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

Submission Title: Preliminary PHY Proposal for IEEE 802.15.4m
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Re: Call for Proposals

Abstract: This contribution presents a preliminary PHY proposal for the IEEE 802.15 TG4m.

Purpose: Technical Proposal for discussion in IEEE 802.15.4m

Abstract

- This contribution presents a preliminary PHY proposal for the IEEE 802.15.4m which is the amendment for use of TV whitespace (TVWS) in IEEE 802.15.4 standard
- This PHY proposal contains
  - Band Plan
  - Suggested PHY options
    - FSK/FH PHY for low-rate applications
    - OFDM PHY for mid-rate applications

  based on the technical requirements in [1] and link budget analysis

Technical Requirements [1]

- Meet at least one, and as many as practical, TV White Space regulatory requirements.
- Specify operations in TV white space frequency bands under regulatory constraints that can be identified.
- Support PHY data rate of typically 40kbps to 2000kbps. (~10Mbps desired).
- Cover operating range of at least 1km.
- Provide at least one operation mode that supports up to at least 1000 direct neighboring devices.

Key elements on the spectrum mask in TVWS
(FCC Third MO&O [2])

Table 1 Key spectrum mask elements in TVWS (FCC)

Type of TV bands device	**Power limit (6 MHz)**	**PSD limit (100 kHz)**	**Adjacent channel limit (100 kHz)**
Fixed	30 dBm (1 Watt)	12.6 dBm	-42.8 dBm
Personal/portable (adj. channel)	16 dBm (40 mW)	-1.4 dBm	-56.8 dBm
Sensing only	17 dBm (50 mW)	-0.4 dBm	-55.8 dBm
All other personal/portable	20 dBm (100 mW)	2.6 dBm	-52.8 dBm

Preliminary Link Budget Analysis

- Assumptions
  - LOS propagation model [1] is considered.
  - Receiver sensitivity level = -85 dBm
    (Highest level of sensitivity requirements in the IEEE Std. 802.15.4-2006 [3])
  - Transmitter PSD emission limit = 2.6dBm/100kHz
    (FCC 3rd MO&O, personal/portable device)
  - Antenna Gain at the base station: G_B=0dBi
  - Antenna Gain at the terminal station: G_T=0dBi

Link Budget Examples

Table 2 Examples of link budget calculations

Parameter	Case 1	Case 2	Case 3	Remarks
Signal Bandwidth	500 kHz	1 MHz	2 MHz	
Average Tx power	9.6 dBm	12.6 dBm	15.6 dBm	2.6dBm/100kHz
Tx antenna gain (G_B)	0 dBi	0 dBi	0 dBi	(Portable)
Center frequency (f_c)	695 MHz	695 MHz	695 MHz	Channel 51 (US)
Path loss at 1 km (L_1)	89.28 dB	89.28 dB	89.28 dB	LOS channel
Rx power at 1 km	-79.68 dBm	-76.68 dBm	-73.68 dBm	-85 dBm or better
Path loss at d km (L_d)	95.30 dB at d = 2 km	95.30 dB at d = 2 km	98.82 dB at d = 3 km	
Rx power at d km	-85.70 dBm at d = 2 km	-82.70 dBm at d = 2 km	-83.32 dBm at d = 3 km	-85 dBm or better

Available Communication Range based on the link budget analysis (preliminary)

- Communication distance to satisfy -85 dBm sensitivity.
  - Portable devices, LOS channel model
- Observations
  - A few hundred kilohertz signal bandwidth is necessary
  - 1 megahertz signal bandwidth seems desirable.

Table 3 Communication distance (in km) to satisfy -85 dBm receiver sensitivity

Center Frequency [MHz]		Signal Bandwidth [kHz]						
		100	500	1000	2000	3000	4000	5000
515	(21 ch)	1.11	2.48	3.51	4.97	6.09	7.03	7.86
596	(35 ch)	0.96	2.14	3.03	4.29	5.26	6.07	6.79
695	(51 ch)	0.82	1.84	2.6	3.68	4.51	5.21	5.82

Preliminary PHY Proposal

- Based on the link budget analysis, we propose the following PHY configurations
  - Band plan
  - PHY for low-rate applications --- FSK/FH
    - Smart Utility Networks (SUN) , Infrastructure monitoring M2M applications
  - PHY for mid-rate applications --- OFDM
    - Intelligent Transportation Systems, Digital Signage System

Band Plan

- 6MHz channel is divided into 4 subchannels with 1.2 MHz bandwidth
- Guard band with 0.6 MHz is reserved at the upper and lower edge of the channel in use
  - To comply with the stringent out-of-band PSD limit

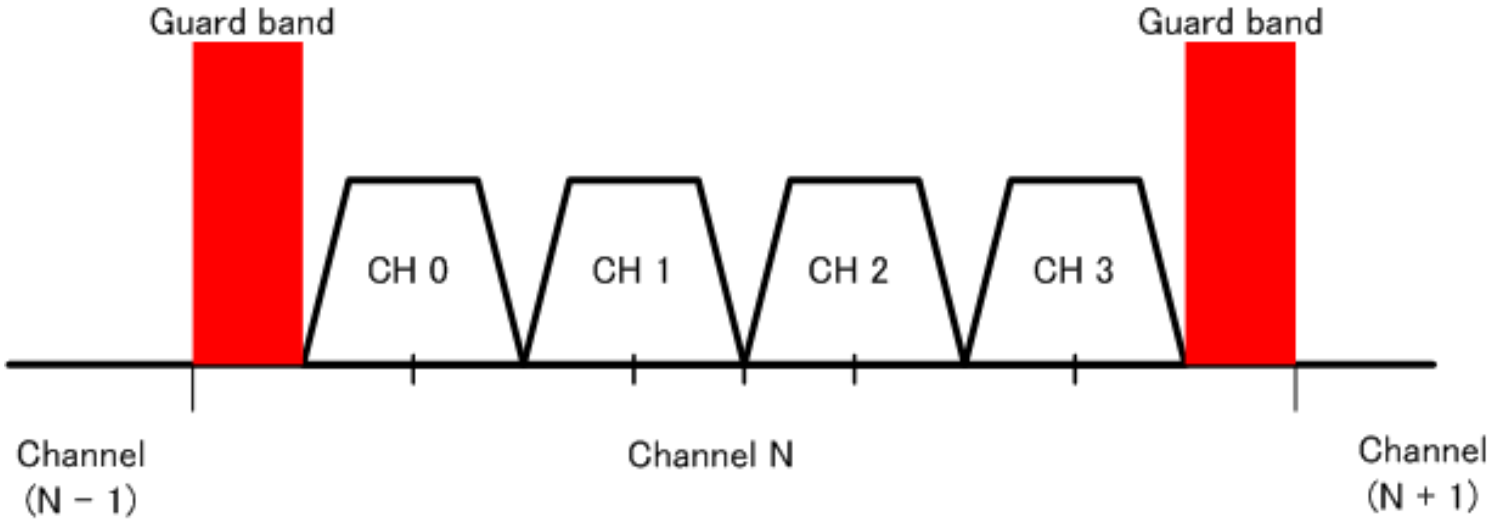
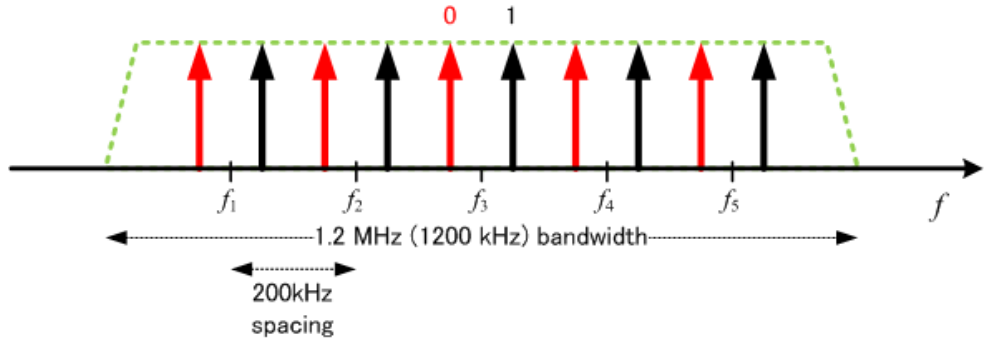


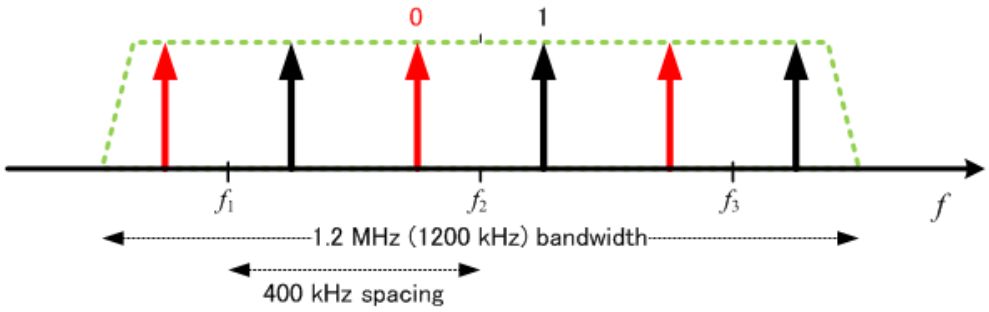
Fig. 1 Proposed Band Plan (1.2MHz x 4 subchannels and 0.6MHz x 2 guard bands)

Preliminary PHY Proposal(1)

- FSK/FH for low-rate applications
  - Compatible to 802.15.4g FSK mandatory PHY
  - Frequency hopping is applied to occupy more bandwidth so that more emission power is available.



(a) Data rate = 50 (kbps), 5 hops



(b) Data rate = 100 (kbps), 3 hops

Fig. 2 Carrier allocation of FSK/FH signals

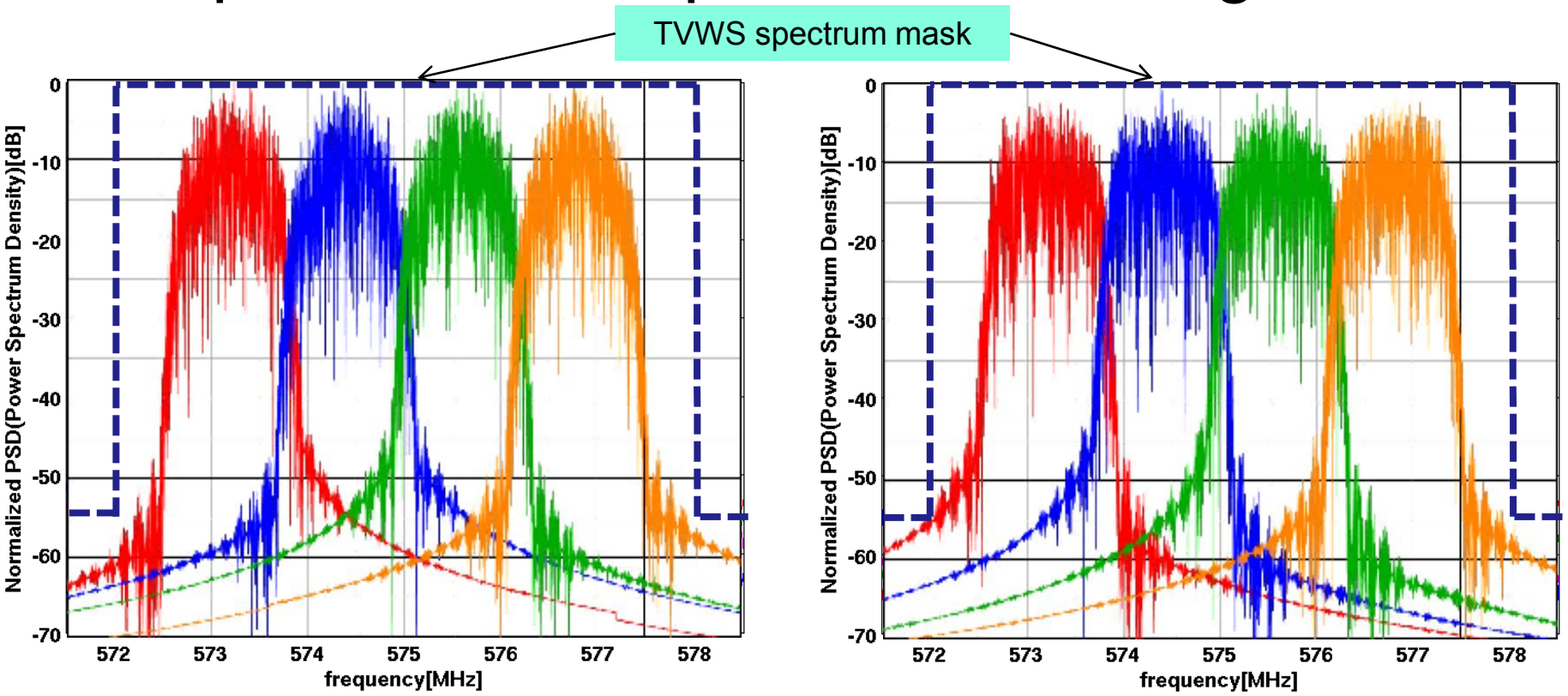
FSK /FH parameters

Table 4 FSK/FH parameters

Parameters	Mode 1	Mode 2	Mode 3	Mode 4
Data rate	50kbps	100kbps	200kbps	400kbps
Modulation	2FSK	2FSK	2FSK	2FSK
freq slot spacing	200kHz	400kHz	400kHz	400kHz
# frequency slots	5	3	3	3
Total bandwidth	1.2 MHz	1.2 MHz	2.4 MHz (1.2 MHz x2)	4.8 MHz (1.2 MHzx4)

- Multiple devices can be supported by using
  - Different subchannels
  - Different hopping sequences

Spectrum Example of FSK/FH signals



(a) Mode 1
- Data Rate: 50kbps
- Freq. Slot Spacing: 200kHz
- Hopping Rate: 50kHz

(b) Mode 2
- Data Rate: 100kbps
- Freq. Slot Spacing: 400kHz
- Hopping Rate: 100kHz

Fig. 3 Spectrum example of FSK/FH signals (4 subchannels)

Preliminary PHY Proposal (2)

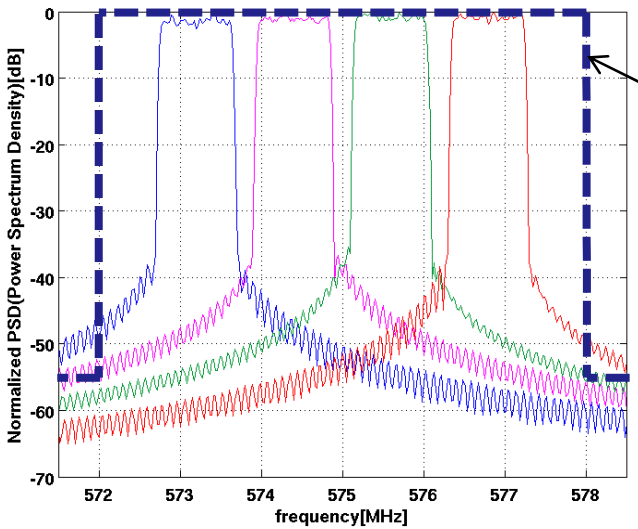
- OFDM for mid-rate applications
  - Based on the 802.15.4g OFDM PHY (mode 1)
- Subchannel spacing : 1.2MHz
  - We have a couple of potential OFDM parameter sets including:
    - Subcarrier spacing
    - symbol rate
    - DFT size
    - Cyclic prefix and data symbol duration

OFDM parameters

Table 5 OFDM parameter options

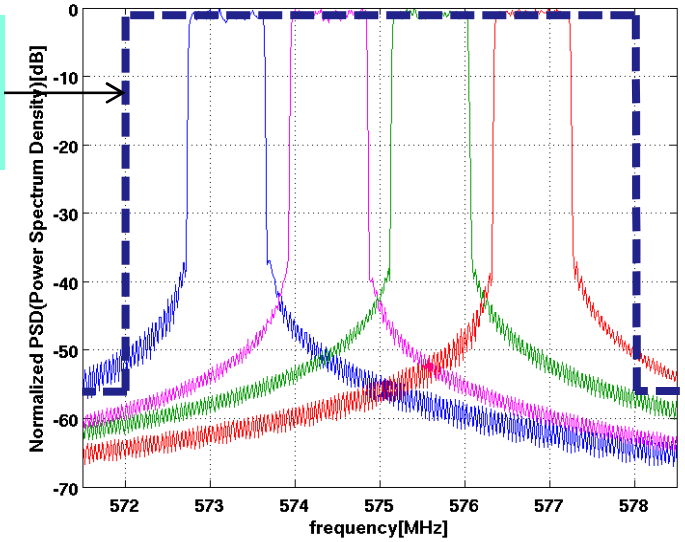
Parameters	Option 1	Option 2	Option 3	Remarks
Subcarrier spacing [Hz]	10416.66	5208.33	2604.16	
Symbol rate [ksymbol/s]	8.33	4.16	2.08	
Symbol duration [μs]	120	240	480	
DFT size	128	256	512	
# of Pilot tones	8	16	32	
# of Data tones	96	192	384	
Data duration [μs]	96	192	384	
Cyclic Prefix (1/4) [μs]	24	48	96	
Subchannel spacing	1.2 [MHz]	1.2 [MHz]	1.2 [MHz]	

- The next slide shows the spectrum overview of the above options of OFDM signals with 4 subchannels

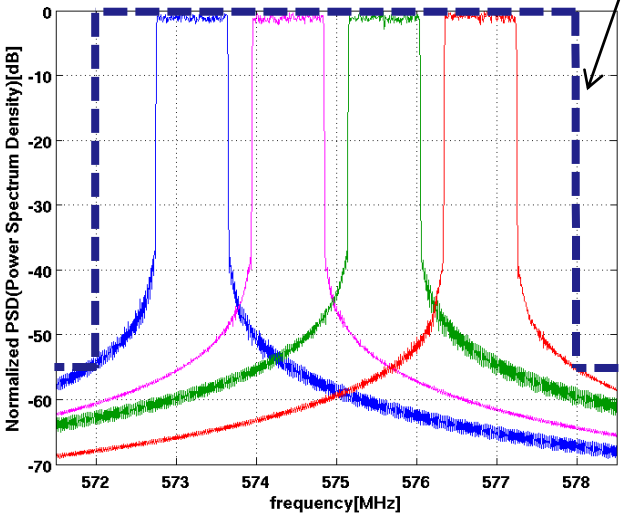


(a) Option 1

TVWS spectrum mask



(b) Option 2



(c) Option 3

•Fig. 4 Spectrum overview of each OFDM PHY option listed in the previous slide.

Modulation Parameters and Data Rate

Table 6 Modulation and coding parameters and data rate per subchannel

Mode	Modulation	Coding rate	Frequency repetition	Data rate	Remarks
1	QPSK	1/2	4	200 kbps	
2	QPSK	1/2	2	400 kbps	
3	QPSK	1/2	1	800 kbps	
4	16QAM	1/2	1	1.6 Mbps	
5	16QAM	3/4	1	2.4 Mbps	
6	64QAM	1/2	1	2.4 Mbps	
7	64QAM	3/4	1	3.6 Mbps	
8	64QAM	5/6	1	4 Mbps	

- It is possible to cover higher data rate up to 16 Mbps by using multiple subchannels

Summary

- Preliminary PHY proposal for IEEE 802.15.4m based on the link budget calculations
  - 4 x 1.2 MHz subchannels and guard band
  - FSK/FH for low-rate applications
  - OFDM for mid-rate applications
- Detail configuration: under investigation

References

1. TG4m Technical Guidance Document, Doc. IEEE 802.15-11-0684-09-004m, Mar. 2012
2. FCC Third MO&O, FCC-12-36A1, April. 2012.
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4. IEEE Draft Std. 802.15.4g/D7, 2011
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6. S. Sasaki, T. Inoko, and Y. Fukaishi, Doc. IEEE 802.15-12-0061-01-004m, Jan. 2012
7. S. Sasaki, T. Inoko, and Y. Fukaishi, Doc. IEEE 802.15-12-0177-01-004m, Mar. 2012