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

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

Abstract: [This document is presentation material for PAC operating in synchronous mode]

Purpose: [Materials for Proposal in 802.15.8 TG]

Contents

- Proposal outline
- MAC Proposal for PAC framework document
  - Discovery
  - Peering
  - Distributed Scheduling
- Conclusion

Proposal outline

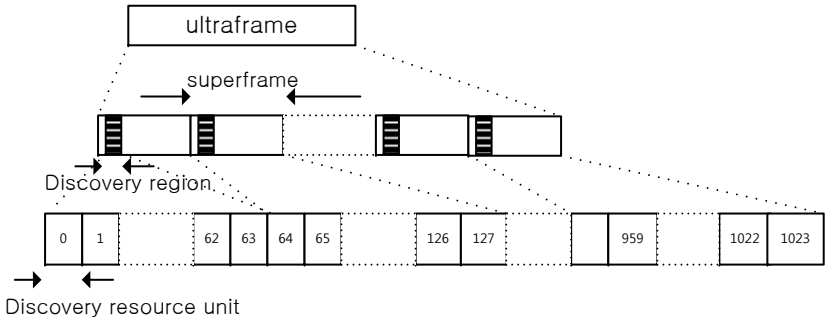
- In May, we presented a preliminary example in licensed bands for PAC in synchronous mode.
  - The presentation(DCN: 15-13-0273-00-0008) covered both PHY and MAC for PAC in licensed bands operating in synchronous mode
- In July, we propose both PHY and MAC in unlicensed bands for PAC in synchronous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

Discovery

- Overview
  - Distributed resource allocation in synchronous fixed frame format
    - Periodic use of selected resource unit after initial selection by each PD
  - Broadcasting based manner with support of query based manner
    - Periodic Device discovery
      - Broadcasting manner
    - Aperiodic service discovery
      - Broadcasting manner and query manner

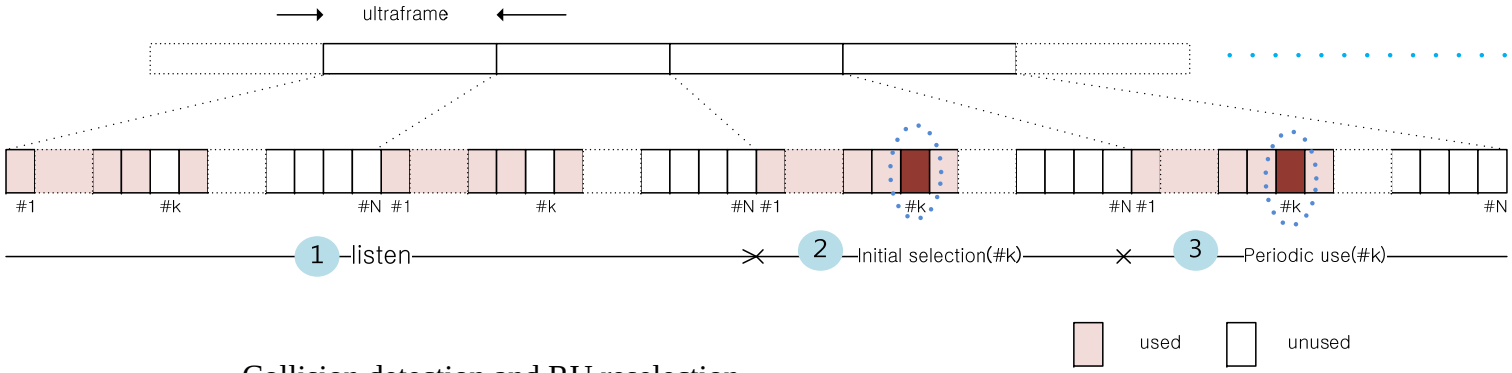
Discovery

- Distributed resource allocation
  - Synchronous fixed frame structure
    - Resources for discovery are divided into a number of resource units
      - An Ultraframe (3.2s) is one discovery repetition period
        - 1024 resources unit(RU) per one discovery repetition period
        - Resources for discovery consist of 16 Discovery regions
        - A Discovery region consists of 64 RUs
        - 25.6 ms per 3.2s (0.8% overhead)



Discovery

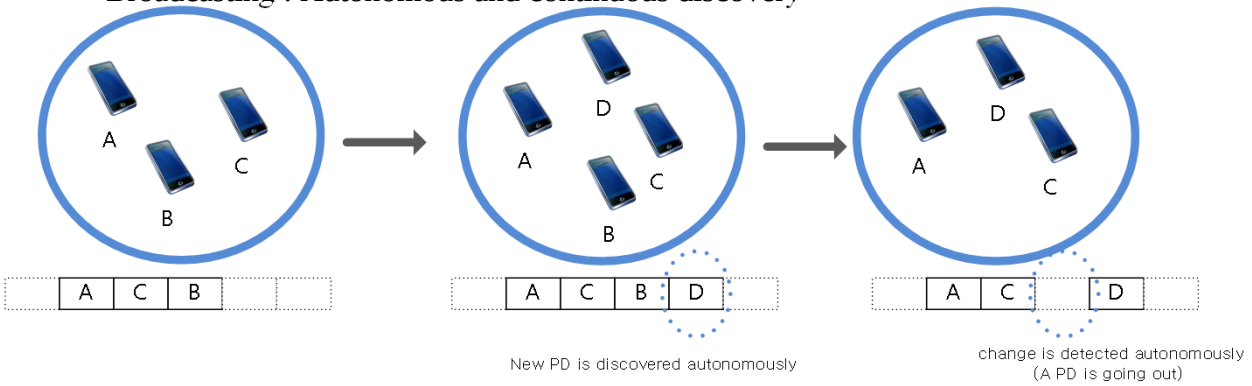
- Distributed resource allocation(cont.)
  - Synchronous fixed frame structure
    - Periodic use of selected RU can be possible after initial selection
      - Initial selection after listening
        - Each PD selects a RU which is not being used(or least congested from PD's perspective)



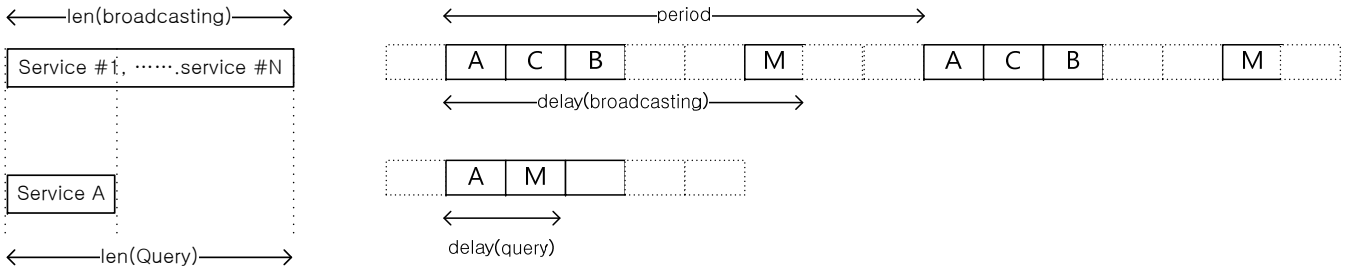
      - Collision detection and RU reselection
        - Randomly listen on the energy from neighbor PD sharing same RU
        - Reselect a RU when the energy on selected resource unit is detected

Discovery

- Consideration of the discovery manner
  - Broadcasting and query
    - Broadcasting : Autonomous and continuous discovery



    - Query: short delay and short length of message

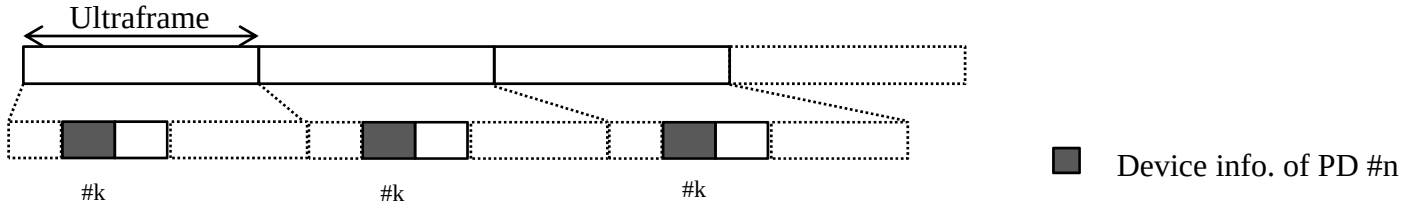


Discovery

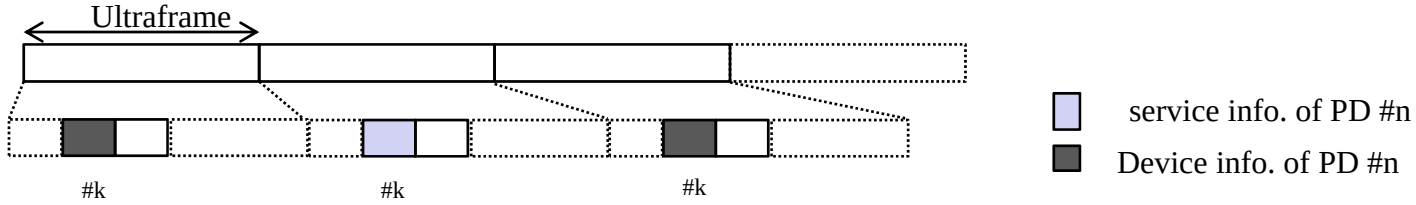
- Broadcasting based manner with infrequent query
  - Based on consideration of the discovery manners, a hybrid manner is proposed to accept the advantages of the two manners
    - Device(/ Presence)discovery is performed by the broadcasting manner to have the autonomous and continuous property
    - Service discovery is performed by the query manner to have the short delay property
      - Aperiodic use of RU(s) for each PD's device discovery to reduce the collision effect of the query manner
      - The version of service information(e.g. service info. Ver.) can be used to represent the information about the services provided by a PD
      - By providing the version of service information(e.g. service info. Ver.) periodically, the request and response procedure can be performed only when it is needed to be update from other PD's perspective

Discovery

- Broadcasting based manner with infrequent query(cont.)
  - Broadcasting based manner
    - Periodically broadcast own information on a selected RU
    - 2 step discovery : Device discovery + service discovery
      - Periodic transmission of the device information for presence(/device) discovery

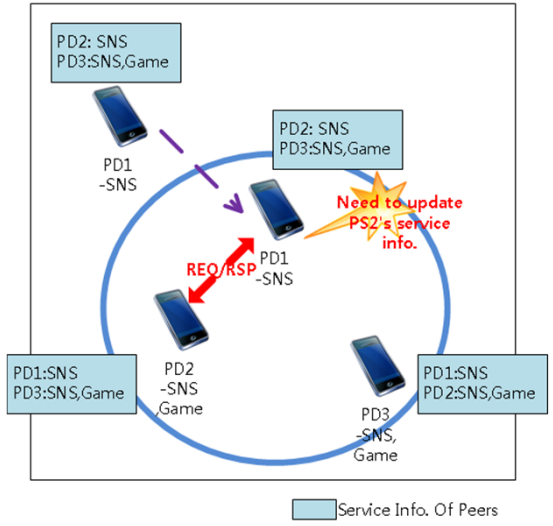


      - Aperiodic transmission of the service information for service discovery in place of device information



Discovery

- Broadcasting based manner with infrequent query(cont.)
  - Query based manner
    - Depend on the circumstances, various request and response information can be provided in place of device information
      - Service information request
        - To request whole or delta information related to target PD's service
          - Request of whole information in case of initial discovery
          - request of delta information in case of rediscovery

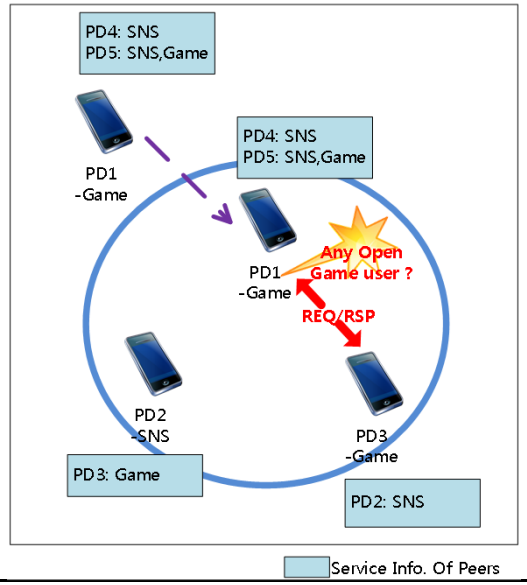


<Request of delta service info>

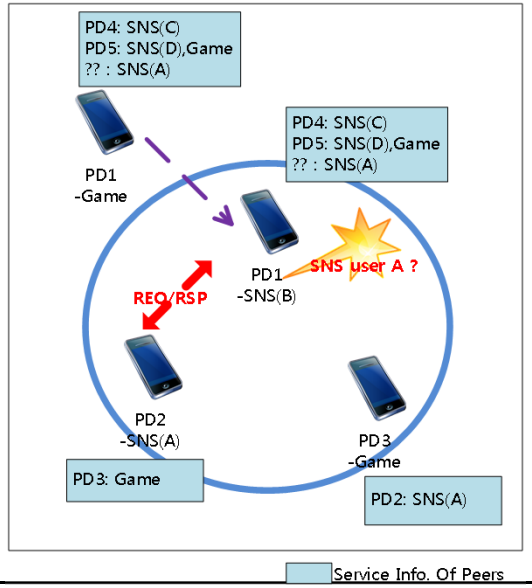
Discovery

- Broadcasting based manner with infrequent query(cont.)
  - Query based manner(cont.)
    - Peer search
      - Anonymous peer using same service : without (target) user ID
      - Target peer of a specific service : with (target) user ID

<anonymous peer search for target service>

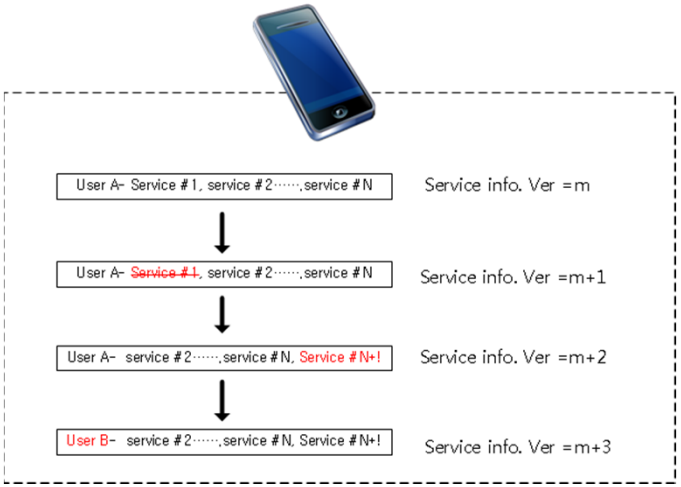


< target peer search for target service>



Discovery

- Consideration of service information
  - Service Info. Ver.
    - To broadcast the whole information about the service provided by each PD's is not efficient
      - Each PD can provide multiple services
      - The change of service provided by each PD is happen infrequently
    - By providing the indicator related to service information(service info. Ver.) periodically, the request and response procedure can be performed only when it is needed to be update from other PD's perspective



Discovery

- Payload of Discovery signal

Contents	Size(Bits)	Description	Notes
Type	3	Type of discovery signal 0: device advertisement 1: service advertisement 2: service info request 3: service info response 4: peer search request 5: peer search response	
ID	48	Identifier of PD Type=0 : (own)device ID (e.g. mac address) Type=1: (own) (app. Type ID + app. specific ID+ app. Specific user ID) Type=2: (target) device ID Type=3: (own) (app. Type ID + app. specific ID+ app. Specific user ID) Type=4:(target) (app. Type ID + app. specific ID+((opt.)app. Specific user ID)) Type=5:(own) (app. Type ID + app. specific ID+ app. Specific user ID)	In case type=4, (target) app. Specific user ID can be included. ID bits are provided from upper layer based on information of application layer

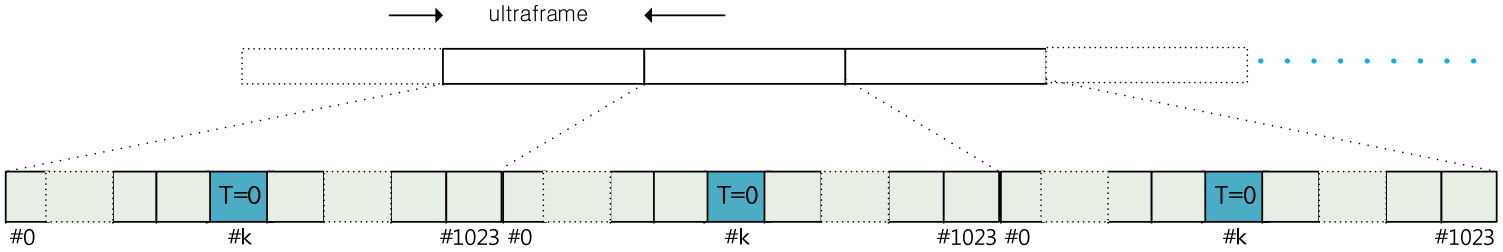
Discovery

- Payload of Discovery signal

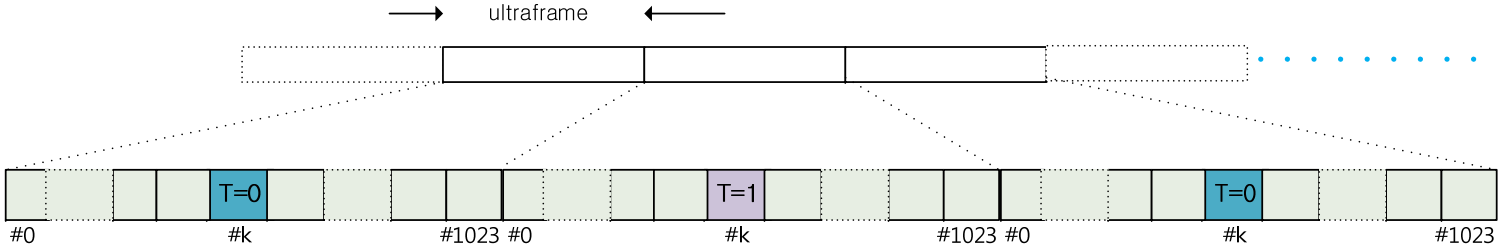
Contents	Size(Bits)	Description	Notes
Service Info. Ver.	5	Version of service information provided by each PD .value:0~31(modulo 32) .value can be changed due to addition/deletion of application(s) or change of user	In case Type=0, type=2, Provided from upper layer based on information of application layer
Request range	1	Request Range of service information - 1: Delta with (pervious) service info. Ver. - 0: Full with (received) service info. Ver.	In case Type=2
SN	5	Sequence number	In case Type=1or 3
End indicator	1	end indication (0: continue, 1:end)	In case Type=1or 3
GI	1	Service info. for group communication (0: individual, 1:group)	In case Type=1,3, 4 or 5
Reserved	7 or 6	Reserved bits	
total	61		

Discovery

- Procedure
  - Broadcasting based manner(T=0 and T=1)
    - Periodic transmission of device information(T=0: device advertisement)

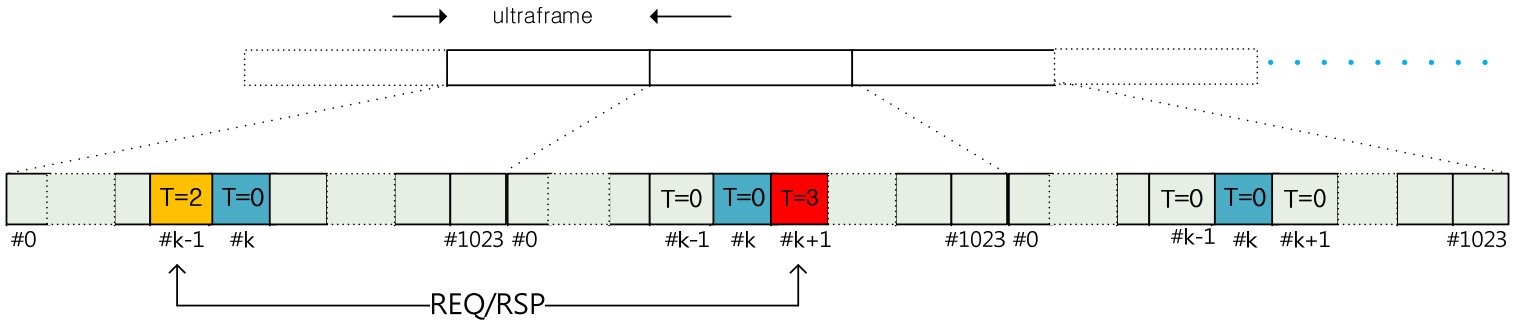


    - (Event triggered) transmission of service information(T=1: service advertisement)
      - Event: e.g. power on , change of service info. Ver.

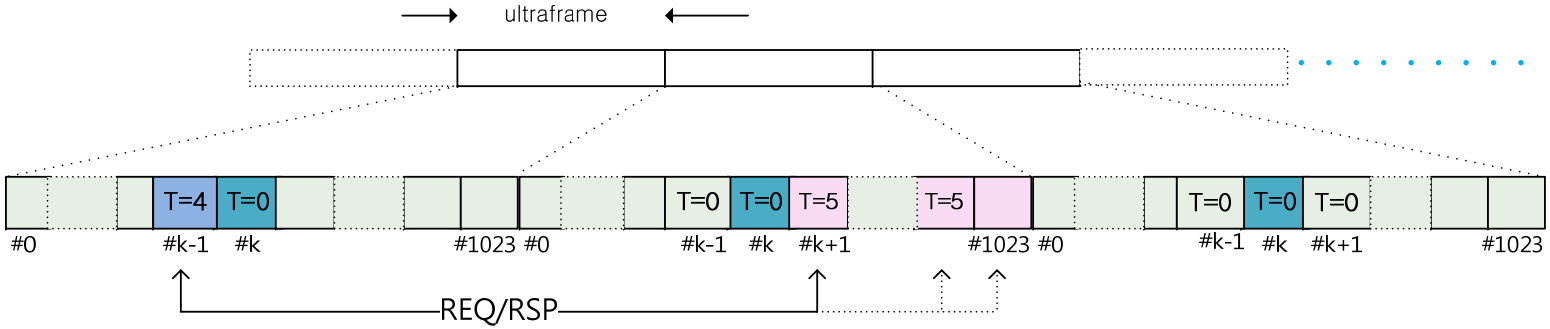


Discovery

- Procedure(Cont.)
  - Query based manner(T=2 and T=3)

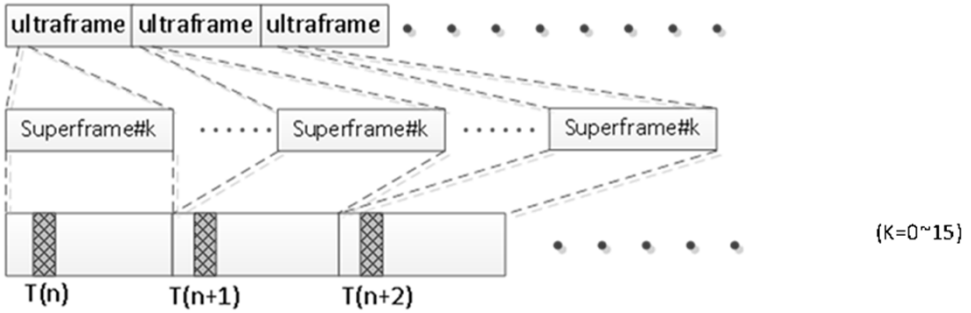


  - Query based manner(T=4 and T=5)



Discovery

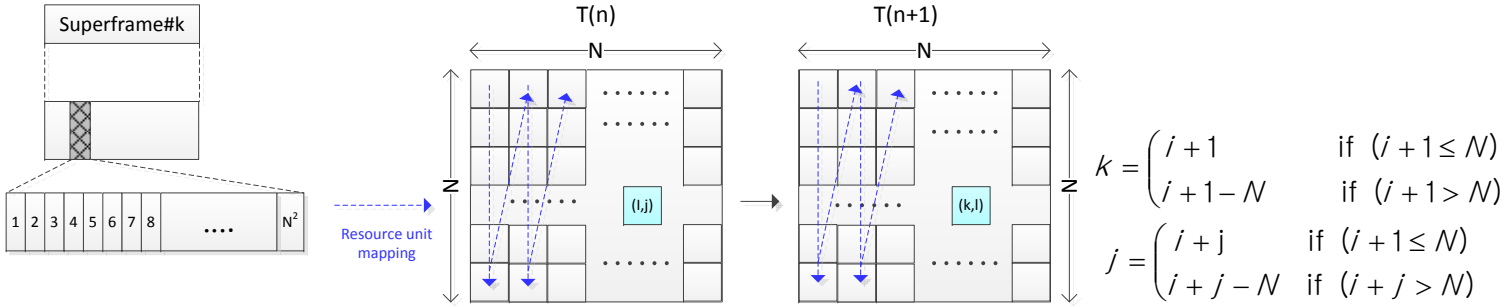
- Consideration for Blocking unit
  - Shuffling pattern
    - Applied to the Discovery region and PID broadcasting interval of peering region in the frame type 0 of the superframe.
  - Shuffling pattern for discovery region
    - Number of RUs required to configure pattern (N*N)
      - Number of RUs in the Blocking unit : N=8
      - Total number of RUs per superframe : N*N=64
    - Same Shuffling pattern is used to all superframes in an ultraframe.
    - Period of pattern change is same as the discovery repetition period(i.e. Ultraframe)



Discovery

– Shuffling pattern for discovery region(cont.)

- The position of a selected RU at ultraframe T(n+1) is calculated using the value of (k,l)th element of the pattern matrix if the position of a selected RU at ultraframe T(n) is calculated using the value of (i,j)th element of the pattern matrix.



$$k = \begin{cases} i+1 & \text{if } (i+1 \le N) \\ i+1-N & \text{if } (i+1 > N) \end{cases}$$

$$j = \begin{cases} i+\mathrm{j} & \text{if } (i+1 \le N) \\ i+j-N & \text{if } (i+j > N) \end{cases}$$

Peering

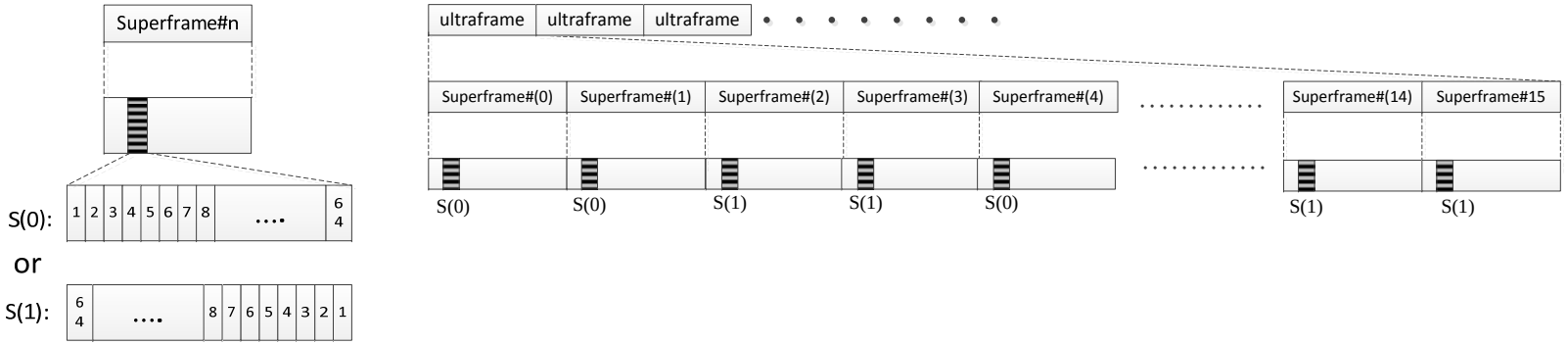
- Peering
  - Peering ID(PID)
    - Used to identify a pair of PDs(PID=0~127)
    - Sharing a PID between a pair of PDs after peering
  - PID broadcasting interval
    - PID usage information is broadcasting in fixed/designated period for orthogonal use of PID
      - The shared PID between a pair of PDs is a basic material for resource contention.
  - PID Request/Response interval
    - A designated allocated interval for random trials of peering triggered by on of the two PDs
      - 4 peering RUs per blocking units(BU) and 4 BUs per superframe(0.2s).
        - A PID REQ RU and a PID RSP RU per peering RU.
      - Average probability of success per peering RU = 1/e
      - Average number of successful trial per 1s = 1/e*16*5 =29.6
    - Based on the acquired PID usage information during PID broadcasting interval, PID REQ signal contains available PIDs and PID RSP signal contains selected PID.

Peering

- Peering(cont.)
  - Average. time to required for peering
    - Acquisition of PID usage information
      - 4*(PID broadcasting interval)=4*200ms
      - Be performed in advance during discovery procedure
    - Transaction of messages related to peering
      - a BU of PID REQ/RSP interval = 0.368 ms

Peering

- Consideration for Blocking unit
  - Shuffling pattern
    - Applied to the Discovery region and PID broadcasting interval of peering region in the frame type 0 of the superframe.
    - PID broadcasting interval of peering region
      - Number of RUs in the Blocking unit : N=64
      - One of two pattern is applied to two consecutive superframes and the same pattern is applied at eight times per ultraframe.

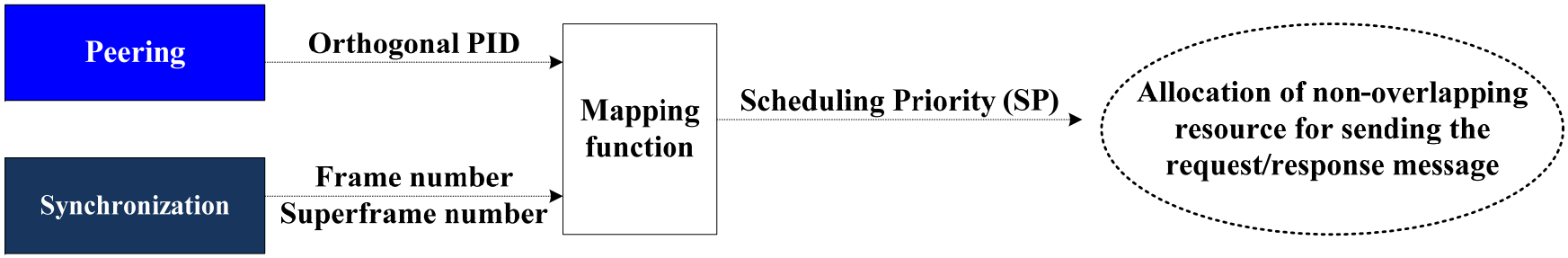


Characteristics of the proposed scheduling

- Fully distributed scheduling
  - There is no coordinator such as Point Coordinator of PCF(Point Coordination Function) in IEEE 802.11.
  - All the contending PDs run the same scheduling algorithm.
- Priority-based distributed scheduling
  - The PD with the highest scheduling priority (SP) among the contending PDs is sure to have resource allocation after successful signaling.
  - PD with higher SP has higher probability of access the air resource
  - The SP of each PD circulates in a predetermined order for the access fairness.

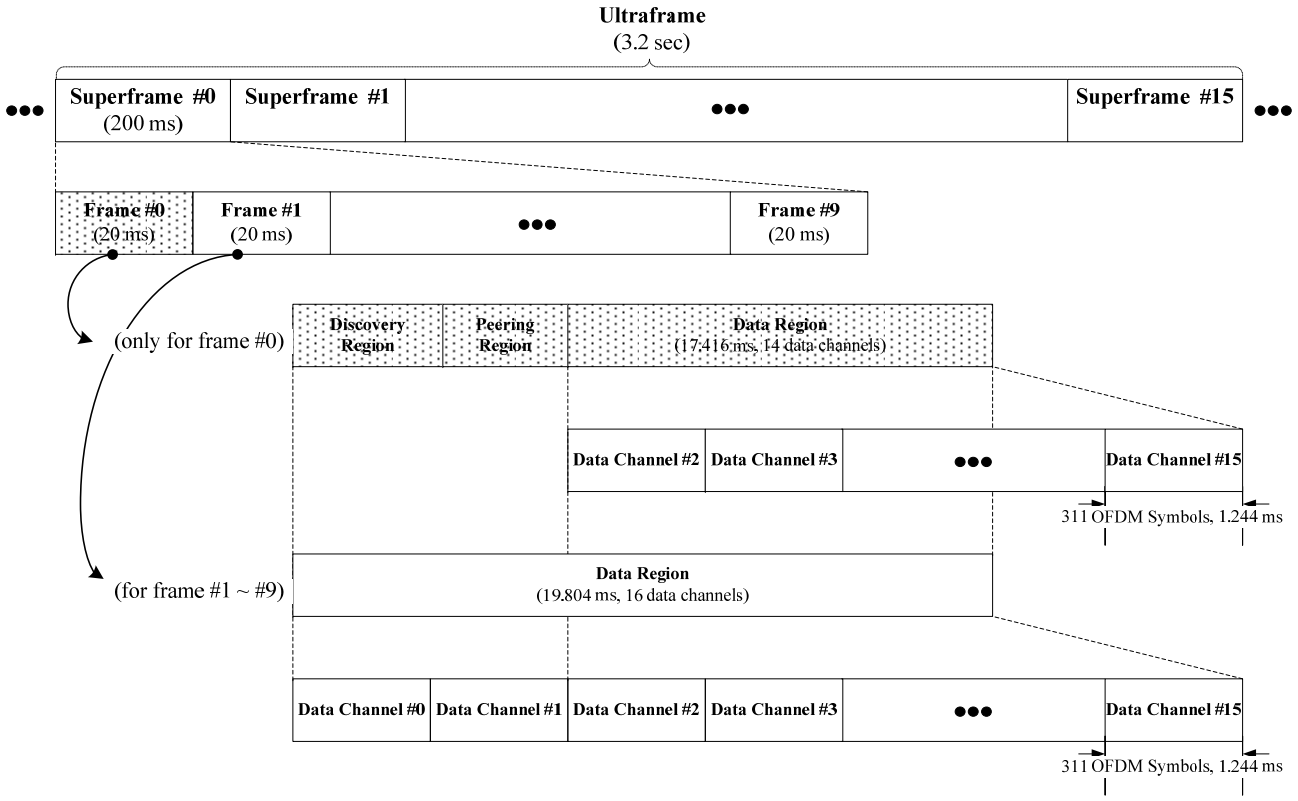
Characteristics of the proposed scheduling (cont.)

- No collision in sending the request/response message used to try to access the resource for data transmission
  - Resource for sending the request/response message is determined by SP
  - Since SP is function of orthogonal PID, orthogonal PID enables each PD to have non-overlapping resource for sending the request/response message



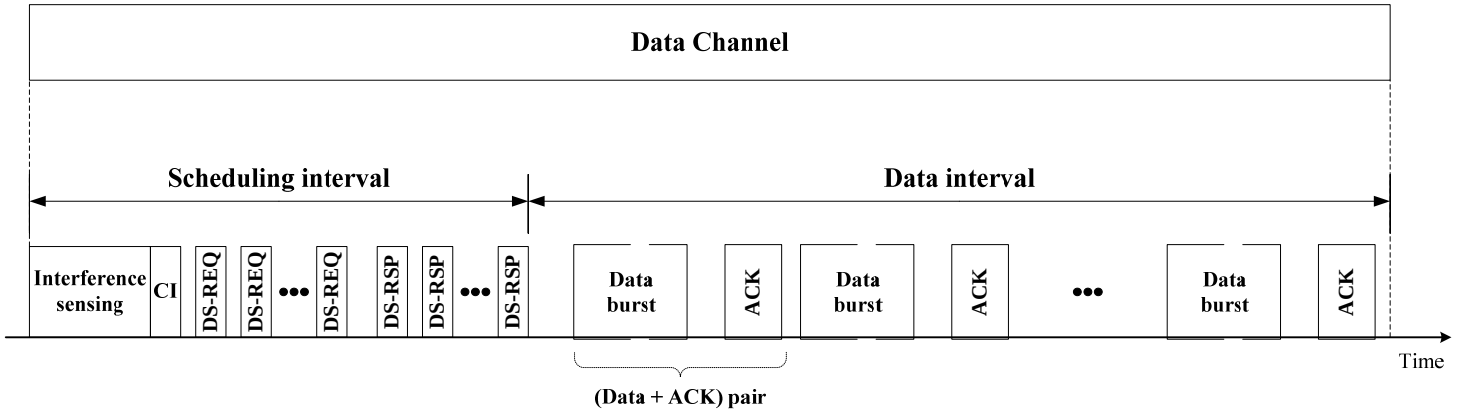
Logical frame structure

- Revisit of logical frame structure



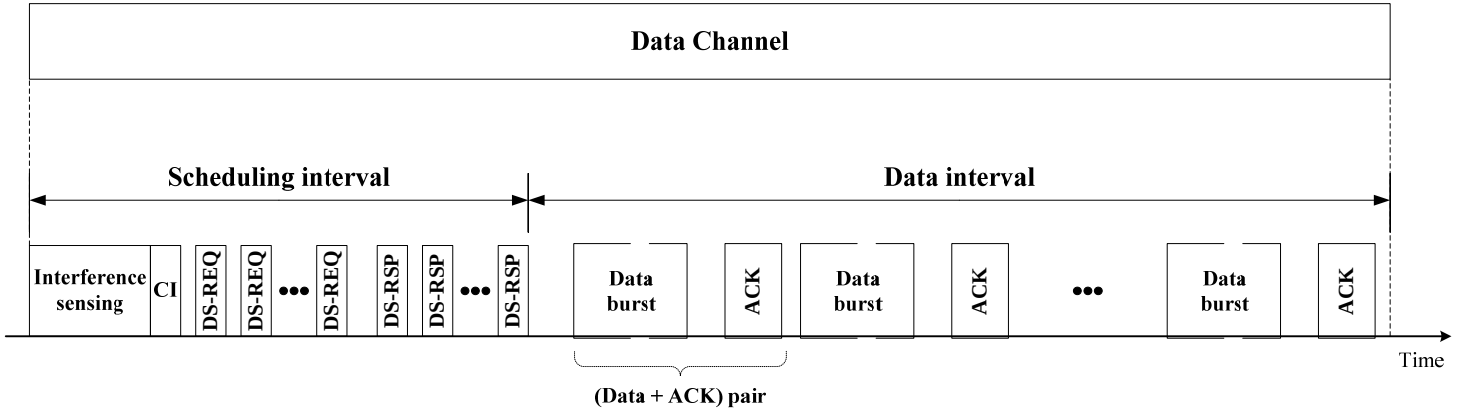
Logical frame structure (cont.)

- Detail logical structure of a *data channel*
  - Scheduling interval
    - CI (Contention Indicator)
      - 1 OFDM symbol-long preamble transmitted by the PD which are going to transmit DS-REQ
    - 8 DS-REQs and 8 DS-RSPs
      - DS-REQ(Distributed Scheduling – REQuest): Transmitted by a contending PD which are trying to access the resource for data transmission
      - DS-RSP(Distributed Scheduling – ReSPonse): Transmitted by the recipient PD in a response to the received DS-REQ



Logical frame structure (cont.)

- Detail logical structure of a *data channel* (cont.)
  - Data interval
    - Maximum 8 (Data + ACK) pairs in the data interval, which means maximum 8 Tx PDs can be allocated.
    - The length of data burst is variable. (The length of ACK burst is fixed)

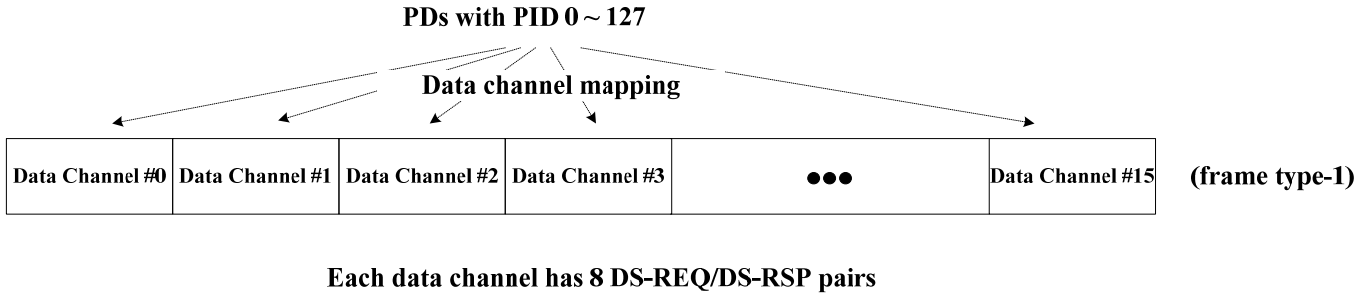


Logical frame structure (cont.)

- Contention occurs in a data channel for the resource allocation in the data interval
  - After peering, every PD exactly knows their resource for transmitting DS-REQ based on both PID and frame index
    - Only peered PDs can access the data channel
    - If the peered PD has nothing to transmit, it has to listen the DS-REQ that can be transmitted by the other peer.
  - Maximum 8 PDs can contend by transmitting DS-REQ in the scheduling interval.

Data channel mapping

- After peering, available data channels for peered PDs are determined based on PID
  - Since there are total 128 PIDs, only one data channel is available for each peered PD.
    - Up to 8 PDs with different PID can contend in a data channel
    - There are 16 data channels in a frame
    - Up to 128 PDs with different PID can contend in a frame type-1



Data channel mapping (cont.)

- Frame number is also used to determine the available data channel
  - A simple shuffling scheme for the data channel mapping is required due to frame type-0
    - Frame type-0 has only 14 data channels
    - Frame type-0 appears once every 10 frames

Data channel mapping (cont.)

- Data channel mapping is a function of PID, frame number, and superframe number
  - The data channel index l (0 ~ 15) for the peered PDs with PID p (0 ~ 127), frame number n (0 ~ 9), and superframe number s (0~15) is given by

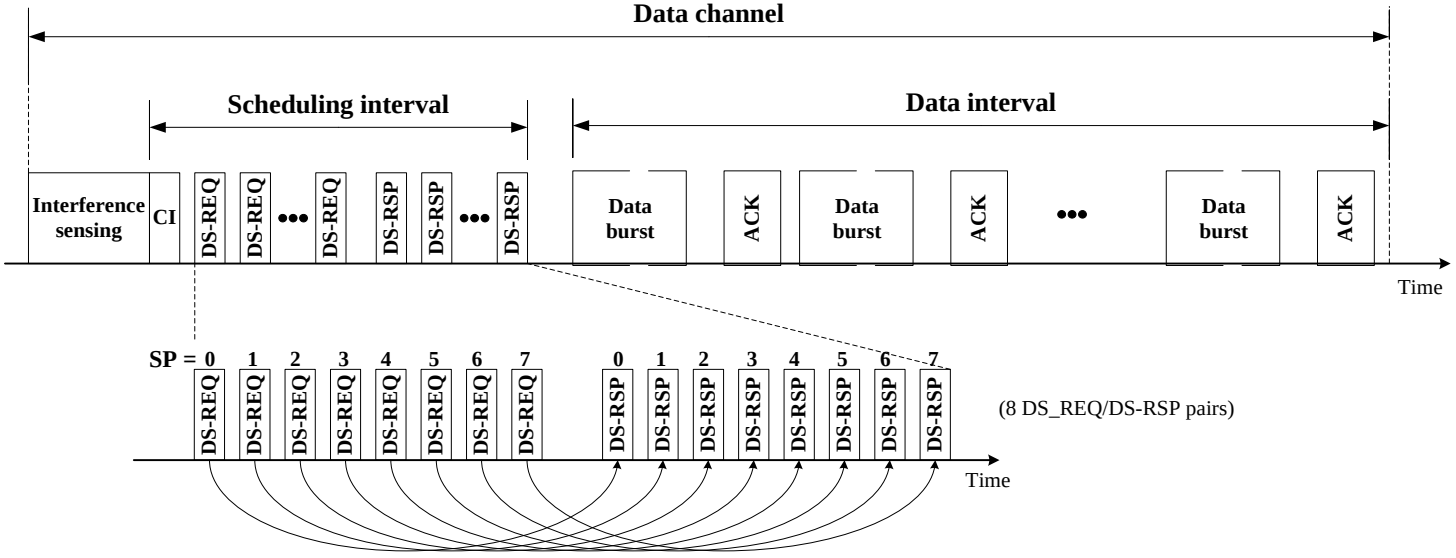
$$data\ channel\ inex, l = (floor(p \div 8) + s \times 10 + n)\ modulo\ 16$$

    - With this scheme, if data channel #l is mapped to the PDs with PID p in a frame, data channel #((l +1) modulo 16) is mapped in the next frame

  - PDs mapped to data channel #0 or #1 in the frame type-0 shall not access it because there are only data channels correspond to #2 ~ #15

Scheduling Priority (SP)

- SP is the priority in access to data interval over other contending PDs
  - SP ranges from 0 to 7 (SP=7 is the highest priority)
  - DS-REQ implicitly represents its SP by the order of appearance in the scheduling interval
    - DS-RSPs are also arranged in order of SP



DS-REQ is transmitted by Tx PD and the paired DS-RSP is transmitted in a response to the received DS-REQ

SP mapping

- After data channel mapping, SP for the peered PDs is determined based on PID, frame number, and superframe number
  - Once data channel mapping is over, SP is mapped to the peered PDs.
    - To know the resources allocated for DS-REQ and DS-RSP
  - SP of PID changes as the frame number increases.
  - SP (0 ~ 7) for the peered PDs with PID *p* (0 ~ 127), frame number *n* (0 ~ 9), and superframe number *s* (0~15) is given by
    - If (PID + s x 10 + n) modulo 8 is 0,

$$SP(p,n,s) = \sum_{k=1}^{(PID + s \times 10 + n) \bmod 8} (-1)^{k+1} \cdot (8-k)$$

    - Otherwise,

$$SP(p,n,s) = 0$$

Mapping example

- The peered PDs can know their mapped data channel and SP through the data channel mapping and SP mapping, respectively.
  - Example:

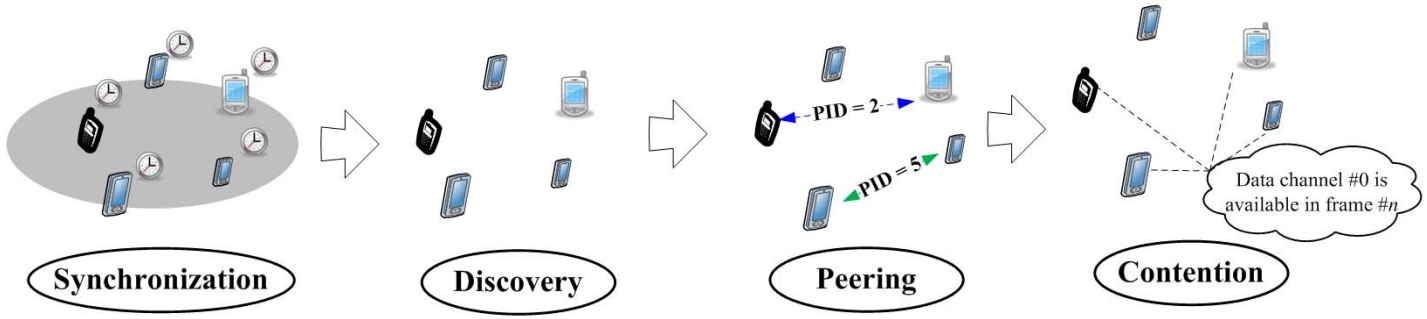
8 PIDs are always mapped to the same data channel

	Frame number	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	…
PID = 0	Data channel index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	0	1	…
	SP	0	7	1	6	2	5	3	4	0	7	1	6	2	5	3	4	0	7	…
PID = 1	Data channel index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	0	1	…
	SP	7	1	6	2	5	3	4	0	7	1	6	2	5	3	4	0	7	1	…
…																				
PID = 8	Data channel index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	0	1	2	…
	SP	0	7	1	6	2	5	3	4	0	7	1	6	2	5	3	4	0	7	…
…																				

  - The highest SP appears once every 8 frames.
  - SP changes as the frame number increases.

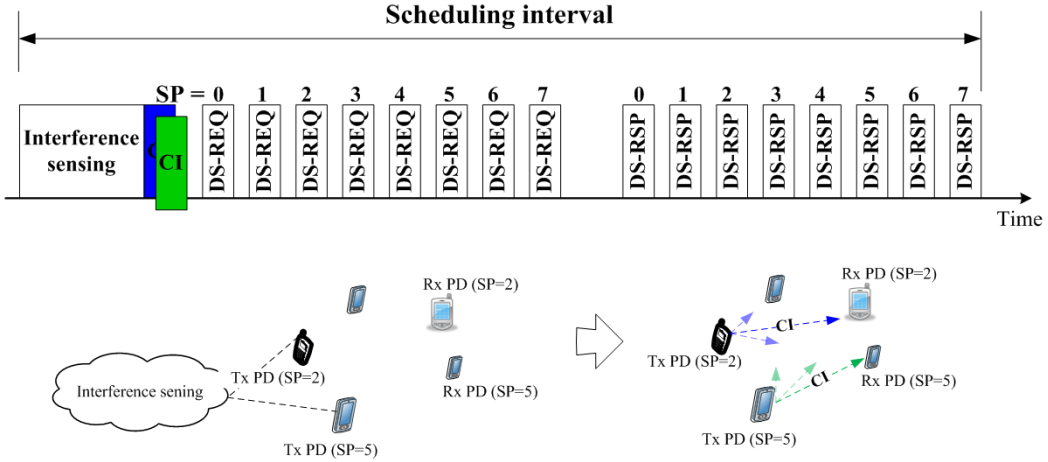
Contention and Scheduling

- Procedure
  - After peering, peered PDs share a common PID
    - Shared PID is locally orthogonal.
    - Only PDs that has completed peering can access the DS-REQ resource.
  - The peered PDs determines their available data channels by the data channel mapping.



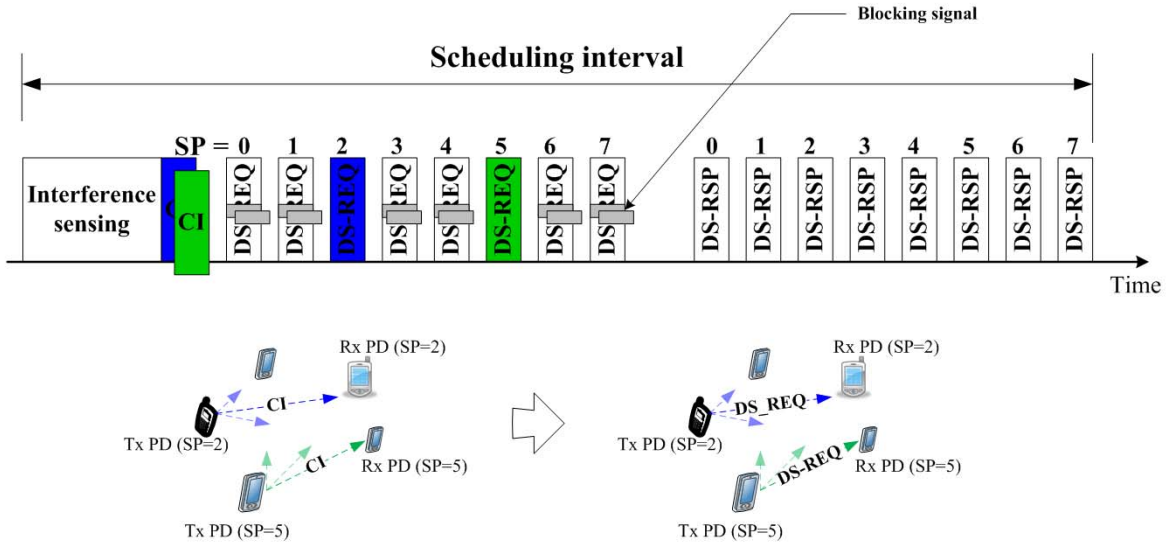
Contention and Scheduling (cont.)

- Procedure (cont.)
  - A PD (Tx PD) trying to transmit data senses interference
  - If the Tx PD does not sense interference, it transmits CI (Contention Indicator)
    - CI is used in consecutive allocation which will be explained in the later slide
    - If Tx PD senses interference, it can not join the contention and it will retry in the next available data channel



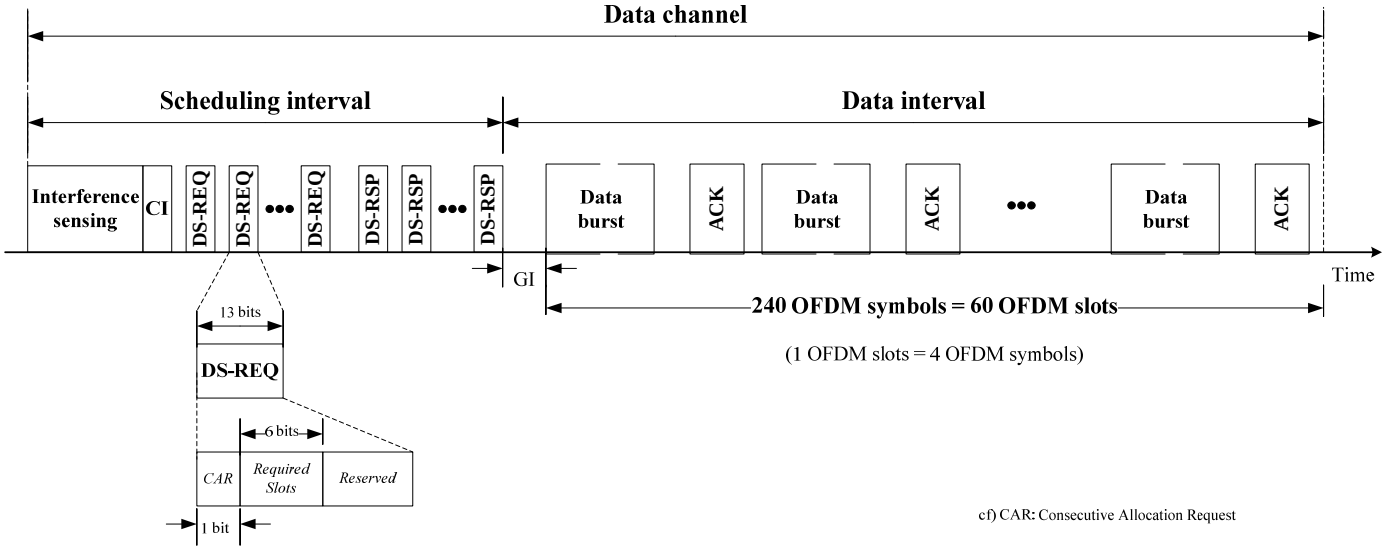
Contention and Scheduling (cont.)

- Procedure (cont.)
  - After transmitting CI, the Tx PD sends DS-REQ corresponds to the mapped SP.
    - Tx PD transmits blocking signals, before and after the transmission of DS-REQ.



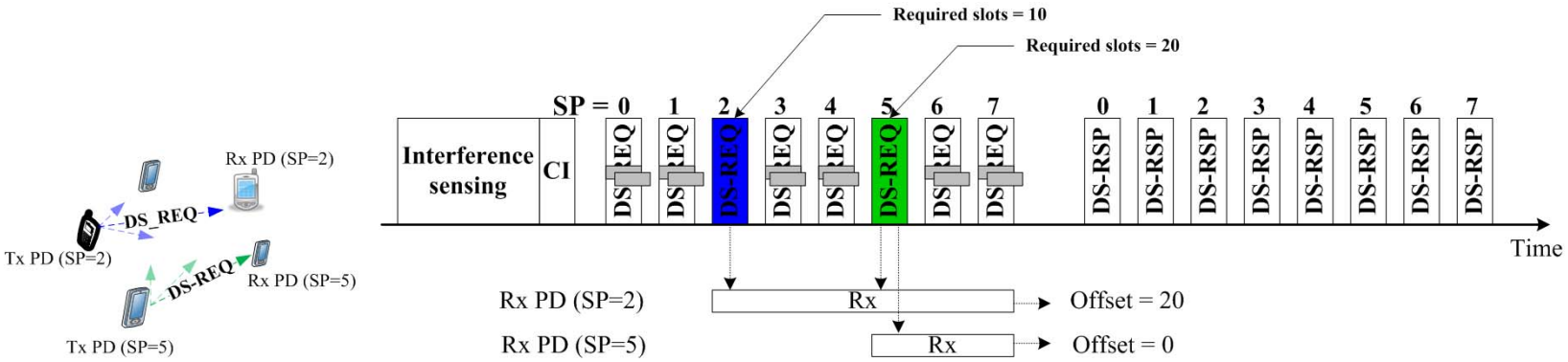
Contention and Scheduling (cont.)

- Procedure (cont.)
  - Tx PD sets “Required slots” field of DS-REQ payload with its required resource in the data interval when it sends DS-REQ.
    - Required resource = data burst for Tx PD + GI(4symbol) + ACK(3 symbol) for Rx PD
    - “Required slots” field is expressed in terms of *OFDM slots*.
      - 1 OFDM slot = 4 OFDM symbols in the data interval



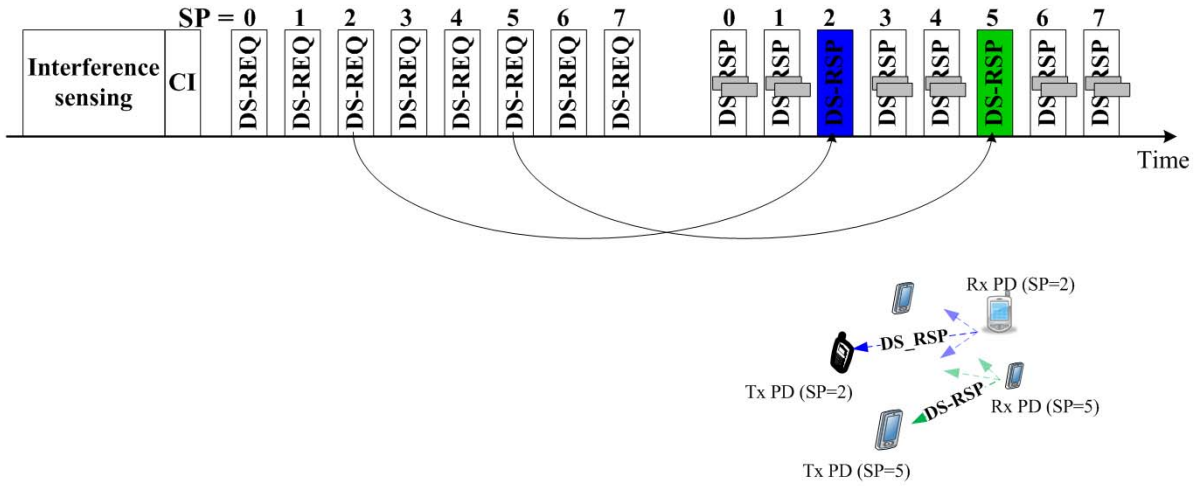
Contention and Scheduling (cont.)

- Procedure (cont.)
  - Rx PD receives all the DS-REQs with equal to or higher than its own SP.
    - If Rx PD fails to receive the DS-REQ from its peered Tx PD, it does not need to receive any other DS-REQs.
  - The Rx PD accumulates the “Required slots” of all the received DS-REQs with higher than its own SP in order to get the allocation “Offset”.
    - Thus, the “Offset” is also expressed in terms of OFDM slots.



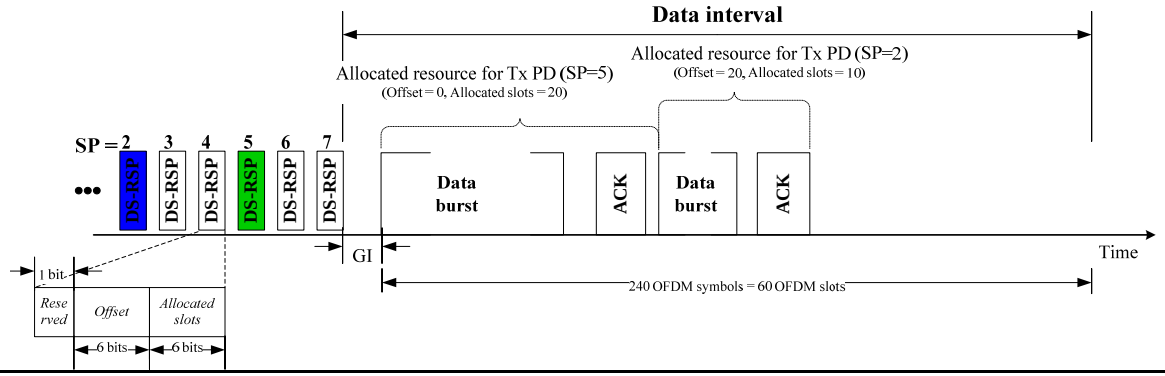
Contention and Scheduling (cont.)

- Procedure (cont.)
  - After successful reception of DS-REQ from its peered Tx PD, the Rx PD sends DS-RSP in a response to DS-REQ
    - Rx PD transmits blocking signals, before and after the transmission of DS-RSP.



Contention and Scheduling (cont.)

- Procedure (cont.)
  - Rx PD sets “Offset” field of DS-RSP payload with the accumulated the “Required slots” of all the received DS-REQs with higher than its own SP.
    - If the “Offset” exceeds data interval boundary, Rx PD does not send DS-RSP.
  - Rx PD sets “Allocated slots” field of DS-RSP payload with the “Required slots” of the DS-REQ received from its peered Tx PD.
    - If “Offset + Required slots” exceeds data interval boundary, Rx PD adjust “Allocated slots” in order not to exceed the data interval boundary.
    - If the adjusted “Allocated slots” is too small to accommodate data burst, GI(4 symbol), ACK(3 symbol), and the gap after ACK(1 symbol), Rx PD does not send DS-RSP.



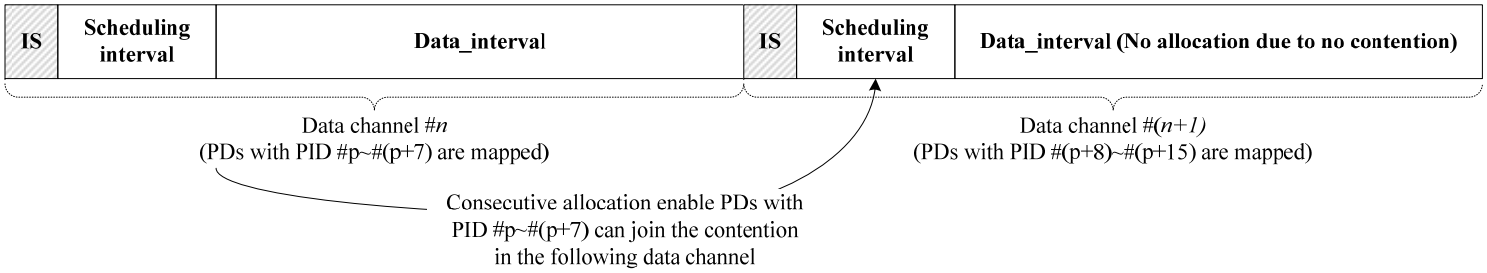
Contention and Scheduling (cont.)

- Procedure (cont.)
  - Tx PD receives all the DS-RSPs with equal to or higher than its own SP.
    - If Tx PD fails to receive the DS-RSP from its peered Tx PD, it does not need to receive any other DS-REQs.
  - Tx PD can know its allocated resource ranging from “Offset” to (“Offset” + “Allocated slots”) by decoding the DS-RSP received from its peered Rx PD.
  - Tx PD checks whether its allocated resource overlaps with other allocated resources for PDs having higher SP than its own.
    - Even if there is partial overlapping, Tx PD shall not use its allocated resource.
    - If there is no overlapping, Tx PD can utilize the allocated resource.

Consecutive allocation

- Motivation
  - Resource contention occurs within a data channel among the fixed set of PDs specified by data channel mapping.
  - Even if there is no contention in data channel #(n+1), PDs mapped to data channel #n cannot join the contention in the following data channel #(n+1).

- Consecutive allocation
  - An allocation mechanism enabling any PDs mapped in a data channel to have an opportunity to be allocated in the following data channel by joining the contention occurs in the following data channel.

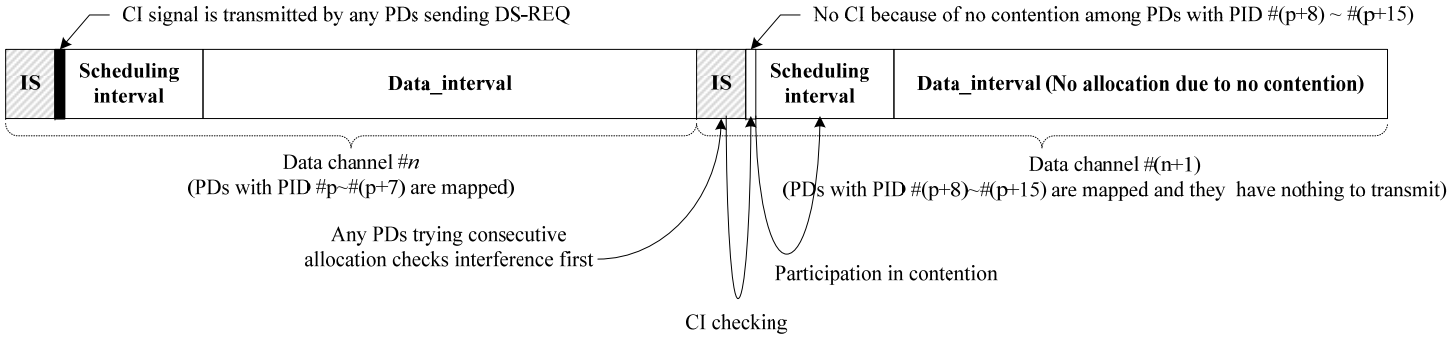


Consecutive allocation (cont.)

- Procedure
  - The Tx PD trying consecutive allocation in the data channel #(n+1) sets CAR (Consecutive allocation request) bit when it sends DS-REQ to the peered Rx PD in data channel #n.
    - By receiving DS-REQ with CAR bit set to 1 in data channel #n, the Rx PD can notice that the peered Tx PD tries consecutive allocation in the following data channel #(n+1).
  - If the Tx PD succeeds in receiving DS-RSP from its peered Rx PD, it joins the contention in the data channel #(n+1)
    - After exchange of DS-REQ and DS-RSP, Tx PD and Rx BD carry out the same contention and scheduling procedure in data channel #n as is described in the previous slides.
  - Before joining contention in data channel #(n+1), Tx BD checks whether there is CI signal in the scheduling interval of data channel #(n+1).
    - As is its usual practice, Tx PD senses interference before checking CI signal.
    - If interference is sensed by Tx PD, it immediately stops consecutive allocation procedure.

Consecutive allocation (cont.)

- Procedure
  - If there is no CI signal, the Tx BD joins the contention in data channel #(n+1) by transmitting DS-REQ with the same SP used in the data channel #n.
    - If CI signal is detected, Tx BD immediately stops consecutive allocation procedure.
    - Rx BD also checks CI signal and immediately stops consecutive allocation procedure if CI is detected
  - In data channel #(n+1), Tx PD and Rx BD carry out the same contention and scheduling procedure as is described in the previous slides.



Conclusion

- Discovery
  - Broadcasting based manner with support of query based manner
    - To support device(/presence) discovery and service discovery at the MAC layer
      - Discovery signal contains different information depending on the purpose
    - Periodic use of a selected resource unit(RU) after initial selection by each PD in synchronous fixed frame format
      - Periodic transmission of the device information for presence(/device) discovery
      - Aperiodic transmission of the service information for service discovery in place of device information
- Peering
  - Sharing a orthogonal PID between a pair of PDs after peering
    - Acquisition of PID usage information in advance
    - Random trials of message transmission related to negotiation of PID during a designated allocated interval

Conclusion (cont.)

- Scheduling
  - "The large number of PDs" was the main design objective.
  - The proposed fully distributed scheduling can distribute single resource to the multiple contending PDs.
  - Consecutive allocation is proposed in order to avoid under-utilization of resource for data transmission.
  - The proposed scheduling scheme in conjunction with orthogonal contention is suitable for PAC considering "*at least a hundred of PDs*"