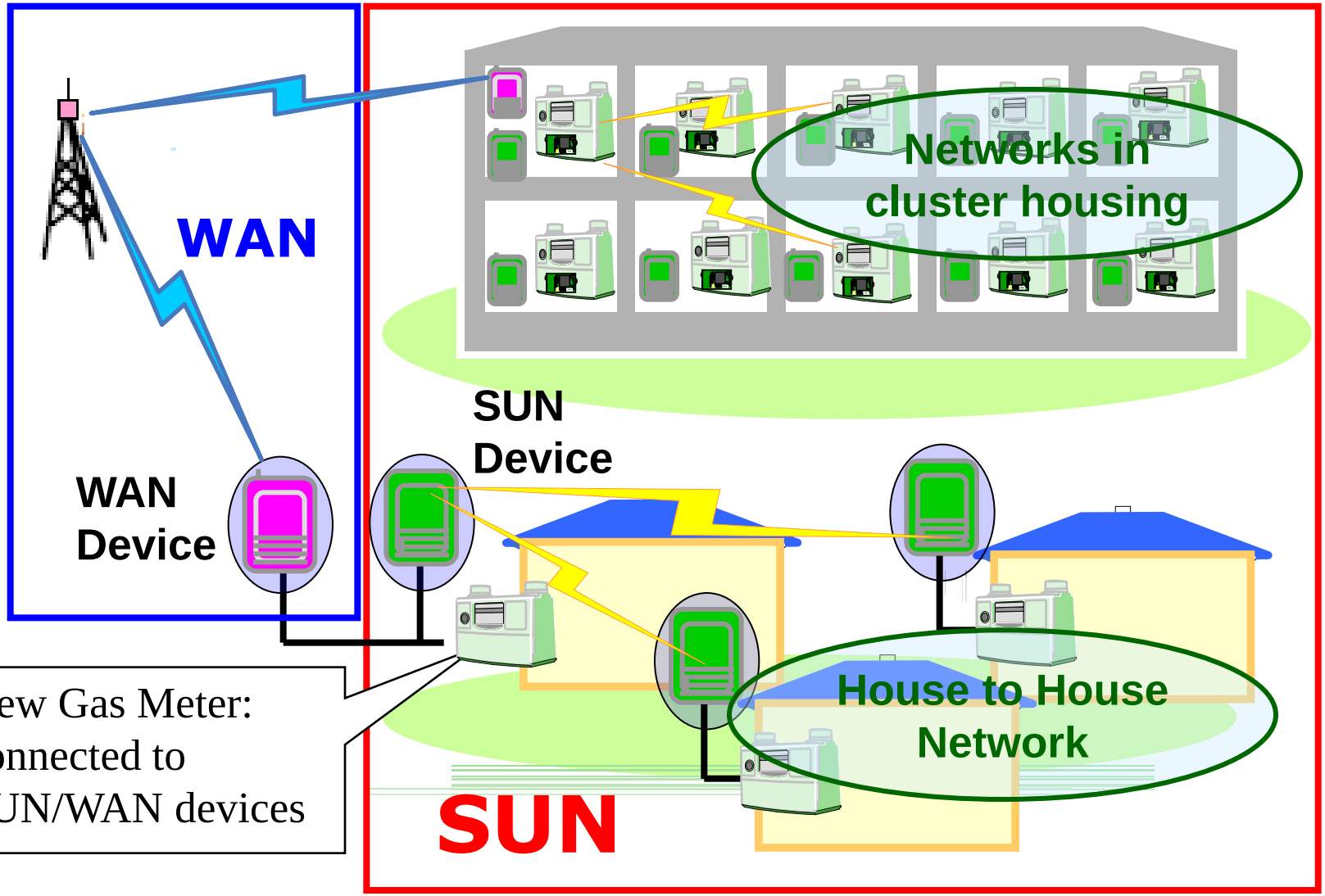
Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [MAC Proposals for low-power consumption]
Date Submitted: []
Source: [Fumihide Kojima[1], Hiroshi Harada[1], Takaaki Hatauchi[2], Minoru Tanabe[3], Kentaro Sakamoto[4], Aiichiro Kashiwagi[5], Takahiro Banno[6], Hirohito Nishiyama[7]]
Company [[1]NICT, [2]Fuji Electric, [3]Panasonic, [4]Tokyo Gas, [5]Osaka Gas, [6]Toho Gas, [7]Mitsubishi Electric Corp.]
Address [[1]3-4, Hikari-no-oka,Yokosuka-shi,Kanagawa239-0847,Japan]
Voice:[[1]+81-46-847-5074]
FAX: [[1]+81-46-847-5440]
E-Mail:[f-kojima@nict.go.jp, harada@nict.go.jp]
Re: [In response to TG4g Call for Proposals]
Abstract: [Proposal of PHY and MAC for low-power consumption SUN]

Summary

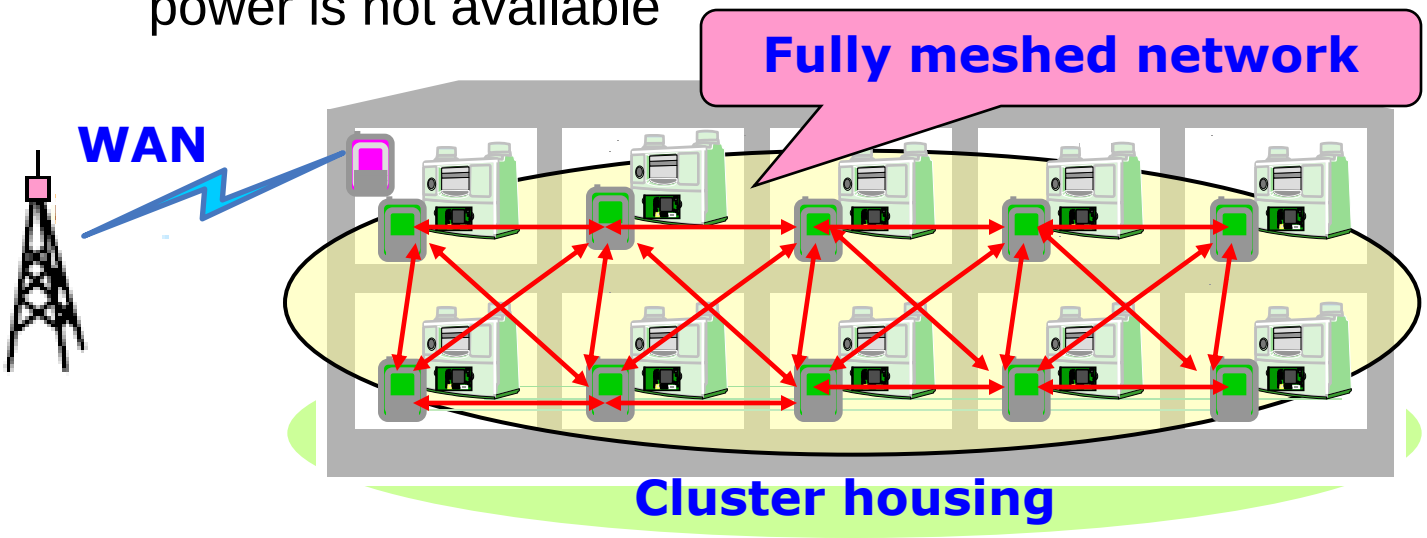
- Confirmation of proposal on the following PHY and MAC
  - PHY: modification from 15.4 to support low-power multi-hop transmission for meter reading utility
    - 950MHz, 400MHz and lower frequency for simple single carrier transmission
    - 200kHz channel spacing assuming two carrier bundling to support 400kHz signal bandwidth
    - 50kbps(2GFSK), 100kbps(2GFSK), 200kbps(2GFSK; Option), 400kbps(4GFSK; Option)
    - No SS option
  - MAC: modification and addition of functions on the basis of 15.4MAC
    - 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
    - Nonbeacon-enabled PAN
      - Data req. command/procedure modification for data communication in the mesh topology

System Concept



Typical application

- Utility meter reading
  - Fully meshed network topology
    - All devices in the network are coordinators
      - having routing function
    - Reliable communication by route diversity
  - 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

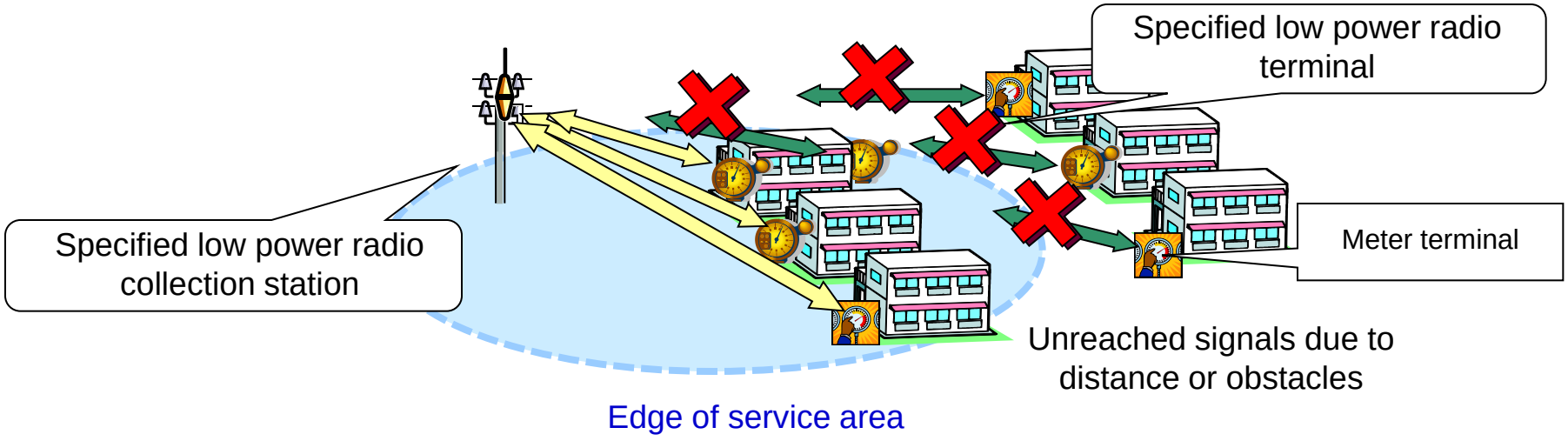
Antenna power	Carrier sense time	Sending duration	Pause duration	The amount of sending time summed for 1 hour
1mW or less	10ms or more	1s or less(Note1)	100ms or more	Don't care
	128μs or more	100ms or less(Note2)	100ms or more	360s or less
	0	100ms or less(Note2)	100ms or more	3.6s or less
more than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

System image of the assumed specified low power radio system

Automatic meter for gas, electricity and water is considered one of very attractive usage of specified low power radio on 400MHz band that realizes rational management and advanced customer services, while the following issues are considered before practice and diffusion.

Issues to be considered

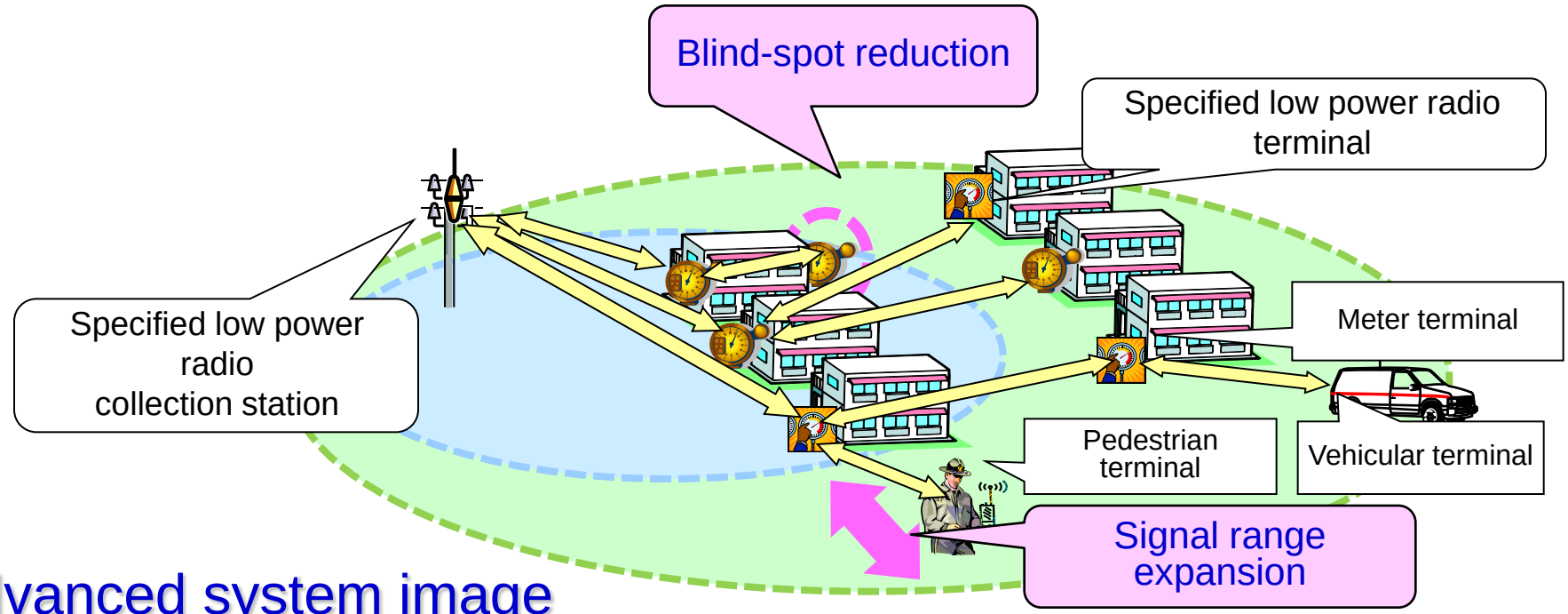
- Small transmission power restricts the service area
- Advanced transmission scheme is required with coexistence with the other systems
- Battery lifetime is required to be improved for radio terminals



Improvement by multi-hop transmission employment

Multi-hop transmission enables service area expansion by the following functions

- Signal range expansion
- Blind-spot reduction



Advanced system image

Our proposal

- PHY: modification from 15.4 to support low-power multi-hop transmission for meter reading utility
  - 400MHz and lower frequency band
  - Up to 300kHz bandwidth for simple single carrier transmission without complexity of higher level modulation such as 16QAM
- MAC: modification and addition of functions on the basis of 15.4MAC to cope with the modified PHY and multi-hop transmission
  - 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
  - Nonbeacon-enabled PAN
    - Data req. command/procedure modification for data communication in the mesh topology

Summary of Proposed PHY and MAC

Center frequency band	950MHz, 400MHz and lower
Channel spacing	200kHz
Spread spectrum	Non-SS mode as optional case
Transmission power	Max 10dBm (antenna input power)
Modulation scheme	2GFSK, 4GFSK
FEC	TBD including Non-FEC mode
Signal bandwidth	100kHz– 400 kHz to support from 50kbps-2GFSK to 400kbps-4GFSK
Data rate (PHY SAP)	50kbps, 100kbps, 200kbps(Option), 400kbps(Option)
MAC scheme	CSMA/CA with sleeping period based on 15.4MAC
Routing scheme	Based on autonomous TREE topology construction
Transmission range	Up tp 150 m @ bandwidth of 150kHz

This proposal is decided on the basis of the following evaluation details of which are depicted in 09/0312r3

- Measurement of propagation characteristic
- Computer simulation
- Evaluation by experimental prototype
- Evaluation by pre-commercialized prototypes that achieve
  - 2.7Ah/3years performance: beacon-enabled PAN
  - 4.4Ah/10years performance: non-beacon enabled PAN (transmit/receive 2000 packets/year)

PHY proposal

- PHY: modification from 15.4 to support low-power multi-hop transmission for meter reading utility
  - 950MHz, 400MHz and lower frequency for simple single carrier transmission
  - 200kHz channel spacing assuming two carrier bundling to support 400kHz signal bandwidth
  - 50kbps(2GFSK), 100kbps(2GFSK), 200kbps(2GFSK; Option), 400kbps(4GFSK; Option)
  - No SS option

PHY parameters

- 400MHz band allocation
  - Channel spacing: 200kHz
  - Channel number: 4~5(w/o bundling), 3~4(w/ bundling)
  - Modulation: 2GFSK, 4GFSK
  - Data rate: 50kbps, 100kbps, 200kpbs, 400kbps

- 950MHz band allocation
  - Channel spacing: 200kHz
  - Channel number: 24(w/o bundling), 23(w/ bundling)
  - Modulation: 2GFSK, 4GFSK
  - Data rate: 50kbps, 100kbps, 200kpbs, 400kbps

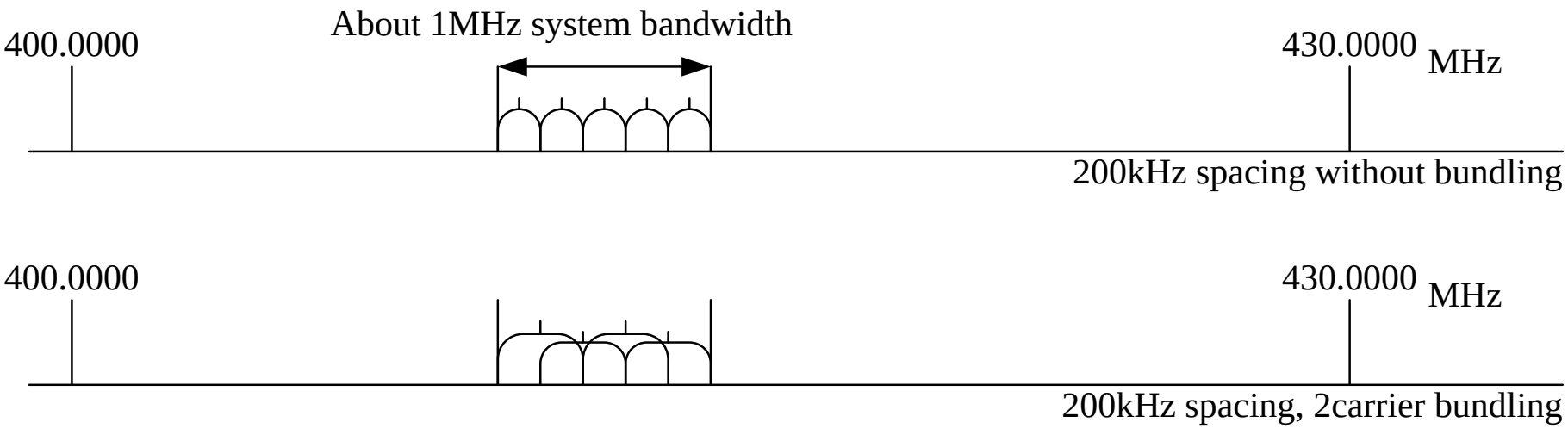
400MHz band utilization

	Low	Mid (Default)	High1 (option 1)	High2 (option 2)
Data rate	50 kbps	100 kbps	200 kbps	400 kbps
Channel Spacing	200 kHz	200 kHz	200 kHz /w two carrier bundling (signal bandwidth is 400kHz)	200 kHz /w two carrier bundling (signal bandwidth is 400kHz)
Number of Channels	4~5	4~5	2(+1)~2(+2)	2(+1)~2(+2)
Modulation Technique	GFSK	GFSK	GFSK	4GFSK
Modulation Index	1.0 (+/- 25 kHz)	1.0 (+/-50 kHz)	1.0 (+/- 100 kHz)	TBD e.g. 50 kHz freq sep (-150, -50, +50, +150 kHz)
BT	0.5	0.5	0.5	0.5

- Japan allocation for the 15.4g on 400MHz:
  - **About 1MHz-system-bandwidth out of 400.0MHz~430.0MHz band** is under consideration that accommodates 5 of 200kHz spacing carriers
- Japan allocation for the conventional specified low power radio:
  - 426.0250 and 426.1375 MHz, 1mW (0dBm)
  - 429.1750 and 429.7375 MHz, 10mW (+10dBm)
  - 429.8125 and 429.9250 MHz, 10mW (+10dBm)
  - 449.7125 and 449.8875 MHz, 10mW (+10dBm)
  - 469.4375 and 469.4875 MHz, 10mW (+10dBm)

Channel allocation on 400MHz

- 200kHz spacing assuming up to two carrier bundling that supports 400kHz signal bandwidth



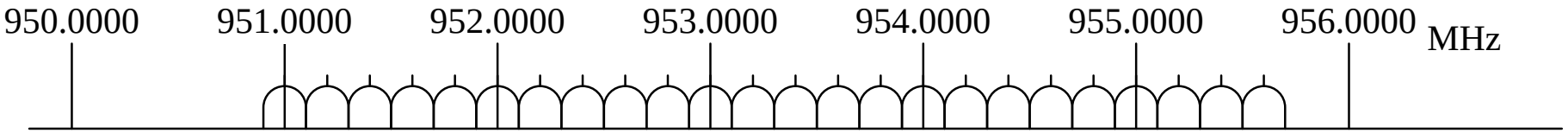
950MHz band utilization

	Low	Mid (Default)	High (option 1)	High (option 2)
Data rate	50 kbps	100 kbps	200 kbps	400 kbps
Channel Spacing	200 kHz	200 kHz	200 kHz /w two carrier bundling (signal bandwidth is 400kHz)	200 kHz /w two carrier bundling (signal bandwidth is 400kHz)
Number of Channels	24	24	12 (+11)	12 (+11)
Modulation Technique	GFSK	GFSK	GFSK	4GFSK
Modulation Index	1.0 (+/- 25 kHz)	1.0 (+/-50 kHz)	1.0 (+/- 100 kHz)	TBD e.g. 50 kHz freq sep (-150, -50, +50, +150 kHz)
BT	0.5	0.5	0.5	0.5

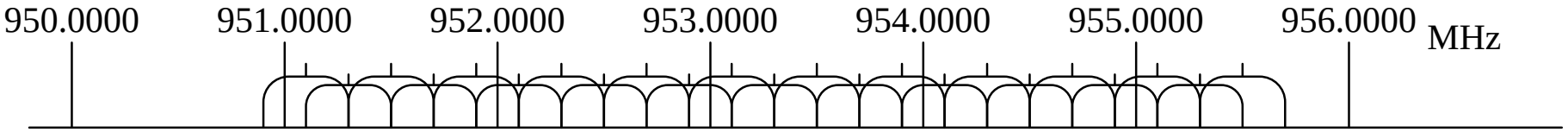
- Japan allocation that copes with the proposal
  - 950.9-955.7MHz

Channel allocation on 950MHz

- 200kHz spacing assuming up to two carrier bundling that supports 400kHz signal bandwidth

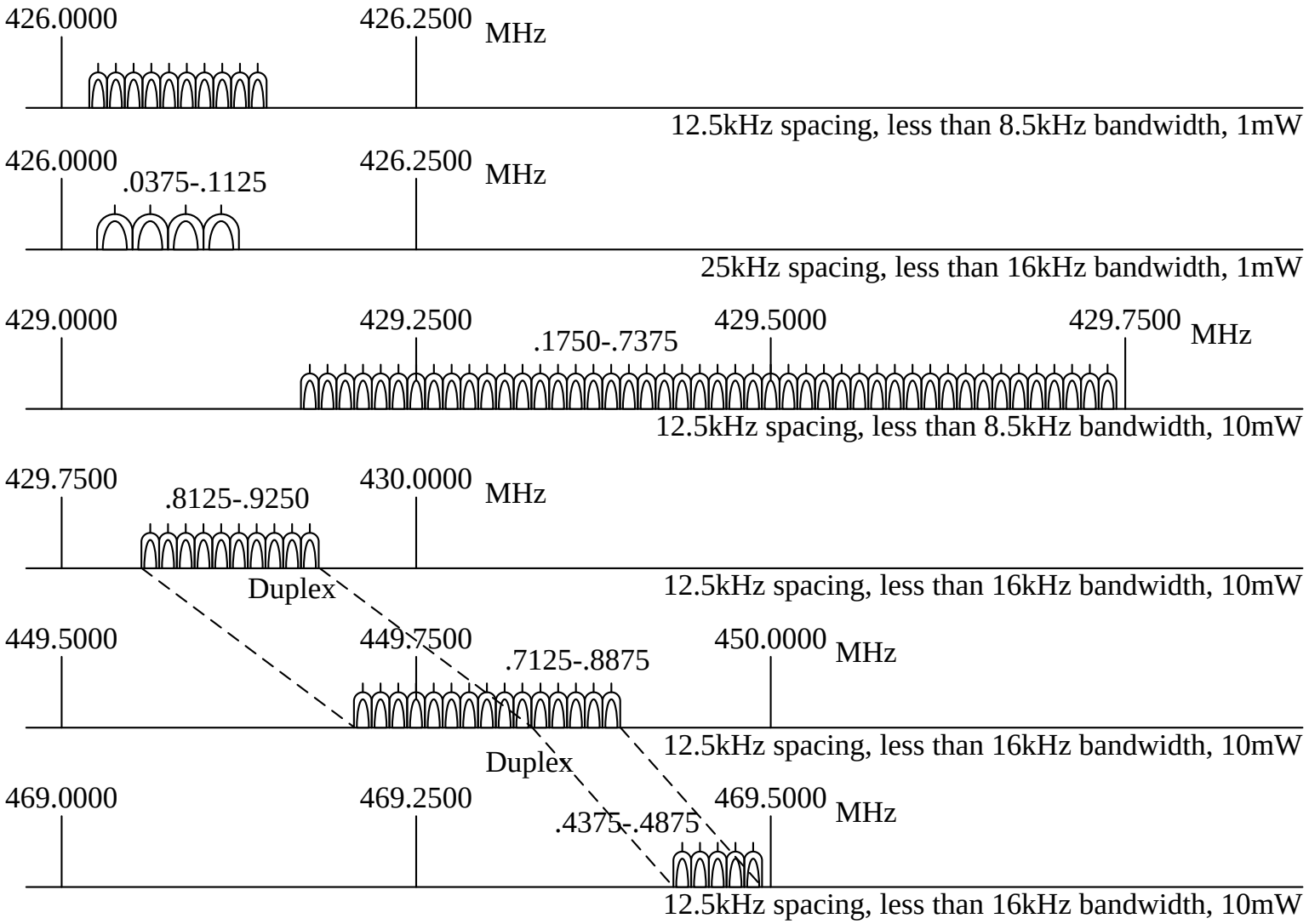


200kHz spacing without bundling



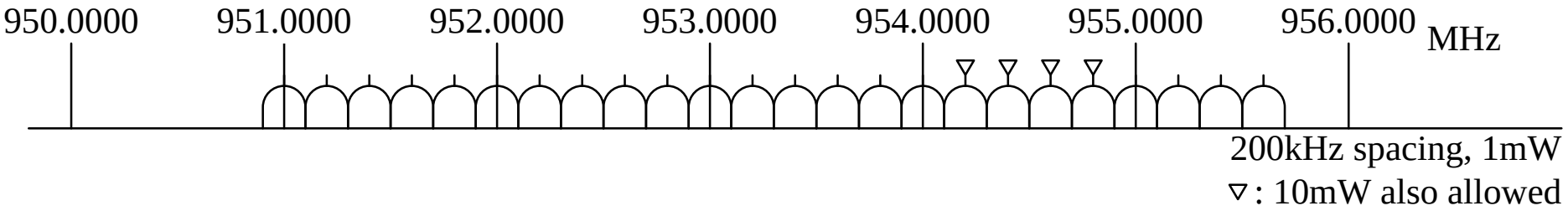
200kHz spacing, 2carrier bundling

Backup1: Japan allocation for specified low power radio on 400MHz

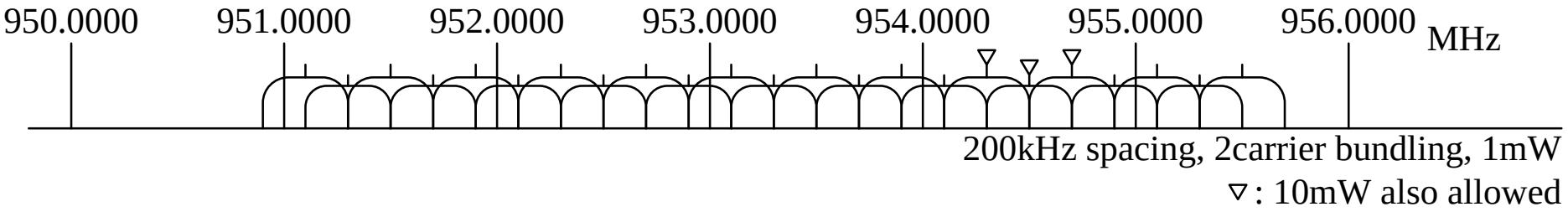


Backup2: Japan allocation for specified low power radio on 950MHz

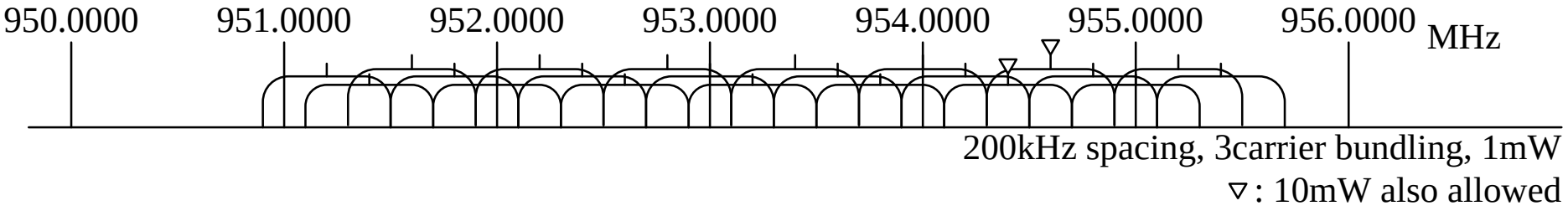
- 200kHz spacing assuming up to three bundling
- No signal bandwidth restriction
- Transmission power restriction of 10mW



200kHz spacing, 1mW
▽: 10mW also allowed



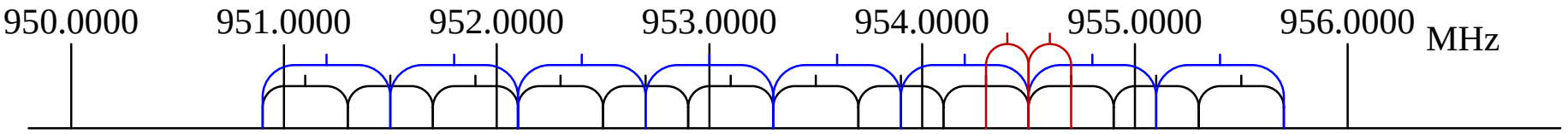
200kHz spacing, 2carrier bundling, 1mW
▽: 10mW also allowed



200kHz spacing, 3carrier bundling, 1mW
▽: 10mW also allowed

Backup3: Allocation for 15.4d on 950MHz

- 200kHz spacing assuming up to three carrier bundling that supports 400kHz signal bandwidth



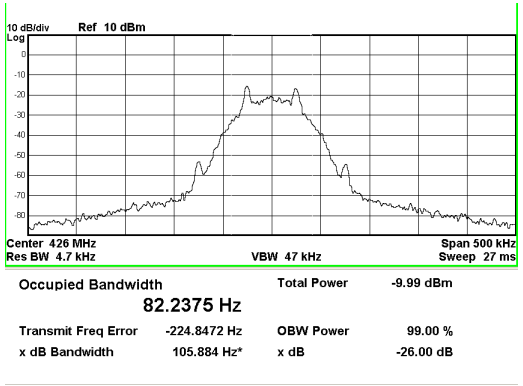
GFSK:400kHz spacing, 1or10mW

BPSK:600kHz spacing, 1mW

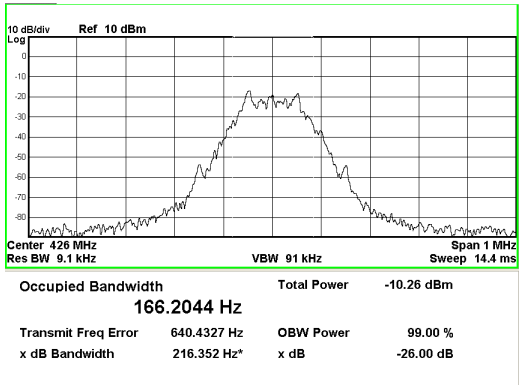
BPSK:200kHz spacing, 10mW

Backup4: GFSK signals

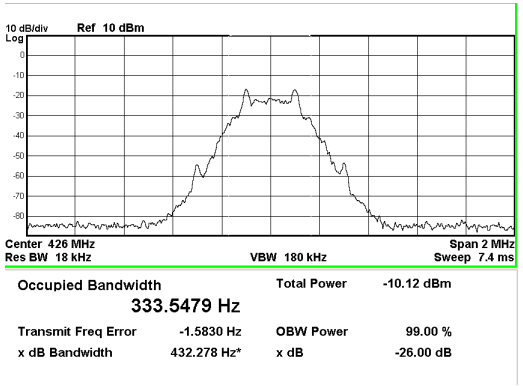
- 50kbpsGFSK
- Frequency deviation: 25kHz
- BT:0.5
- Signal bandwidth: 82.3kHz



- 100kbpsGFSK
- Frequency deviation: 50kHz
- BT:0.5
- Signal bandwidth: 166.3kHz



- 200kbpsGFSK
- Frequency deviation: 100kHz
- BT:0.5
- Signal bandwidth: 333.6kHz



MAC proposal

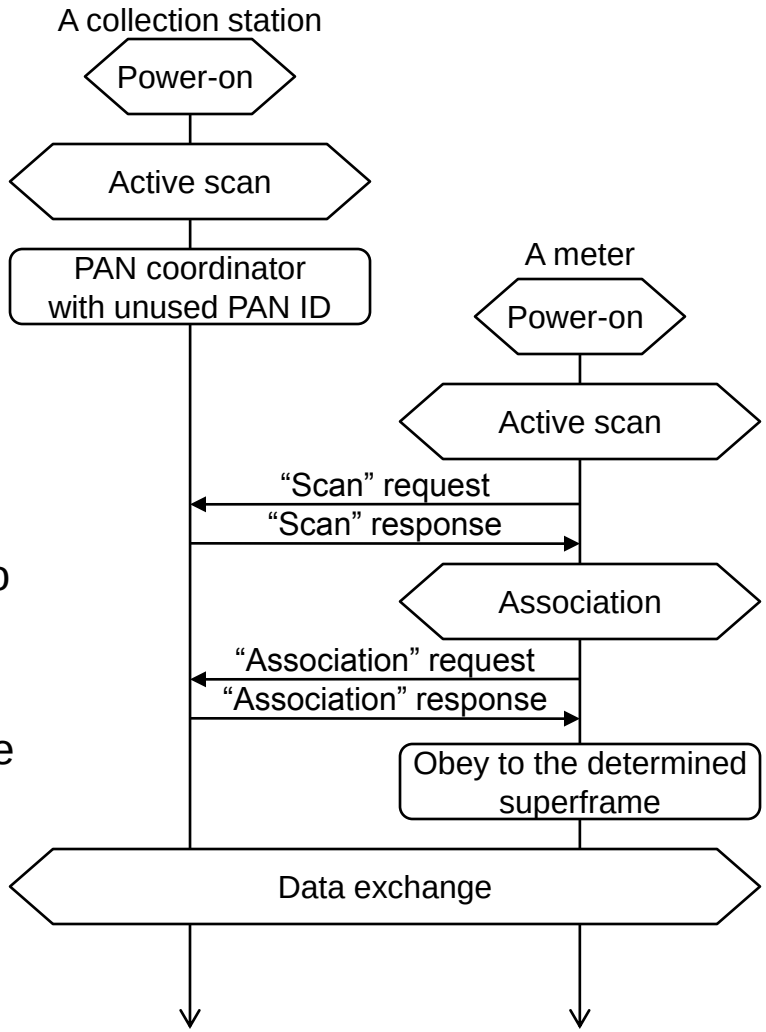
- MAC: modification and addition of functions on the basis of 15.4MAC
  - Beacon-enabled PAN
    - Beacon turn off mode with active period
    - Intermittent hearing using CAP and receiving in the following inactive period
    - Tree topology with independent superframe determination
  - Nonbeacon-enabled PAN
    - Data req. command/procedure modification for data communication in the mesh topology

MAC proposal

- Beacon-enabled PAN

MAC specification (1): topology

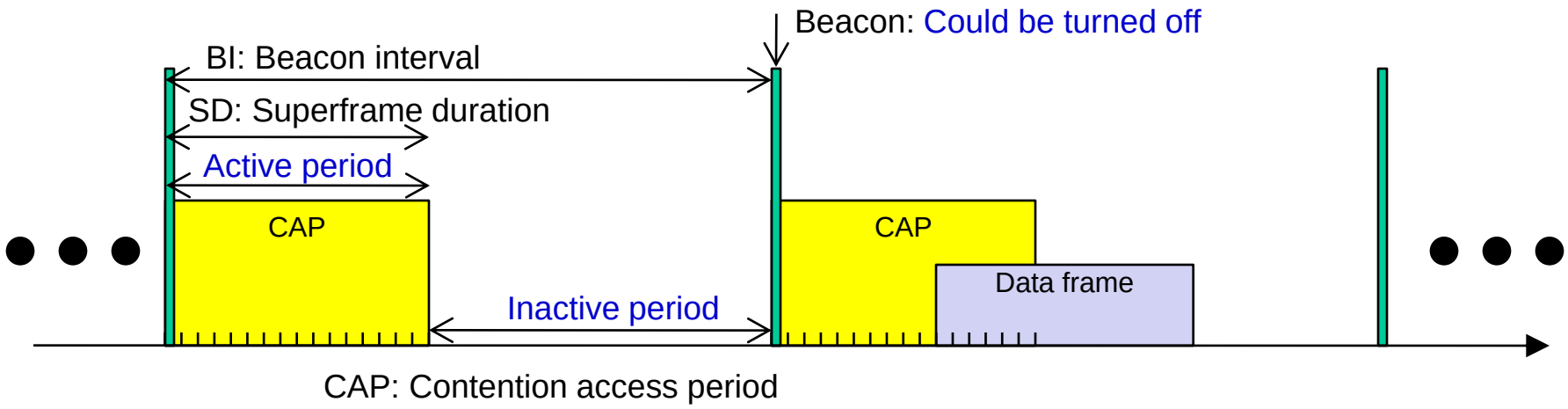
- Two types of devices as defined in 15.4MAC
  - FFD (Full function device) as collection station or meter that can determine superframe and accept association by other meters
  - RFD (Reduced function device) as meter
- After power-on
  - The collection station makes a PAN by determining PAN ID and 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
- 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



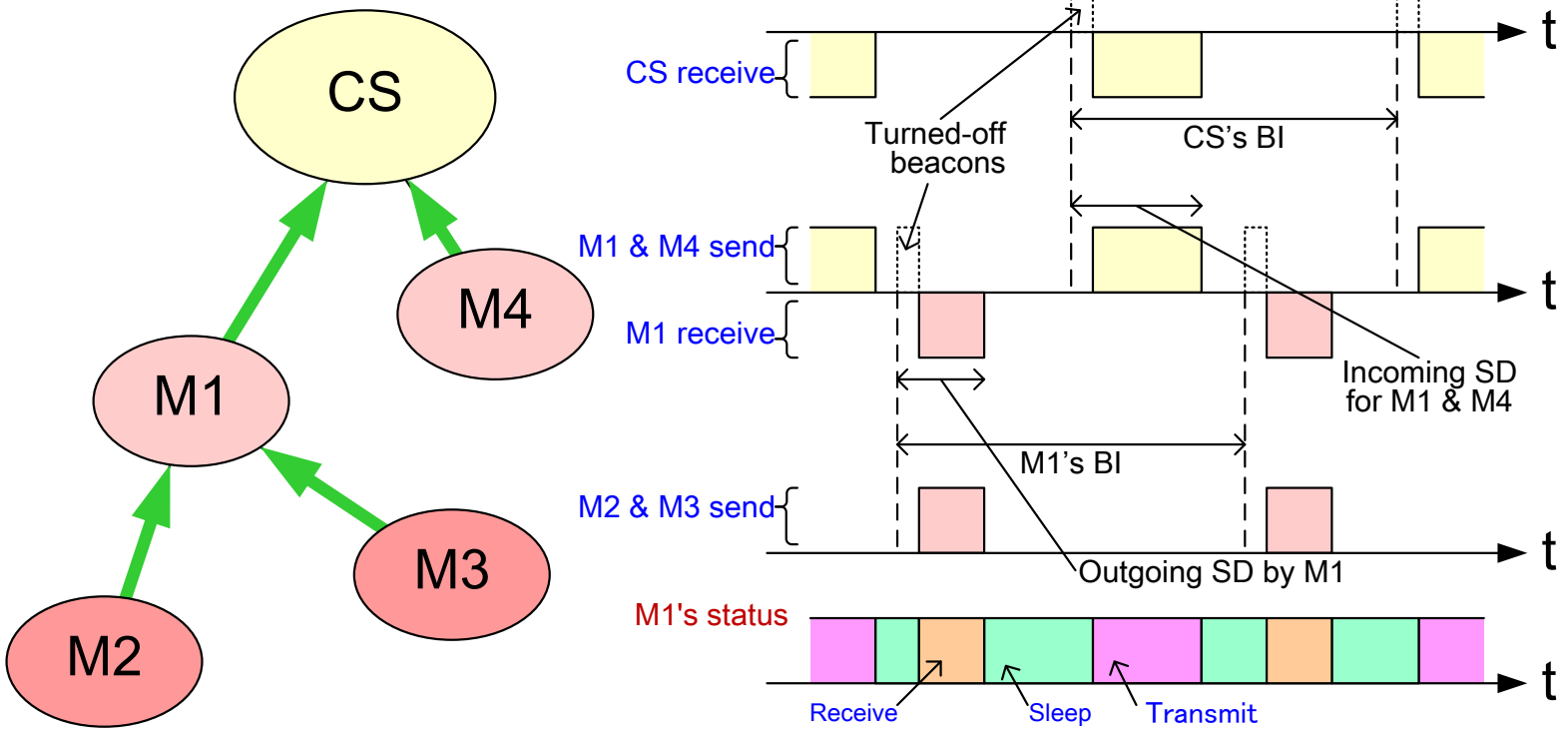
MAC specification (2): superframe-2

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: Might include superframe configuration information
  - 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)

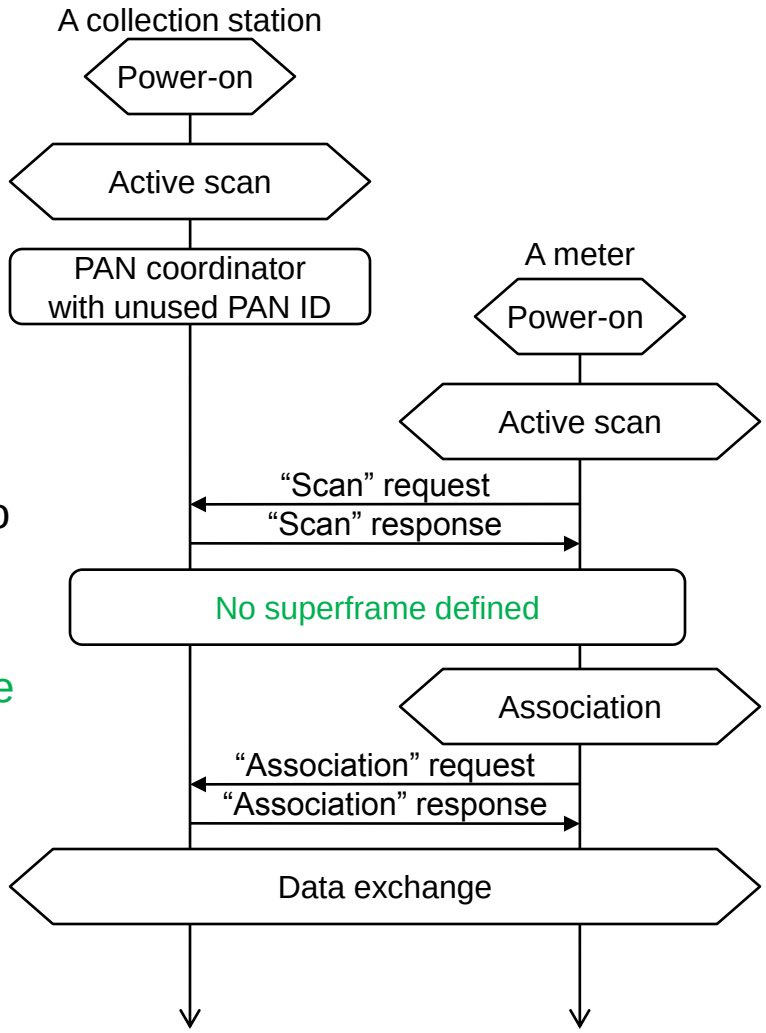
Assumed MAC can successfully provide multi-hop transmission as for meter reading utility by exploiting the following features

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

MAC proposal
- Non-beacon enabled PAN

MAC specification (Nonbeacon-1): topology

- FFD devices as defined in 15.4MAC
  - FFD as both collection station and meter that can accept association without superframe
- After power-on
  - The collection station makes a PAN by determining PAN ID denoting nonbeacon-enabled PAN
  - 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 without superframe
  - The associated FFD can further accept the association request by unassociated meters

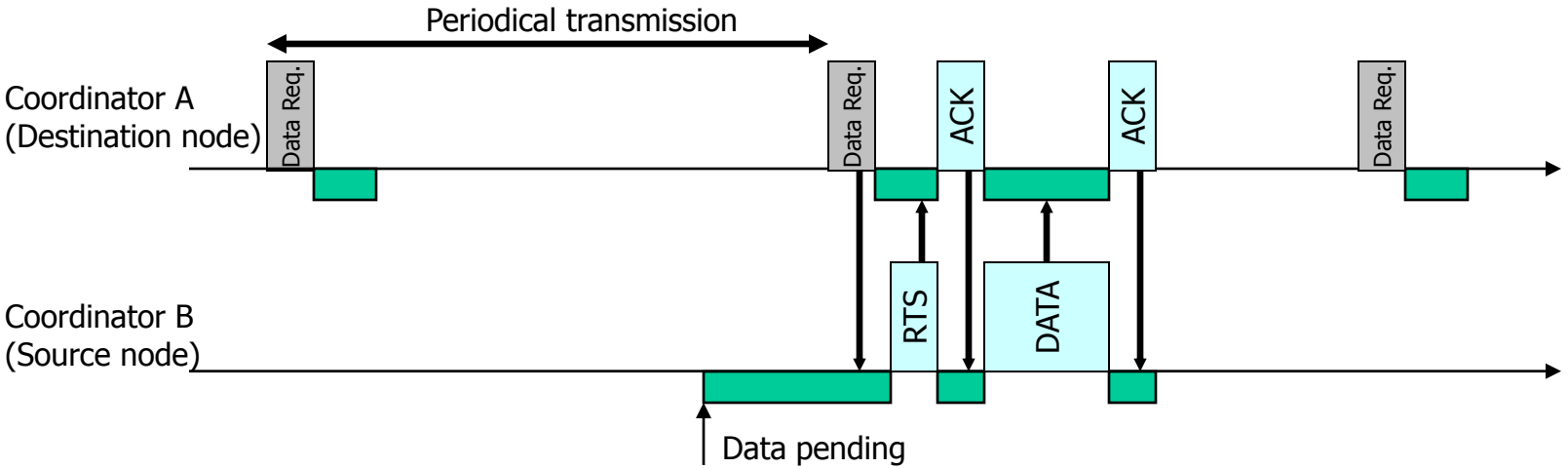


MAC specification (Nonbeacon-2): superframe

- No superframe is defined

MAC specification (Nonbeacon-2): channel access

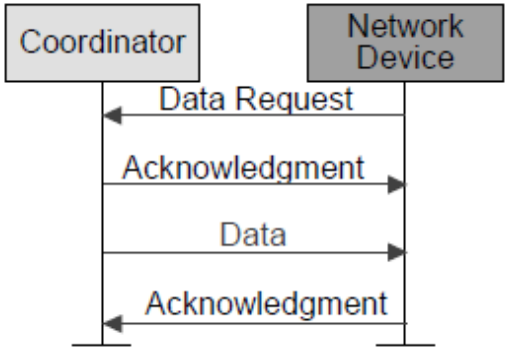
- Based on “Receiver-Initiated CyclEd Receiver” scheme
  - En-Yi A. Lin, et al, “Receiver Initiated Rendezvous Schemes for Sensor Networks”, IEEE Globecom 2005
  - Well-suited for low duty cycle, intermittent operation with relatively low traffic

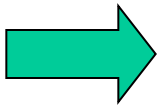


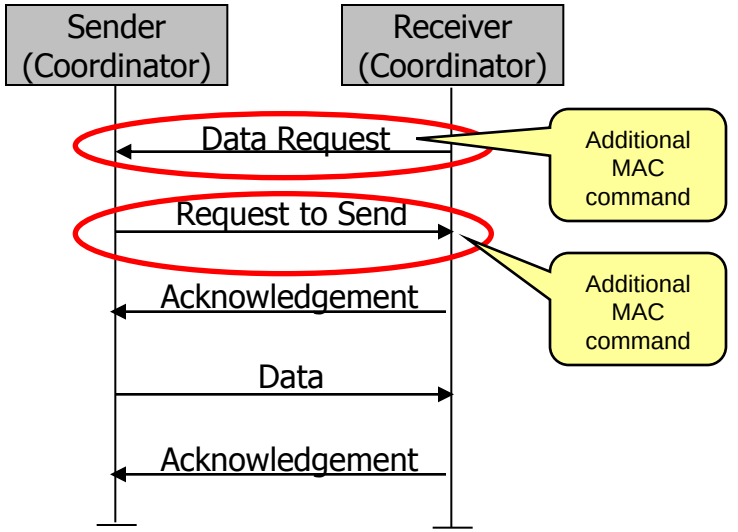
- All nodes periodically wake up, transmit Data Request command, go into receive mode for a short period of time and go back to sleep, asynchronously
- When the transmission request is generated from higher layer, it enables the receiver and waits for Data Request command from the destination device
- Upon reception of a Data Request command, the source node establishes a link with the destination node and transmits Data

MAC specification (Nonbeacon-3): data transfer

- Modification from the current non-beacon enabled PAN
  - Addition of “Request-to-Send” command in reply to Data Request
    - ACK is required before Data frame to be transmitted
    - Better support of the Receiver initiated scheme







Data transfer for non-beacon enabled PAN (from coordinator)

MAC specification (Nonbeacon-4): frames

15.4MAC frames are used with suitable modification in Data req. command frame

- Beacon frame
- Command frames
  - Association req./res.
  - Diassociation notification
  - Data req.: used for data transmission in the mesh topology
  - PAN ID conflict notification
  - Orphan notification
  - Beacon request (for “scan” request)
  - Coordinator realignment
  - GTS req.
- Data frame: available for necessary control sequence exchange the Receiver initiated scheme
- ACK frame

MAC specification (Nonbeacon-5): functions

15.4MAC functions are used with suitable modification

- Channel access
- Start and maintain PAN
- Association and disassociation
- Synchronization
- Transaction
- Transmission and reception: supports data exchange in the mesh topology
- (GTS(Guaranteed time slot) allocation)
- (Security)

15.4MAC advantage on multi-hop transmission for meter reading (non-beacon enabled)

Assumed MAC can successfully provide multi-hop transmission as for meter reading utility by exploiting the suitable routing algorithm on the upper layer controls as following

- Tree-topology
- AODV
- Other routing algorithm

MAC PIB attributes addition to realize the proposed MAC

Five MAC PIB attributes enable the proposed low energy MAC

MAC PIB attribute	Description
• macLowEnergySuperframeSupported	Enables intermittent hearing in CAP with turned-off beacon
• ritPeriod • ritDataWaitPeriod	Enable receiver initiated transmission (RIT)
• sslUseWakeUpSequence • sslSampleTiming • sslRemainRxEnablePeriod	Enable advanced functions of sample listening

Conclusions

- Confirmation of proposal on the following PHY and MAC
  - PHY: modification from 15.4 to support low-power multi-hop transmission for meter reading utility
    - 950MHz, 400MHz and lower frequency for simple single carrier transmission
    - 200kHz channel spacing assuming two carrier bundling to support 400kHz signal bandwidth
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    - Beacon-enabled PAN
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