IR-UWB Radio Architecture for Wireless Sensors Network based on Pilot Signal Assisted MAC

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***Abstract*—Due to low power consumption and strength to multipath fading Impulse Radio-UWB is an excellent platform for the short-range wireless communication. One of the most promising Radio architecture for impulse radio based communications is RAKE. But as RAKE requires CSI (Channel State Information) for the signal processing (which consumes extra energy), it is not an ideal choice for Wireless Sensor Network. In this research we have proposed light weight UWB Radio architecture specifically for WSN. We have compared its performance with the traditional RAKE architecture and results show that our proposed architecture well suits to Wireless Sensors Network and works better than RAKE for indoor short range UWB based WSN applications.**

Our suggested architecture was tested with Pilot Signal Assisted MAC (medium access control) algorithm and is found very well-matched with WSN's MAC needs.

***Index Terms*— Transmitted Reference Delay hopped transmission, Ultra Wideband, Wireless Sensor Networks.**

I. Introduction

Traditional Ultra Wideband based radios like RAKE are designed to counter the effect of multipath fading, for this reason multiple correlators called fingers are used. Additionally for the processing of the received signal CSI (channel state information) is also required. This results high signal to noise ratio (SNR); which is a good solution for common wireless radios. But when we talk about wireless sensors network, the main emphasis is on energy saving and indeed MAC layer compatibility. Thus lightweight radio architecture is essential. In this paper we have proposed a different approach than RAKE. Our proposed architecture saves energy, as it does not need channel estimation. Furthermore proposed architecture is compatible with MAC layer that makes it an ideal platform for short range indoor UWB based WSN communication.

As we know the major constraints for WSN-Architecture are low cost, low power and simple circuitry so we have focused on a type of radio architecture, which is lightweight and compatible with MAC layer. At this point a simple question comes to our mind: why UWB-Impulse Radio? The answer is simple, 7.5 GHz of free spectrum provides us a high range of data rate, exceptionally little transmission energy, it is very grim to intercept, it has a multipath fading resistance and last but not the least it is low cost (due to mostly digital design).

Due to the above-described qualities, a simple IR-UWB base architecture is proposed here, which uses Transmitted Reference Delay Hopped scheme. The rest of the paper is formatted as follows. In section II, brief explanation of Delay Hopped Transmitted Reference Scheme is described; section III explains the system architecture model. In section IV BER performance is evaluated, simulations' results and summary is explained in Section V and VI respectively.

II. Transmitted Reference Delay Hopped Scheme

The traditional IR-UWB system receiver works on an analog correlation manner to spot UWB signal but it has it's drawbacks for instance; long synchronization time, complex assembly, channel estimation requirements etc.

Fundamentally, when we are designing radio architecture for WSN; in order to save power and keep the system simple and light channel state information should be avoided.

In order to achieve the above, the most prominent solution is to use Transmitted Reference structure. Therefore, architecture designed in this manner can sidestep dense channel estimation, reduce the plea of synchronization accuracy, and accumulate

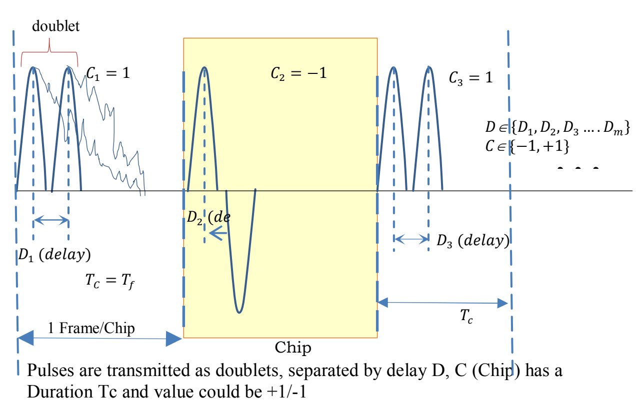

Fig.1. TRDH Pilot pulse structure [1]

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multipath energy and ease compactness. As a result this proposed structure has become a vital research track for wireless sensor networks.

In this Transmitted Reference UWB structure (with delay hopped for multi user environment), a pulse pair (doublet) as opposed to single pulse is transmitted Fig.1. The first pulse works as a pilot and does not carry any information. It is delayed at the receiver to act as a correlation pilot (reference) for the second pulse. In-fact the data/information is carried in the 2nd pulse of the doublet. Relating a particular delay code sequence to each user works well in a multi user environment. However, since it is hard to exactly implement a large delay with analog circuits [3], the use of delay for TR communication is limited to a few choices. One of the choices is CDMA (code division multiple access) code, which was applied by Hoctor [2], [3] for Transmitted Reference multi users environment. We have selected a different approach and used 2nd order Volterra model [5].

Volterra model generates a sequence of codes for multi user environment. It is basically an approximation method and works same as Tayler series. The general equation for 2nd order Volterra model which is given below is explained in [10]

$$y_{j,q}[i] = \sum_{k1=1}^{N_k} . \sum_{k_2=1}^{N_k} a^{(k_1)[i]^T} . Y_{j,q}^{(k_1,k_2)} . a^{(k_2)[i]}$$

(Where q is a sample of symbol i for correlator j, and k represents user, k $\in \{1,2,3,..N_k\}$)

III. SYSTEM MODEL

The MAC layer design we have considered as the basis for the suggested UWB-Radio architecture was presented in [1], *(this MAC is based on 802.15.4 standard [7], although it differs from the standard in a few extents but use of pilot signal for communication control, guarantees time allocation).*

As the scope of this paper is to weigh the performance of the radio part, we have focused only on the transceiver side. Here the proposed transmitter is based on energy efficient pulse generator Fig.2, similarly receiver design is TRDH based Fig.3. Transceiver supports data rate from 5 kbps to 1.2 Gbps, and it can reach BER of roughly 2x10e-4 for a link space of 10 m. Here reducing the data-rate can upturn the link distance or increase the BER. The transmitter disperses less than 600 µW of power, which makes it a good choice for short range WSN-applications. As we know that the primary motivation of a PHY layer model is to correctly symbolize “Signal to bit” and “Bit to signal” conversion that’s why we have used BER/SNR (bit error rate/signal to noise ratio).

Overall system performance (including MAC as major) was evaluated in [1]. Following are the key parameters used in calculation.

ω(t) = pulse waveform.

$N_p = total\ number\ of\ transmitted\ pulses$

$d_k \in \{0,1\} => symbols(alphabets) for\ BPPM$

$a_k \in \{-1,1\} => symbols(alphabets) for\ BPAM$

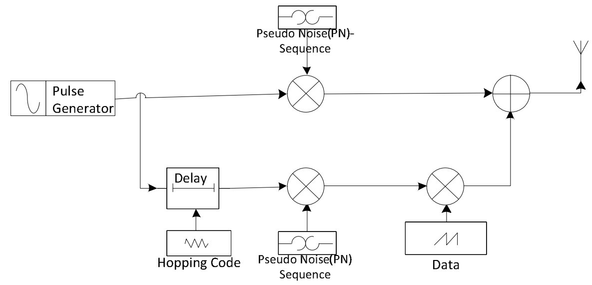

Fig.2. Block Diagram of TRDH-Transmitter

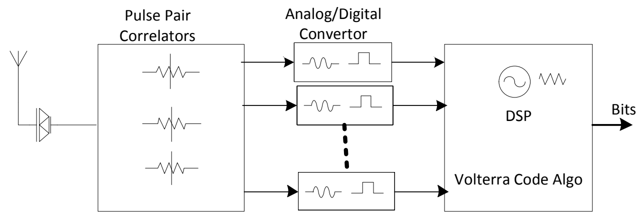

Fig.3. Block Diagram of TRDH-Receiver

D ≥ $T_p + T_g$ => *modulation delay*

$T_p => Pulse\ duration\ time$

$T_c => Frame\ repetation\ time$

For the Transmitted Reference Delay Hopped the received signal can be defined as [6]

$$s^{TRDH}(t) = \sum_{i=0}^{\frac{N_p}{2}-1} \sqrt{\frac{E_b}{N_p}}\ \omega(t - iT_c - gd_k D) + \sqrt{\frac{E_b}{N_p}} a_k\ \omega(t - iT_c - T_m - gd_k D) \quad (1)$$

In case of BPPM (binary pulse position modulation), modulation delay (D) is less than T_c

D < T_c , whereas T_m is minimum delay between two pulses ($doublet$). In order to avoid IPI(inter pulse interference) and ISI (inter symbol interference), T_c and D are set with different values.

For TRDH (Receiver’s) variable "g" $= 1$ (g will be zero for RAKE receiver).

Subsequent will be the received signal in case of RAKE.

$$s^{RAKE}(t) = \sum_{i=0}^{NP-1} \sqrt{\frac{E_b}{N_p}} a_{k,} i\omega(t - iT_c - d_k D) \quad (2)$$

For the said signals’ structures defined in overhead equations, the symbol (energy) is correspondingly spread over N_p (pulses putting together a symbol)

So we can say the received signal =>

r(t) = s(t)*h(t)+n(t), (3)

‘*’ = continuous time convolution

h(t) = impulse response .

n(t) = white Gaussian random value.

As the purpose of the paper is to compare the effectiveness of RAKE and TRDH for WSN. Only an Additive white Gaussian noise “AWGN” channel is used (With the assumption that there is no IPI and ISI)

A. Architecture Theory

Our proposed TRDH receiver comprises of a set of pulse-pair correlators, each of which can identify a doublet(pulse pair) with a specific delay followed by a Volterra (hoping)code sequence.

Architecture of Receiver and Transmitter is defined in Fig.2 and Fig.3. The Volterra code sequence is {+1,-1,+1,-1} and delay is {D1,D2,D3,D4}. In the architecture, there is no correlation with the locally created waveform. To bound the noise impact, filtering process is necessary, therefore we have used a BPF (Band Pass Filter). The output of this filter produces an undistorted signal.

For the in-depth behavior study, system performance is calculated on two different schemes (BPPM and BPAM) Fig.4. For the receiver structure we have modified the described structure in [6]. In case of BPPM, (say *xth* bit)

$$d_x = \max\left(C_{1,x}, C_{2,x}\right) \tag{4}$$

$C_{1,x}$ and $C_{2,x}$ are the outputs of correlator.

Say $C_x = \left(C_{1,x} - C_{2,x}\right)$ (5)

In equation (5) we have compacted the decision variable to '1'one, as for the BPAM case there is only 1 correlator for output, so the decision formula will be change to equation (6).

$$C_x \underset{0}{\overset{1}{\gtrless}} 0. \tag{6}$$

For the TRDH receiver, the output of $N_p - 1$ Correlations (BPPM case)

$$C_x^{TRDH-BPPM} = \sum_{i=0}^{\frac{N_p}{2}-1} \int_0^T \tilde{S}_{r,x}(t - iT_c)\tilde{S}_{r,x}(t - iT_c - T_m)dt$$

$$-\sum_{i=0}^{\frac{N_p}{2}-1} \int_0^T \tilde{S}_{r,x}(t - iT_c - gD)\tilde{S}_{r,x}(t - iT_c - T_m - D)dt \tag{7}$$

(In case of BPAM)

$$C_x^{TRDH-BPAM} = \sum_{i=0}^{\frac{N_p}{2}-1} \int_0^T \tilde{S}_{r,x}(t - iT_c)\tilde{S}_{r,x}(t - iT_c - T_m)dt \tag{8}$$

In case of RAKE receiver (BPPM case)

$$C_x^{RAKE-BPPM} = \sum_{i=0}^{\frac{N_p}{2}-1} \int_0^T \tilde{S}_{r,x}(t - iT_c)\tilde{S}_{r,x}(t - (i+1)T_c)dt$$

$$-\sum_{i=0}^{\frac{N_p}{2}-1} \int_0^T \tilde{S}_{r,x}(t - iT_c - D)\tilde{S}_{r,x}(t - (i+1)T_c - D)dt, \tag{9}$$

(In case of BPAM)

$$C_x^{RAKE-BPAM} = \sum_{i=0}^{\frac{N_p}{2}-1} \int_0^T \tilde{S}_{r,x}(t - iT_c)\tilde{S}_{r,x}(t - (i+1)T_c)dt \tag{10}$$

$$BER_{TRDH-BPPM} = Q\left[\sqrt{\frac{\frac{2E_b}{N_O}}{(4+2g+2N_p2TW\frac{N_O}{E_b})}}\right] \tag{11}$$

$$BER_{TRDH-BPAM} = Q\left[\sqrt{\frac{\frac{2E_b}{N_O}}{(4+N_p2TW\frac{N_O}{E_b})}}\right] \tag{12}$$

For RAKE Receiver

$$BER_{RAKE-BPPM} = Q\left[\sqrt{\frac{\frac{2(N_p-1)E_b}{N_pN_O}}{4\frac{N_p}{N_p-1} - \frac{6}{N_p-1}(N_p2TW\frac{N_O}{E_b})}}\right] \tag{13}$$

$$BER_{RAKE-BPAM} = Q\left[\sqrt{\frac{\frac{2(N_p-1)E_b}{N_pN_O}}{4\frac{N_p}{N_p-1} - \frac{6}{N_p-1}(N_pTW\frac{N_O}{E_b})}}\right] \tag{14}$$

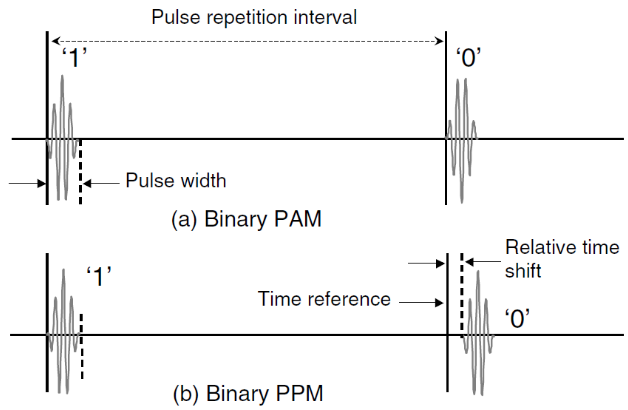

Fig.4. BPPM and BPAM Modulation schemes Structure [8]

IV. BER PERFORMANCE (INDOOR ENVIRONMENTS)

Due to space restrictions only major performance constraints are explained here. For the Transceiver performance evaluation BER/SNR (bit error rate/signal to noise ratio) model was simulated under MATLAB. The overall system performance was already evaluated in our previous work [1], where Mixim (omnet++)'s UWB (modified) model is used.

In order to analyze the bit error rate of two architectures, we have measured the output of the correlator as Gaussian, so that the bit error rate (BER) can be signified as tail probability (Q-Function), using the Signal to Noise Ratio(SNR) formulation for Transmitted Reference .

V. SIMULATION RESULTS

In radio architecture analysis, for accurate performance understanding Eb/No (energy per bit to noise power spectral density ratio) is the most common parameter. In Fig.5 BER is plotted versus Eb/No . It can be seen that TRDH performs well in both BPPM and BPAM cases. Between RAKE schemes, RAKE-BPAM performs better than RAKE-BPPM. On the other hand both schemes of TRDH has almost the same performance (TRDH-BPAM's performance is slightly better). At BER=10e-4, the RAKE-BPPM system performance is less than 2dB (less than the worst case of TRDH). When Eb/N0≈24 both TRDH schemes (BPPM and BPAM) have equal performance.

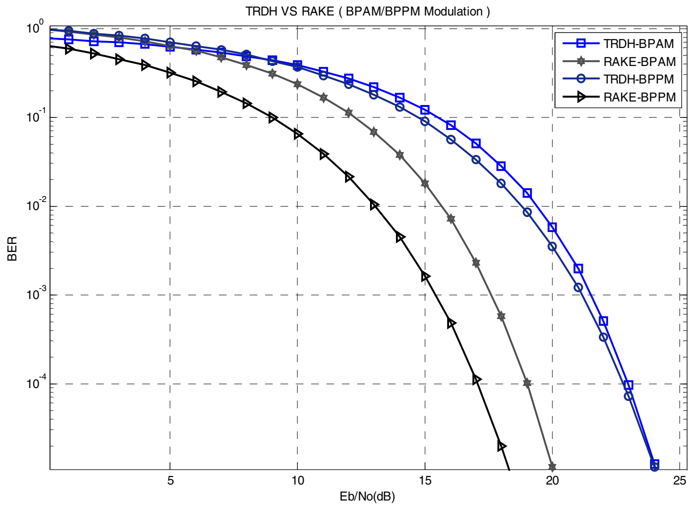

Fig.5.BER for Np=15 for TW=150 and Eb/No=20dB

At the next stage, in Fig.6, bit error rate (BER) vs. Np (no of transmitted pulses) is plotted. It can be seen that as Np (no of transmitted pulses) increases BER also increases. TRDH's performance is again better than RAKE. Here for the RAKE, bit error rate (BER) is 10e-3 for Np=2 to 4. In case of TRDH

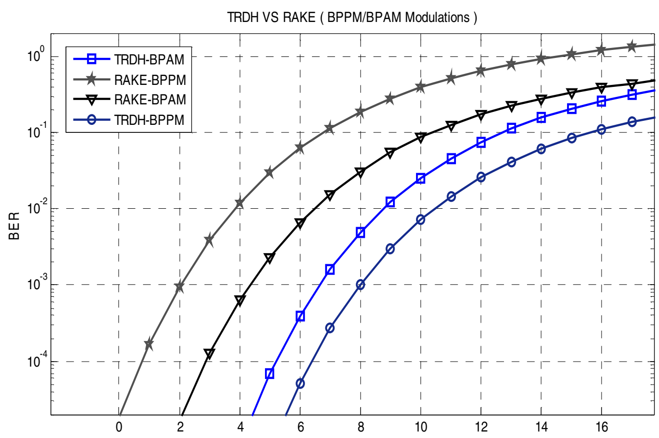

Fig.6. BER vs. Np for TW=150 and Eb/No=20dB

same BER measurement was calculated on higher number of transmitted pulses (Np=6 to 8). The RAKE-BPPM/BPAM structures are severely inclined due to pulse repletion.

In Fig.7, BER performance against TW is plotted, TRDH-BPAM and BPPM show better performance at low TW values, and RAKE-BPPM is slightly lower than TRDH interms of performance. Furthermore the RAKE (BPPM) slightly outperforms the TRDH due to abridged number of signal-noise cross terms that states the decision variable.

In the last graph, SNR vs. TW is plotted in Fig.8. As expected TRDH gives better signal to noise ratio even at higher number of TW. For example, for both TRDH (BPAM and BPPM) SNR >20, and TW is over 70. On the other hand RAKE-BPAM gives SNR about 25 but for the lower value of TW (e.g. TW<40).

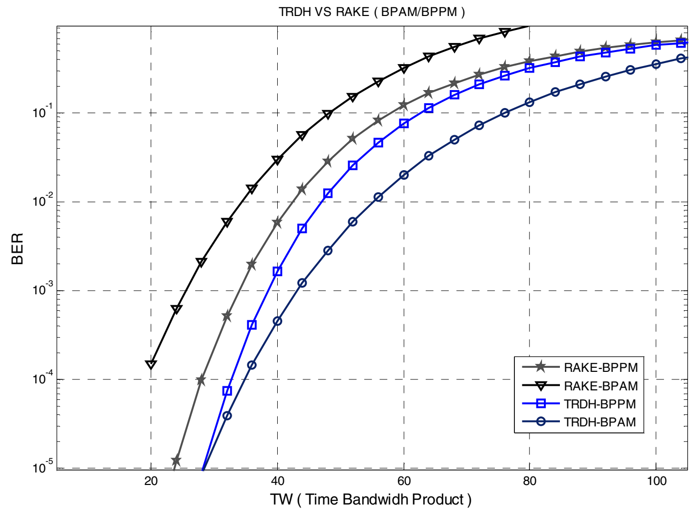

Fig.7. BER vs. Np for TW=150 and Eb/No=20Db

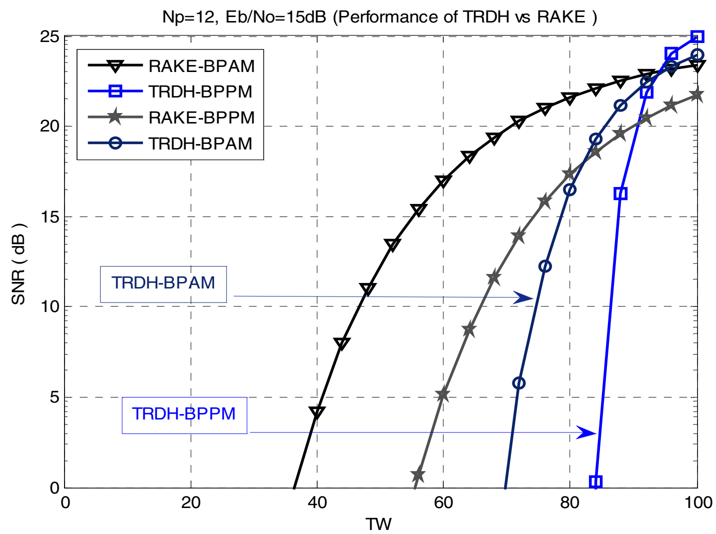

Fig.8. SNR vs. Np for TW =15

VI. Conclusions & Summary

RADIO (and the MAC) plays a crucial role in calculating the amount of energy consumed during a successful transmission. The aim of this research is to propose an effective light weight Radio architecture for Ultra Wideband wireless sensor network based on Pilot signal assisted MAC. Pilot assisted MAC was designed in [1]. This research is divided in 3 major sections, starting with a discussion about Transmitted Reference architecture, its usefulness and how it can be used in a multi user environment. Later on, we have briefly discussed proposed technique (Volterra model) for multi user environment in TRDH architecture. In the next section a light weight Radio Transceiver is proposed in which we have compared proposed architecture with the RAKE structure. For the performance measurement we have used two different modulation schemes BPAM and BPPM. In the final section we have measured performance in multiple scenarios. The most important were BER vs. Eb/No, BER vs. Np, and SNR vs. TW etc. From the simulation results it has been noted that TRDH based architecture is better than RAKE for Wireless Sensors Network. This is due to its lightweight radio architecture and avoidance of Channel Estate Information. Research was purely based on PAT (Pilot assisted Transmission) system specifically designed for Wireless sensors network.

In future, we aim to use the suggested architecture with U-MAC and an extensive clustering approach. To summarize, we can say that, the proposed TRDH architecture does not require CSI (channel state information) plus it reduces the sampling speed. Therefore it is an attractive choice for indoor WSN applications.

VII. References

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