An Energy-efficient Clock Synchronization Protocol for Wireless Sensor Network

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Abstract-- The behavior of Wireless detector (sensor) networks (WDN) is today widely analyzed. One in all the foremost necessary problems is said to their energy consumption, as this contains a major impact on the network time period. Another necessary application demand is to make sure information sensing synchronization, that results in further energy consumption as a high range of messages is distributed and received at every node. Our proposal consists in implementing a combined synchronization protocol supported the IEEE 1588 normal that was designed for wired networks and therefore the PBS (Pair wise Broadcast Synchronization) protocol that was designed for detector networks, as none of them is ready to produce the required synchronization accuracy for our application on its own. The most goals of our new synchronization protocol are: to make sure the accuracy of native clocks up to a tenth of a unit of time and to produce a crucial energy saving. Our results obtained victimization NS-2 (Network Simulator) show that the performance of our resolution (IEEE 1588-PBS) matches our application needs with relation to the synchronization, with a major improvement in energy saving.

Keywords-- Wireless detector network; energy efficiency; Clock Synchronization exactitude (CSP).

I. INTRODUCTION:

Researches within the field of sensing element networks show the range and sizeable ness of applications during which these forms of systems square measure used. Of these studies square measure drained order to boost the practicality of such communication systems. One among their main options is that the sizable amount (up to many elements) of sensors that has got to be distributed in several environments. This results in the event of inexpensive sensors [1], with restricted process capability. Intrinsically systems can not be blocked into an eternal power offer and because the range of components could also be terribly high (which implies important network traffic), a vital downside is to reduce energy consumption [2]. In [3], an impact answer for energy transmission for every node is planned so as to increase the life of the network while not poignantly the practicality of the system. Another proposal consists in creating routing selections so as to cut back the energy consumption. In [4] the proposal is to work out that node ought to move (awake mode) at a time or not (asleep mode). Looking on the appliance needs, guaranteeing synchronous network practicality is presently a challenge. a lot of specifically, the sensors collect data that they then send to the collector. The collector should receive the knowledge from all sensors during a negligible timeframe: the time synchronization downside as represented in [5]. This has lead, in ancient laptop networks, to the planning of the many protocols wont to maintain the synchronization of physical clocks. As an example, a protocol like NTP (Network Time Protocol) isn't an honest alternative for WSN, as a result of assumptions not valid in WSN [6]. The solutions projected till now in literature, solutions that take under consideration these 2 aspects together (energy and synchronization), don't seem to be adequate. In [7] the authors propose a clock synchronization protocol that is energy economical, supported the estimation of the clock offset relative to a virtual clock. The context of our study is said to the SACER project, funded by part vale [8]. This project aims at coming up with a wireless device network of many hundred nodes placed on craft wings, which is able to take pressure and temperature readings, throughout totally different flight take a look at phases. the foremost vital demand during this application is that the synchronization and exactness of those readings terribly) very little temporal window of regarding many nanoseconds, therefore on permit the correlation of the collected knowledge and to boost the fluid dynamics

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modeling. Therefore it had been obligatory to make sure the synchronization performance while not decreasing the period of time of the network. This paper describes our proposal supported the extension of IEEE1588-PBS (Pair wise Broadcast Synchronization [10]). Then we tend to show its implementation and simulation and the way its performance is compared to the one amongst IEEE 1588 [9]. The paper proposes a state of the art of existing analysis relating to the decrease of energy consumption and therefore the drawback of guaranteeing correct synchronization for Wireless device Networks (Section II). Section III describes our projected resolution with its edges supported by the results of the simulation. In Section IV we tend to create a comparison between performance in terms of synchronization and power consumption between the IEEE 1588 commonplace and our protocol. Finally, Section V is devoted to the conclusion and to future work.

II. RELATED WORK:

The problem of the synchronization of wired networks has been solved because of the event of triple-crown protocols, in terms of their accuracy. Sadly, art they're unsuitable for wireless device networks as a result of the variations between wired and wireless networks are manifold. One in every of the foremost vital variations is that sensors will suffer from power outage, that limits the employment of existing technologies and communications protocols. Our strategy is to take advantage of the performance of synchronization protocols for wired networks by adapting them for WSN. At constant time we have a tendency to take into account that reducing energy consumption is crucial to the extension of the period of time of the network.

A. Synchronization issues and Protocols:

The process of clock synchronization for distributed systems is to produce a typical notion of your time across the complete system. However the time of a code clock can't be excellent. That's why we tend to have an interest in its accuracy, which might be calculated by analyzing parameters such as: the clock frequency, the clock offset, the skew and also the drift of the clock [5]. Thus, NTP uses the tactic of Offset Delay Estimation [6], and performs the time synchronization of the central server with the UCT (Universal Coordinated Time). The disadvantage of this answer is that though it ensures high synchronization, it wills it at the expense of message quality. A lot of recently, the IEEE1588 common place [11] became the new reference in clock synchronization for industrial applications, as a results of its performance (accuracy to a hundredth of a time unit (10ns)). However as wireless networks are restricted in terms of size, power and quality, most implementations of the IEEE 1588 are used on wired networks. On this matter, [12] presents experiments and a performance analysis supported correct time synchronization with IEEE1588 in WSNs. Results have shown that the synchronization between the master clock and also the slave clocks of the network nodes is achieved with Associate in Nursing accuracy to a tenth of a time unit (100ns). Many clock synchronization protocols are planned for wireless device networks, with higher or worse performance. The Reference Broadcast Synchronization (RBS) [13] is that the most representative protocol with a receiver-receiver theme. By exploiting the printed property of the wireless communication medium, this protocol is in a position to attain synchronization of a bunch of nodes that are within the communication vary of a reference sender. Nodes that receive the broadcasted beacon can record the time of arrival and exchange this data with others. The preciseness of this protocol in 802.11 with kernel time stamping is of six.29 ± 6.45µs [13].Timing-sync Protocol for sensing element Networks (TPSN) is an implementation of the sender-receiver synchronization methodology. This idea consists of 2 phases: the invention and therefore the synchronization. In [14] the authors enforced TPSN on Berkeley's transparent substance design and planned a waterproof layer time-stamping procedure that is in a position to with efficiency cut back the medium time interval. The typical error obtained is sixteen.9 µs. The try wise Broadcast Synchronization (PBS). Theme planned in [10] describes a replacement synchronization approach, referred to as receiver-only synchronization (ROS) for a network wide synchronization. The accuracy is comparable to it obtained for RBS (tens of µs) on Berkeley Motes. PBS needs solely NPBS =2N temporal order messages for every synchronization cycle wherever N represents the quantity of changed messages. Also, N doesn't rely on the quantity of network parts, which suggests an excellent advantage in terms of energy savings.

B. Energy downside:

One of the foremost necessary parameters for a WSN is its energy consumption, as a result of the constraints obligatory upon it. For this reason existing studies propose totally different ways to attain this challenge. The primary proposal is to boost routing protocols, which might be divided into 3 major categories: data-centric, hierarchal and location-based [2]. Data-centric protocols show the
advantage of eliminating several redundant transmissions; the hierarchal ones, through aggregation, are able to do energy savings, whereas the last class (location based mostly protocols) is intended to supply some QoS (Quality of Service) capabilities in conjunction with the routing perform [16]. On the opposite hand, solutions that admit energy-efficient meckintosh protocols have many blessings [17]. Selecting a TDMA medium access is engaging as a result of it eliminates the chance of collisions and also the network becomes self-organized owing to slot assignment and synchronization. Moreover, combining the benefits of TDMA and people of cluster topology increase energy potency [18]. As we will see, satisfying the requirement for synchronization and energy saving isn’t a straight forward task as a result of these criteria are con in terms of performance. More specifically, to make sure correct synchronization, the network can consume a major quantity of energy. Researches for this purpose area unit quite recent [19]. In [20] and [21] the authors propose a brand new theme of clock synchronization so as to optimize energy consumption and compare the results with performance of the TPSN protocol. To satisfy the necessity of synchronizing mobile nodes in an exceedingly network [22] shows a hybrid resolution that integrates the RBS and TPSN protocols. We have a tendency to discovered for this drawback that PBS is the solely synchronization protocol that, thanks to its modus quantity i, is in a position to realize energy savings likewise.

C. Key Observations

This summary of major existing resolutions and protocols can guide North American nation within the definition a brand new solution to satisfy the wants of our application. TABLE I summarizes a comparison between these existing solutions, supported varied parameters, where I, N represents the amount of changed packets in an exceedingly synchronization cycle and L the amount of network nodes. Many key observations area unit found here to justify the utilization of our proposal during this wireless sensors application. Therefore on eliminate the danger of interference thanks to proximity of the parts we have a tendency to created a alternative for the TDMA medium access. As we tend to noted in numerous studies during this field, selecting a hierarchal routing resolution implies energy conservation and permits United States to require advantage of the advantages of the aggregation technique. Moreover, if the information square measure unendingly transmitted to the collector, it’s a lot of economical to use a hierarchical data structure. Within the next section we tend to gift well the design of our network. By analyzing TABLE I, it should be seen that existing synchronization protocols have either a awfully smart synchronization accuracy with a high energy consumption or contrariwise. Our plan is to require advantage of the performance, in terms of synchronization accuracy, of the IEEE1588 customary and so of the energy saving capability of the PBS protocol.

TABLE I. CLASSIFICATION ON SYNCHRONIZATION AND ENERGY ISSUES

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Scheme used</th>
<th>Number of messages</th>
<th>Time clock prediction</th>
<th>Implementation level</th>
<th>Power Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBS [13]</td>
<td>Receiver - to receiver</td>
<td>N*L’</td>
<td>29.1 µs</td>
<td>App</td>
<td>High</td>
</tr>
<tr>
<td>TPSN [14]</td>
<td>Sender- to receiver</td>
<td>2^N*L</td>
<td>16.9 µs</td>
<td>MAC</td>
<td>Average</td>
</tr>
<tr>
<td>FTSP [15]</td>
<td>Sender- to receiver</td>
<td>N*L</td>
<td>1.7 µs</td>
<td>MAC</td>
<td>Low</td>
</tr>
<tr>
<td>PBS [10]</td>
<td>Sender- et Multi hop</td>
<td>2^N</td>
<td>29.1 µs</td>
<td>App</td>
<td>Low</td>
</tr>
</tbody>
</table>

By taking under consideration all the constraints of our system and so selecting applicable communication technologies, we’ve devised a brand new resolution that is playacting each in terms of accuracy and energy consumption. By analyzing however every of the said protocols is meant and considering our application necessities we have a tendency to over that none of the prevailing solutions is appropriate for our system. Thus we have a tendency to visualize the event of a replacement synchronization protocol.

III. OUR PROPOSED SOLUTION

A. Network Model Organization:

As mentioned earlier, our network consists of an oversized variety of things (64 active parts on every
wing) that has to communicate on the wing, so as to concentrate the collected data to the craft cabin (Figure 1).

Thus we have a tendency to propose a hierarchal organization resolution that consists of 3 distinct classes of parts (the concentrator, routers and nodes) in Fig. 1. The concentrator is meant to assemble all data from routers and transmit them to the cockpit. Further, every one of the eight routers collects data from its nodes (which area unit eight in variety as well).

**B. The IEEE1588-PBS Hybrid Protocol**

In this sub-section we have a tendency to gift our energy-efficient extension of the clock synchronization protocol IEEE 1588. During this approach, a bunch of nodes synchronizes by overhearing the temporal arrangement messages of a slave-master try, in keeping with the PBS protocol principles. The method it works is explained within the following example of a bunch reduced to solely three nodes. In such a bunch, the master (M) and also the slave (S) nodes can synchronize mistreatment the IEEE1588 standard; the third node (X) can use the already existing synchronization (with high accuracy) between master and slave. This can be done as in PBS with the idea that node X is within the communication vary of nodes M and S. Simply by paying attention to the transmissions, X can synchronize its internal clock therewith of node M with the assistance of the received messages. Fig.2 shows how the protocol works for a three nodes cluster. The rule starts at node M by broadcasting a sync_message (1) to the slave then storing at the physical layer the sent time-stamp (T1M). Afterwards, M broadcasts the follow_up message (2), containing the hold on time-stamp. The primary synchronization packet arrives at S at T2 S and at the PBS node (X) at T2 X. Each nodes additionally store the receive time-stamps at the physical layer. Within the next stage, at the slave's civil time T3 S, S broadcasts the request message three (delay_request). This can be received by M at T4 M and additionally by X at T4 X. M answers with delay_reponse. (Message 4), that contains the time-stamp T4M. At the top of the synchronization session, X has received T1M, T2X, T4M, T4X, contained in received broadcasted messages. Let XM be the clock offset between X and M and dXM the propagation delay between X and M. we have a tendency to assume that the messages sent by S attain the master and at the PBS node at constant time (which implies that dSM - dSX = 0). So, the offset and therefore the propagation delay between the nodes M and X become:

![Figure 1. Network organization](image)

![Figure 2. Exchanging messages in 1588-PBS protocol](image)

**IV.PERFORMANCE ANALYSIS AND COMPARISON STUDY:**

This section provides a close chemical analysis examination the performance of our IEEE1588-PBS protocol and also the customary IEEE1588. The standards taken into consideration during this
analyses are:
* The accuracy of synchronization,
* The facility consumption within the nodes,
* The amount of synchronization messages.

A. Performance Analysis

To check and validate the behavior and also the performance of the planned resolution, the essential settings required in our analysis got to run initial. Thus, we have a tendency to start the synchronization mechanism within the first-level (concentrator-routers) at zero.3s and within the second level (routers-nodes) when 7s. In this means, nodes modification their internal clock by taking as reference the clock of the router that is already synchronized. To get precise time synchronization in WSN, it's necessary that the clock of the processor be controlled by a TCXO (Temperature remunerated Crystal Oscillator) at thirty seven.5MHz [12], that encompasses a one. 5PPM frequency tolerance, so as to cut back the drift rate. For our simulation, the inner clock of every node within the network was enforced with a drift of one.5 microseconds per second. To attain high performance then to check our protocol with the IEEE1588 commonplace, it had been additionally determined to time-stamp the messages at the Physical layer. These info area unit then employed in the synchronization theme at the applying level. Another necessary facet is that the graded organization of our system, that is achieved through cooperation between the mackintosh, Routing and Transport levels.

B. Synchronization accuracy:

Our simulations were performed for the entire network (one concentrator, eight routers and sixty four nodes). Thanks to the graded organization, the behavior for a subgroup of 1 concentrator(R), one router (R) and eight nodes (N) is analogous to it of the other subgroup. For this reason and since we tend to are restricted in range of pages, the graphical results solely concern one such subgroup. It’s shown in Fig. three that the accuracy of the synchronization between the concentrator and therefore the routers is around one to two hundred nanoseconds. We tend to note that throughout the simulation the network components stay synchronal at a high level (50-250ns). Please bear in mind that the IEEE1588 protocol results square measure quite a similar (100-200ns), that is traditional because the synchronization algorithmic rule is that the same. At the Router-Nodes level (Fig. 4), we tend to notice that for the Router-Node1588 combine the synchronization has Associate in nursing order of magnitude of many nanoseconds and for the Router-Node PBS pairs it varies between 1µs and forty six µs. The results for the IEEE1588 normal within the R<->Ns level square measure comparable the accuracy of the Router-Node1588 combine in our answer (100-250ns). We tend to specify that the network wide synchronization is achieved in regarding twenty seconds when the start of the simulation. Thus it’s clearly shown by these results that the achieved accuracy is incredibly smart, near the simplest ones found in literature.

C. Energy analysis and variety of messages:

In this section we have a tendency to have an interest within the analysis of the energy consumption of our system, however particularly the consumption within the nodes. We have a tendency to set to use the energy consumption parameters of a Berkeley stuff [12] so as to simulate real world conditions. In our network the energy consumption of causation a message is evaluated by NS-2 as 7mW which of receiving a message as four.5mW. Total initial energy is 2700J that matches a CR2032 cell (3V, 230mA). What interests U.S.A. is that the distinction between energy consumption for the 2 protocols. Fig. five shows that the distinction in energy consumption between a PBS node and a fifteen88 node is within the order of 15.07J. In different words, a PBS node consumes eighty four but a 1588 node. This can be directly associated with the quantity of messages needed to attain synchronization. Thus we have a tendency to gift in TABLE II the variety of synchronization messages for the 2 analyzed protocols.

<table>
<thead>
<tr>
<th>Protocols</th>
<th>Number of messages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level C&lt;-&gt;Rs</td>
</tr>
<tr>
<td>IEEE1588-PBS</td>
<td>120 messages cycle</td>
</tr>
<tr>
<td>IEEE1588</td>
<td>120 messages cycle</td>
</tr>
</tbody>
</table>

TABLE II. SYNCHRONIZATION MESSAGES
Figure 3. Energy Consumption for PBS and 1588 Nodes.
This analysis permits North American country to examine why our resolution is a lot of appropriate for a wireless sensing element network. We tend to evidenced that with smart synchronization accuracy our resolution achieves at constant time satisfactory energy savings.

V. CONCLUSION AND FUTURE WORK:
The protocol extension we tend to planned supported mixture the IEEE1588 and therefore the PBS protocols for a hierarchical data structure was simulated victimization NS-2. The obtained results show that this resolution is ready to get synchronization accuracy at level of a tenth of time unit (100ns) with economical energy savings at constant time. Because the measurability of this resolution terribly is extremely is incredibly necessary within the very next future, the quantity of nodes must be extended to review the impact of the hierarchy. We tend to conjointly decide to use directional antennas to cut back consumption and interference problems. Another improvement could also be done victimization one TDMA per subgroup and not only 1 for the whole WSN.

References