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Energy Efficient on Aspect of Clock Synchronization in a Wireless Sensor Network

[1]Zeyad Ghaleb Al-Mekhlafi, [1]Zurina Mohd Hanapi, [1]Mohamed Othman,
[1]Zuriati Ahmad Zukarnain and [2]Ahmed M. Shamsan Saleh
[1]Department of Communication Technology and Network,
Faculty of Computer Science and Information Technology,
Universiti Ptura Malaysia (UPM), Malaysia
[2]Faculty of Information Science and Technology (FIST), Multimedia University (MMU), Malaysia

Abstract: Recent advances in the areas of Micro-electrical Mechanical Systems (MEMS) spurred the interest of researchers in Wireless Sensor Networks (WSNs). These networks are made up of sensor nodes which have the capability to sense, process and transmit gathered data of an environmental phenomenon of interest. Such synchronization is vital for the proper coordination of the power cycles for energy conservation. Here, a large presence of fireflies employ the principle of pulse coupled oscillators for the emission of light flashes for the attraction of mating partners. With respect to WSNs, the nodes are generally unable to afford packet transmission and reception simultaneously, thus preventing complete network synchronization. This study presents a literature overview concerning the energy efficient on aspect of clock synchronization in a wireless sensor network. In addition, the idea of data transmission based on synchronization can be ensured through the optimization of energy usage periodic data capturing in the wireless sensor network. This study serves as a useful source on clock synchronization to assist WSN researchers and novices to gain a better understanding of the energy efficient on aspect of clock synchronization in a wireless sensor network and to promote effective designs and systems that address this problem.

Key words: Wireless sensor networks (WSNs), clock synchronization, efficient energy, firefly

INTRODUCTION

Recent advances in the areas of Micro-electrical Mechanical Systems (MEMS) spurred the interest of researchers in Wireless Sensor Networks (WSNs). These networks are made up of sensor nodes which have the capability to sense, process and transmit gathered data of an environmental phenomenon of interest. Some of the applications of WSNs are military surveillance systems, industrial monitoring, etc. The sensor nodes are often constrained by their limited energy, processing and storage capacity and hence, usually transmit the sensed data to a more resource-rich node called the sink node (base station). Moreover, as mentioned earlier, the WSN technology is characterized by limited processing capability and communication radius (Dutta *et al*., 2012) and because these limitations are critical to the overall lifetime of the WSN, it is prudent that they are considered in the routing protocol design (Saleh *et al*., 2012). Since, individual node failure has a direct repercussion on the whole network with time, regular sensing and packet relaying to the sink may be seriously jeopardized as more and more sensors cease to operate as they exhaust their limited energy (Senouci *et al*., 2012). Each routing protocol algorithm sends data from the sources to the targets and is expected to increase network exposure even as the propagation value decreases (Jacobsen *et al*., 2011). In general, WSN is a collection of self-directed devices that are associated wirelessly. Sensor networks are an example of wireless networks that need every sensor to execute events in synchronization. This synchronization coordinates power cycles conserve energy and ensures the smooth operation of WSNs that calculate time-sensitive events. So, our study focus in energy efficient is sensor network which classify in Fig. 1.

Clock synchronization is an important issue in the operation of any distributed WSN. Synchronization sets the same time limit for different sensor nodes, which unifies functions for video and voice data, organizes different wakeup or sleep node scheduling schemes and ensures time-based channel distribution (Wu *et al*., 2011). Clock synchronization has several advantages over

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Corresponding Author: Zeyad Ghaleb Al-Mekhlafi, Department of Communication Technology and Network,
Faculty of Computer Science and Information Technology,
Universiti Ptura Malaysia (UPM), Malaysia

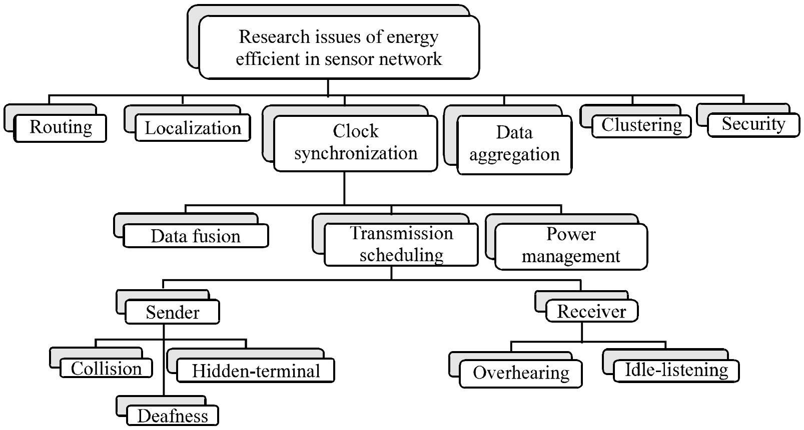

Fig. 1: Classification of energy efficient issues in sensor networks

unsynchronized systems (Chu *et al*., 2006) and is often inherently assumed to facilitate certain techniques and algorithms on physical and Medium Access Control (MAC) layers. From the physical layer perspective, slot synchronization enables advanced cooperative transmission technologies. From the perspective of the MAC layer, slot synchronization enables the coordinated packet transmission of nodes in order to attain optimal throughput and power efficiency. This study provides an extensive overview of the energy efficient on aspect of clock synchronization in a wireless sensor network. In addition, the idea of data transmission based on synchronization can be ensured through the optimization of energy usage periodic data capturing in the wireless sensor network.

This study presents an overview of the energy efficient on aspect of clock synchronization in a wireless sensor network. The main goal of this study is to assist WSN researchers and novices to gain a better understanding of the energy efficient on aspect of clock synchronization in a wireless sensor network and to promote effective designs and systems that address this problem.

WIRELESS SENSOR NETWORK (WSN)

Recent advances in the areas of Micro-electrical Mechanical Systems (MEMS) spurred the interest of researchers in Wireless Snsor Networks (WSNs). These networks are made up of sensor nodes which have the capability to sense, process and transmit gathered data of an environmental phenomenon of interest. A persistent issue in the wireless sensor network is the problem of coverage-holes. In medium and large deployments in hostile regions, random dropping of sensor nodes by unmanned vehicles or low flying helicopters may remain the only feasible deployment option. Even where deterministic deployment is possible, coverage-holes will emerge as the sensors run out of battery energy. This problem becomes even more pronounced for nodes located within close proximity to the base station, which are usually the system bottleneck due to their high data relaying task. Moreover, the sensor nodes are left to operate on their own after initial deployment, thereby making the coverage problem even more difficult to solve. As mention above, various researchers have provided different definitions of WSN. Ramirez *et al*. (2012) defined WSN as a collection of autonomous devices or nodes that are connected wirelessly. Sharma *et al*. (2010) described WSN as a group of thousands of tiny sensor nodes that can perform wireless communication, limited calculation and sensing.

Hanapi *et al*. (2009) stated that WSN can be a heterogeneous sensor network that consists of many low-cost and low-power sensor nodes that are more likely deployed at fixed locations. These sensor nodes can communicate with one another through Radio Frequency (RF), sense and relay sensor data to other users and compute physical attributes (e.g., pressure, temperature, motion, sound and vibration). Stojcev *et al*. (2011) explained that WSNs are large-scale sensor networks that monitor and observe various aspects of the natural world. An excerpt from the Defense Advanced Research Project Agency in Bala (2009) states that sensor node networks use many devices that can compute, sense and communicate through additional devices to compile local data and formulate conclusions about the physical world. Bala (2009) also mentioned that according to the United States National Research Council, sensor node networks are composed of a large number of sensors that are commonly used in mechanical and electrical systems to manage (i.e., effect) and observe (i.e., sense) almost all aspects of the natural world.

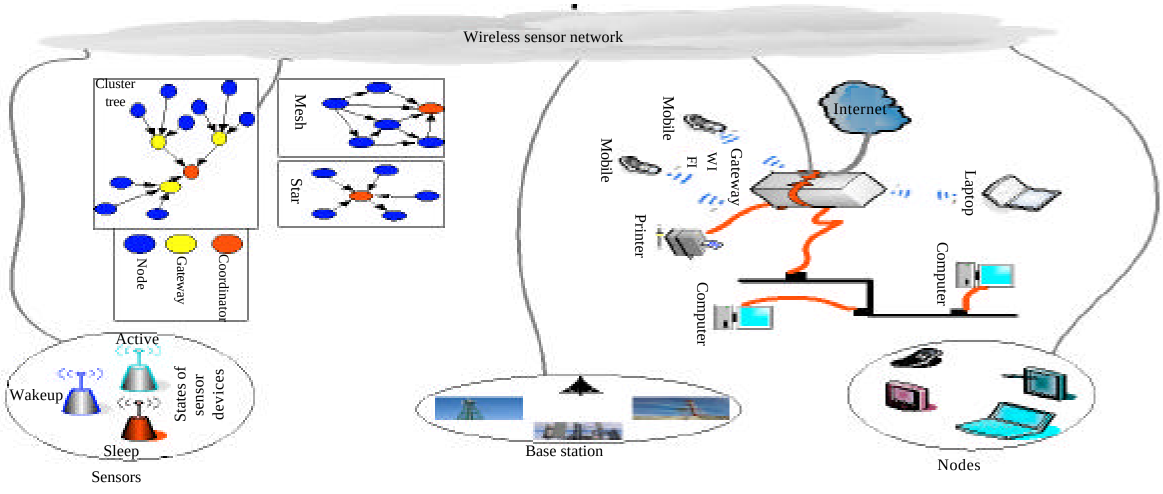

Fig. 2: Typical wirless sensor network elements

Table 1: Description of sensor network elements

Elements	Definition
Sensors	Sensors are the heart of network devices. They obtain data from the medium and convert the data into wireless signals
Nodes	Nodes are the basic units of WSN. These nodes obtain data from the sensors and relay the information to the base station (Wang *et al*., 2008; Racherla and Radhakrishnan, 2012; Senouci *et al*., 2012). Nodes are small devices that have a few kbs of memory, MHz processors, a radio scope of a few meters and one or two batteries
Gateway	The gateway acts as an entrance or a proxy server and firewall to another network. Gateways facilitate intelligent wireless sensor network network-data (TCP/IP) network connection
Base Station	Base stations have a centralized point of control within the network. They extract information from the network and disseminate control information back into the network (Senouci *et al*., 2012). They also collect data and are based on a common computer or embedded system
Coordinator	The coordinator parses and buffers messages and reads raw sensor data that is broadcast from the sensor networks. For each connection request, the coordinator allocates a configuration and a port for the gateway (Carter and Ragade, 2006)

A WSN comprises a sensor, node, base station, gateway and coordinator. Figure 2 illustrates the WSN elements and Table 1 provides the definition of each element.

As shown in Fig. 1, the research issues of energy efficient in WSN classified into routing, localization, clock synchronization, data aggregation, clustering, security and so on. In this study, we focus the energy efficient issue on aspects of the clock synchronization in WSN.

CLOCK SYNCHRONIZATION IN WSNS

As mentioned earlier, Wireless Sensor Networks (WSNs) is an example of a wireless network that needs each sensor to cooperatively participate in synchronization, event detection and transmission. Such synchronization is vital for the proper coordination of the power cycles for energy conservation. Moreover, each sensor node in WSNs has its own clock. Clock synchronization provides a common clock/time frame for widely distributed sensors. However, this task is not easy to accomplish because of the unique properties of WSNs. A universal time is normally unavailable in WSNs. Therefore, traditional clock/time center-based synchronization methods or tools cannot be applied directly on each of the services at the sensor nodes (e.g., sensing, routing, group management, localization, time synchronization, power management and medium access control). Moreover, sensors often have limited processing and sensing capabilities. Therefore, sensors have to cooperate to perform a task over a wide physical region, which can be achieved with the use of information aggregated across the entire network and sensors. Hence, a low-overhead method and accurate clock synchronization are ideal for sensor-based applications. In national schemes, clock synchronization is unnecessary because clock confusion does not exist. By contrast, in disseminated systems such as WSNs, no universal memory or time exists (Stojcev *et al*., 2011).

Clock synchronization in WSNs has attracted extensive attention because it is a crucial issue in the operation of WSNs (Tripathi *et al*., 2010). It unifies different functions, such as video and voice data from

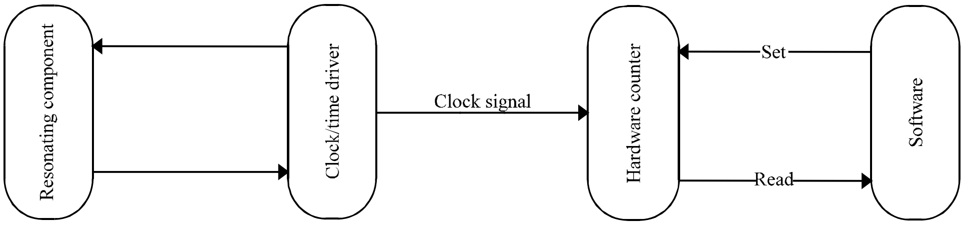

Fig. 3: Basic block diagram of clock elements and associated timer hardware

dissimilar sensor nodes, wake/sleep scheduling for nodes and time-based channel sharing (Mei, 2010; Sundararaman *et al*., 2005). A consistent clock/time is important for sense functions to ensure precise time stamping of sectioned information (Jacobsen *et al*., 2011). Clock synchronization is a complex problem that can be resolved by using the computer system of a distributed scheme. The classification of clock synchronization is shown in Fig. 1. Data Fusion is a fundamental operation in all disseminated WSNs for integrating and processing gathered data. WSNs typically span vast geographic regions and consist of many nodes because of the limitations of individual sensor nodes. One single sensor cannot capture all information and thus, information from all sensors should be obtained. Data fusion requires several or all nodes in the WSN to have a common time scale. An event can be monitored simultaneously by multiple sensors. Information at dissimilar sensors can be combined to contain extra data. Such information integration requires several or all sensors to have a common time scale. This condition is necessary when the environment under surveillance is time varying. In entity tracking, every sensor node discovers a moving entity when it enters the sensor's vicinity. The entity can be tracked by cross-referencing its time and position as recorded by sensors along its path. The recorded time is accurate when the times of the sensors are synchronized (Hall and Llinas, 1997; Madden *et al*., 2002; Waltz and Llinas, 1990; Yuan *et al*., 2003). Power Management is unattended and are battery powered. In addition, they do not undergo regular servicing or battery changes. Most fundamental operations in WSN will adopt wake/sleep protocols to conserve energy wherever certain sensors enter a low-power sleep mode or switch off when their neighboring sensors are on duty. Therefore, network-wide clock synchronization is important because it can ensure time synchronization precision and efficient power cycling (Bekmezci and Alagoz, 2009). In contrast, transmission scheduling has many protocols that require synchronization. For example, Time Division Multiple Access (TDMA) accesses and permits multiple devices to distribute access to a common communication medium (Heidarian *et al*., 2012). One transmission period is classified into multiple slots in TDMA to allow transmission without collisions or interference and every slot is allocated to only one sensor node in a suitable area. Each sensor node is enabled to transmit only throughout the dedicated time slot (Bekmezci and Alagoz, 2009). Such protocols are valid only in a synchronized network. So, in the transmission scheduling there many problems happened such as deafness problem, idle listening problem, collision-free, hidden terminal problem and overhearing problem.

Importance of clock synchronization: Each sensor node maintains a local time generated by its own clock (its own concept of time). Different factors make flexible and robust clock synchronization especially important. Time in sensor nodes is typically conserved by a particular sub-scheme, as shown in Fig. 3 (Schmid *et al*., 2010).

The time driver stimulates the resonating component that eventually resonates and filters at a certain frequency. Software can use this hardware counter for time measurement and timers. The hardware counter utilizes a signal to increase a counting register at regular intervals.

For any two clock C_a and C_b, our study will propose the following terminologies, as shown in Table 2, which are consistent with definitions given in (Mills, 1992a, b; Moon *et al*., 1999; Sundararaman *et al*., 2005).

For existing algorithms and applications that use WSNs, we aim to know more about time synchronization, including classification according to the relative arrangement of actions that occurred in different sensor nodes, the time of the day when an event occurred in a particular sensor node and the time period among two actions that occurred in various sensor nodes. For the

Table 2: Components of clock terminology

Clock terminology	Definition
Time	The time of a clock is assumed by the function Cp (t) = t
Frequency	The frequency at time t of the clock Ca is C'a (t)
Offset	Time offset is the dissimilarity among the time reported by the actual time and a clock. The offset of the clock Ca is assumed by Ca (t). The offset of clock Ca relative to clock Cb at time t = 0 is assumed by Ca (t)-Cb (t)
Skew	The skew of a clock Ca relative to clock Cb at time t is C'a (t)-C'b (t). Whether the skew is surrounded by p, then as per eq. (1), clock costs can diverge at a rate that ranges from 1-p to 1+p
Drift	The drift of clock Ca is the second derivative of the clock cost with respect to time, namely, C''a. The drift of clock Ca relative to clock Cb at time t is C''a (t)-C''b (t)

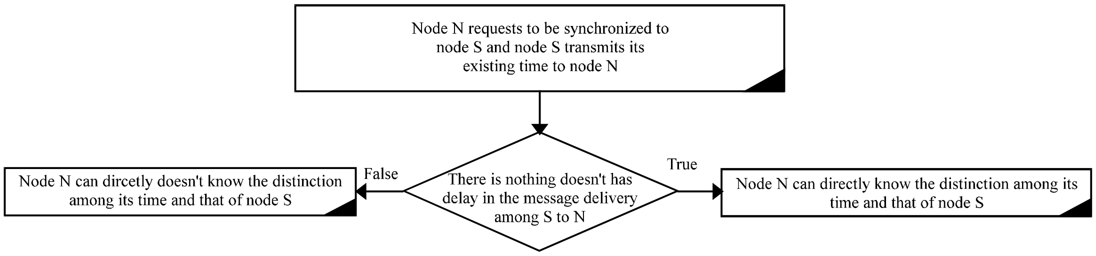

Fig. 4: A sample design of clock synchronization in WSN

system design of applications and algorithms, clock synchronization sets a common clock/time throughout a distributed system and ensures that WSNs can perform basic operations.

Challenges to clock synchronization: In recent years, numerous algorithms/protocols have been designed to maintain synchronized clocks over computer networks. A flowchart of planned clock synchronization is presented in Fig. 4. Unfortunately, in an actual wireless network, various component delays affect message delivery. Table 3 explains the causes of each contribution and indicates the variability of the delays and randomness (Maggs *et al.*, 2012; Sivrikaya and Yener, 2004). Ensuring time synchronization is more difficult than it appears to be.

A communication propagation sequence should be created to approximate the relative time offsets and skews between nodes. Time synchronization in WSNs should be considered when eliminating the impacts of random delays from the technique communication propagations forwarded in WSN channels.

Delay components can be classified into random and fixed delays. Random delays rely on diverse network parameters (e.g., traffic and network status). Thus, it applies to different cases and has been modeled as random delays in WSNs that contain gamma sharing, gaussian sharing, exponential sharing and weibull sharing based on different applications and validations (Bovy *et al.*, 2002; Leon-Garcia, 1994; Papoulis, 1991).

Fixed delays are typically unfamiliar and if they are not modeled properly, they will be considered a part of the clock offset, which results in less precise timing parameter estimation (Abdel-Ghaffar, 2002). WSNs also have to deal with limited and non-rechargeable power resources in clock synchronization. Time synchronization contributes to energy consumption because of the great amount of energy used by radio propagations to transmit time data. RF requires 3 J to transmit 1 kb over a hundred meters, which is equal to the energy required to transmit to transmit to three million directions (Pottie and Kaiser, 2000). Thus, efficient synchronization algorithms can reduce communication overhead and computational power.

Fundamental approaches to clock synchronization for WSN: Transmitting sensors are the basic components involved in time synchronization, which could be accomplished by transferring timing communications to the sensor nodes; these timing communications are timestamped. Fundamental clock synchronization approaches can be classified into three timing communication signaling approaches (Maggs *et al.*, 2012; Wu *et al.*, 2011), as shown in Table 4.

Requirements of clock synchronization schemes for WSN: Clock synchronization requirements can be considered metrics for evaluating clock synchronization designs for WSNs (Reis and Carvalho, 2013). Compromises among the requirements of an efficient synchronization approach (Maggs *et al.*, 2012;

Table 3: Description of message delivery affect in sensor network

Time	Definition	Cause	Randomness
Send	After transmitting the request, the operating system shows the time spent in constructing the communication at the application layer among delays. The sender also spends this time to synchronize communication and leave by this message to the network limit. This time is nondeterministic and can be over 100 of (msec) depending on the amount of system work	Build synchronization message	Low
Access	Time spent to access channels when arriving at the MAC layer. This time is an important factor and is extremely variable depending on the precise MAC protocol, which differs from (msec) to seconds depending on existing network traffic	Locate message on medium according to the MAC protocol	High
Transmission	The time spent to transmit a message at the Physical layer (PHY). This time is approximately tens of (msec) and is normally deterministic, which could be expected from the message length and radio speed.	Physical transmission of signal	Transmission time
Propagation	This is the time it takes for the message to be transmitted from the sender to the receiver across a wireless channel. This time is deterministic and in general, is less than one (μsec), which is approximately negligible compared with other delay mechanisms	Physical propagation of signal	Propagation time
Receive	The time at the application layer for the receiver or spent by the recipient to process the message and inform the host of its arrival. This is also the time spent to build and send the received message. This time can vary because of variable delays in usage system operations	Process synchronization message	Receive time
Reception	At the PHY layer for the time required by the receiver to receive a message, this time is equal to the transmission time, is normally deterministic and can be estimated from the message length	Processing (queuing) incoming message	Medium

Table 4: Fundamental approaches of clock synchronization in WSN

Approaches	Definition	Protocol
Receiver–receiver synchronization	Sensor nodes perform their local clocks autonomously, but they contain data on the relative drift and offset of their clock to other clocks in the network (Peng *et al*., 2010)	RBS (Elson *et al*., 2002), HRTS (Dai and Han, 2004), PBS (Noh *et al*., 2008)
One-way message dissemination	The easiest form of clock synchronization, this involves requesting messages or events. Determining whether event E1 occurred before or after a new event E2 is possible by using this model (Kosanovic and Stojcev, 2011)	FTSP (Maroti *et al*., 2004), SPS (Ganeriwal *et al*., 2008), NTP (Mills, 1985)
Two-way message exchange	This is a multifaceted form of synchronization in which the time of every sensor node is synchronized to the network (Skog and Handel, 2010).	TPSN (Ganeriwal *et al*., 2003), LTS (Van Greunen and Rabaey, 2003)

Table 5: The main requirements of clock synchronization in WSN

Criteria	Definition
Energy efficiency	The most significant issue is the limited energy resources for all protocols of sensor node networks. Sensor node networks use small, low-cost high performance batteries particularly in large-scale networks and when sensor nodes are in difficult-to-serve locations. Thus, synchronization designs should consider the limited energy resources of sensor nodes (Maggs *et al*., 2012)
Scalability	WSNs contain many sensors. Thus, a perfect clock synchronization protocol must be able to adapt to and exhibit consistent performance despite a large number of nodes and/or a high-density network. Scalability cannot be achieved by structures that require global information such as routing table entries or addresses (Karl and Willig, 2007). Therefore, such information should be limited, and infrastructureless protocols are ideal (Olariu *et al*., 2012)
Robustness	Sensors node can shift in/out of every other communication range because of mobility and a sensor node can break down because of limited power. Furthermore, a sensor node network is normally left unobserved for long periods of time in probably hostile environments. To prevent sensor nodes from failing, the synchronization scheme must be valid and useful all throughout the network (Kielpinski *et al*., 2002)
Precision or accuracy	The requirement for accuracy or precision may vary depending on the particular application and the function of synchronization. For some applications, a simple ordering of messages and events might suffice, whereas other require synchronization precision or accuracy in the order of some microseconds (Ingram *et al*., 2012; Kassouf *et al*., 2013)
Lifetime	The clock synchronized between sensor nodes by a synchronization algorithm may be last or first depending on the operation time of the network (Moinzadeh *et al*., 2012)
Scope	The synchronization design can provide a global clock base for local synchronization only between spatially close nodes or every node in the network. Scalability issues make global time synchronization difficult to accomplish or expensive (bandwidth usage and considering energy) in a large sensor node network. Moreover, a common clock/time base for many sensors is required to aggregate information from distant nodes, which requires global clock synchronization (Sundararaman *et al*., 2005)
Size and cost	As previously noted, WSN nodes are small, low-cost devices. Thus, a synchronization method for sensor networks that considers the limited size and cost must be developed (Maggs *et al*., 2012)
Immediacy	In emergency detection, the sensor network needs to convert an event immediately to the aggregation node. For this type of application, the network could not tolerate any delay after such an emergency is identified. Immediacy can prevent the protocol designer from depending on too much processing when an event of interest happens, which requires that nodes be pre-synchronized at all times (Kusy *et al*., 2006)

Sivrikaya and Yener, 2004) exist, as shown in Table 5. As a result, a single scheme may not satisfy all the requirements.

Clock synchronization protocols for WSN: Depending on network size, clock synchronization protocols can be classified into network-wide and pairwise synchronization.

Network-wide clock synchronization for WSN concentrates on sensor nodes that are organized into a multi-hop network. This type of synchronization can generally be obtained by extending pairwise clock synchronization derived from diverse communication structures, for which perfect structures must be robust, low cost and scalable. Network-wide clock synchronization also aims to develop a common time frame for a group of sensor nodes such that any two sensors have very similar clock readings (Lemmens *et al*., 2012).

Pairwise clock synchronization for WSN concentrates on two neighboring sensor nodes that are in every other node's communication range, for which perfect algorithms achieve precise clock synchronization and reduce random effects caused by communication delays through communication load and minimum computation. Pairwise clock synchronization for WSN in the presence of unknown exponential delays was also considered under a two-way message exchange mechanism (Wu *et al*., 2012).

ENERGY EFFICIENT ON ASPECT OF CLOCK SYNCHRONIZATION IN WSN

Sensor networks are an example of a wireless network that needs each sensor to execute events in synchronization. This synchronization is necessary to coordinate power cycles to conserve energy and to ensure the proper functioning of sensors that measure time-sensitive events. For example, the problem nature world has solved some of biological systems such as the beating of a heart and synchronized flashing of fireflies, can keep a globally synchronous oscillation based only on local observations. In the case of fireflies, this can be over significant distances. The deafness problem, which is the main problem of clock synchronization for WSNs. Deafness occurs when sensor nodes could not receive and transmit simultaneously. So, the deafness leads to longer delay, wasting energy, excessive packet drop and channel access unfairness.

Given the fact that the whole WSN communicate through a single frequency channel, concurrent communication of two or more nodes within communication range could result in packet collision and deafness. In order to avoid such a problem, a random offset is attached to the synchronization messages. Using the offset values, the receiving node can then reconstruct the required synchronization instant and thus adjust the clock rate in accordance with the received offset. In this way, the random offset selection may lead to the reception of synchronization messages in a way that may be out of order; thus causing a problem especially in the case of simple synchronization models. This problem can however, be solved using the reachback algorithm. Here, the synchronization events are collected up to the end of the period in order to attain the time information from the last period. The energy consumption plays an important role for the device lifetime in battery-powered wireless sensor networks, especially if no infrastructure is available.

As mentioned above, we can classify how to solve the impact of deafness problem on clock synchronization in WSN through see the design in Fig. 5.

Example of impacts deafness problem on clock synchronization in WSN performance are investigated several nodes of sensor network (Taniguchi *et al*., 2013). It was classified in Fig. 6 (Taniguchi *et al*., 2007; Degesys *et al*., 2007) based on PCO in order to the hop count.

Figure 7 shows the energy consumption in term of the number of nodes. It is found, as expected, that the consumed energy ratio of the randomization-based mechanism in term of the number of nodes is lower than that of the desynchronization-based mechanism. As a result, the desynchronization-based is appropriate for WSN applications that require high data collecting. Nevertheless, it needs added control overhead to keep away from collisions and deafness between hidden-terminal nodes. In contrast, randomization-based is appropriate for WSN applications which require simplicity of mechanism and energy efficiency instead of data collecting ratio. Even though the randomization-based does not clearly believe the hidden-terminal node problem, it is simpler and needs less control overhead.

Also, this study comparison among existing methods on energy efficient aspect of clock synchronization in WSN as depicts in Table 6.

This table presents studies that address deafness from different perspectives. Studies 1, 2, 3, 4, 6, 8 and 9 adopt the antenna perspective to avoid deafness. Studies 5, 7, 10 and 12 take the MAC protocol perspective to mitigate deafness.

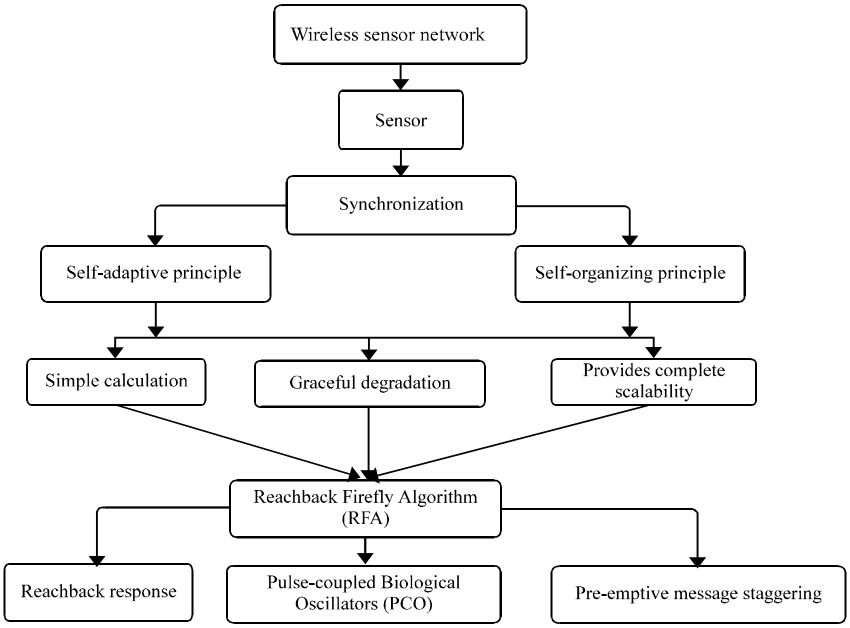

Fig. 5: Impact design of deafness problem on clock synchronization in sensor network

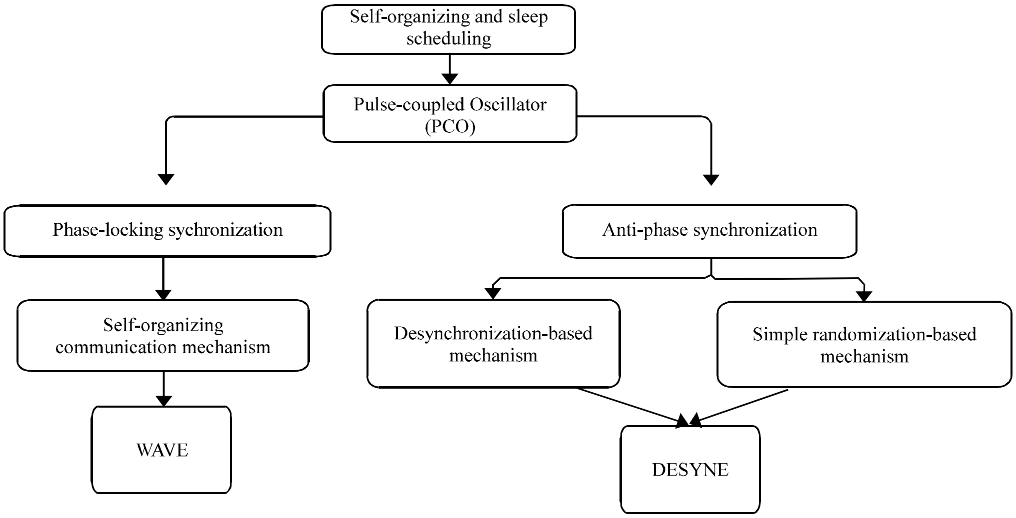

Fig. 6: Classified of pulse coupled oscillator in deafness problem

Table 6: Comparison of existing mechanisms on energy efficient aspect of clock synchronization in WSN

Authors	Methods	Advantages	Disadvantages	QoS
1. Choudhury *et al.* (2002)	This study considers two Medium Access Control (MAC) protocols for an ad hoc network using directional antennas	This study proposes multi hop request to send (RTS) MAC (MMAC), which covers multi-hop RTS to gain the advantage of upper antenna gain over directional antennas that outperform 802.11. The issues of directional MAC and deafness are discussed	This study neglects the design of more efficient directional MAC protocols and the impact of directional antennas on the performance of routing and other higher-layer protocols. No solution is offered	End-to-end delay and throughput
2. Korakis *et al.* (2003)	This study proposes a MAC protocol suitable for networks with directional antennas	This study significantly reduces the hidden terminal and describes deafness problems	The protocol does not assume any knowledge of the location of neighbors	Throughput

Table 6: Continue

Authors	Methods	Advantages	Disadvantages	QoS
3. Choudhury and Vaidya (2004)	This study addresses deafness, a result of exploiting the beam-forming capabilities of directional antennas and proposes a tone based on directional MAC protocol (ToneDMAC)	This study proposes ToneDMAC, which conserves the benefits of beam-forming while mitigating the adverse impacts of deafness on MAC layer performance	This study does not clarify whether modifying 802.11 optimizes performance. MAC protocols designed specifically for directional antennas may be more efficient. The study also fails to explore the possibilities of using tones more effectively and analyze the effects of fading and interference. Thus, this is clearly false with regard deafness, as discussed in this study	Packet drops, end-to-end delay and throughput
4. Takata *et al.* (2004)	This study proposes a smart antenna-based wider-range access MAC protocol (SWAMP) for a wireless ad hoc network or smart antennas based on the IEEE 802.11 MAC protocol, which ensures spatial reuse and range extension through two kinds of access modes	The study shows that SWAMP is more effective with a proper load in multi-hop ad hoc networks. Qualitative evaluation against objectives is conducted	This study addresses deafness. However, deafness was not solved by the proposed protocols	Overhead, end-to -end delay and throughput
5. Takata *et al.* (2006)	This study proposes receiver-initiated directional MAC (RI-DMAC) to address deafness in directional MAC protocols for wireless ad hoc networks using a polling scheme	This study addresses deafness in directional MAC protocols. Potential deafness can be identified when the future receiver becomes idle and a packet is directly delivered after receiving ready-to -receive. Among the polling table nodes that may encounter deafness, the least recently transmitted node is used because a polled node yields fairness. The study also shows that RI-DMAC outperforms other directional MAC protocols in terms of throughput and fairness	This study does not enhance RI-DMAC to incorporate quality of service requirements.	Fairness, end-to-end delay and throughput
6. Jain and Agrawal (2006)	This study proposes an algorithm for mitigating deafness in beam-forming antennas. The algorithm is implemented for two medium access protocols (MMAC with node-based backoff [MMAC-NB] and explicit synchronization via intelligent feedback [ESIF]) for multiple beam antennas. The performance of MMAC-NB improves and ESIF implementation is simplified by this algorithm	The study shows that performance gains can be increased by the proposed algorithm	The study develops an algorithm for mitigating deafness but disregards fairness and energy wastage.	End-to-end delay and throughput
7. Tyrrell and Auer (2007)	This study proposes the modification of reference nodes where a common time scale can be imposed on a set of distributed oscillators by firefly synchronization	The study proposes solving deafness by modifying reference nodes by firefly synchronization. Deafness can be solved by dividing the synchronization cycle into two parts: (1) for local phase update and pulse firing and (2) for listening to other firing nodes. This division can easily be accomplished by repeating unique time (T to 2T)	The study proposes the modification of reference nodes but not normal nodes, which follow only a self-organized synchronization strategy. The nodes were modified only in the mesh network and not in wireless sensor networks (WSNs).	
8. Korakis *et al.* (2008)	This study proposes a MAC protocol to exploit directional antennas in wireless networks completely	This study reduces hidden terminals and deafness, which are the primary causes of decreased efficiency in directional transmissions in ad hoc networks	This study assumes no knowledge of the location of neighbors. Given the dynamic nature of protocol functionality, the protocol behaves efficiently in an environment with both static and mobile users.	Throughput

Table 6: Continue

Authors	Methods	Advantages	Disadvantages	QoS
9. Jain *et al.* (2008)	This study includes identifying fundamental issues related to medium access with multiple beam antennas by using a single channel, designing a cross-layer hybrid MAC that maximizes the benefits of multiple-beam smart antennas and proposing wireless mesh network architecture with heterogeneous antenna technologies	This study argues that deafness cannot be entirely determined because no assurance exists that all nodes are informed of all incoming or continuing transmissions in its area when distributing to a single channel. Deafness can be mitigated only to a limited extent by taking either reactive or proactive actions	This study does not model the multipath effect, which occurs when multiple copies of the same signal are received by the receiver from different directions.	End-to-end packet delay and throughput
10. Karapistoli *et al.* (2009)	This study proposes a Directional Ultra-wideband MAC protocol (DU-MAC) that effectively addresses deafness and resolves the location of neighbors	This study proposes a protocol that outperforms the IEEE 802.15.4 a omni mode standard in terms of throughput and energy consumption, Thus, jointly utilizing UWB transmission with directional communication in shared wireless medium sensor networks would be beneficial	This study does not examine the DU-MAC protocol in greater depth, that is, by finding a prediction mechanism based on a probabilistic model. In the study scenario, beam hops are probability-dependent and thus severely reduce the number of times preamble trailers are sent and subsequently minimize the rotation phase before packet sending	Energy consumption and throughput
11. Ekbatanifard and Monsefi (2012)	This study surveys and classifies state-of-the art multi-channel MAC protocols proposed for WSNs	Deafness indicates that a receiver may be missing from the protocol. The synchronization column shows whether the protocol assumes that clock synchronization is externally required. The channel switching column lists the number of rate switching instances requested by the protocol in all steps		
12. Phung *et al.* (2013)	This study suggests a multichannel protocol for high-bandwidth WSNs based on a combination of time-division and frequency-division multiple access to avoid collisions and the deafness scheduling of transmissions by using reinforced learning for joint scheduling and routing in each node	They are achieved more easily and more often, latency is lower and packet loss is smaller. The proposed protocol also shows better performance in terms of end-to-end delivery rate, end-to-end latency and high energy efficiency	The authors aim to improve network throughput by scheduling node transmissions to avoid collisions and deafness in multichannels. However, the study provides only collision free operation. This study also does not implement the proposed protocol in combination with an appropriate time synchronization protocol on an operational sensor node test bed nor evaluate its performance with real devices	Packet delivery ratio, end to end latency and energy waste factor

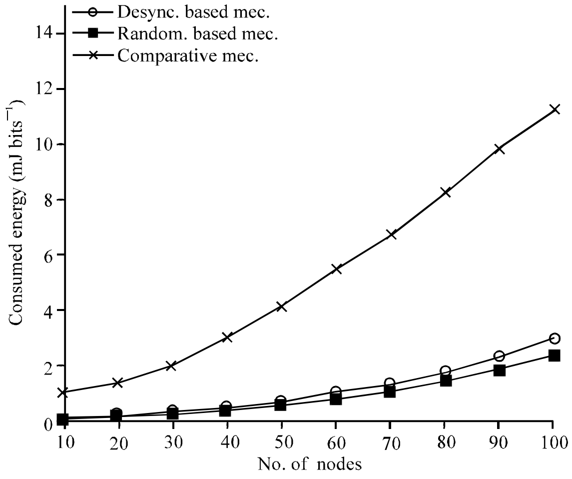

Fig. 7: Energy consumptions relative to the No. of node in WSN (Taniguchi *et al.*, 2013)

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This study presents previous studies of the impact of deafness problem on clock synchronization in a wireless sensor network. A comparison among methods is, presented in Table 6, which can facilitate the process of ensuring clock synchronization in WSNs. In addition, this study can significantly help not only in ensuring efficient sensor network use but also in reducing energy consumption and therefore, increasing the potential for increasing the lifespan of a sensor network. This work is a useful source on clock synchronization that can provide WSN researchers and novices with a better understanding of the deafness problem to promote effective designs and systems.

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