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

Submission Title: [Samsung Proposal: PAC Operations and Frame Structures]
Date Submitted: [7 July 2013]
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Re: [.]

Abstract: [Presentation of PAC synchronous operations and frame structure with identified features for working consensus to work on PFD]

Purpose: [Corresponding to Call for Proposal]

Samsung Proposal: PAC Operations and Frame Structures

July, 2013

Samsung

System Design Approach

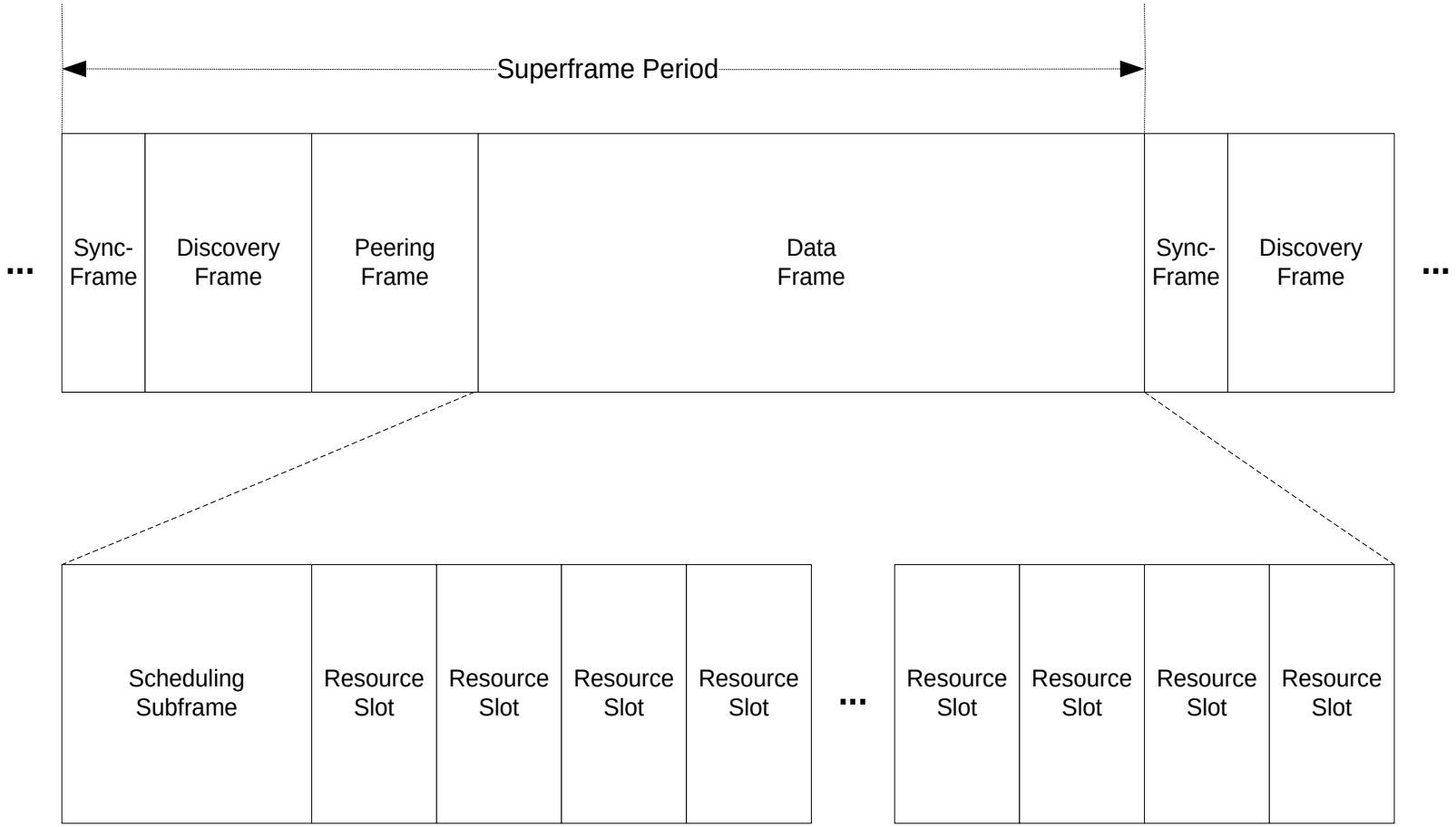
- Synchronous Operation
  - Low power consumption for peer discovery
  - Higher throughput for communication

- Frame Structure
  - Synchronization
  - Peer discovery
  - Peering
  - Data transmission
    - Scheduling for efficient slot allocation
    - Designed for unicast transmission

Fully Distributed Operations

- Synchronization
  - Based on Pulse-Coupled Oscillator (PCO) algorithm
- Peer Discovery
  - Prior to peering
  - Broadcast Peer Discovery Message via selected resource
- Peering
  - Link establishment
- Data transmission
  - Scheduling and interference management
  - Resource request and response

PAC Frame Structure



Synchronization

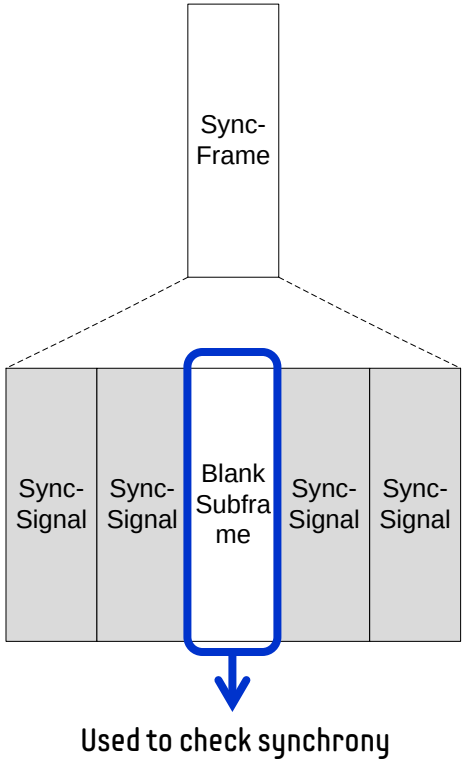
- Synchronization for Scalable Network
  - Distributed synchronization
    - Master-slave synchronization should be avoided
      - PDs between two different synchronized group happen
    - It is matched well to flat architecture (no hierarchy)
  - Synchronization should be done before peer discovery
    - Peer discovery prior to link connection (peering)
    - Broadcast-based synchronization mechanism is required
- Proposed Design Approach
  - Physical layer signaling based synchronization

Synchronization

- Initial Synchronization
  a. Start in initial synchronization mode
  b. PD monitors sync-signals during sync-period
  c. If at least one sync-signal is detected during sync-period, perform according to distributed synchronization mechanism
  d. Else, start PAC operations based on frame structure in maintaining synchronization mode

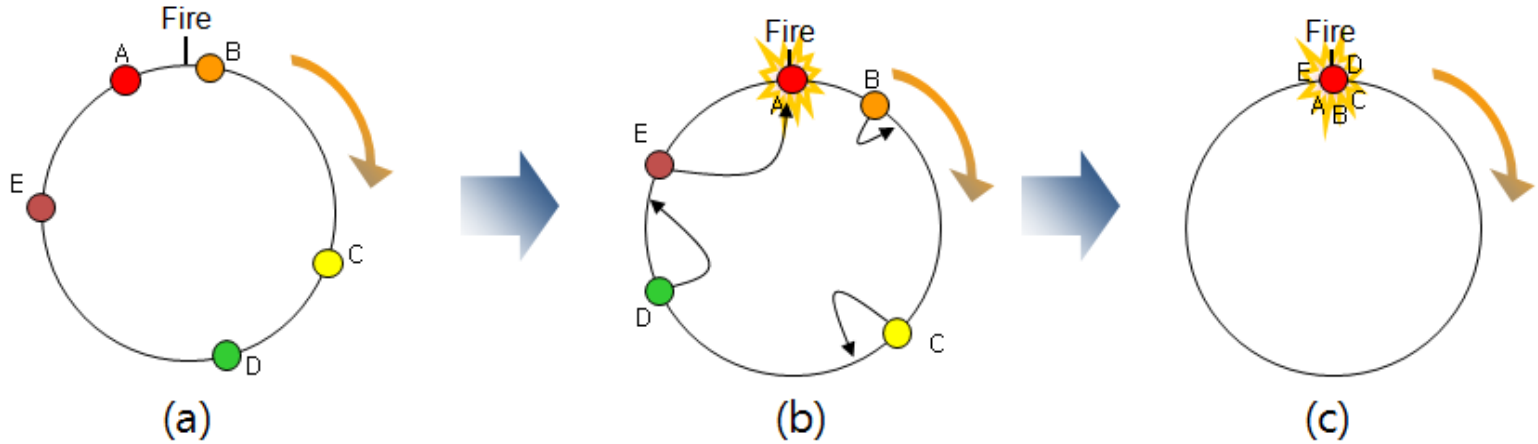
Synchronization

- Maintaining Synchronization
  a. PD sends sync-signal periodically, but checks synchrony state sometimes without sending sync-signal
  b. If in-synchrony, PD adjusts oscillator for phase drift compensation
  c. If out-of-synchrony, go to initial synchronization mode



Synchronization

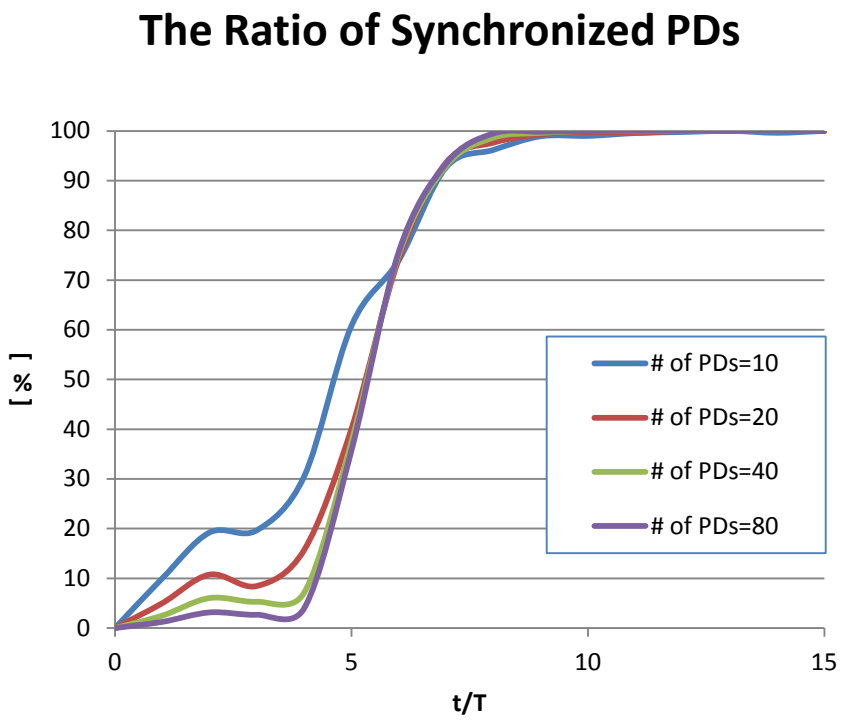
- PCO Synchronization [1]
  - In initial synchronization mode
  - Pulse-based approach
    - Oscillator coupled by pulse exchange via physical layer



(a) All nodes have oscillator with the same phase increment rate
(b) One node fires, then other nodes adjust oscillator according to the predefined function without state other than it's internal phase
(c) Finally, all nodes converges to the same time base

Synchronization Performance

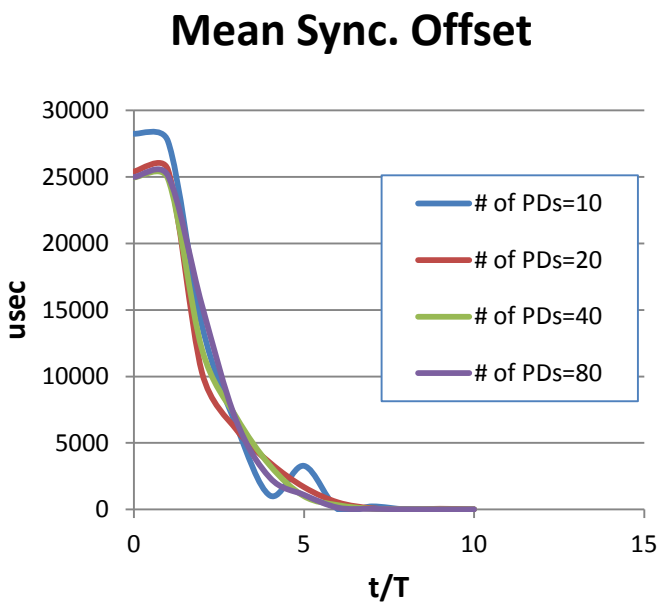
- Simulation Condition
  - Dimension
    - 500 x 500 m^2
  - Coupling factor
    - 0.05
  - Dissipation factor
    - 10
  - Sync-signal period
    - T = 10 msec



* Simulation methodology refers from [2]

Synchronization Performance

- Synchronization Accuracy

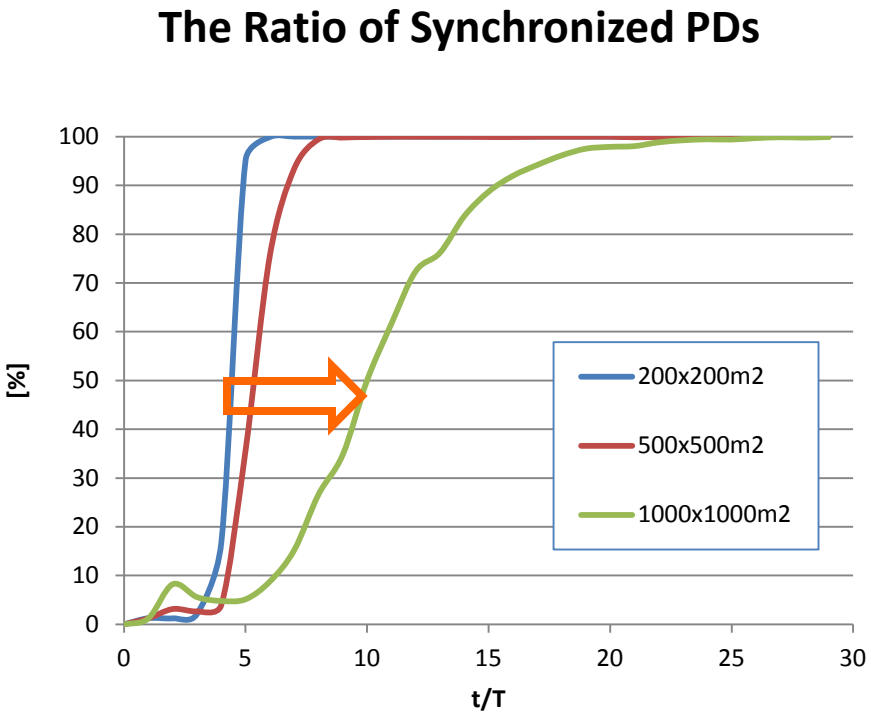


	$N_{PD}=10$	$N_{PD}=20$	$N_{PD}=40$	$N_{PD}=80$
0	28260.18	25418.36	24975.59	25000
1	27694.1	25552.14	24881.05	25101.9
2	13833.46	10297.46	12051.57	15352.84
3	6376.196	6033.111	6973.267	6729.542
4	1036.911	3505.74	3294.19	2374.513
5	3273.107	1669.398	985.3763	1094.029
6	0.248531	517.5309	312.7014	126.0405
7	223.569	78.55826	40.29059	36.55889
8	0.217967	0.239922	28.45693	14.23396
9	0.2067	39.74689	2.751351	0.258708
10	0.211183	0.253245	0.250434	0.257205

Achieves under 1 usec synchronization accuracy!

Synchronization Performance

- Simulation Condition
  - # of PDs
    - 80
  - Coupling factor
    - 0.05
  - Dissipation factor
    - 10
  - Sync-signal period
    - T = 10 msec



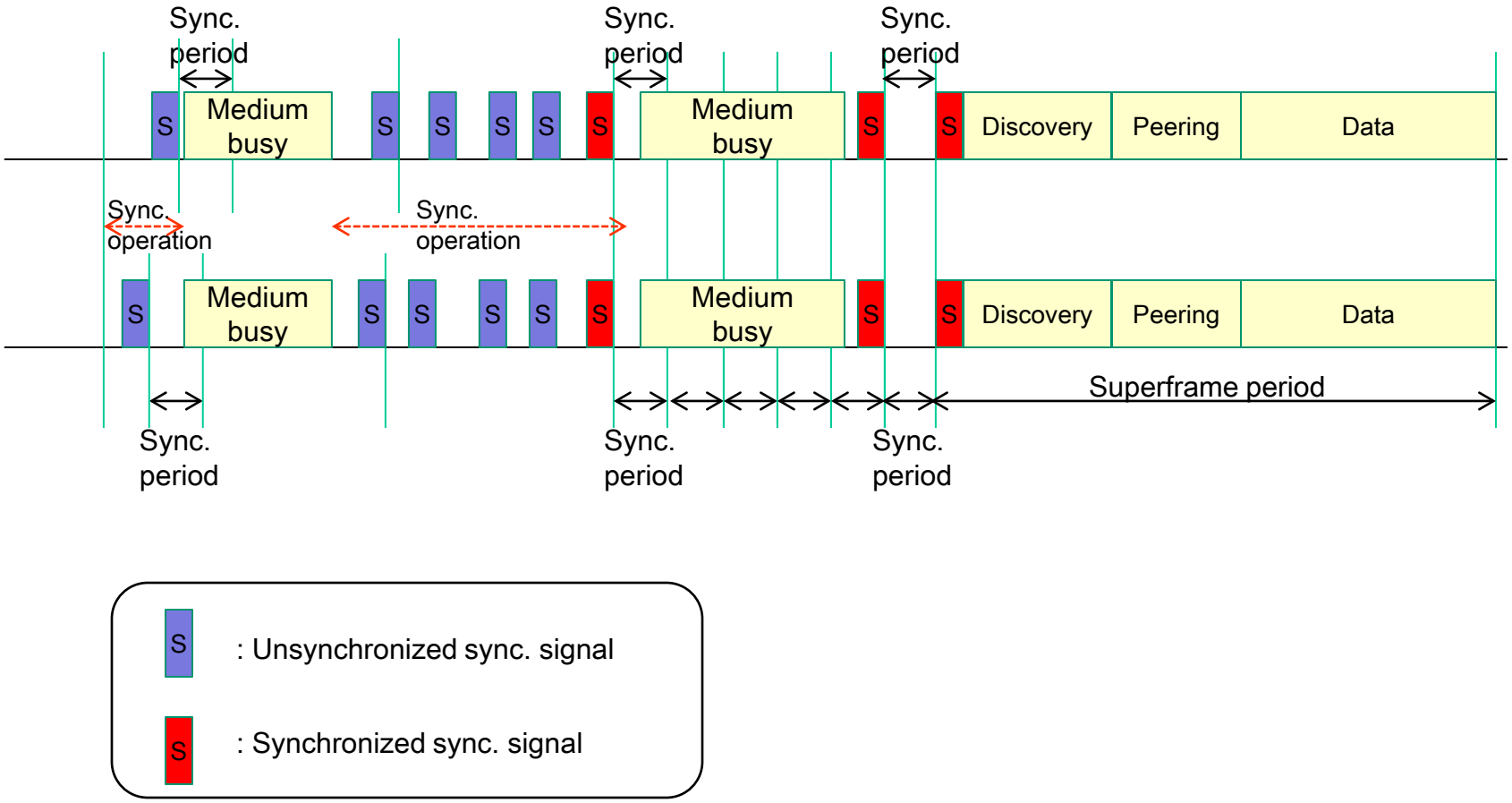
Long latency as being in low density

Synchronization for Unlicensed

- In Initial Synchronization Mode
  a. PD senses energy level while doing sync. operation
  b. If medium is busy,
     - Pend synchronization operation

     else
     - Keep synchronization operation
  c. Check synchrony state
     - Two conditions
       - No sync-signals during sync. period
       - Medium is not busy during sync. period
     - Superframe starts in maintaining synchronization mode

Synchronization for Unlicensed

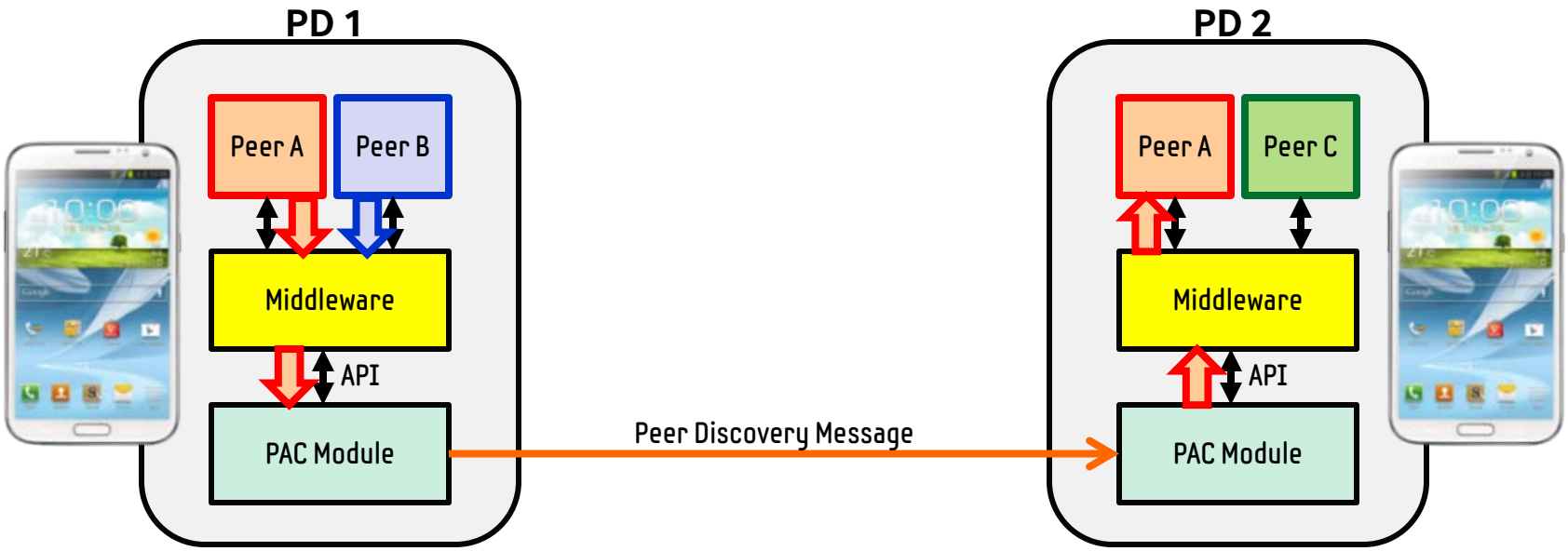


Peer Discovery

- Design Considerations
  - The meaning of Peer Discovery
    - It depends on what is discovered
      - Discovery of application → PACbook
      - Discovery of friend → bob@PACbook
      - Discovery of group → IEEE802@PACbook
  - Who gives peer discovery information (PDI)
    - Application or middleware
      - They may have access to internet or may not
    - Authentication
      - Only PDs with same PDI can be discovered each other
      - PDI may be pre-installed or given from network
  - Unified Peer Discovery mechanism required

Peer Discovery

- What is peer discovery?
  - A peer is an application, not a device
  - Application-centric discovery

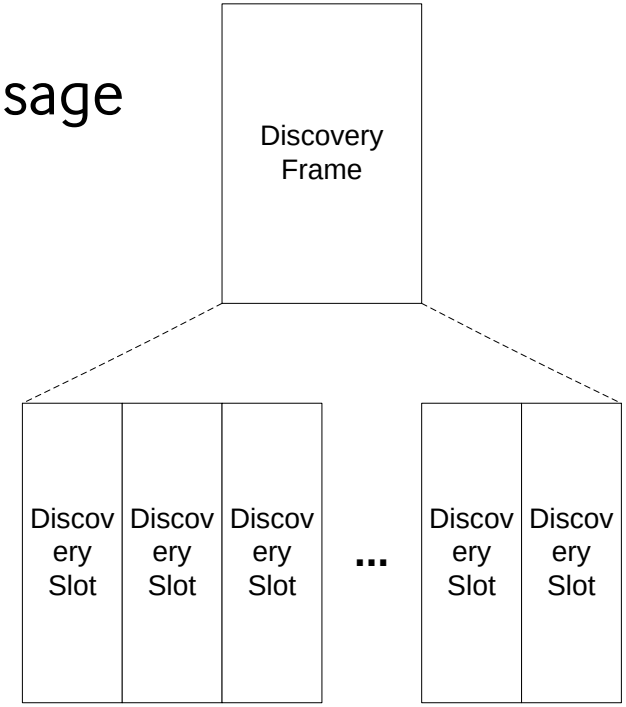


Peer Discovery

- Peer Discovery Message (PDM)
  - It is generated based on PDI including
    - Application-specific ID,
    - Application-specific user ID,
    - Application-specific group ID,
    - Or any upper layer discovery information
  - Middleware in PD1 indicates PDM to PAC module
  - At PAC module of PD1, it is broadcasted to PD2
  - At PAC module of PD2, it is delivered to middleware
  - Middleware in PD2 is aware of nearby peer
    - By matching result with pre-stored PDM

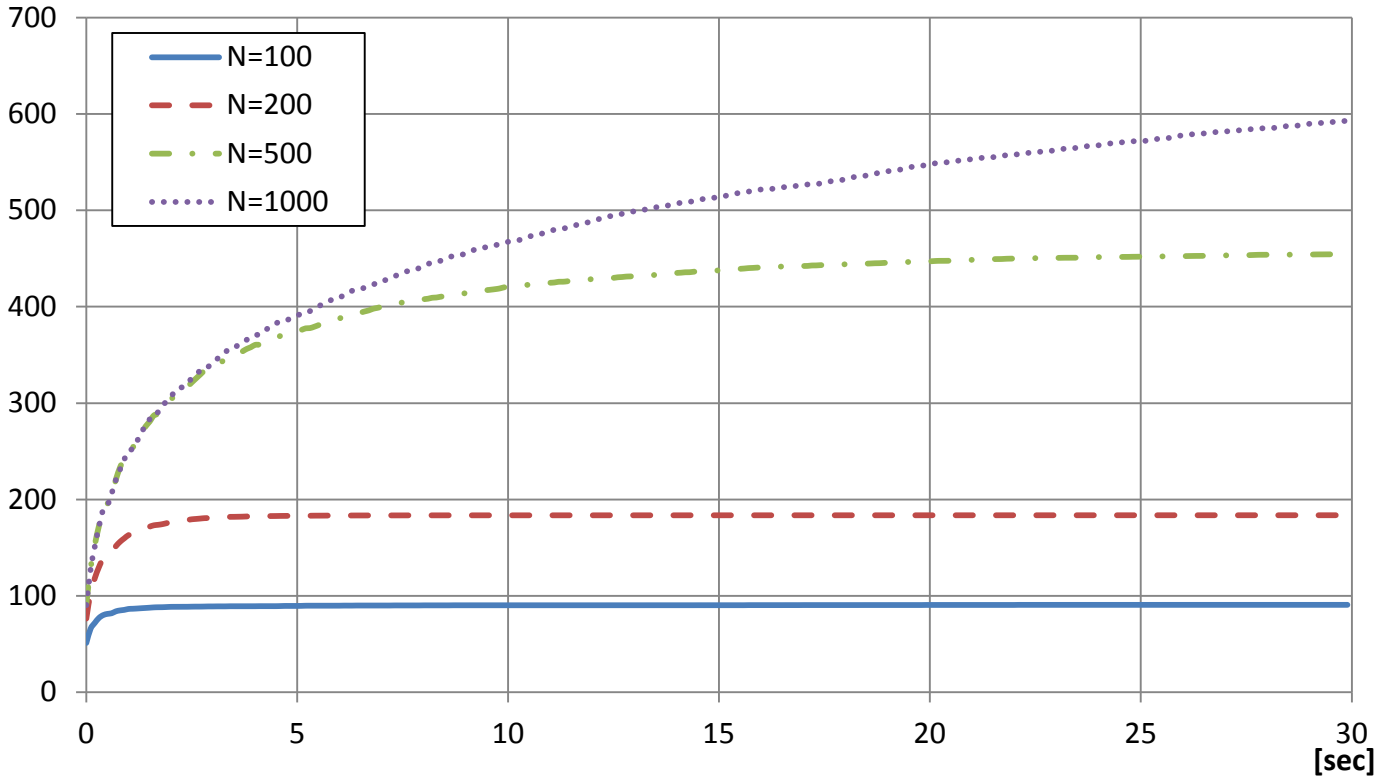
Peer Discovery

- Discovery Frame
  - It is comprised of multiple Discovery Slots
  - PD selects one Discovery Slot
  - PD broadcasts Peer Discovery Message
    - At selected Discovery Slot
  - PD monitors congestion
    - If congested, PD selects different Discovery Slot for next transmission
    - If not congested, PD keeps the current Discovery Slot



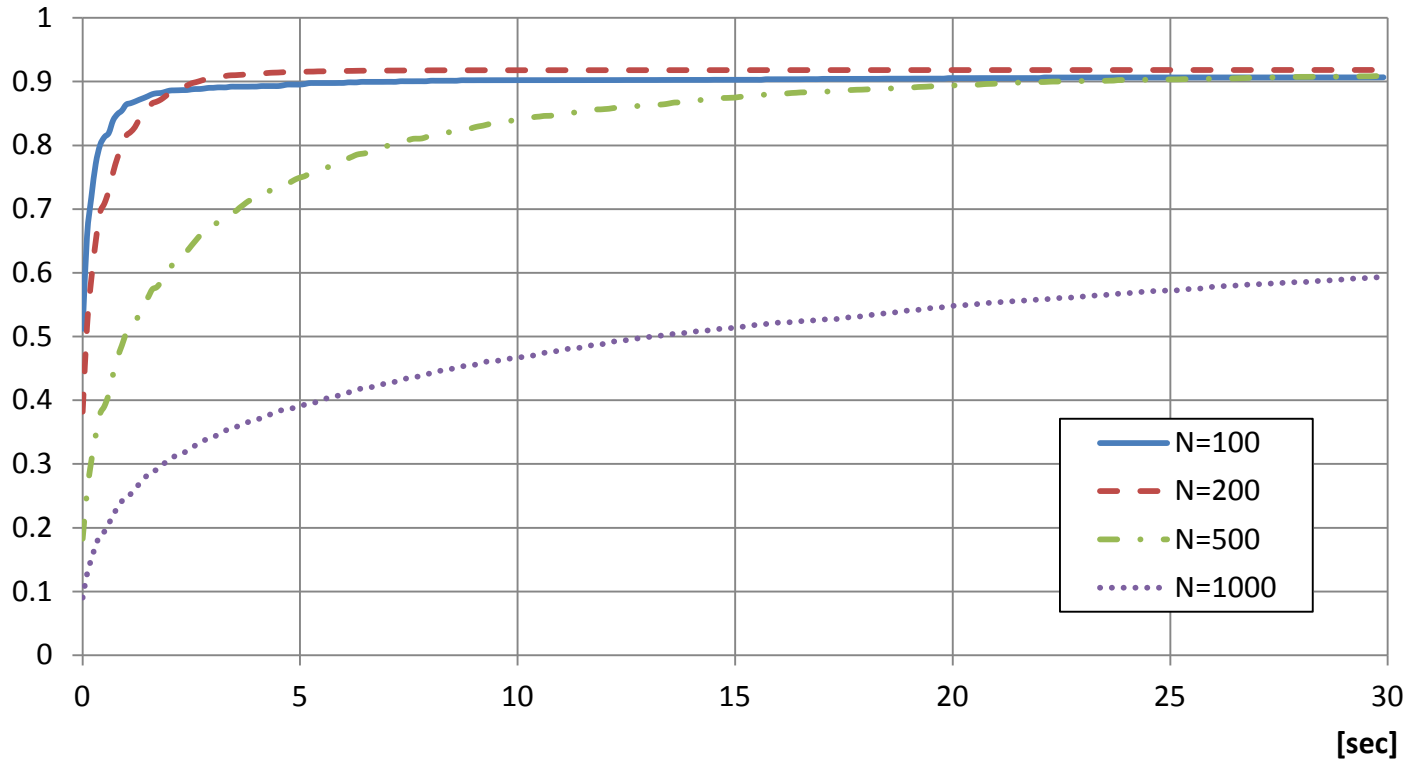
Peer Discovery

- Performance Results
  - The number of discovered PDs



Peer Discovery

- Performance Results
  - The ratio of discovered PDs (normalized by total PDs)

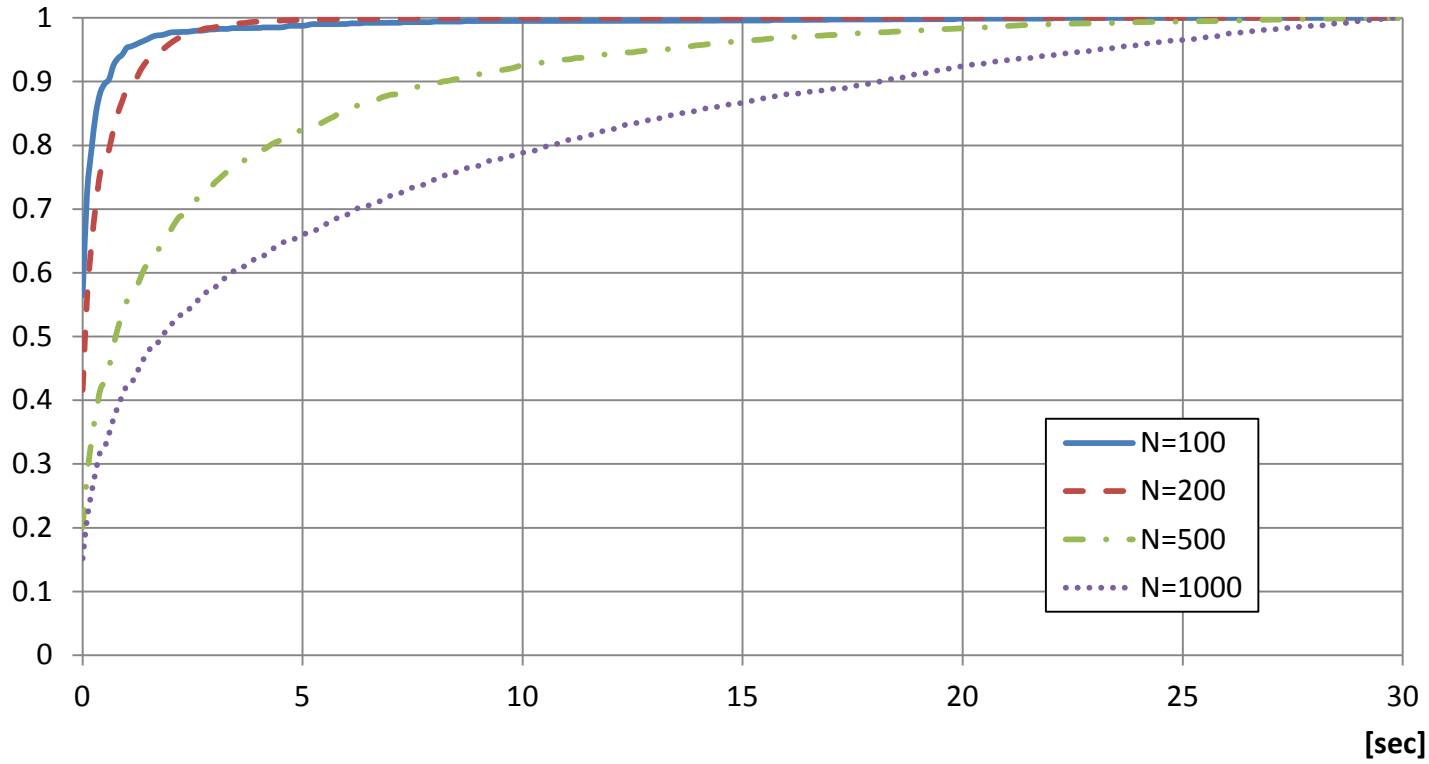


<90% Except 1000 PDs

60% at 1000 PDs

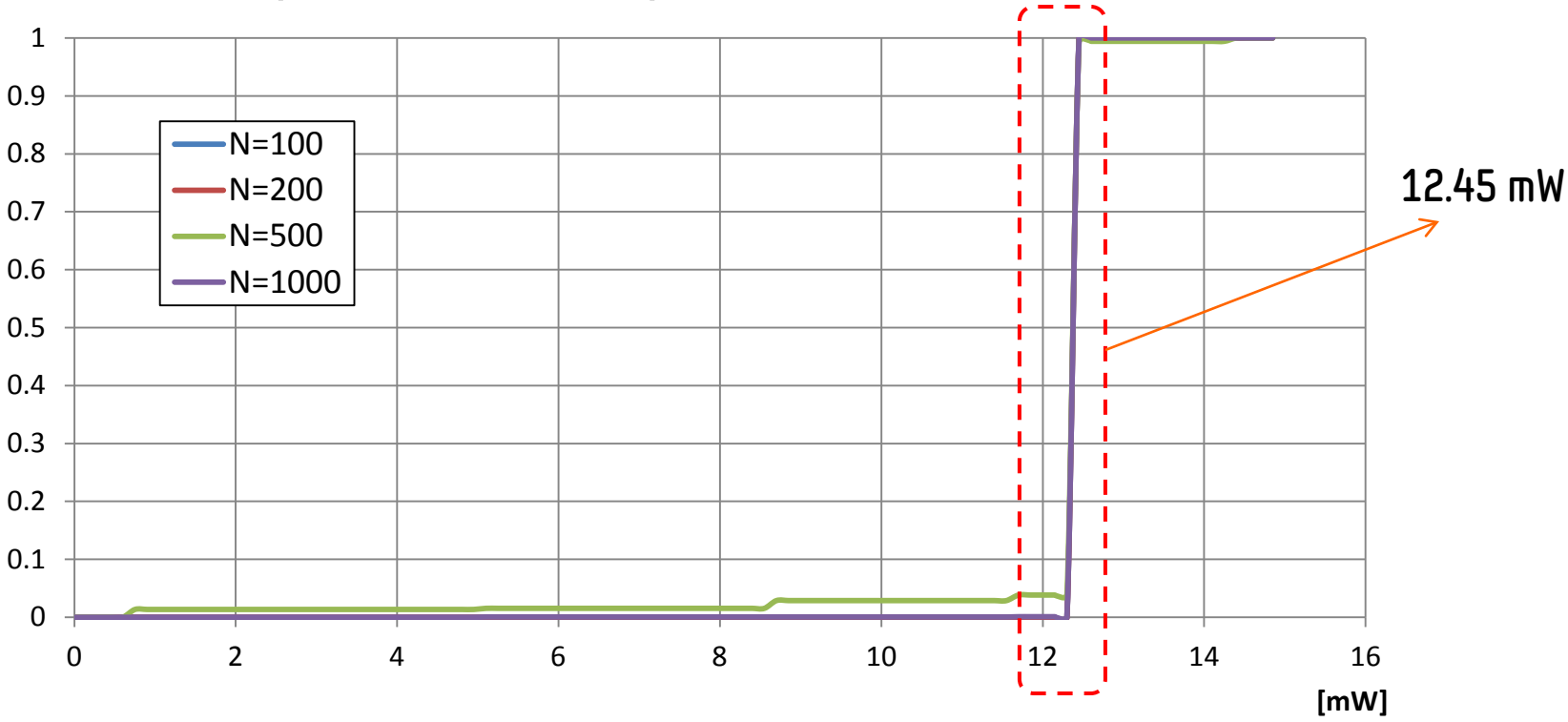
Peer Discovery

- Performance Results
  - CDF of the discovery latency



Peer Discovery

- Performance Results
  - CDF of power consumption



Peering

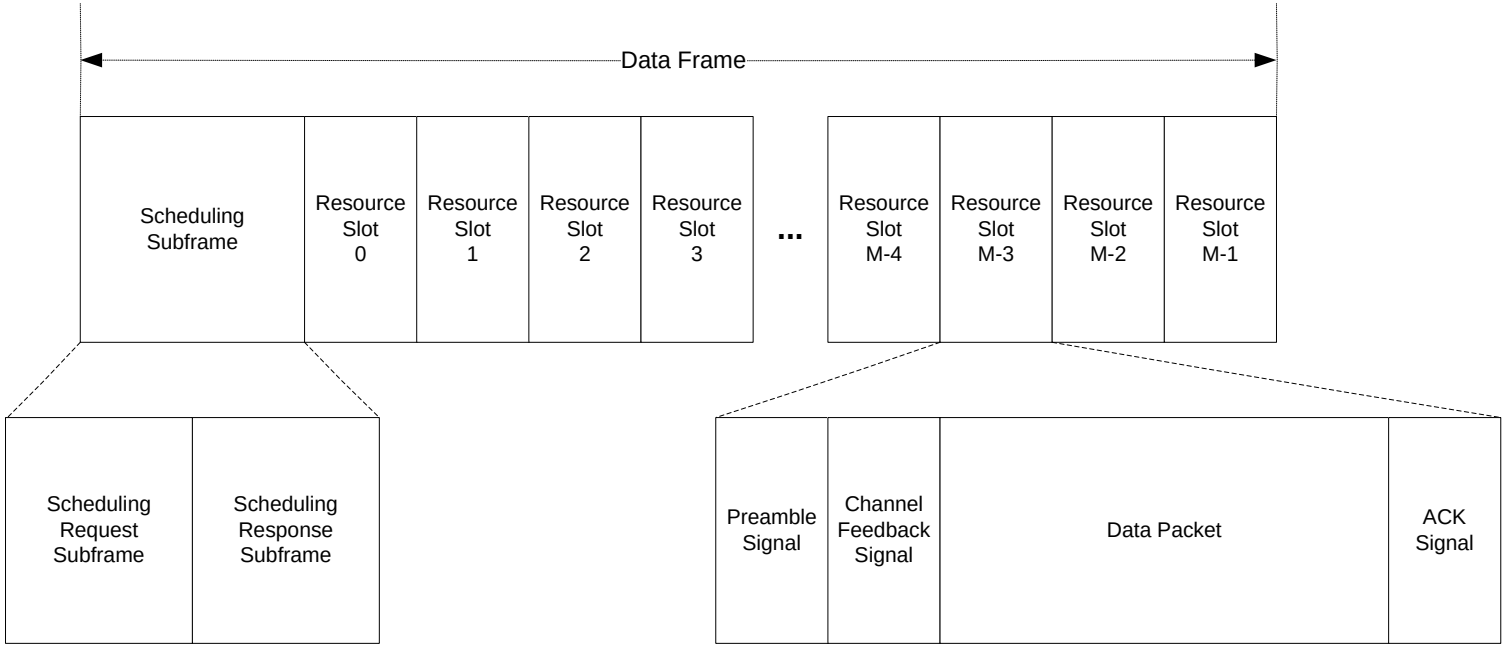
- The role of Peering
  - A procedure to connect to discovered peer
    - Triggered by application automatically or by user manually
  - Link establishment
    - Between the discovering peer and the discovered peer
    - Exchange of information for setup
      - device capability, or etc
    - Determine link related parameters
      - Link ID, QoS class, link range, or etc
  - Messages
    - Peering Request
    - Peering Response

Data Transmission

- Data Frame
  - Only accessed by peered PDs
  - Signaling reduction using Link ID set up during peering
    - No necessity of keeping two IDs for both Tx PD and Rx PD
- Design Considerations
  - Connection is the result from peering
    - Unicast/multicast including single/multi-hop
    - Network protocol shall be operated only over connected links
      - E.g. routing, grouping, etc

Data Transmission

- Data Frame
  - Scheduling subframe
  - M Resource Slots



Data Transmission

- Design Approach
  - Synchronized slotted channel access
  - Distributed scheduling to avoid slot confliction
    - Scheduling Request and Scheduling Response
    - These signaling messages contain resource information
      - Related to resource slot assignment
      - Broadcasted to nearby PDs

Scheduling Request :

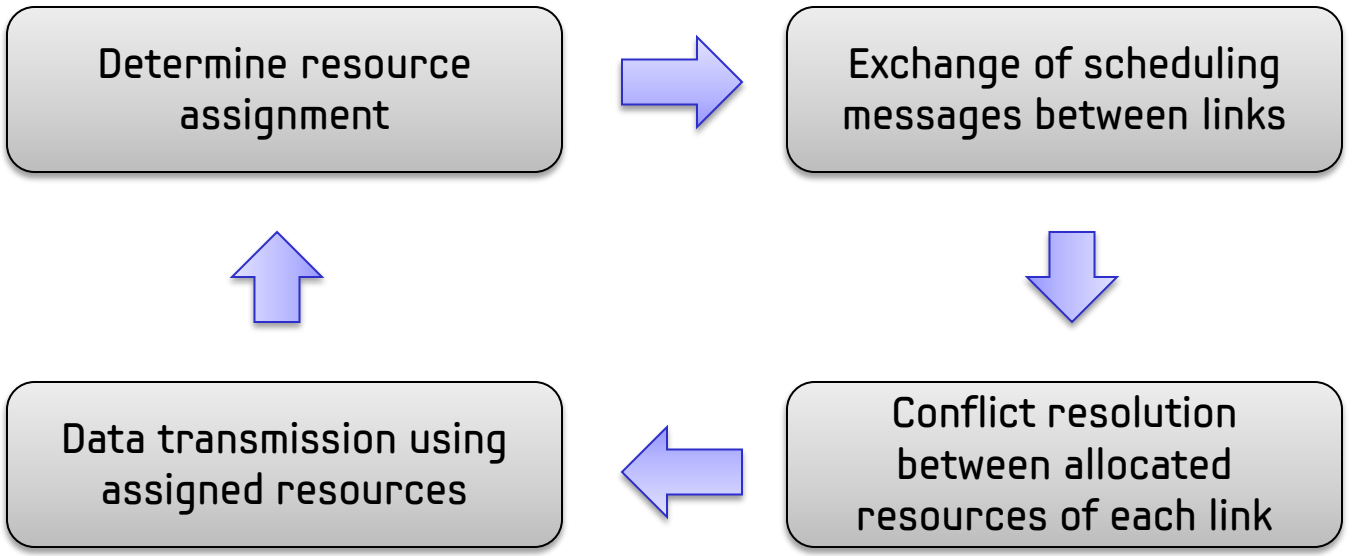
Link ID	Resource Slot Start Index	Resource Slot Length

Scheduling Response :

Link ID	Resource Slot Adjusted Index	Resource Slot Adjusted Length

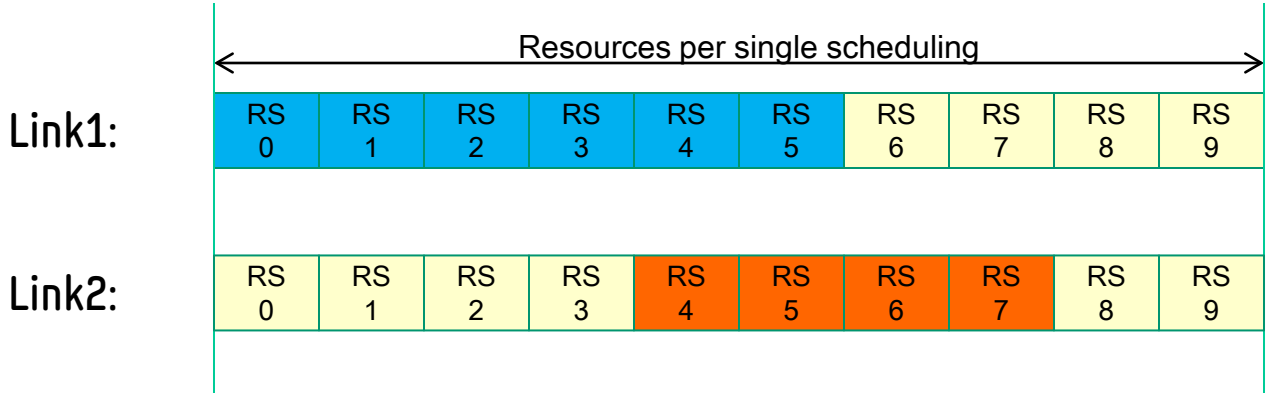
Data Transmission

- Concept of Distributed Scheduling Procedure

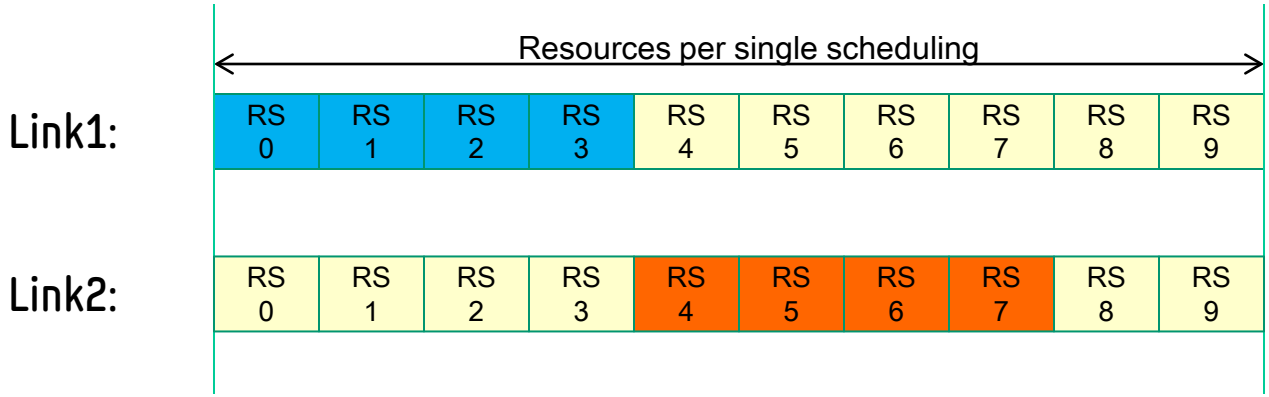


Data Transmission

Determine resource assignment

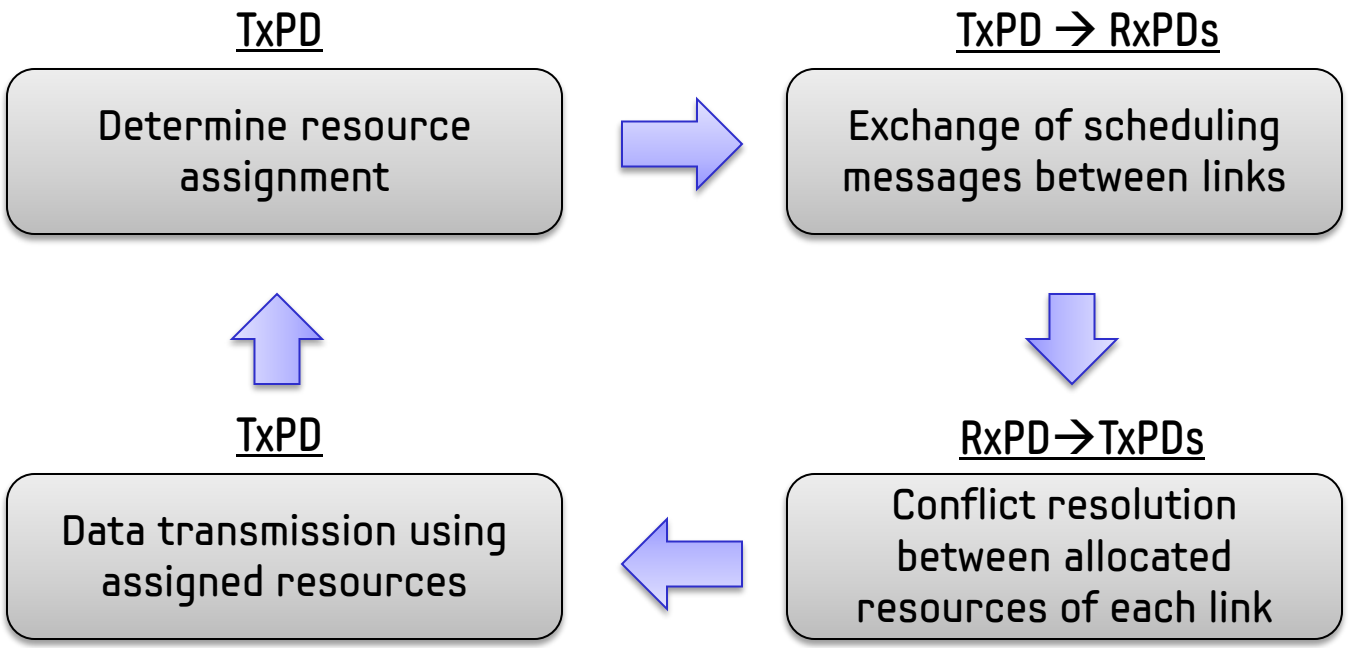


Conflict resolution between allocated resources of each link



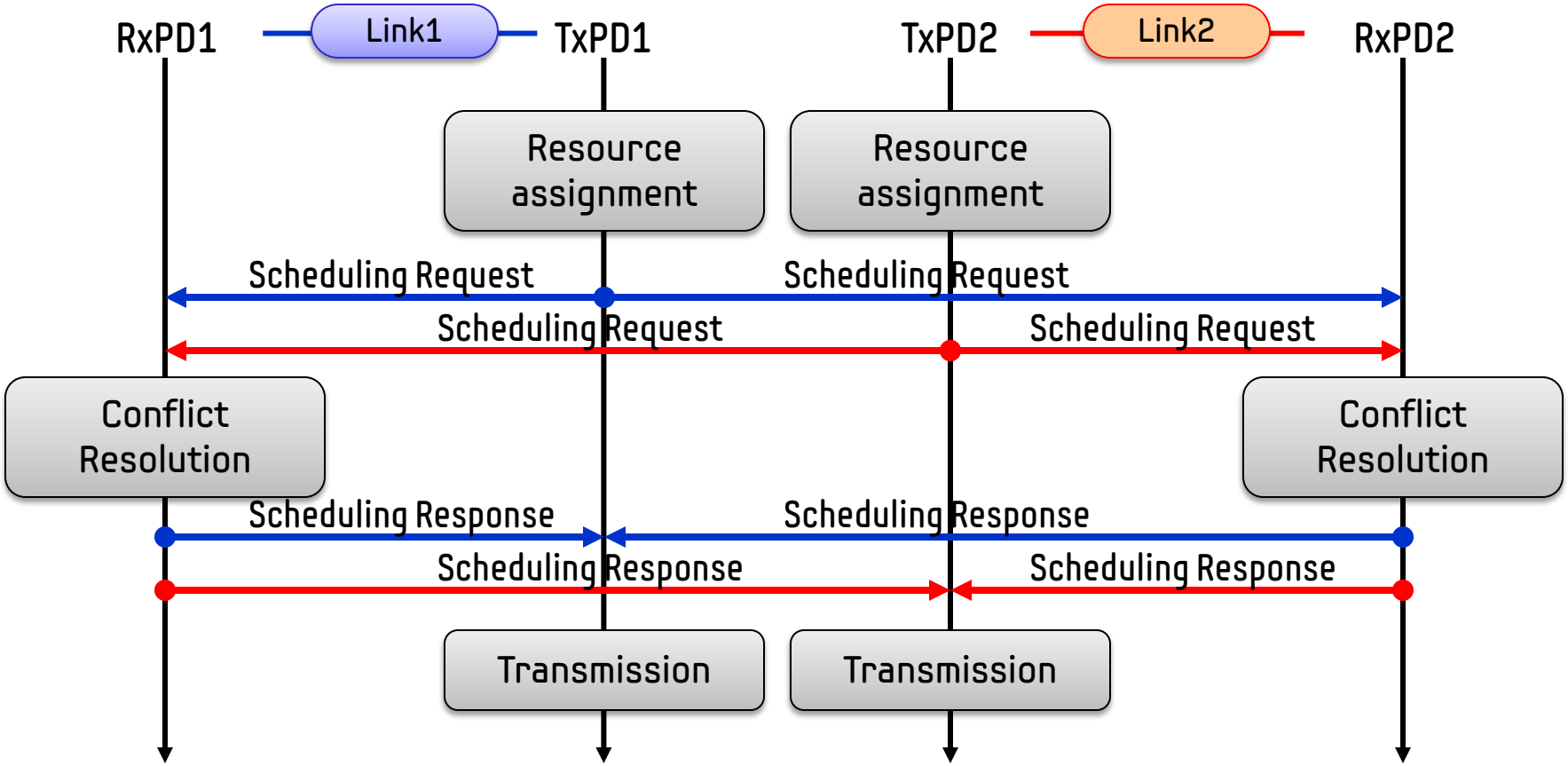
Data Transmission

- Concept of Distributed Scheduling Procedure



Data Transmission

- Operation Flowchart

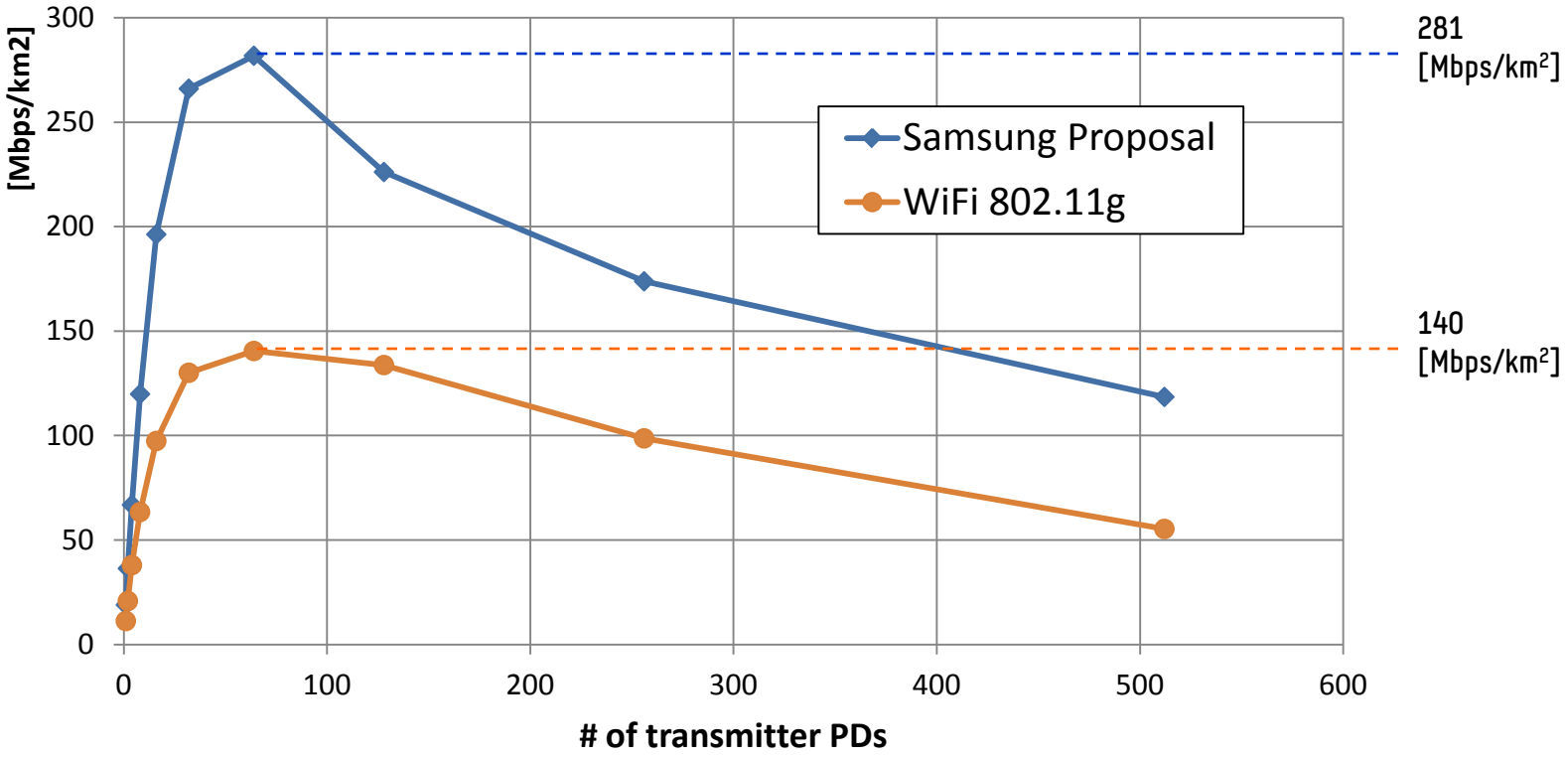


Data Transmission

- How to achieve higher throughput?
  - TDMA
    - CSMA/CA : protocol overhead due to asynchronous access
  - Low signaling overhead
    - Each scheduling message needs 16 bits ($2^{16}=2^6x2^5x2^5$)
      - E.g. 64 Link IDs, 32 slot start index, 32 slot length
    - 3.125% as assuming 256 FFT size
  - Spatial resource reuse
    - According to the threshold value used for conflict resolution
      - 9 dB is used for simulation
    - Maximize the number of concurrent transmission links

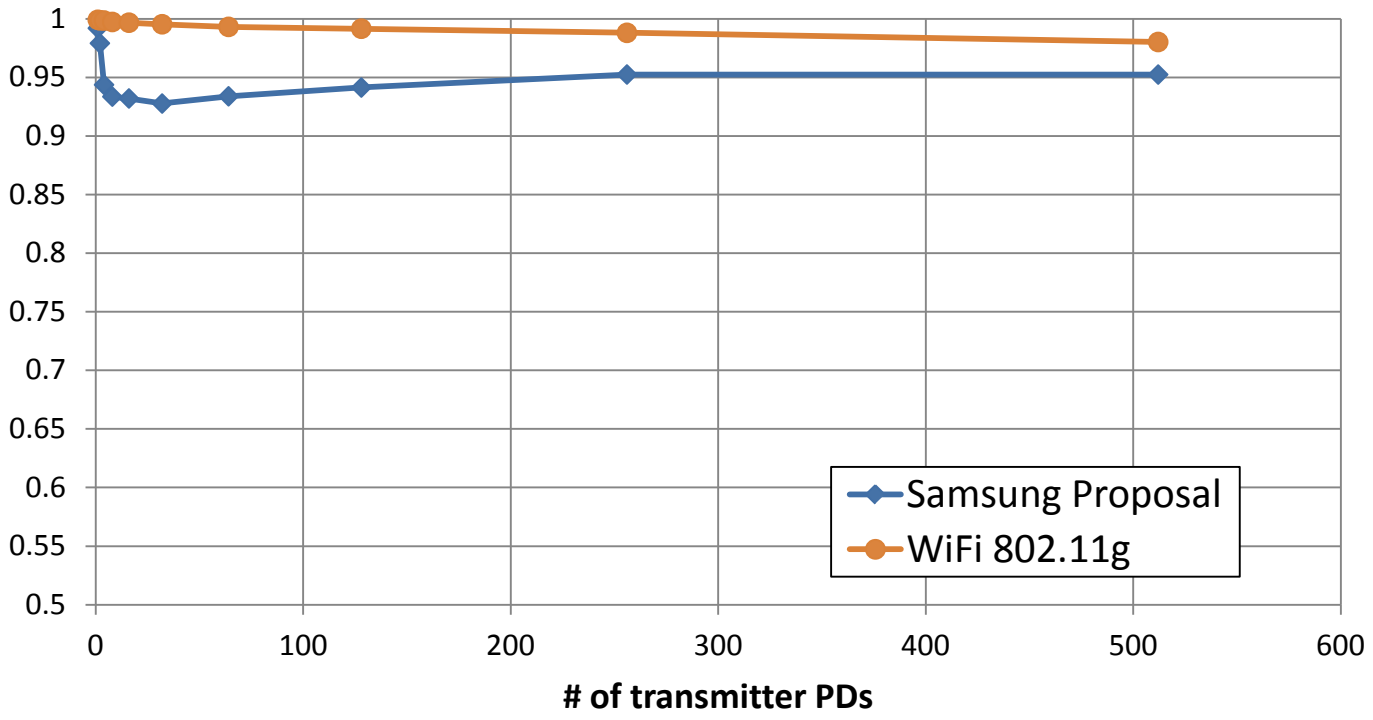
Data Transmission

- Performance Results (full buffer)
  - Areal sum goodput [Mbps/km^2]



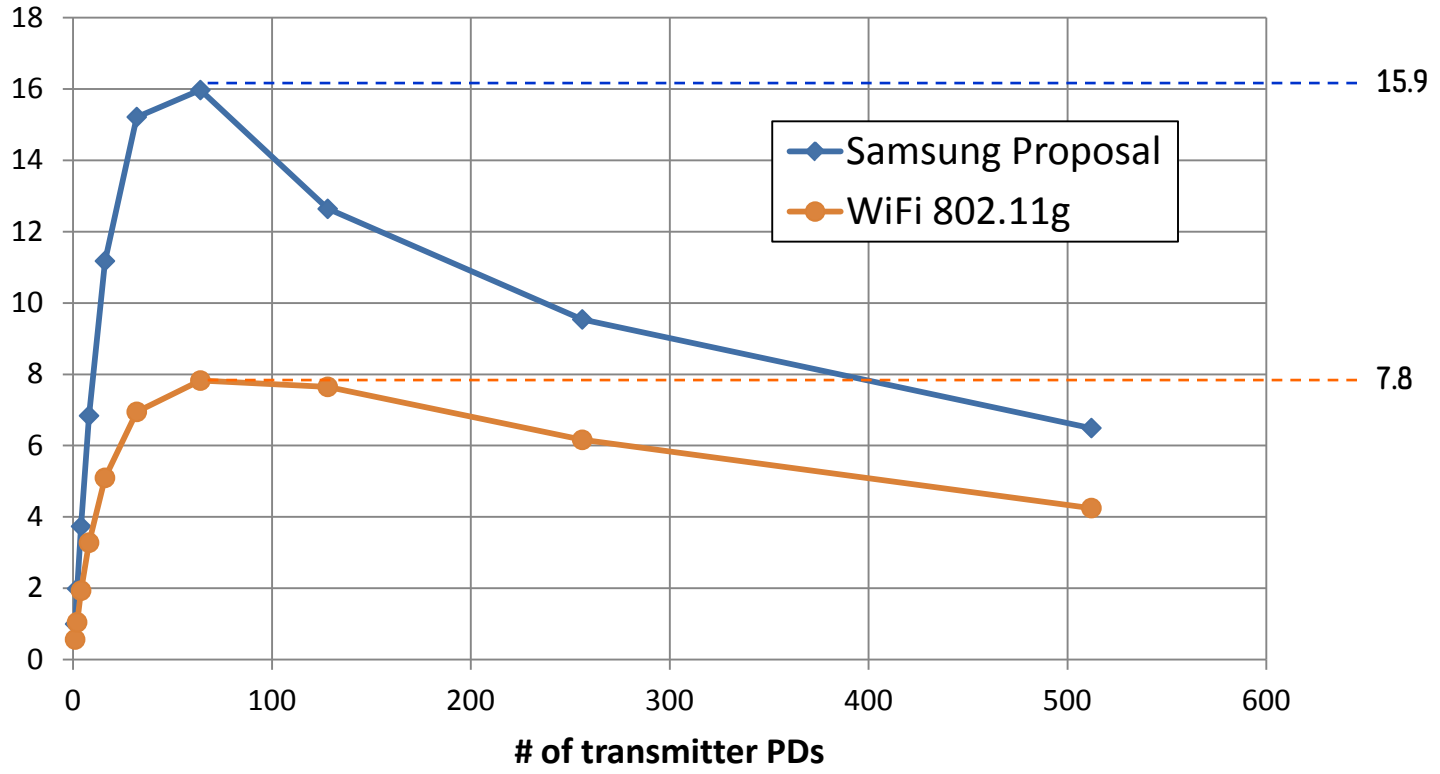
Data Transmission

- Performance Results (full buffer)
  - Data packet reception efficiency [ratio]



Data Transmission

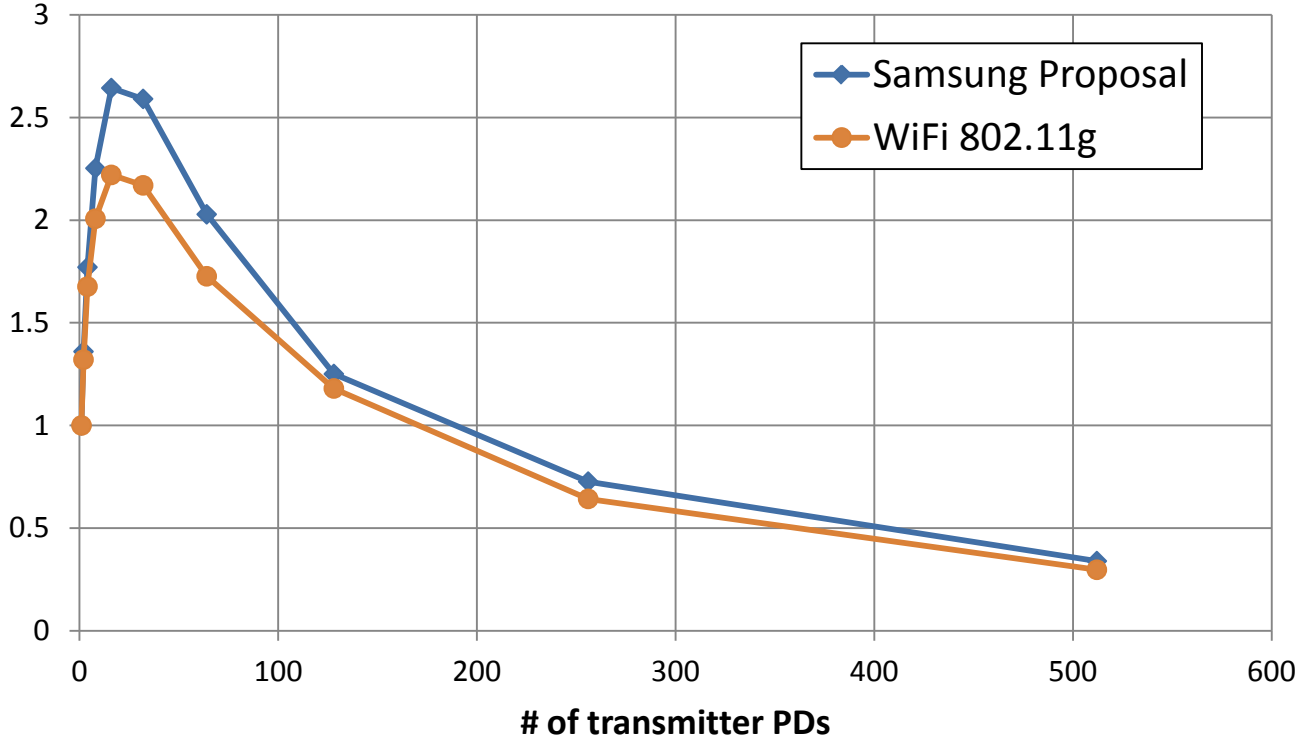
- Performance Results (full buffer)
  - The number of concurrent transmission links



Data Transmission

- Performance Results (full buffer)
  - Jain's fairness index (modified)

$$J(x_1, x_2, \ldots, x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{\sqrt{n} \cdot \sum_{i=1}^{n} x_i^2}$$



Summary

- Key Design Considerations
  - Synchronization prior to peer discovery
    - PCO synchronization
  - Peer discovery
    - Application-centric discovery
    - Congestion-aware slotted discovery resource selection
  - Peering
    - Triggered by application or users
    - Preparation for channel access frame
  - Channel access
    - Slotted scheduling by request and response messages

Identified Working Consensus

- Channel-access
  - IEEE802.15.8 PAC shall consist of several types of frames to serve different operations, based on contention-free channel-access scheme
- Discovery
  - Only PDs with same PDI shall be discovered each other
- Peering
  - Peering Request message and Peering Response message shall be exchanged to establish a link.
  - Network protocol such as routing shall be operated only over connected links.

Identified Working Consensus

- Synchronization
  - A PD shall be in synchrony state prior to peer discovery procedure and peering procedure
  - IEEE802.15.8 PAC has two synchronization mode including Initial Synchronization mode and Maintaining Synchronization mode

Identified Working Consensus

- Scheduling
  - A PD shall determine Resource Slot based on the predetermined distributed scheduling algorithm.
  - A PD shall determine one or multiple Resource Slot during Scheduling subframe as contention-free channel access scheme.

References

- [1] *Distributed synchronization in wireless networks*, Simeone, Osvaldo ; Spagnolini, Umberto ; Bar-Ness, Yesheskel ; Strogatz, Steven H., Signal Processing Magazine, IEEE Volume: 25 , Issue: 5, Digital Object Identifier: 10.1109/MSP.2008.926661, Publication Year: 2008 , Page(s): 81 – 97
- [2] *Emergent Slot Synchronization in Wireless Networks*, Tyrrell, A.; Auer, G.; Bettstetter, C., Mobile Computing, IEEE Transactions on, Volume: 9 , Issue: 5, Page(s): 719 – 732, Digital Object Identifier: 10.1109/TMC.2009.173, Publication Year: 2010 , Page(s): 719 – 732
- [3] *Selective Pulse Coupling Synchronicity for Sensor Network,* Yu Niu ; d'Auriol, B.J. ; Xiaoling Wu ; Jin Wang ; Jinsung Cho ; Sungyoung Lee, Sensor Technologies and Applications, 2008. SENSORCOMM '08. Second International Conference on, Digital Object Identifier: 10.1109/SENSORCOMM.2008.59 Publication Year: 2008 , Page(s): 123 - 128

Appendix

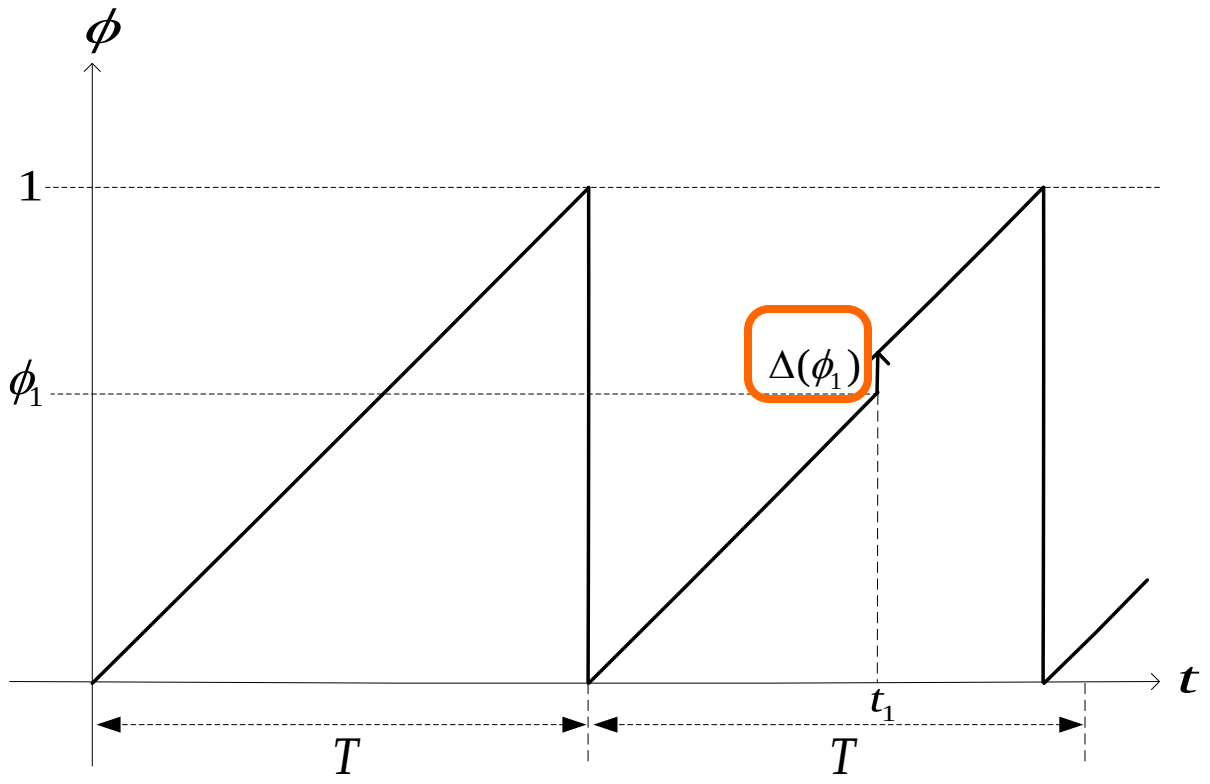
- PCO Synchronization
- Comparison of two ways for Peer Discovery

PCO Synchronization

- Pulse Coupled Oscillator (PCO) Synchronization
  - Fully distributed synchronization algorithm
  - Doesn't need other PDs timing information
  - Each PD has
    - an oscillator (or counter) with the identical increment rate
    - a same function to adjust phase of oscillator
  - Features
    - Simple
    - Scalable
    - no hierarchy (=flat)
    - Fast convergence time

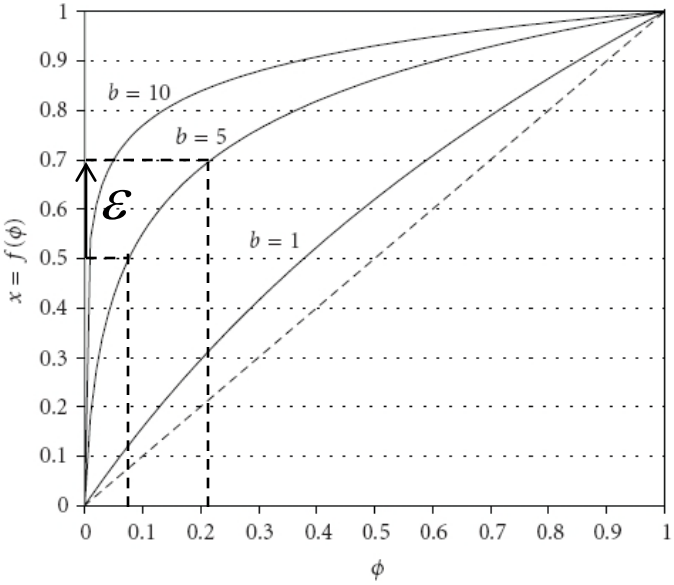
PCO Synchronization

- Phase adjustment using only internal value



PCO Synchronization

- Phase adjustment algorithm [2][3]
  - $\phi + \Delta(\phi) = f^{-1}\left(f(\phi) + \varepsilon\right)$
  - $f(\phi) = \frac{1}{b} \cdot \left(1 + \left[e^{b} - 1\right] \cdot \phi\right)$
    - ε : coupling factor
    - b : dissipation factor

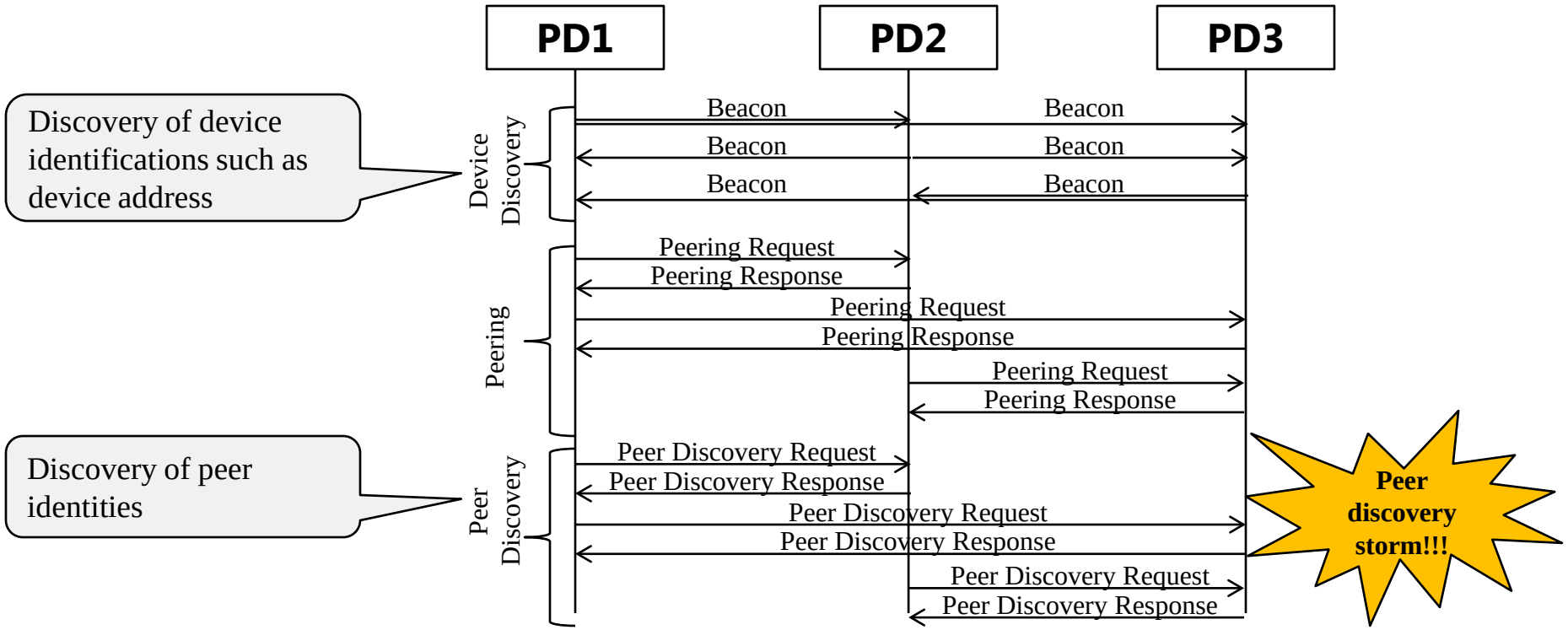


PCO Synchronization

- Phase adjustment algorithm [2][3]
  - selective update for fast convergence
    - If $\left(2\times\phi+\Delta(\phi)\right)>1$,
      $$\hat{\phi}=\min(1,\phi+\Delta(\phi))$$
    - else no update
  - Refractory period to avoid ping-pong effect
    - No update when $\phi<\frac{2\times T_{\max.\ propagation\ delay}}{T}$

Comparison of two ways for Peer Discovery

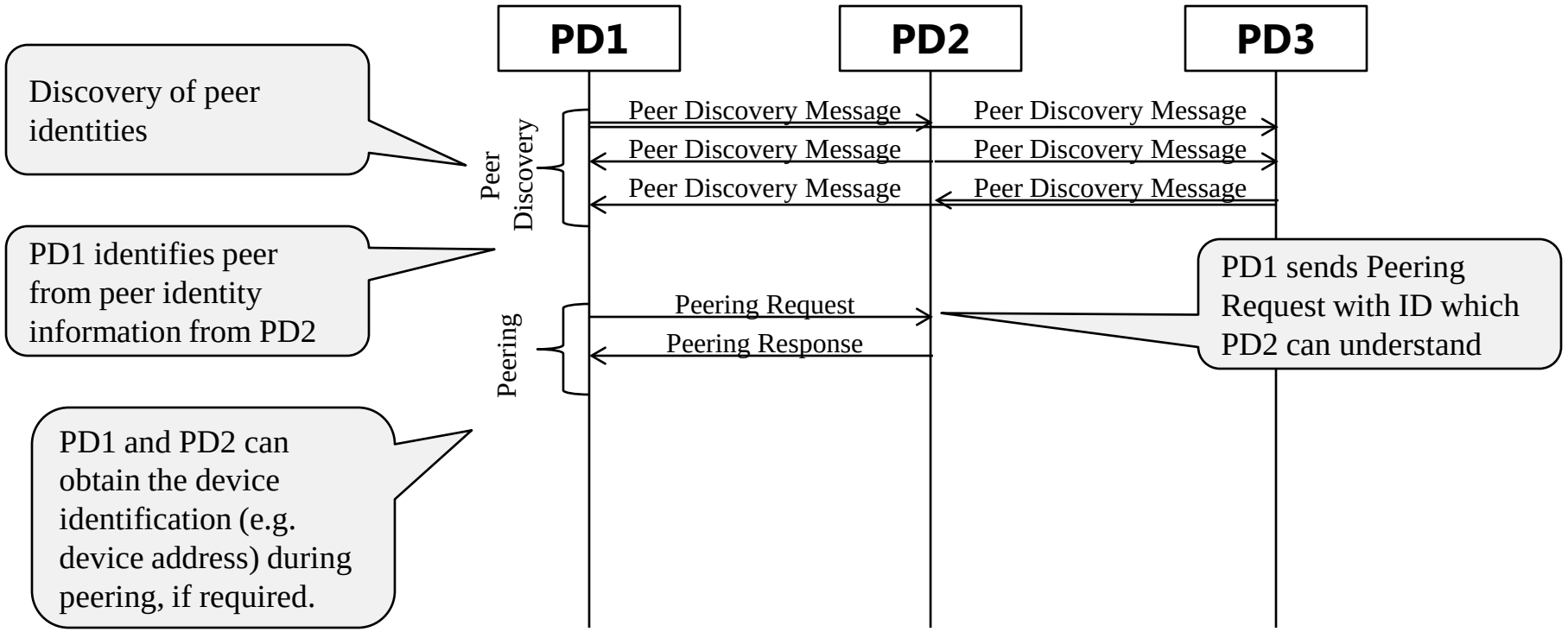
- Peer discovery after peering



* Terminologies are temporally used for explanation

Comparison of two ways for Peer Discovery

- Peer discovery before peering



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