Adoption features and approach for UWB Wireless Sensors Network based on Pilot Signal assisted MAC
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In the field of wireless sensor network (WSN), Pilot Assisted Transmission (PAT) is a new concept. Earlier we had designed a MAC Layer protocol “PA-MAC” based on this theory. And used IR-UWB at the Radio layer. The performance of PA-MAC was excellent under a single hop structure or a network with light traffic. But when it was used for the dense network structure, where multi-hoping is required the performance really declined due to interference and transmission range issues. Technically there are two ways to tackle dense network traffic in a wireless sensor network. One is to use the multi hop structure and the other one is clustering. In this research paper we have demonstrated our adopted strategy. We used dynamic clustering approach and applied multiple optimization features, like clustering formation based on transmission range, dynamic cluster head selection and use of Volterra code for the mitigation of interference. These adoption features have not only improved the media access performance but also optimized the network lifetime.

Keywords: Clustering, Energy efficiency, Media Access Control, Ultra wide band, Wireless Sensor Network.

1. Introduction

Due to its attractive properties, UWB is an excellent choice for WSN. Though PAT (Pilot assisted transmission) is a new concept in the field of wireless sensors communication, but it has shown tremendous results when used with impulse radio ultra wideband. Earlier we had proposed one of the first medium access control protocol based on PAT (pilot assisted transmission). That is in fact a schedule based MAC algorithm. Though the performance of pilot signal assisted MAC PA-MAC [1] was exceptional under a single hop structure but it declined in a multi-hop dense architecture. Traditional clustering and optimization procedures did not help much to overcome this issue, mainly because in our architecture the physical layer is based on Transmitted Reference/Delay Hopped Impulse Radio (TR/DH IR-UWB). In this paper we have countered the performance issue and optimized wireless sensor network architecture by applying multiple formation procedures. Our proposed architecture uses (the same) pilot signal assisted mac with impulse radio that does not require channel estimation, alike it saves energy and improves network lifetime. Use of proposed combination; makes it an ideal platform for the short range UWB based WSN communication.

It is known that the main job of a sensor network is to transfer sensed data to the sink securely and smoothly. This is only possible if a proper formation of a cluster and relevant communication is in place. Instead of relying on multi-hop technique we have used a light weight clustering approach for the data communication. The rest of the research paper is divided as follows. Section 2 gives a brief overview of our media access control algorithm. In section 3, a brief explanation of radio layer (Delay Hopped Transmitted Reference Scheme) is defined. Section 4 explains the proposed adoption features. In section 5 the network performance & simulation results are evaluated. The summary and conclusion are explained in Section 6.

2. Media Access Control Layer

Use of PAT in WSN saves receiver’s energy and avoids channel estimation that is very attractive for wireless sensor network [1]. The main design of PA-MAC is based on two phases. Phase-1 is an initial phase which remains active unless the media access requests cross the threshold level. Right after the 1st collision (due to media access requests) Phase-2 becomes active. Phase 2 deals with different bottlenecks through prioritization and scheduling. See table 1 based on main steps of PA-MAC algorithm [1].

<table>
<thead>
<tr>
<th>(Phase1) Step1</th>
<th>//FCFS- No Synchronization- low activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>For (i = 1 to</td>
<td>//All nodes will set Tp to Tmax</td>
</tr>
<tr>
<td>Tp(n(i))=Tmax;</td>
<td>While(Tp&gt;0) //During Priority time</td>
</tr>
<tr>
<td>Node State= Rx</td>
<td>//Listen only while Tp</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(Phase2) Step2</th>
<th>//After Tp (Priority Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node State= Tx(Pilot)// If interested for Tx</td>
<td></td>
</tr>
<tr>
<td>If Media= IDLE //If media is not idle -</td>
<td></td>
</tr>
<tr>
<td>Go to Phase 2 //Collision</td>
<td></td>
</tr>
<tr>
<td>Else //Synchronize and Prioritize the</td>
<td></td>
</tr>
<tr>
<td>Continue till collision</td>
<td></td>
</tr>
<tr>
<td>Node State= Tx</td>
<td>// Next node</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(Phase2) Step3</th>
<th>Synchronization and Priority scheduling</th>
</tr>
</thead>
<tbody>
<tr>
<td>//Tp will be used for Tx</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 1. Main steps of PA-MAC algorithm [1].

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The priority strategy in this algorithm is based on the following principles:

- The nodes that have completed their access time slot, and don’t have any more data, will not be considered for the next (priority) polling.
- After the completion of a (priority) schedule, the cluster head will create a new schedule by collecting access requests (through pilot). And once the priority schedule is finalized and shared with the member nodes. No new request will be accommodated. Nodes with new access request will have to wait for the existing schedule completion.
- During the new schedule design, privilege will be given to the nodes who could not complete their turn during the previous round. If time of arrival (of two or more than two nodes) is same, priority will be decided on “shortest job first” rule.

At the end of each schedule, if there is no access request (in response to pilot signal from CH), Phase 2 will be deactivated and control will transfer to Phase 1. TRDH does not require channel estimation [5]. It gives very accurate synchronization, and accumulates multipath energy very efficiently. See Fig.1 for the TRDH pilot pulse design.

### 3. Radio Layer Architecture

PA-MAC works best with Transmitted Reference Delay Hopped (TRDH) receiver architecture [2]. TRDH consumes less energy than any other scheme when used for Impulse Radio.

![Fig.1. Delay Hopped Transmitted Reference UWB Scheme [5]](Image)

As described in [2], radio layer uses a pair of pulses (doublet) instead of single pulse Fig.1. The first pulse (pilot signal) does not carry any data and is delayed (by a code) at the receiving node and works as a correlation pilot (reference) for the next pulse. Data/information is carried by the 2nd pulse of the pair (doublet). Multi access model can be achieved by adding a Volterra generated [3] delay code to each user. Here signal receivers are based on modified (version of) energy detector. This process works asynchronously with power level 5-16dBm for 5.4 GHz. Where radio dissipates Elec = 5.0 Nano Joule/bit, for a 1 Mbps data stream. IR-UWB Transmitter achieves pulse duration of 5ns for the bandwidth of 500 MHz and consumes 250 Pico Jules/bit energy at 1 Mbps. PA-MAC algorithm’s duty cycling (scheduling) saves energy by turning radio in sleep mode.

### 4. Proposed Strategy

In the traditional clustering approach, usually clusters are formed before the selection of cluster head. And based on the residual energy or other common factors, cluster head is selected. We have used a slightly different technique. And have used clustering adoption features in two segments [6].

In our model, adoption technique is divided in two parts; Formation-phase and Stabilize-phase. Formation phase focuses on cluster setup and CH selection, whereas data transmission and routing is managed in Stabilize-phase.

Following are the major steps (with some assumptions):

- Nodes are deployed randomly across the target region.
- At the start of the simulation all nodes have the same amount of energy.
- All nodes have the ability to transfer data to any other node or to the BS (base station) using power control.
- IR-UWB is used at radio layer. And channel characteristics are symmetric (transmission power for a message from x node to y, (x→y) node is same as (y→x).
4.1 Formation Phase:
Cluster Formation & CH Selection: In the cluster formation segment, nodes are divided in groups based on their transmission range from the base station. To limit the number of nodes; a threshold level is defined. CH will not exceed the membership of nodes (as described by threshold level). Following are thigh level steps.

- ‘n’ nodes are randomly deployed in the designated region.
- At start up, the base station by using the pilot signal collects the information of all the nodes.
- Every active node; on reception of the pilot, sends the basic details such as node id, energy level and distance to the base station.
- Based on the received data, factions or groups are derived Fig.2. Accordingly CH is selected from the available candidates.
- Here each faction is based on the transmission range from the BS. (e.g. nodes within base station’s Tx range are Faction1) and faraway nodes are defined in higher level (e.g. Faction 2) and so on.

(CH selection is first step, keeping the threshold limit each CH defines it cluster membership and forms clusters.)

Fig.2. Faction based Clustering Technique

After the selection of CH, (CH uses pilot signal assisted mac [1]) schedule is formed and shared with the member nodes.

1. Data sensing process starts.
2. Based on the activity when data is sensed and gathered the nodes wait for their turn and transmit data to CH (according to MAC defined in [1]).
3. At the end of the cycle CH performs aggregation process and transfers data to the base station.

Explanation

In a common clustering algorithm CH is selected based on distance or residual energy. Here we have used slightly different cluster head selection techniques. In our case each node selects CH based on the cost function (cost function was explained in [4] which takes into account not only the energy level but also distance). Here a threshold level is adjusted for the number of member nodes for a cluster. In our approach threshold level is calculated as simple as 10% of total nodes. We have used Cost function [4] for the selection of cluster head.

\[
C(i) = \frac{B_{\text{init}}}{B(i)} + \frac{T_{\text{BS}}(i)}{T_{\text{max}}}
\]

Here ‘T’ is distance (BS is used for base station, \( T_{\text{max}} \) is maximum range). Based on the cost theory [4], other nodes (have not selected CH) will select cluster head from the available candidates (of CH). Cluster formation will be as per the following formula.

\[
C(i) = E_{\text{TOT}}(i) \frac{B_{\text{init}}}{B(i)} + \frac{T_{\text{BS}}(i)}{T_{\text{max}}}
\]

At higher level once CH is selected, nodes with lower cost are ignored. In our approach member nodes (of a cluster) are limited as per the threshold value that increases the CH lifetime (as well as network). Right after the schedule is shared with all member nodes, the formation phase is assumed completed and the stabilize phase (data transmission phase) gets started.

4.2 Stabalize Phase
Completion of cluster formation and CH selection triggers the stabilize phase. During this phase each cluster manages its data gathering and routing schedule by using MAC algorithm [1]. Stabilize phase carries two important communications, communication within cluster, and communication with sink (& other CHs). Fig. 4 explains the design of stabilize phase of our proposed method.

4.2.1 Intra-Cluster Communication:
After the cluster formation and CH selection, member nodes collect data, and according to the mac-schedule forward it to the cluster head. Cluster head assembles (collected) data, and performs aggregation. At the end, data is forwarded to the base station (via neighboring cluster head or direct to BS) see Fig.2, Fig.3.

4.2.2 Inter-Cluster Communication
Each cluster head designs the communication schedule based on the Pilot signal Assisted-MAC, it is a multi-phase
algorithm explained in [1]. See Fig.4 showing both types of communications with the logical paths.

4.3 Interference Management

Due to the design nature of cluster based architecture, interference is a well-known issue (specifically in Impulse Radio UWB). Primarily interference is due to the nearby communication of adjacent cluster or coexisting communication among cluster heads. It can be dealt on multiple layers, commonly on physical layer and link layer. In our case, ‘Near-Far’ effect is managed at radio/physical layer (thoroughly described in publication [2]), also at the MAC Layer. The coding technique (Volterra Model) excellently deals with inter-cluster interference. Besides this proposed model is centrally coordinated and synchronization is well bonded by ‘Transmitted Reference’ scheme see Fig.1.

5. Simulations & Performance Evaluation

Starting with the experimental design and performance matrices. We have used MixiM for the overall modelling, and MATLAB for the optimization analysis. Same radio model is used here as we used in our last publication [2].

5.1 Average Energy

Here energy consumption for the transmutation of an x-bit is derived from [4]

\[ E_{TOT}(i) = E_{Tx} + E_{Rx} \]  (3)

And \( E_{TOT} \) is the total energy consumed at node ‘i’. \( E_{Tx} \) is the energy consumed at the transmitter and it’s given by

\[ E_{Tx}(b,d) = (E_{elec} \times b) + (E_{Tx} \times b \times d^2) \]  (4)

Similarly \( E_{Rx} \) is receiver’s consumption and its equal to

\[ E_{Rx}(b) = E_{elec} \times b \]  (5)

\( E_{elec} \) is presenting the expended energy (of radio) and it was assumed that during the formation phase nodes are aware of each other’s location. The datagram packet size is fixed to 4Kbits.

When battery life of a node depletes to “zero” it will be disconnected. Here different scenarios are implemented for 50 runs. The network size is 100X100 m with 100 nodes. We have validated and compared our results with famous LEACH protocol [7]. Table 1 shows the parameters and their values used in the simulation.

Energy is an important factor for the overall performance of a wireless sensor network. From our simulation results Fig.5, we can see that optimized-clustering technique performs very well even in a dense network case (n=100). We compared it with LEACH protocol for the same parameters and it outclasses the LEACH in both energy and packet delivery. There are many factors behind energy performance, MAC scheduling and use of UWB at radio layer are the major once.

TABLE 2. Simulation parameter values.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Area (m)</td>
<td>100x100</td>
</tr>
<tr>
<td>No. of Nodes (n)</td>
<td>100</td>
</tr>
<tr>
<td>Initial Energy (of nodes)</td>
<td>1 J</td>
</tr>
<tr>
<td>( E_{elec} )</td>
<td>5 nJ/b</td>
</tr>
<tr>
<td>Datagram</td>
<td>4 Kbits</td>
</tr>
<tr>
<td>Pulse Duration</td>
<td>5 ns</td>
</tr>
<tr>
<td>No. of runs</td>
<td>50</td>
</tr>
<tr>
<td>( \varepsilon_{fs} )</td>
<td>250 pJ/b</td>
</tr>
<tr>
<td>d</td>
<td>50m</td>
</tr>
</tbody>
</table>

5.2 Lifetime of the Network

Lifetime of a network depends on the lifetime of its nodes as well as succession of packet delivery. Increase number of jamming during data transmission or packet dropping during a session, can put repetitive burden on the network flow that consumes lots of additional energy, hence effects overall network performance.

From the simulation results, it can be observed that when we used optimization-techniques (e.g. clustering) with pilot-signal assisted MAC, the overall lifetime of wireless sensor network improved. Even it was slightly better than LEACH (though we have used dense network environment).

Fig.5. Energy Consumption (LEACH vs. OCT)
Just to make sure results are accurate we have repeated this experiment many times. And most of the time we have noted that our technique has better results (a few time both have same results). Our optimized clustering scheme has (statistically) smooth performance. One of the reasons; why optimization technique provides smooth results is due to the use of cost function. Where not only energy but also other factors are also considered. We can see simulation results in Fig.6.

5.3 Packet Delivery Ratio

It is calculated on the basis of following formula,

\[ \text{Percentage of successfully transported packets} = \frac{\text{Total No. of Received packets}}{\text{Total No. of Transmitted packet}} \]

From Fig.7 we can see that optimized clustering approach has better packet delivery value than LEACH (and performance is consistent even when the number of nodes were increased e.g. n=100). That proves success of PA-MAC in dense network environment. It was also observed that as the number of nodes increases, the packet delivery improves. This is because more nodes means more options of direct connectivity with BS and more candidates for the cluster head. From Fig.7, we can observe that more packets were arrived on base station when optimization techniques (e.g. dynamic clustering) was used.

6. Conclusion

PA-MAC is the first “PAT” (pilot signal assisted transmission) based MAC designed for the wireless sensor network. Research has proved that it has many advantages over the conventional MAC protocols. When PA-MAC is used in a dense network environment. Due to use of UWB-IR at physical layer it’s performance in terms of packet delivery, energy consumption and network lifetime degrades. We investigated these issues, and noticed that the main reasons are topology and weak routing structure. In this paper we focused on these issues and applied multiple adaption features (e.g. “LMC” clustering). In our strategy, selection of cluster head is based on cost function. That considers multiple properties e.g. transmission range, residual energy etc. Similarly proposed features keeps the cluster structure balanced. Clustering based on transmission range gives a stable as well as control cluster heads mechanism. Simulation results show that our optimization technique has improved the performance of PA-MAC even in dense network environment. Consolidated results with LEACH verify, that in most of the cases our optimized clustering technique has better performance than LEACH. In future we have a plan to deeply investigate its self-organization feature.

References

