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

Submission Title: Low Clock Rate Ranging for Non-coherent System
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Re: [Response to IEEE 802.15.4a Call for Proposals (04/380r2)]
Abstract: [Proposal for the IEEE 802.15.4a PHY standard based on the chaotic UWB system technology.]
Purpose: [Proposal for the IEEE 802.15.4a PHY standard.]

Low Clock Rate Ranging for Non-coherent System

Presented by: Jae-Hyon Kim

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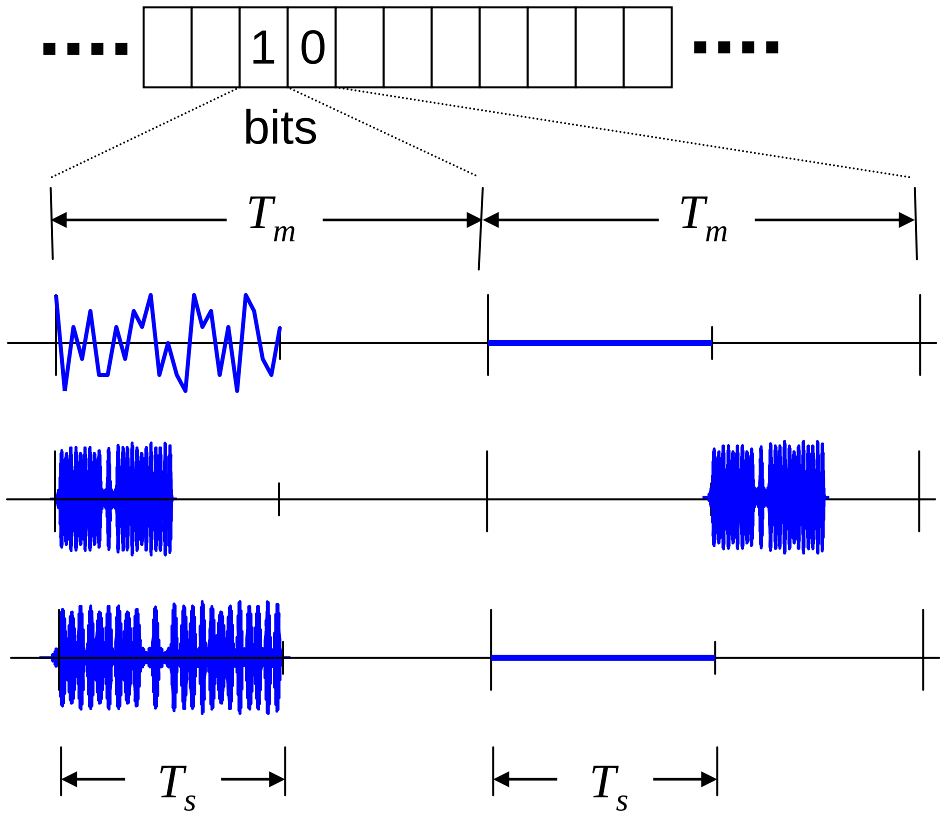
Objective

- Provide the simulation result of non-coherent ranging system based on chaotic signal with proposed preamble
  - Show the low cost solution using low rate clocks for non-coherent ranging system
  - It also can be applied to the system based on burst impulse radio

Chaotic Signal

- Chaotic is flexible enough to change the data rate in a very simple way



OOK, the burst chaotic signaling time can be
Ts = 100 ns, Tm = 400 ns => 2.5Mbps

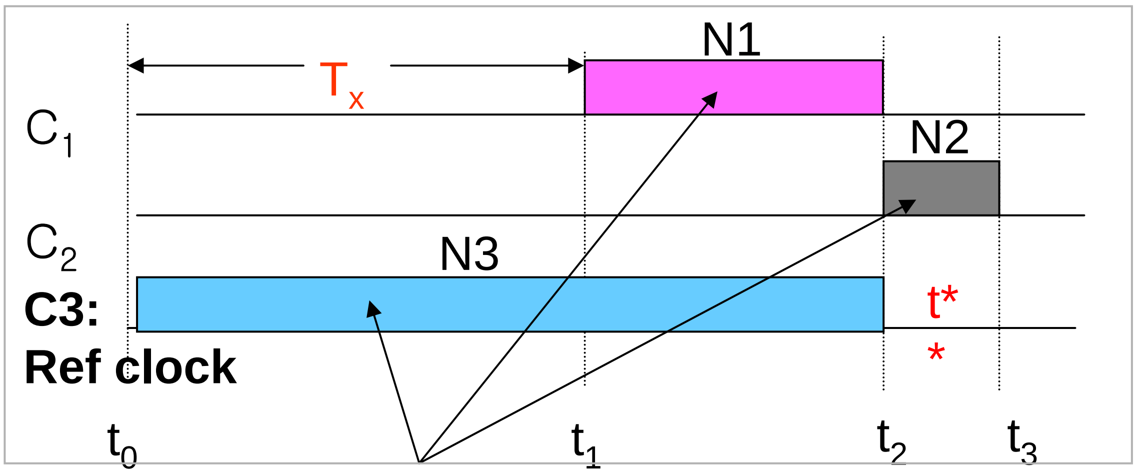
And Ts and Tm values can be flexibly changed to any specification in case of chaotic signal
Ex: Ts = 50 ns, Tm = 200 ns => 5.0Mbps

PPM (Mitsubishi, TDC, I2R, etc)

OOK Wellborn (Freescale)
Ts = 109 ns, Tm = ~218 ns => burst rate avg. 2.3 MHz

Low Clock Rate Ranging Method

This ranging algorithm can be applied to a system that compare the reference clock and the received waveform or only by comparison of two different rate of clock waveform



N1, N2, N3 – pulse numbers

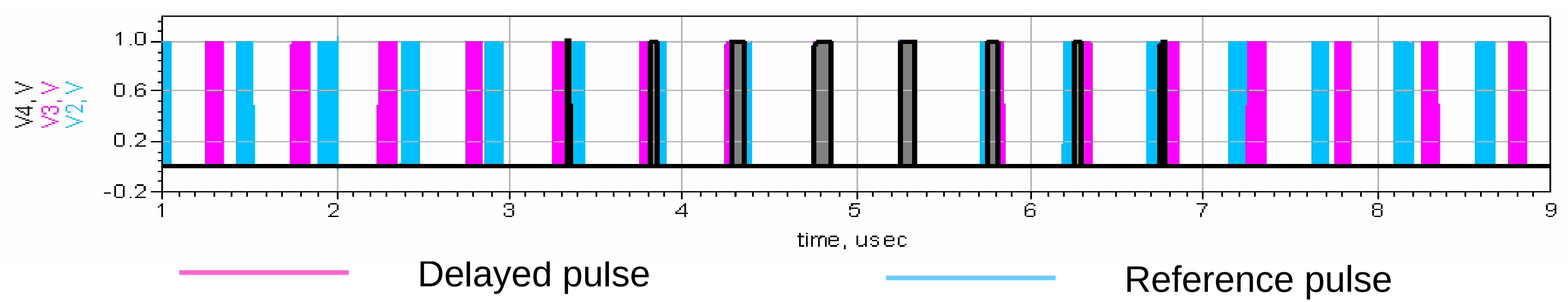
$$T_x = (N3+0.5*N2)/f_1 - (N1+0.5*N2)/f_0$$

distance

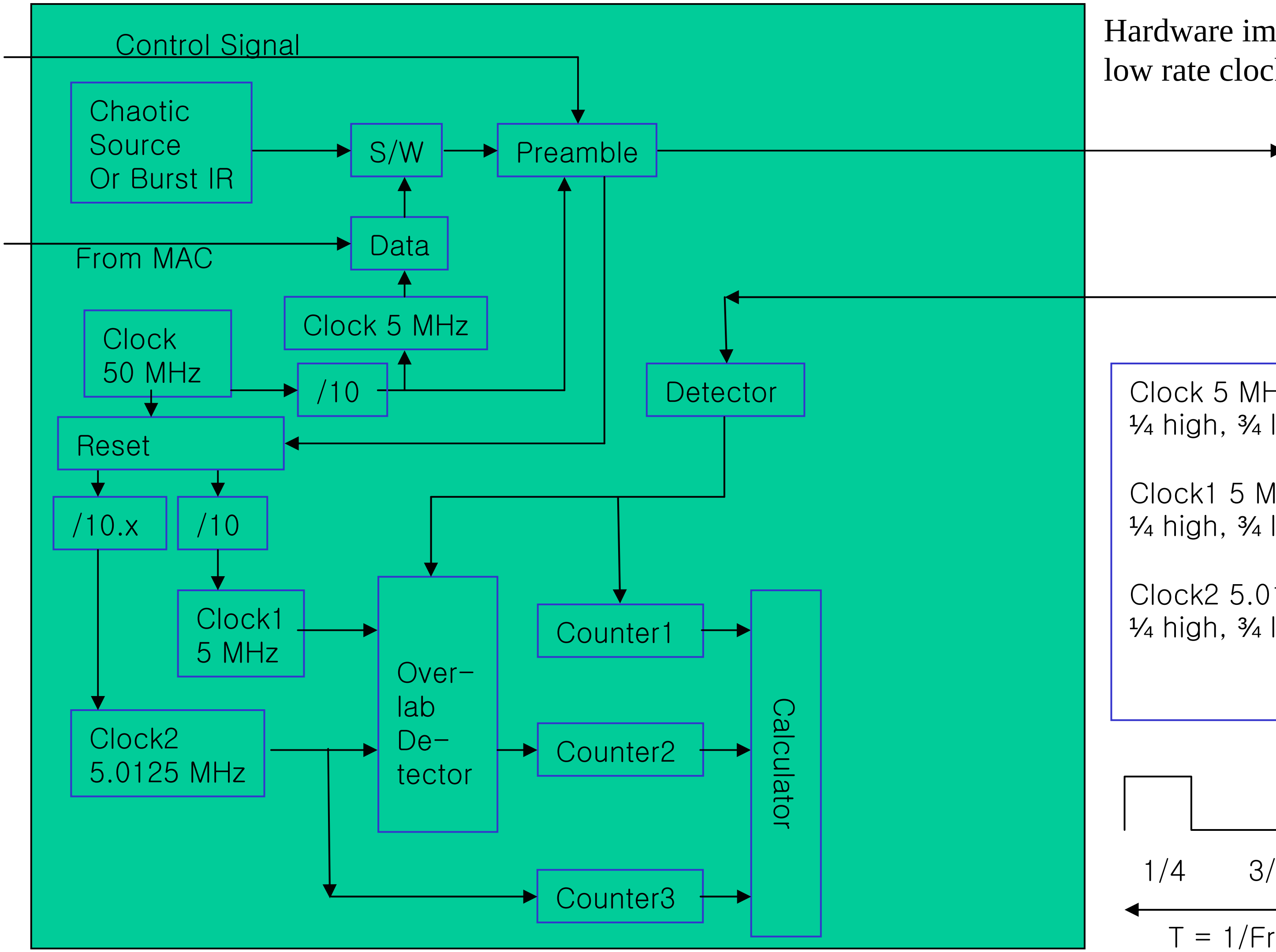
$$S = 0.5*c*(T_x-\tau_0)$$

τ_0 **– retranslation time**

Operation time of counters $\mathbf{C_1, C_2, C_3}$.



Low Clock Rate Ranging System

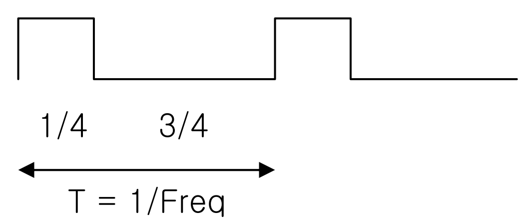


Hardware implementation in case of two low rate clock wave form comparison

Clock 5 MHz
¼ high, ¾ low state

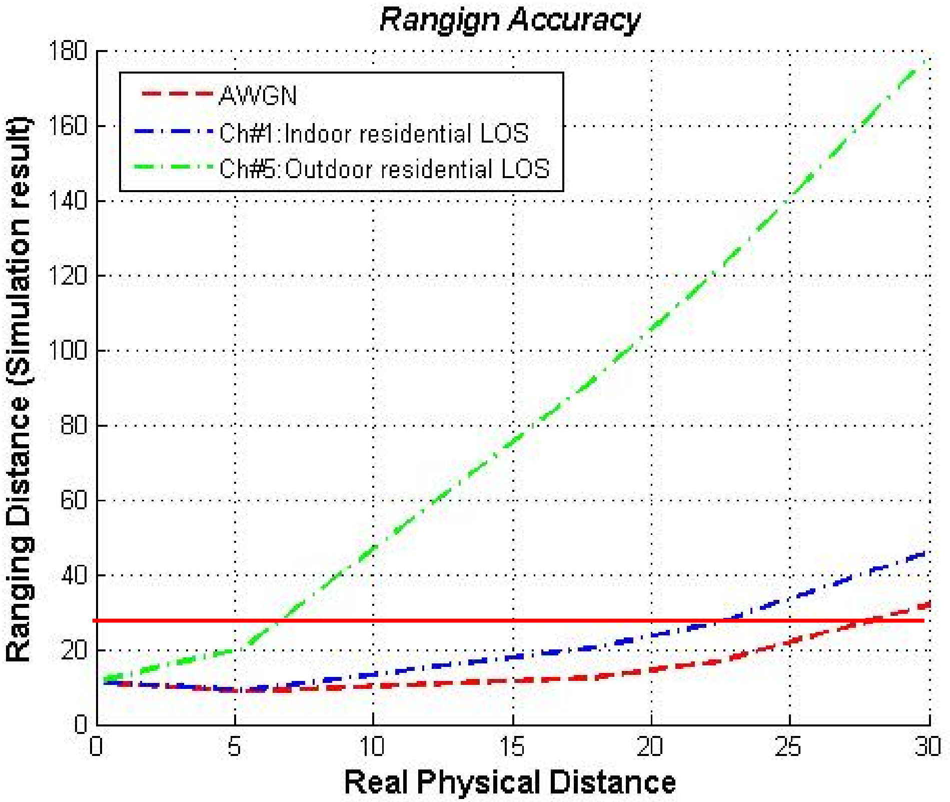
Clock1 5 MHz
¼ high, ¾ low state

Clock2 5.0125 MHz
¼ high, ¾ low state



Simulation Result

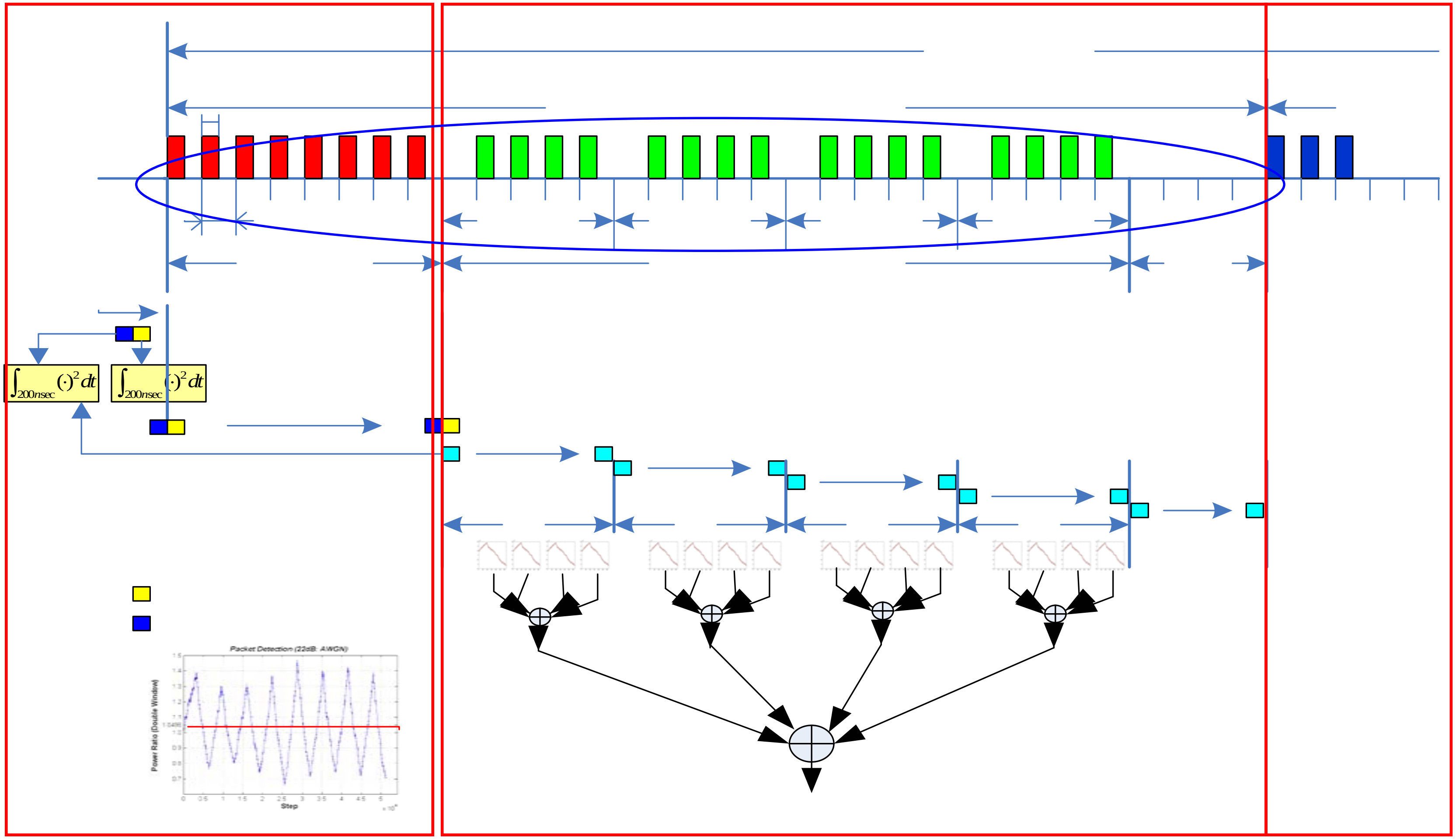
- Simulation result of ranging system using the proposed preamble, detection, double window synchronization, and low rate clock ranging algorithm



Preamble Used for Simulation

Four bytes preamble structure

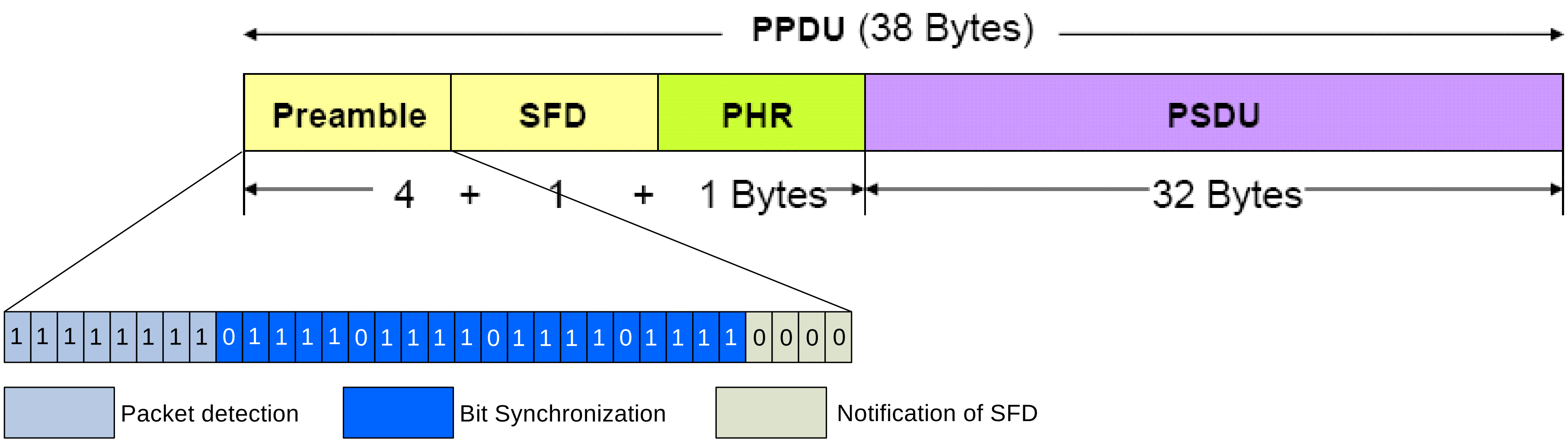
Packet Detection → Symbol Synchronization → Discernment for SFD



Back-up Slides

Preamble

- Proposed preamble consists of packet detection part, symbol synchronization part for non-coherent ranging system



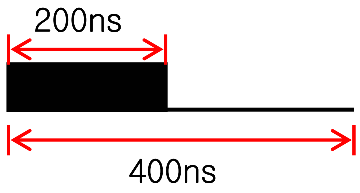
Preamble Design

- **Proposed Preamble Format**
  - **1 1 1 1 1 1 1 1 | 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 | 1 1 1 0 | 0 0 0**

    (1) (2) (3)

- **(1) → Packet Detection Interval: 1 1 1 1 1 1 1 1**
  - One Symbol : 2.5MHz → 400ns
  - Half Duty Cycle (Adapted into All Preamble Format)

    1)Multipath Immunity 2)Efficient Sync.



- **(2) → Symbol Synchronization Interval: 01111 * 4**
  - First 0 : Detected by threshold already decided during the packet detection period

    1)First 0 : Switching Double window into Single Window

    → Symbol Sync.

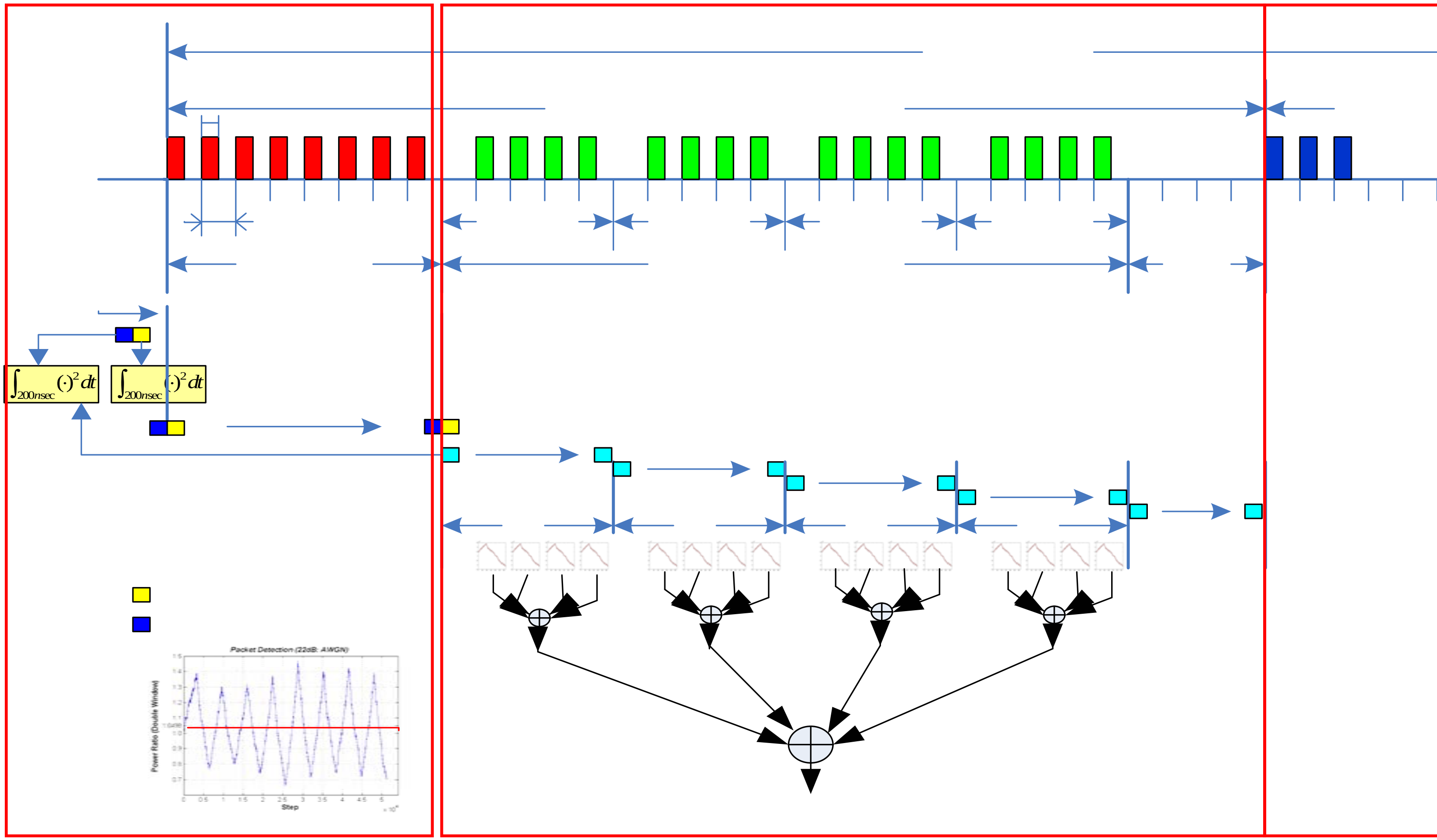
    2)Next 0 : Reset Memory for next symbol sync. period

    → 4 Same Period : improve the possibility of detecting the accurate symbol sync.

- (3) → **Discernment for SFD** (1 1 1 0 0 1 0 1: 1 byte (IEEE 802.15.4)) : **0000**
  - Detected by threshold, same with detecting 0 for symbol sync.

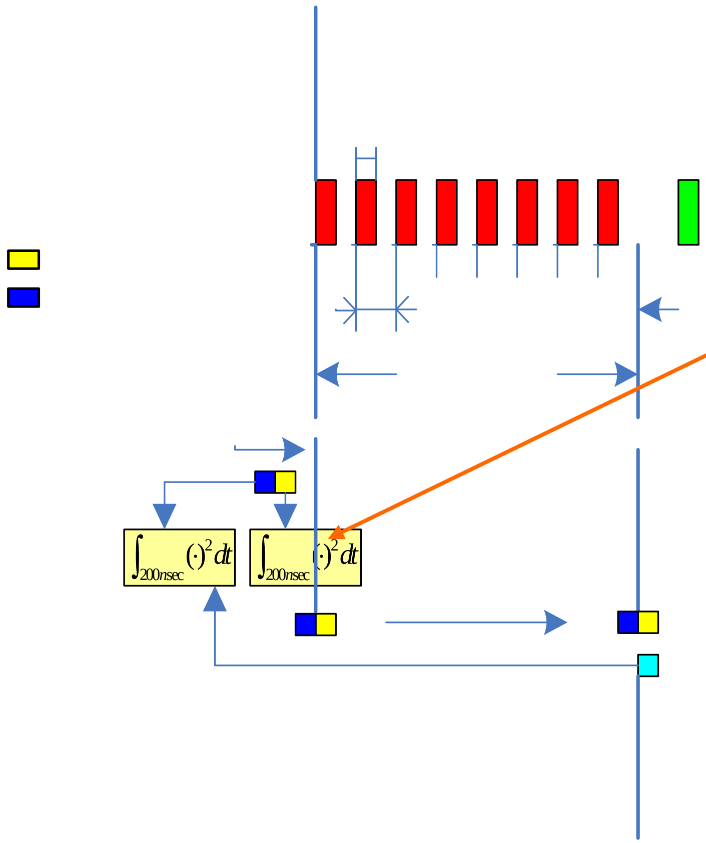
Synchronization (Proposed Algorithm)

Packet Detection → Symbol Synchronization → Discernment for SFD



Synchronization (Cont'd)

Proposed Algorithm (Packet Detection)



- **Double Window Method**
  - **Two sequential window**
    (same integration interval: half duty cycle(200ns))
  - **Decision for threshold (COOK Modulation)**
    → Ideally, at exact the incoming packet time,
    the value of the beyond the equation is satisfied

$$\frac{\text{A Window Integration result}}{\text{B Window Integration result}} = 1 + SNR$$

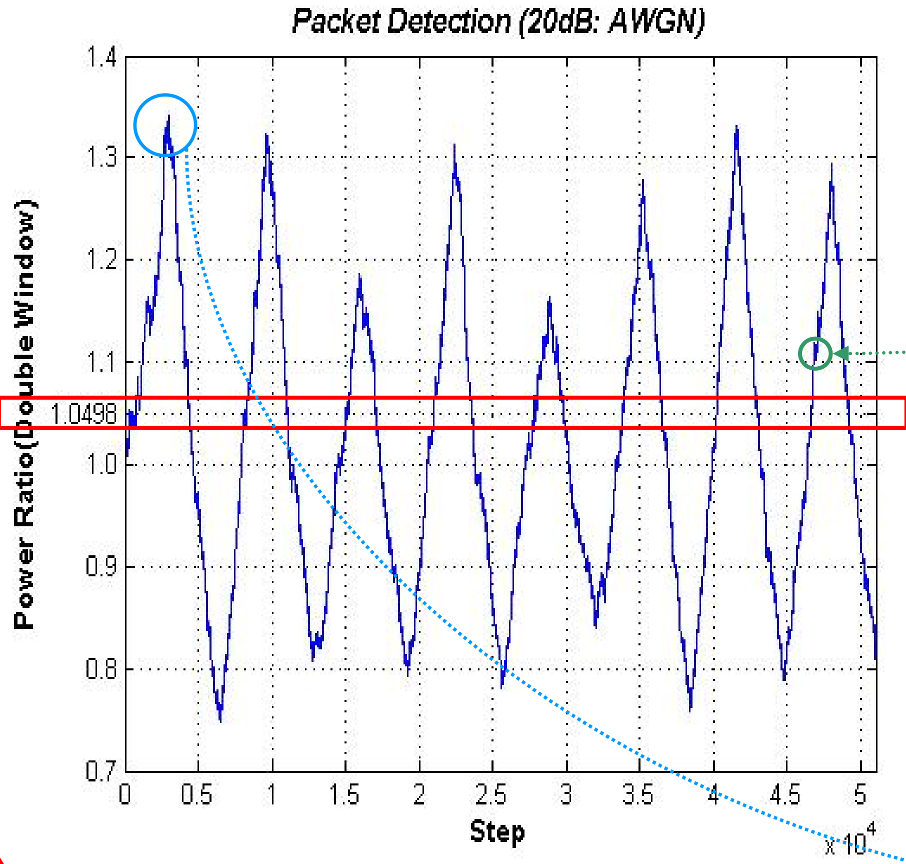
- **Output of the Double Sliding Window**

$$m_n = \frac{a_n = \sum_{m=0}^{M-1} |r_{n-m}|^2}{b_n = \sum_{l=1}^{L} |r_{n+l}|^2} \quad \text{where } a_n, b_n \text{ are power of sliding window}$$

- **Threshold**

$$\textbf{threshold} = \frac{\text{mean}(\text{Peak}_{\max}) + 1}{2}$$

Synchronization (Cont’d)



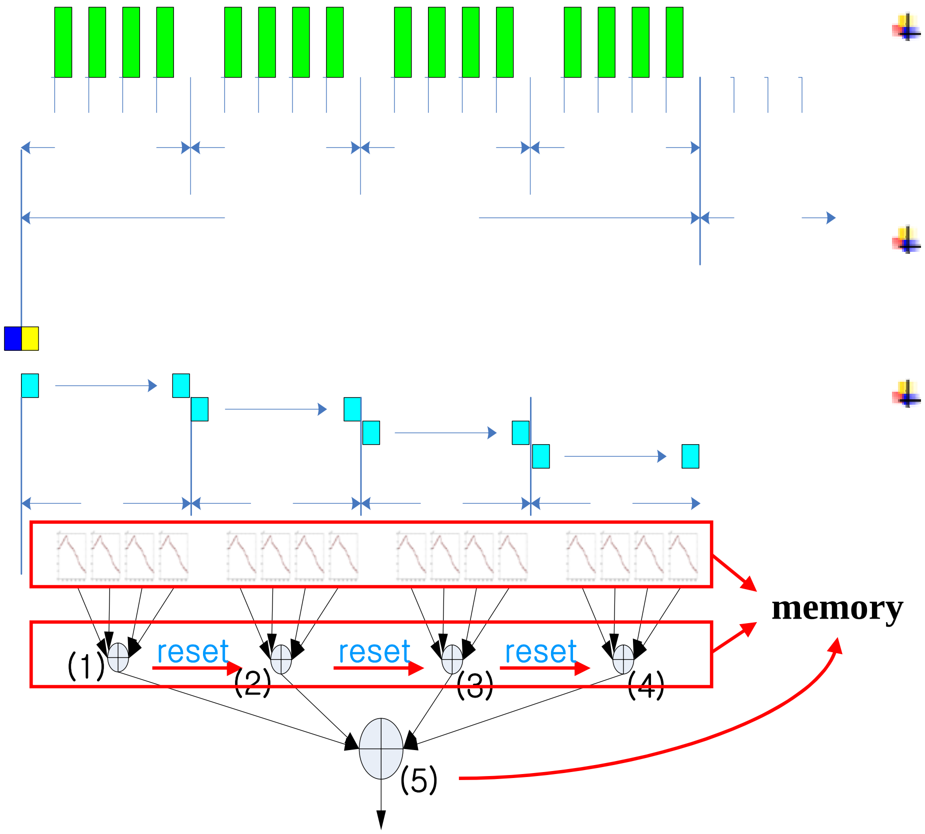
Threshold: 1.0498
(2.5Mbps, Half Duty Cycle)

- **All 8 Peak from the Output of Double Sliding Window → Packet Detection Success (Statistically, 20dB is enough)**
- **Soon after detecting the packet by aforementioned packet detection procedure, the last exact point above the threshold is stored in memory for symbol sync. → Coarse Sync.**
- **After deciding the incoming of the packet, Detecting the first 0 of symbol sync. Composition(20bit)by the threshold (Coarse Decision)**
  →Max Pw(Signal + Noise)/Min Pw(Noise) at fist peak point

$$\text{threshold} = \frac{\text{Output of Window A}}{\text{Output of Window B}}$$

Synchronization (Cont'd)

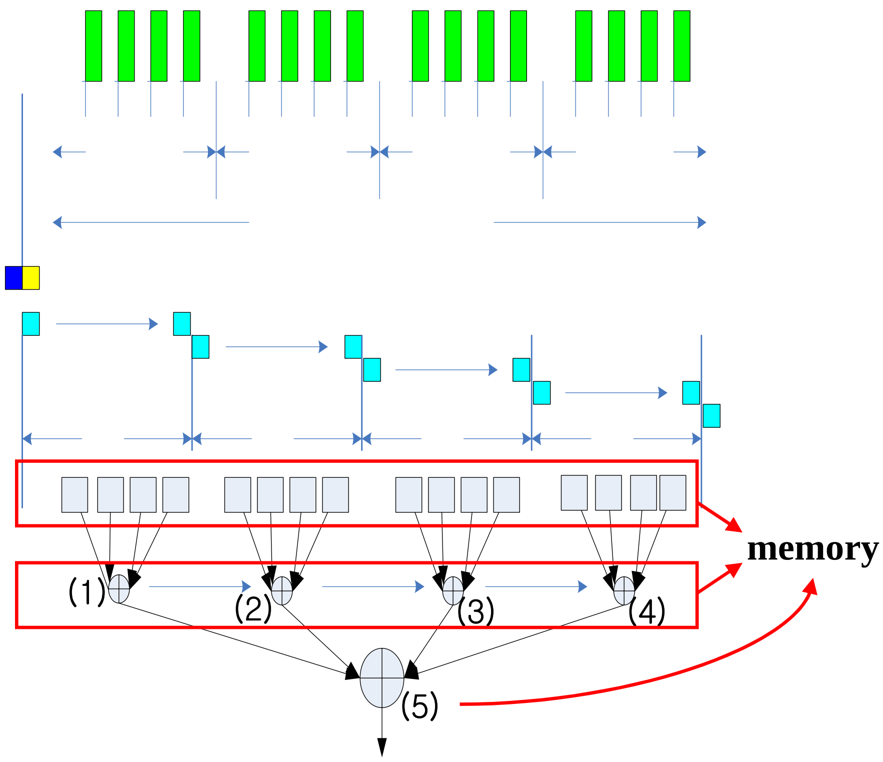
Proposed Algorithm (Symbol Synchronization)



- **Single Window Method**
  - **Why Single Window? (instead of Double Window)**
    - → **No need for the exact threshold w.r.t. different EbNo**
    - → **Half computation complexity**
  - **From the previous Threshold, first 0 detection trigger the change of the window from double into single.**
  - **Two symbol Synchronization Method**
    - 1st approach (complex method)
      - At the coarsely synchronized point, stored during packet detection process, start to preserve all the sliding integration output till detect the next 0 bit.
      - Advantage → High accuracy with Chaotic pulse
      - Disadvantage → High Memory requirement

Synchronization (Cont'd)

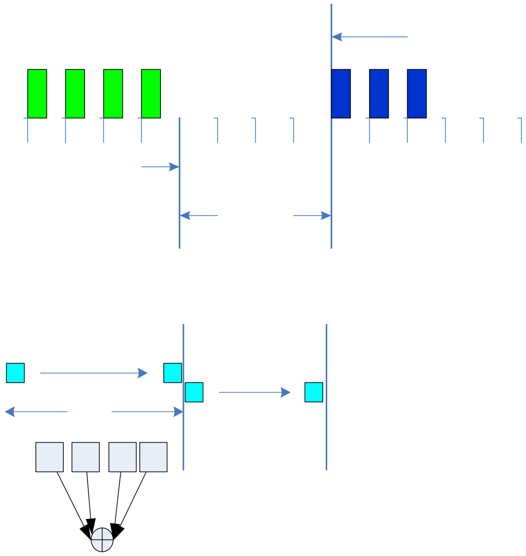
Proposed Algorithm (Symbol Synchronization)



- **Single Window Method**
  - 2nd approach (Simple method)
    - At the coarsely synchronized point, stored during packet detection process, start to preserve only distance difference value between the coarse sync. point and max. point till detect next 0 bit.
    - Advantage → low memory requirement
    - Disadvantage → less accurate sync. Accuracy (refer to the simulation result)
  - **Detecting the next 0 bit (inside the next sync. bit period(5bit)), sum all the value in the memory , send the value into other memory and reset the memory for the next sync. Period**
  - **Keep doing the previous procedure till the last period**
  - **Realizing the end of the sync. Period(4), all four value will be summed and find exact the Symbol sync. Point**

Synchronization (Cont'd)

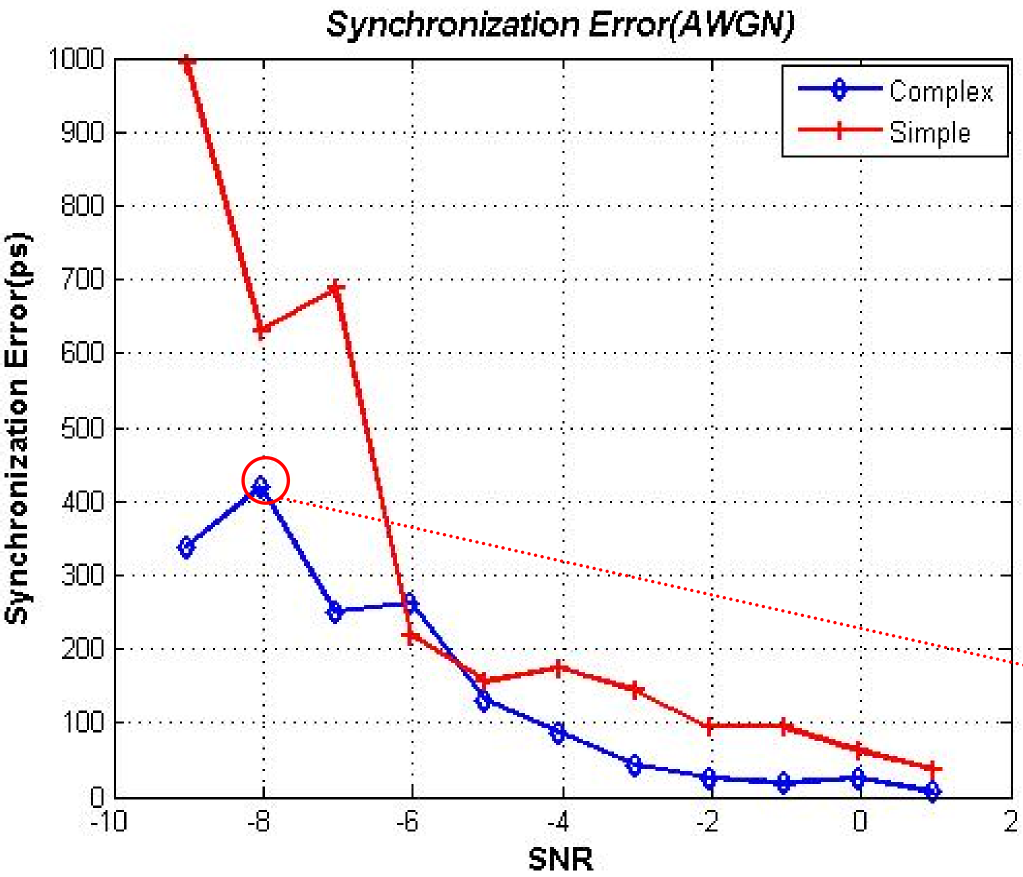
Proposed Algorithm (Discernment for SFD field)



- **Distinguish the SFD field (1 1 1 0 0 1 0 1)**
  - **Due to the knowledge of the exact start of the symbol, start to detect the next symbol with the same threshold as the symbol synchronization process.**
  - **As all 4 zero sequence is detected, then receiver know the exact start time of SFD field and prepare for reading the SFD field**

Synchronization

Simulation Result (AWGN channel)



- EbNo : 20dB~30dB
- Assumption(Adapted to all result)
  - Packet Detection failure →Discard that packet
  - Minimum EbNo for the success of statistically enough possibility of packet detection(1%) →20dB : Only Chaotic Pulse Case
  - 10 iteration to improve the statistical reliability
- Evaluation for two symbol sync. Method.

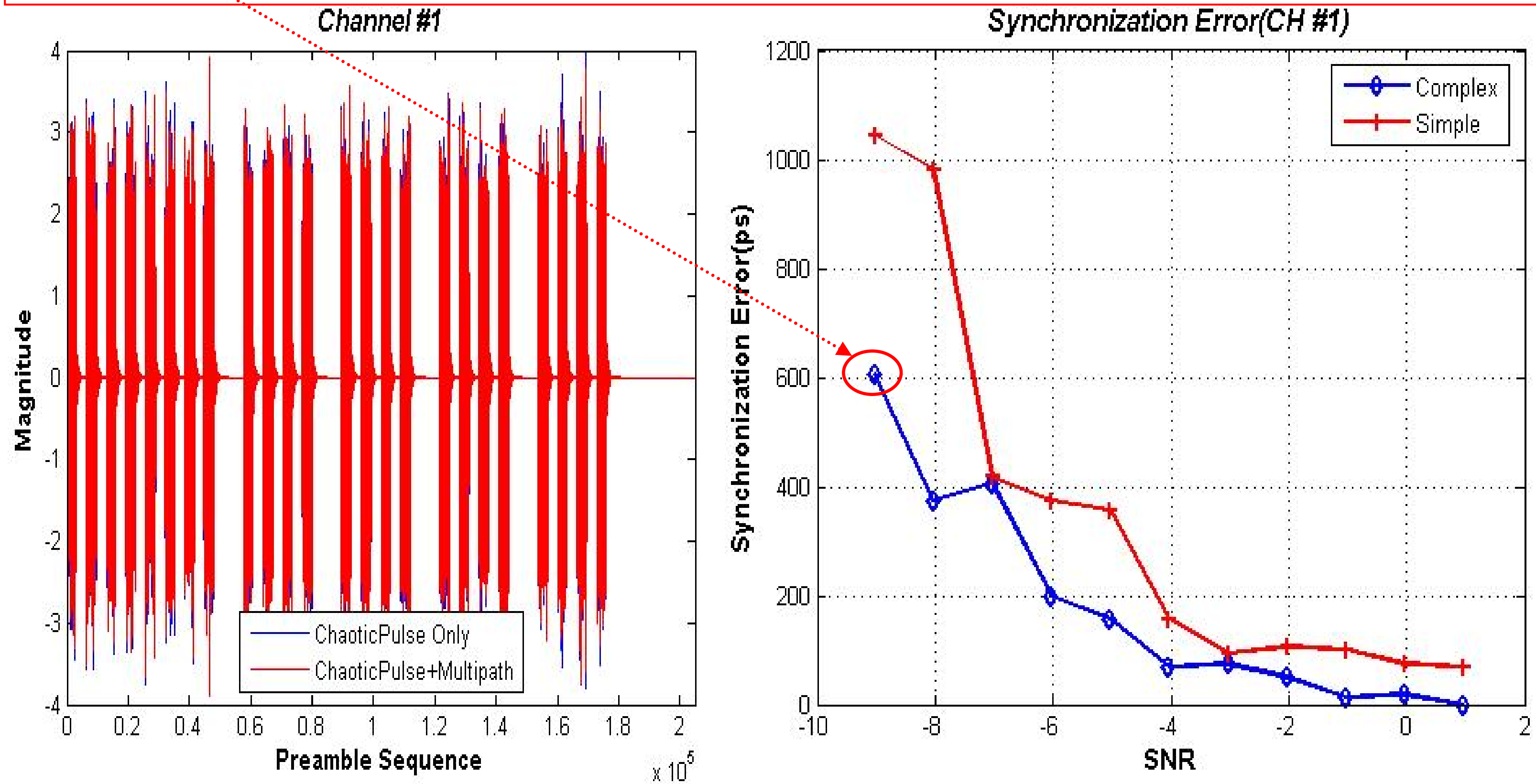
  Complex > Simple

- Sufficiently reliable for the ranging purpose → **maximum 437 pico.sec** synchronization error in case of complex method → small ranging error

Synchronization

Simulation Result (Ch #1: Indoor Residential LOS)

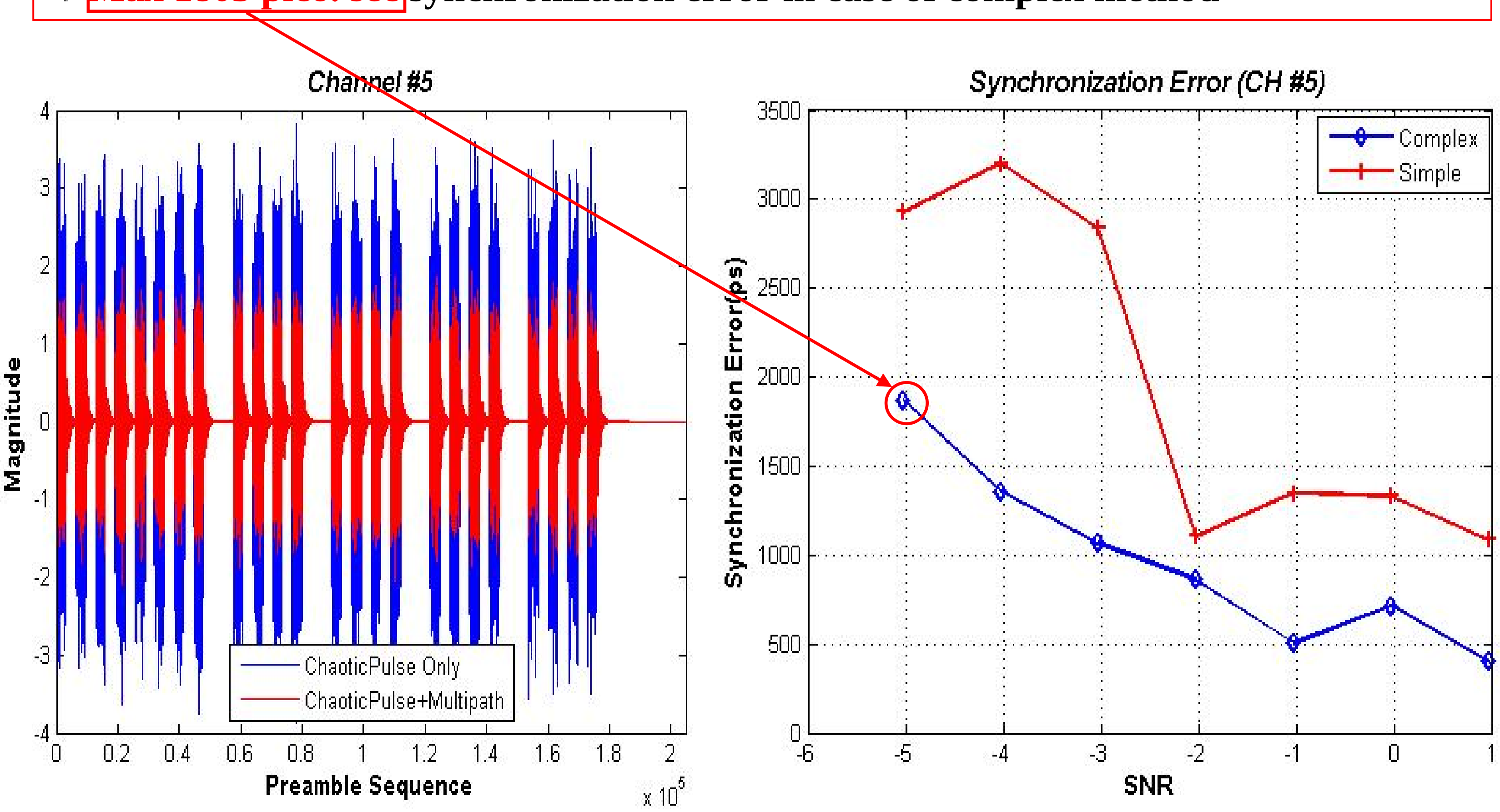
- **Almost the same Sync. Error as the AWGN case (Minimum 20dB requirement for 1% packet detection, same as AWGN)**
- **Max 608 pico. sec synchronization error in case of complex method**



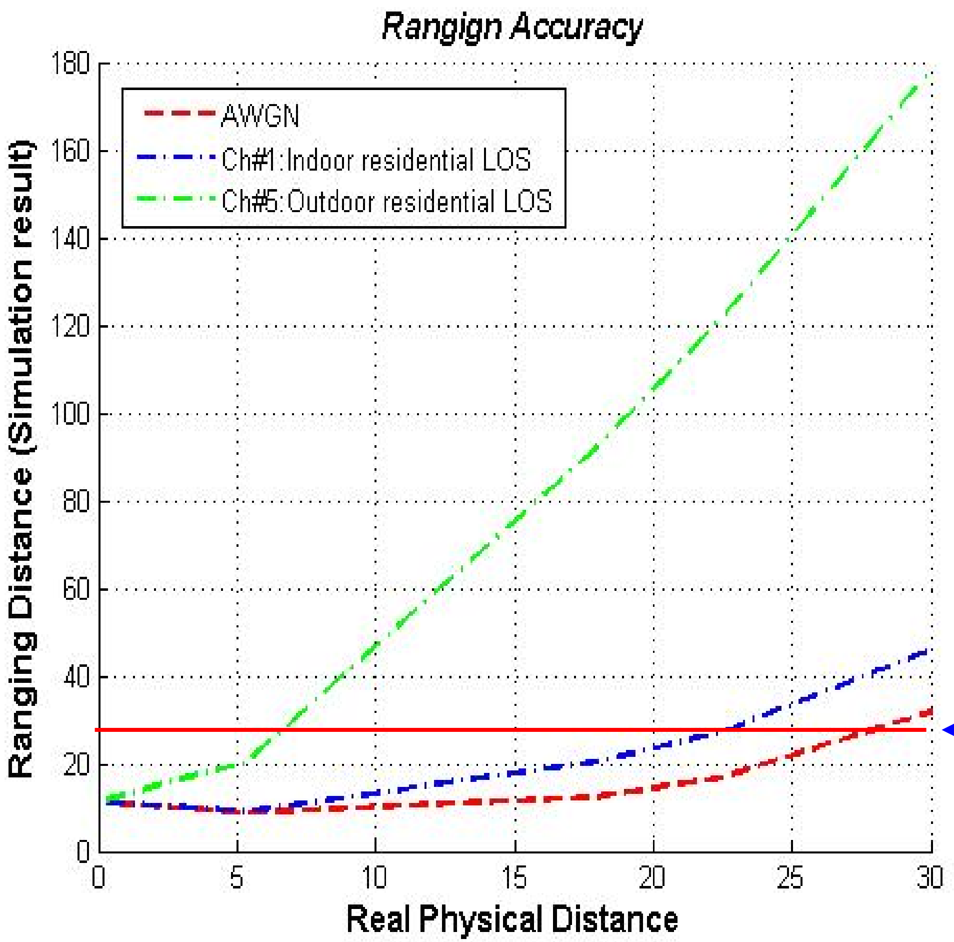
Synchronization

Simulation Result (Ch #5: Outdoor Residential LOS)

- **Minimum 24dB requirement for 1% packet detection**
- **Max 1803 pico. sec synchronization error in case of complex method**



Ranging Accuracy



- **Assumption**
  - **Retransmission time: 50ns**
  - **F1 = 2.5125MHz**
  - **F0 = 2.5MHz**
  - **0 ~ 20 meter**
    → Synch. Error + Ideal Ranging Algorithm Distance Difference
  - **20~30 meter**
    → Expectation based on the Simulation Error (Not statistically Reliable results)

Technical Requirement
→ 25 cm