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

Submission Title: [NICT Final Impulse Radio Ultra Wideband PHY proposal in response to CFC]
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Re: [TG8 Call for Contributions (CFC) (15-14-0087-00-0008)]
Abstract: [This is the presentation of the NICT Impulse Radio Ultra-Wideband PHY proposal to IEEE 80215.8.]

Purpose: [To provide details of the NICT IR-UWB PHY proposal]

NICT Final Impulse Radio Ultra Wideband PHY Proposal in response to CFC

Part of Merged DecaWave and NICT IR-UWB PHY proposal to IEEE 802.15.8

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Motivation

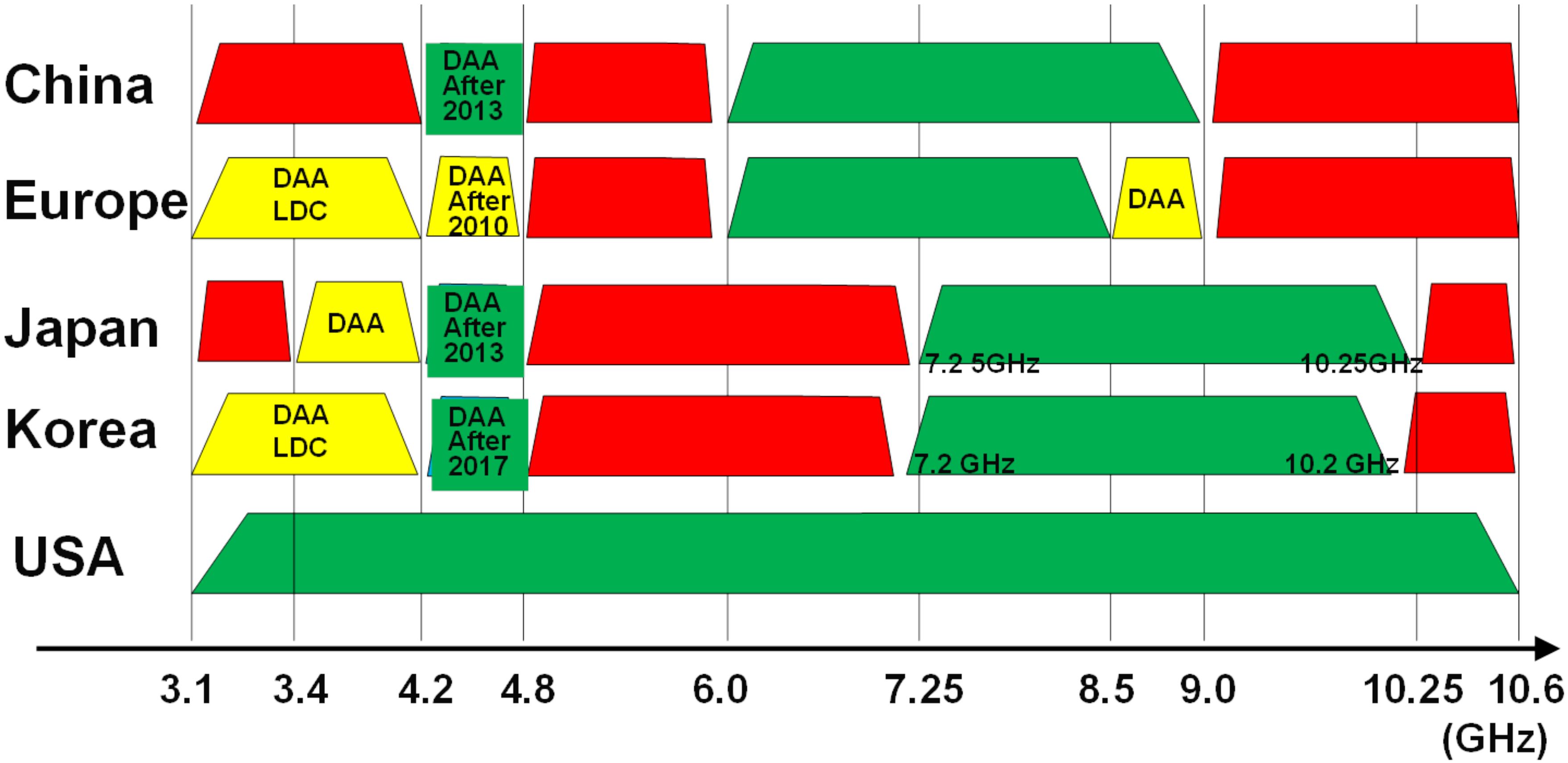
Advantages:

- UWB band is regulated worldwide.
- Power consumption of IR-UWB devices is low.
- Due to large bandwidth precise localization is possible.

Downside:

- Low regulated Power Spectral Density (PSD) levels of -41.3 dBm/MHz allow low Tx power levels.

UWB Regulations Worldwide



Overall

Merged proposal includes:

- DecaWave IEEE 802.15.4a based proposal
- NICT OOK proposal

Commonalities among proposals:

- The same band plan.
- The same concatenated coding scheme.

In order to lower the impact of interference among two radios:

- Two different preamble sequences sets.
- Two different pulse repetition frequencies.

Dotlic, Li, Hernandez, Miura (NICT)

Band Plan

Channel index	Lower band edge (MHz)	Upper band edge (MHz)	Region	Comment	Available mandatory frequencies
1	4200	4800	China	Low band in China	a
2	3100	4800	Europe, Korea	Low band in Europe and Korea	a,b,c
3	3400	4800	Japan	Low band in Japan	a,b,c
4	3100	5700	USA	Low band in USA	a,b,c
5	6000	9000	Europe, China	High band in Europe and China	d,e,f,g
6	7250	10250	Japan	High band in Japan	e,f,g,h
7	7200	10200	Korea	High band in Korea	e,f,g,h
8	6000	10600	USA	High band in USA	d,e,f,g,h
9	5925	7200	USA	Wideband in USA	d

Mandatory frequency* allocation			
Index	Mandatory frequency (MHz)	Index	Mandatory frequency (MHz)
a	3500	e	7500
b	4000	f	8000
c	4500	g	8500
d	6500	h	9000

* Mandatory frequency is frequency at which PSD level is less than 6 dB below maximum.

NICT Impulse Radio Ultra Wideband PHY Proposal to IEEE 802.15.8

Dotlic, Li, Hernandez, Miura (NICT)

Pulse shape and duration

- We do not define a specific pulse shape.
    - Allow different low-complexity pulse generators.

Pulse shape is constrained

- In spectrum by the proposed band plan.
- In duration by the Duty Cycle (DC) of no more than DC=1/32=3.1%.

Packet structure

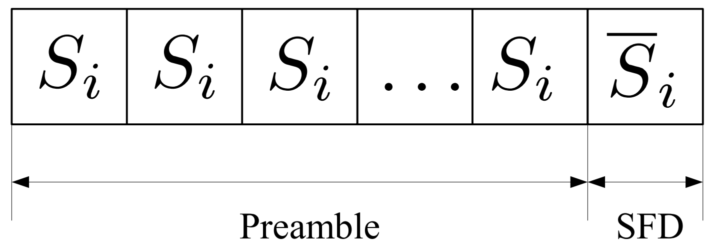
SHR	PHR	PPDU

SHR – Synchronization Header

PHR – PHY Header

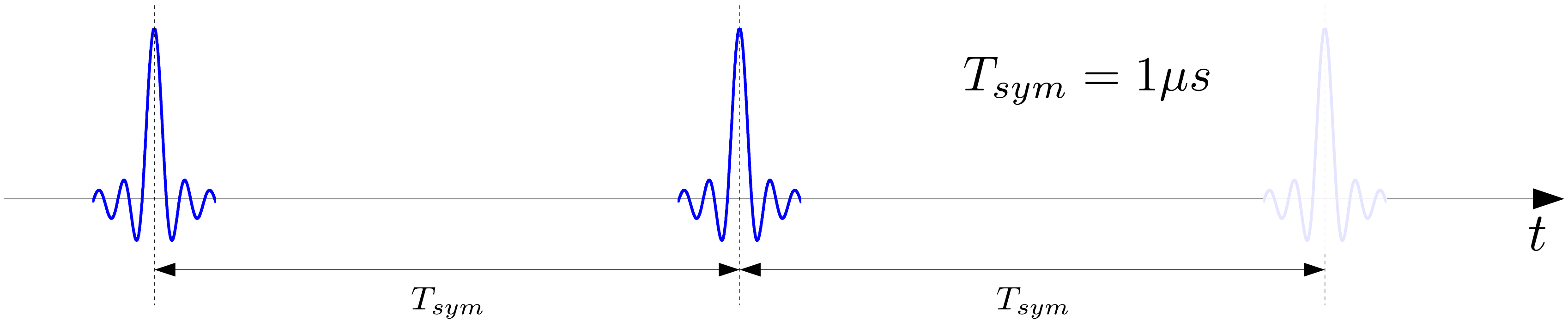
PPDU – Physical Layer Protocol Data Unit

SHR Structure



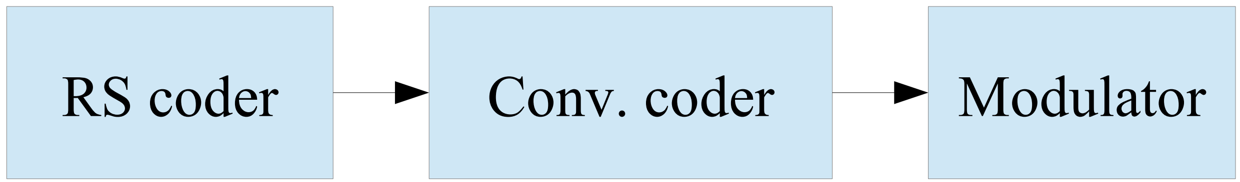
- Preamble consists of *M=8* times repetition of the sequence S_i.
- S_i is one of the Gold sequences of length 31.
    - Relatively short length with good circular autocorrelation properties.
- Sync. Frame Delimiter (SFD) represents inversion of S_i used in the preamble.

Symbol structure



- On-Off Keying (OOK) modulation is used.
- The same symbol structure is used in all parts of the packet (SHR, PHR, PSDU).
- There is no time hopping.
- Pulse phase is exchanged using the same sequence as in the preamble and the SFD.

Channel coding and data rates



- Coding is concatenation of outer Reed-Solomon $RS_6(63,55)$ codes and inner ½ convolutional code.
- Different data rates have different number of chips per symbol.

Data rate (Kbps)	54.56	109.12	218.25	436.51	873.02
Conv. Coding rate	1/2	1/2	1/2	1/2	1/1
Chips per symbol	8	4	2	1	1

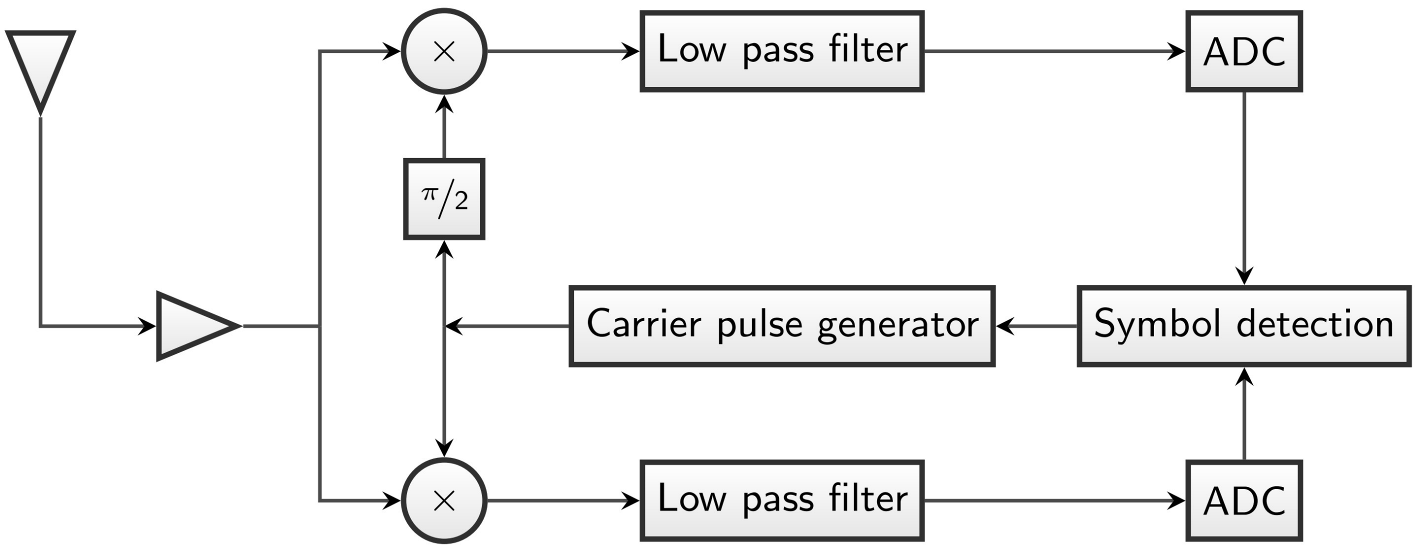
Simulation results.

Basic simulation parameters

- Carrier frequency: 8 GHz.
- Pulse Bandwidth: 1.25 GHz.
- Chirp pulse of duration 32 ns.
- 1-256 bytes packets.
- 5000 packets per simulation point
  - 50 scenarios.
  - 100 packets transferred per scenario.
- IEEE 802.15.4a-2007 CM1 Channel Model

Simulation results (cont'd).

Coherent receiver architecture.

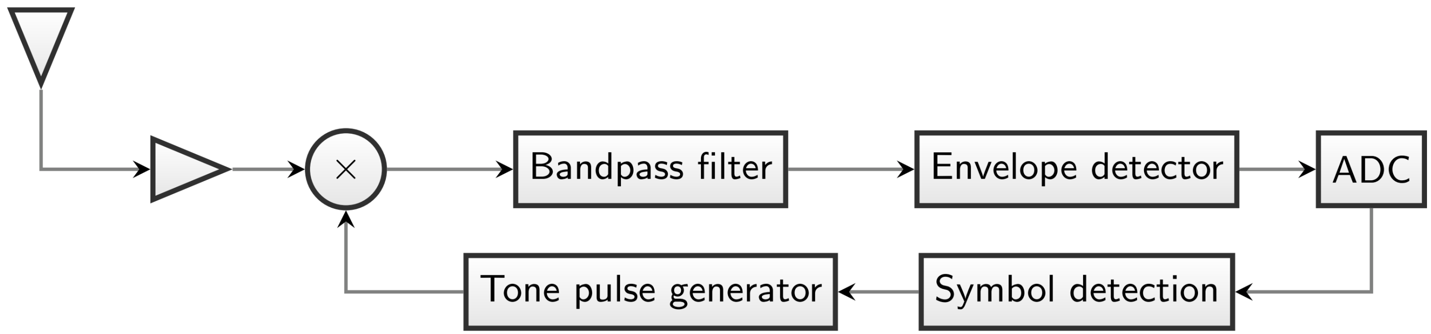


Nyquist sampling rate of 1.25 GHz.

Period of sampling: 60 ns per symbol.

Simulation results (cont'd).

Envelope sampling receiver architecture.

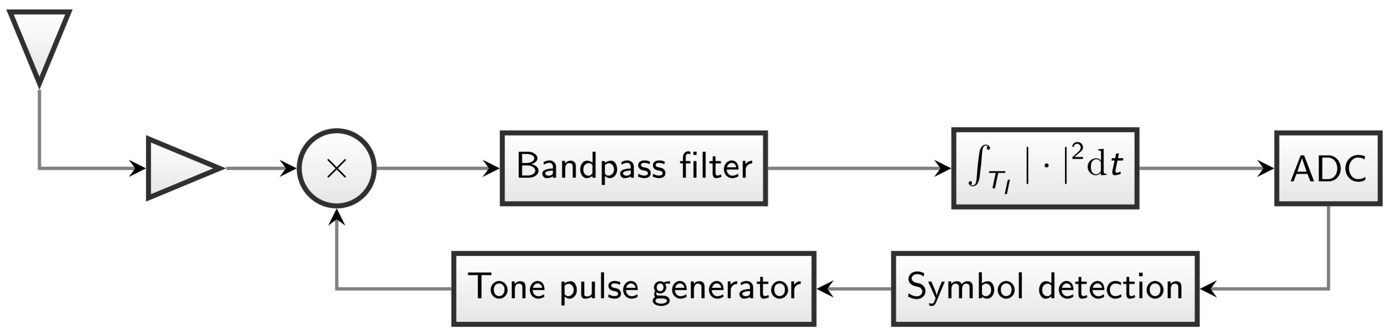


Sampling rate of 1.25 GHz.

Period of sampling: 60 ns per symbol.

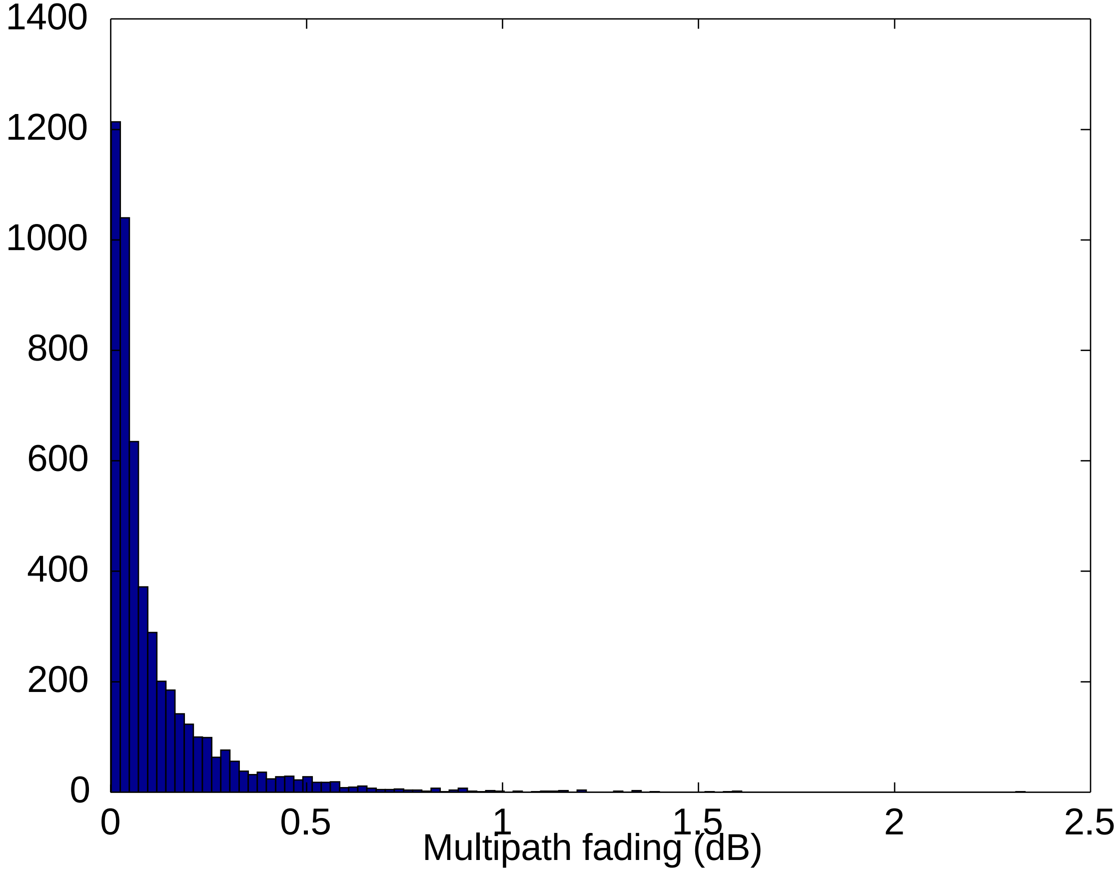
Simulation results (cont'd).

Energy detection receiver architecture.

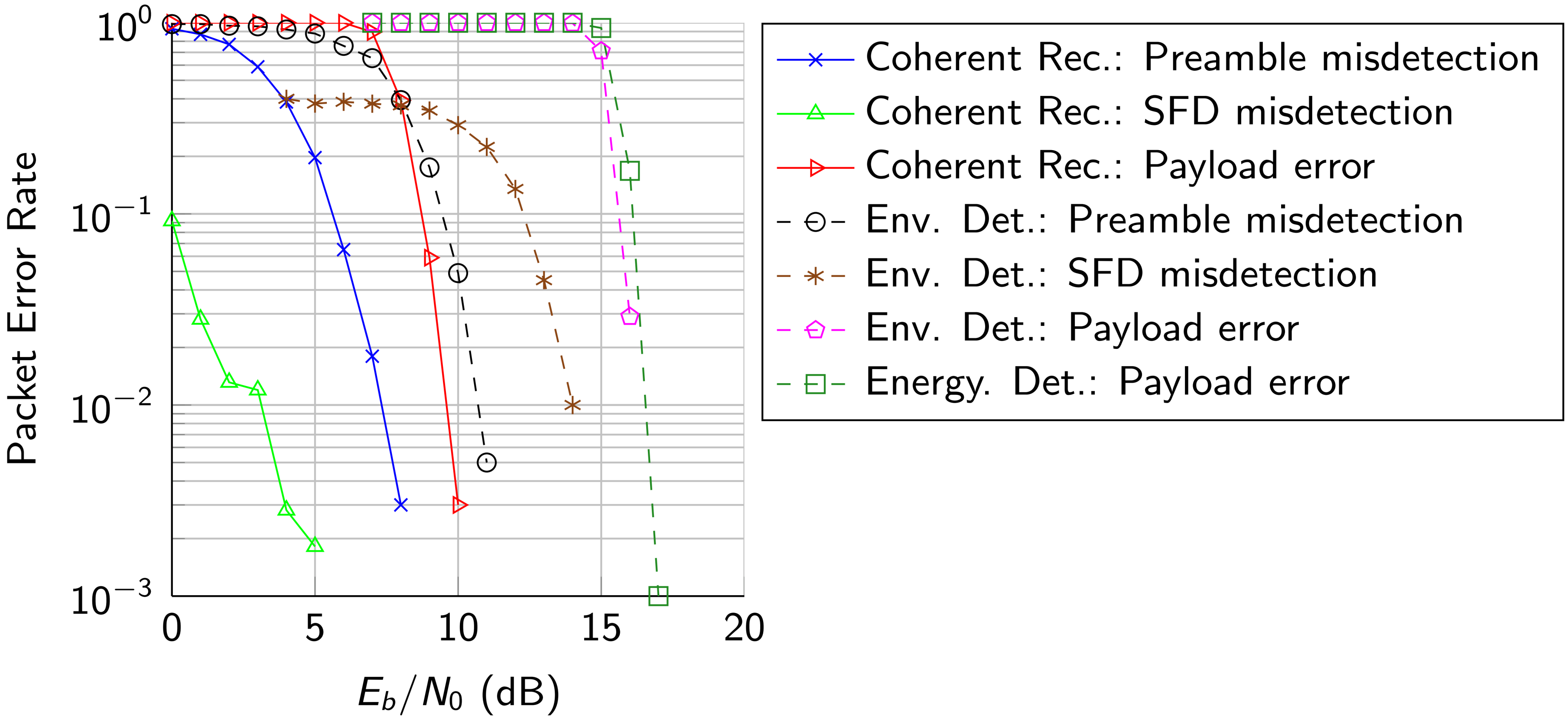


Integration interval of 60 ns per symbol.

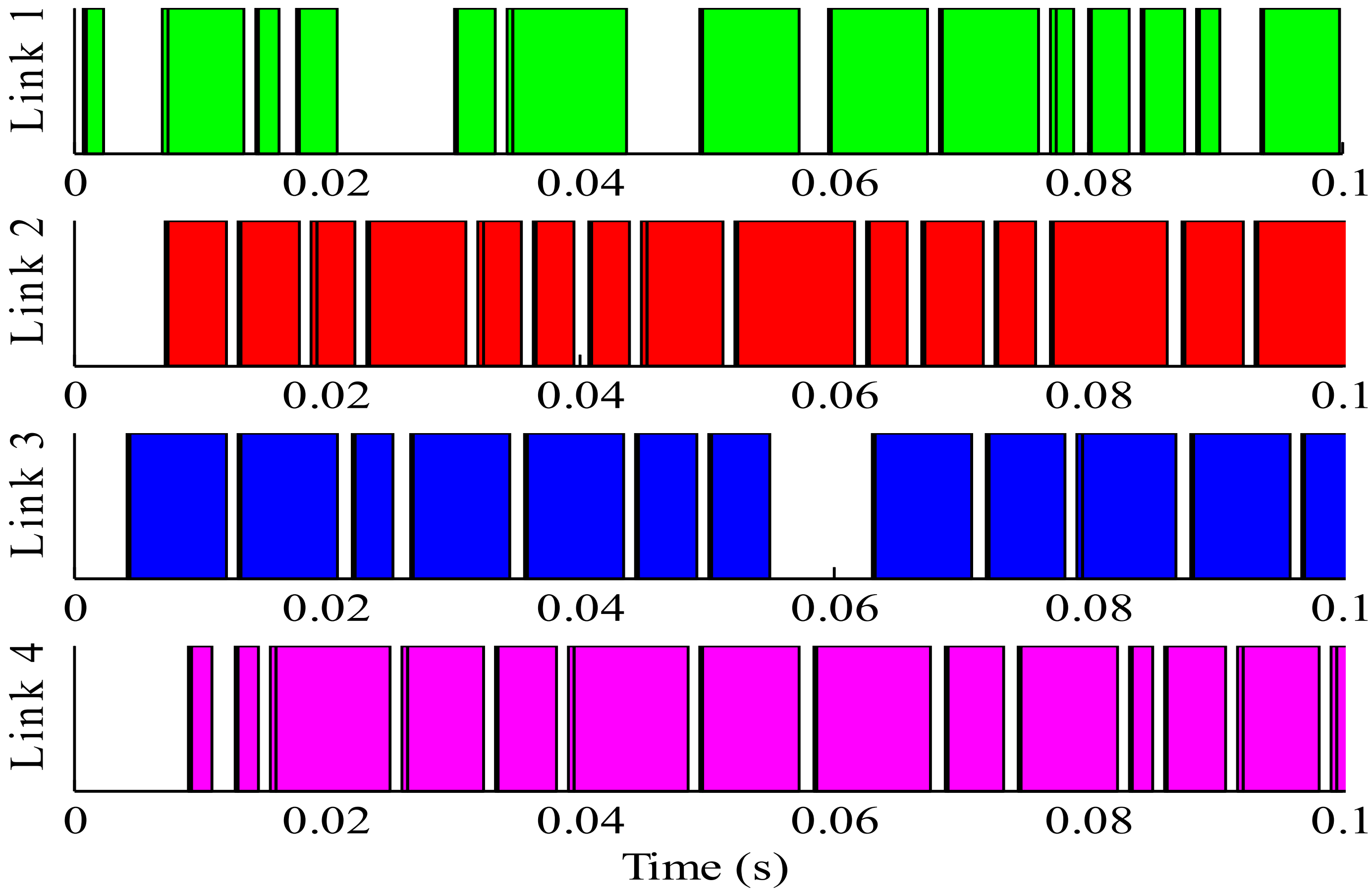
Multipath fading with reception window of 60ns.



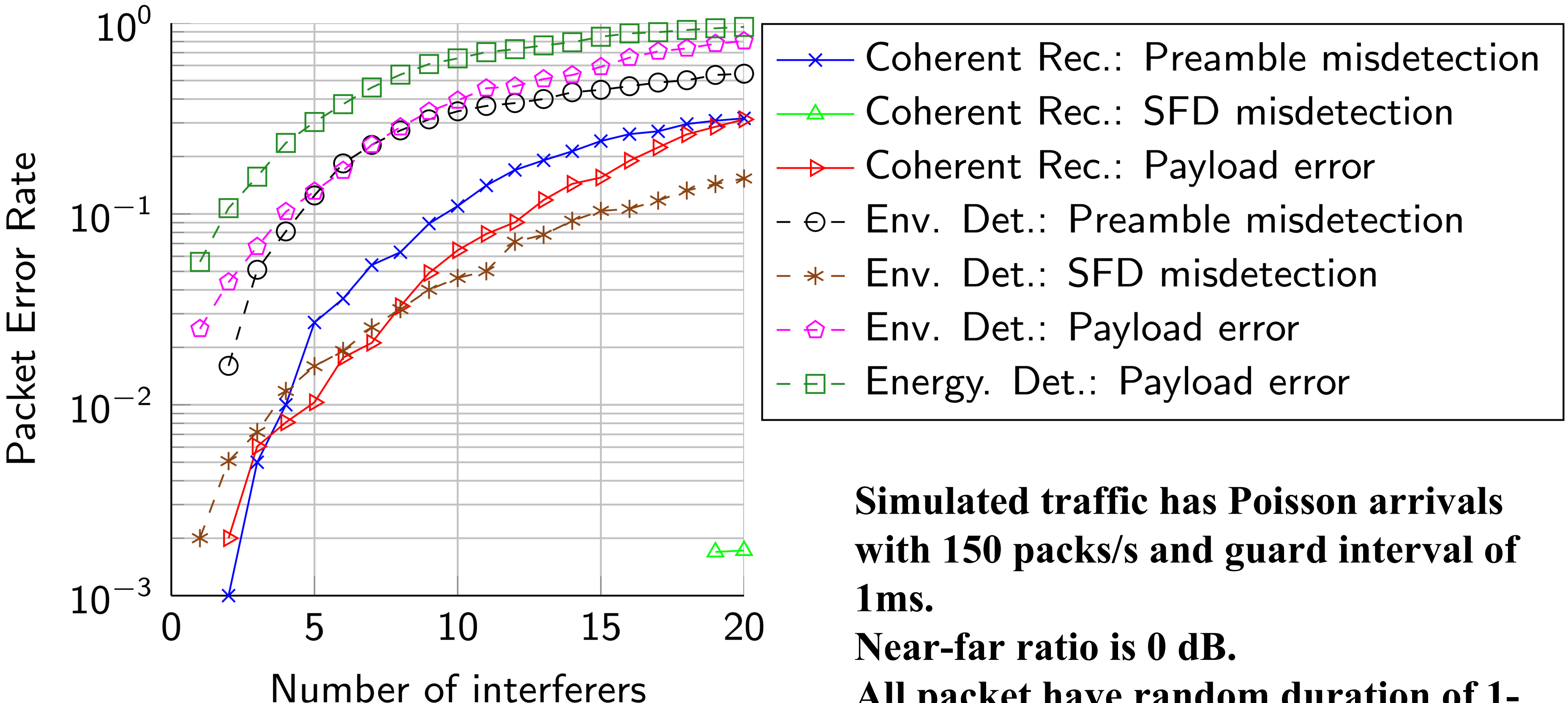
Performance in noise @ 218 Kbps



Simulated MAI traffic @ 218 Kbps

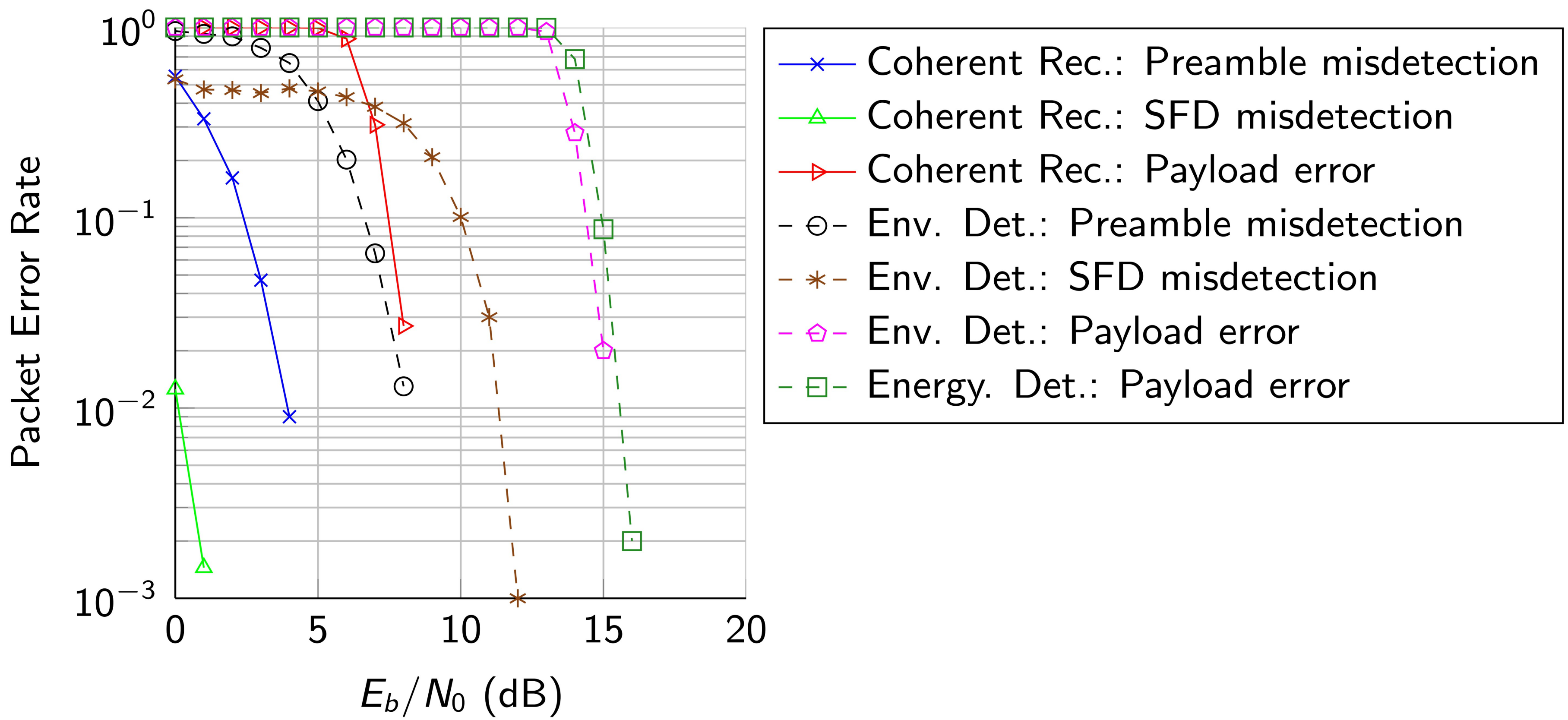


Performance in Multiple Access Interference @ 218 Kbps

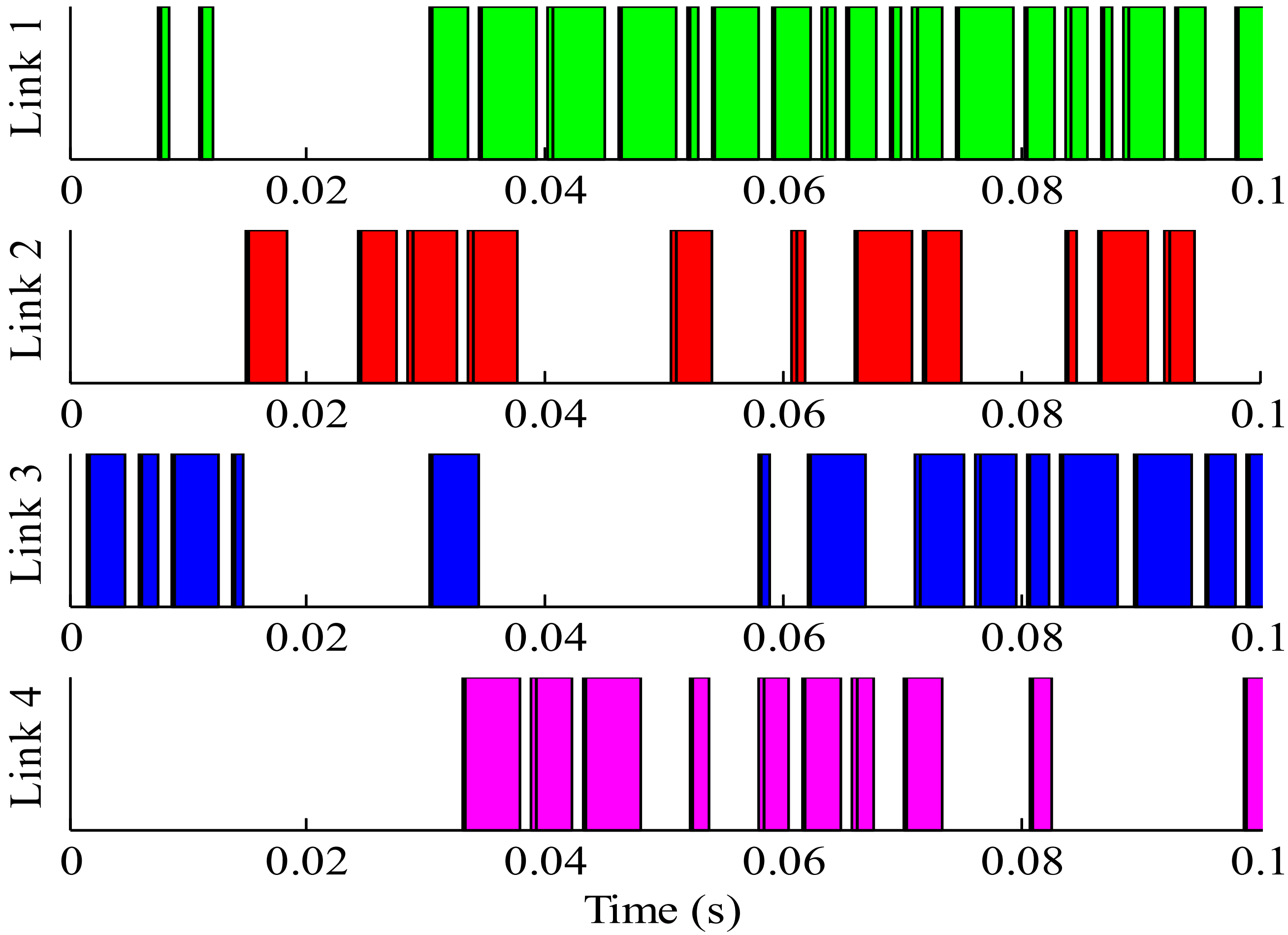


Simulated traffic has Poisson arrivals with 150 packs/s and guard interval of 1ms.
Near-far ratio is 0 dB.
All packet have random duration of 1-256 bytes.

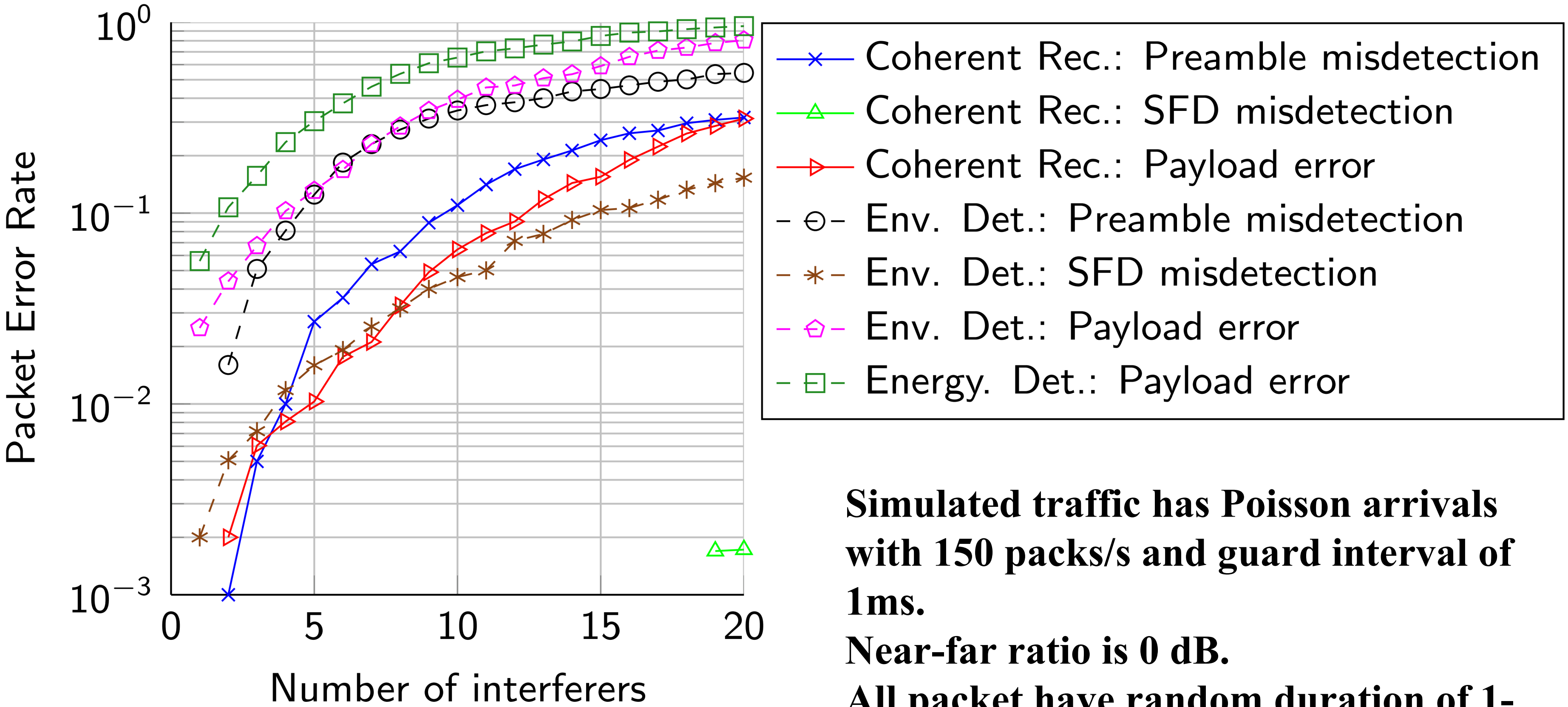
Performance in noise @ 436 Kbps



Simulated MAI traffic @ 432 Kbps

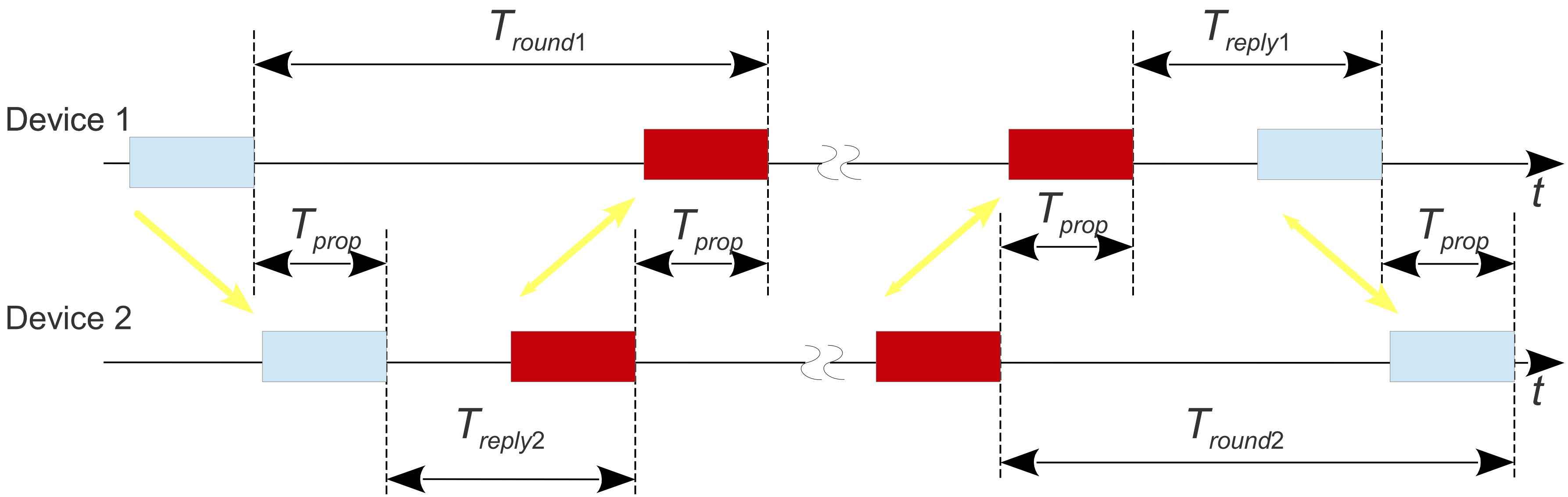


Performance in Multiple Access Interference @ 436 Kbps



Simulated traffic has Poisson arrivals with 150 packs/s and guard interval of 1ms.
Near-far ratio is 0 dB.
All packet have random duration of 1-256 bytes.

Symmetrical Double-Sided Two-Way Ranging (SDS TWR)



T_{round} ... round trip time

T_{reply} ... reply time

T_{prop} ... propagation of the packet

$$\hat{T}_{prop} = \frac{T_{round1} - T_{reply1} + T_{round2} - T_{reply2}}{4}$$

Effects of crystal timing inaccuracies on ranging

$$T_{round1} = T_{round} \times (1 + e_1)$$

$$T_{round2} = T_{round} \times (1 + e_2)$$

$$T_{reply1} = T_{reply} \times (1 + e_1)$$

$$T_{reply2} = T_{reply} \times (1 + e_2)$$

$$\hat{T}_{prop} = T_{prop} \left(1 + \frac{e_1 + e_2}{2}\right)$$

$e_1,\ e_2$ are typically 20 ppm

Link budget

Parameters								
Bandwidth (GHz)	1.25	3	1.25	3	1.25	3	1.25	3
Carrier frequency (GHz)	8	8	8	8	8	8	8	8
Tx power (dBm)	-11	-7.2	-11	-7.2	-11	-7.2	-11	-7.2
Distance (m)	10	30	30	100	100	150	100	250
Pathlos (dB)	70.5	80	80	90.5	90.5	94	90	96.5
Rx power (dBm)	-82.5	-87	-87	-97.7	-101.5	-101.3	-101.5	-103.7
NF (dB)	7	7	7	7	7	7	7	7
Imp. loss (dB)	3	3	3	3	3	3	3	3
G_Tx=G_Rx (dBi)	0	0	0	0	0	0	0	0
Data rate (Kbps)	432	432	219	219	109	109	54.5	54.5
Eb/N0 req. (dB)	10	10	10	10	10	10	10	10
Eb/N0 (dB)	26	20	19.5	12.9	12.1	12.4	15	12.9
Link margin (dB)	16	10	9.5	2.9	2.1	2.4	5	2.9
Sensitivity (dBm)	-97.6	-97.6	-100.6	-100.6	-103.6	-103.6	-106.6	-106.6

Conclusions

- IR-UWB PHY features
  - Low complexity
  - Low Tx power
  - Low data rate
  - Low power consumption
  - Low to medium range
  - High localization accuracy