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

Submission Title: ETRI FSK PHY Proposal for TG4m

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Re: Call for proposals

Abstract: This contribution presents a final proposal for the TG4m

Purpose: Final proposal to 802.15m

Contents

- Requirements overview
- Dual PHY for TVWS WPAN
- TVWS WPAN PHY Considerations
- Narrowband FSK PHY
- Location capability for FSK PHY
- Summary

Requirements Overview

- Key requirements for TVWS WPAN (Doc. 11-684-11)
  - Operations in TVWS frequency bands under regulatory constraints
  - Data rate of typically 40Kbps to 2Mbps & optionally 10Mbps
  - Optimal & power efficient device command & control applications
  - Operating range of at least 1Km
  - At least 1000 direct neighboring devices
  - Multi-band capability
  - Coexistence with primary users (TV broadcasting)

Dual PHY for TVWS WPAN

- Wide range of PHY data rate
  - Typically 40Kbps~2Mbps, optionally ~10Mbps
- Various applications in TGD(doc.11-0684-11)
  - Single PHY may not cover all the applications
  - FSK PHY: Low data rate & low complexity PHY
  - OFDM PHY: High data rate & high reliability PHY

Application	Candidate PHY
Smart Utility Networks	FSK
Infrastructure Monitoring Networks	FSK
Intelligent Transportation System	OFDM
Surveillance Control & Monitoring Networks	OFDM

TVWS WPAN PHY Considerations (1)

- Main considerations for TVWS WPAN PHY proposal
  - Reliability
  - Compatibility

TVWS WPAN PHY Considerations (2)

- Reliability
  - Rural areas
    - Easy to find available TVWS channels
    - Usually not crowded: free from interference
    - Max. 100mW TX power for Mode I/II devices
    - 1km service coverage is easily met
  - Metropolitan areas
    - Difficult to find TVWS channels
    - Reduced TX power (Max. 40mW) for Mode I/II devices due to operation in adjacent channel
    - Usually crowded: several services in one TVWS channel
    - Reliability enhancing features are optionally required

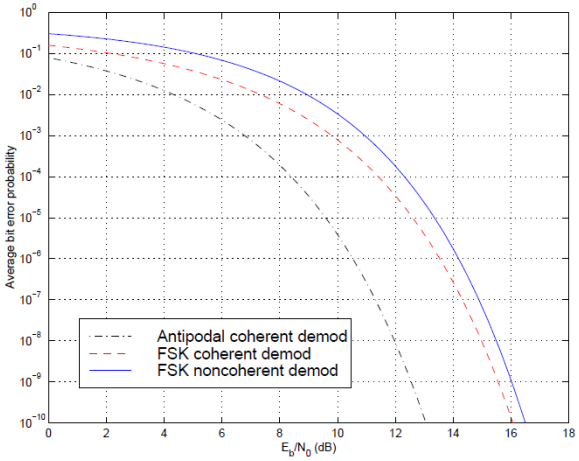
TVWS WPAN PHY Considerations (3)

- Compatibility
  - TVWS channel availability is not guaranteed, especially in metropolitan areas
  - Seamless WPAN services should be maintained regardless of TVWS channel status
  - Transition to other legacy bands may be required
    - e.g., SUN standard is well established in 900MHz band
  - There should be at least one operation mode to provide connectivity between TVWS WPAN and SUN

Narrowband FSK PHY

Motivation for NB FSK PHY

- Benefits
  - No need of high-linearity power amplifier (PA)
  - Non-coherent receiver: low-power consumption
    - No need to track the phase of the carrier
    - Performance difference between coherent receiver and non-coherent receiver: roughly 1dB
    - Suitable for battery-powered Mode I devices
  - Simple, cheap and proven technology
    - SUN & LECIM standards take FSK PHY



* Wong & Lok: *Theory of Digital Communications*, Chapter 2. Modulation & Demodulation, p221

FSK PHY for TVWS WPAN (1)

- Propose to adopt mandatory SUN FSK PHY for TVWS WPAN
  - Data rate: 50Kbps
  - Channel BW: 200KHz
  - Modulation: 2 Filtered FSK
  - Whitening: off
  - FEC & Interleaving: off

- Proposed FSK PHY mandatory mode
  - Provide compatibility between SUN and TVWS WPAN
  - Operate well in good channel condition, such as rural areas.

FSK PHY for TVWS WPAN (2)

- Link Budget for mandatory FSK mode
  - Path loss: Modified Hata model is considered (Doc.11-684-11)
  - Reliability enhancing features are required

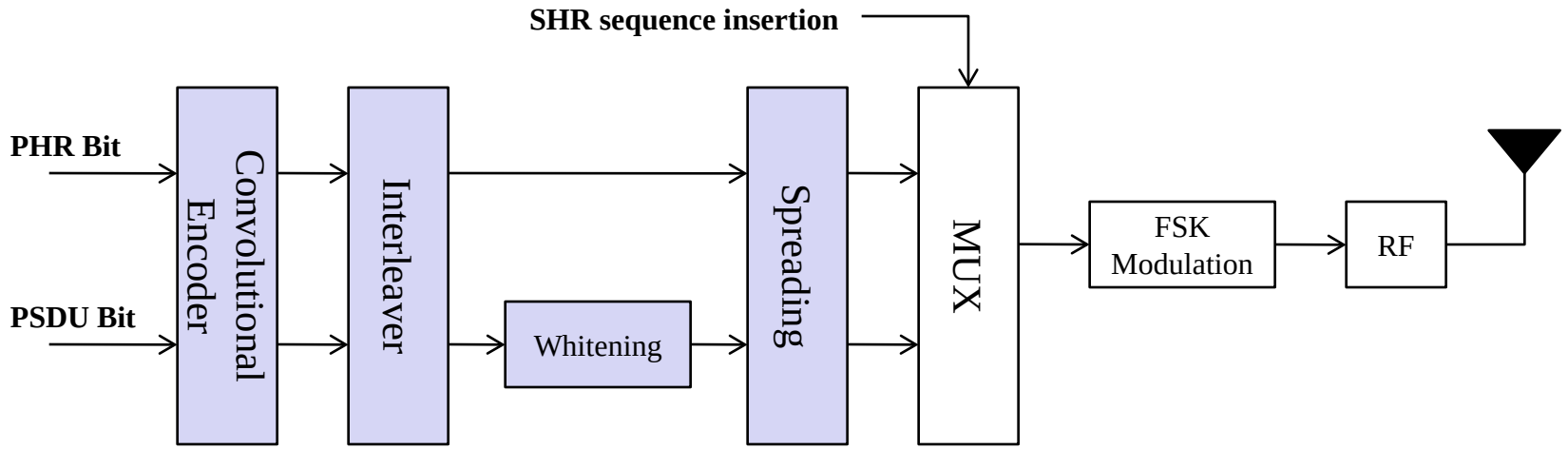
Link Budget for TG4m TVWS WPAN FSK PHY 50Kbps		
Parameters	Unit	Value
1) Bandwidth [BW]	MHz	0.2
2) Average TX Power [Pt] (PSD limit: 2.6dBm/100KHz)	dBm	5.6
3) TX antenna gain [Gt]	dBi	0.0
4) Center frequncy [fc]	Hz	6.9500E+08
5) Path loss at 1km [PL] (From modified Hata model)	dB	112.0
6) RX antenna gain [Gr]	dBi	0.0
7) RX power [Pr=Pt+Gt+Gr-PL]	dBm	−106.4
8) Receiver AWGN noise floor [N=-174+10log(BW)]	dBm	−121.0
9) RF noise figure [Nf]	dB	10.0
10) Average noise power [Pn=N+Nf]	dBm	−111.0
11) Minimum Eb/No [S] (13dB@10^{-5} for FSK)	dB	13.0
12) Implementation loss [I]	dB	3.0
13) Link Margin [LM=Pr-Pn-S-I]	dB	−11.4

FSK PHY for TVWS WPAN (3)

- Propose to include reliability enhancing features
  - Parity bit in PHY header (mandatory)
  - Whitening (optional)
  - FEC & Interleaving (optional)
  - Spreading (optional)
  - Longer SFD sequence (optional)

FSK PHY for TVWS WPAN (4)

- Overall FSK PHY transmitter block diagram



Function block that can be selected based on regional regulations and deployment environments

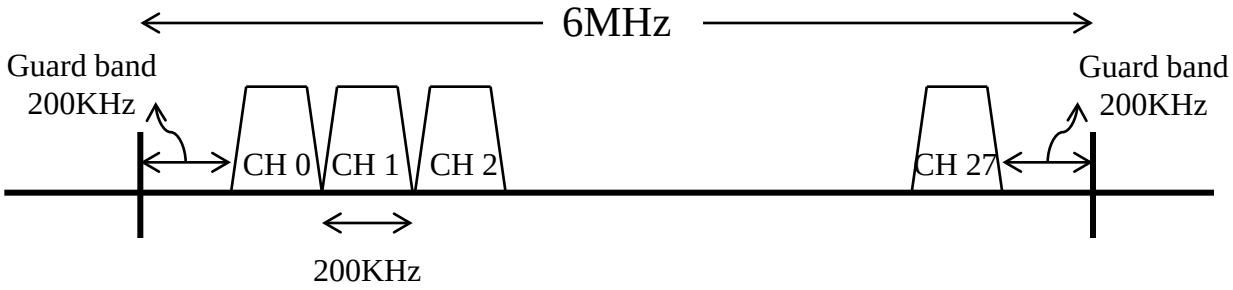
FSK PHY for TVWS WPAN (5)

- Modulation & channel parameters
  - Mode #1: mandatory 50Kbps (same as TG4g)
  - Mode #2: 100Kbps
    - 100Kbps is more attractive than 150Kbps when considering implementation
  - Mode #3: 200Kbps (same as TG4g)

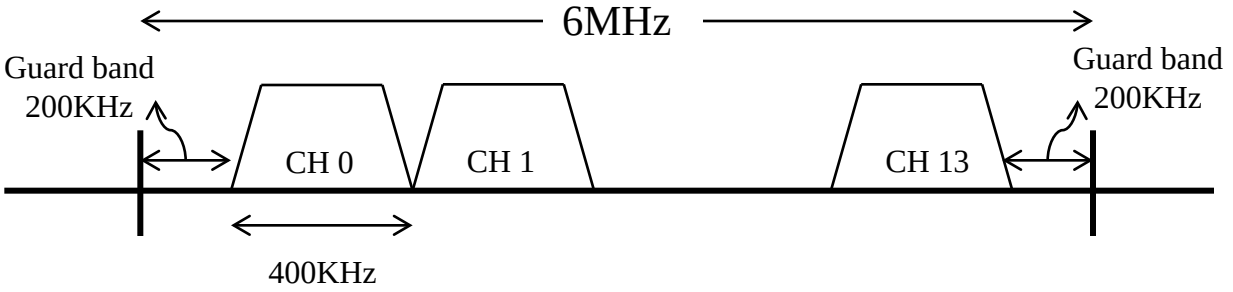
	Operating Mode #1	Operating Mode #2	Operating Mode #3
Data rate (Kb/s)	50	100	200
Modulation	Filtered 2FSK	Filtered 2FSK	Filtered 2FSK
Modulation Index	1	0.5	0.5
Channel Spacing (KHz)	200	400	400

FSK PHY for TVWS WPAN (6)

- Channel Plan for 6MHz bandwidth
  - 50Kbps mode (200KHz BW): 28 channels

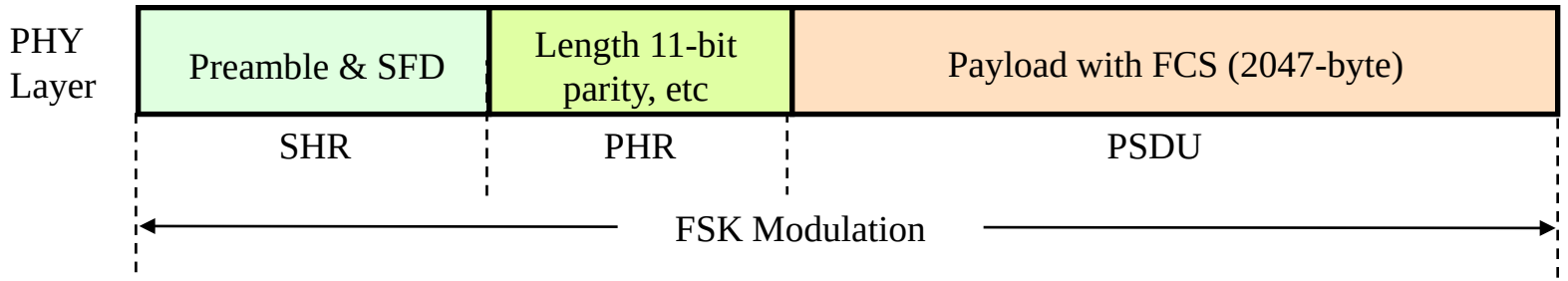


  - 100Kbps & 200Kbps mode (400KHz BW): 14 channels



FSK PHY for TVWS WPAN (7)

- FSK PHY packet format



  - Preamble
    - multiples of “01010101” as specified in SUN FSK PHY
    - Length: 4-100 octet
  - SFD
    - Basically, same as SUN FSK PHY
    - Optionally, suggest to consider a longer SFD sequence to reduce false alarm rate (doc. 12-0048-00 & 12-0094-00)

FSK PHY for TVWS WPAN (8)

- PHY header (PHR)
  - Bit string index [3:15]: same as SUN FSK
    - Frame length: 11bit → max. 2047-octet PSDU
  - Bit string index [2]: Ranging packet indication for ranging counter
  - Bit string index [1]: Parity bit
    - Simply detect PHR error to stop demodulation process
  - Bit string index [0]: Reserved bit
    - Set to “0” for compatibility between TVWS WPAN & SUN

Bit string index	0	1	2	3	4	5-15
Bit mapping	0	Parity	RNG	FCS	DW	L_{10}-L_0
Field name	Reserved	Parity	Ranging packet	FCS type	Data whitening	Frame Length

FSK PHY for TVWS WPAN (9)

- FEC & Interleaving
  - Propose to use the same FEC & Interleaving in LECIM FSK PHY (as in doc.12-089-06)
- Spreading
  - Propose to use the same spreading scheme in LECIM FSK PHY (as in doc.12-089-06)

FSK PHY for TVWS WPAN (10)

- The parameters configuring the use of FEC & interleaving and spreading are listed in PHY PIB attributes
  - phyTVWSFSKFECEnabled: on/off
  - phyTVWSFSKInterleavingEnabled: on/off
  - phyTVWSFSKSpreadingEnabled: on/off
  - phyTVWSFSKSpreadingFactor: 2-bit (0,1,2,4)
  - phyTVWSFSKSFDLength: 0 (2-byte SFD), 1 (longer SFD)

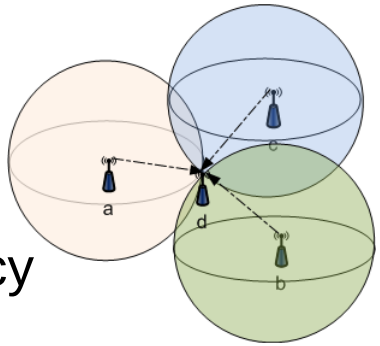
Location Capability for FSK PHY

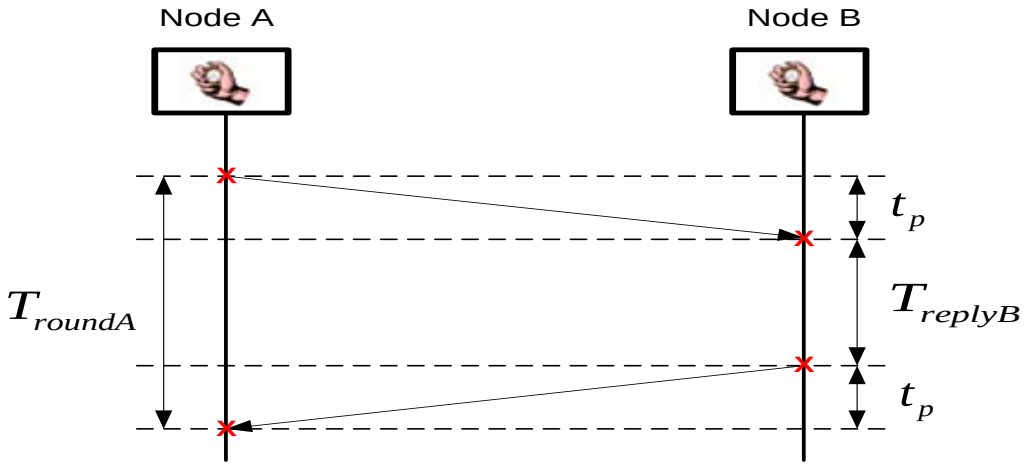
RF Localization for TG4m

- Initially, Doc.12-167-00 (RF localization in TVWS) started to discuss about RF localization issue
- Motivation
  - Mode II device must have location capability with accuracy of ±50m and Mode I device may require location capability
  - GPS is not 100% available such as indoors, urban canyons and GPS jamming/spoofing attack environments
  - Battery-powered Mode I devices may not equip with GPS receiver
- Suggest to use optional RF localization for TG4m

RF Localization

- Positioning
  - At least 3 references with known positions are required to retrieve a 2D-Position from 3 ranging (distance) measurements
- Ranging methods
  - TWR (Two Way Ranging) is desirable for accuracy





Time of Flight (ToF) :

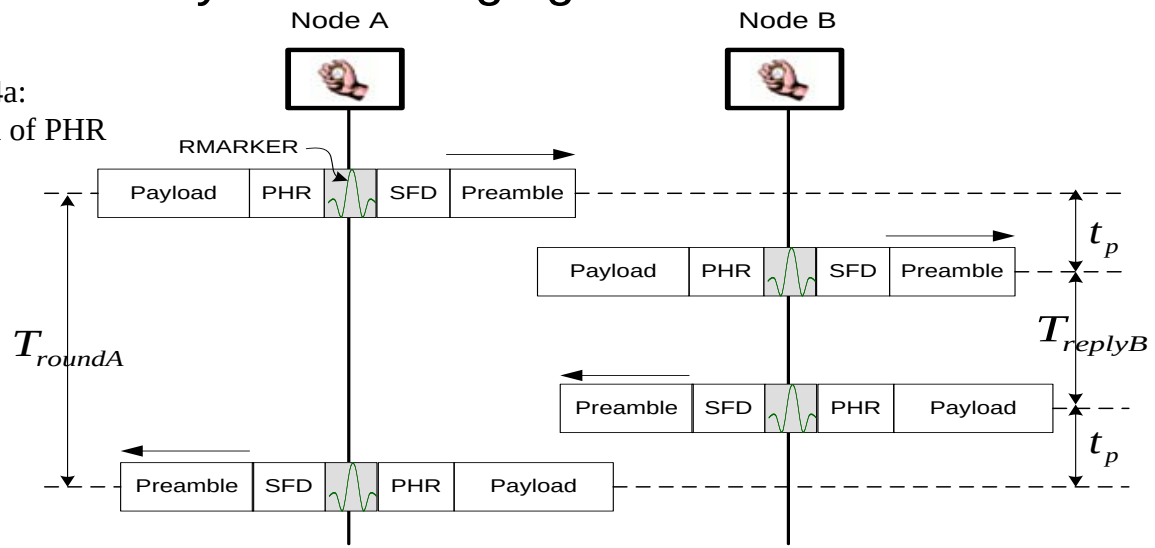
$$t_p = \frac{T_{roundA} - T_{replyB}}{2}$$

Distance d = ToF x speed of light

Ranging Mechanism in 15.4a IR-UWB (1)

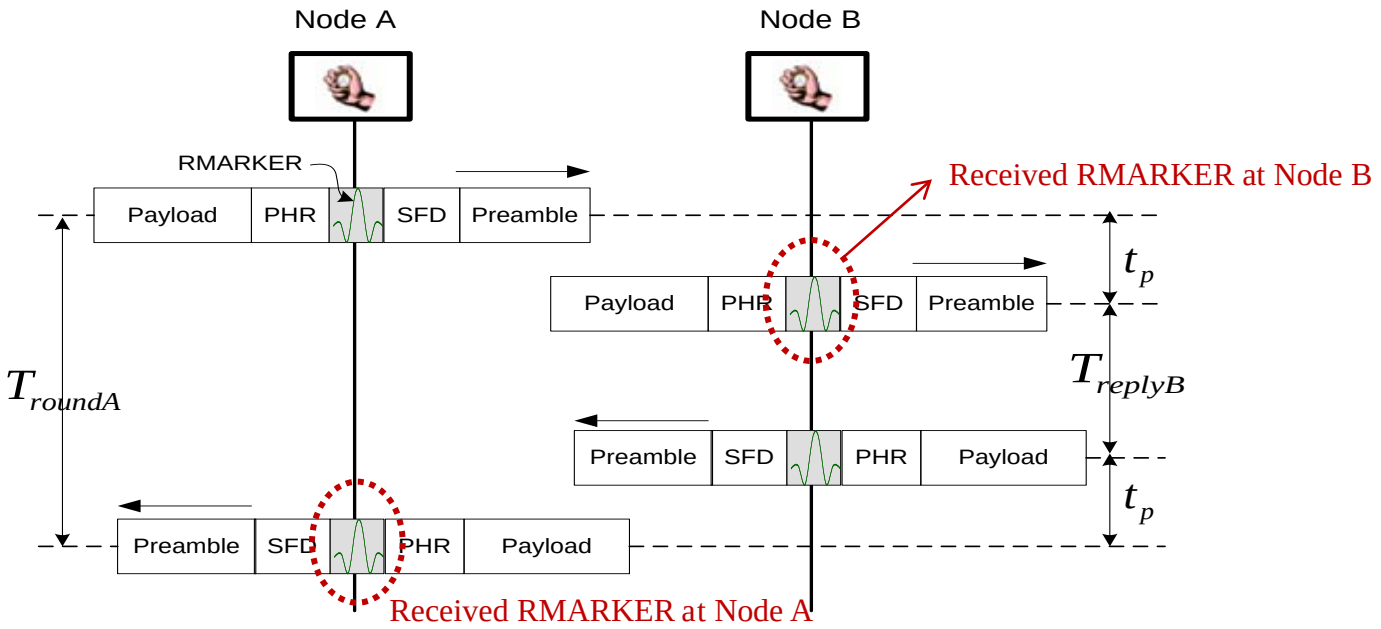
- ToF calculation in 15.4a TWR ranging mechanism
  - Ranging counters in Node A & Node B
    - Can measure timestamps for precise instant at which RMARKER are transmitted and received
    - At each receiver, timestamp for the received RMARKER is valid only when “ranging indication bit” in PHR is “1”

RMARKER in 15.4a:
First impluse signal of PHR



Ranging Mechanism in 15.4a IR-UWB (2)

- When is the precise instant for the received RMARKER?
  - It depends on Time of Arrival (ToA) estimation at the receiver
  - ToA estimation error occurs at both receiver sides in TWR
    - 1 nsec error leads to -30cm ~ +30cm ranging accuracy



Ranging Supporting PHY

- Ranging supporting PHY should provide the following features
  - Ranging counter
  - RMARKER
  - Ranging indication bit in PHR

  } PHY independent

  - Sequence for Time of Arrival (ToA) estimation } PHY dependent

- Sequence for ToA estimation should be designed based on PHY characteristics and desired ranging accuracy

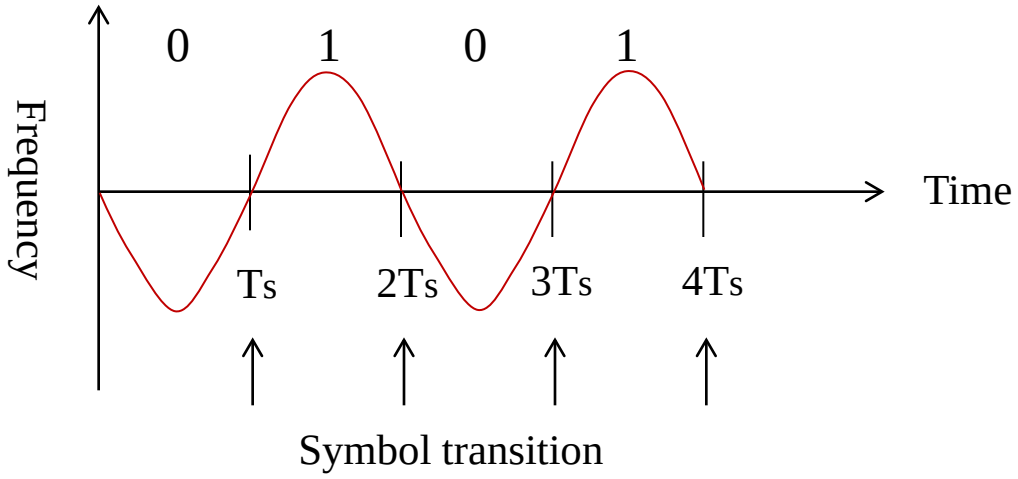
Ranging in FSK PHY (1)

- Ranging for TG4m can be performed in OFDM PHY
  - Wider bandwidth & STF (good for ToA estimation)

- FSK PHY may also require location capability even though its accuracy is generally worse than OFDM PHY
- How can we obtain ToA information in FSK PHY?
  - It is difficult to retrieve ToA from correlation based methods which are commonly used in UWB or OFDM PHY
  - It is desirable to extract FSK symbol transition timing

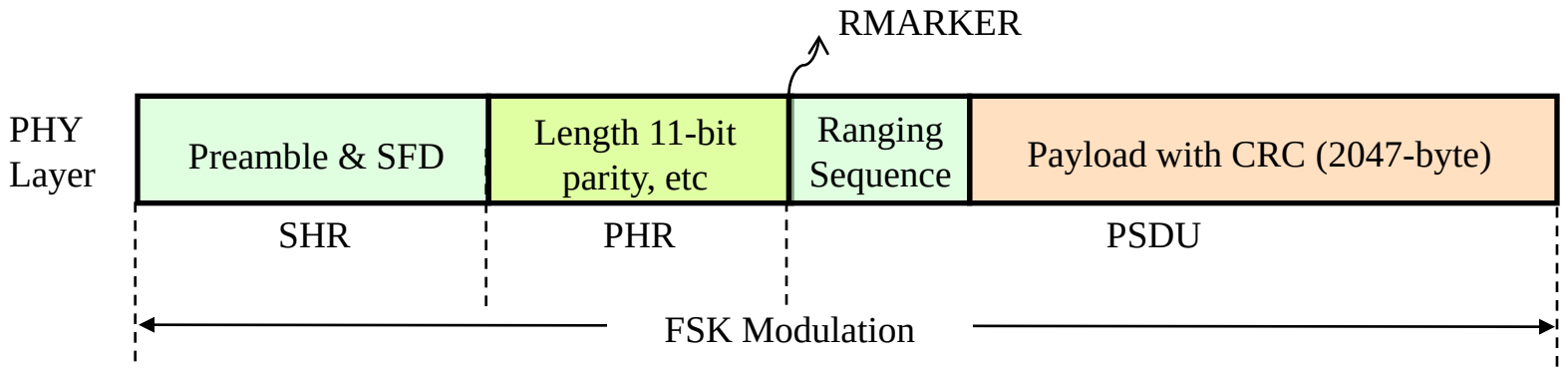
Ranging in FSK PHY (2)

- Ranging sequence
  - Select best sequence for retrieving symbol transition timing
  - Repetition of “01” pattern would be good



Ranging in FSK PHY (3)

- Ranging sequence insertion
  - If RNG bit in PHR is “1”, insert ranging sequence right after PHR
- RMARKER
  - Last PHR symbol transition

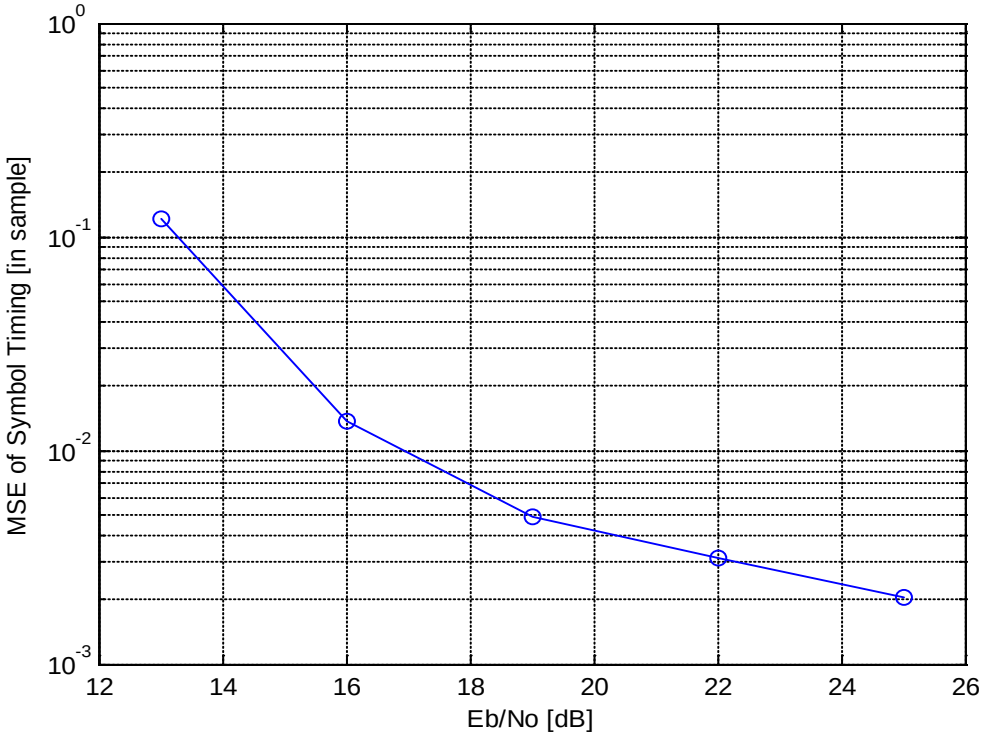


Symbol Transition Estimation (1)

- Simulation environments
  - Data rate: FSK 200Kbps
  - Ranging sequence: 8 repetition of “01”
  - Operation clock used in FSK demodulator: 16 x 200KHz
  - FSK demodulator type
    - Quadricorrelator (QC) based frequency discriminator
    - Frequency discrimination is achieved by applying the FSK signal and a delayed FSK signal to the inputs of a multiplier
    - QC output for the received FSK signal “0” and “1” is represented as phase difference
  - Symbol transition estimation
    - Simply finding zero phase at QC output
  - AWGN & no clock drift environment

Symbol Transition Estimation (2)

- Symbol transition estimation error
  - 0.1 sample unit (31.25 nsec) @ 16dB
  - Ranging error: -10m ~ 10m



TG4m Ranging Considerations

- Ranging mechanism
  - Suggest to use well-established 15.4a ranging mechanism
- Performance (ranging accuracy) degradation factors
  - ToA estimation error at the receiver
  - Clock drift due to finite crystal tolerance causes error in ToF calculation

$$\hat{t}_p - t_p \approx \frac{1}{2} \times t_{replyB} \times (e_A - e_B)$$

    - SDS-TWR in 15.4a may resolve this problem, but network traffic will increase due to increased message exchange
    - Additionally, enhanced ranging protocol may be required

Summary

- FSK PHY for TG4m
  - Adopt basically SUN FSK PHY for compatibility
  - Include reliability enhancing features
    - Parity in PHR, Whitening, FEC & Interleaver, Spreading
- Location capability for FSK PHY (Optional)
  - Adopt basically 15.4a ranging mechanism
  - Ranging indication bit in PHR
  - RMARKER for ranging counter operation
    - Last PHR symbol transition
  - Insert ranging sequence for FSK symbol transition estimation