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Performance Evaluation of Self-Organizing Feature of Cluster-based WSN for Pilot Assisted-MAC under IR-UWB

KAMRAN Ayub[1,2], VALARIJS Zagurskis[2]
1 Technology Group, NYUAD. New York University
2 IECS Riga Technical University, Riga Latvia

Abstract: Ultra wideband is an excellent platform for the short range wireless sensor networks. We had used UWB in our earlier proposed framework with PAT (pilot assisted transmission) technique. The PAT based UWB combination is excellent under single hop structure, but its performance deteriorates as the network density increases. To overcome this issue we have added optimized clustering adaption feature. In this paper, we have evaluated the self-organizing capability of the framework. Applied adaption features show a significant improvement in the network lifetime. Comparison of proposed scheme was done through multiple scenarios, e.g. network behavior when one node is down, and when the cluster head is down. Simulation results prove that the proposed optimization feature reduces the network energy consumption and makes the network eligible to organize it's topology in case of any node failure. Our optimized clustering architecture was tested with Pilot Signal Assisted MAC (medium access control) algorithm and is found very well-matched with wireless sensor network's MAC needs.

Keywords: Adaption feature, Clustering, Impulse Radio Ultra Wideband, MAC, Wireless Sensor Network

1 Introduction

UWB based Wireless Sensor Network is an excellent solution for the modern sensor applications. Especially Impulse Radio UWB is very attractive for the low data rate short range indoor communications.

Our UWB based WSN framework has some tremendous capabilities to work in both light and dense network topologies. As we have used PAT (Pilot Assisted Transmission) with Impulse Radio, it provides excellent control on the MAC scheduling. MAC algorithm [1] works in two phases, during the low access requests, it works on First Come First Serve (FCFS) rule, but as soon as the first collision occurs, it triggers the phase 2 (part of) the algorithm, which prioritizes the access requests and controls MAC requests according to the set priority. To make it more robust and compatible, PAT based Impulse Radio is used at PHY layer. Implementation of UWB at PHY for WSN is very challenging due to UWB's sensitive receiving capability and WSN's energy constraints. Keeping wireless sensor network's requirement in mind, we have proposed a very lightweight radio architecture in our previous work [2]. Where instead of the RAKE receiver we introduced the Transmitted Reference Delay Hoped (TRDH) receiver Fig. 3, which saves energy by avoiding channel estimation.

After the implementation of TRDH architecture in our framework, the network performance was very good for the small indoor networks, but when performance was tested under the dense network conditions, network lifetime was seriously affected. To rectify this issue we applied some adaption features, e.g. clustering. The main goal of this paper is to evaluate the "Self Organizing Capability" of our framework for the dense network condition.

The rest of the paper is formatted as follows. In section 2, brief explanation of our framework (MAC and PHY layers) is described. The system architecture model and self-organizing capability are explained in section 3 and 4 respectively. In section 5 performance is evaluated, simulations results and summary is explained in Section 6.

2 Mac & PHY Layers

MAC layer has significant importance in the WSN architecture. In the 2nd phase of our proposed MAC "PA-MAC" (Pilot Signal assisted MAC) [1] Cluster head broadcasts UWB Pilot signal to all alive nodes, in response he receives nodes' details e.g. residual energy, the size of data etc. The whole process works under TRDH technique where doublet (2 pulses) is used. Here first pulse works as a reference and does not contain any data, and the 2nd pulse contains the actual data. Doublet concept removes the need of channel estimation and saves energy. Fig. 1, explains the 2nd phase of the PA-MAC algorithm.

RAKE is the most common receiver architecture for the conventional radio, e.g. narrow band wireless systems. It has an analog part for the received signals correlation

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that takes long synchronization time. So does not fit for the ultra-wideband based wireless sensor network. In TR-IR (Transmitted Reference Impulse Radio) receiver, signal transmission works on a doublet principal, where a pair of pulse (doublet) is transmitted, 1st pulse operates as a pilot pulse, and it is delayed at the receiver to act as a reference for the second pulse. The data is carried in the 2nd pulse of the doublet. By using a code sequence (e.g. Code Division Multiple Access) as a delay code multiuser functionality can be achieved. In our case here we have used the 2nd order Volterra model [3].

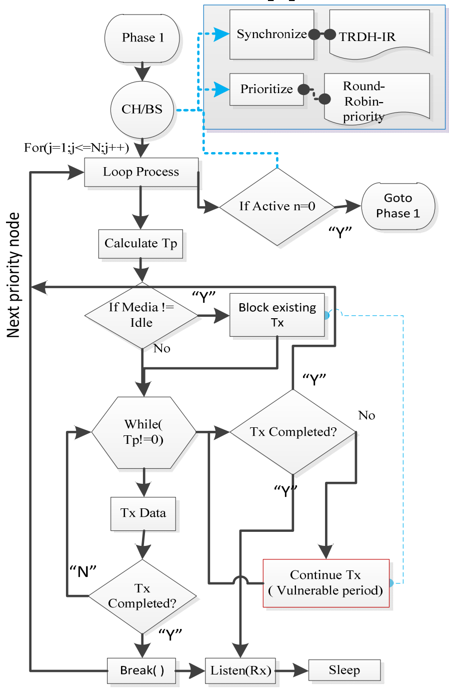


Fig.1 Pilot Assisted MAC - phase 2 [1]

3 System Model

Here the same system model is used as our previous work [4]. Hence, the MAC and the PHY processes are the same. Transmission range for the nodes is considered fixed (no mobility is applied).

Cluster size is controlled by the threshold value, which is 10% of the total deployed nodes. Fig. 2, shows our proposed clustering model. Our clustering mechanism is based on two parts: Formation and Stabilize phases. Formation phase deals with the initial cluster design, also re-clustering for the self-organization.

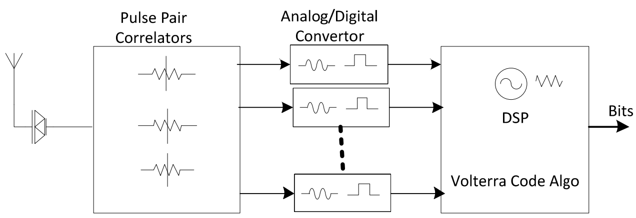


Fig.3 Block Diagram of TRDH-Receiver

Network operations, e.g. data transmission and routing is managed in the Stabilize-phase. Following are the core steps and assumptions.

- Random deployment of sensor nodes across the selected area.

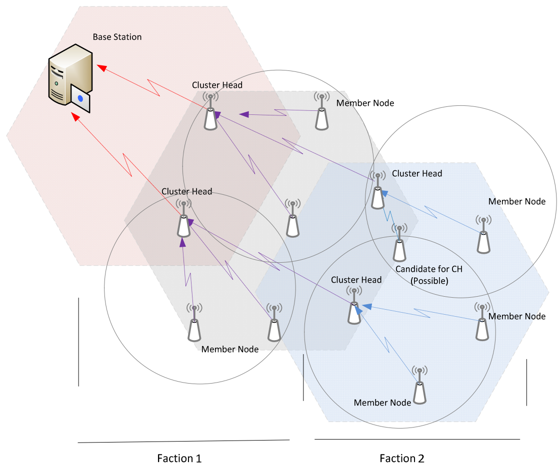


Fig.2 Faction based Clustering

- The startup energy is same for all nodes but randomly change with the time.
- Nodes can transmit data to any other node (including BS) by setting their transmitter power.
- Ultra wideband (Impulse radio) is underneath communication framework with symmetric characteristics.

3.1 Clustering Algorithm

1- Deployment of N nodes. N ∈ {n_1, n_2, n_3…n_K}.
2- Transmission range ($T_r R$) calculation from BS.
For i = 1 to N
Function call TrR(i)
3- Calculate Threshold Value ThV = 10%/N
4- Faction formation
From BS to TrR[n] /"n" is the node with least TrR
Faction =TrR/ThV
5- Function call Cost(N) / calculate the Cost value of each node. [5]
6- Select Cluster Head.
CH(i)= Max(Cost())/Faction(i).
7- While (CH membership != >ThV) accept Membership
8- CH calls PA-MAC( ) // Mac scheduling for member nodes as per Pilot assisted MAC
9- Sensing( ) // data gathering
10- Inter Cluster Communication >> Intra cluster communication.

A node can only be a member of one CH at a time, and can act as a regular node or CH. As the CH role is not a fixed or permanent role, during MAC schedule sharing the highest cost (value) node will replace the existing CH.

3.2 Network Model

The same network model is used as our previous work [4]. Following are the core properties of our network model.

1. The deployment of nodes is random across the selected region.
2. The position of the base station is fixed and located far from the regular nodes.
3. The rate of energy consumption depends on the transmission range.
4. Nodes have limited processing capability.
5. Cluster heads are well distributed over the sensor field as per the faction distribution.

3.3 Energy Model

The energy model of the framework is derived from [4][6], where the network has variable size from 100-500 nodes (for each scenario). The coverage area for nodes deployment is 100x100 square meters. Fig. 4.

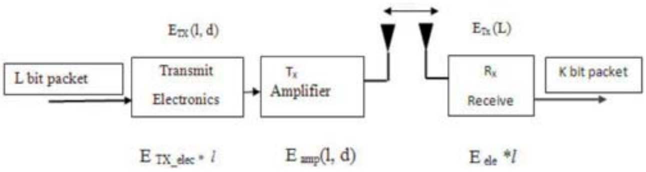


Fig.4 Energy Model of the proposed framework [6]

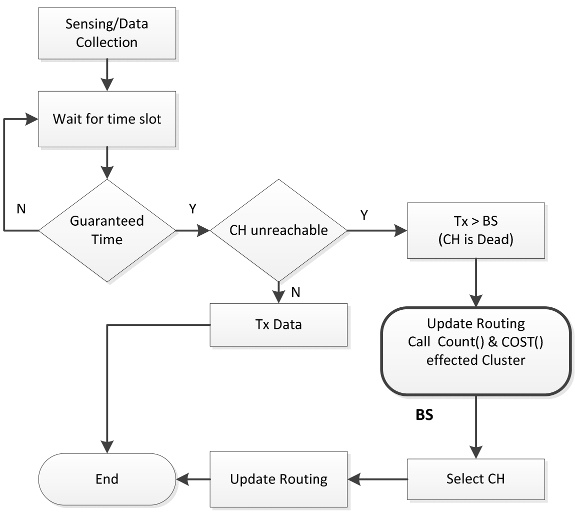


Fig.5 Self-Organization flow diagram

Energy model shown in Fig. 4 is used for the energy dissipation [6]. Free space (d2) is used for the distance/energy corresponding's between the source and destination nodes.

Similarly for the multi-path fading effect (d4) channel models are considered. Energy used for the transmission of x bit can be calculated from the following equation [7].

$$E_{TOT}(i) = E_{Tx} + E_{Rx} \qquad (1)$$

Where E_{TOT} is the total energy used at 'i' and E_{Tx} is transmission energy at the transmitter

$$E_{Tx}(b,d) = (E_{elec} \times b) + (\varepsilon_{fs} \times b \times d^2) \qquad (2)$$

In the same way E_{Rx} is the energy at the receiver's end

$$E_{Rx}(b) = E_{elec} \times b \qquad (3)$$

E_{elec} is (radio's) expended energy and we have assumed that the nodes are aware of neighboring nodes' location.

Default packet size is = 4 Kbits (Amount of data any node wants to transmit to CH varies as per random pseudo code) When nodes energy reaches to "zero". It will be disconnected from the network.

4 Self-Organizing Capability

Self-organizing capability is an important feature of wireless sensor networks. It improves scalability and auto adaption to changing network conditions [8]. Network's ability to auto adjust its topology in case of environmental changes is the key idea behind self-organization. Self-organizing capability cooperates with the network topology and provides stability.

For the evaluation of our network framework, we have focused on the major areas of self-organization, e.g., routing resiliency, forming and maintaining the topology structure (by using threshold value and the transmission range based factions). For the said purpose, we have executed multiple scenarios and tried to measure network limitations in terms of its self-organization capability. Due to the paper limitations only the major and average results are described here.

Scenario 1: Death of a single (randomly selected) node.

We started our evaluation with the simplest case, where single (random) nodes is selected and its battery's energy was changed to "zero". Means node went down Fig. 6 (a).

Scenario 2: Death of a CH in a random order.

In this scenario, we have randomly selected a cluster head and changed its battery energy to "zero". To get more accurate results, the scenario was repeated multiple times with the different numbers of CH Fig. 6 (b)

Scenario 3: Death of CH and a node at the same time.

In this scenario we have brought down one node as well as the cluster head. We repeated the scenario with multiple cases, e.g. selection of CH and node from the same cluster, CH and node from two adjacent clusters, CH and node from two randomly selected clusters etc. Both random and manual ways were used, Fig. 6(c).

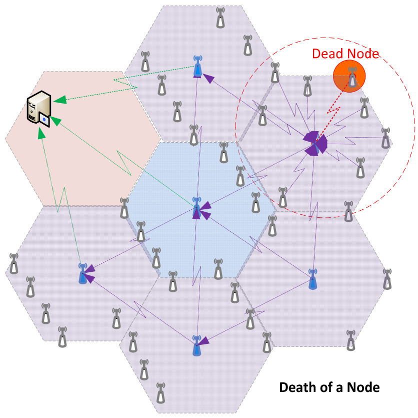


Fig.6 (a) Self-Organizing Mechanism framework

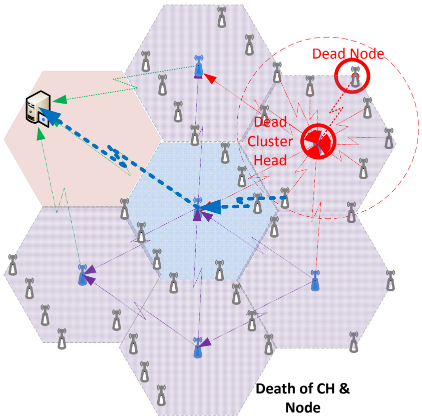


Fig.6 (b) Self-Organizing Mechanism framework

5 Simulations & Performance Evaluation

Omnet++ was used for the simulation of our framework. Following are the simulation parameters we have used. Simulation was executed for the multiple scenarios where node count was from 100-500.

Tab. 1 Simulation Parameters

Parameters	Values
Network Area (m)	100x100
No. of Nodes (n)	100-500
Initial Energy (of nodes)	100 J
E_{elec}	5 nJ/b
Datagram	4 Kbits (default)
Pulse Duration	5 ns
No. of runs	50-100
ε_{fs}	250 pJ/b
d	50m

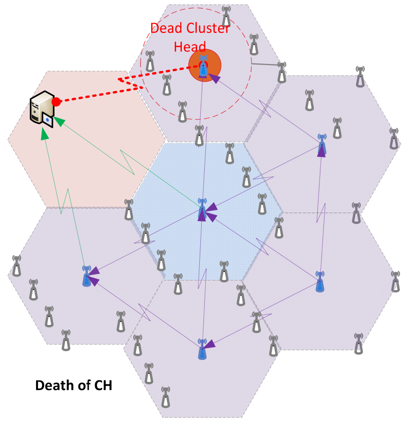
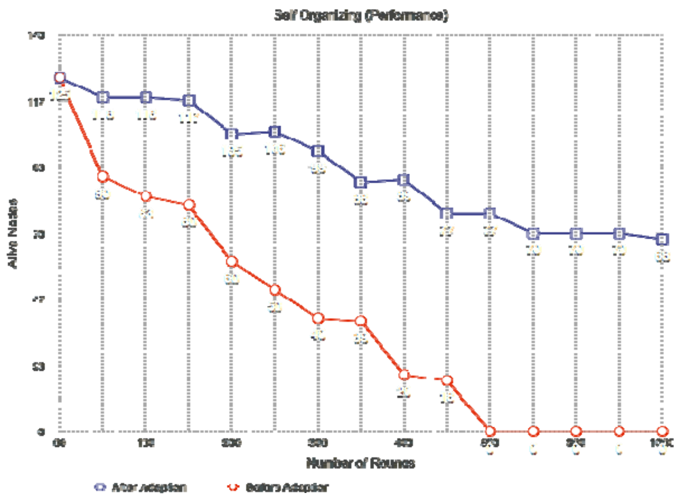


Fig.6 (c) Self-Organizing Mechanism framework

Fig. 7. Network Lifetime before and after Adaption Features

Following evaluations are drawn for the performance of self-organizing feature of our framework.

Here we have examined the network lifetime of the proposed framework, before and after applying adaption features. Looking at the Table II and Fig. 7: before adaption, HND (half nodes death) was at 152nd round. On the other hand, after the implementation of adaption, HND was noticed at 890th round. That is over 60% improvement in the network lifetime. By looking at the comparison between "packet delivery before adaption" and packet delivery after adaption" Table III and Fig. 8



Tab. 2 Network Lifetime

S#	Scenario	1st Node Death	HND	%Improvement (Lifetime)
1	After Adaption	45	890	59.23
2	Before Adaption	4	152	NA

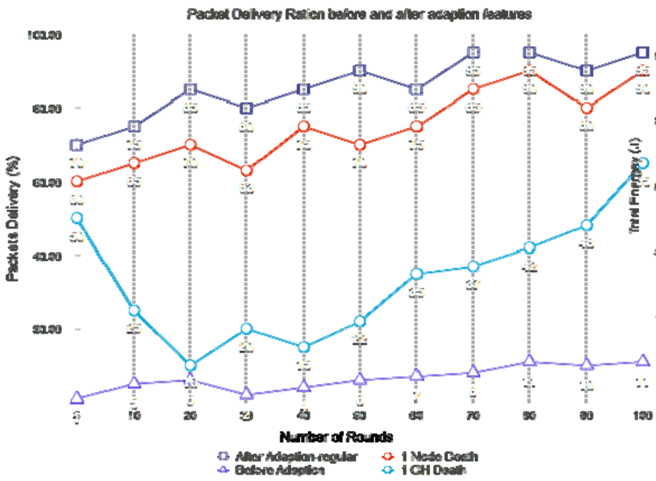


Fig. 8 Packet Delivery Ratio in different Scenarios

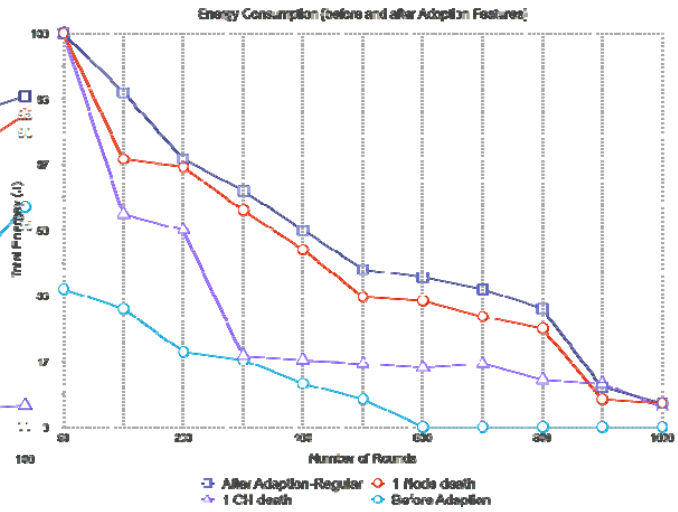


Fig. 9. Energy comparison of different cases

Tab.3 Packet Delivery

S#	Scenario	% Delivery Ratio
1	Before Adaption	15%
2	After Adaption (Regular)	95%
3	At 1 CH-Death	65%
4	At 1 Node Death	90%

One can observe that the Packet delivery ratio was seriously affected and the success ratio was just 15%. After implementing adaption features, it was significantly improved and packet delivery ratio increased to 95%. Similarly for the 1 node death case, performance was slightly down to 90%. But when a cluster head went down, performance decreased to 61%. That's logical as death of cluster head impacts the whole network.

Tab.4 Remaining Energy

S#	Scenario	Total Energy (remaining)
1	Before Adaption	0.045 joule/second
2	After Adaption (Regular)	8.124 joule/second
3	At 1 CH-Death	2.183 joule/second
4	At 1 Node Death	7.782 joule/second

Comparative analysis of energy consumption shows that before the implementation of optimization strategy, remaining energy was 34 J at 50th round and at 800th round it dropped to 0.057 J. On the other hand, remaining energy at the 1000th round for CH death case was 2.1 J, and for 1 node death and regular case about 8 joule/sec. That is a significant improvement in terms of energy.

6 Conclusions & Summary

Use of UWB (Ultra wide band) and PAT (pilot assisted transmission) in wireless sensor network is a new concept. In our previous work we have explored the power of both technologies thoroughly and developed a new well-matched UWB and PAT based framework. The new framework was tested in multiple cases, and we have worked out that the weak topology bonding is causing serious performance issues, especially when the network is dense. In order to overcome these issues we applied some adaption features, e.g. dynamic clustering based optimization. Which has not only resolved the weak bonding topology issue, but also improved the network lifetime. That makes it an attractive solution for the short range, dense network environments.

Performance of our framework was tested for both light network and dense network cases. And from the results we can say that it is not only capable of organizing itself in the complex network conditions, but also has scalability and energy saving competencies.

Results proves that proposed framework can assure QOS for both light and the dense networks at the cost of very minimum energy consumption. We are in the process of implementing this framework for WBAN (Wireless body Area network). Beside this another goal is to test its performance under mobile nodes.

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