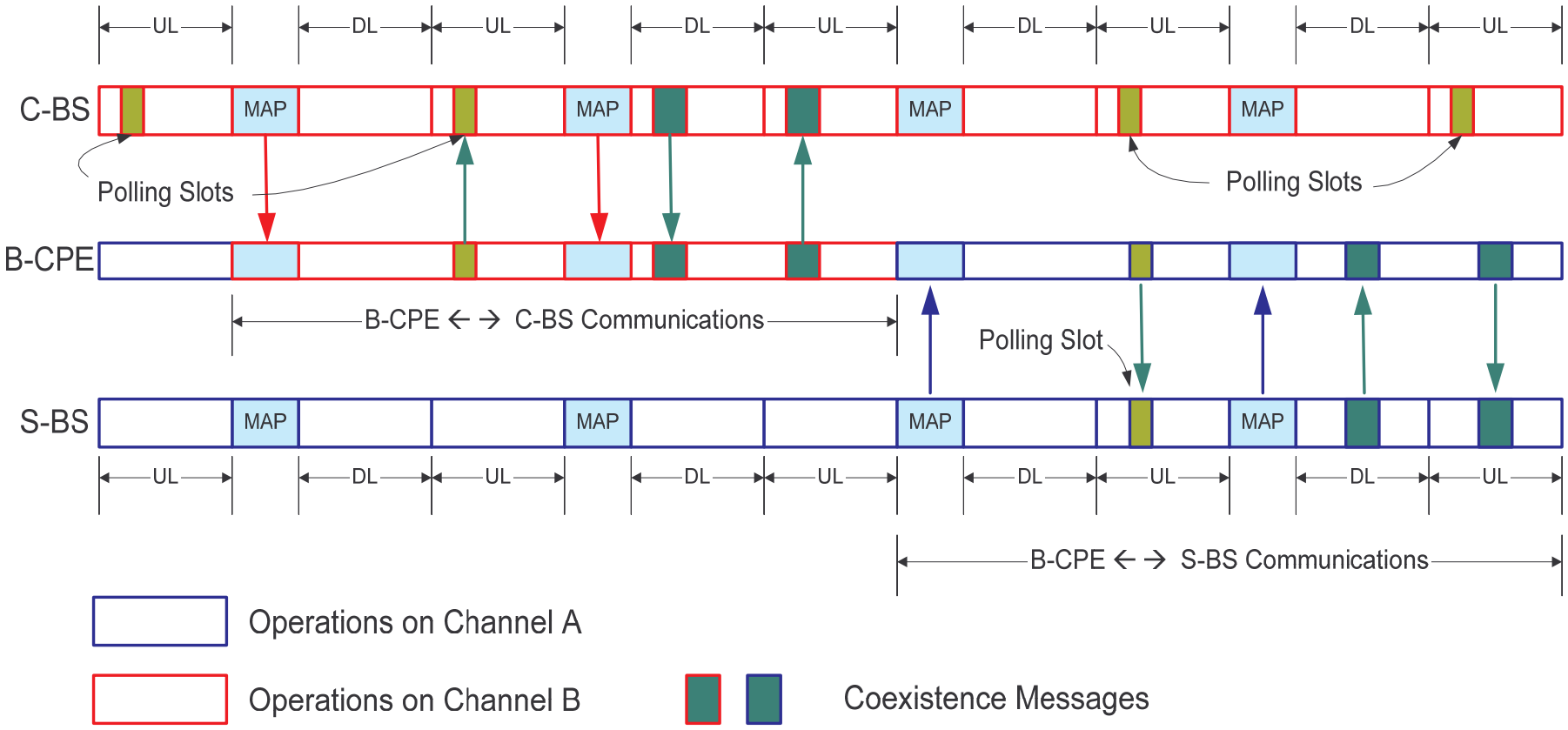
- **S-BS and C-BS announce their existence in self coexistence window (SCW).**
  - If SCW is used, announcements can be done by base stations themselves or via bridge CPEs.
- **S-BS and C-BS use the offeror slots (OS) to enable offeror and renter BSs to communicate for CTRP (discovery, negotiation)**
- **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



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.

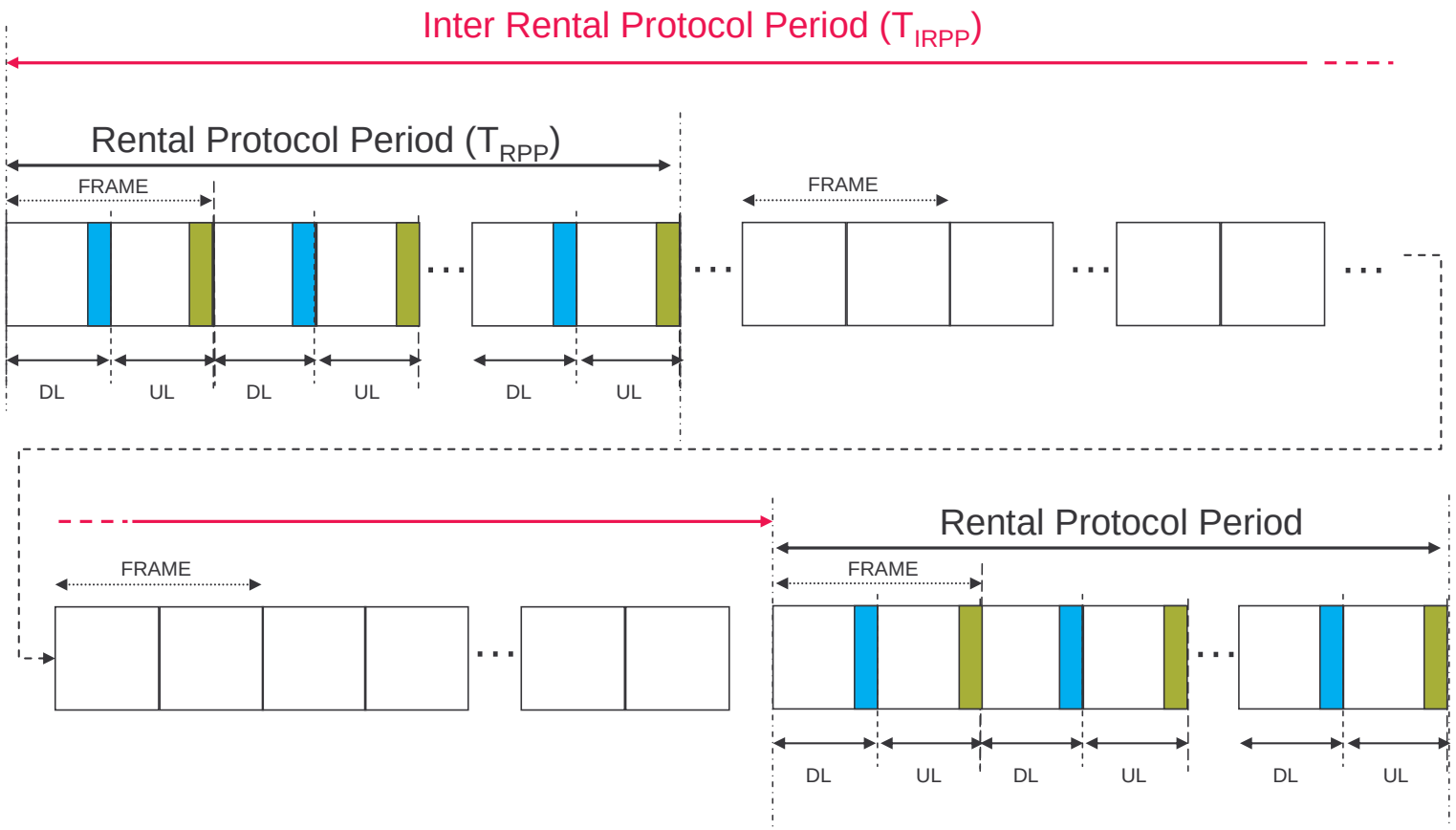
Joint LCC and Credit Token based Co-existence Protocol (CTCP) Usage

- CTCP 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 CTCP 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.
- CTCP can use specific time intervals to convey these messages with the support of the LCC establisment and maintenance procedures.

Rental Protocol Frame Structure (1/3)

OS: Offeror Slot

CPS: Coexistence polling slots



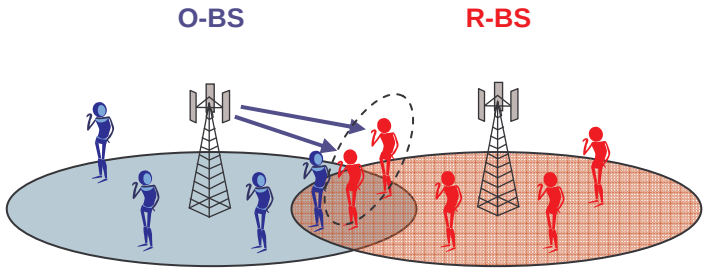
Rental Protocol Frame Structure (2/3)

- 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.

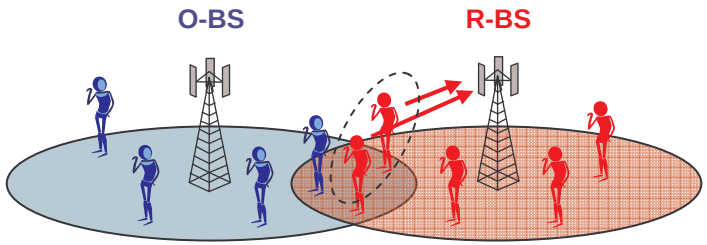
Rental Protocol Frame Structure (3/3)

- 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 $B_{offeror}$-CPE for each O-BS <-> R-BS connection:
  - The OS DL is dedicated for all the DL connections with the $B_{offeror}$-CPEs,
  - There are as many CPSs as $B_{offeror}$-CPEs.

Discovery Phase

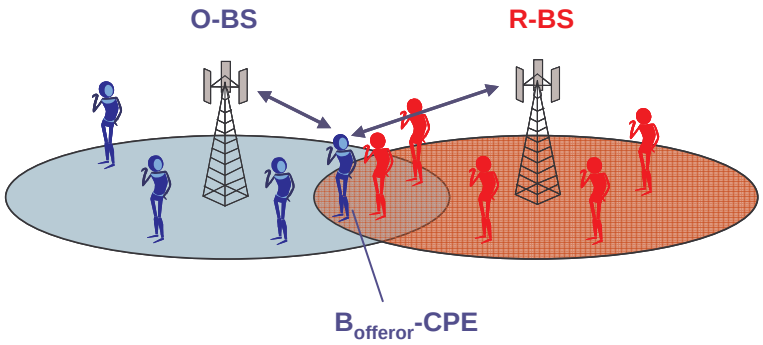


- O-BS broadcasts periodically its offer (e.g. starting time of the renting period T_{start}, ending time of the renting period T_{End}, reserve price auction RPA, etc) in a DL-OS he is assigned within RPP.
- Detection and identification of the O-BS's offer by the renter $B_{renting}$-CPEs (discovery 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.

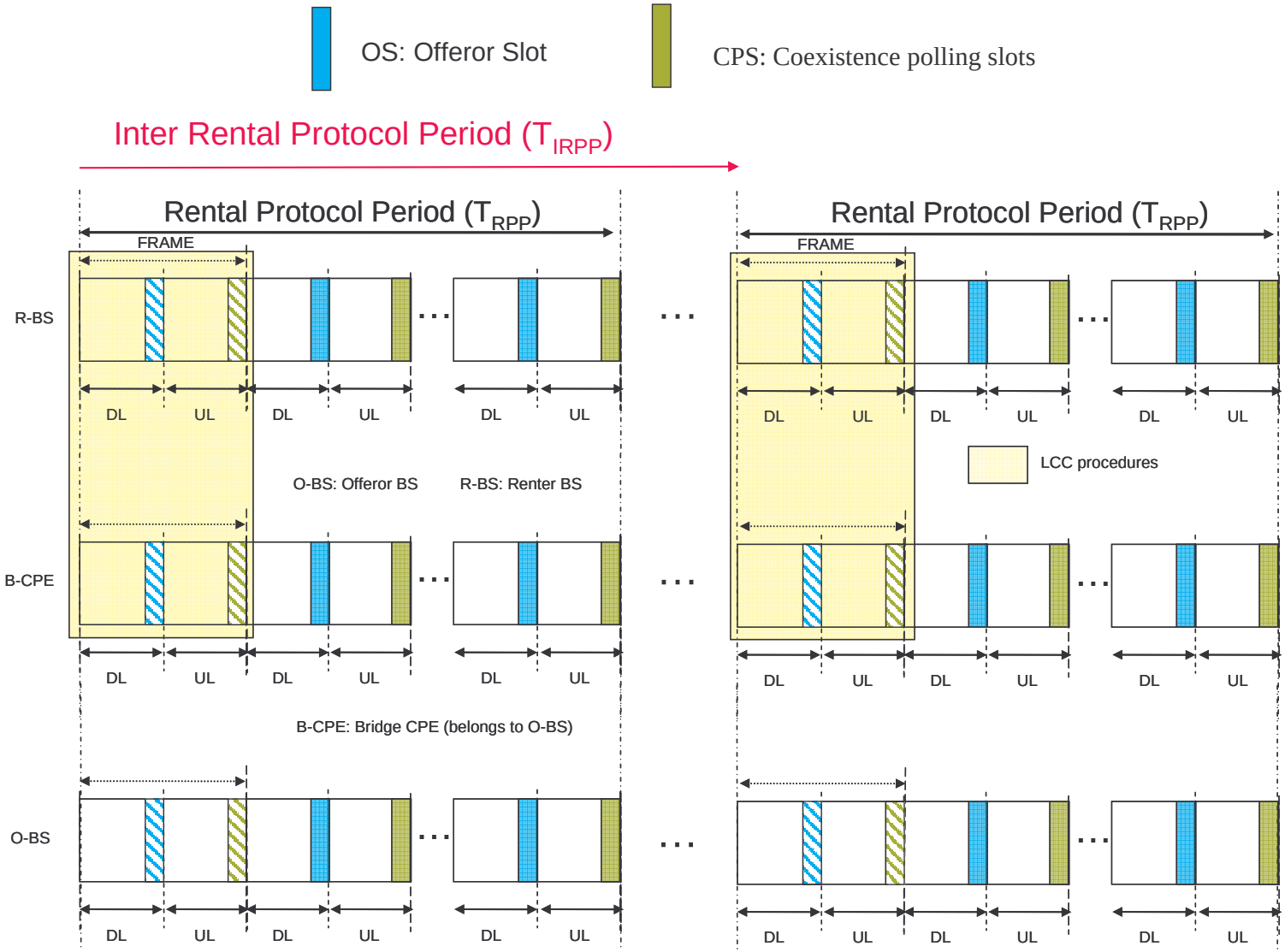
Negotiation Phase (1/3)



- 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 $B_{offeror}$-CPE <-> R-BS and $B_{offeror}$-CPE <-> O-BS communications.

- With respect to LCC terminology:
  - B-CPE ($B_{offeror}$-CPE) belongs to O-BS
  - S-BS = O-BS
  - C-BS = R-BS

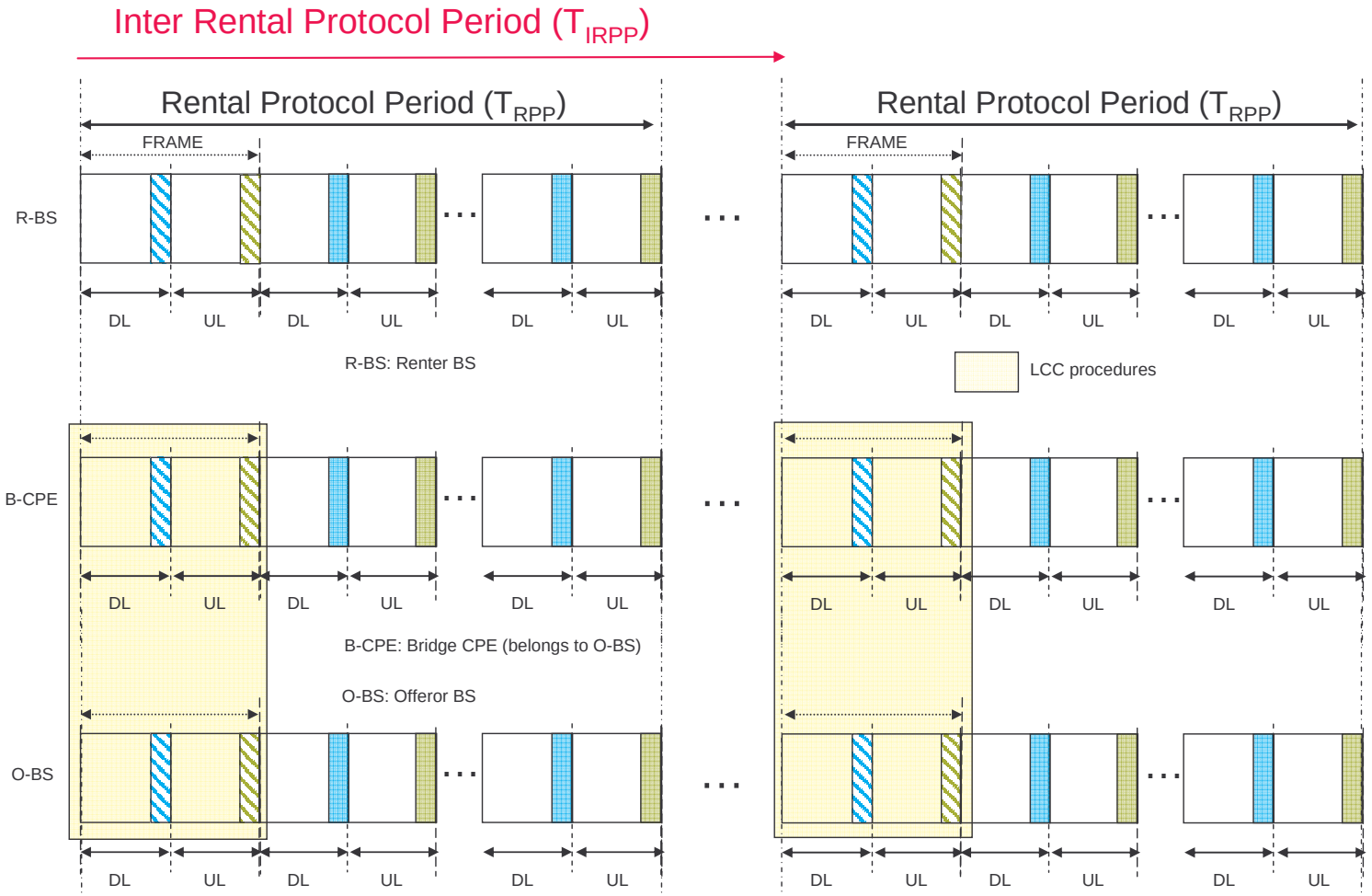
Negotiation Phase (2/3)



Negotiation Phase (3/3)

OS: Offeror Slot

CPS: Coexistence polling slots

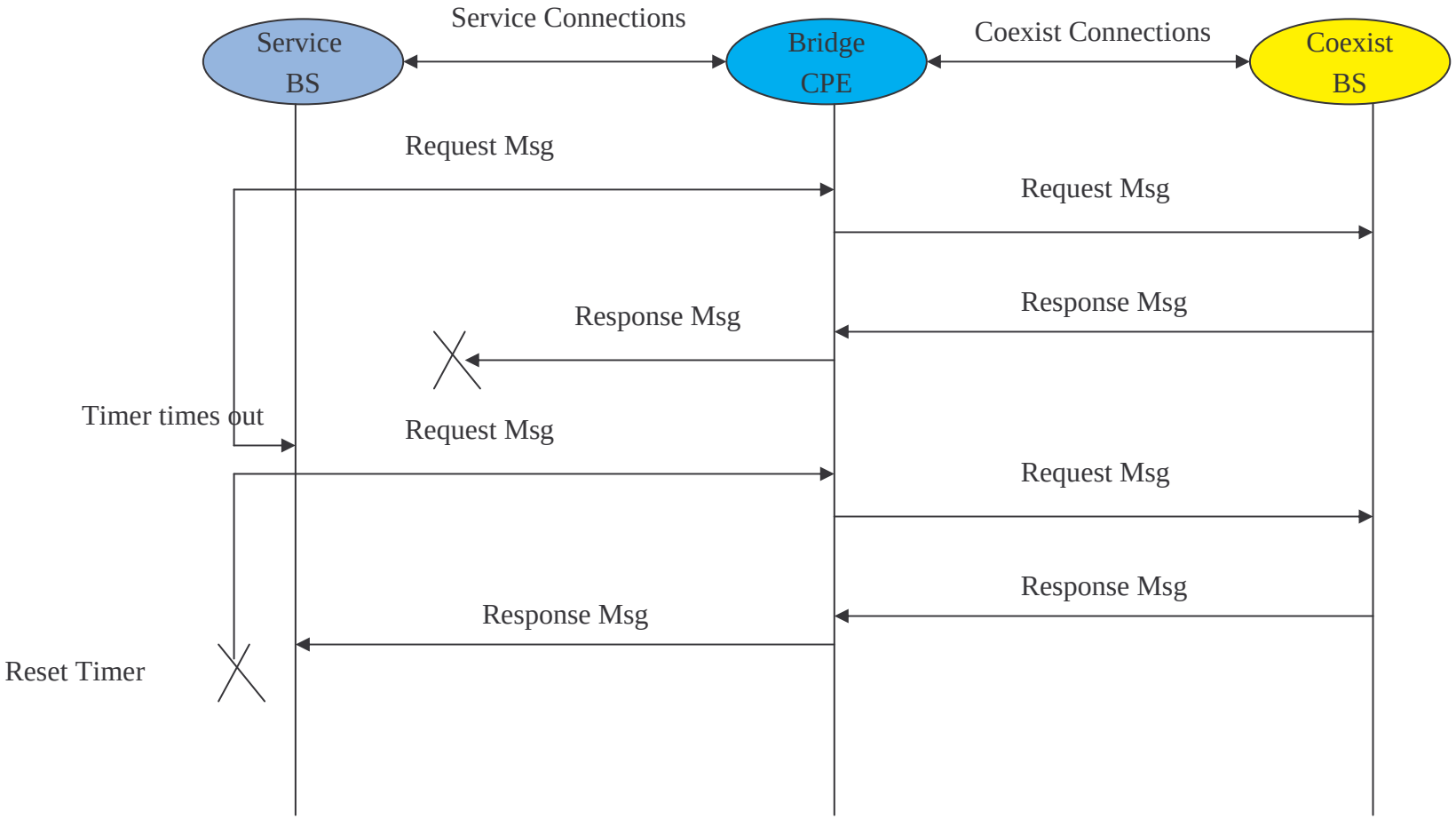


Reliability Enhancement for Logical Control Connection

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



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

$$delta = measuredRT\ \ T - srtt$$

$$srtt = srtt + g * delta$$

$$rtt\ \text{var} = rtt\ \text{var} + h * (|delta| - rtt\ \text{var})$$

$$RTO = srtt + 4 * rtt\ \text{var}$$

srtt: smoothed RTT.
rttvar: smoothed mean deviation estimator.
RTO: retransmission timeout.
h, g: value which are smaller than 1.

Thank you!