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

Submission Title: [A MAC proposal for PAC operating in synchronous mode (ppt)]
Date Submitted: [July 15th, 2013]
Source: [Seungkwon Cho, Hyungjin Kim, Seokki Kim, Soojung Jung, and Sungcheol Chang]
Company: [ETRI]
Address: [218 Gajeong-ro, Yuseong-gu, 305-700, Republic of Korea]
Fax: [+82-42-861-1966] **E-Mail:**[skcho@etri.re.kr]

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

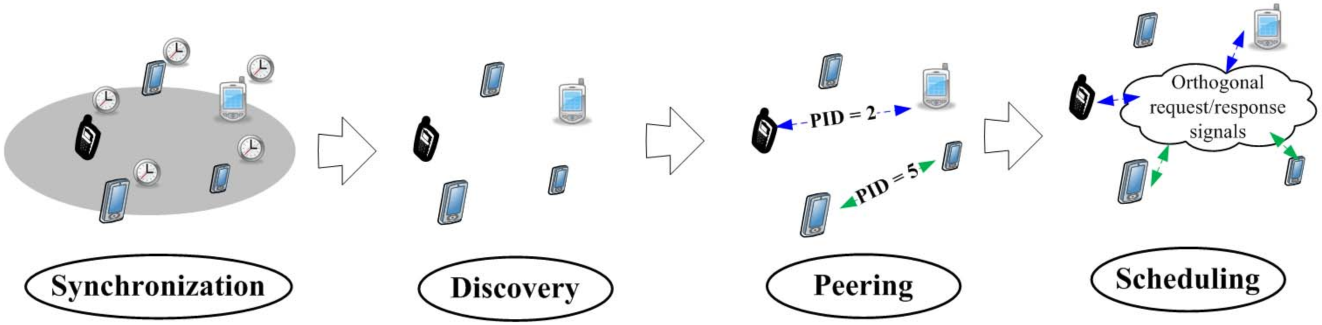
- Proposal outline
- MAC Proposal for PAC framework document
  - Discovery
  - Peering
  - Distributed Scheduling
- Conclusion

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 15-13-0391-01-0008 or the latest version: Overview of proposal (ppt)
  - DCN 15-13-0393-00-0008 or the latest version: PHY proposal (ppt)
  - DCN 15-13-0390-01-0008 or the latest version: MAC proposal (ppt) (This document)
  - DCN 15-13-0392-00-0008 or the latest version: Text proposal (doc)

Overview

- Discovery/Peering/Scheduling procedure
  - A synchronized PD can discover other PDs in a broadcasting manner with support of query.
  - After peering, an orthogonal PID is shared between a pair of PDs.
  - Resource for a peered PD can be allocated by priority-based distributed scheduling with orthogonal requests/responses signals

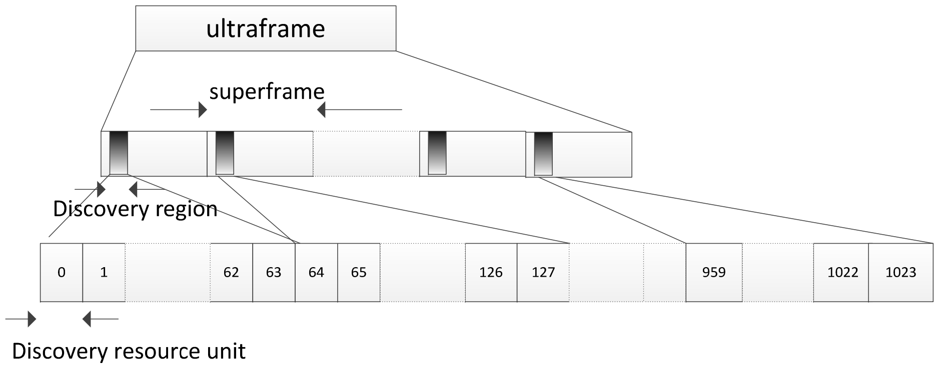


Discovery

- Overview
  - Distributed allocation of discovery resource
    - A resource unit(RU) is selected by each PD after monitoring usage of resources provided periodically in frame structure
    - Periodic use of selected RU after initial selection by each PD
  - Broadcasting manner that supports a query-based manner
    - Periodic Device discovery
      - Broadcasting manner
    - Aperiodic service discovery
      - Broadcasting manner and query manner

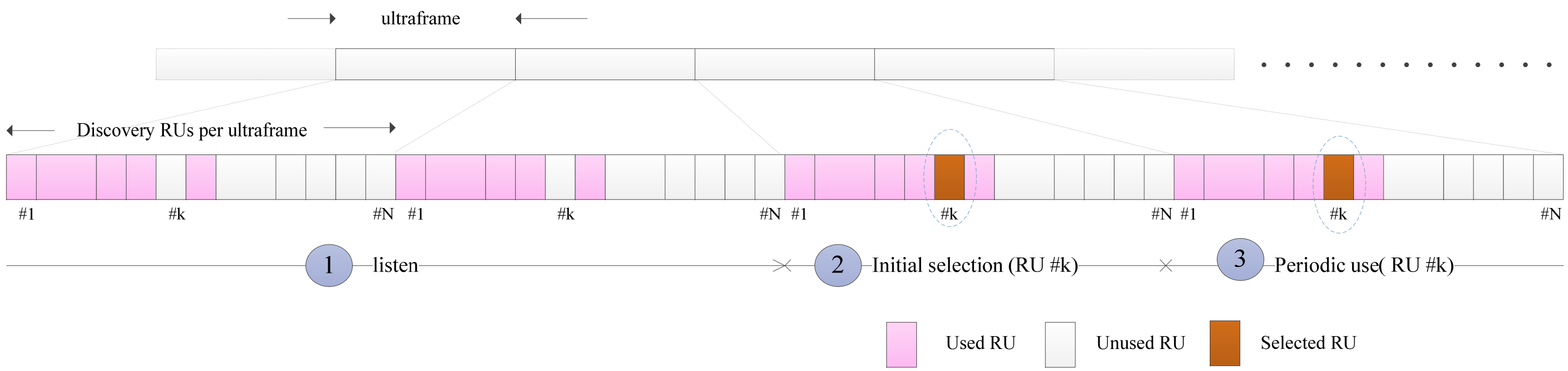
Discovery

- Distributed resource allocation
  - Resources is provided periodically in the form of one region in the frame
    - Resources for discovery are divided into a number of RUs
      - An Ultraframe (3.2s) is a discovery repetition period
        - A Discovery region consists of 64 RUs
        - Resources for discovery consist of 16 Discovery regions
        - 1024 RUs per discovery repetition period
      - 0.8% overhead (25.6 ms per 3.2s)



Discovery

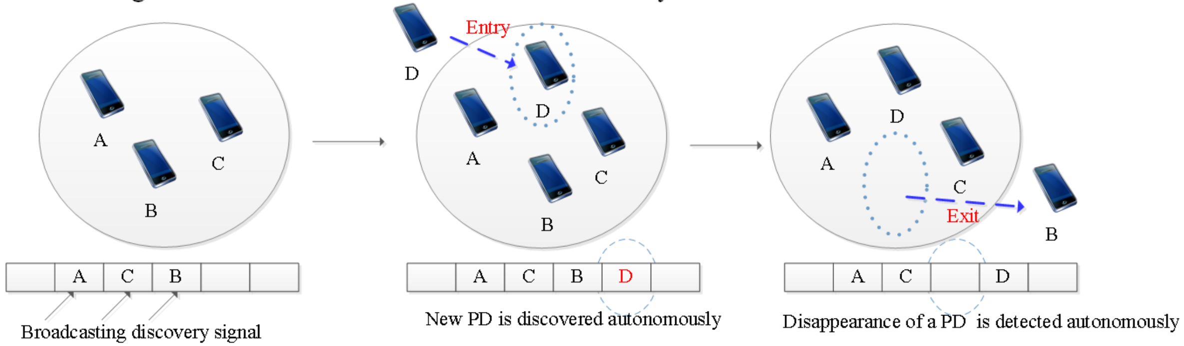
- Distributed resource allocation(cont.)
  - Resource in the synchronous fixed frame structure(cont.)
    - Periodic use of selected RU can be possible after initial selection
      - Initial selection after listening
        - A PD selects a RU which is not being used(or least congested from a PD's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



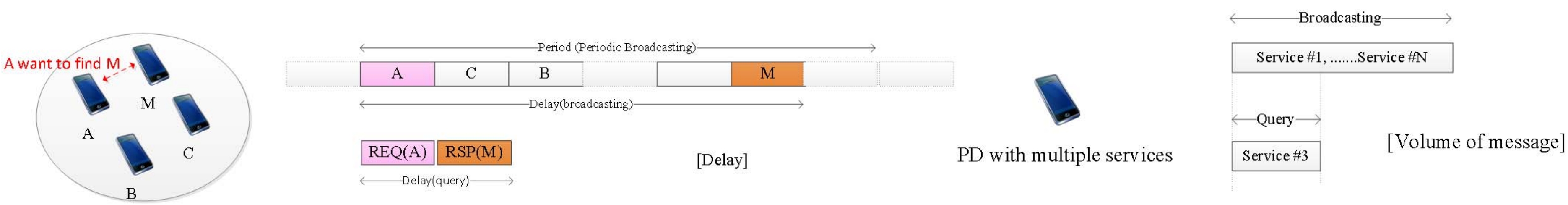
      - Collision detection and RU reselection
        - Receive signals from other PDs on the selected RU at randomly selected time
        - Reselect a new RU when the energy is detected on the selected RU

Discovery

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

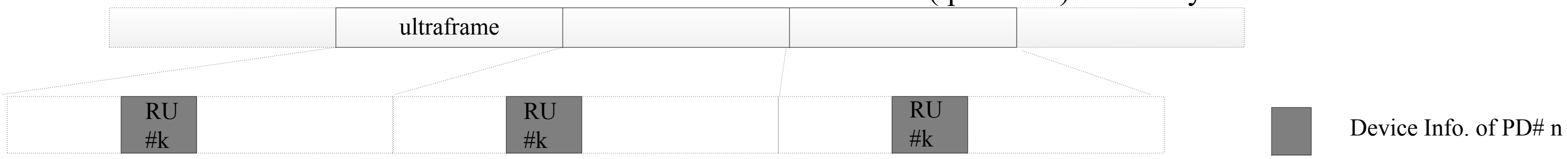


    - Query: short delay and small message volume

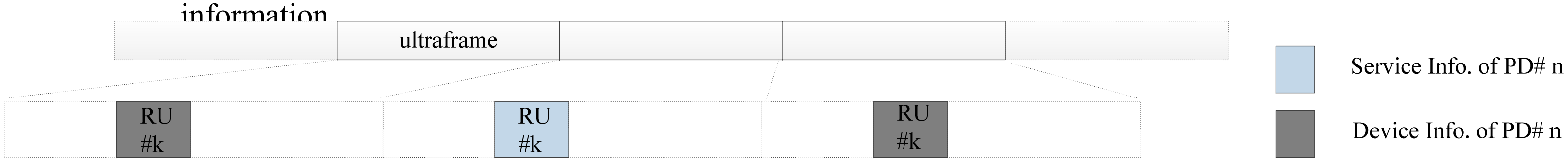


Discovery

- Broadcasting manner with infrequent query(cont.)
  - 2 step discovery : Device discovery + Service discovery
    - Broadcasting manner to have autonomous and continuous property
      - Device discovery & service discovery
    - query-based manner to use messages with small volume
      - (Target) Service discovery
  - Broadcasting manner
    - Periodically broadcast own information on a selected RU
      - Periodic transmission of the device information for device(/presence) discovery

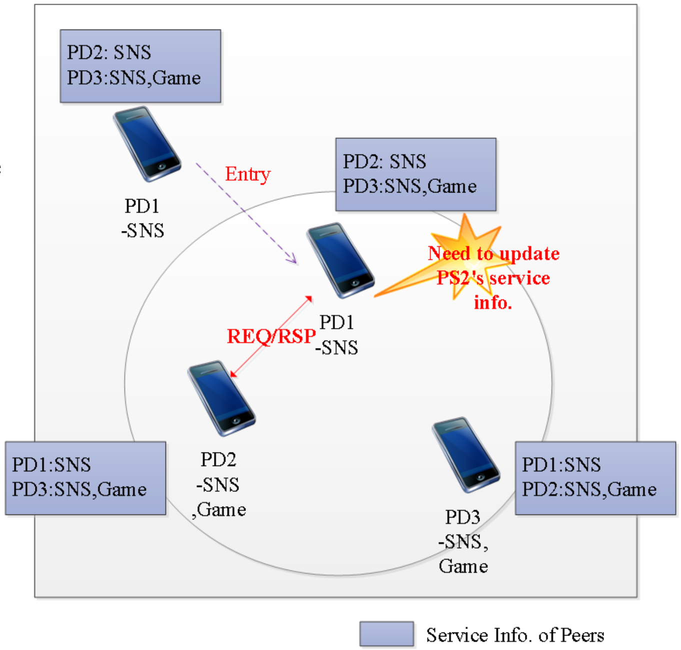


      - Aperiodic transmission of the service information for service discovery in place of device information



Discovery

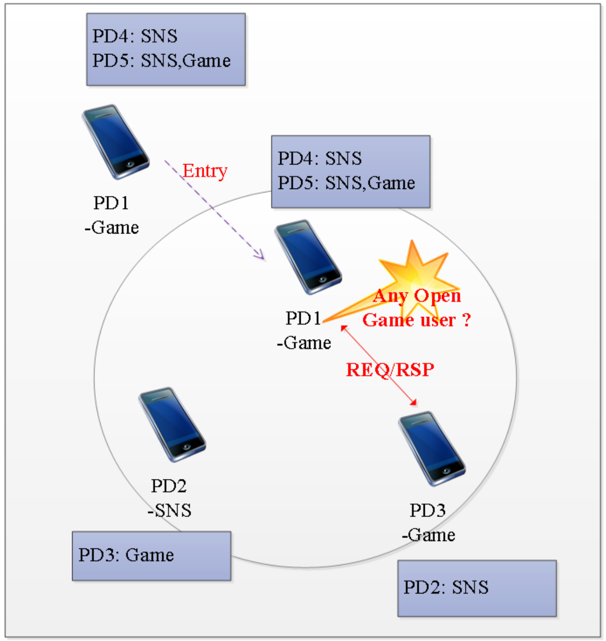
- Broadcasting manner with infrequent query(cont.)
  - Query-based manner
    - Depending on the situation, various request and response messages can be provided in place of device information
    - Scenario #1: service information request
      - Request of whole information related to target PD’s service in case of initial discovery
      - Request of delta information related to target PD’s service in case of rediscovery



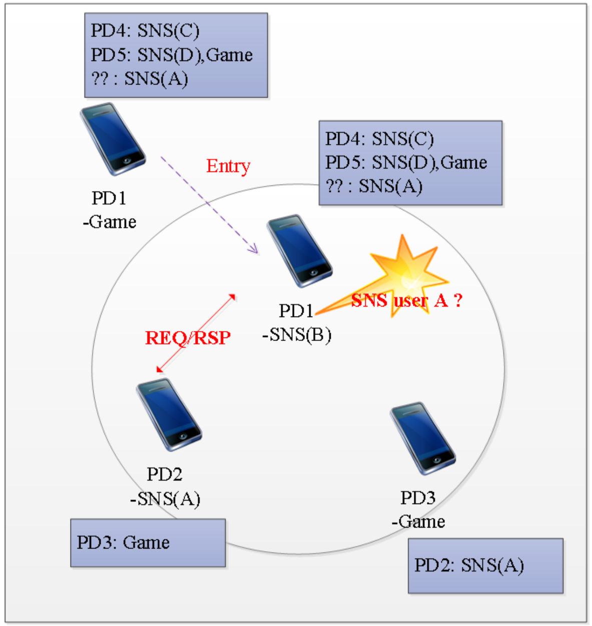
< Request of delta service info>

Discovery

- Broadcasting manner with infrequent query(cont.)
  - Query-based manner(cont.)
    - Scenario #2: Peer search
      - Anonymous peer using same service : without (target) user info.(e.g. app. specific user ID)
      - Target peer of a specific service : with (target) user info(e.g. app. specific user ID)



<anonymous peer search for target service> Service Info. of Peers

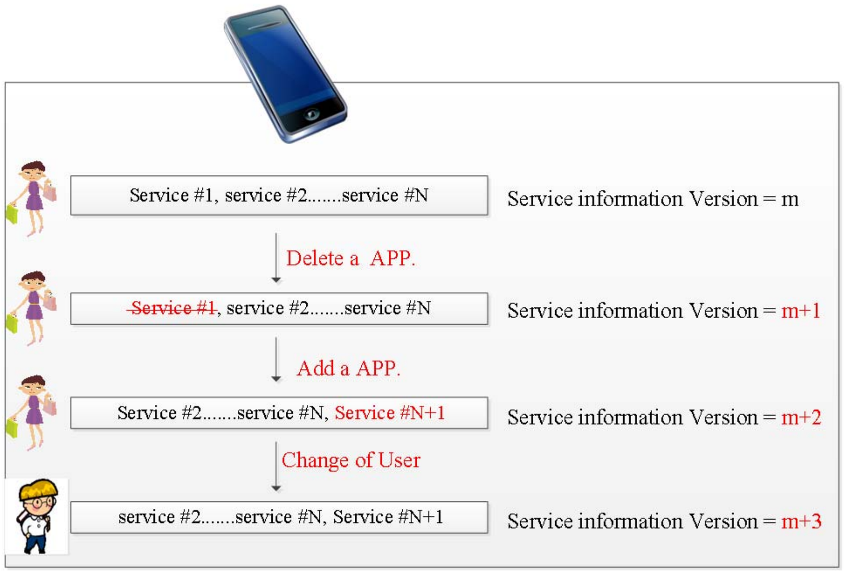


< target peer search for target service> Service Info. of Peers

Discovery

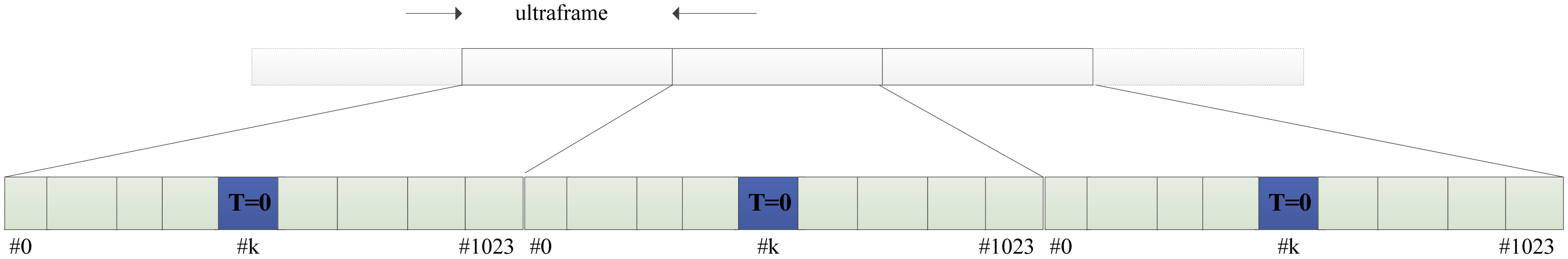
- Consideration of service information
  - Service Information Version
    - To broadcast the whole information about the service provided by each PD's is not efficient
      - Each PD can provide multiple services
      - The change of service provided by each PD is happen infrequently

- A parameter can be used to represent the information about the services provided by a PD
- By providing a parameter related to service information(e.g. Service Information Version) periodically, exchange of request and response messages can be performed only when it is needed to be update from other PD's perspective

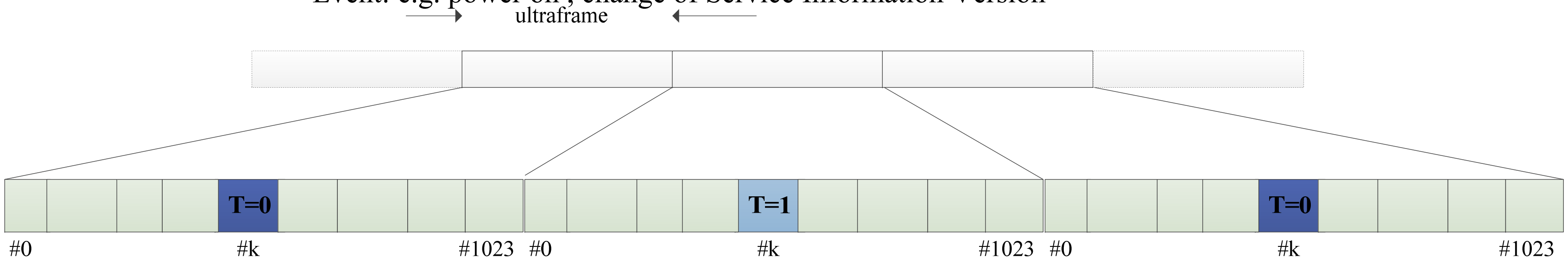


Discovery

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

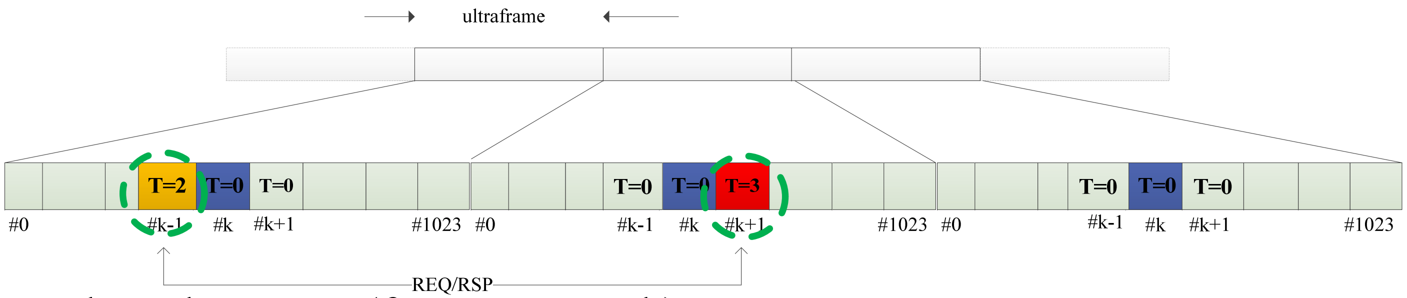


    - (Event triggered) transmission of service information(T=1: service advertisement)
      - Event: e.g. power on , change of Service Information Version

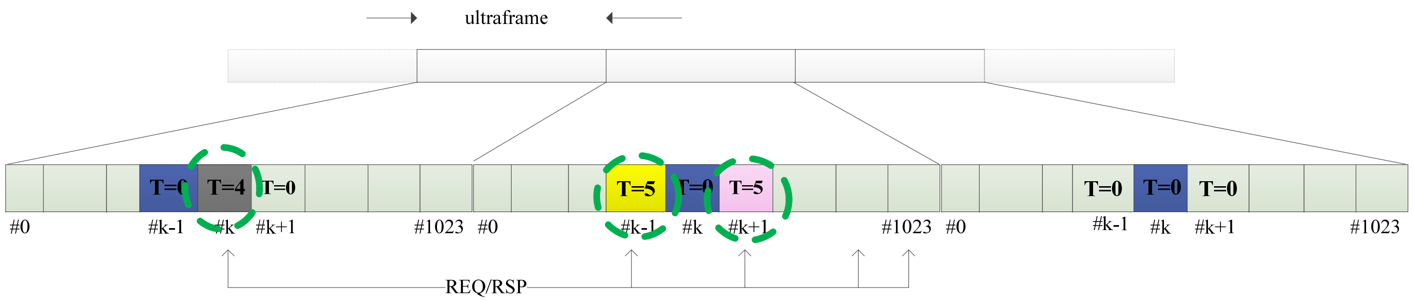


Discovery

- Procedure(Cont.)
  - Query-based manner (for service information)
    - T=2: service information request, T=3: service information response

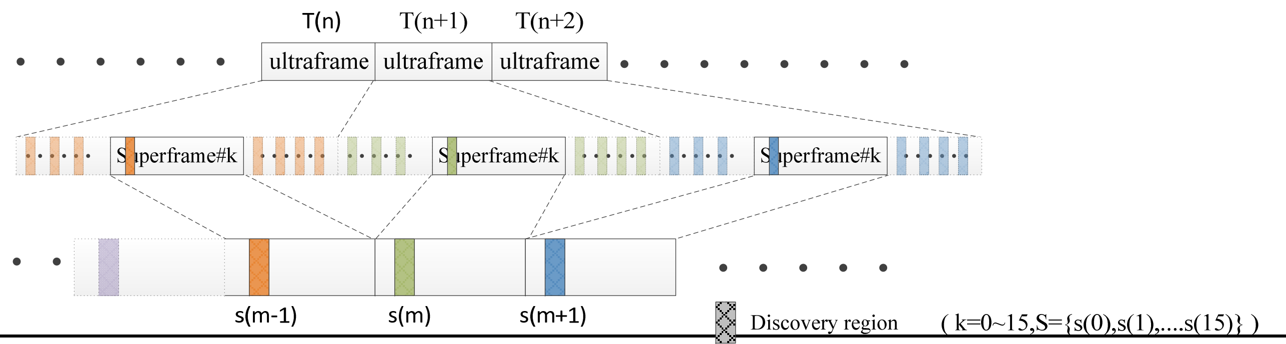


  - Query-based manner (for peer search)
    - T=4: peer search request, T=5: peer search response



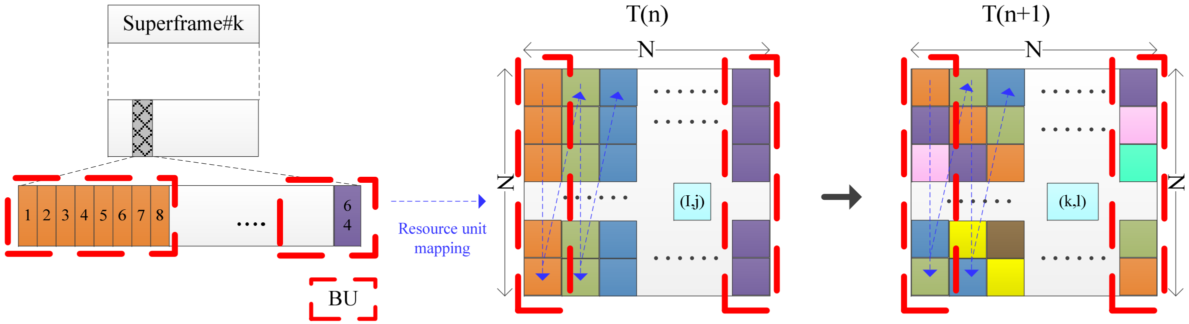
Discovery

- Consideration for BU(Blocking unit)
  - Shuffling pattern
    - Used to vary a configuration of PDs which use the RUs in a BU
  - Shuffling pattern for discovery region
    - Number of RUs required to configure pattern in matrix form (N*N)
      - Number of RUs in a BU & Number of BUs in a superframe: N=8
      - Total number of RUs per superframe : N*N=64
  - Period of pattern change is same as the discovery repetition period(i.e. Ultraframe)
  - Same Shuffling pattern is used to all superframes in an ultraframe.



Discovery

– Resource shuffling
  - The next position (k,l) of selected RU is determined by the previous position (i,j) of shuffling pattern.



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

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

$$\text{where} \quad 1 \le i, j, k, l \le N$$

Peering

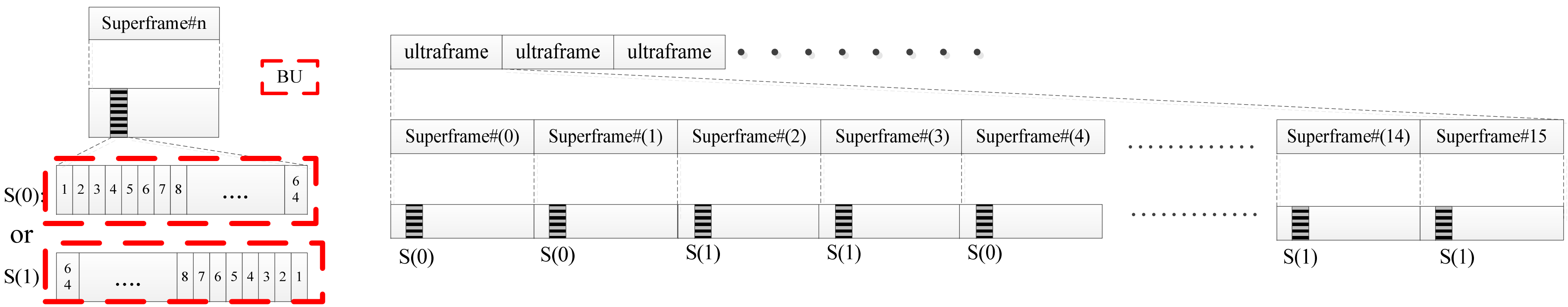
- Peering
  - Peering ID(PID)
    - Used to identify a pair of PDs(PID=0~127)
    - Sharing a PID between a pair of PDs after peering
    - The shared PID between a pair of PDs is a basic material for scheduling
  - PID broadcasting interval
    - PID usage information is broadcasting in fixed period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

Peering

- Peering(cont.)
  - Average. time to be 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
      - Interval between a RU of Peering-REQ and a RU of Peering-RSP = 0.214 ms

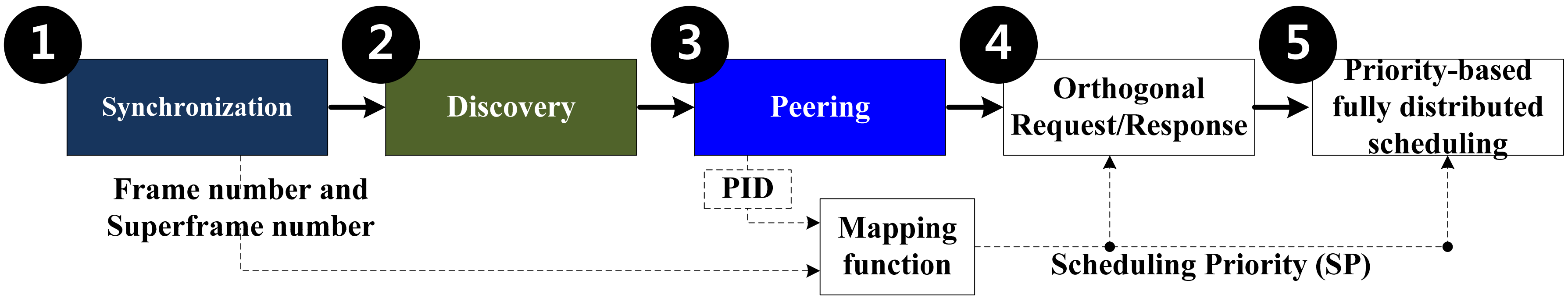
Peering

- Consideration for BU
  - Shuffling pattern
    - Used to vary a configuration of PDs which use the RUs blocked by a PD
    - PID broadcasting interval of peering region
      - Number of RUs in the BU : N=64
      - One of two pattern is applied to two consecutive superframes and the same pattern is applied at eight times per ultraframe.



Overview of the proposed scheduling

- Overall procedure



- Contention-free access with orthogonal requests/responses and priority-based fully distributed scheduling

Characteristics of the proposed scheduling (cont.)

- No collision in sending the request and response signals used to try to access the resource for data transmissions
  - Orthogonal PID enables the peered PDs to have orthogonal resources for the request and response signals.

- Fully distributed scheduling

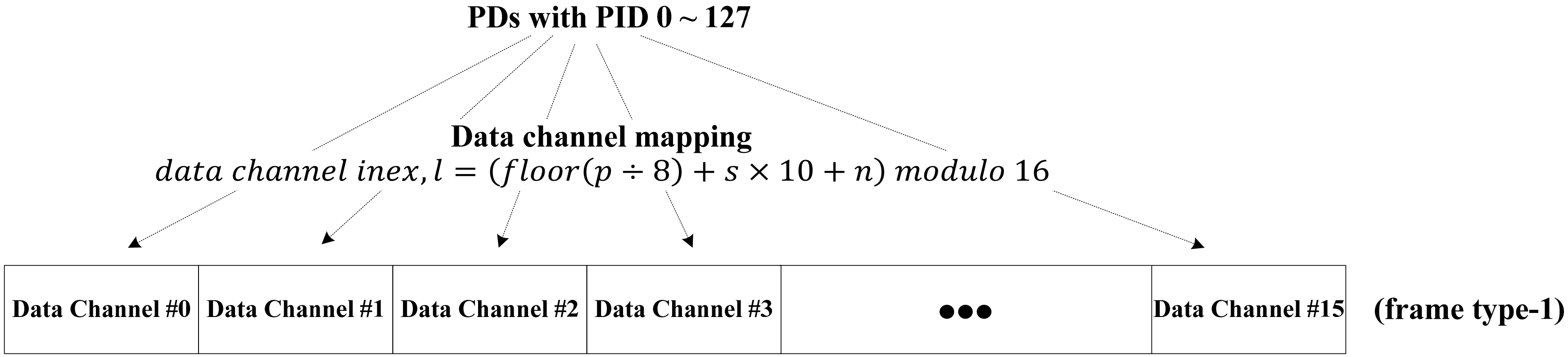
- Priority-based distributed scheduling
  - PD with higher SP(Scheduling Priority) has higher probability of access to the resource for data transmission.

Resource mapping

- After peering, available resources for sending request/response signals are *orthogonally* assigned to all the peered PDs.
  - SP(Scheduling Priority) mapping in conjunction with data channel mapping is used for the assignment.
- Data channel mapping
  - A function that determines available data channels for the peered PDs based on PID, frame number, and superframe number.
- SP mapping
  - A function that determines the SP of the peered PDs in the mapped data channel based on PID, frame number, and superframe number.

Data channel mapping

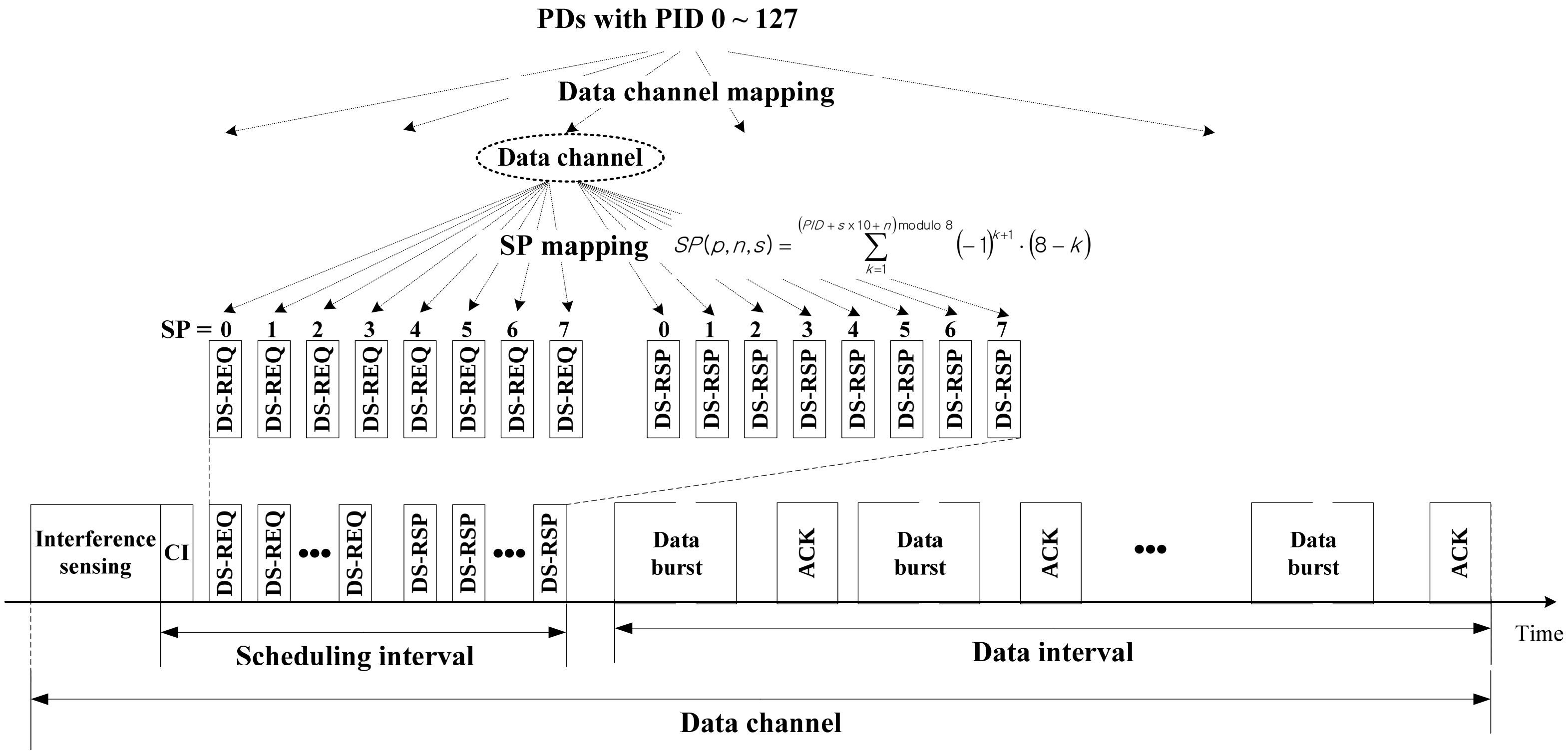
- After peering, available data channels for peered PDs are determined based on the *orthogonal* PID



***l*: assigned data channel index for the peered PDs (0 ~ 15)**
***p*: PID (0 ~ 127)**
***n*: frame number (0 ~ 9)**
***s*: superframe number (0~15)**

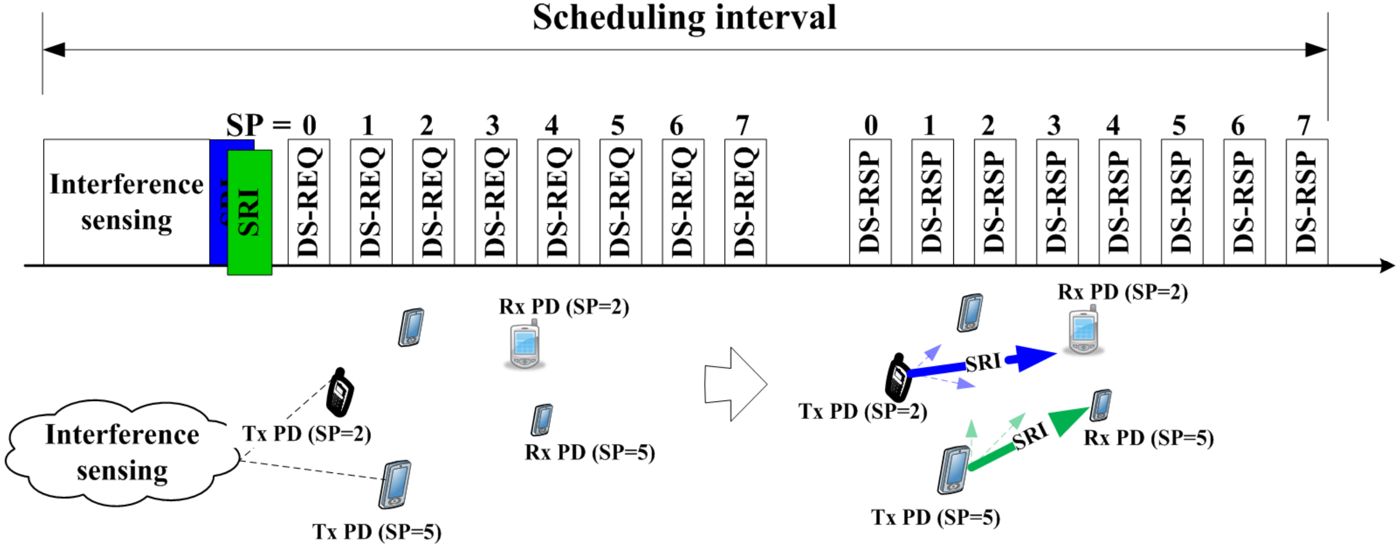
Scheduling priority mapping

- SP is the priority in access to data interval
  - SP is also used to determine the *orthogonal* resource for both DS-REQ and DS-RSP.



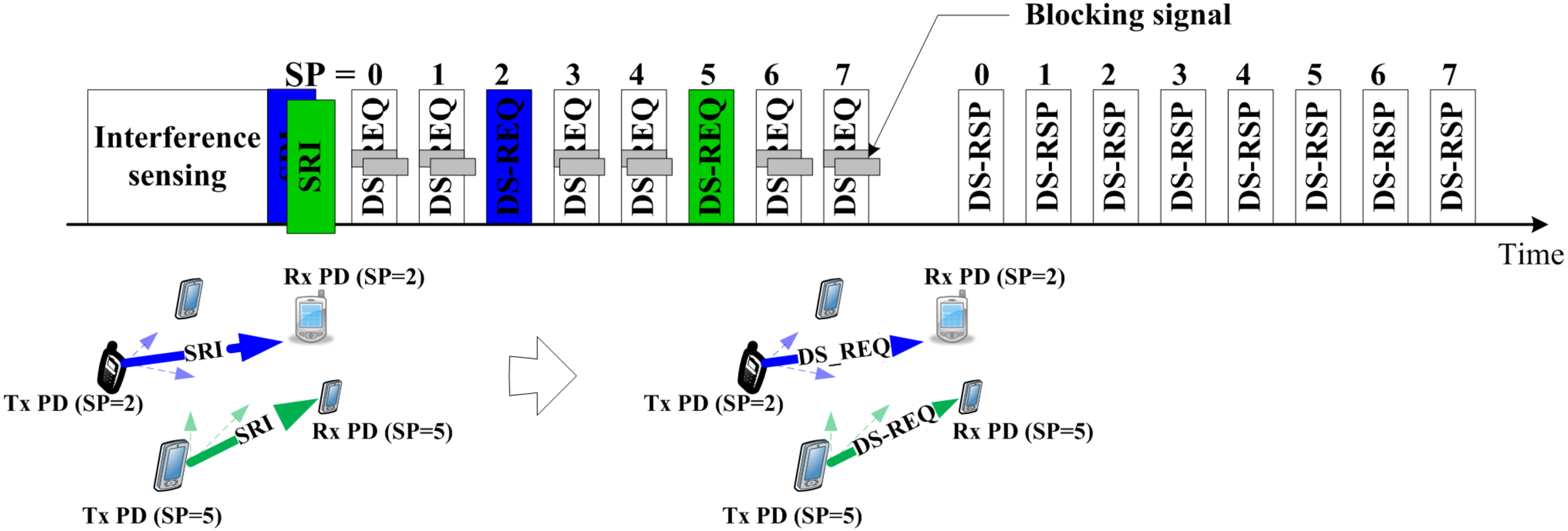
Distributed scheduling (Normal allocation)

- Procedure
  - If the Tx PD does not sense any interference, it transmits SRI (Scheduling Request Indicator)
    - All the PDs trying to send DS-REQ shall transmit SRI signal.
    - If Tx PD senses interference, it can not participate in the scheduling and it will retry in the next available data channel.



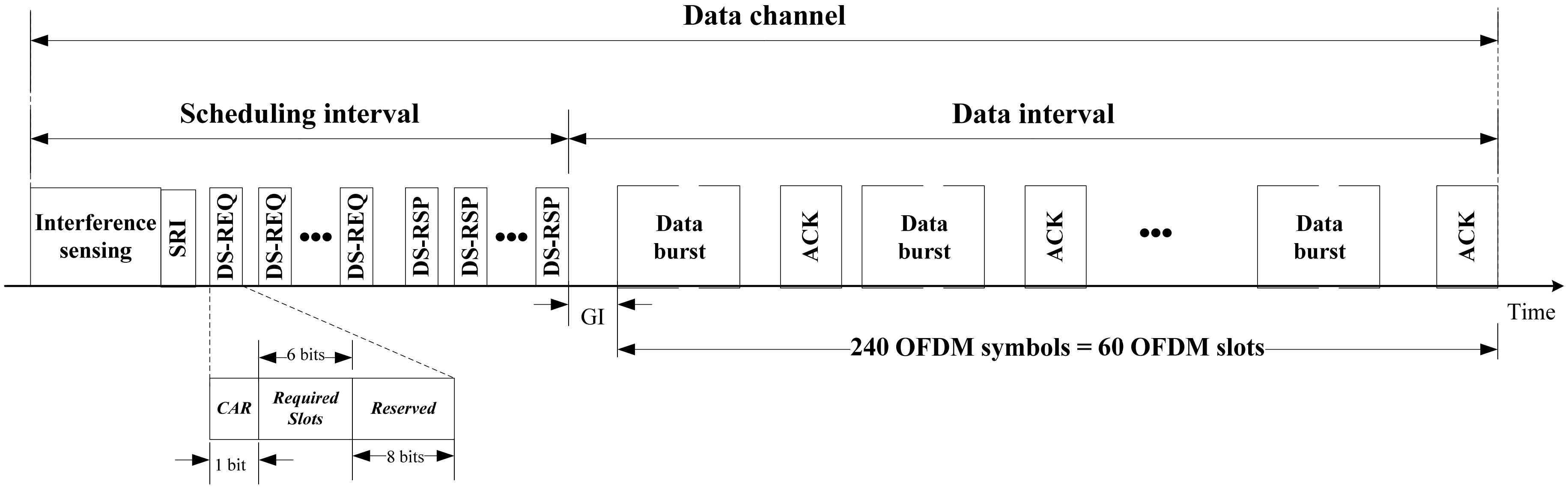
Distributed scheduling (Normal allocation) (cont.)

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



Distributed scheduling (Normal allocation) (cont.)

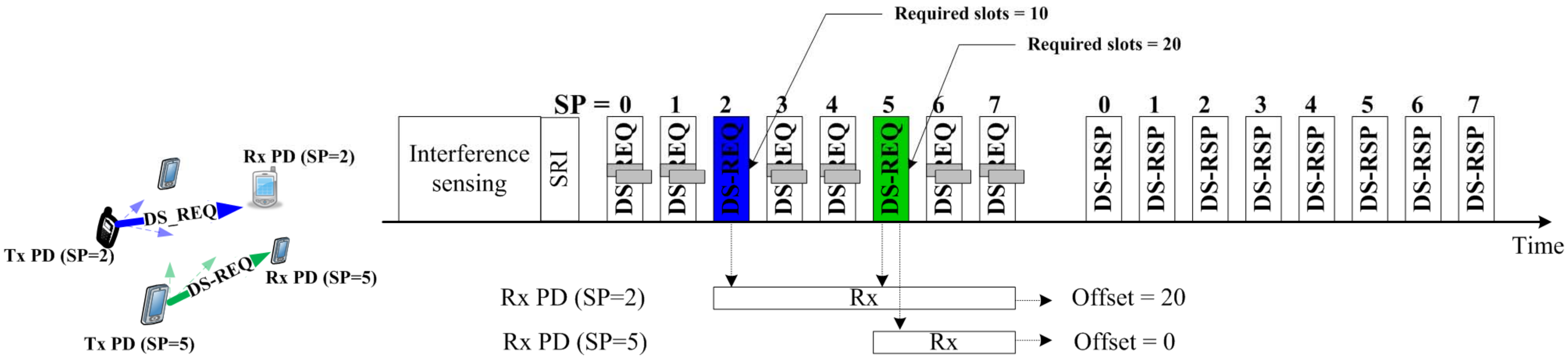
- Procedure (cont.)
  - Tx PD sets “Required slots” field of DS-REQ payload with its required resource (Data burst + ACK) in the data interval when it sends DS-REQ.
    - “Required slots” field is expressed in terms of *OFDM slots*.
      - 1 OFDM slot = 4 OFDM symbols in the data interval



cf) CAR: Consecutive Allocation Request

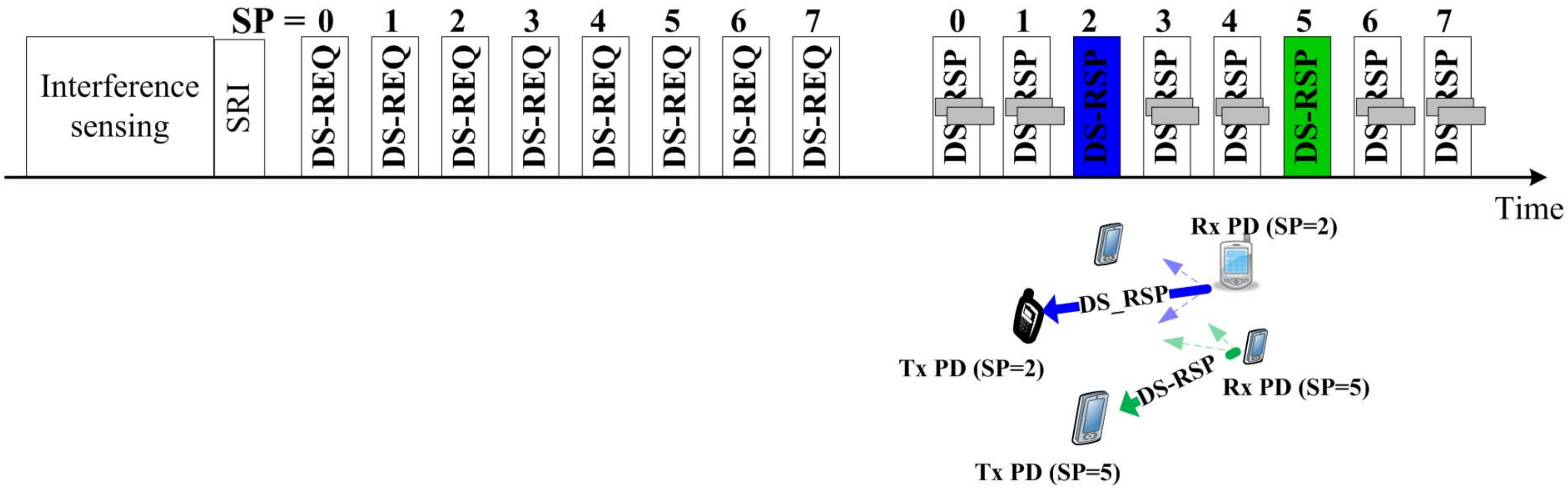
Distributed scheduling (Normal allocation) (cont.)

- Procedure (cont.)
  - Rx PD receives all the DS-REQs with equal to or higher SP than its own.
  - The Rx PD accumulates the Required slots fields of all the received DS-REQs with higher SP than its own in order to get the allocation offset.



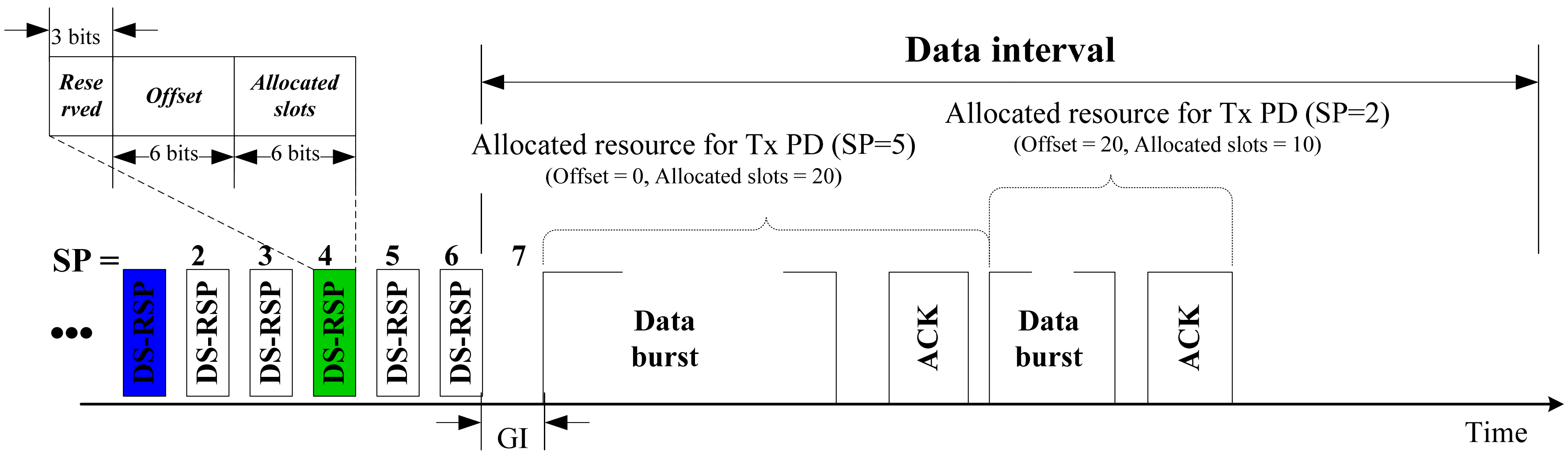
Distributed scheduling (Normal allocation) (cont.)

- 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.



Distributed scheduling (Normal allocation) (cont.)

- Procedure (cont.)
  - Rx PD sets Offset field of DS-RSP payload with the accumulated offset using Required slots fields of all the received DS-REQs with higher SP than its own.
  - Rx PD sets Allocated slots field of DS-RSP payload with the Required slots field of the DS-REQ received from its peered Tx PD.

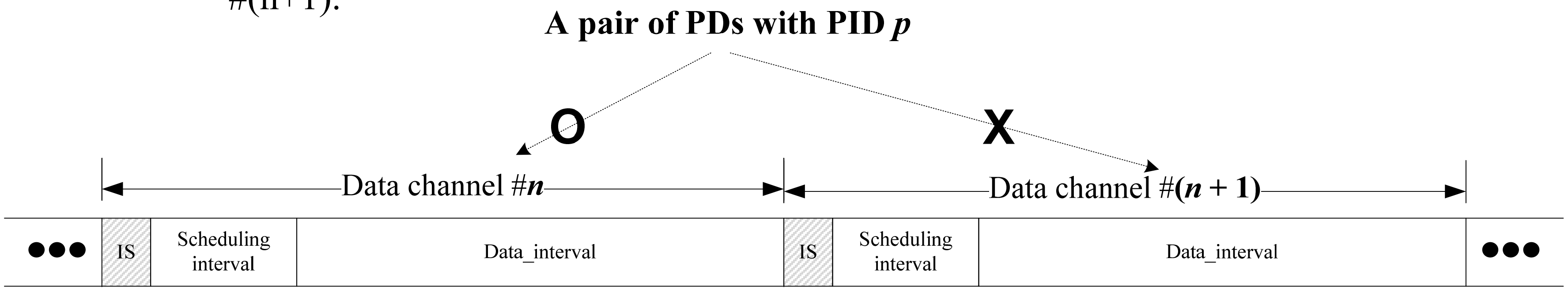


Distributed scheduling (Normal allocation) (cont.)

- Procedure (cont.)
  - Tx PD receives all the DS-RSPs with equal to or higher than its own SP.
  - 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
  - Even if there are no PDs to be scheduled in data channel #(n+1), PDs mapped to data channel #n cannot participate in the scheduling in the following data channel #(n+1).



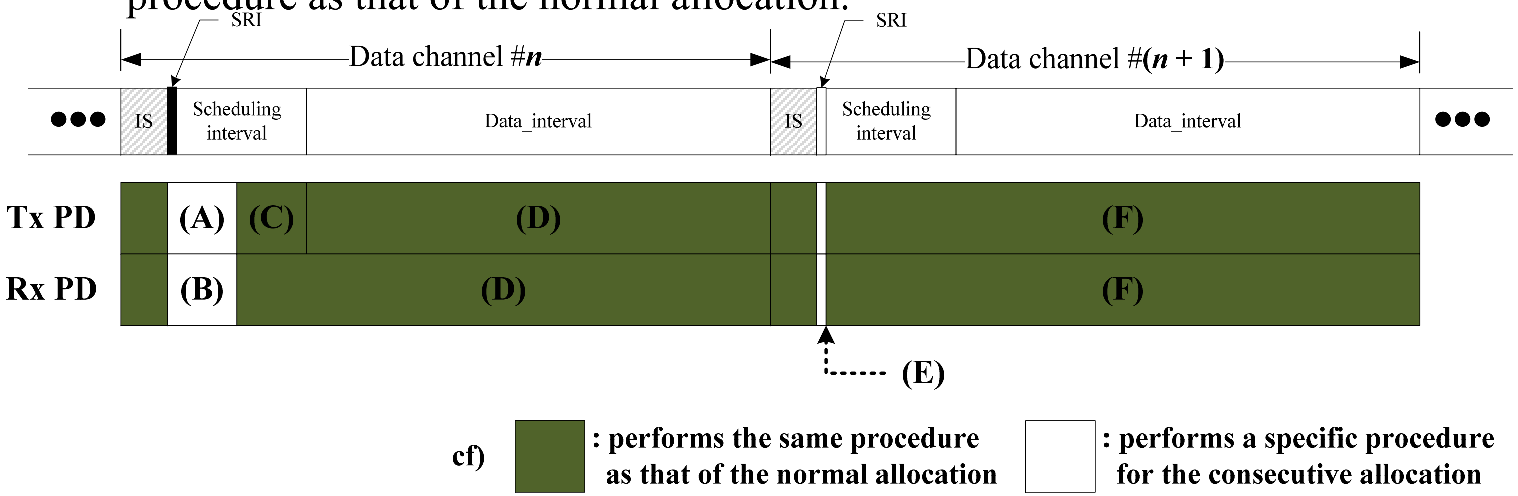
- Consecutive allocation
  - An allocation mechanism enabling any PDs scheduled in a data channel to have another scheduling opportunity in the following data channel.

Consecutive allocation (cont.)

- Procedure
  - (A) 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.
  - (B) By receiving DS-REQ with SRI 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).
  - (C) If the Tx PD succeeds in receiving DS-RSP from its peered Rx PD in data channel #n, it can participate in the scheduling in the data channel #(n+1)
  - (D) In data channel #n, both Tx PD and Rx BD carry out the same scheduling procedure as that of the normal allocation.

Consecutive allocation (cont.)

- Procedure
  - (E) In data channel #(n+1), both Tx PD and Rx BD check whether there is SRI signal in the scheduling interval of data channel #(n+1) or not.
    - If there is no SRI signal, the Tx BD participating in the scheduling in data channel #(n+1) by transmitting DS-REQ with the same SP used in the data channel #n.
    - If SRI signal is detected, both Tx BD and Rx BD immediately stop consecutive allocation procedure.
  - (F) In data channel #(n+1), Tx PD and Rx BD carry out the same scheduling procedure as that of the normal allocation.



Conclusion

- Discovery
  - Broadcasting manner with support of query
    - To support device(/presence) discovery and service discovery at the MAC layer
    - 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 an orthogonal PID between a pair of PDs after peering
    - Acquisition of PID usage information in advance
    - Random trials of peering request message

Conclusion (cont.)

- Scheduling
  - The proposed scheduling scheme with orthogonal resource requests is suitable for PAC considering "*at least a hundred of PDs*"
  - The proposed fully distributed scheduling can distribute single resource to the multiple PDs without collision.
  - Consecutive allocation is proposed in order to avoid under-utilization of resource for data transmission.

APPENDIX

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 (or management block) based on information of application layer

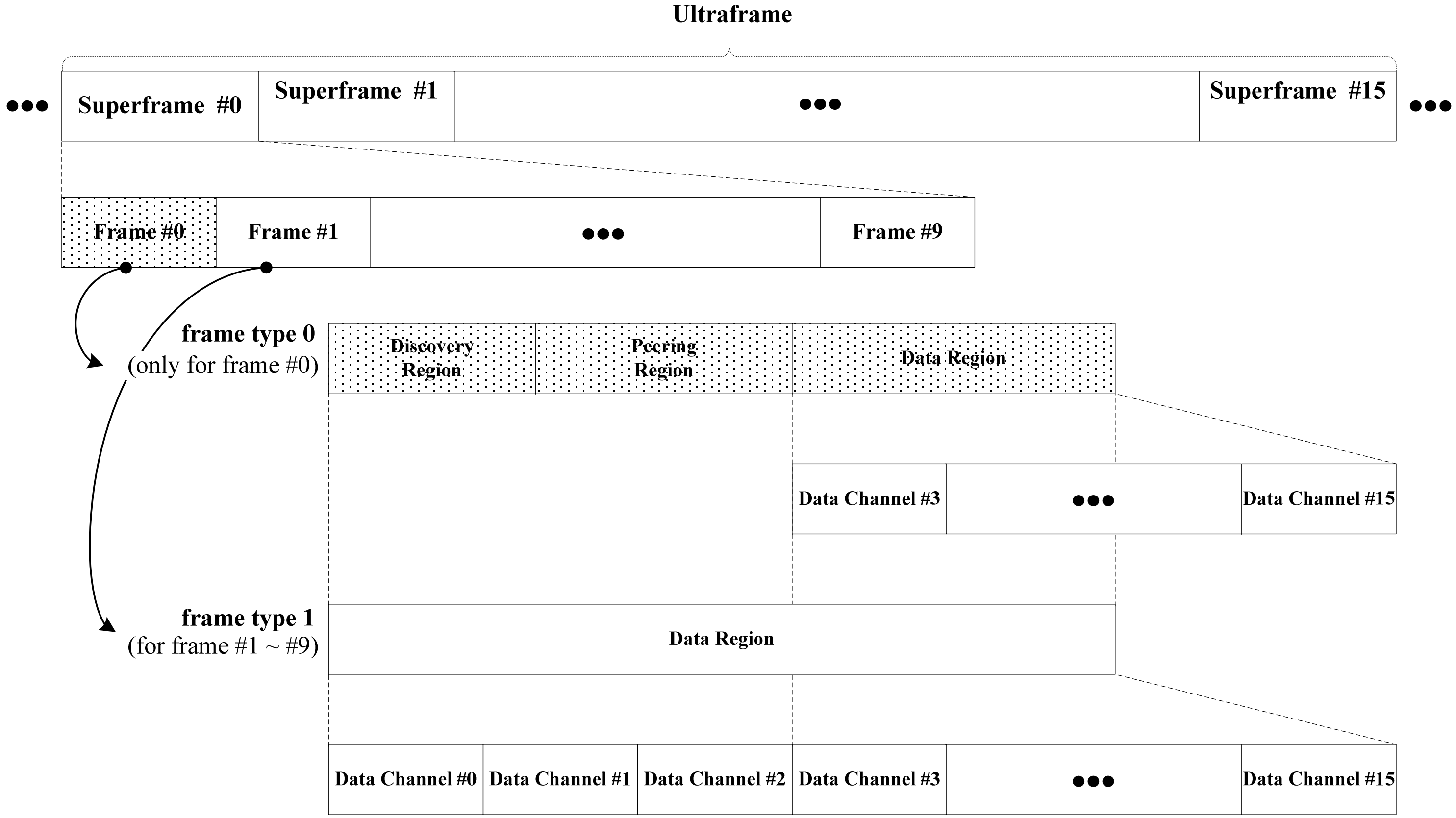
Discovery

- Payload of Discovery signal(cont.)

Contents	Size(Bits)	Description	Notes
SIV(Service Information Version)	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		

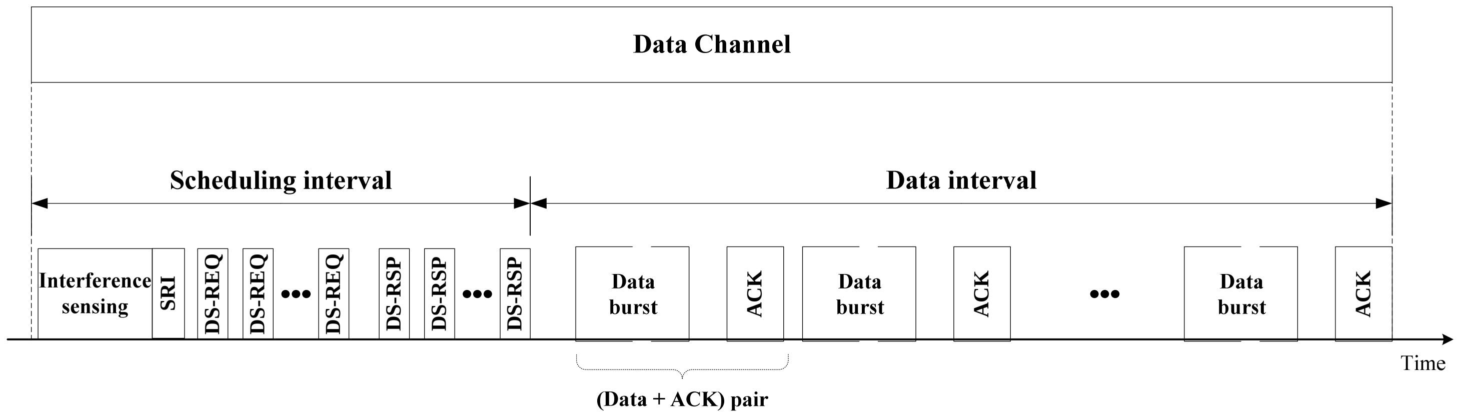
Logical frame structure

- Revisit of logical frame structure



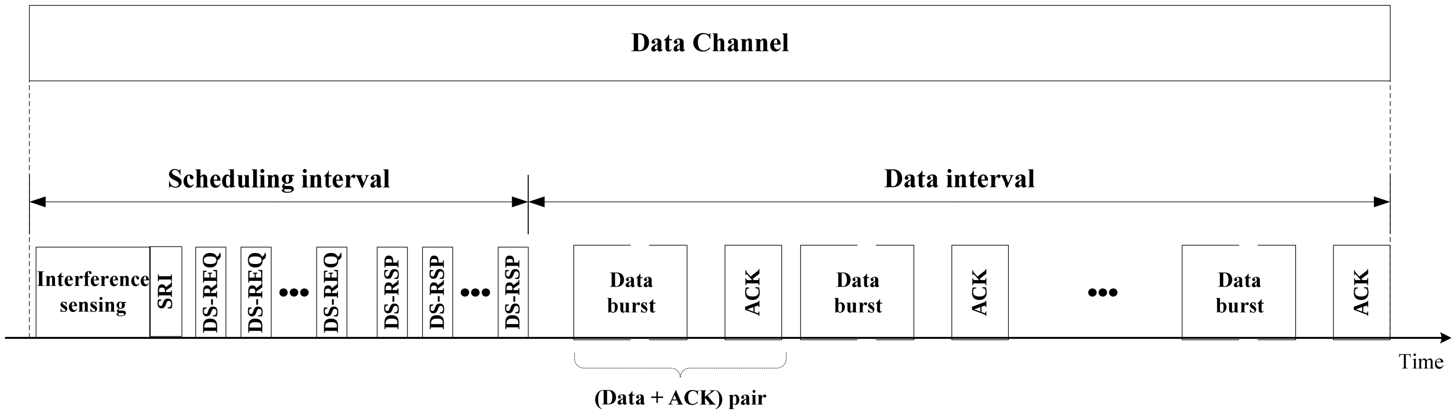
Logical frame structure (cont.)

- Detail logical structure of a *data channel*
  - Scheduling interval
    - SRI (Scheduling Request 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 PD which are trying to access the resource for data transmission
      - DS-RSP(Distributed Scheduling – ReSPonse): Transmitted by the peered 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)



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 (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 ≠ 0,

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

    - 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

	Superframe number	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	…
	Frame number	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**…**
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.