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

Submission Title: [A PHY proposal for PAC operating in synchronous mode (ppt)]
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Re: [In response to call for proposals to TG8]

Abstract: [This document contains a PHY proposal for PAC operating in synchronous mode]

Purpose: [Materials for Proposal in 802.15.8 TG]

Contents

- Proposal Outline
- PHY Overview
- PHY Proposals
- Conclusion

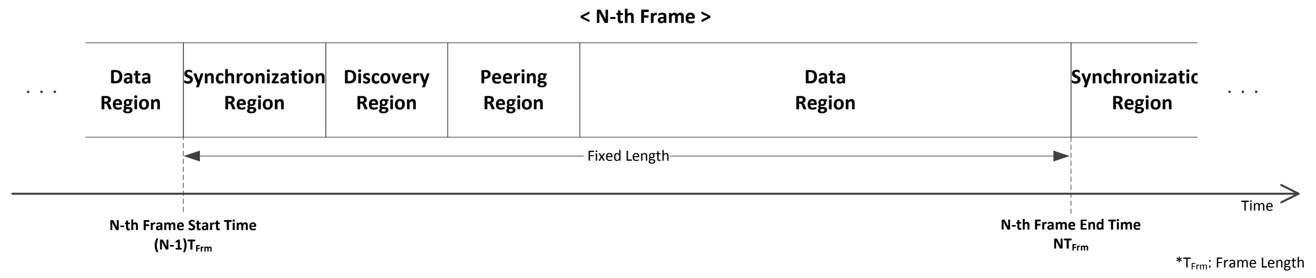
Proposal outline

- In May, we presented a preliminary example in licensed bands for PAC in synchronous mode.
  - The presentation(DCN: 15-13-0273-00-0008) covered both PHY and MAC for PAC in licensed bands operates in synchronous mode
- In July, we propose both PHY and MAC in unlicensed bands for PAC in synchronous mode.
  - DCN 15-13-0391-00-0008 or the latest version: Overview of proposal (ppt)
  - DCN 15-13-0393-00-0008 or the latest version: PHY proposal (This document)
  - DCN 15-13-0390-00-0008 or the latest version: MAC proposal (ppt)
  - DCN 15-13-0392-00-0008 or the latest version: Proposal details (doc)

PHY Overview

Fixed and Sectionized Frame Structure

- PAC operation with fixed and sectionized frame structure to meet PAC requirements
  - A large number of devices
    - High spectral efficiency
    - Low signaling overhead
  - Power saving
    - Sleep and wake up at the predefined time
- Fixed frame structure
  - Frame with fixed length is continuously repeated



- Synchronization for configuration of fixed frame structure
  - Fully distributed synchronization scheme known as firefly synchronization

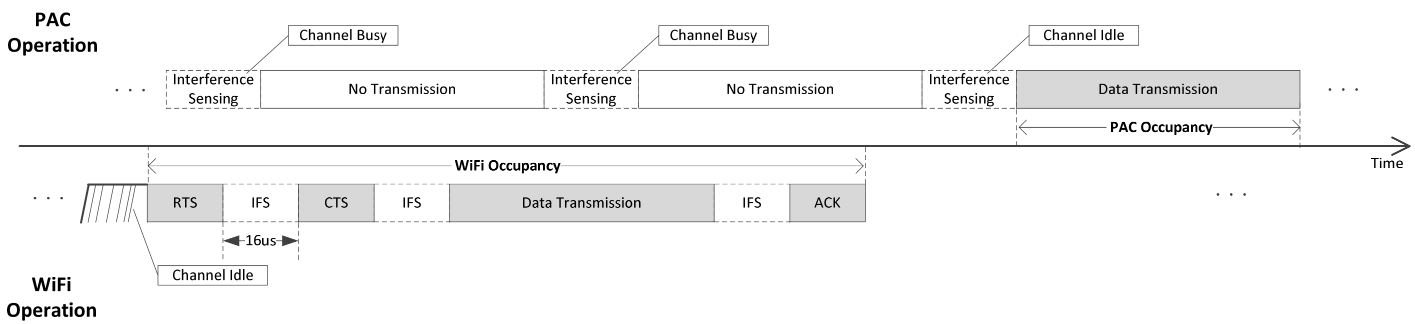
Coexistence Methodology

- Coexistence criteria
  - Avoidance of conflict between different kinds of devices
  - Prevention of exclusive resource occupancy of specific kinds of devices
  - No critical impact each other between different kinds of devices

- Coexistence policy: Concession, Preoccupancy and low power transmission
  - Concession
    - If different kinds of devices are using a resource, PDs give up the transmission through the resource
    - Implemented by 'Interference Sensing'
  - Preoccupancy
    - PDs can occupy some resources prior to different kinds of devices
    - Implemented by 'Blocking Signal'
  - 'Low power transmission'
    - PDs can use some resources without interference sensing whenever PDs need it
    - Instead, the transmit power should be sufficiently low

Interference Sensing

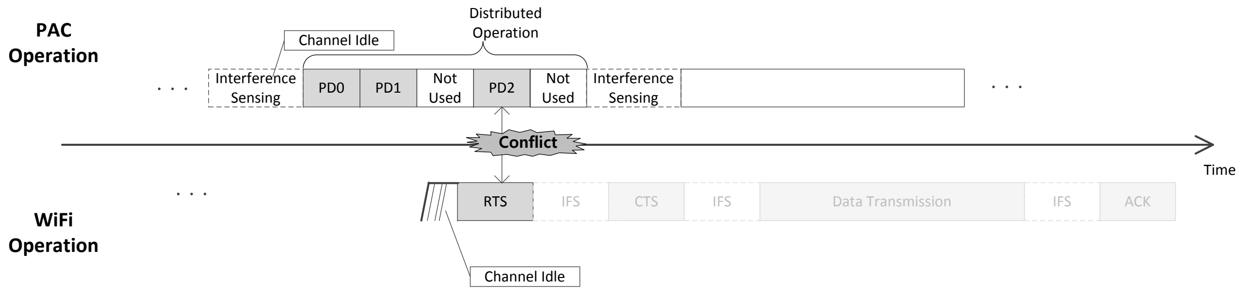
- Basic coexistence scheme using interference sensing
  - PDs use a resource if the channel state is idle
  - Recommended interference sensing interval
    - Same as or longer than Short IFS interval(16us) of WiFi



- Applied throughout the frame

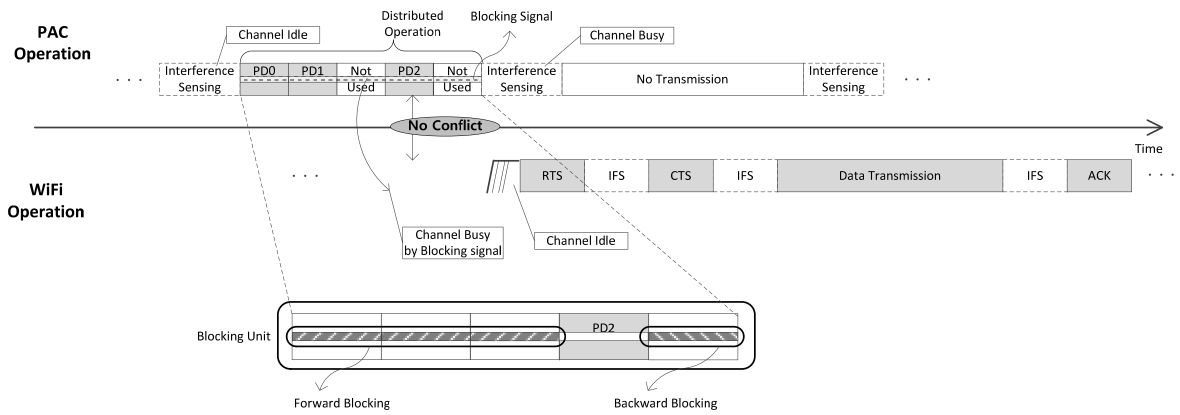
Blocking Signal

- Issue
  - Because of the fully distributed operation of PDs, there may be some unused resources
  - Different kinds of devices can try to occupy the resources even though PDs have already begun the transmission after interference sensing



Blocking Signal

- Blocking scheme
  - To prevent intrusion of different kinds of devices, blocking signal can be transmitted by PDs which are going to use the resources within a blocking unit
  - Blocking unit
    - Consists of multiple resource blocks for multiple PDs
    - Bundle of the resources which PDs can reserve prior to different kinds of devices
    - Should not be too long
  - One or more subcarriers can be used for transmission of blocking signal
  - PAC devices can transmit the blocking signal both before(Forward blocking) and after(Backward blocking) the transmission within a blocking unit

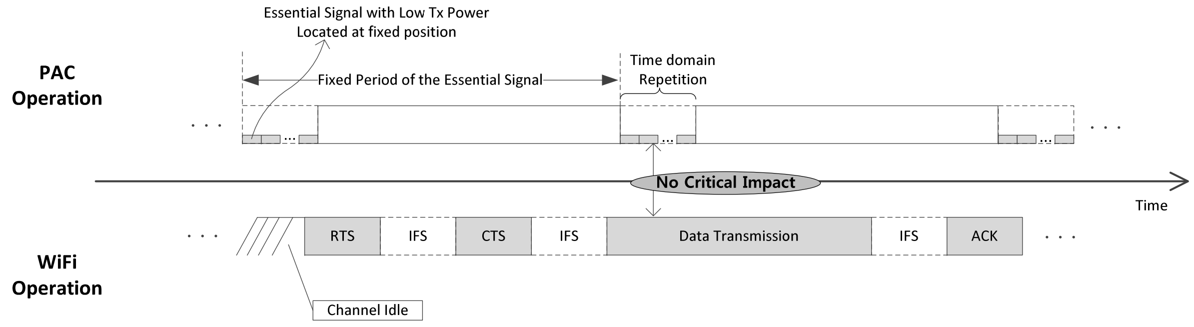


- Applied to control(Discovery, Peering, Scheduling) signal transmission

Low Power Transmission

- Issue
  - There are essential control signal which need to be present at fixed positions such as synchronization signal
  - The presence of the essential signal cannot be guaranteed just by the basic coexistence operation based on the interference sensing

- Low power transmission scheme
  - Essential control signal is always transmitted at the fixed position without interference sensing
  - To minimize inference between different kinds of device, the essential control signal is transmitted in low power
  - To enhance reliability of the signal, it is repeatedly transmitted in time domain



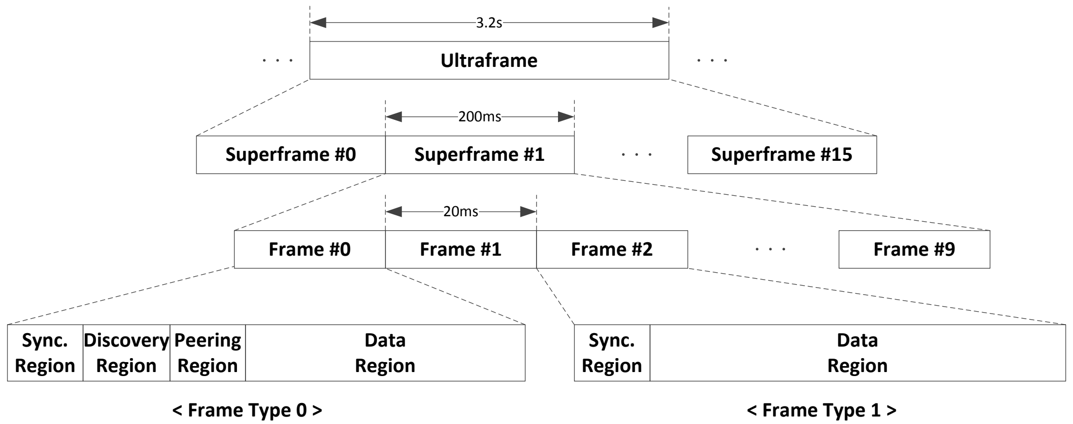
- Applied to synchronization signal transmission

PHY Proposals

Frame Structure

- Hierarchy of the frame
  - Ultraframe consists of 16 superframes
    - Its length is related to the period of Discovery signal transmitted by a PD
  - Superframe consists of 10 frames
    - Its length is related to the period of Discovery and Peering region
  - Frame consists of Synchronization, Discovery, Peering and Data region
    - Its length is related to the data rate of voice codec

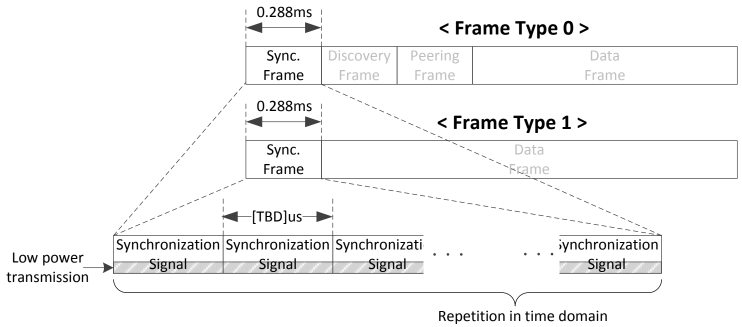
  - Two kinds of frame type
    - If frame number is 0, type 0 is used
    - Otherwise, type 1 is used



Synchronization Region

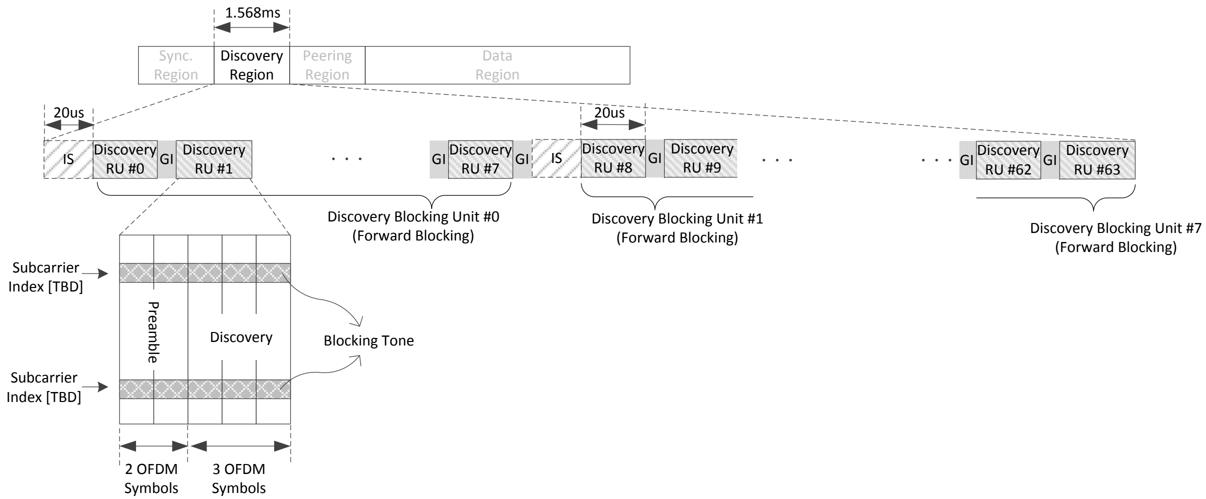
- Located at the head of a frame
- Perform distributed synchronization procedure by transmitting or receiving synchronization signal in the synchronization region
- Two kinds of synchronization signals are used to identify the first frame in a ultraframe

- Low power transmission scheme is applied
  - Synchronization signal is repeatedly transmitted
  - Transmit power is deboosted



Discovery Region

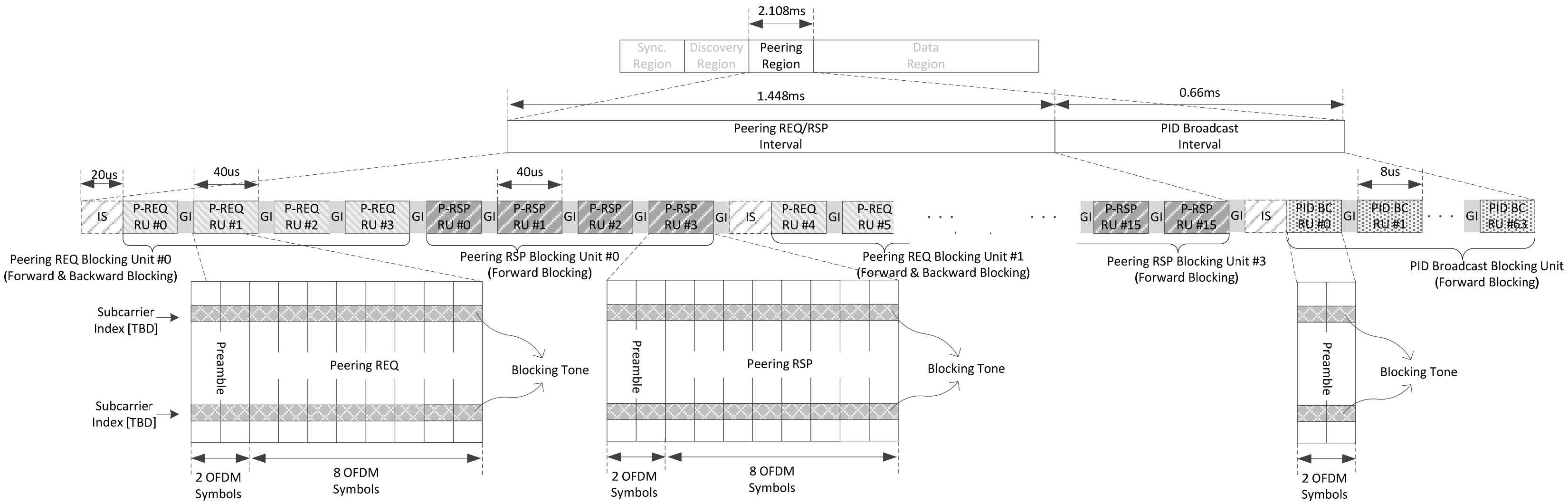
- Consists of 64 discovery RUs(Resource Unit) for multiple PDs
- Components
  - IS(Interference Sensing)
  - GI(Guard Interval) for transition time and synchronization error
  - Preamble for AGC, timing and frequency synchronization and channel estimation
  - Discovery signal for transmission of discovery-related information



- Blocking Scheme is applied

Peering Region

- Consists of 16 Peering REQ/RSP and 64 PID broadcast RUs for multiple PDs
- Components
  - IS(Interference Sensing)
  - GI(Guard Interval) for transition time and synchronization error
  - Preamble for AGC, timing and frequency synchronization and channel estimation
  - Peering REQ/RSP for exchanging peering-related information
  - PID broadcast for broadcasting PID being used

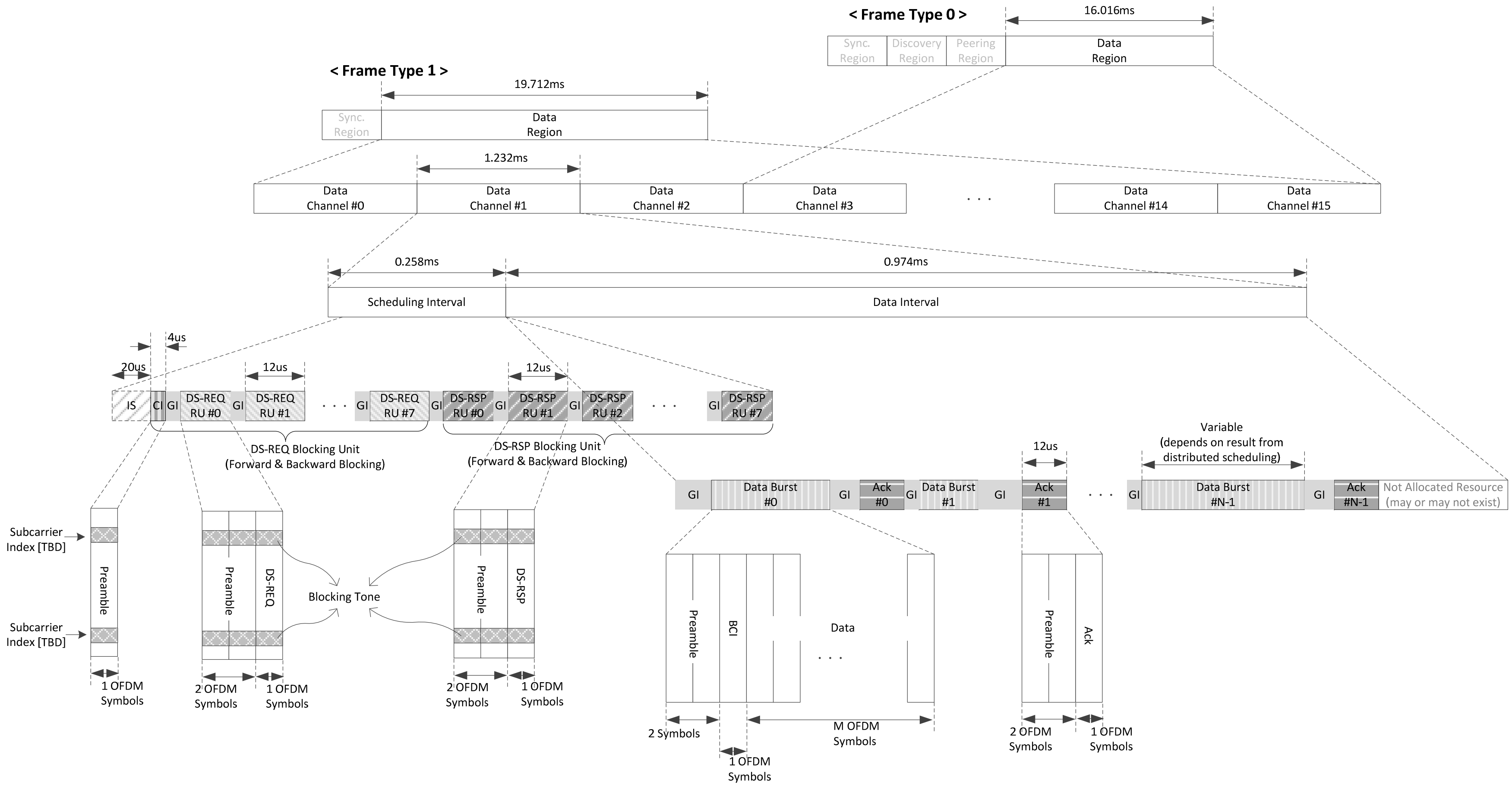


- Blocking Scheme is applied

Data Region

- Consists of 16 data channels
- A data channel consists of
  - 8 DS-REQ/RSP RUs for distributed scheduling between multiple PDs
  - N(≤8) data bursts and ACKs resulting from distributed scheduling
- Components
  - IS(Interference Sensing)
  - GI(Guard Interval) for processing delay, transition time and synchronization error
  - Preamble for AGC, timing and frequency synchronization and channel estimation
  - SRI(Scheduling Request Indicator) for consecutive allocation
  - DS-REQ/RSP for exchanging scheduling-related information
  - BCI (Burst Control Indicator) for indication of burst format and MCS information
  - Data burst
  - ACK

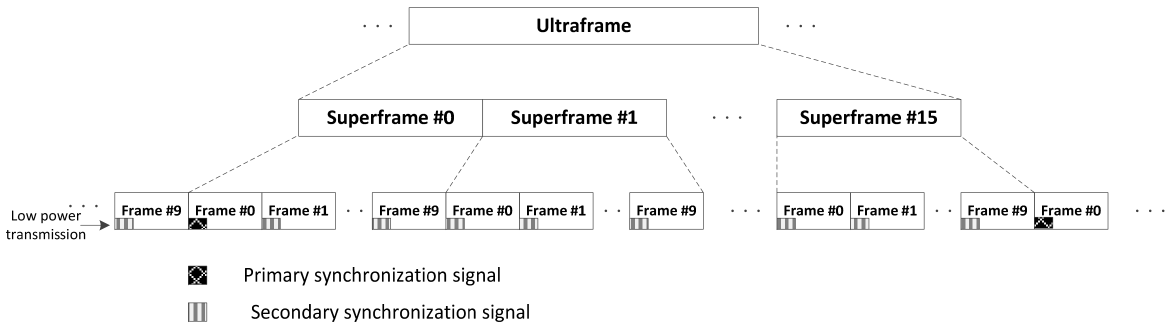
Data Region



- Blocking scheme is applied in the scheduling interval only

Distributed Synchronization

- Pulse-based PHY-level synchronization and fully distributed operation
- Timing adjustment is performed by (See Appendix)
  - Difference between current time and received signal time
  - Received signal power
- Primary synchronization signal is used to distinguish start of ultraframe
- Secondary synchronization signal is used for frame synchronization
- Stochastic decision as to whether PDs transmit the synchronization signal or receive the synchronization signal



Conclusion

- PAC operation with fixed and sectionized frame structure to meet PAC requirements
- Fully distributed operation and synchronization
- Signaling resources
  - 1024 Discovery resources per 3.2 second => up to 1024 PDs can be discovered
  - 128 PID broadcasting resources (per 0.8 second) => up to 256 PDs can be concurrently activated
  - 16 Peering REQ/RSP resources per 0.2 second => up to, about 30(≈16x0.37x5) pairs of PD per second can be peered
- Signaling overhead: 26.7% (ratio of non-data interval to total occupied interval)
  - Synchronization + Discovery + Peering + Scheduling + Preamble(in data interval) + ACK + etc.
- Consideration of coexistence
  - Interference sensing, blocking signal and low power transmission

Appendix

Distributed Synchronization

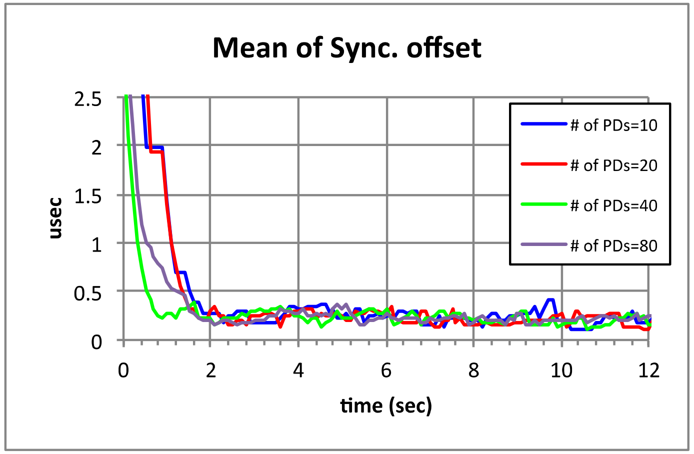
- Synchronization algorithm [1]
  – $$t_i(n+1) = t_i(n) + T_i + \varepsilon_0 \cdot \sum_{j=1, i \neq j}^{N} \alpha_{ij} \cdot \left(t_j(n) - t_i(n)\right)$$
    - $t_i(n+1)$: (n+1)-th frame sync. time of i-th device
    - $t_i(n)$: n-th frame sync. time of i-th device
    - T_i : frame sync. period of i-th device
    - ε_0 : loop filter coefficient
    - α_{ij} : received signal power weighting factor
    - $t_j(n)$: n-th frame sync. time of j-th device

  – $\alpha_{ij} = \dfrac{P_{ij}}{\sum_{j \in I_i} P_{ij}}$, $\sum_j \alpha_{ij} = 1$ (normalized)
    - $I_i = \left\{ j : P_{ij} > P_0 \right\}$
    - P_{ij} : received signal power from j-th device to i-th device
    - P_0 : received signal power threshold

[1] Osvaldo Simeone, Umberto Spagnolini, Yeheskel Bar-Ness, and Steven H. Strogatz, “Distributed Synchronization in Wireless Networks,” IEEE Signal Processing Magazine, September 2008, pp. 81-97.

Performance Evaluation

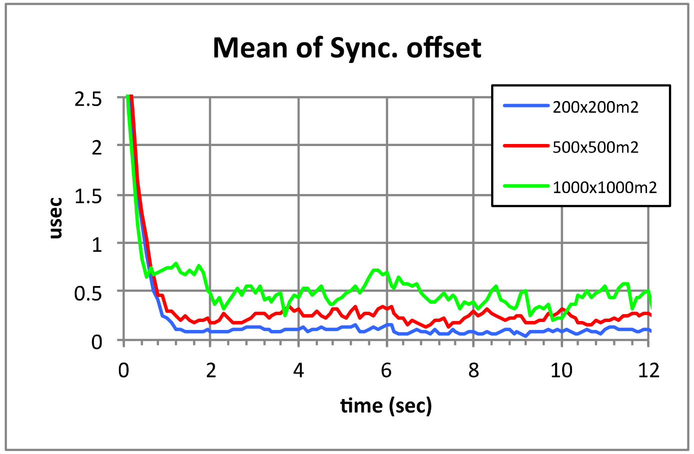
- Simulation Condition
  - Area
    - 500 x 500 m^2
  - Loop filter coefficient
    - 0.3
  - Sync. Period
    - 100ms



- Simulation result

Number of PDs	10	20	40	80
Mean of Sync. offset	0.27us	0.26us	0.22us	0.22us
95% of Sync. offset	0.84us	0.86us	0.75us	0.76us

Performance Evaluation

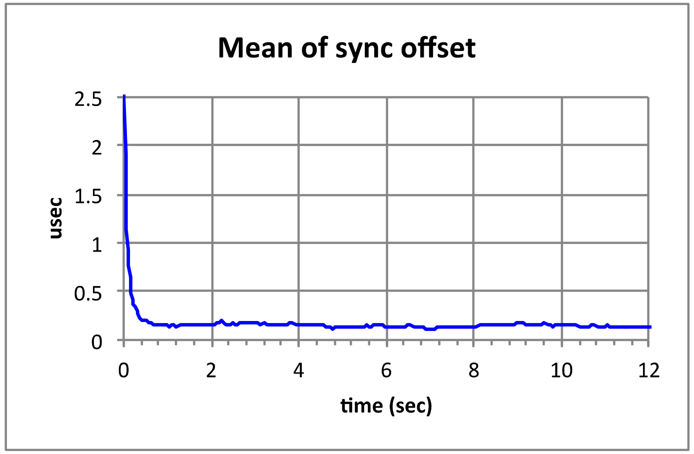


- Simulation Condition
  - Number of PDs
    - 80
  - Loop filter coefficient
    - 0.3
  - Synchronization signal transmission period
    - 100ms

- Simulation result

Area	$200x200m^2$	$500x500m^2$	$1000x1000m^2$
Mean of Sync. offset	0.09us	0.22us	0.43us
95% of Sync. offset	0.32us	0.78us	1.48us

Performance Evaluation



- Simulation Condition
  - Area
    - 500 x 500 m^2
  - Number of PDs
    - 1000 PDs
  - Loop filter coefficient
    - 0.3
  - Synchronization signal transmission period
    - 20 ms

- Simulation result
  - Mean of sync. offset: 0.15 us
  - 95% of sync offset: 0.52 us