Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Olympus MAC Proposal]
Date Submitted: [May 2009]
Source: [Gang Ding] Company [Olympus Communication Technology of America]
Address [8605 Scranton Rd., Suite 830, San Diego, CA 92121]
Voice[+1 858 6429722], FAX: [+1 858 642 6850], E-Mail:[gding@olympus-cta.com]

Abstract: [This presentation proposes a MAC protocol that avoids interference to beacon and data communications in body area networks that involve multiple coordinators]

Purpose: [Olympus MAC proposal for IEEE P802.15.6.]

MAC Protocol for Tree-Topology Multi-Coordinator BAN

Gang Ding

Olympus Communication Technology of America

Outline

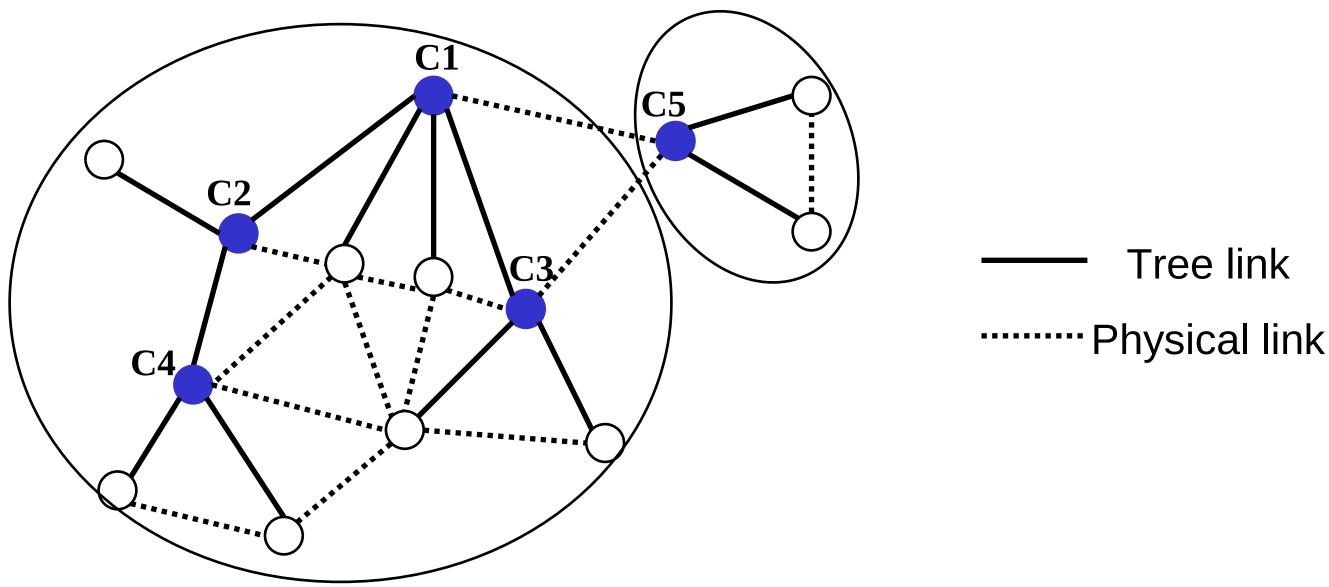
1. Requirement and problem
2. MAC for a star-topology BAN
3. MAC for tree-topology multi-coordinator BAN
   3.1. Interference-free beacon communication
   3.2. Interference-free data communication
   3.3. Network alignment
4. Conclusions
5. References

Requirements for MAC

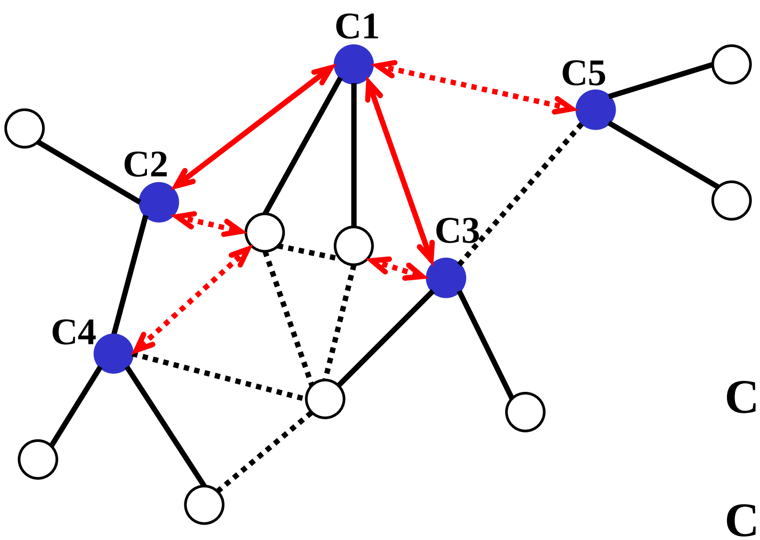
- QoS
  - Guaranteed response time for emergency scenarios (< 1 sec.)
  - Guaranteed throughput and latency for real-time applications
- Scalability
  - Support up to 256 end devices
- Coexistence and Interference
  - Support co-located operation of at least 10 randomly distributed BAN
- Power efficiency

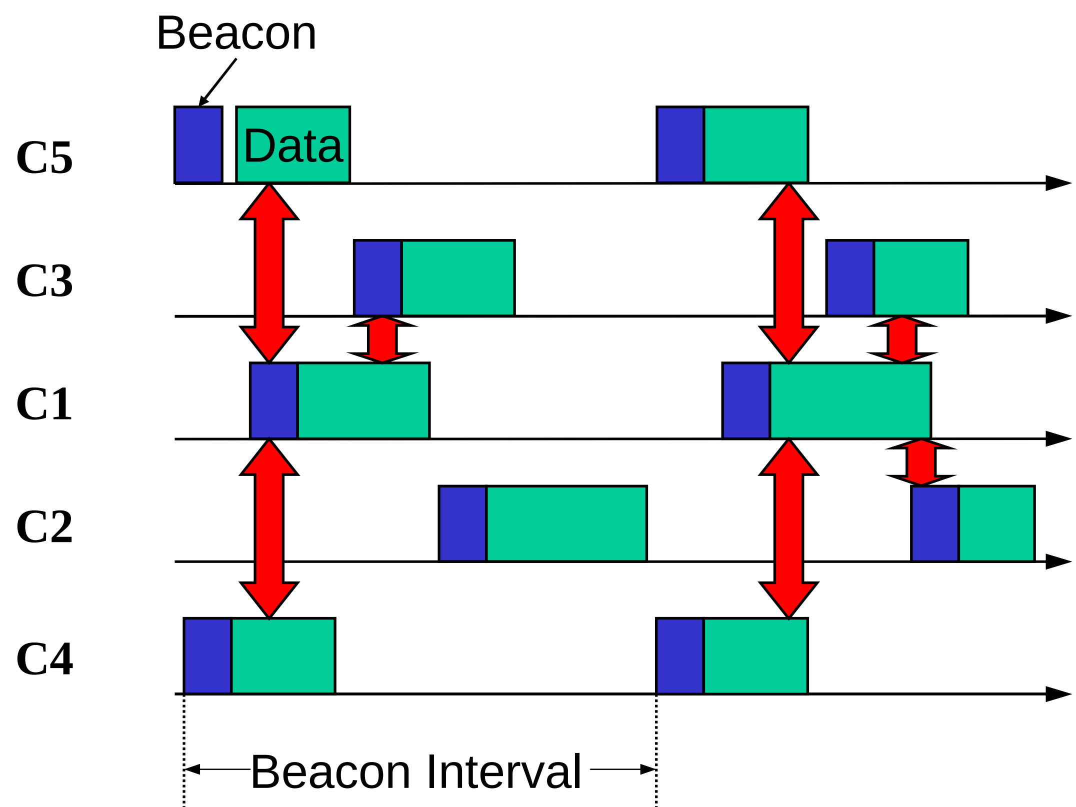
Problem

- So far we mostly consider a star-topology BAN with one coordinator
  - 256 end devices within one piconet can be too crowded
  - Different BANs may come across each other over the time
- What if there are multiple coordinators?
  - Coexistence of multiple BANs → A BAN may involve multiple trees → Each tree may have multiple coordinators



Interference in an Unaligned Tree-Topology Network

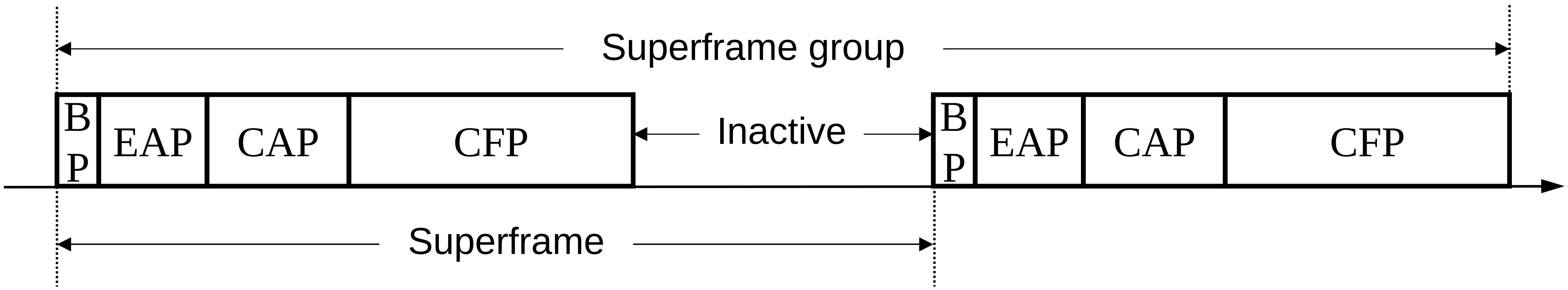




2. MAC for a Star-Topology BAN

MAC Superframe

- Beacon Period (BP): coordinator sends beacon periodically to bound the superframe (or Beacon Interval)
- Emergency Access Period (EAP): coordinator reserves slots for periodical guaranteed communication with end devices
- Contention Access Period (CAP): end devices contend to get access to communicate with coordinator
- Contention Free Period (CFP): reserved time slots to communicate data packets between coordinator and end devices

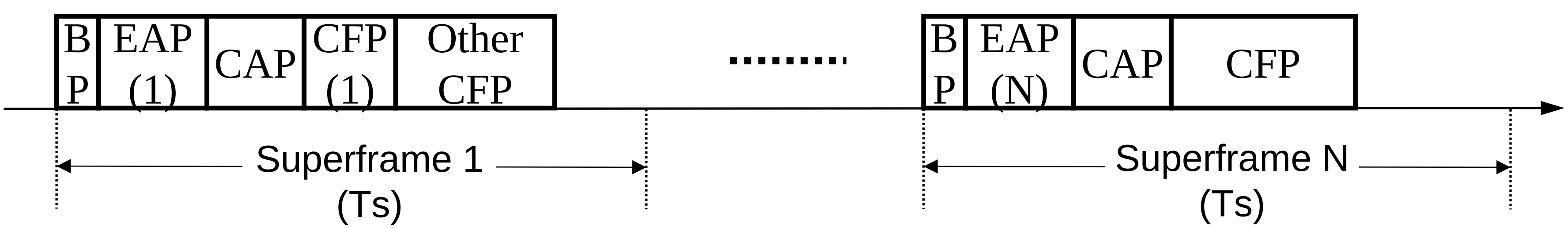


Beacon Period (BP)

- Each coordinator sends a beacon in BP at the beginning of superframe
- Every awaken end device should listen to beacon in BP
- A beacon includes control information:
  - ID for coordinator and network
  - EAP slot number, size, direction, and device ID
  - CAP slot number and size
  - CFP reserved slot number, size, and device ID

Emergency Access Period (EAP)

- At least one EAP slot is required to poll every end device periodically.
- If one EAP slot is not enough, it can be used to reserve more CFP slots.
  - Faster way to get CFP than going through CAP
- The upper bound of response latency is Ts*N

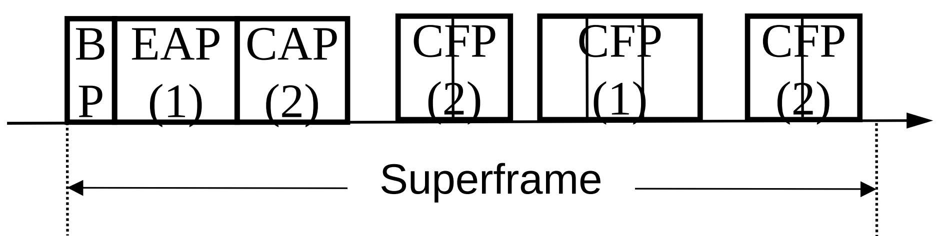


Contention Access Period (CAP)

- When an end device wants to communicate with its coordinator, it uses CAP before its next turn in EAP
- Contention method:
  - CSMA / CA
  - Slotted Aloha
  - Prioritized contention
- After getting access, the end device sends
  - CFP reservation request / response
  - Any other control information
  - Non-periodic data

Contention Free Period (CFP)

- Beacon sent by a coordinator includes
  - Reservation request / response to end devices
  - Reserved time slots and corresponding devices
- Each end device may send reservation request in CAP and/or EAP
- A device can reserve multiple time slots within one superframe, or one time slot for multiple superframes
- The reserved slots do not need to be consecutive (good for real-time applications)



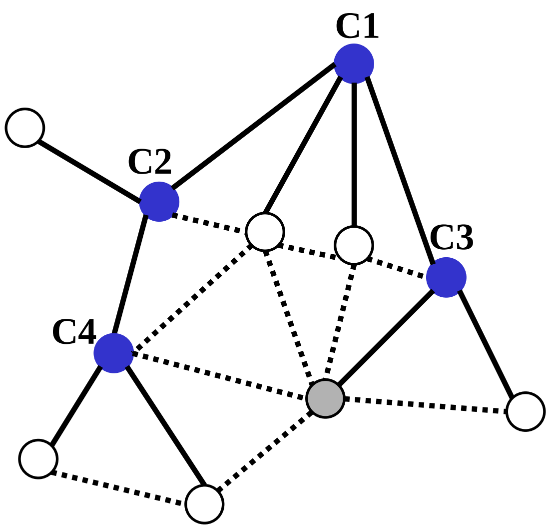
Power Saving

- Coordinator and end devices can sleep during inactive period within a superframe
- An end device may hibernate for multiple superframes
  - Before hibernation, coordinator must know when the end device will wake up
  - Can wake up earlier than expected. E.g. when there is sth. urgent to send to coordinator
  - Must wake up one superframe earlier than expected to scan one superframe in order to synchronize with coordinator
  - Recommended to wake up before its next EAP slot in order to receive potential emergent data from coordinator

3. MAC for Tree-Topology Multi-Coordinator BAN

3.1. Interference-Free Beacon Communication

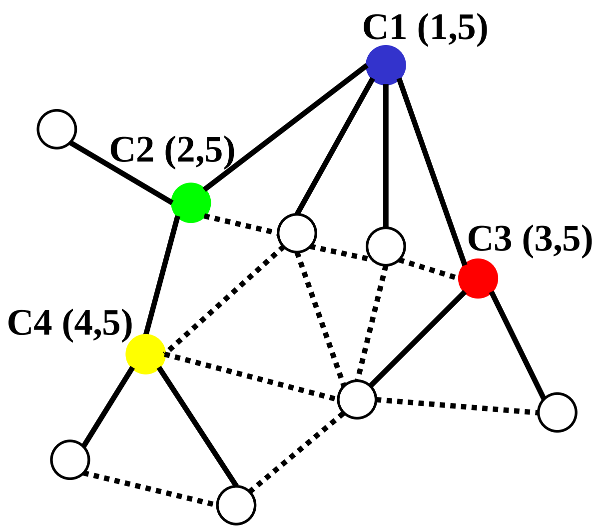
Interference-Free Beacon Transmission

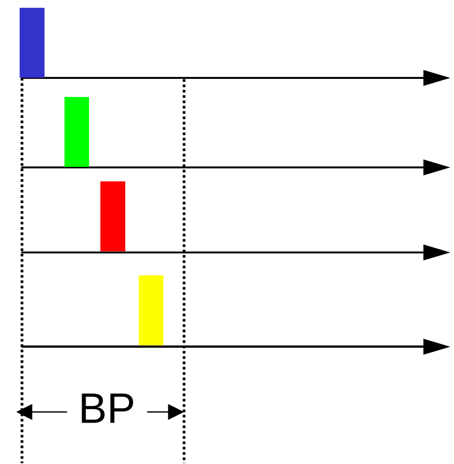


- Any beacon sent by a coordinator must be correctly received by
  - Its parent coordinator
  - All its children coordinators
  - All its children end devices

- Simultaneous beacons are prohibited among:
  - A coordinator, its parent, and all its children coordinators
  - Any two coordinators that share a physical neighbor device

Beacon Scheduling



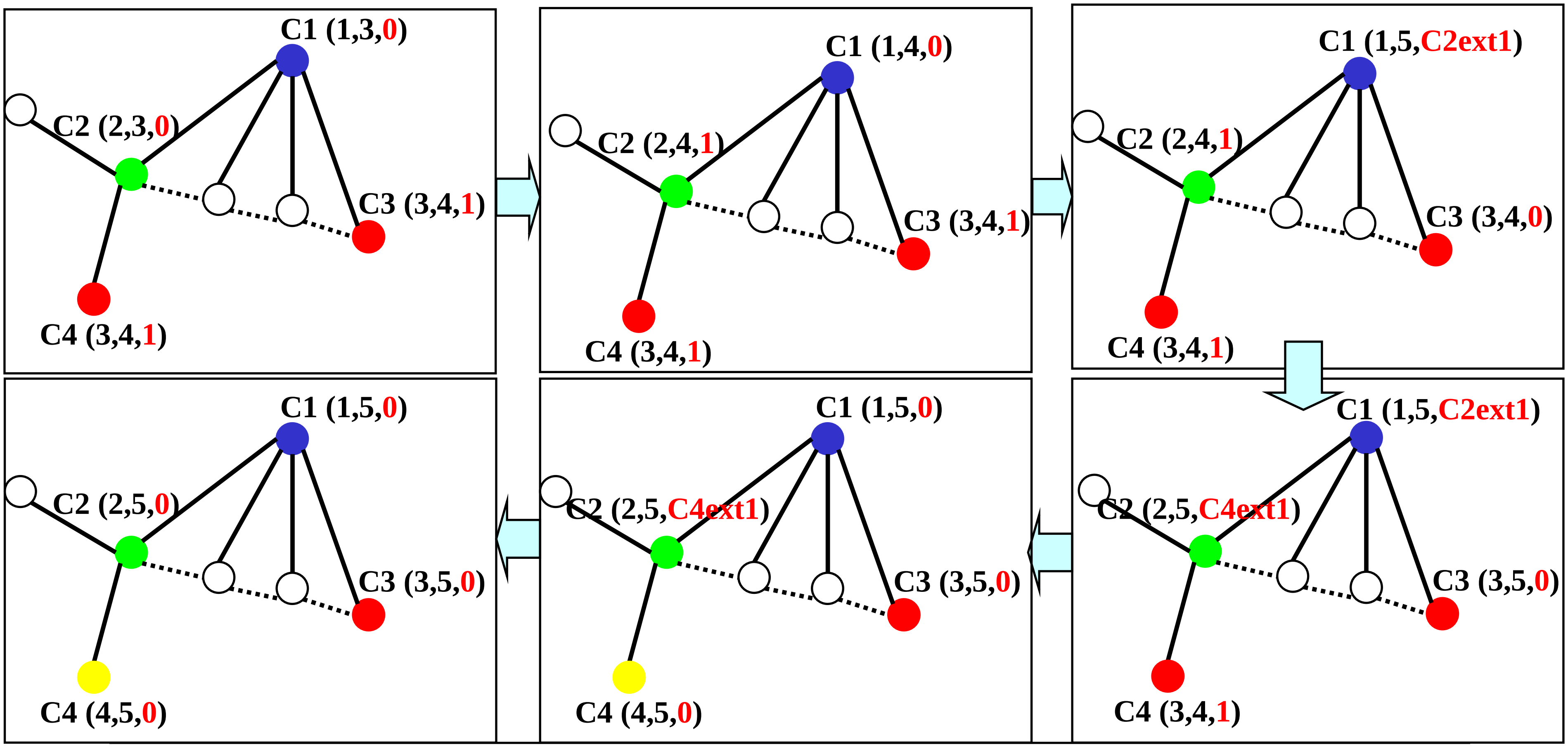


Coordinator (slot #, next available slot #)

- BP includes multiple beacon slots
- Each coordinator includes its perceived next available beacon slot in its beacon
- When a new coordinator joins the network, It gets a new beacon slot from its parent coordinator
- The parent coordinator is responsible for expanding or contracting the BP when a child coordinator joins or leaves, respectively.

Beacon Slot Confliction

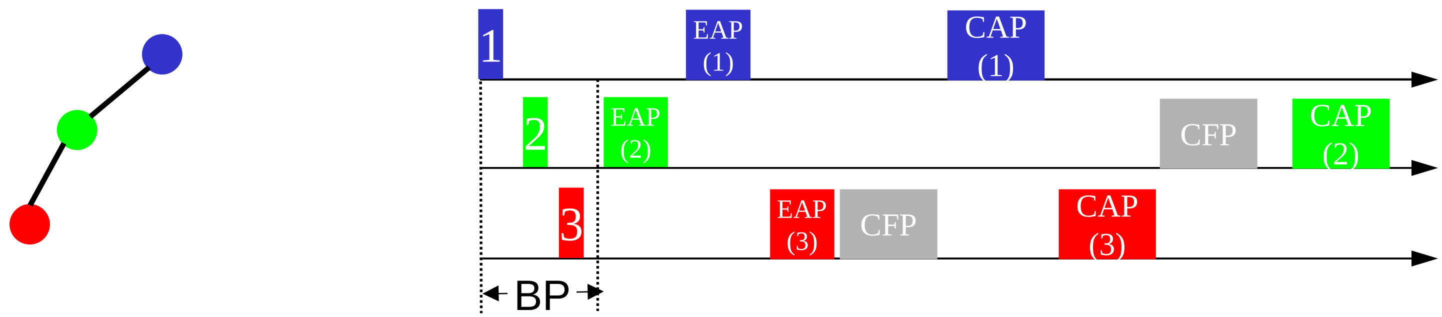
- When multiple coordinators join network at the same time, they might take the same beacon slot



Distributed Beacon Slot Scheduling Protocol

- Assume each coordinator maintains a 3-tuple (a,b,c) representing its own beacon slot number, its perceived next available beacon slot number, and the beacon slot increment number in the sub-tree rooted at this coordinator.
- When a coordinator receives a beacon from its child coordinator showing a positive parameter c, it increases its own parameters b and c by c.
- After processing beacons from all its children and parent, if a coordinator's parameter b is equal to every child and parent's parameter b, no confliction, reset its parameter c to zero.
- Else if the coordinator's parameter b is only different from its parent's parameter b, do nothing, let the parent handle this.
- Else, choose one of the children that has a less parameter b and positive parameter c, and signal that child to extend its sub-tree's beacon slot number by number d equal to the positive difference of parameter b.
- When the child receives such signal from its parent, it will continue to signal its own children until the leaf child that newly joined the network. The new child will extend its parameter b by d and reset its parameter c to zero.
- When a coordinator receives a beacon from its parent or child coordinator that has a larger parameter b than its own and a non-positive parameter c, it should update its own parameter b to the larger one.
- When a coordinator receives a beacon from its parent with the same parameter b but a zero parameter c, it should reset its own parameter c to zero too.

Interference-Free EAP and CAP

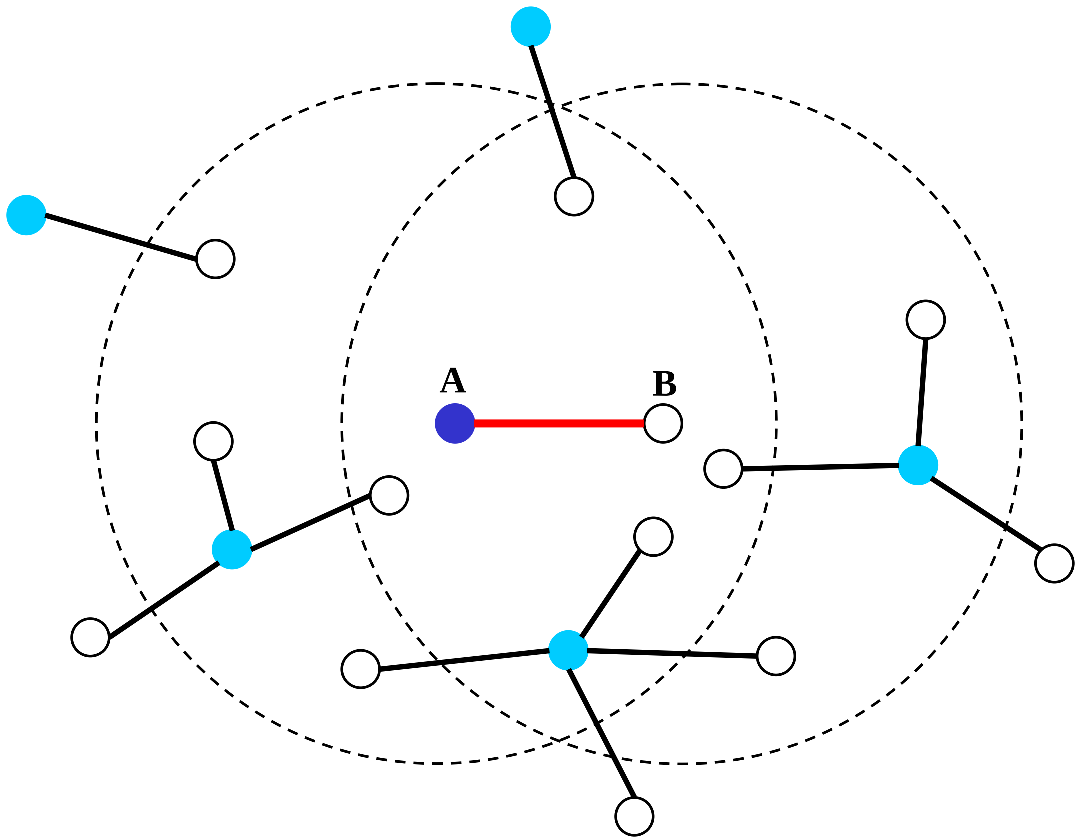


- EAP and CAP should use the same scheduling as BP to avoid interference, but
  - They do not need to be at the beginning of superframe or in the same order as beacon slots: a coordinator with beacon slot number k can use certain pre-defined mapping to find its unique EAP and CAP slot numbers
- More complicated algorithms can be used to exploit slot reuse, but the end devices have to participate, which is often impractical.

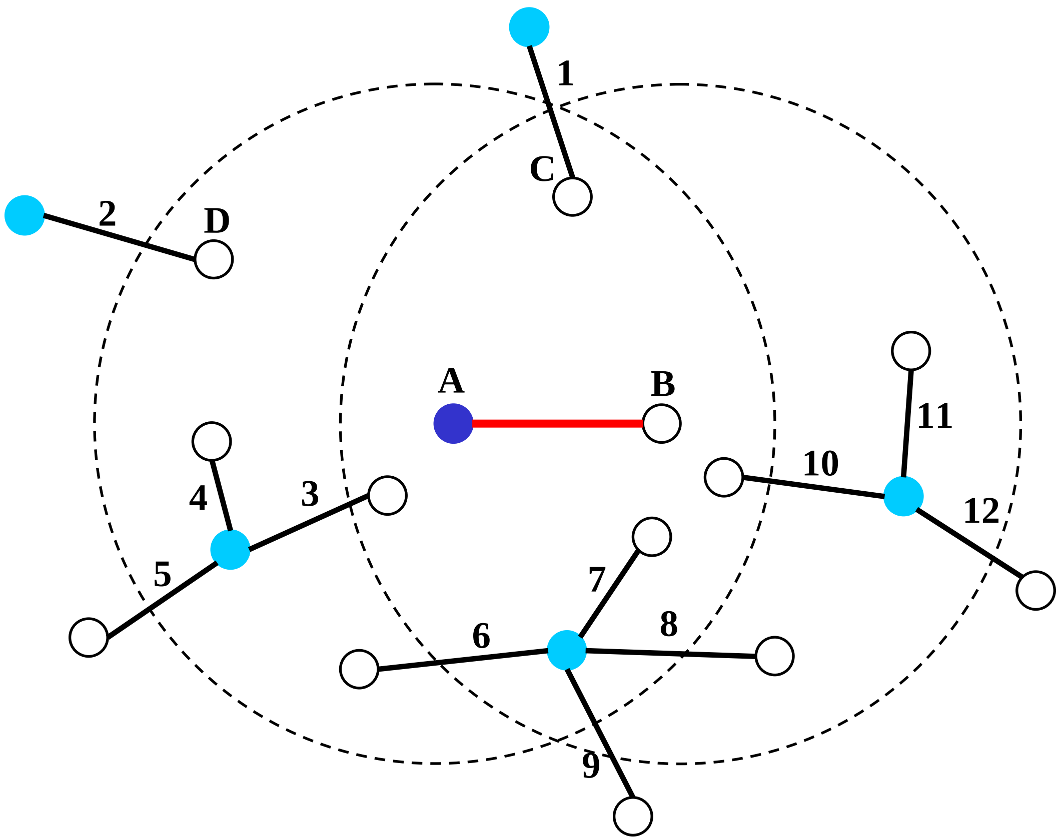
3.2. Interference-Free Data Communication

Interference to a Reservation in CFP

- A block of slots in CFP reserved for a coordinator and one of its end devices may get interference from other coordinators or end devices in their transmission ranges



Localized CFP Slot Reservation – An Example

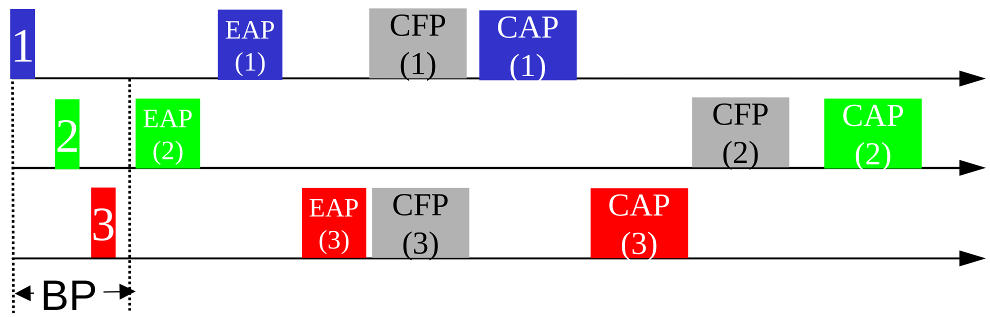


- A: {1,2,10,11,12}
- B: {1,2,3,4,5}
- A requests {1,2,11}
- B declines due to {11}
- A re-requests {1,2}
- B accepts it
- A includes {1,2} in beacon
- C and D resign {1} and {2}, respectively, after listening to A’s beacon

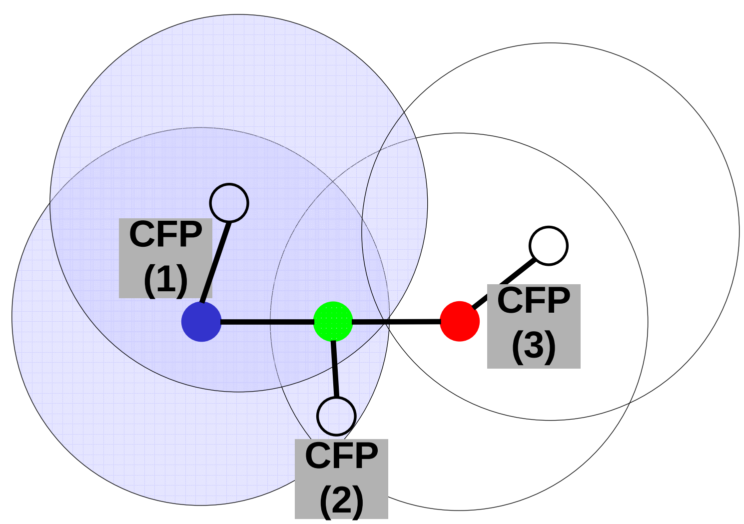
Interference-Free CFP Slot Reservation Protocol

- The coordinator includes reservation information in its beacon
- Both coordinators and end devices listen to all beacons in BP, and maintain an available slot list.
- When A (or B) initiates a reservation request to B (or A), it only reserves those slots in its own available list
  - If the requested slots are also available to B (or A), it accepts it;
  - Otherwise, B (or A) declines the request, but may include its available slot list in the reply in order to facilitate a new reservation
- When a device detects a reservation confliction when listening to other coordinators' beacons, it will report to its own coordinator with its updated available slot list and ask for changing the reservation

Slot Reuse

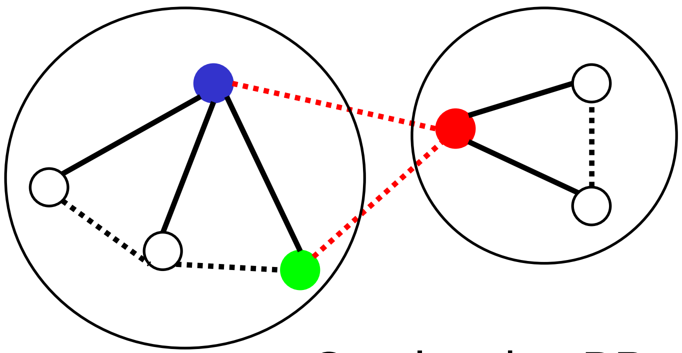


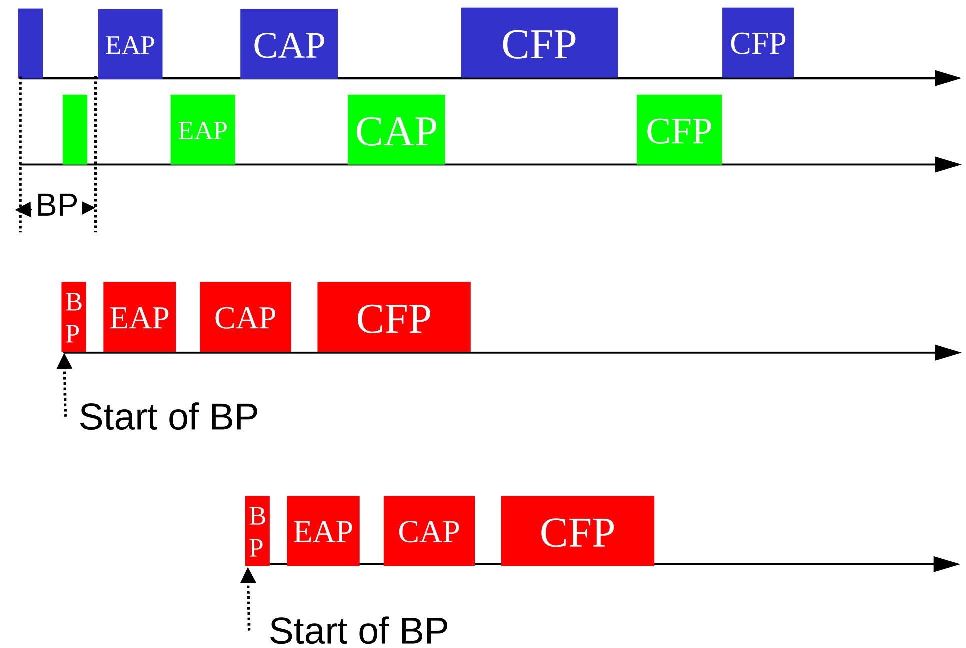
CFP slots may overlap with each other



3.3. Network Alignment

Network Interference: Two Cases



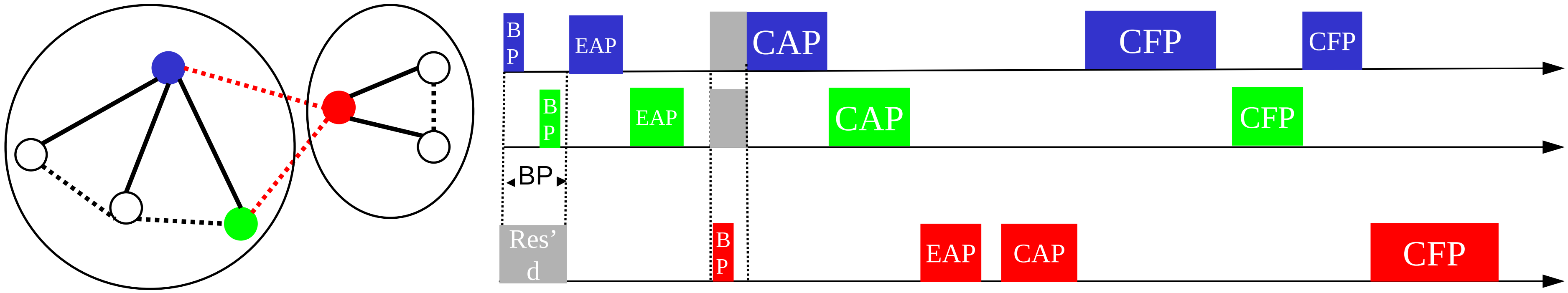


- Overlapping BP: there is overlap between two BPs
  - Can be easily detected when listening in BP
- Non-overlapping BP: there is no overlap between two BPs
  - Can not be detected at normal operation; a coordinator has to scan the whole superframe to detect another non-overlapping BP

Network Alignment – Merging

- One of the networks changes its superframe to synchronize with another network. For each coordinator in the network:
  - Stop all current CFP reservations and reschedule its beacon slot to be the next available slot in new network's BP;
  - Notify its end devices to change BP after certain number of superframes and start counting down;
  - When counting down reaches zeros, both the coordinator and all its end devices should merge to the new network by using new BP and beacon slot;
  - Parent coordinator in the new network expands the BP accordingly.

Network Alignment – Non-Merging



- When a coordinator detects another unaligned coordinator, it reserves the slots corresponding to another network's BP.
  - Coordinators and end devices listen to beacons in these reserved slots in order to update their own list of available slots and make change of their reservations
- Preferable in a dynamic environment that requires frequent network alignment

Conclusions

- TDMA based MAC protocol provides flexibilities for different QoS requirements:
  - EAP is a necessary part for time-bounded response
  - CFP provides guaranteed QoS for data communications
  - Beacons must be carefully protected
- MAC for tree-topology multi-coordinator BAN requires new technologies than those for a star-topology BAN
  - Interference from other coordinators in the same or different BAN affects both beacon and data communications
  - Distributed beacon scheduling protocol
  - Localized CFP slot reservation protocol
  - Network alignment

References

1. “IEEE 802.15.6 Technical Requirements,” 15-08-0644-09-0006, 2008.
2. “NICT MAC preliminary proposal, Part I and II,” 15-09-0162-00-0006, March 2009.
3. “Network Merging,” 15-09-0133-00-0006, March 2009.
4. “Collision-Free Beacon Scheduling Mechanisms for IEEE 802.15.4/Zigbee Cluster-Tree Wireless Sensor Networks,” in 7th International Workshop on Applications and Services in Wireless Networks, 2007.
5. “IEEE Std 802.15.4 – 2006”.
6. “Enhancements to IEEE 802.15.4,” 15-04-0313-01-004b, 2004.
7. “Beacon Collision Avoidance Mechanism for IEEE 802.15.4e MAC,” 15-08-0618-01-004e, 2008.
8. “IEEE Std 802.15.3b – 2005”.
9. “Distributed MAC for Wireless Networks,” WiMedia MAC Specification, 2008.

Thank you

Questions