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

Submission Title: [Low energy superframe for beacon enabled PAN]
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Re: [In response to TG4g Call for Proposals]
Abstract: [Proposal of PHY and MAC for low-power consumption SUN]

Summary

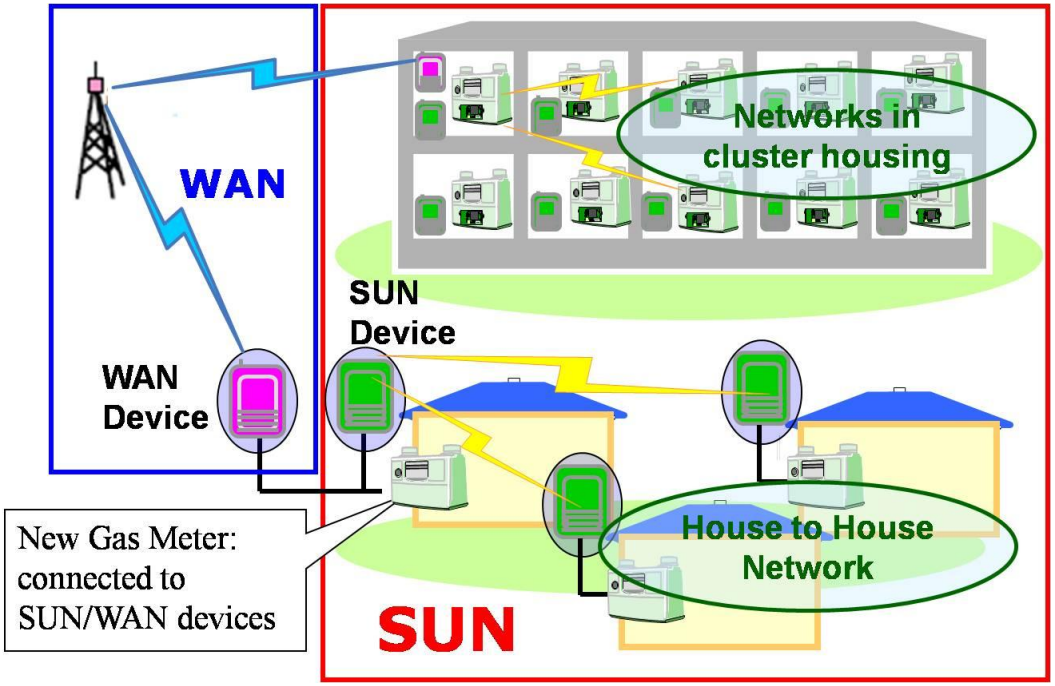
- Optional low energy superframe employment for beacon enabled PAN works effectively to realize low energy consumption performance for systems such as TG4g related smart utility networks(SUN)
  - MAC modifications on the basis of 15.4MAC for beacon enabled PAN
    - Beacon turn off mode with active period
    - Intermittent hearing using CAP and receiving in the following inactive period
    - Tree topology with independent superframe determination
  - One MAC PIB attribute addition is required to realize those MAC modifications
    - macLowEnergySuperframeSupported

Tracks of our proposal

- PHY amendment proposal with MAC modifications for TG4g CFP on May12 (upload on May 2) as 1st proposal(4g: 09/312r2) and on July 15 as revised proposal(4g: 09/478r2)
- Presentation of the low energy MAC technology on July 13
- Proposal on draft modifications in Low Energy subgroup on the joint meeting with Tg4e/4f/4g (4e: 09/544r2) on July 14, and advised by Leader Wei Hong to be rather discussed in EGTS subgroup
- Upload in EGTS subgroup draft rev4 (4e: 09/377r4)
- Revised in EGTS subgroup draft rev6 (4e: 09/377r6)

System Concept of SUN

- TG4g defines PHY amendment to IEEE802.15.4 when addressed to Smart Utility Network(SUN)
- One of typical SUN applications: Automatic meter reading
  - Tree or mesh network topology
    - Meter data collection by multi-hop transmission expands system service area
  - Battery operation
    - Required for gas or water meter reading, where AC main power is not available



System specifications

Item	Specification
Communication Environment	Urban area (dense installation)
Communication Control	Center polling, Terminal initiate a call
Network Topology	Mesh structure
Radio	Max 50
Number of Meters	Max 50 (1/ radio)
Neighbor Nodes	4 ~ 12 nodes
Number of relays	Average: 5 hops, Max: 15 hops
Data Size	110 bytes/ Packet
Duration	10 years
Communication frequency	200 times/ year
Battery Size	two 2400mhA batteries (typical)
Duty cycle	A few ~ dozen seconds

Back up: Restriction in Japanese 950MHz band

- Sending duration (packet length) is limited by transmit power, carrier sense time, pause duration and duty cycle
  - Extracted from ARIB STD-T96

Table 3.9 Possible combinations of sending control parameters and carrier sense time

Antenna power	Carrier sense time	Sending duration	Pause duration	The amount of sending time summed for 1 hour
1mW or less	10ms or more	1s or less(Note1)	100ms or more	Don't care
	128μs or more	100ms or less(Note2)	100ms or more	360s or less
	0	100ms or less(Note2)	100ms or more	3.6s or less
more than 1mW and less than or equal to 10mW	10ms or more	1s or less(Note1)	100ms or more	Don't care

Our MAC proposal

Optional MAC functions for low energy consumption

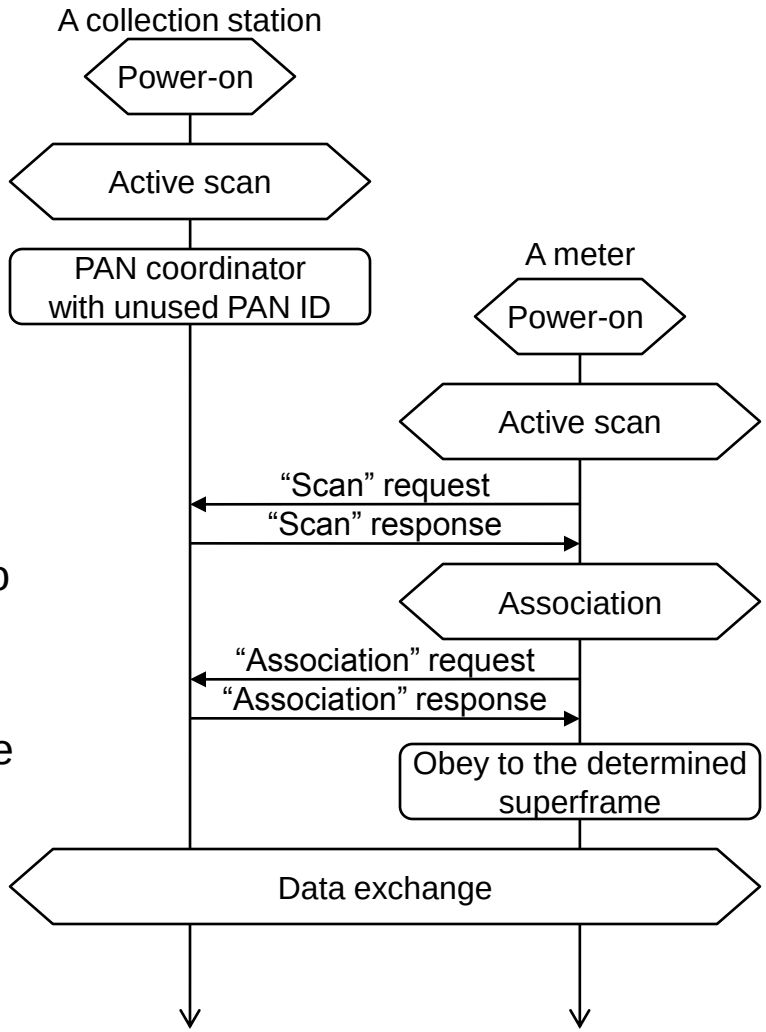
- Beacon-enabled PAN
  - Low energy superframe employment
    - Beacon turn off mode with active period
    - Intermittent hearing using CAP and receiving in the following inactive period
    - Tree topology with independent superframe determination
- Nonbeacon-enabled PAN
  - Data req. command/procedure modification for data communication in the mesh topology

MAC proposal details

for Beacon-enabled PAN

MAC specification (1): topology

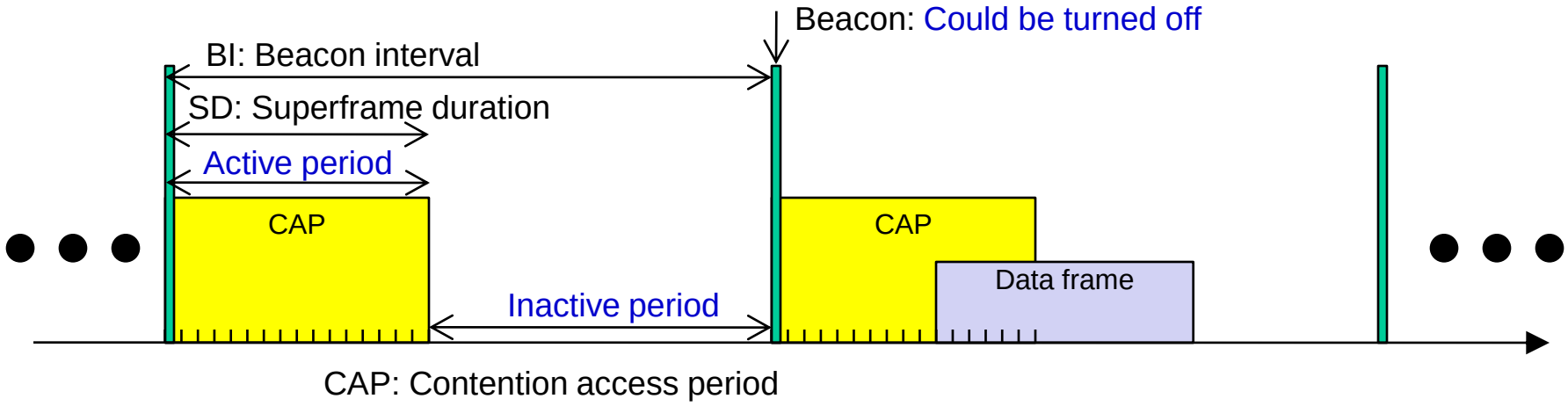
- Two types of devices as defined in 15.4MAC
  - FFD (Full function device) as collection station or meter that can determine superframe and accept association by other meters
  - RFD (Reduced function device) as meter
- After power-on
  - The collection station makes a PAN by determining PAN ID and superframe duration
  - A meter conducts active scan to find the collection station or meter that is FFD connected to the collection station, then tries to associate one of suitable FFD found
- After association
  - The associated FFD can return response to the active scan request by determining outgoing superframe
  - The associated FFD can further accept the association request by unassociated meters



MAC specification (2): superframe-1

Data receiving in the inactive period can improve low-power consumption performance

- FFD can determine superframe consists of an active period and an inactive period with/without a beacon and without any GTSs
- Turned-off beacons with active period
  - Collection stations only send beacon after receiving "scan" request. In other period, the collection stations does not transmit any beacon:
- Intermittent hearing only in active period
  - Active period consists of only CAP
  - Data frame shall start in active period and end in the beacon interval. If data frame is sensed in CAP, the destination device continues receiving till the frame end



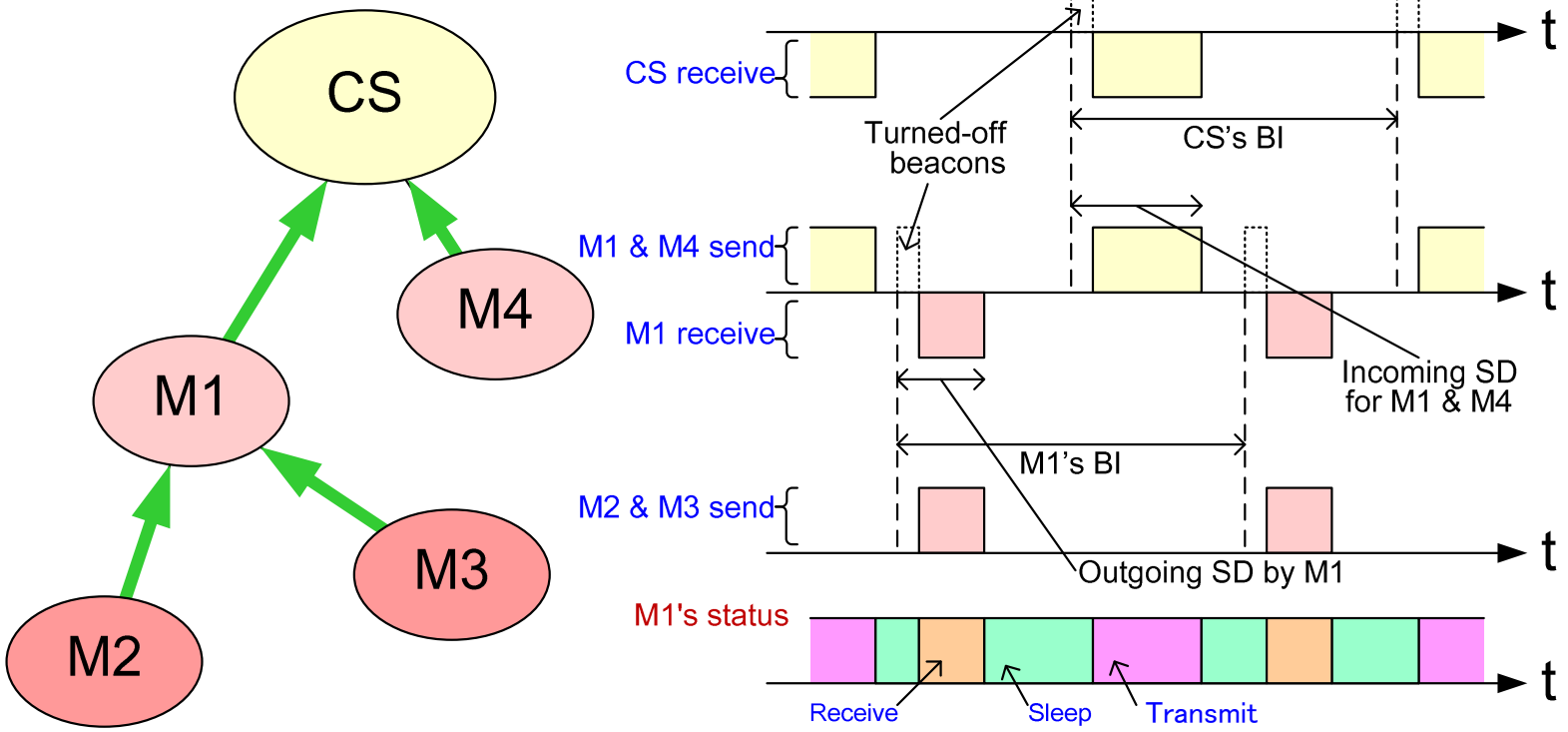
MAC specification (2): superframe-2

Collection station and meters construct tree-shaped topology where each device determines superframe with turning off beacon. In the figure below, device M1 is handling both incoming superframe by CS and outgoing superframe by M1 itself in order to conduct successful data relaying in such tree topology.

- 15.4MAC defines same BI and SD shall be employed in both incoming and outgoing superframe
- Assuming cluster -tree topology, different BI and SD might be suitable for incoming and outgoing superframe

CS: Collection station (First PAN coordinator)
Mn: Meter n (Coordinator or device)

BI: Beacon interval, SD: Superframe duration



MAC specification (3): frames

15.4MAC frames are used with suitable modification

- Beacon frame: Might include superframe configuration information
- Command frames
  - Association req./res.
  - Diassociation notification
  - Data req.
  - PAN ID conflict notification
  - Orphan notification
  - Beacon request (for “scan” request)
  - Coordinator realignment
  - GTS req.
- Data frame
- ACK frame

MAC specification (4): functions

15.4MAC functions are used with suitable modification

- Channel access: Needs to be modified
  - Replies to the following type active scan need to include indications of low-power mode employment and independent superframe configuration
    - Active channel scan by beacon request command, replied by beacon
    - Orphan channel scan by orphan notification command, replied by coordinator realignment command
- Start and maintain PAN: : Needs to be modified
  - Beacon frame needs to include the superframe indications of low-power mode employment and independent superframe formation
- Association and disassociation
- Synchronization
- Transaction
- Transmission and reception
- (GTS(Guaranteed time slot) allocation)
- (Security)

15.4MAC advantage on multi-hop transmission for meter reading (Beacon-enable)

Assumed MAC can successfully provide multi-hop transmission as for meter reading utility by exploiting the following features

1. Autonomous topology construction by the association functions that can cope with situation of meter addition and removal
2. Autonomous data collection based on the tree topology
3. Sleeping period employment according to the inactive period configuration in each superframe

Proposal on required changes for EGTS extension

Summary of required change proposal

1. One optional MAC PIB attribute addition required
2. Suitable explanations that clarify new and optional superframe definitions are required according to the MAC PIB attribute
3. No other additional frame types, command frames and procedures

Revision(1/4):MAC PIB attribute

- The following row will be inserted in the bottom of Table 86

Attribute	Identifer	Type	Range	Description	Default
macLowEnergySuperframeSupported	TBD	Boolean	TRUE/ FALSE	Indication of whether the low energy superframe is operational or not. If this attribute is TRUE, the coordinator shall not transmit beacon frames regardless of BO value. This attribute shall be set to FALSE if the device is aware of the existence of allocated GTS or EGTS in its two-hop neighborhood.	Implementation specific

Revision(2/4):Superframe definition

- The following modifications are added in subsections 7.5.1.1.

- 7.5.1.1. Superframe structure: *add the following modification*
- *(Second paragraph)* If BO = 15 **and macLowEnergySuperframeSupported is FALSE,** the coordinator shall not transmit beacon frames except when requested to do so, such as on receipt of a beacon request command. The value of macSuperframeOrder shall be ignored if BO = 15**. Moreover, if macLowEnergySuperframeSupported is TRUE the coordinator shall not transmit beacon frames except when requested to do so, regardless of BO value.**
- *(Third paragraph)* If BO = 15 **and macLowEnergySuperframeSupported is FALSE,** the superframe shall not exist (the value of macSuperframeOrder shall be ignored),

Revision(3/4):CAP

- The following modifications are added in subsections 7.5.1.1.1.

- 7.5.1.1.1. Contention access period (CAP) : *modify as following*
- *(Second paragraph)* All frames, except acknowledgment frames and any data frame that quickly follows the acknowledgment of a data request command (see 7.5.6.3), transmitted in the CAP shall use a slotted CSMA-CA mechanism to access the channel. A device transmitting within the CAP shall ensure that its transaction is complete (i.e., including the reception of any acknowledgment) one IFS period (see 7.5.1.3) before the end of the CAP **when macLowEnergySuperframeSupported is FALSE**. If this is not possible, the device shall defer its transmission until the CAP of the following superframe. **When macLowEnergySuperframeSupported is TRUE, on the other hand, transaction shall been sured to be completed one IFS period before the end of the inactive period. Finally, if a device senses frame in CAP that does not end within CAP when macLowEnergySuperframeSupported is TRUE, the device may continue receiving the frame until it ends before the end of the inactive period. When macLowEnergySuperframeSupported is TRUE, the coordinator shall not locate GTSs in order to avoid the interference from the frames in CAP. When macLowEnergySuperframeSupported is TRUE, the coordinator shall notify the devices that already associated or intend to associate the condition of macLowEnergySuperframeSupported in the beacon frames.**

Revision(4/4):Incoming and outgoing superframe timing

- The following modifications are added in subsections 7.5.1.2.
- 7.5.1.2 Incoming and outgoing superframe timing: *modify as following*
- *(Second paragraph)* The beacon order and superframe order ~~**shall**~~ **may** be equal for all superframes on a PAN. All devices ~~**shall**~~ **may** interact with the PAN only during the active portion of a superframe.

Conclusions

- Optional low energy superframe employment for beacon enabled PAN works effectively to realize low energy consumption performance for systems such as TG4g related smart utility networks(SUN)
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    - macLowEnergySuperframeSupported