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

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

Summary

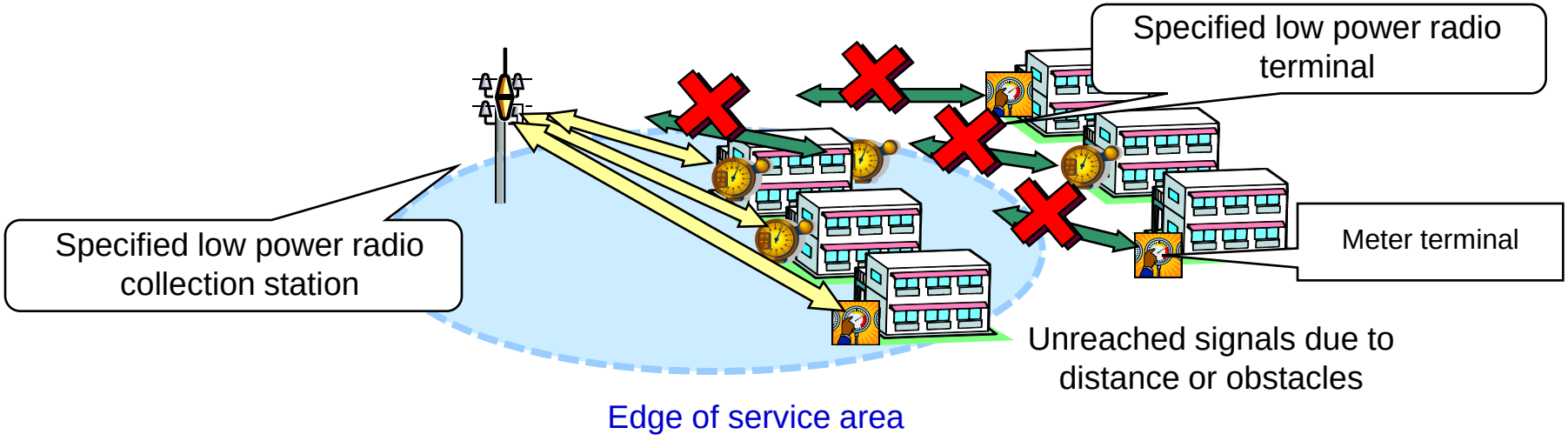
- Propose the following PHY and MAC
  - PHY: modification from 15.4 to support low-power multi-hop transmission for meter reading utility
    - 400MHz and lower frequency band up to 300kHz bandwidth for simple single carrier transmission
  - MAC: modification and addition of functions on the basis of 15.4MAC
    - Beacon turn off mode with active period
    - Intermittent hearing using CAP and receiving in the following inactive period
    - Cluster-tree topology with independent superframe determination
- Introduce the environment of experimental study and computer simulations and the results of power consumption by small low power terminal
  - 2.7Ah/3years performance

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

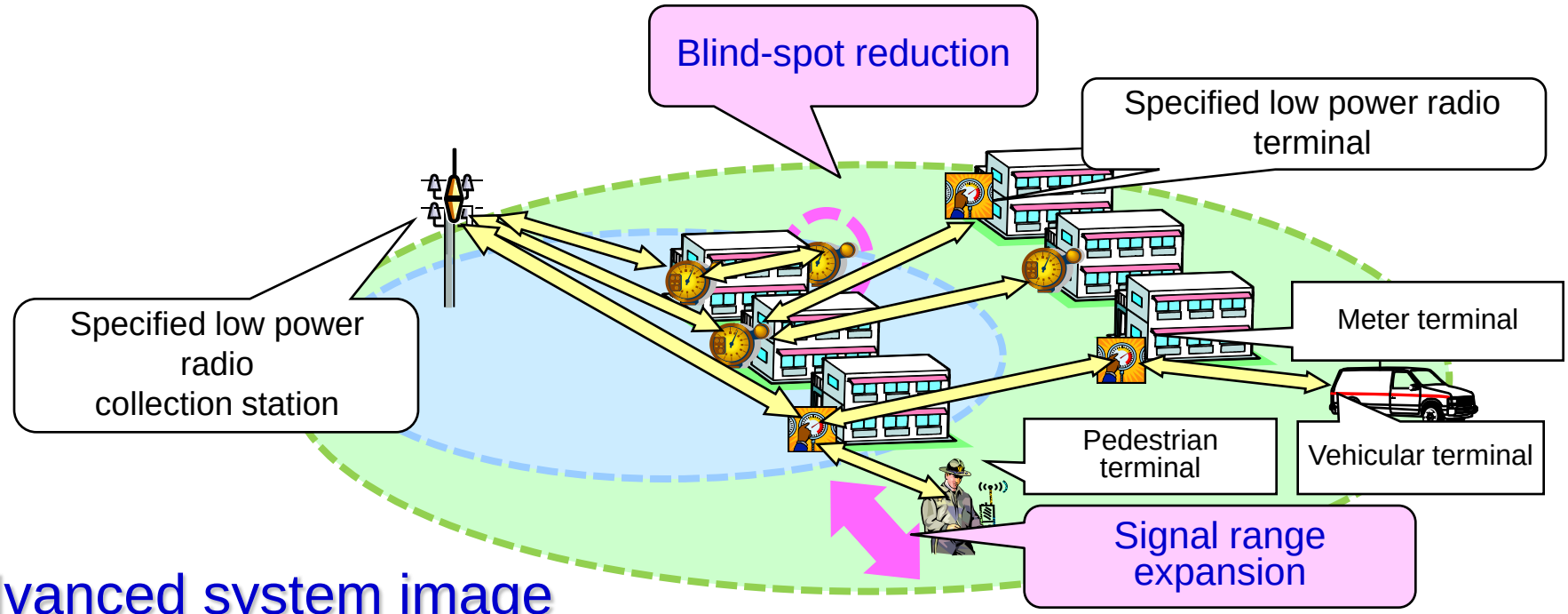
- Small transmission power restricts the service area
- Advanced transmission scheme is required with coexistence with the other systems
- Battery lifetime is required to be improved for radio terminals



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 turn off mode with active period
  - Intermittent hearing using CAP in active period and receiving in the following inactive period
  - Cluster tree topology construction with independent superframe determination

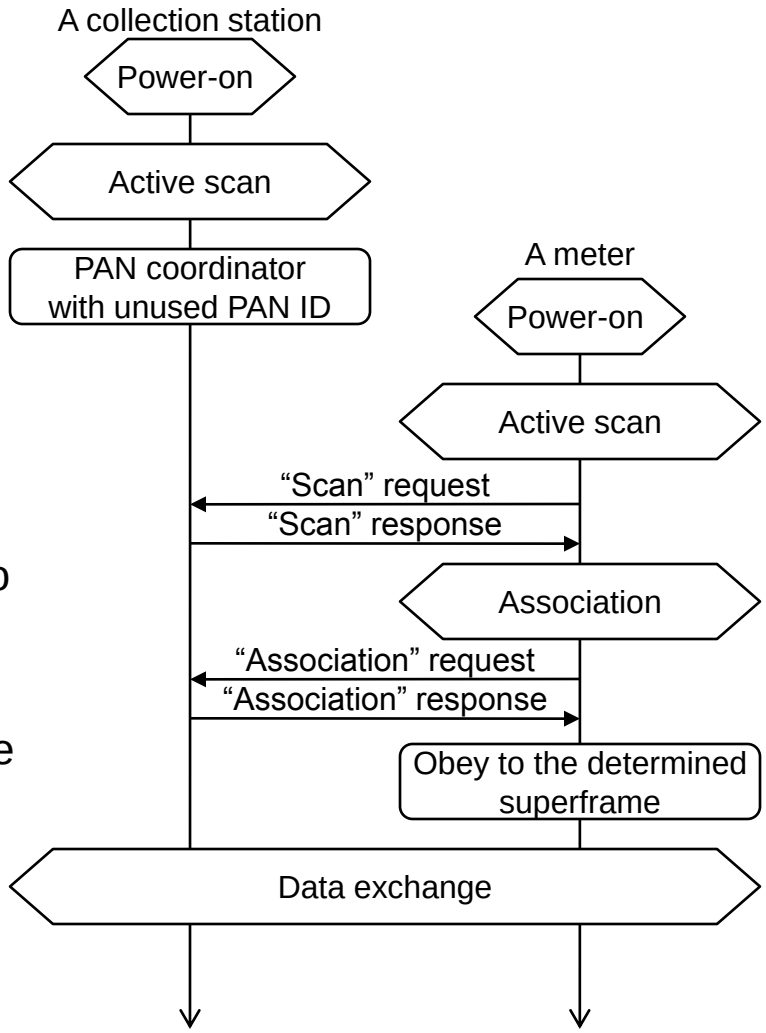
Proposed PHY and MAC

Center frequency band	400 MHz and lower
Transmission power	Max 10dBm (antenna input power)
Modulation scheme	ASK, FSK, GMSK, B(Q)PSK
Signal bandwidth	32 kHz (Min) – 150 kHz (Max)
Data rate	20 kbps – 160 kbps
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
  - Measurement of propagation characteristic
  - Computer simulation
  - Evaluation by experimental prototype
  - Evaluation by pre-commercialized prototype

MAC specification (1): topology

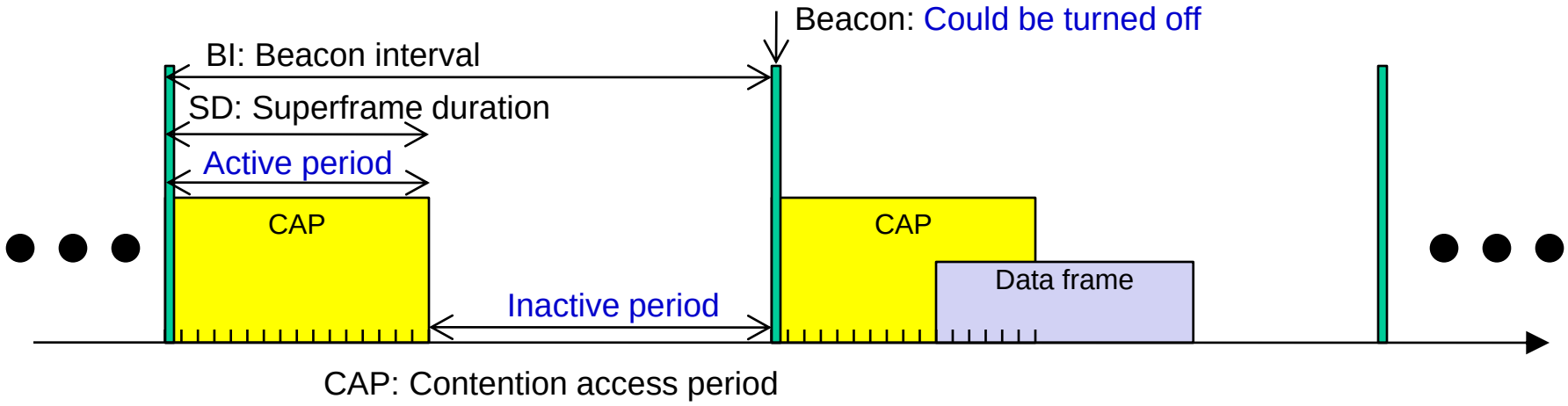
- Two types of devices as defined in 15.4MAC
  - FFD (Full function device) as collection station or meter that can determine superframe and accept association by other meters
  - RFD (Reduced function device) as meter
- After power-on
  - The collection station makes a cluster by determining PAN ID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



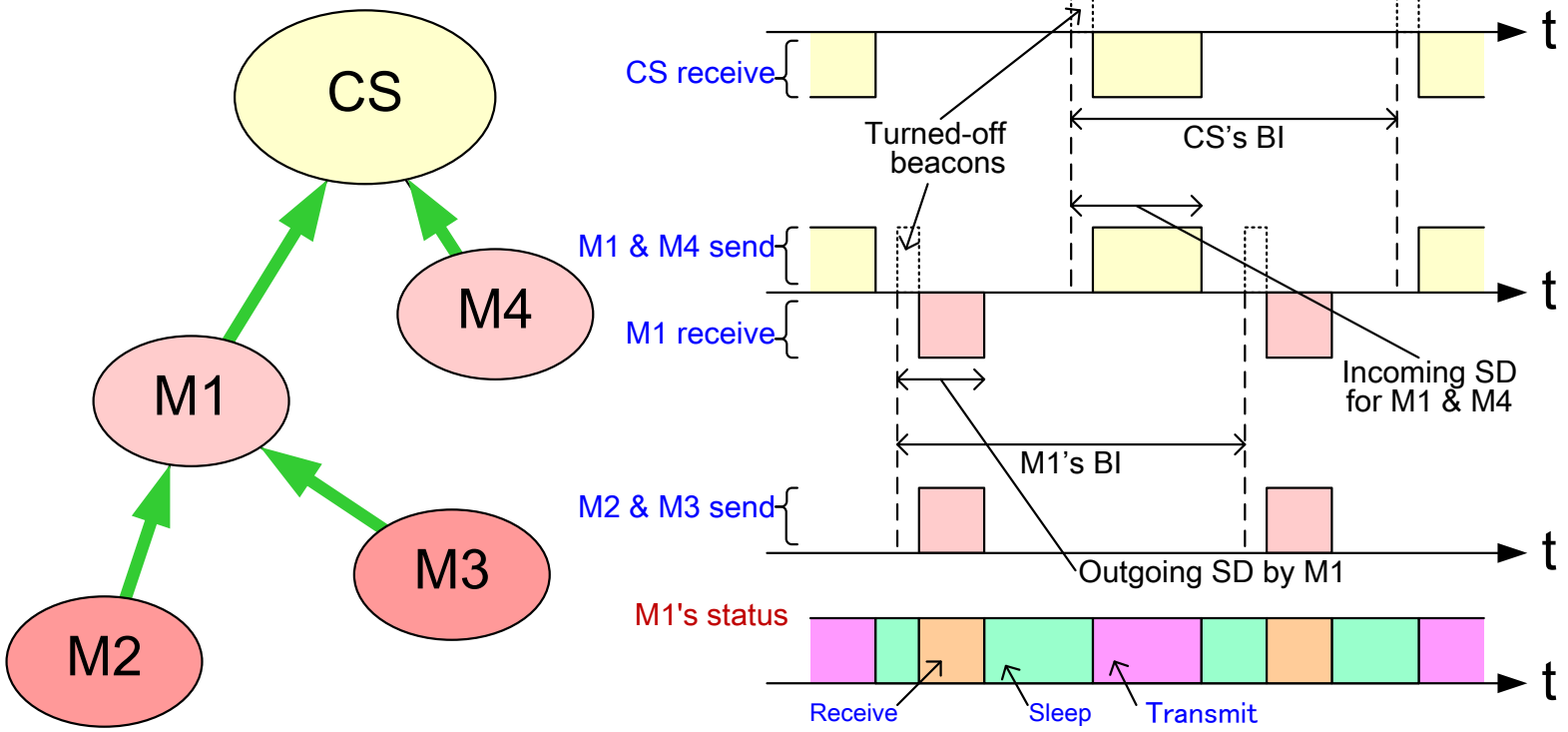
MAC specification (2): superframe-2

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

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

Feasibility study to support the proposed PHY and MAC

Propagation characteristics evaluation experiments

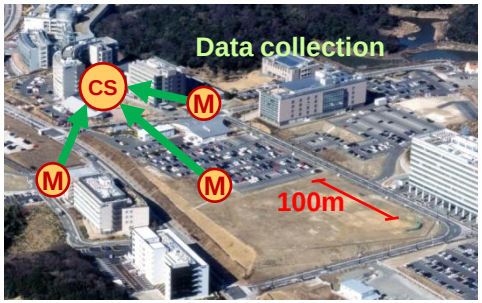
Propagation characteristics have been evaluated according to service area conditions, and meter located situations, thereby obtaining suitable models for several degradations.

Consideration of area conditions

Two different areas are defined each of which has further different profiles as for LOS/NLOS conditions. Such areas are used as parameters to evaluate the propagation characteristics.

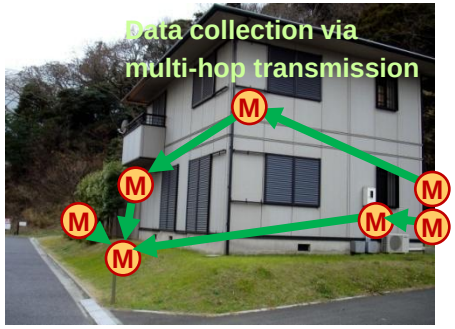
Wide area

Area for collection station having higher located antenna and meter communication

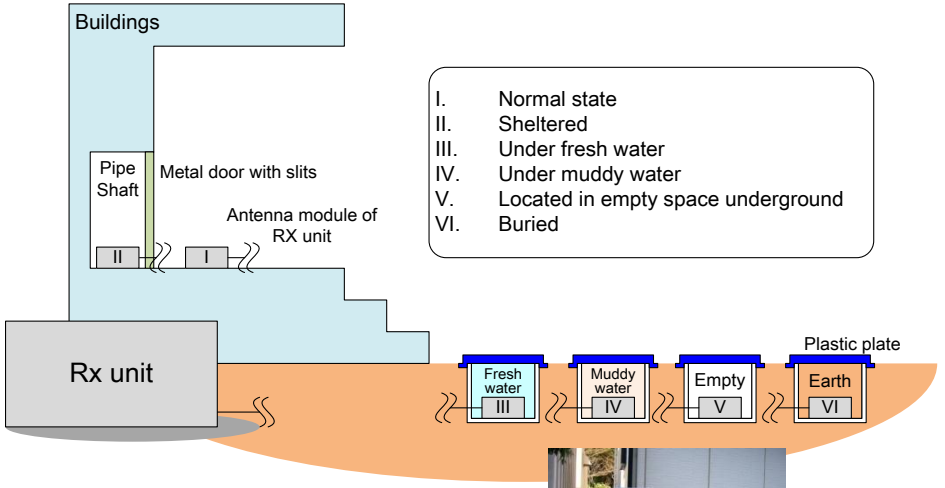


Meter located area

Area for meter and meter communication with multi-hop transmission



Degradation evaluation due to meter location



Antenna conditions assuming meter locations

Under fresh water

Under muddy water

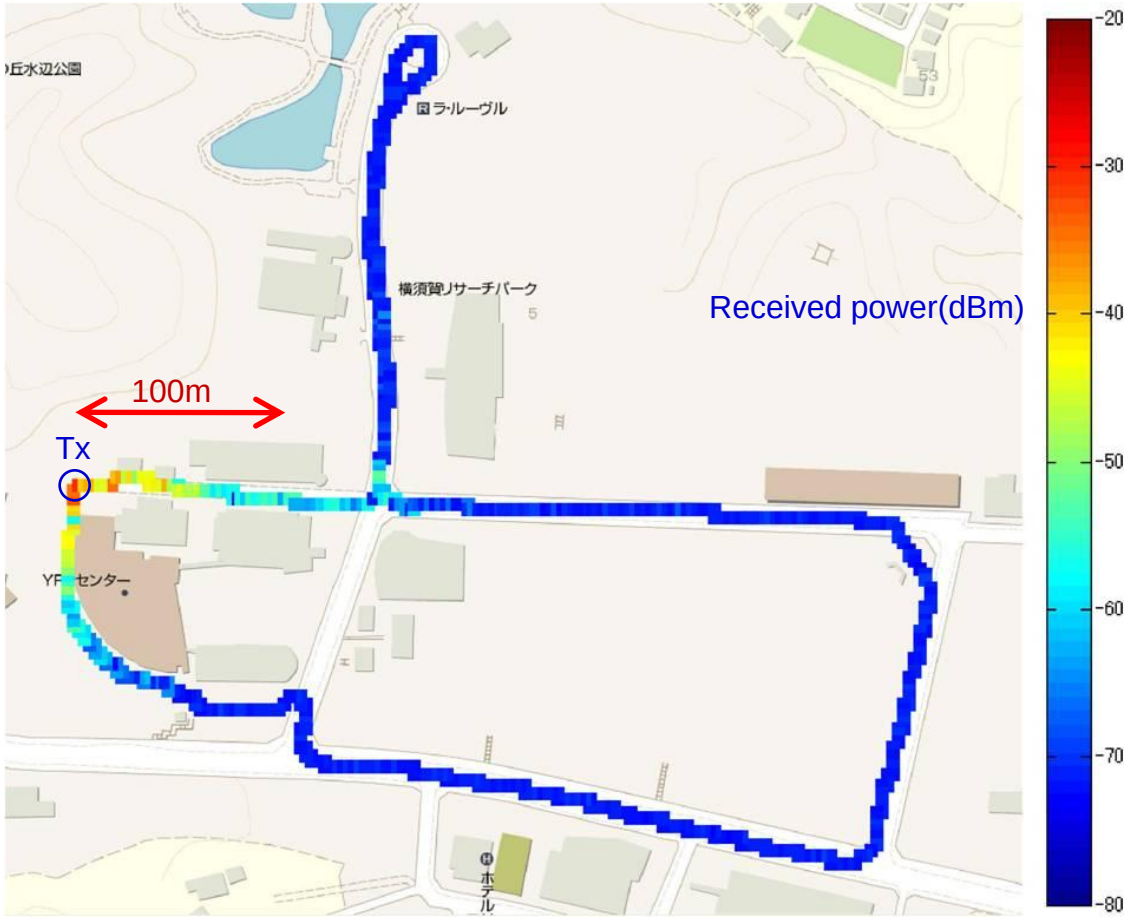
Buried

Experimental results

More than -60dBm received power is achieved up to the propagation range of 150m in both case of 5.2m and 1.25m antenna height.

Center frequency	426.0375MHz
Transmission power	10dBm
Antenna gain	2.15dBi
Antenna height	5.2m/1.25m
Modulation scheme	BPSK
Signal bandwidth	800kHz
Symbol rate	312.5kbps

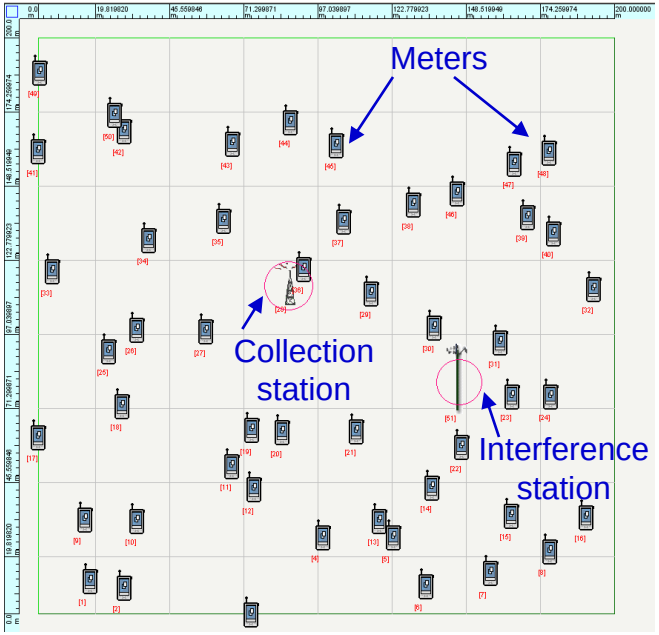
Received power characteristics for 5.2m height Tx antenna



Evaluation by computer simulation

Computer simulation results confirmed that system parameters should be suitably configured in order to cope with real usage model such as crowded terminal situation or interference situation.

Simulator interface



Simulator activation image including 50 meters with an interference station

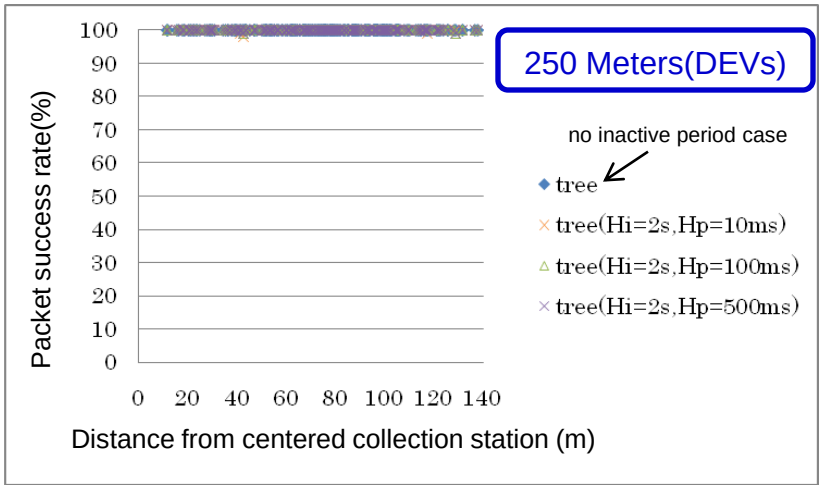
Parameter introduction

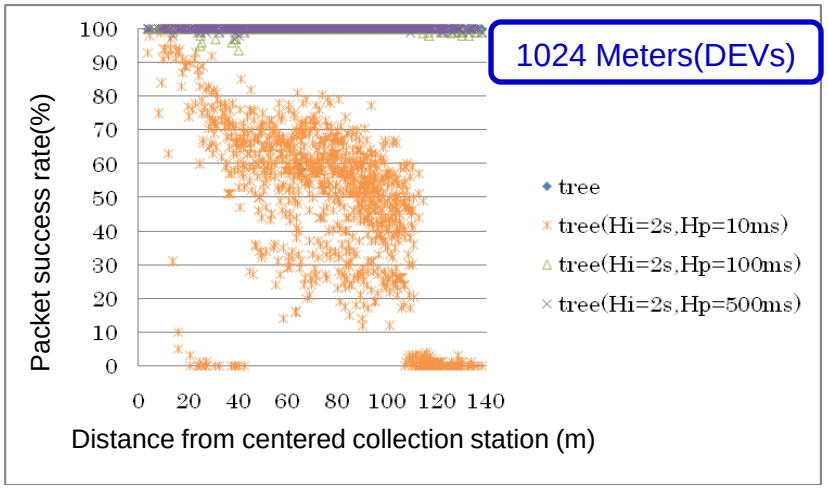
Four parameter categories are employed to simulate strict usage models

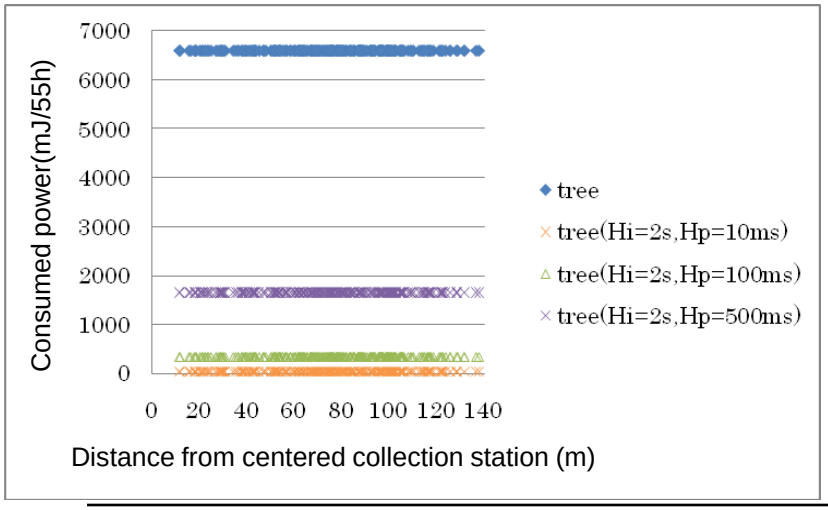
Computer simulation parameter	Detailed parameter	Values in simulation
Collection station and meter location parameters	Simulation area size	200m x 200m based on assumed service area
	Number of meters	250, 1024
Propagation parameters	Shadowing	6.5dB
	Path loss factor	2.0
	Center frequency	426MHz
	Antenna setting	Collection height 5m, meters: 1m
	Degradation for each meter #1: Building penetration loss	-10dB for 10% of meters
	Degradation for each meter #2: Meter location (PS; Pipe shaft)	-20dB, assuming propagation experiment results
	Degradation for each meter #3: Meter location (Other than PS)	Based on propagation experiment results
	Degradation for each meter #4: Interference suffering condition	Existing telemeter system model
Traffic parameters	Packet length	16ms
	Traffic model	Periodical arrival(1/1800s)
Protocol parameters	Radio communication scheme	802.15.4PHY
	Beacon interval(Hi: Hearing interval)	2s
	Active period (Hp: Hearing period)	10, 100, 500ms
	Routing scheme	Tree topology

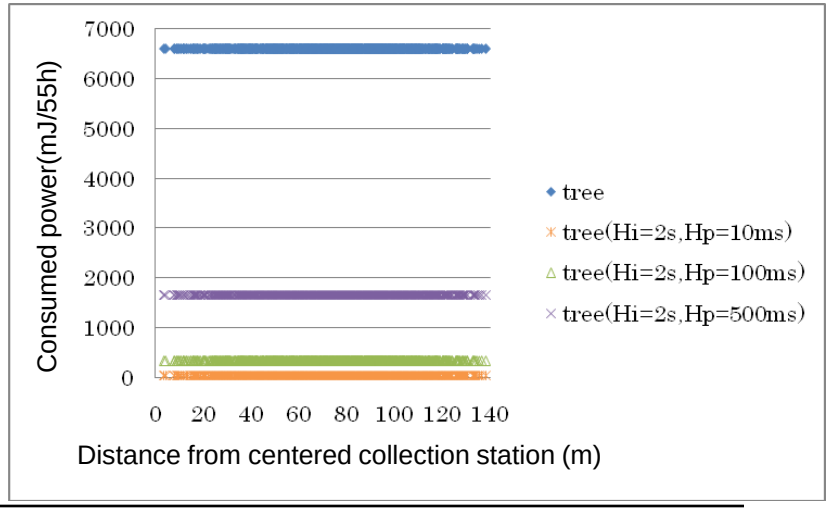
Simulated results

Computer simulation results confirmed that the modified MAC with 100ms active period for 2s beacon interval could support 1024 meters(DEVs) employment in a system with keeping almost 100% of data success rate









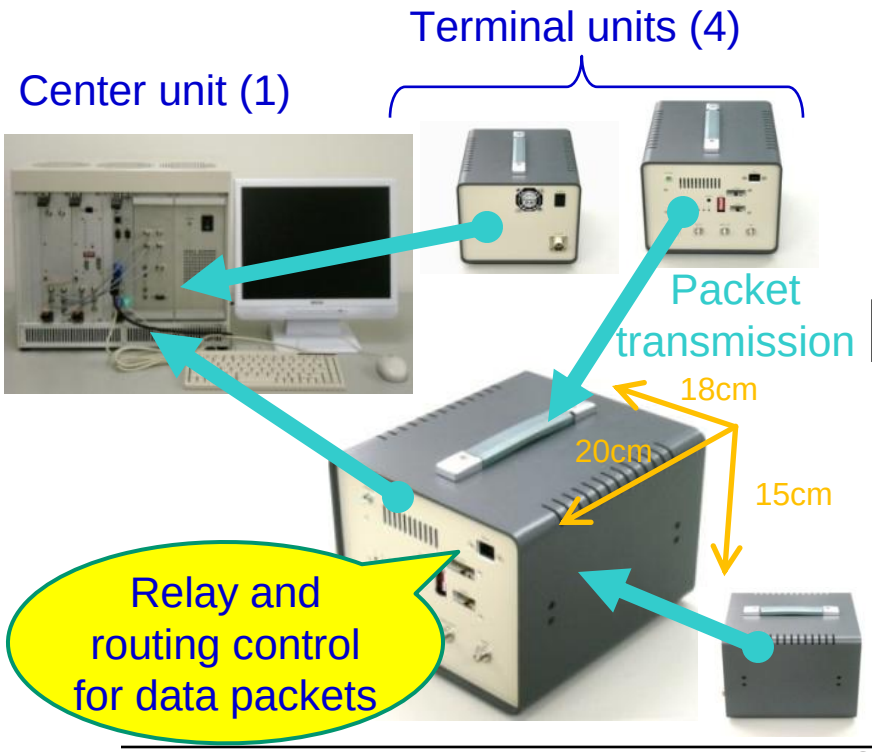
Prototype terminal for experimental evaluation

NICT has proposed a prototype terminal with the following features

1. A variety of modulation schemes and data rates
2. Low power MAC with suitable sleeping periods
3. Autonomous routing scheme based on tree topology construction

Outline

After power-on, each terminal unit establishes route to the center unit by examining units around.

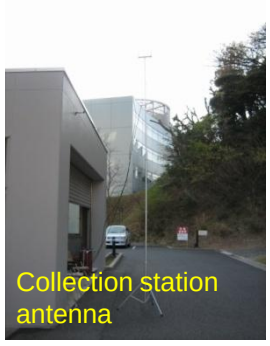


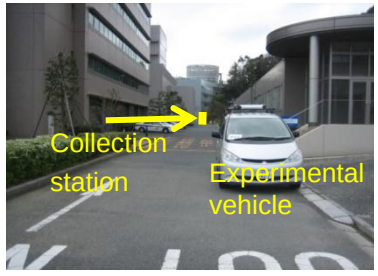
Specifications

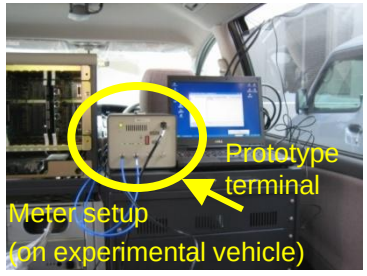
Size and weight	W18cm x H15cm x D20cm, 2.5kg			
Center frequency	426.0375MHz			
Transmission power	10dBm			
Antenna gain	2.15dBi /9dBi			
Modulation scheme	ASK	FSK	BPSK	QPSK
Signal bandwidth	150kHz	300kHz	150kHz	150kHz
Data rate	80kbps	80kbps	80kbps	160kbps
MAC scheme	Modified 15.4MAC			
Routing scheme	Based on autonomous TREE topology construction			

Experiments

Multi-hop packet transmissions are confirmed to improve system performance



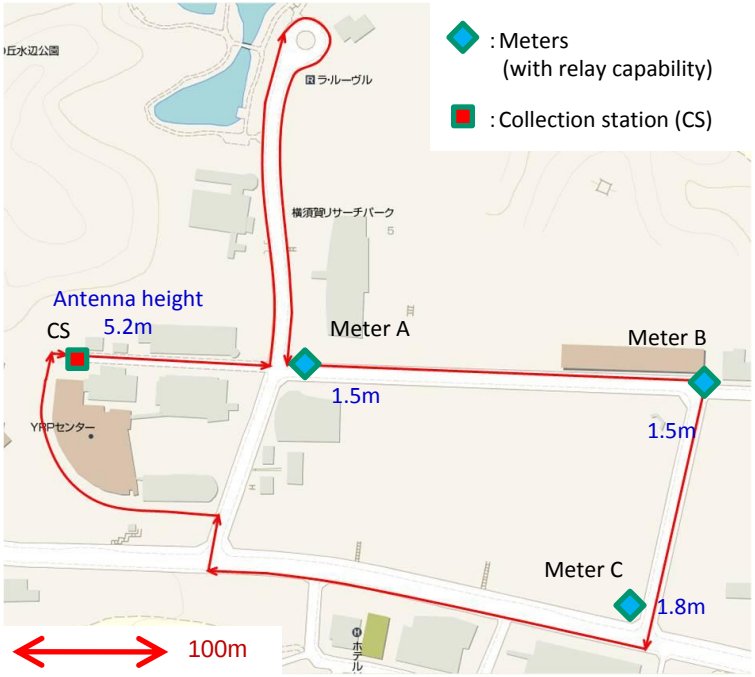


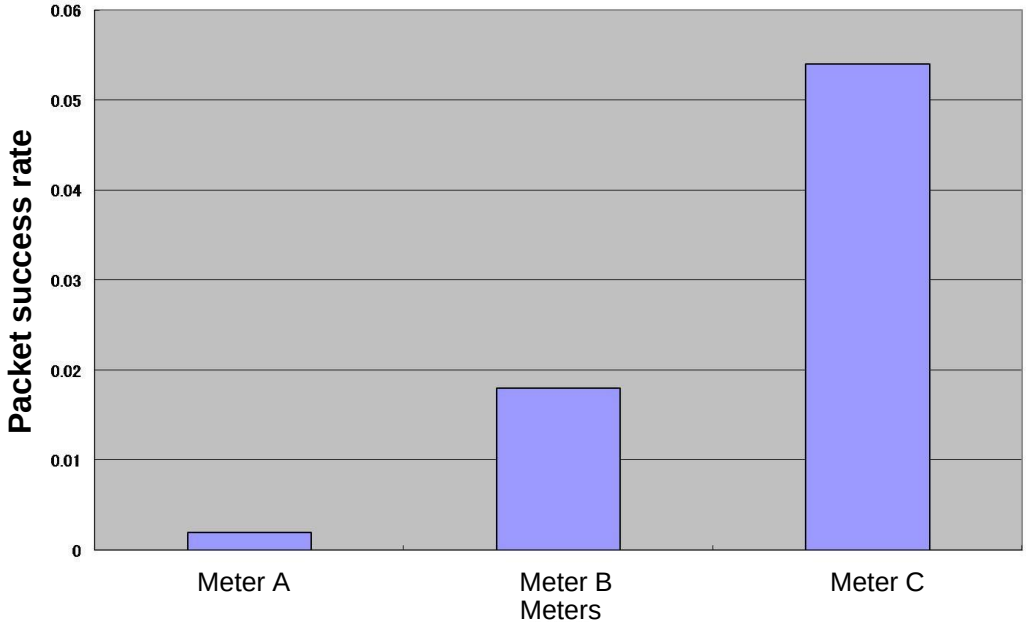


Experimental results

Experimental results shows the prototypes with the modified 15.4MAC can achieve almost 100% success rate of packet throughput in 400m radius (equivalent to the distance between CS and Meter C) area by activating two hopping relayed transmission.

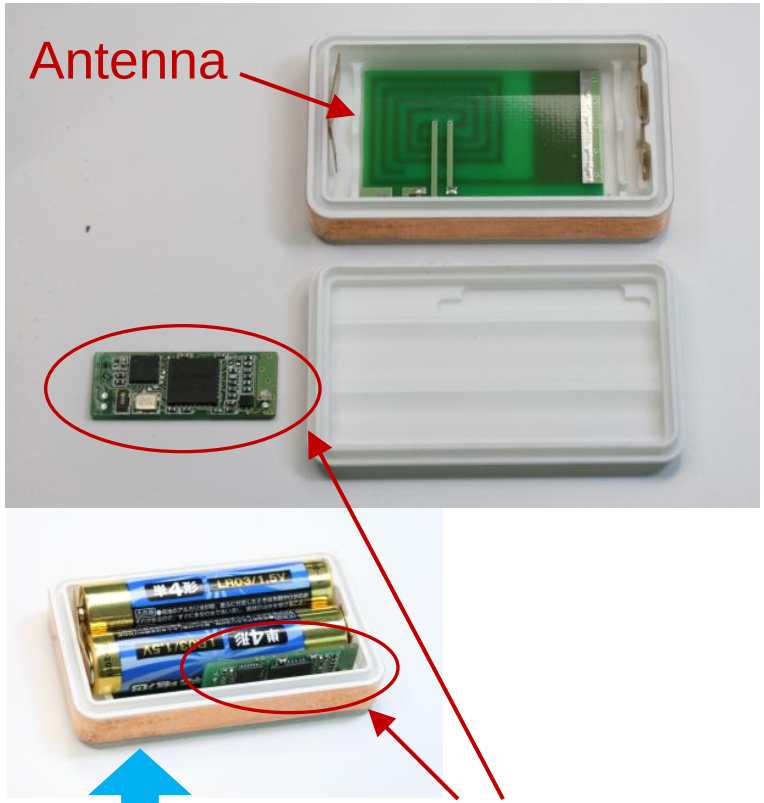
Center frequency	426.0375MHz
Transmission power	10dBm
Antenna gain	2.15dBi
Modulation scheme	ASK
Signal bandwidth	150kHz
Data rate	80kbps
Data traffic	Equally on Meter A, B and C towards CS(Collection station)
Data packet length	13ms
Data arrival interval	6s
Beacon interval	2s
Active period	200ms
Routing scheme	Based on autonomous TREE topology construction among five prototypes





Small sized and low power terminals

NICT has also developed small sized and low power prototype terminals with reduction of several functions from the previous prototype. This “customized” terminals could be used in order to evaluate performances under the strict situations for concrete use cases in the future.



Specification of Small sized and low power terminals

Center frequency band	400 MHz and lower
Transmission power	Max 10dBm (antenna input power)
Modulation scheme	FSK
Signal bandwidth	32 kHz
Data rate	19.2 kbps
MAC scheme	Modified 15.4MAC
Routing scheme	Based on autonomous TREE topology construction
Beacon interval	1s
Active period	3.5ms
Data frame length	12.5ms

An example of configurations as for power consumption performance

- 103uA average power consumption
  - Sleep mode: 3uA
  - Receive/Hearing mode: 79.6uA (Hearing interval: 1s)
  - Transmission mode: 20.4uA (Transmission interval: 30s)
- Equivalent to 2.7Ah/3years

Conclusions

- Propose the following PHY and MAC
  - 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
  - MAC: modification and addition of functions on the basis of 15.4MAC
    - Beacon turn off mode with active period
    - Intermittent hearing using CAP and receiving in the following inactive period
    - Cluster-tree topology with independent superframe determination
- Introduce the environment of experimental study and computer simulations and the results of power consumption by small low power terminal
  - 2.7Ah/3years performance