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

Submission Title: [PHY and MAC Proposal for IEEE 802.15.4m]
Date Submitted: [May 7, 2012]
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Re: [A PHY and MAC proposal for 802.15.4m]

Abstract: [This document presents a proposal on the PHY and MAC system design for 802.15.4m]
Purpose: [This document provides a list of the editing staff that will be working on 802.15.4m.]

Executive Summary

- This document presents a unified PHY and MAC proposal for TG4m
- The PHY proposals consists of
  - FSK PHY Parameters: to equip TG4m devices with compatibility with SUN in 802.15.4g for smart metering applications
  - OFDM PHY Parameters: to equip TG4m device with high data rate capability for applications such as digital signage and advanced sensors
  - Channel Plan: channel plan for TG4m PHY layer design
- The MAC proposals consists of
  - TVWS Operation Enabling Protocol: to equip TG4m device with the capability to comply with TVWS rules
  - Dynamic Band Switching: to equip TG4m device with out-of-band communication capability
  - Power Saving Mechanism: to equip TG4m device with scalable power saving features
  - Direct Device-to-device Data Transfer: to equip TG4m device with peer-to-peer communication capability for network redundancy
- Each proposal has respective summary, motivation and design details

Executive Outline

- PHY proposal
  - PHY Parameters
  - Channel Plan
- MAC proposal
  - TVWS Operation Enabling Protocol
  - Dynamic Band Switching
  - Power Saving Mechanism
  - Direct Device-to-device Data Transfer

Summary of PHY Proposal

- Two PHY Modes
  - FSK based PHY
  - OFDM based PHY
- PHY Specifications
    - PPDU format
    - Modulation and coding
    - Pilot allocation and Subcarrier mapping (Will update later)
    - Frequency Interleaving (Will update later)
    - Preamble design (Will update later)
- Channel plan

PHY Parameters

Summary of FSK PHY Proposal

- Motivation
  - Based on TG4g PHY FSK configuration, we propose the FSK PHY for TG4m.
  - Based on the analysis, proposed FSK PHY supports filtered 2FSK and filtered 4FSK with both FEC enabled and disabled selection
  - To better cope with burst errors, a new interleaver scheme for FEC enabled case is also proposed to replaced the code-symbol interleaver specified in TG4g system.

FSK PPDU Format

PPDU Format for FSK

Variable	2 octets	2 Octets	Variable
SHR		PHR	PPDU
Preamble	SFD		

PHR header

Bit String Index	**0-3**	**4**	**5-15**
Bit Mapping	R_3-R_0	FEC	L10-L0
Field Name	Reserved	FEC Type	Frame length

Proposed FSK PHY Specifications

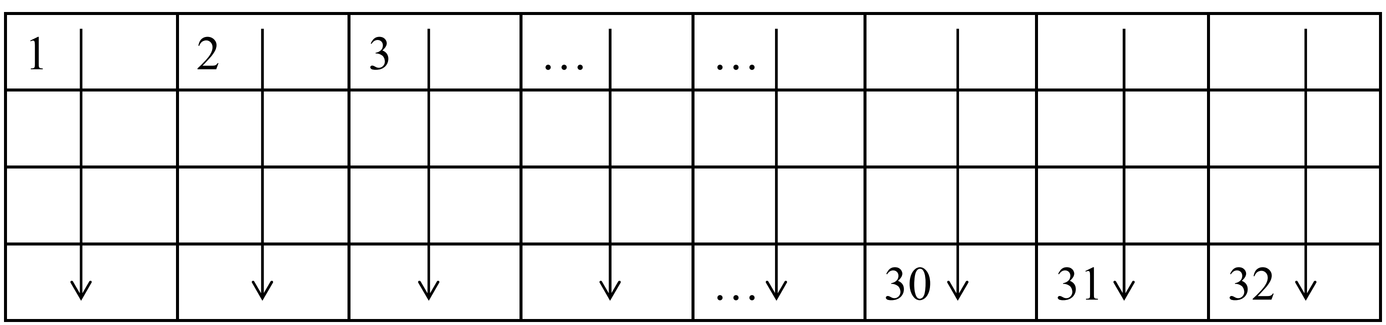
- Modulation and Coding Scheme
  - Filtered 2FSK with 2 operating modes
  - FEC: Uncoded and Recursive Systematic Code as defined in TG4g
  - Respective parameters are specified as follows

Parameter	Mode 1	Mode 2	Mode 3
Data rate (kb/s)	50	100	200
Modulation	Filtered 2FSK	Filtered 2FSK	Filtered 2FSK
Modulation index	1	1	1
Channel spacing(kHz)	200	400	600

Proposed Bit Interleaver for FSK PHY

8 by 4 block interleaver as shown below

Row by row write in



Column by column read out

Summary of OFDM PHY Proposal

- Based on the FCC's revised PSD and adjacent channel emission limits, with respect to 100kHz resolution, for fixed devices, the PSD limit is 12.6dBm and adjacent channel limit is -42.8dBm; for all other personal/portable devices, PSD limit is 2.6dBm and the adjacent channel limit is -52.8dBm.
- To meet the requirement of adjacent channel limit and utilize the highest available PSD limit requirement, the difference of in band and adjacent band emission limits are 55.4dB.
- A new OFDM PHY is proposed for TG4m to replace TG4g OFDM PHY and provide a better utilization of power and bandwidth.

OFDM PPDU Format

PPDU Format for OFDM

<table>
<tr><td colspan="6"></td><td>Variable</td><td>Variable</td></tr>
<tr><td colspan="6">SHR</td><td rowspan="2">PHR</td><td rowspan="2">PPDU</td></tr>
<tr><td>STF</td><td>STF</td><td>STF</td><td>STF</td><td>LTF</td><td>LTF</td></tr>
</table>

PHR header

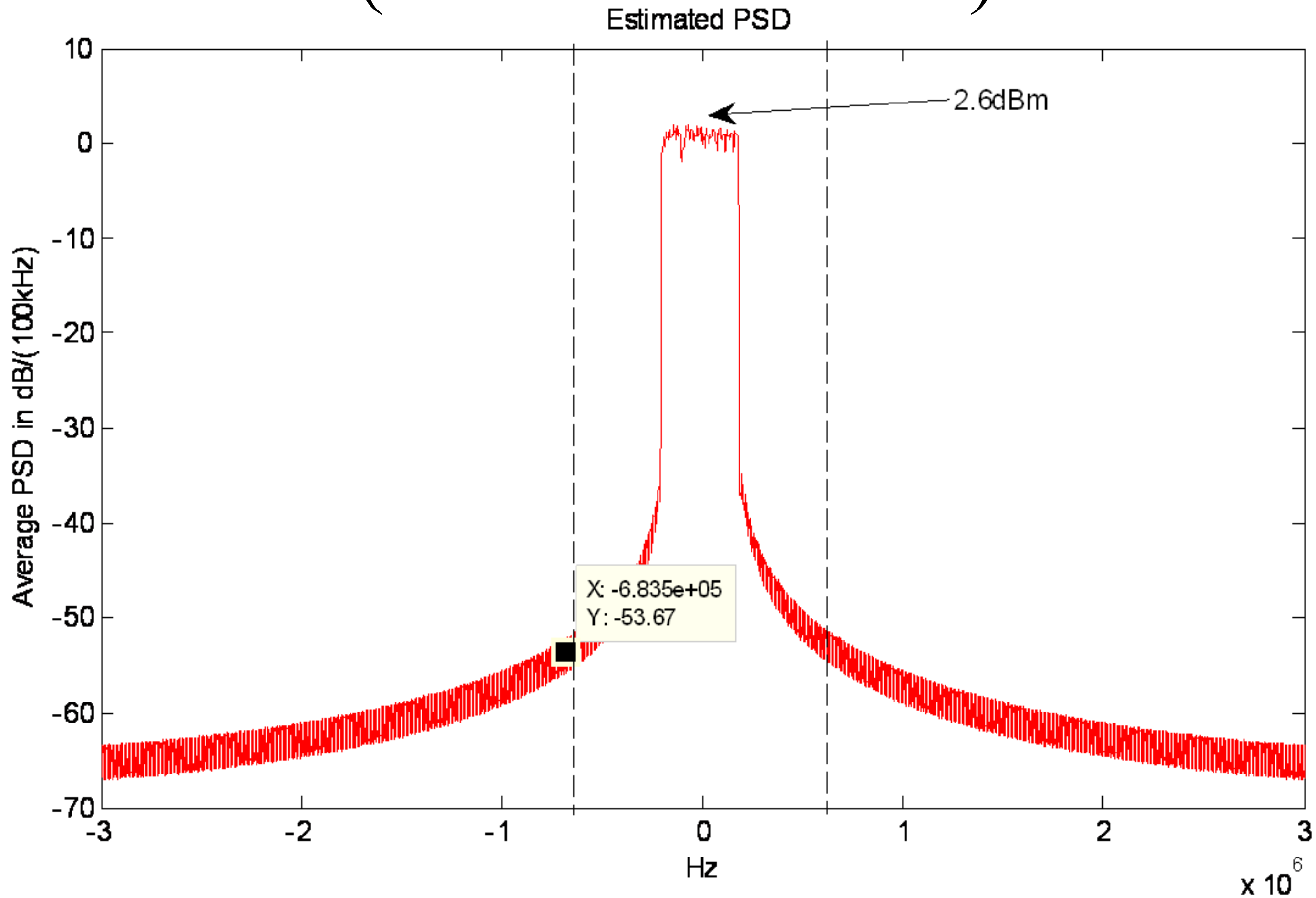
Bit String Index	0-3	4-7	8-9	10-20	21-24	25	26-33	34-39
Bit Mapping	R_3-R_0	M_3-M_0	F_1-F_0	L_{10}-L_0	A_3-A_0	R	H_7-H_0	T_5-T_0
Field Name	Reserved	Modulation Type	FEC Type	Frame length	Channel aggregation	Reserved bit	HCS	Tail

Proposed OFDM PHY Specifications

OFDM PHY System Parameters

Channel bandwidth	6M	8M	TG4g(6.5M)
Nominal bandwidth	380.95k	380.95k	281k
No. of sub-channels	11	16	16
Channel spacing	400kHz	400kHz	400k
Subcarrier spacing	0.99206kHz	0.99206kHz	31250/3=10.417kHz
Guard band	800kHz for each side of 6MHz band	800kHz for each side of 8MHz band	100kHz
No. of Effec. subcarriers per subchannel	384	384	26
No. of Pilot subcarrier per subchannel	32	32	2
No. of Data subcarriers per subchannel	352	352	24

PSD of Proposed OFDM PHY (Welch Estimation)



Based on new FCC revision, for portable devices, in band PSD limit (100kHz) is 2.6dBm, adjacent channel limit (100kHz) is -52.8dBm.

Proposed OFDM PHY Specifications

- Modulation and Coding Scheme
  - Modulation:
    - OFDM+(BPSK, and QPSK, 8PSK, 16QAM, 64QAM with bit interleaving)
  - FEC: Convolutional Code with varied rate from ½ to 7/8
- Pilot allocation and Subcarrier mapping (To be updated)
- Frequency Interleaving (To be updated)
- Preamble, STF, LTF (To be updated)

Proposed OFDM PHY Specifications

- Carrier frequency spacing: 0.99206kHz
- Effective symbol length:1008μs
- Guard interval length:
  252 μs (1/4),126 μs (1/8),63 μs (1/16),31.5 μs (1/32)
- 204 OFDM symbols in each frame of one sub-channel

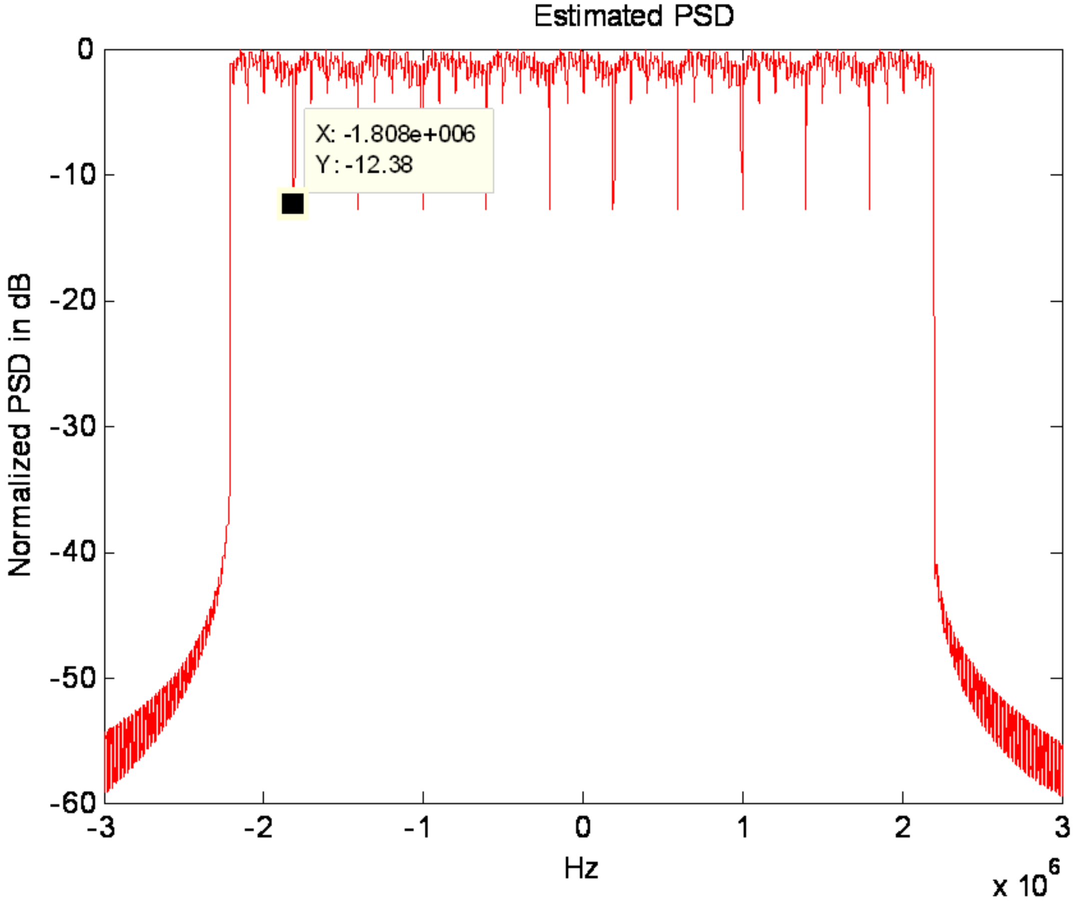
Proposed OFDM PHY Specifications

- Supported data rate per 400kHz subchannel

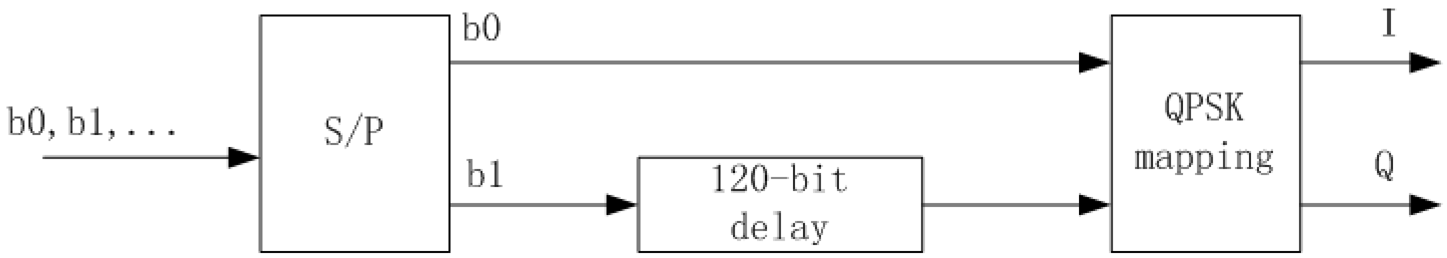
FEC Code rate	½				¾				7/8			
Guard Interval Ratio	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
BPSK	139.68 kbps	155.2 0kbps	164.33 kbps	169.31 kbps	209.52 kbps	232.80 kbps	246.50k bps	253.97kb ps	244.44k bps	271.60 kbps	287.58k bps	296.30kbp s
QPSK	279.37 kbps	310.4 1kbps	328.66 kbps	338.62 kbps	419.05 kbps	465.61 kbps	493.00k bps	507.94kb ps	488.89k bps	543.21 kbps	575.16k bps	592.59kbp s
8PSK	419.05 kbps	465.6 1kbps	493.00 kbps	507.94 kbps	628.57 kbps	698.41 kbps	739.50k bps	761.90kb ps	733.33k bps	814.81 kbps	862.75k bps	888.89kbp s
16QAM	558.73 kbps	620.8 kbps	657.3k bps	677.2k bps	838.10 kbps	931.2k bps	986.0kb ps	1.02Mbp s	977.78k bps	1.09M bps	1.15Mb ps	1.19Mbps
64QAM	838.1k bps	931.2 kbps	986.0k bps	1.02M bps	1.26M bps	1.40M bps	1.48Mb ps	1.52Mbp s	1.47Mb ps	1.63M bps	1.73Mb ps	1.78Mbps

Channel Aggregation

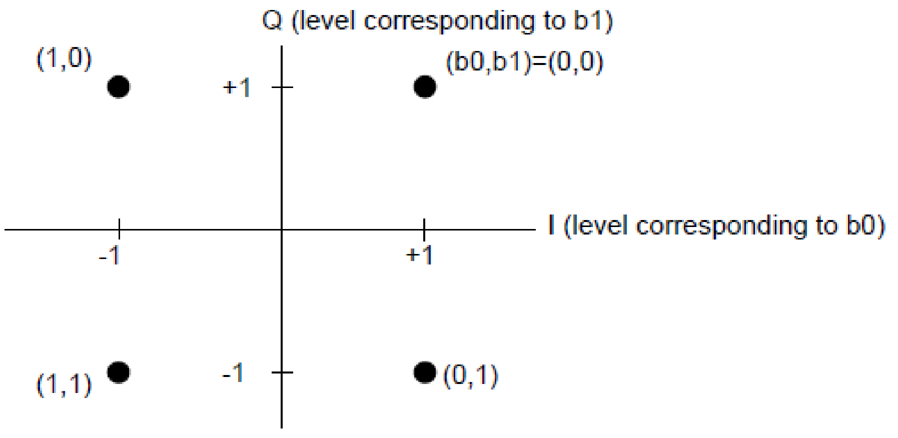
For fixed device, more than one, up to 11 subchannels can be aggregated and form one channel in a 6MHz Band to support data rate of more than 10Mbps.



QPSK with bit interleaving

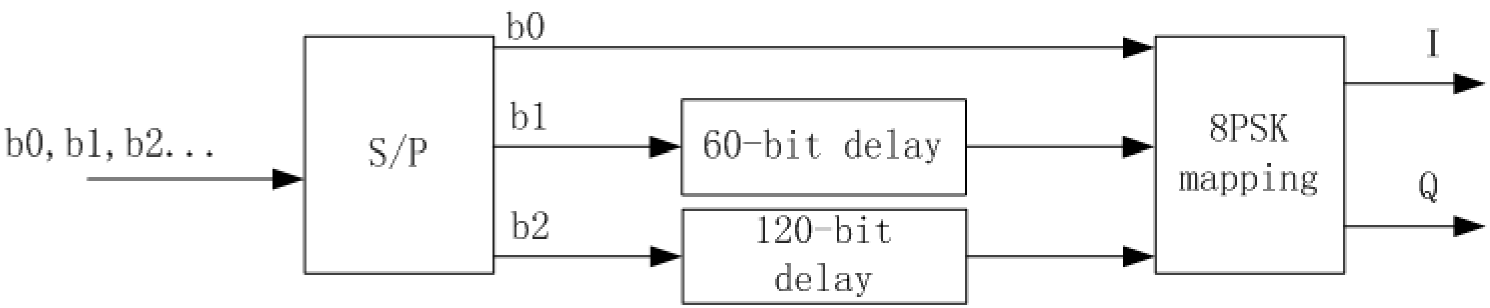


QPSK Modulation with bit interleaving Diagram

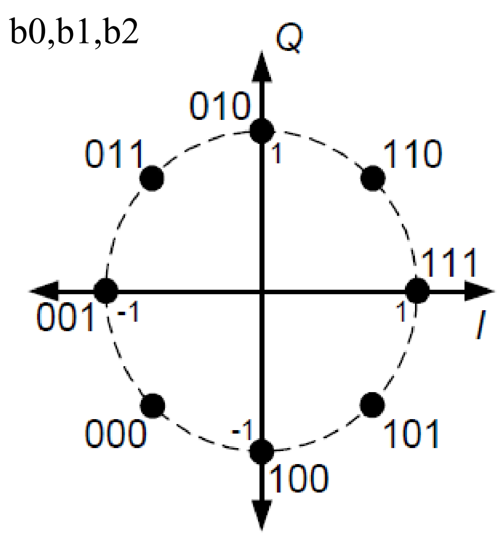


QPSK constellation

8PSK with bit interleaving

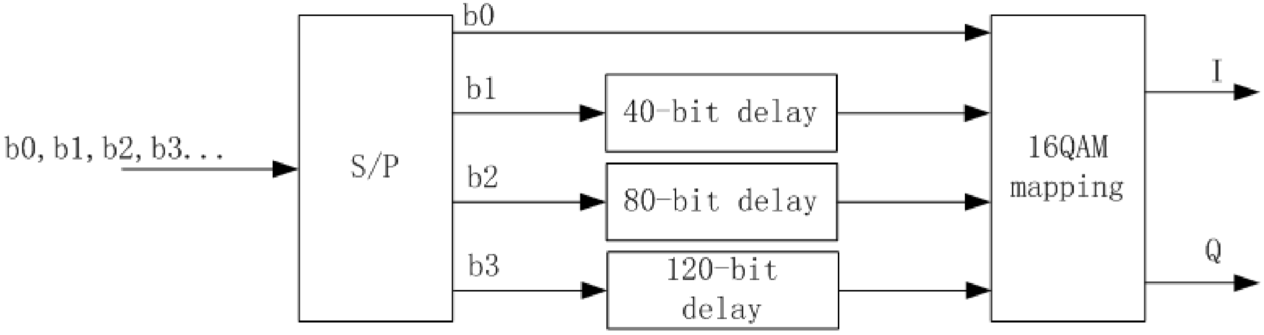


8PSK Modulation with bit interleaving Diagram

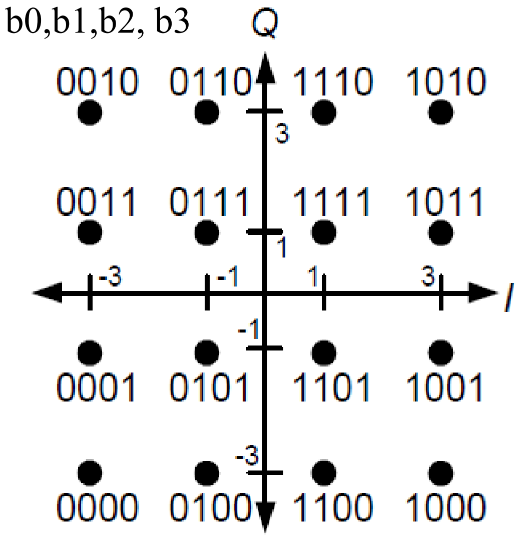


8PSK constellation

16QAM with bit interleaving

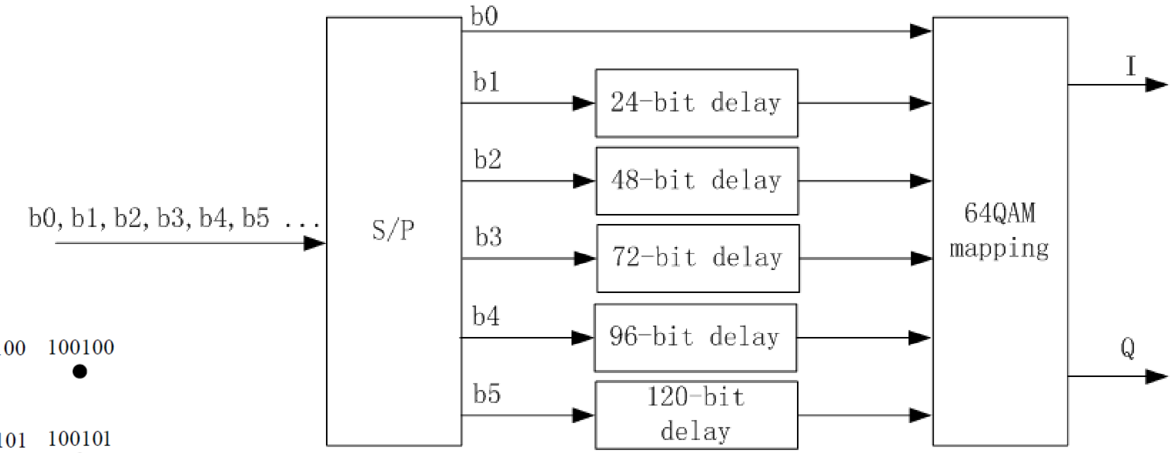


16QAM Modulation with bit interleaving Diagram

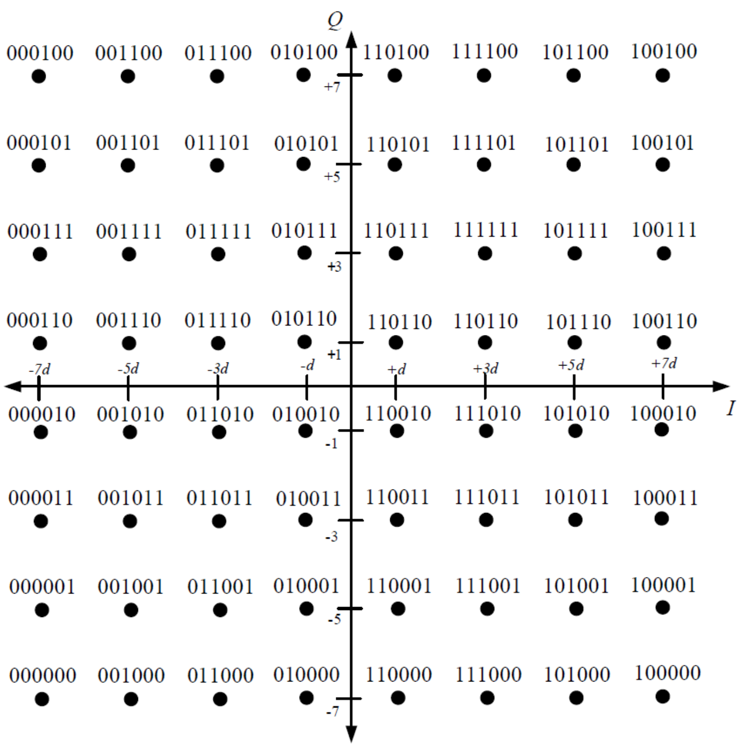


16QAM constellation

64QAM with bit interleaving



64QAM Modulation with bit interleaving Diagram



I channel – level corresponding to b0 b2 b4
Q channel – level corresponding to b1 b3 b5

64QAM constellation

Channel Plan

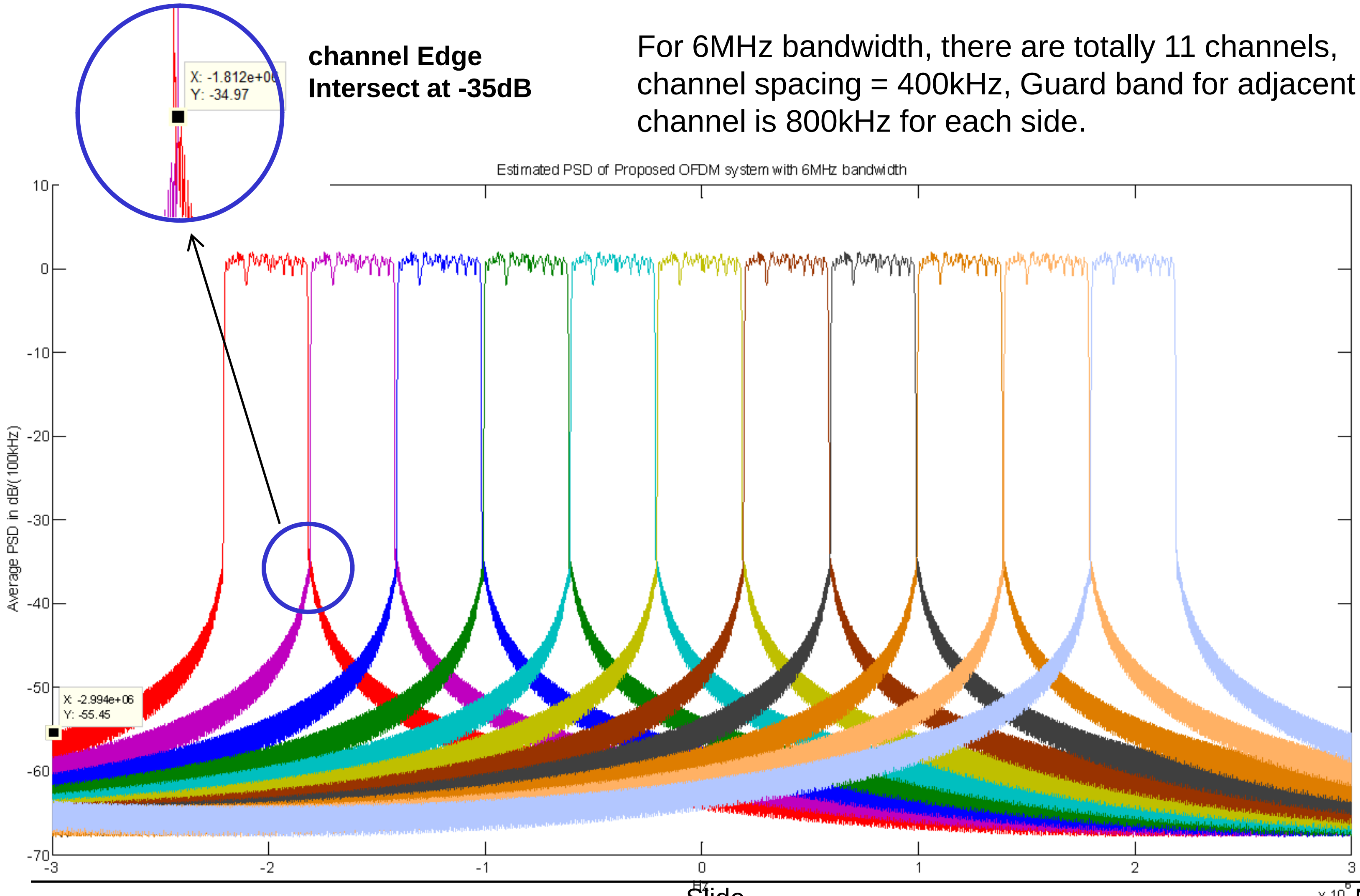
Channel Plan

- For FSK PHY with 6MHz bandwidth, there are 3 modes. 29 channels with 200kHz channel spacing; 14 channels with 400kHz channel spacing; 9 channels with 600kHz channel spacing.
- For OFDM PHY with 6MHz bandwidth, 11 channels are allocated with channel spacing 400kHz, each side of 6MHz TV channel required a guard band of 800kHz
- For OFDM PHY with 8MHz bandwidth, 16 channels are divided with channel spacing 400kHz. Each side of 8MHz TV channel required a guard band of 800kHz.

Estimated PSD of Proposed OFDM System with 11 Channels for 6MHz Bandwidth

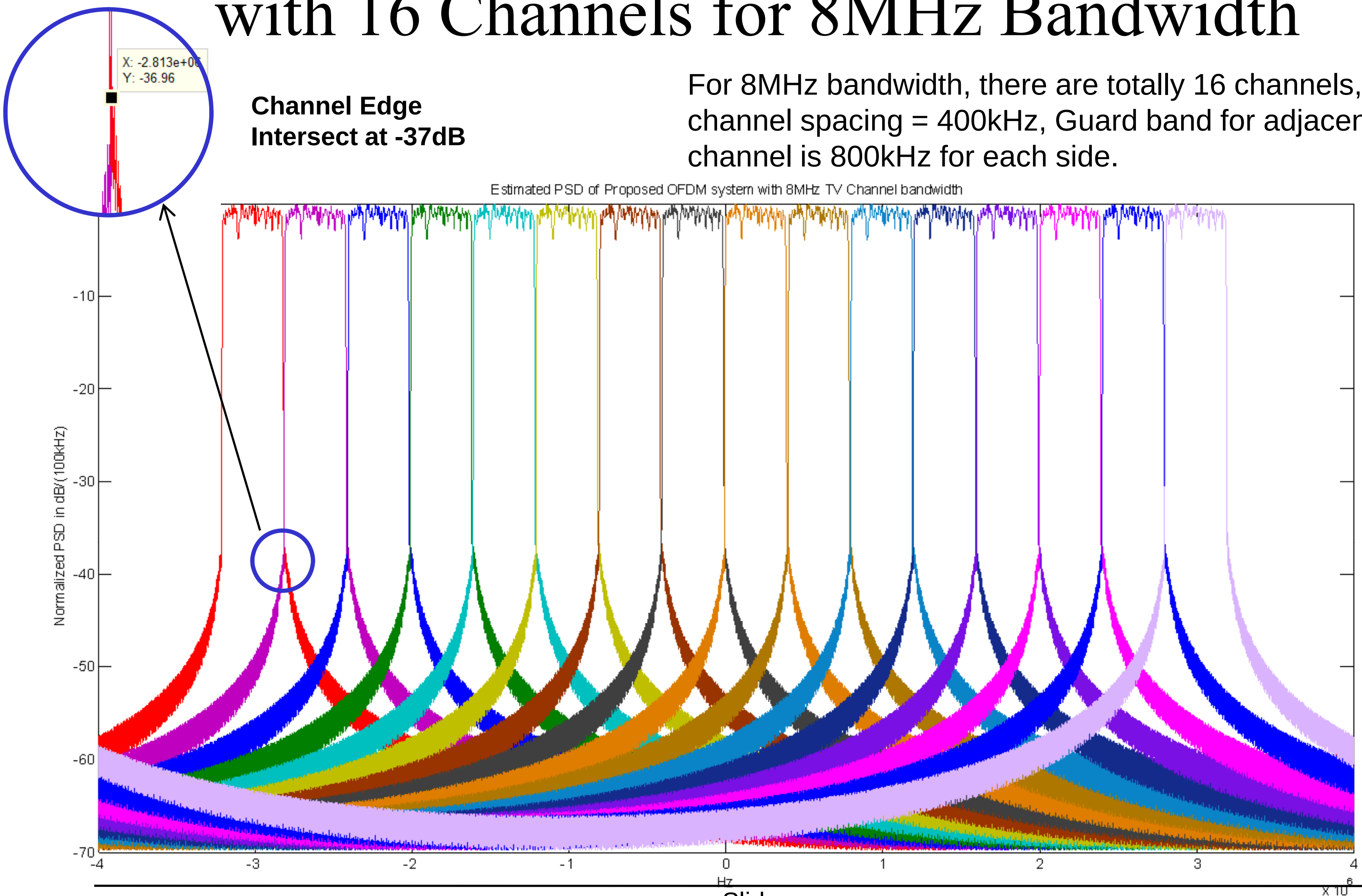
channel Edge Intersect at -35dB

For 6MHz bandwidth, there are totally 11 channels, channel spacing = 400kHz, Guard band for adjacent channel is 800kHz for each side.



Estimated PSD of Proposed OFDM System with 16 Channels for 8MHz Bandwidth

For 8MHz bandwidth, there are totally 16 channels, channel spacing = 400kHz, Guard band for adjacent channel is 800kHz for each side.



Channel Centre Frequency

- The channel centre frequency can be derived based on the formulas below
- For FSK: ***ChanCenterFreq = ChanFreq0 +(NumChan-1)* ChanSpacing***
- For OFDM

  ChanCenterFreq = ChanFreq0 +floor(NumChan/11) +mod(NumChan-1, 11)* ChanSpacing *(6MHz TV Band)*

  ChanCenterFreq = ChanFreq0 +floor(NumChan/16) +mod(NumChan-1, 16)* ChanSpacing *(8MHz TV Band)*
- Where *ChanCenterFreq* is channel centre frequency
- *ChanFreq0* is the starting channel centre frequency of every continuously available TV channel
- *NumChan is the index of channel in every continuously available TV channel*
- *TotalNumChan* is total number of channel in every continuously available TV Channel band
- *ChanSpacing* is channel spacing

Total number of channels and first channel centre frequencies for proposed PHYs

Freq. band (MHz)	Modulation	ChanSpacing(MHz)	TotalNumChan	*ChanFreq0*
54-60	Filtered 2FSK	0.2	29	54.2
	Filtered 2FSK	0.4	14	54.4
	Filtered 2FSK	0.6	9	54.6
	OFDM	0.4	11	55
76-88	Filtered 2FSK	0.2	58	76.2
	Filtered 2FSK	0.4	28	76.4
	Filtered 2FSK	0.6	18	76.6
	OFDM	0.4	22	77
174-216	Filtered 2FSK	0.2	203	174.2
	Filtered 2FSK	0.4	98	174.4
	Filtered 2FSK	0.6	63	174.6
	OFDM	0.4	77	175
470-602	Filtered 2FSK	0.2	638	470.2
	Filtered 2FSK	0.4	308	470.4
	Filtered 2FSK	0.6	198	470.6
	OFDM	0.4	242	471
620-698	Filtered 2FSK	0.2	377	620.2
	Filtered 2FSK	0.4	182	620.4
	Filtered 2FSK	0.6	117	620.6
	OFDM	0.4	143	621

(based on FCC available TV Channel Table)

Future Potentials

- Requirements of TVWS regulations pose limitations not only to maximum allowable transmit power but also maximum allowable power spectral density
- In other words, for narrowband systems, the effective allowable transmit power becomes lower
- This in turn, affects the achievable transmission range
- It is therefore, noted here that, there may be advantages to employ spectrum spreading that expands to a larger bandwidth
- Possible mechanisms are **frequency hopping**, **spread spectrum** and others
- This topic will be reserved as a future topic in subsequent proposal stages

Summary of MAC Proposal

- TVWS Operation Enabling Protocol
- Dynamic Band Switching
- Power Saving Mechanism
- Direct Device-to-device Data Transfer

TVWS Operation Enabling Protocol

Summary

- This document proposes an enabling protocol for 802.15.4 WPAN operating in TV white space, meeting the requirement by TV white space regulations
- The TV white space regulations and corresponding relationship mapping (device classes, architecture etc) to 802.15.4 system is presented
- High level system design is presented to provide an overview on the mechanism without the details
- This document presents the basic procedure, state transition, frame format and service primitives for the enabling protocol

Outline

- Motivation
- Summary of Regulatory Bodies
- Example of Regulation Requirement
- Low Rate WPAN Architecture Example
- Regulatory Requirement Example – FCC
- Regulation-WPAN Relationship Mapping
- Basic Operational Procedure
- State Transition Diagram
- Message Sequence Charts
- Frame Format
- Service Primitives

Motivation

- Region-specific regulations (*e.g*. FCC) have outlined requirements on operation in TV white space such as device classes, operating conditions and system architecture
- In order to deploy 802.15.4 devices in the TV white space (*i.e*. the task for TG4m), it is important to compare the requirements specified in the regulations and the specifications in the 802.15.4
- Relationship mapping between the regulation requirements and 802.15.4 specification is a timely and important task

Summary of Major Regulatory Bodies

Regulatory Domains	FCC, USA	OFCOM, UK	Industry Canada, Canada	CEPT ECC, Europe
TV Channel-ization	6 MHz	8 MHz	6 MHz	8 MHz
Available TV Channels	Ch2 to Ch4: 54 to 72 MHz Ch5 to Ch6: 76 to 88 MHz Ch7 to Ch13: 174 to 216 MHz Ch14 to Ch51: 470 to 698 MHz	Ch21 to Ch60: 470 and 790 MHz	Ch2 to Ch4: 54 to 72 MHz Ch5 to Ch6: 76 to 88 MHz Ch7 to Ch13: 174 to 216 MHz Ch14 to Ch51: 470 to 698 MHz	470 to 790 MHz
Device Type	Fixed device (FD) Personal/portable device (PPD) Mode II PPD Mode I PPD Sensing-only device (SOD)	Master device (MD) Slave device (SD)	Fixed WSD (FWSD) Mobile WSD (MWSD) Mode II MWSD Mode I	Master device (MD) Slave device (SD)
TX Power	FD: 4W PPD: 100mW PPD SOD: 50mW FD disallowed in first adjacent channel PPD: 40mW (adj. channel)	DB informs the allowable transmit power	FWSD: 4W MWSD: 100mW MWSD: 40mW (adj. channel)	DB informs the allowable transmit power
Access Rules	FD: Ch2, Ch5 to Ch35, Ch39 to Ch51 PPD: Ch21 to Ch35, Ch39 to Ch51	MD and SD: Ch21 to Ch30 and Ch39 to Ch60	FWSD and MWSD: Ch2 to Ch36 and Ch38 to Ch51	–
DB Access	FD: once/day PPD Mode II: once/day, every 100m relocation PPD Mode I: not required PPD SOD: not required PPD Mode II may access DB via other PPD Mode II	MD: required SD: not required DB informs available channels and information time validity	MWSD: required FWSD: required FWSD Mode II may access DB via other FWSD Mode II	DB informs available channels and information time validity
Geo-location	FD: accuracy 50m PPD Mode II: accuracy 50m, re-establish location every 60s PPD Mode I: not required PPD SOD: not required	MD: accuracy 100m SD: not required	MWSD: required FWSD Mode II: required FWSD Mode I: not required	MD: required SD: not required
Spectrum Sensing	PPD SOD: required	DB informs whether sensing is required	–	DB informs whether sens-ing is required
Additional Notes	Contact Verification Signal re-quired by PPD Mode I every 60s	–	The channels bands are currently being shared with low power ap-paratus (LPA) and remote rural broadband systems (RRBS)	–

Example of Regulation ~ FCC Rules Summary ~

FCC has specified the most complete set of rules and is thus used as the example in this proposal

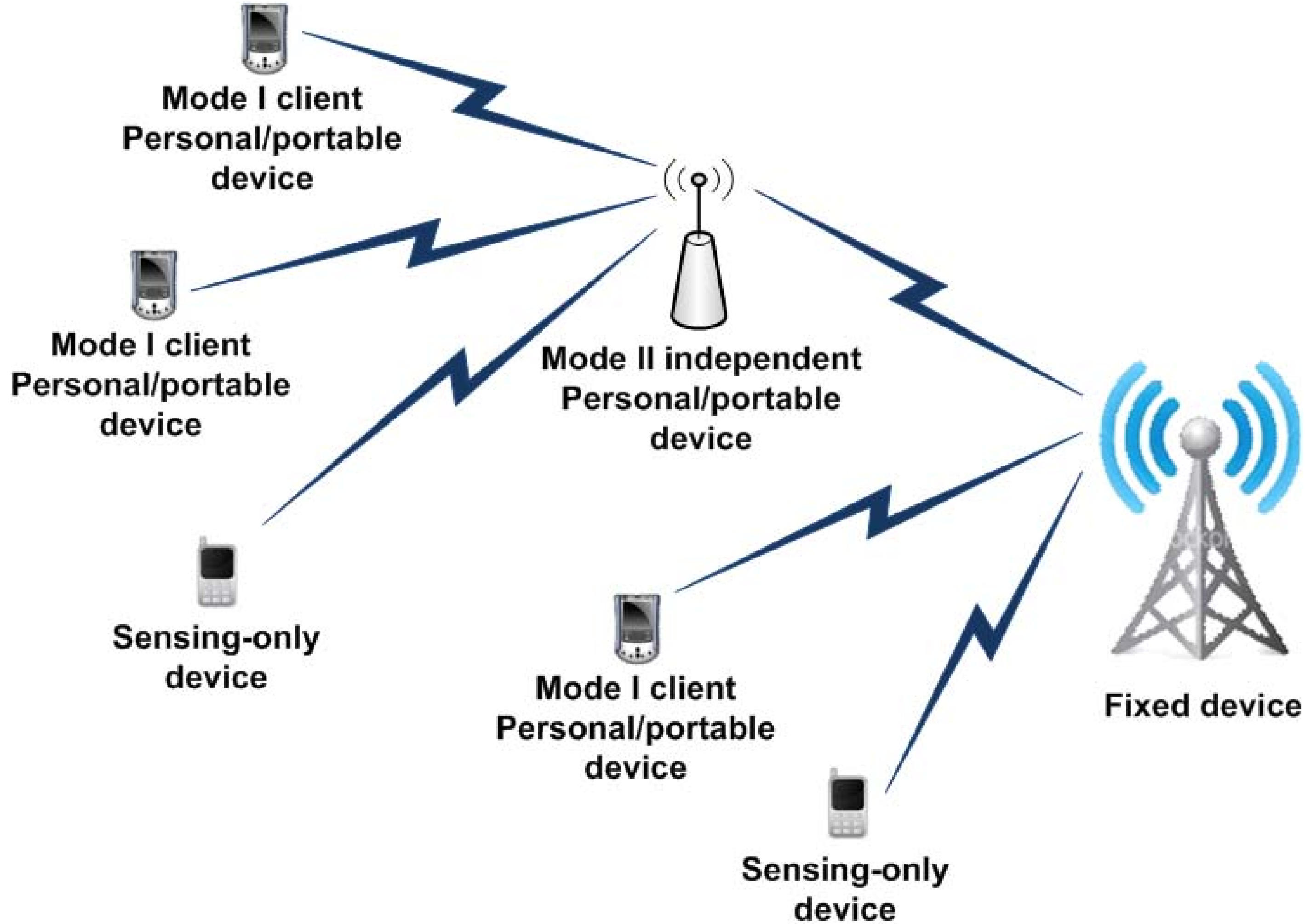
	Fixed device	Personal/portable device		
		Mode I (Client)	Mode II (Independent)	Sensing-only
Geo-location Awareness	Required (accuracy $\pm$ 50 m)	Not Required	Required (accuracy $\pm$ 50 m)	Not Required
Geo-location Re-establishment	Not Required	Not Required	Required (once / minute)	Not Required
Database Access	Required (once / day)	Not Required	Required (upon location change)	Not Required
Available Channels	2-51 (except 3,4,36-38)	21-51 (except 36-38)		
Power (EIRP)	4W	100 mW		50 mW
Spectrum Sensing	Not Required			Required

Source: Second Memorandum Opinion and Order, Federal Communications Commission, Document 10-174, Sept 23 2010

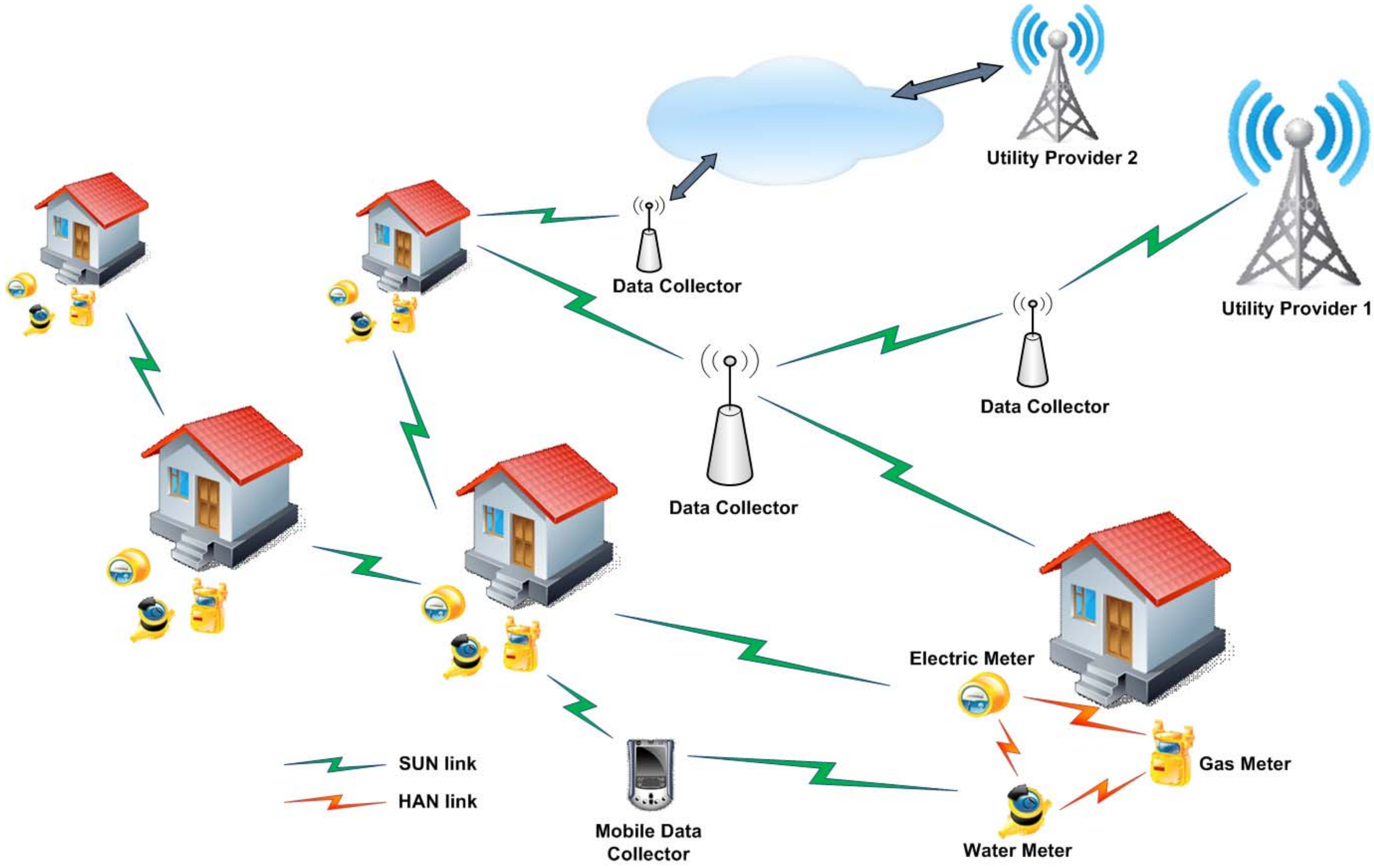
Example of Regulation ~ GDB and Enabling Protocol ~

- It is a fundamental requirement for devices operating in the TV white space not to transmit energy into the air without determining the absence of primary user in the channel of interest
- A mandatory method of determining the presence/absence of primary user is accessing a geolocation database (GDB) to obtain a list of channel which are vacant
- Fixed and Mode II independent devices are required to access the GDB through the Internet
- Upon determining vacancy of the channel of interest, fixed and Mode II then enables the Mode I devices to operate in TVWS
- Only upon being enabled, can the Mode I client devices start transmitting energy in the TV white space

Example
~ Regulatory Requirement – FCC ~



Example
~ Low Rate WPAN Architecture -SUN ~



Regulation-WPAN Mapping
~ SUN Components to TVBD ~

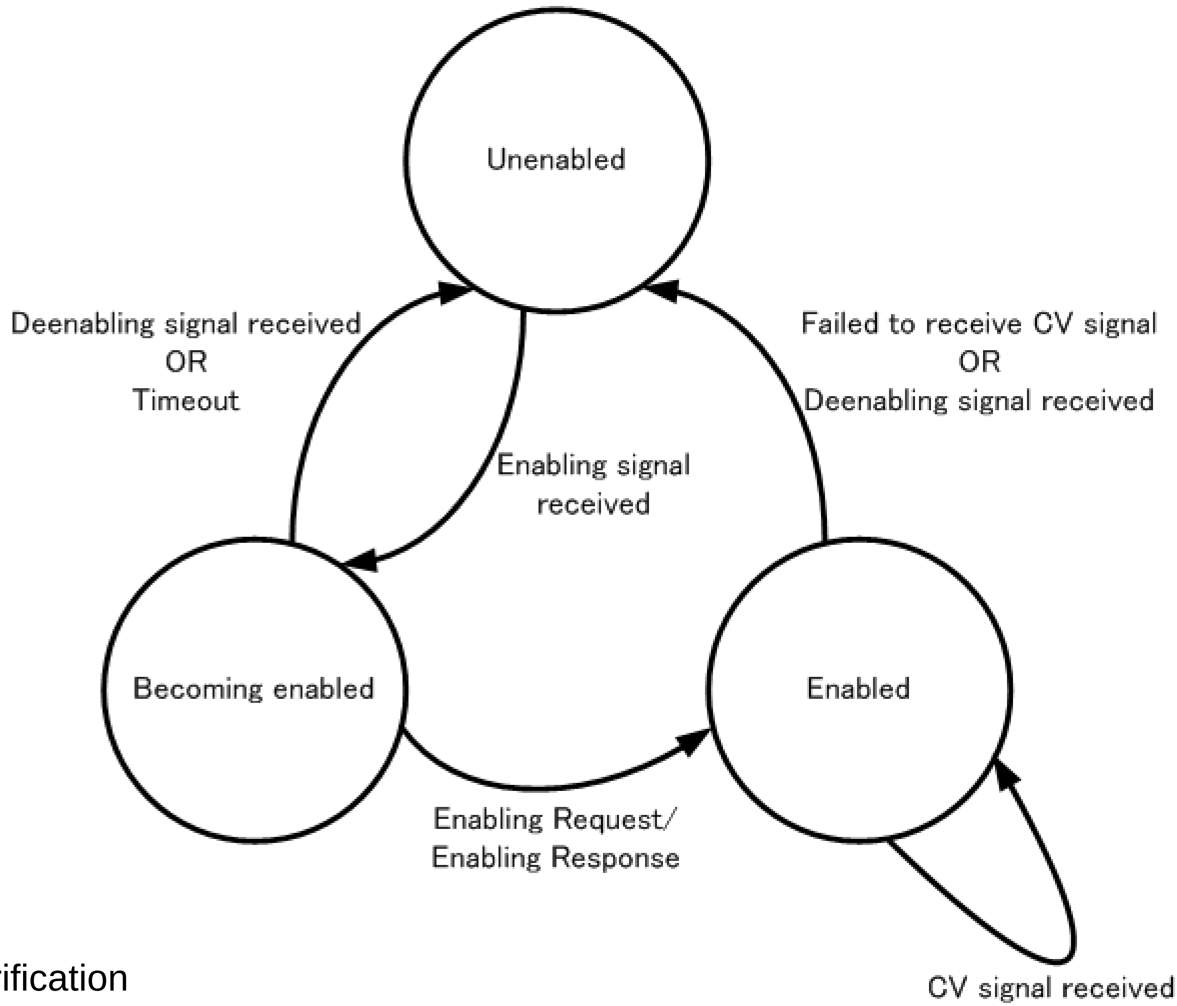
SUN Components	802.15.4 Device Type	TVBD Classes	Sensing Capability	Geolocation Awareness	Transmit Power
Utility provider base station	FFD	Fixed device	Not required	Required	4 W
Data collector	FFD	Mode II independent device	Not required	Required	100 mW
Electric/gas/water meter	FFD/RFD	Mode II independent device	Not required	Required	100 mW
		Mode I client device	Not required	Not required	100 mW
Mobile data collector	FFD/RFD	Mode II independent device	Not required	Required	100 mW
		Sensing-only device	Required	Not required	50 mW

Note: SUN components are examples to illustrate the mapping relationship between 802.15.4 networks and FCC requirements. Networks other than the 802.15.4 and regulations other than FCC may also go through the same mapping process

Enabling Protocol ~ Basic Operational Procedure ~

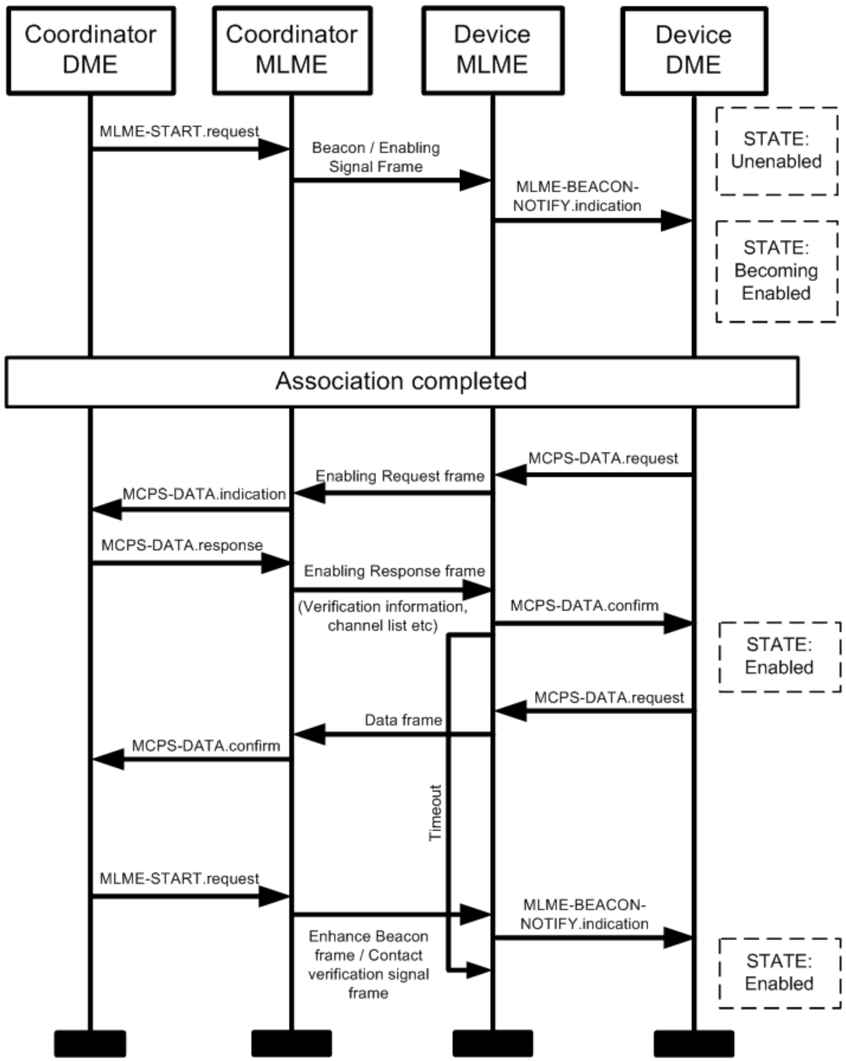
- Fixed and Mode independent II devices (*i.e.* 802.15.4m FFD) obtain the list of available TV channels from the GDB through the internet
- Then, the TV channels are mapped to corresponding WPAN channels
- Next, the fixed and Mode II devices transmit the enabling signal in the channel of interest to surrounding devices attempting to join the network
- Upon receiving the enabling signal, the Mode client I devices (*i.e.* 802.15.4m RFD) are to provide information for verification
- After verification, the fixed and Mode II devices send the WPAN channel list to the Mode I devices
- Besides the list of WPAN channels, the signal may also contain other information such as timing schedule for the occupancy of the channel and nearby locations where the channels are available
- Upon receiving the channel list, Mode I devices are then able to transmit signal in the specific channel(s) of interest
- Additionally, a periodic contact verification signal is required to constantly update the status of enablement
- For both the enabling signal and contact verification signals, the 802.15.4 beacon frame or enhanced beacon frame can be reused with additional IEs
- For the verification signaling handshake, the 802.15.4 command frames can be reused with additional IEs

State Transition Diagram



CV: contact verification

Message Sequence Chart ~ Enabling Protocol ~



Beacon-enabled and Non-beacon-enabled Networks

- The enabling protocol can be used in beacon-enabled and non-beacon-enabled networks
- In a beacon-enabled network, network structure is the superframe where enabling signal can be the periodic beacon and CV signal can be the enhanced beacon
- In a non-beacon-enabled, no superframe structure and enabling signal can be the beacon frame sent by the coordinator at will, active scanning by device not allowed

Frame Format

- Enabling signal frame (may reuse existing beacon frame)
  - Information on regulation and operating channel
- Enabling Request and Response Frame (may reuse existing command frame)
  - Verification information
  - List of vacant WPAN channels
  - Timing schedule for the vacancy
  - Information on vacancy for the channels in nearby locations
- CV Signal frame (may reuse existing enhanced beacon frame format)
  - Update on enablement status

Service Primitives

- Primitives between DME and MLME of initiator and responder devices on Enabling Signal and CV Signal frames (parameter addition to existing primitives)
  - MLME-START.request
  - MLME-START.indication
- Primitives between DME and MLME of initiator and responder devices on Multipurpose frames (parameter addition to existing primitives)
  - MCPS-DATA.request
  - MCPS-DATA.indication

Required Modification

- In order to support the enabling protocol
  - Three types of frame need to be defined
  - Two service primitives need to be defined
- For the frames, existing frame types can be modified
  - Enabling signal frame: beacon frame
  - Enabling Request and Response Frame: command frame
  - CV Signal frame: enhanced beacon frame
- For the service primitives, only addition of parameters to the existing primitives

Dynamic Band Switching

Summary

- This document proposes a Dynamic Band Switching (DBS) protocol to facilitate frequency band switching for IEEE 802.15.4 low rate WPAN systems
- High level system design is presented to provide an overview on the mechanism without the details
- This document presents the definition, motivation, basic procedures, state transition, frame format and service primitives for DBS

Outline

- What is DBS
- Why is DBS Needed
- Basic Operational Procedure
- Message Sequence Chart
- State Transition Diagram
- Frame Format
- Service Primitives

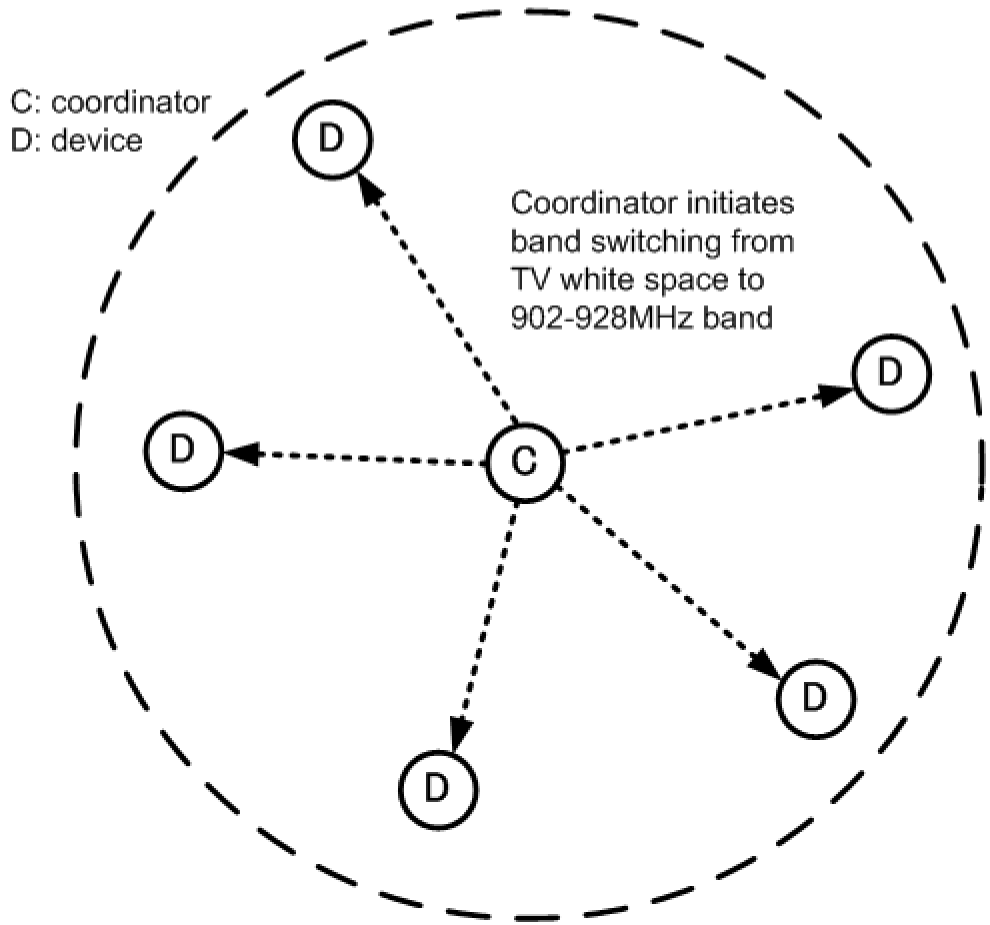
What is DBS

- Dynamic band switching (DBS) is a protocol facilitating switching between operating frequency bands
- There are many regulatory-domain specific frequency bands applicable only in certain locations
- Currently existing frequency bands that could be included into the DBS mechanism
  - TV White Space frequency bands
  - SUN frequency band specified in IEEE 802.15.4g
  - Other 802.15.4 frequency bands
  - ISM band

Why is DBS Needed

- Compatibility Improvement
  - With DBS, multi-band devices can be manufactured to simultaneously target multiple regulatory domains
- Performance enhancement
  - In times or locations where a certain frequency band has regulatory operating limitations, congested traffic or degrading performance, DBS facilitates band switching to a better environment, *i.e.* increasing number of supported users and reducing interference
- Risk reduction
  - Reducing the risk of relying on implementing a system in one particular band

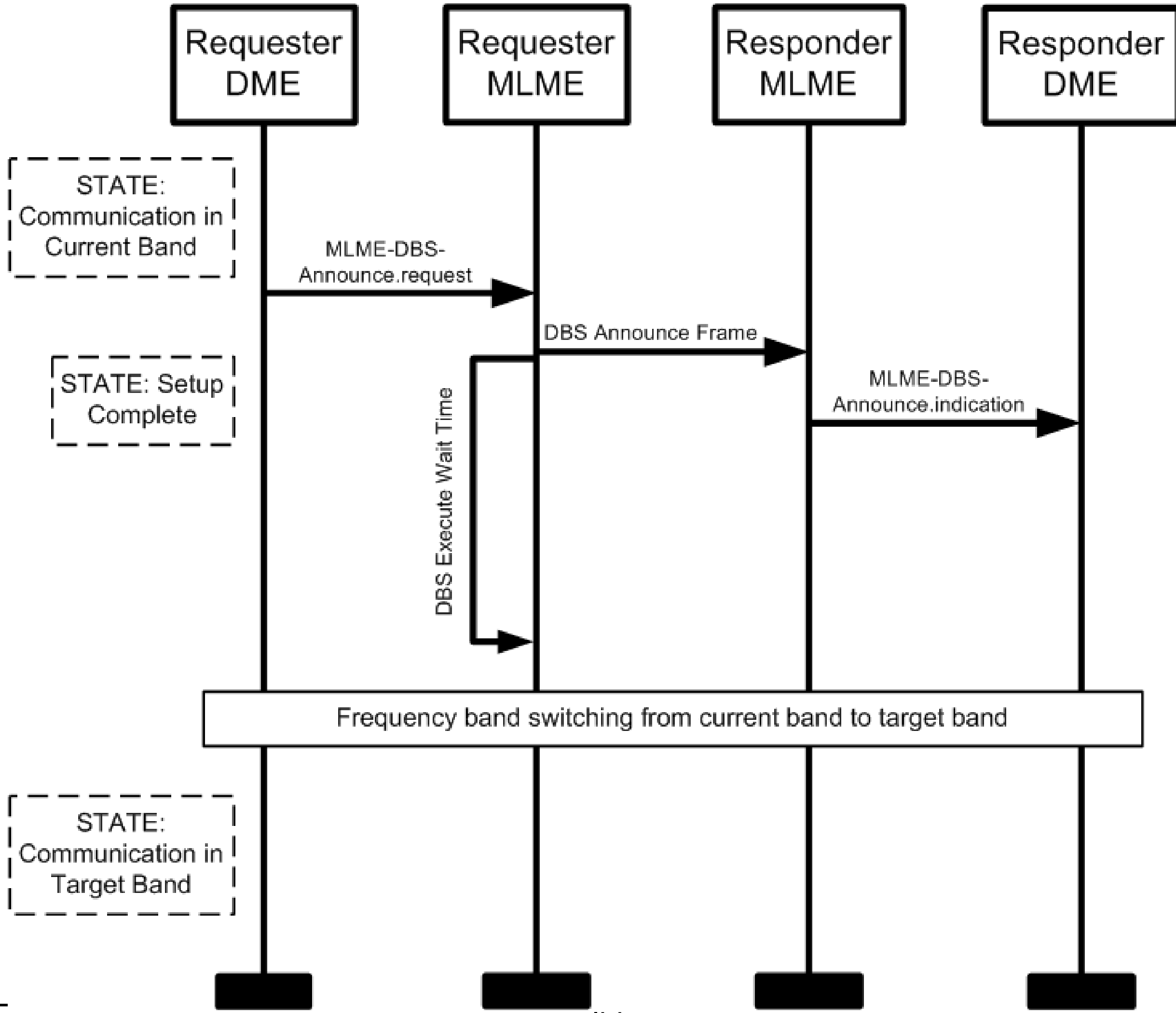
Use Case Example



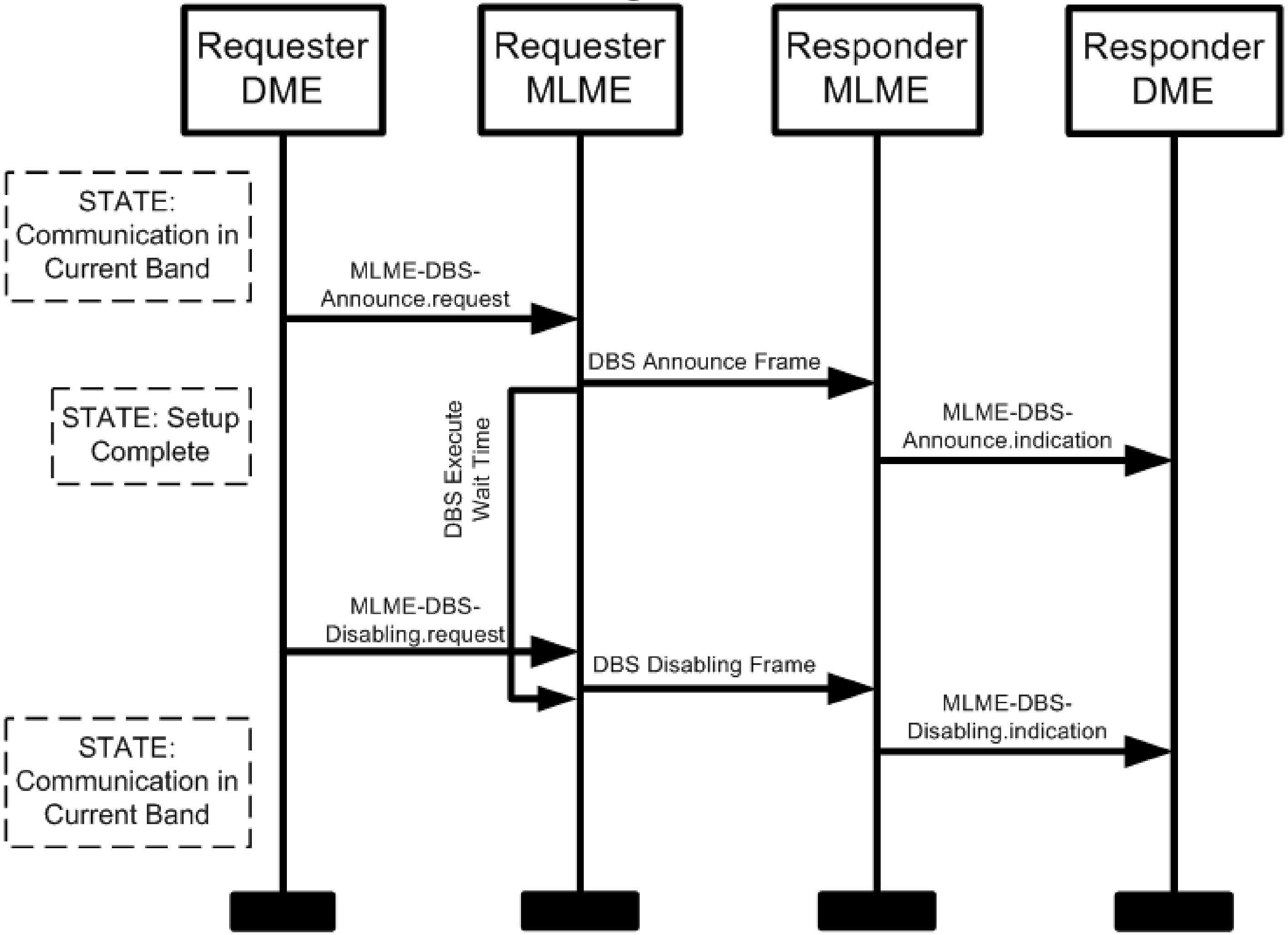
Basic Operational Procedure

- To start DBS, the list of supported frequency bands are exchanged between devices in the network
- The requester sends out the DBS Announce frame containing all information needed to perform band switching, including the time for all the devices to commence the band switching
- When the Execute time scheduled by the requester arrives, the operating band of both the requester and responder will be switched to the new band parameters
- During the period of Execute time waiting, if for any reason, the requester decides to cancel DBS, the DBS Disabling frame can be used to cancel the operation

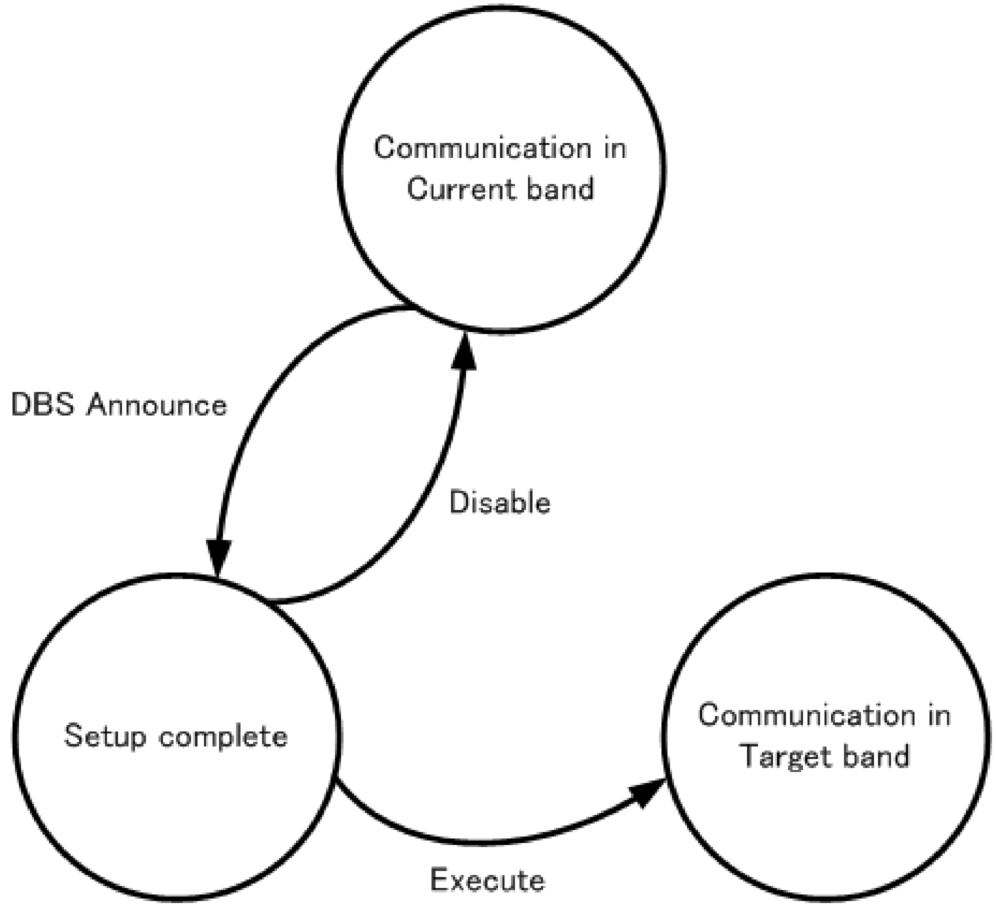
Message Sequence Chart ~ Switching Successful ~



Message Sequence Chart ~ Switching Disabled ~



State Transition Diagram



State Description

- Communication in Current Band:
  - Data communication in current (old) frequency band
  - Initiator (normally the coordinator) announces the intention to switch frequency band
  - DBS Announce frame used to initiate state change
    - DBS Announce frame consists of the time to commencement of band switching
- Setup Completed:
  - Running Timer for band switching
  - If initiator decides to disable the band switching, DBS disabling frame is sent
- Communication in Targeted Band:
  - Data communication in target (new) frequency band

Frame Format

- Frame containing the list of supported frequency bands
  - Bitmap representation of the list of supported frequency bands
  - Multi-band capability
- DBS Announce Frame
  - Target frequency band and channel information
  - Timing to perform switching to the target band
- DBS Disabling Frame
  - Disabling the switching process and continue operating in the current frequency band
- Alternatively, the list of supported frequency bands, DBS Announce frame and DBS Disabling frame can be formatted as IEs in a part of any current existing frame

Service Primitives

- Primitives between DME and MLME of requester and responder devices on DBS Request and Respond frames
  - MLME-DBS-Announce.request
  - MLME-DBS-Announce.indication
- Primitives between DME and MLME of requester and responder devices on DBS Disabling
  - MLME-DBS-Disabling.request
  - MLME-DBS-Disabling.indication

Required Modification

- In order to support the band switching protocol
  - Two types of frame need to be defined
  - Two service primitives need to be defined
- For the frames, existing frame types can be modified
  - DBS Announce Frame: command frame
  - DBS Disabling Frame: command frame
- For the service primitives, existing primitives can be reused with addition of parameters

Power Saving Mechanism

Summary

- This document proposes a low energy consumption mechanism for scalable power saving modes in IEEE 802.15.4 low rate WPAN systems
- High level system design is presented to provide an overview on the mechanism without the details
- The proposed mechanism is based on a generic network architecture addressing both symmetrical and asymmetrical energy consumption models
- The basic operational procedure, illustrations, message sequence charts, flow chart, frame formats and service primitives are presented

Outline

- Motivation
- Basic Operational Procedure
- Illustration of Procedure
- Message Sequence Charts
- Flow Chart
- Frame Format
- Service Primitives

Motivation

- Battery lifespan is an important feature for utility and sensor networks where most of the nodes are wireless meters
- One of the energy draining mechanism is the scanning process of a device
- Low energy consumption and extended battery lifespan can be achieved if the total time used for scanning is reduced
- On the other hand, if scanning is reduced, data exchange probability between two devices becomes lower

Basic Operational Procedure

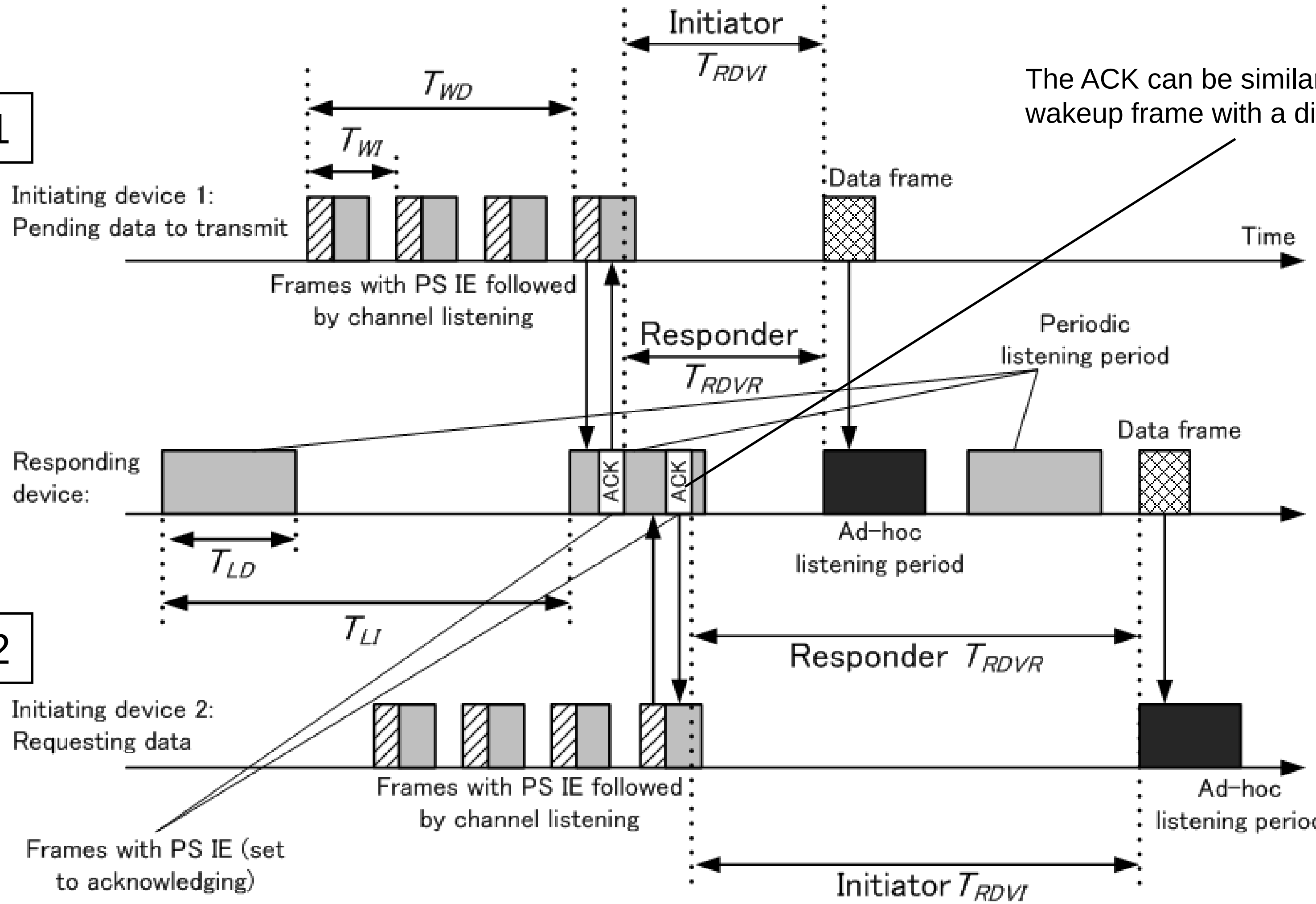
- The responding device switches on the periodic listening periods T_{LI} apart each with duration T_{LD}
- The initiating device transmits multiple Wakeup frames (followed by channel listening), *TWI* apart for maximum total duration T_{WD} (or upon receiving an ACK, whichever occurs first)
  - Note: $T_{WI} <= T_{LD}$ and $T_{LI} <= T_{WD}$
  - Note: upon receiving ACK from the responding device, transmission of Wakeup frames will be stopped
- The Wakeup frame contains information on:
  - Whether the initiating device is transmitting pending data (case 1) or requesting for data (case 2)
  - Timing information for rendezvous
- Upon receiving a Wakeup frame, the responding device
  - Case 1: Switches on an ad-hoc listening period to receive the data from the initiating device at rendezvous time (the ad-hoc listening period can be the subsequent periodic listening period)
  - Case 2: Transmit the data requested by initiating device at rendezvous time
- Rendezvous time can be set by initiator and updated by responder if necessary

Illustration of Procedure

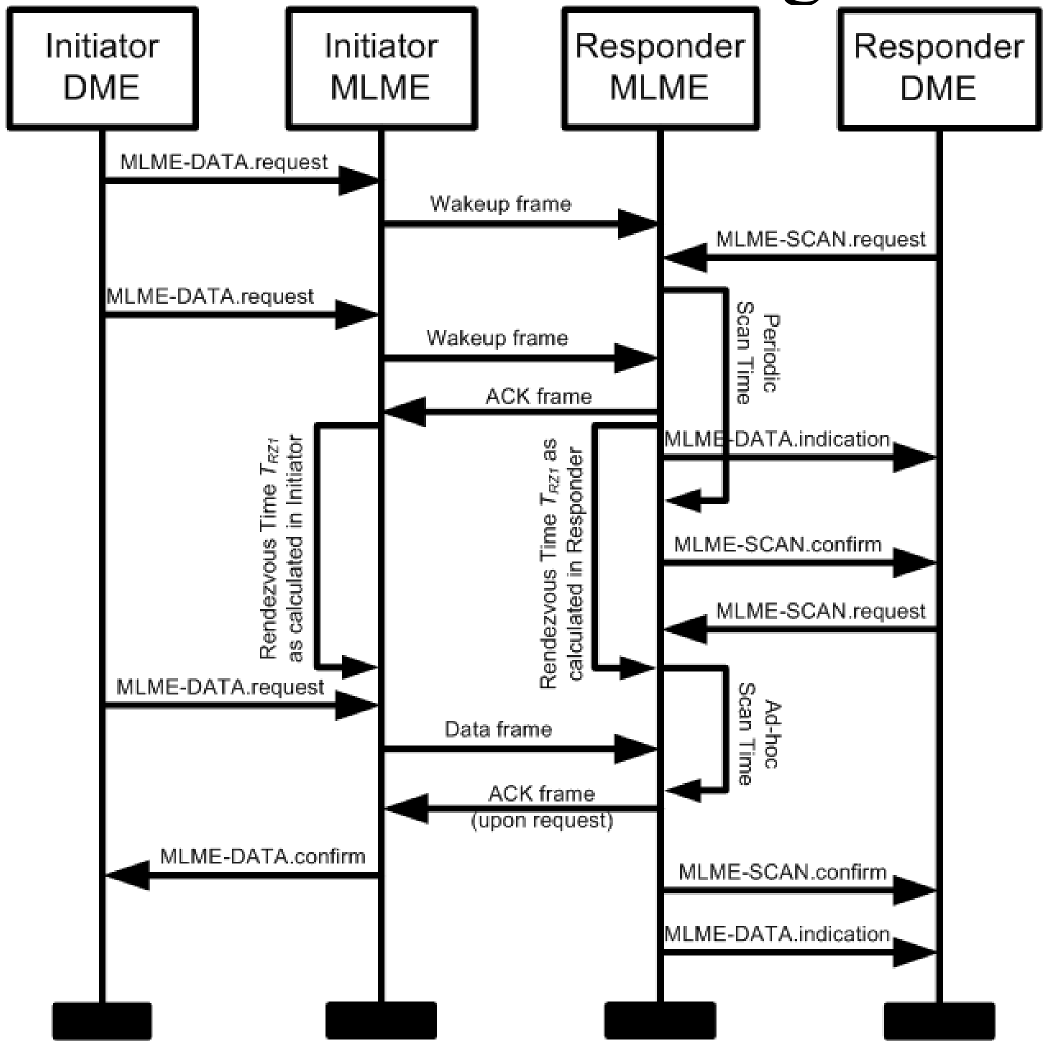
Case 1

Case 2

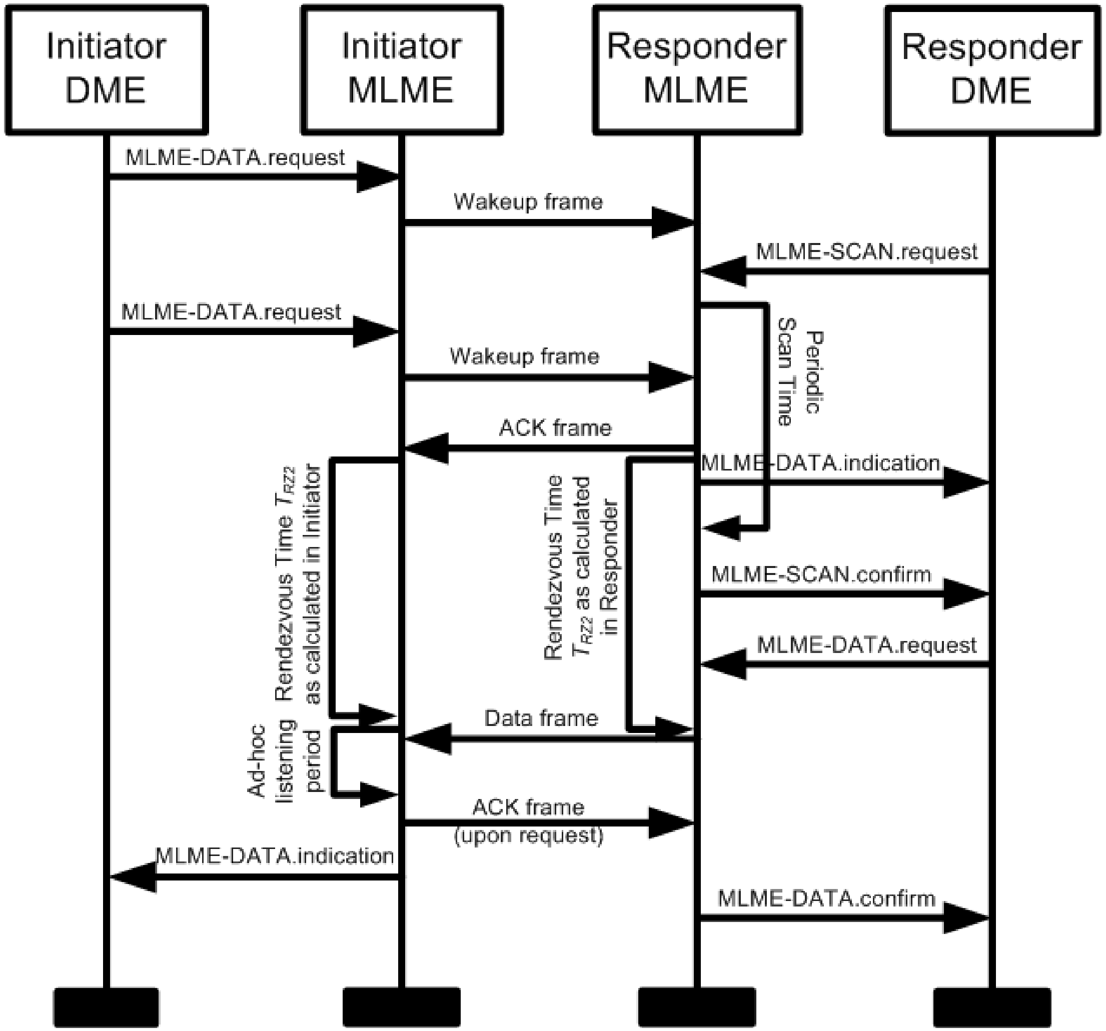
The ACK can be similar to a wakeup frame with a different IE



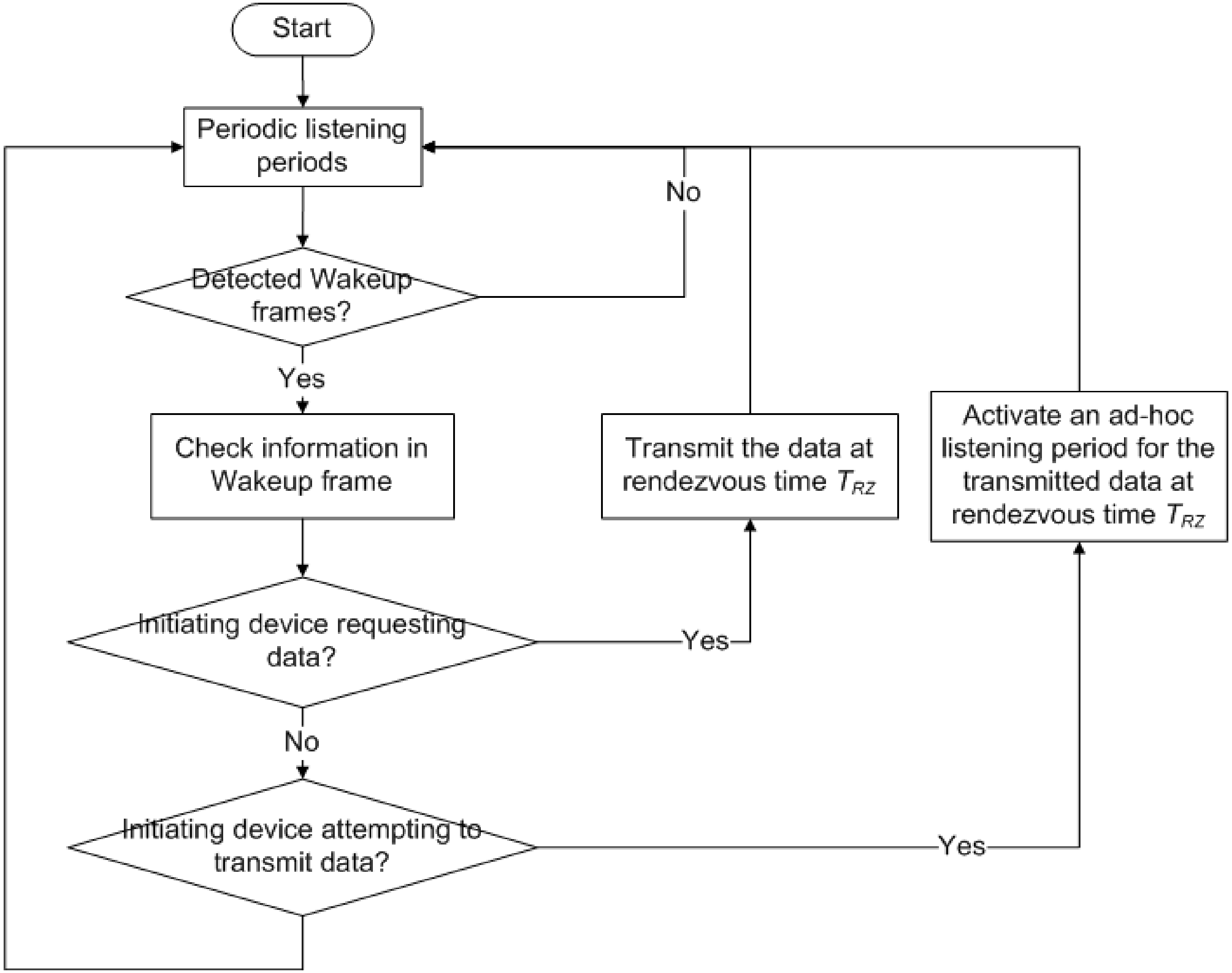
MSC for Case 1 ~ Initiator with Pending Data~



MSC for Case 2
~ Initiator with Data Request ~



Responding Device Flow Chart



Frame Format

- Wakeup frame (may reuse existing frame format)
  - whether the initiating device intends to
    - Transmit pending data
    - Request data
  - rendezvous time
  - size of data to be exchanged
  - timing information T_{WI} , T_{WD} , T_{LI} , T_{LD} and T_{RZ}
- The information in the Wakeup frame to be inserted into the beacon for beacon-enabled network

Service Primitives

- Primitives between DME and MLME of initiator and responder devices on Wakeup frame (parameter addition to existing primitives)
  - MLME-DATA.request
  - MLME-DATA.indication
  - MLME-DATA.confirm
- Primitives between DME and MLME of initiator and responder devices for periodic and ad-hoc scan (parameter addition to existing primitives)
  - MLME-SCAN.request
  - MLME-SCAN.indication

Required Modification

- In order to support the power saving protocol
  - One type of frame need to be defined
  - Two service primitives need to be defined
- For the frame, existing frame types can be modified
  - Wakeup Frame: enhanced beacon frame
- For the service primitives, existing primitives can be reused with addition of parameters

Direct Device-to-device Data Transfer

Summary

- This document proposes four modes of direct device-to-device data transfer in IEEE 802.15.4 WPAN, including neighbor discovery mechanism
- Main operation procedures as well as message sequence charts are presented

Outline

- Legacy data transfer methods
- Disadvantages of legacy data transfer methods
- Concept of direct data transfer and advantages
- Category and enabling conditions of direct data transfer
- Neighbor discovery mechanism and message sequence chart
- Mechanism of Probing-mode direct data transfer
- Mechanism of Polling-mode direct data transfer
- Mechanism of Broadcast-mode direct data transfer
- Mechanism of Multicast-mode direct data transfer

Legacy Data Transfer Methods

- There are three legacy data transfer transactions in IEEE std 802.15.4-2011
  - Data transfer to a coordinator in which a device transmits the data
  - Data transfer from a coordinator in which the device receives the data
  - Data transfer between two peer devices
- In star topology, only the first two transactions are used because data is exchanged only between the coordinator and a device
- In peer-to-peer topology, all three transactions are used

Disadvantage of Legacy Data Transfer Methods

- In star topology, data transfer is only allowed between coordinator and device. If one device has data for another device in the same PAN, data transfer needs to be relayed by the coordinator. Compared to direct data transfer, it likely has larger time delay, consumes more power and band resource
- As there is no technical details of data transfer between two peer devices in peer-to-peer PAN network in current 802.15.4-2011 standard, relay may be required for data transfer from one device to another device even they are within radio range each other. Similarly, it may has larger time delay, consumes more power and band resource

Direct Device-to-device Data Transfer

- With direct device-to-device data transfer, two devices of a PAN within radio range each other may transfer data directly
- Advantages of device-to-device data transfer
    - Shorter time delay, which is critical in time-delay sensitive applications
    - May save energy, which is very critical for PAN devices using battery
    - May save header cost and bandwidth, which is critical for resource-limited PAN applications

Category of Direct Device-to-device Data Transfer

- Depending on network topology, there are two possible cases that direct device-to-device data transfer may be applied:
  - In the first case, the two devices associate with the same coordinator, i.e., the two devices have the same father. Examples are devices of a PAN with STAR topology, and devices with the same father in a cluster tree topology.
  - In the second case, the two devices associate with different coordinators of a PAN, i.e., the two devices have different fathers.
- In this design we consider the first case, since in the second case, transmission between two devices with different father may introduce interference to other devices due to overlapped superframe timing.

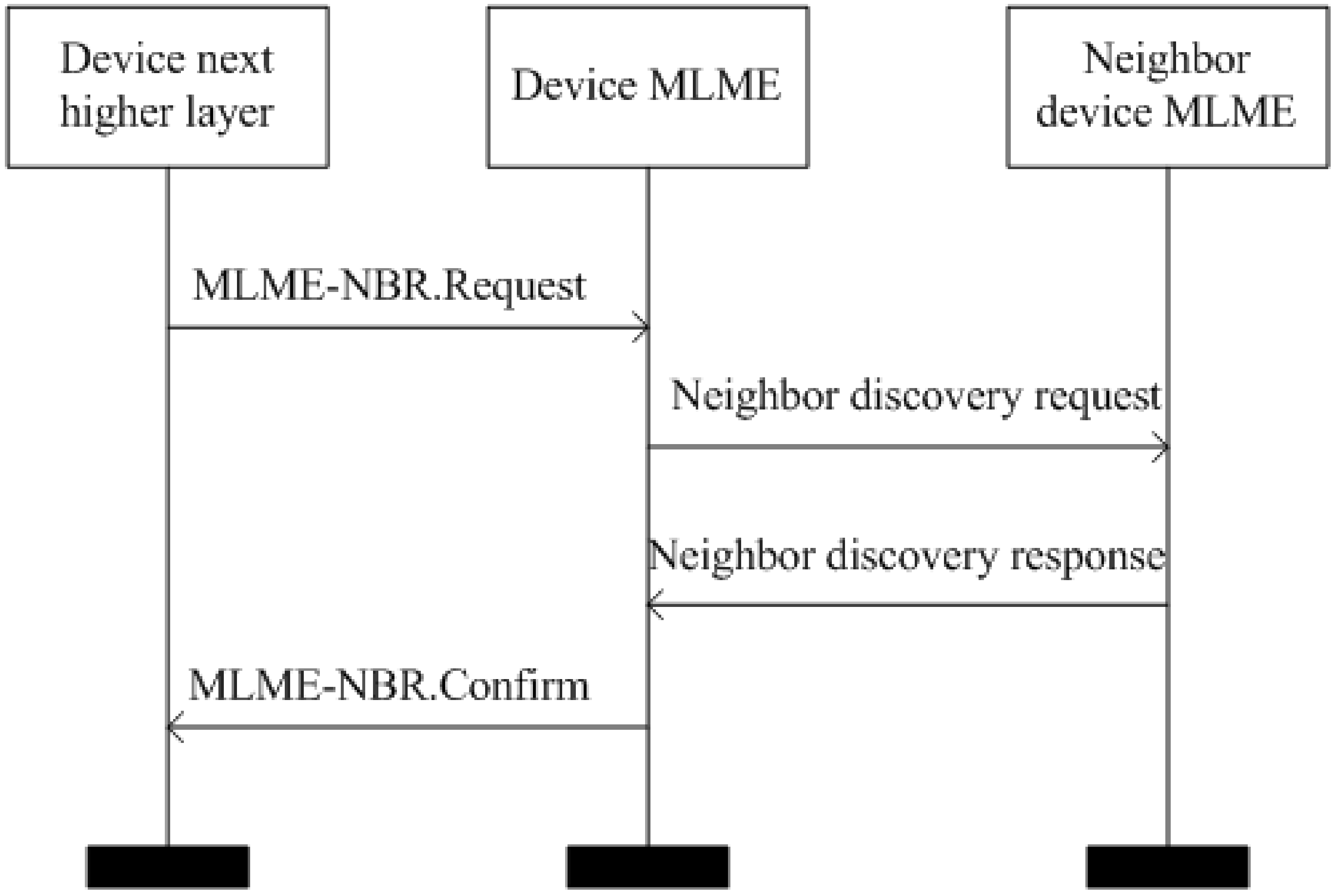
Enabling Conditions

- There are three enabling conditions for direct device-to-device data transfer
  - Operating channel
    - For direct data transfer, the two devices shall operate in the same frequency channel (TVWS channel)
    - In this design, we assume that mechanism has been applied and the two devices operate in the same frequency channel during command and data exchange
  - Radio range
    - The two devices shall be within communication radio range each other
    - This requires neighbor discovery mechanism
  - Device status
    - Both data source and destination device shall be awake (transmitter and/or receiver are turned on)

Neighbor Discovery

- A device may carry out neighbor discovery after association with its coordinator, at appropriate time when receives order from its next higher layer
- Neighbor Discovery Procedure:
  - Requester device broadcasts Neighbor Discovery Request command at appropriate time
  - When a neighbor device receives a Neighbor Discovery Request command, it replies a Neighbor Discovery Response command if it has same father device of the requester. Otherwise, it ignores the message
  - When the requester receives corresponding Neighbor Discovery Response command, it adds the neighbor in its neighbor list if the neighbor is not included

Message Sequence Chart for Neighbor Discovery



Mechanism of Direct Device-to-device Data Transfer

- Four modes of direct data transfer are proposed:
  1. Probing Mode – hi, are you there? I have data for you!
  2. Polling Mode – hi, do you have data for me?
  3. Broadcast Mode – to broadcast data to all neighbor devices
  4. Multicast Mode – to send data to a list of neighbor devices

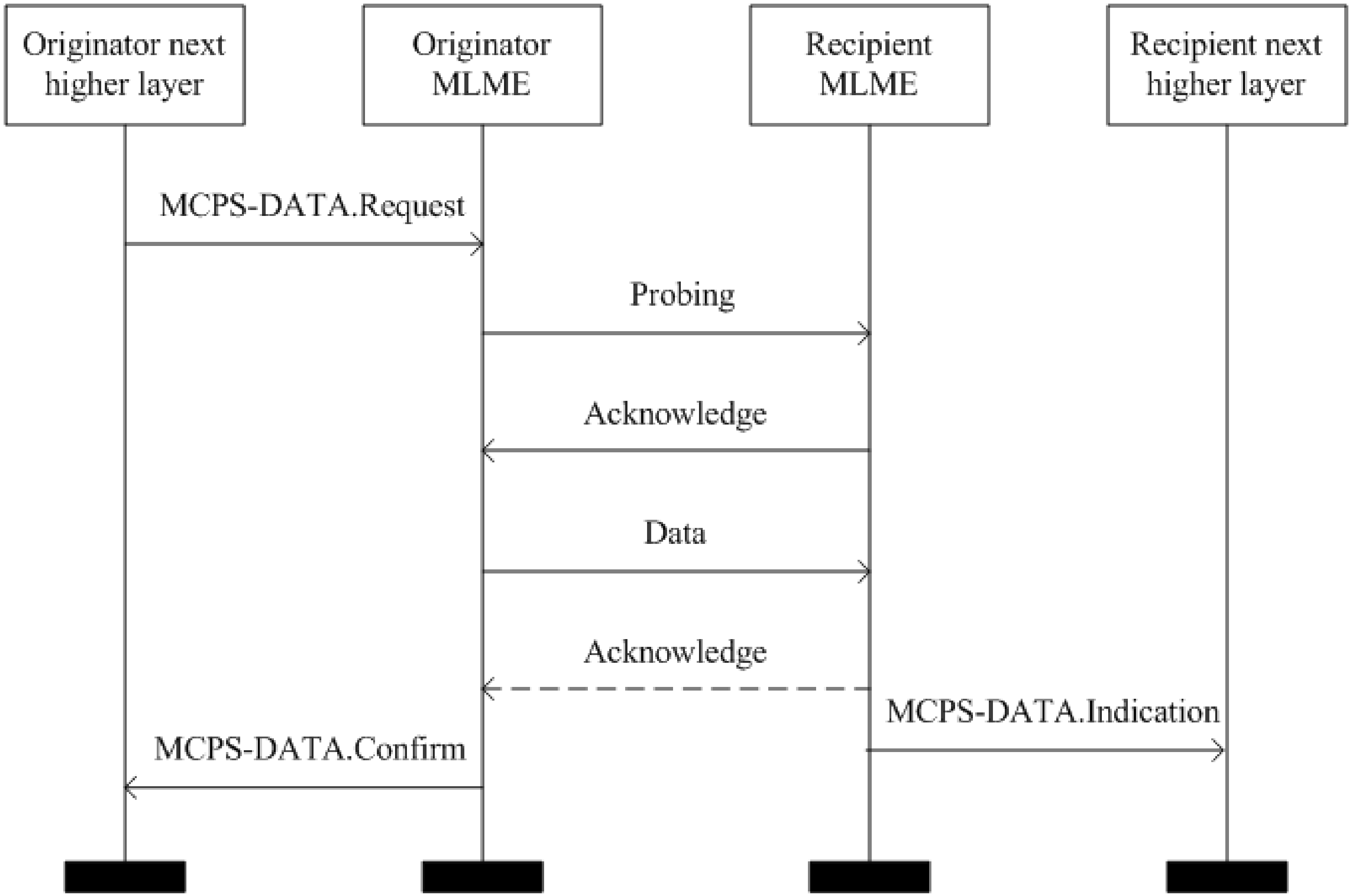
Additions and Modifications when Compared to Legacy Data Transfer Methods

	Coordinator to Device	Device to Coordinator	Probing mode	Polling Mode	Broadcast Mode	Multicast Mode
Beacon-enabled PAN	Indicating data pending in beacon; sends data to device when request	Device sends to coordinator when synchronize	Source device probes status of destination device before transmitting	Device polls neighbor device for data	Device simply broadcasts data to neighbor devices directly	Device simply multicasts data to a list of neighbor devices directly
Non-beacon Enabled PAN	Device polls coordinator for data	Device simply transmits to coordinator				

Probing Mode

- When a device has data for one of its neighbor devices, it sends a Probe command to the destination device if the status of the destination device is unknown
- When a destination device receives a Probe command, it acknowledges reception of Probe command and it enables its receiver for certain time duration to receive data
- When receives Acknowledgement of Probe command, the source device sends data to the destination device at appropriate time
- If within certain time period, the source device hasn’t received Acknowledgement, then it has two options:
  - First, the source device sends the data to the coordinator using legacy method. The coordinator stores the data and sends it to the destination device using legacy method
  - Second, the source device stores the data, and tries to send to the destination device in future

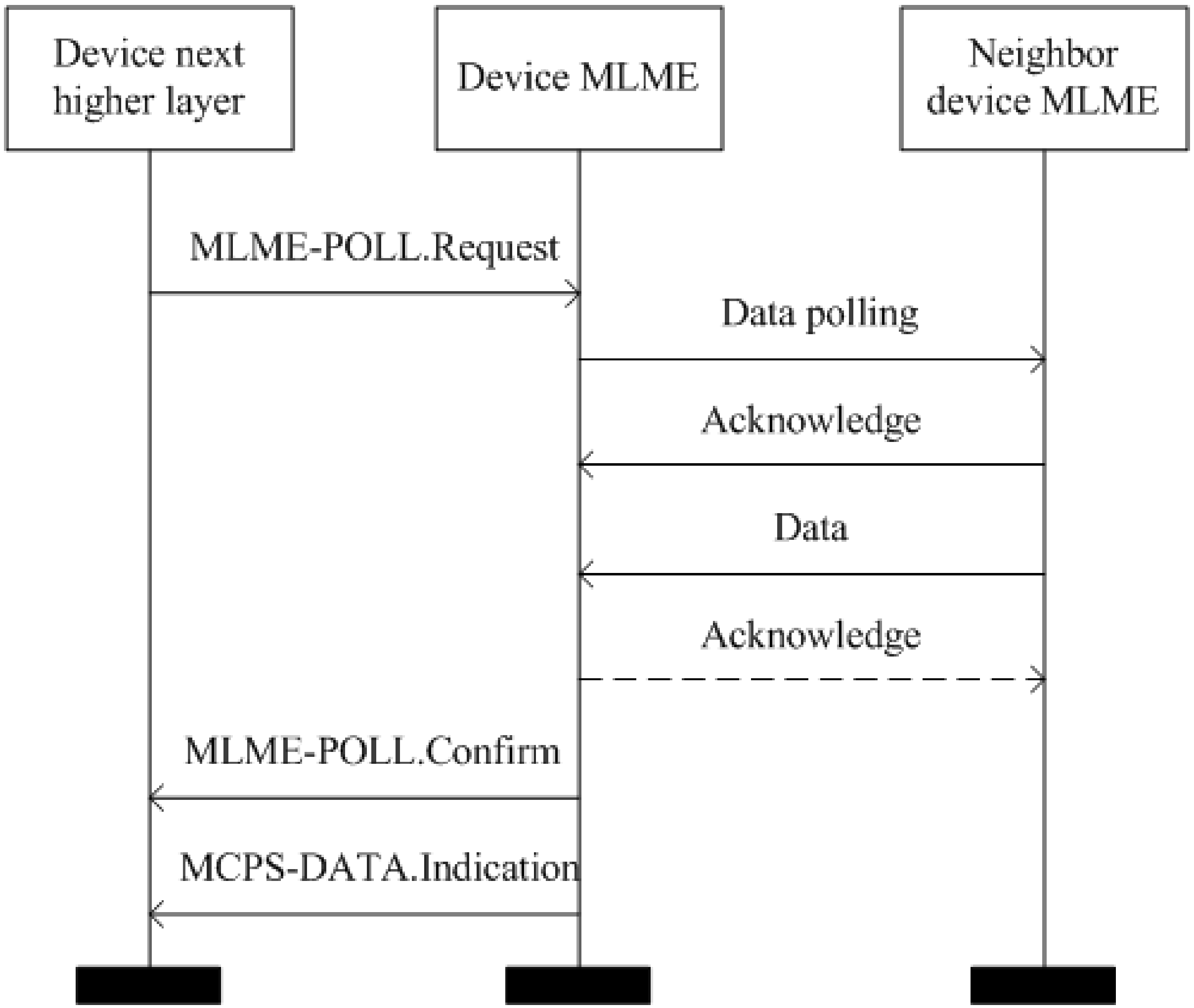
Message Sequence Chart of Probing-Mode Direct Data Transfer



Polling Mode

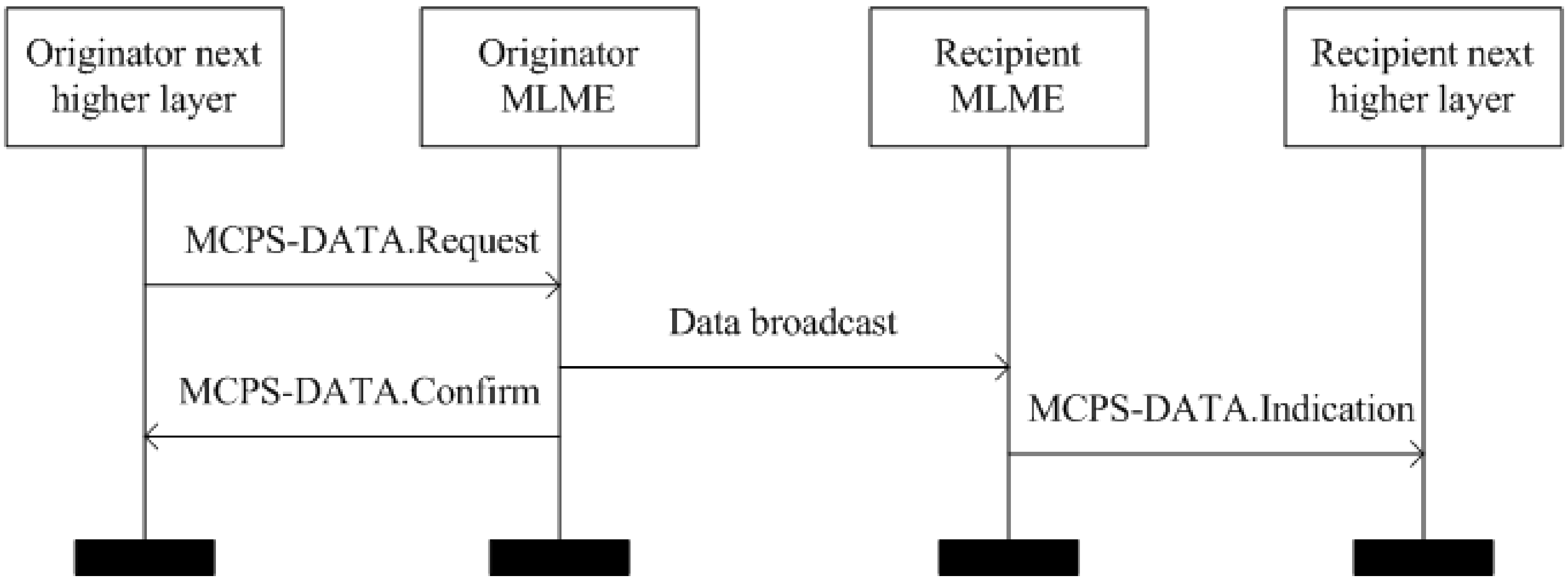
- A device sends Data Polling command if its next higher layer has such a request
- When receives Data Polling command, a device acknowledges reception and indicates whether it has data for the polling device
- If a device has data for the polling device, it sends data to it after acknowledgement. After receiving data, the polling device acknowledges reception of data if required

Message Sequence Chart of Polling-Mode Direct Data Transfer



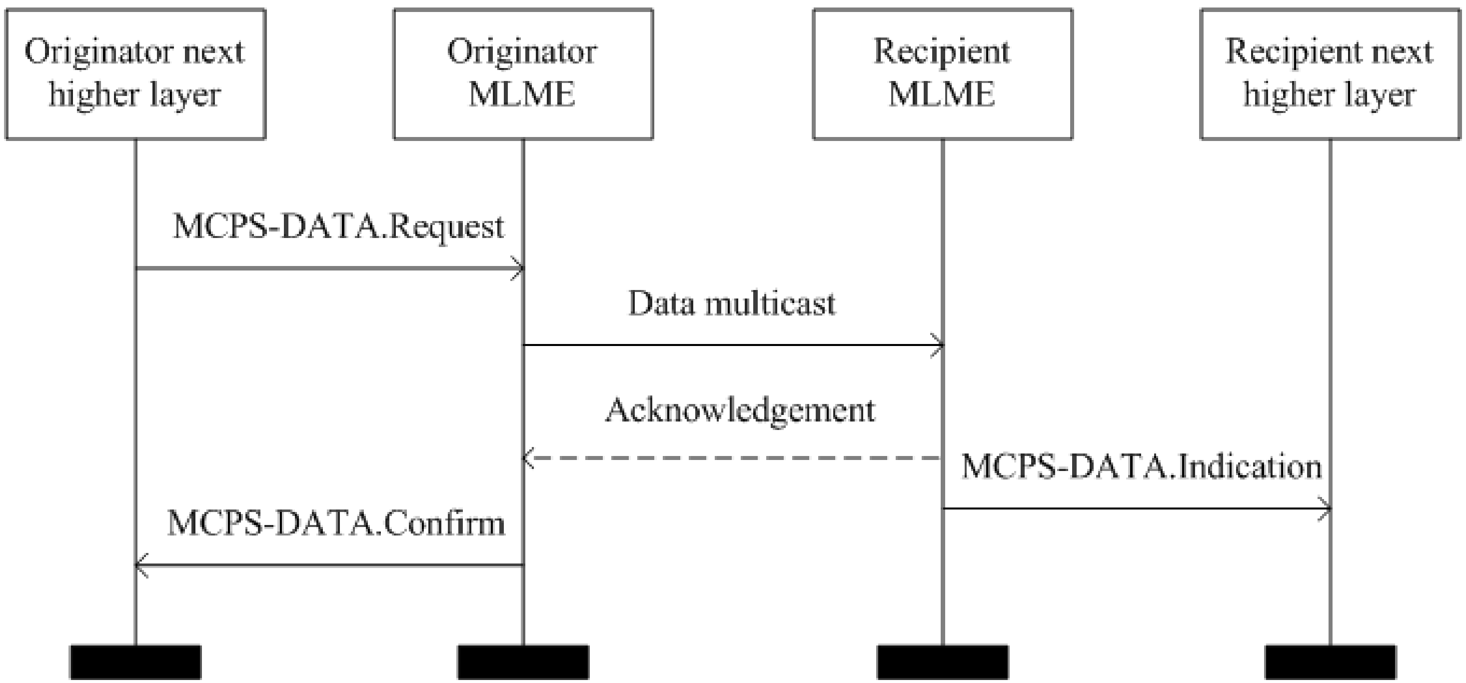
Broadcast Mode

- In broadcast mode, a device directly broadcast to all of its neighbors



Multicast Mode

- In multicast mode, a device sends directly to a list of its neighbors



Overall Conclusion

- This document presents 2 PHY and 4 MAC proposals for the TG4m devices
- This document gives the basic idea of the proposals
- Details for each mechanism will be given in the next round of proposal