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MAC & Mobility In Wireless Sensor Networks

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1. Introduction

The recent climate change has a significant impact on our planet environment. Therefore, deploying sensor networks to monitor the environment is becoming important. With sensor networks deployed in strategic location can provide the scientific communities useful data to be analyzed and take action if necessary. Typical environmental applications of sensor networks include, but not limited to, monitoring environmental conditions that affect crops and livestock, biological, Earth, and environmental monitoring and many more. Monitoring hazardous environment like volcanic activities is one of the important applications for Wireless Sensor Network (WSN) (Sohraby et al, 2007). WSN communicate wirelessly to pass and process information – see Figure 1.

These sensor networks are deployed far away from the nearest permanent energy source available which make them depending on their own energy source to provide the needed information.

WSNs usually consist of a large number of low-cost, low-power, multifunctional (or unifunctional) wireless devices deployed over a geographical area in an ad hoc fashion and with or without careful planning (this depends on the application mainly whether it is related to a real-time applications or non-real-time application). Individually, these devices have limited resources and have limited processing and communication capabilities. The cooperative operation behavior of these sensing devices gives a significant impact on a wide range of applications in several fields, including science and engineering, military settings, critical infrastructure protection, and environmental monitoring (Yu et al, 2006).

Networking distributed sensors are used in military and industrial applications and it dates back at least to the 1970s. back then the systems were primarily wired and small in scale. wireless technologies and low-power Very Large Scale of Integration (VLSI) design became feasible and emerged in 1990 and after that researchers began envisioning and investigating large-scale embedded wireless sensor networks for dense sensing applications (Krishnamachari, 2005).

However, wireless sensor networks have a major problem, that is, “network life time”. Since WSN uses batteries, it does them in terms of storage, and processing power. Limited capabilities results in limited information efficiency. Current available technology on-shelf allow us to produce sensors that consumes as little power as 100mW which means that the sensors can remain operational efficiently (depending on the application and the deployed nodes own capabilities) for about 10 months. Yet the life time of the network can be extended for further than 10 months.

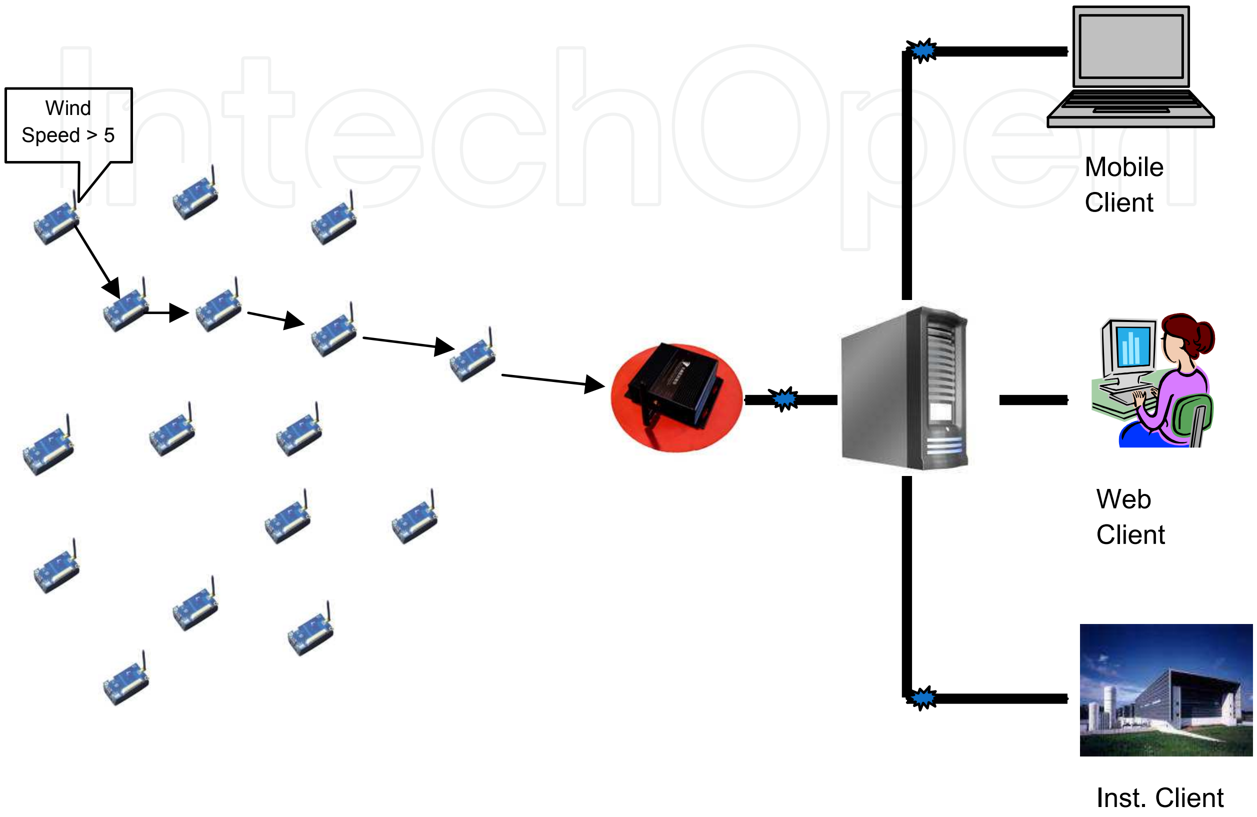

Fig. 1. Wireless Sensor Networks Example.

Some researchers proposed methods includes energy harvesting, solar energy and vibration energy. But these methods can only provide a small amount of energy to power these sensors, typically 20mw or less (Mainwaring et al,2002; Raghunathan et al, 2002). Maintenance and recharging these sensors is not a good option, and it will increase the expenses to keep the network alive and operational. Another alternative is to use energy efficient information processing and transacting algorithms to manage the network operation. We envisage that efficient routing and Medium Access Control (MAC) Protocols can help resolve this problem.

Information processing and routing is a technique used widely when it comes to provide a longer life time operation in wireless sensor networks however these techniques lacks the integrity as it has to compensate between either providing an energy efficient operation with the lack of high throughput or vice versa (Boukerche et al, 2005; Branyard et al, 2006).

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One of the major levels of tweaking in networking systems is to manipulate the timing when to deliver particular packets at a precise times to achieve efficient operation. From the literature provided most of the available approaches consider the main purpose of manipulating information processing technique is to achieve better energy consumption in the nodes while sacrificing the system throughput quality and robustness (Branyard et al, 2006). the next section will discuss MAC theory and the related works that where done in this area of research follows it in section three our own theory and methodology. Section four and five will discuss the results that where obtained during our research . Section six will review Mobility issues in brief and section seven reviews our proposed future goals in this research.

2. MAC protocols effect in WSNs

MAC is the second layer after the physical layer in the Open System Interconnection (OSI) model in networking systems, MAC protocols controls when to send and receive distinguished packet between different nodes in a network. It controls the network interface when to establish the connection or the transaction between two or more hosts. Manipulating the operation of a MAC protocol can give its effect in terms of energy consumption and message delay between nodes (Van Hoesel, Havigna, 2004).

Different MAC protocols were defined for WSN because of its application dependency. MAC protocols have to compensate between providing energy efficient consumption with the availability of decent throughput to make the system dependable (Van Hoesel, Havigna, 2004; Law et al, 2005) .

An essential characteristic of wireless communication is that it provides an inherently shared medium. All MAC protocols for wireless networks manage the usage of the radio interface to ensure efficient utilization of the shared bandwidth. MAC protocols designed for wireless sensor networks have an additional goal of managing radio activity to conserve energy. Thus, while traditional MAC protocols must balance throughput, delay, and fairness concerns, WSN MAC protocols place an emphasis on energy efficiency as well (Krishnamachari, 2005). MAC layer affects the energy efficiency mainly through the adjustment of transmission scheduling and channel access. A common way to do that is via sleep scheduling from a long time scale, or time-division multiple access (TDMA), from a short time scale perspective. Similar to the shutdown technique of CPUs, sleep scheduling also explores the energy *vs.* response time tradeoffs in wireless communication. From previous studies, the response time is translated to network or application layer transmission delay or throughput.

(Mathioudakis et al, 2008) presented the most energy wastage sources in MAC protocols for WSNs:

The first source is caused by collisions, which occur when two or more nodes attempt to transmit simultaneously. The need to re-transmit a packet that has been corrupted by collision increases the energy consumption.

The second source of energy wastage is idle-listening, where a node listens for traffic that it is not sent. In a sample fetching operation, a silent channel can be high in several sensor applications.

The third source of waste is overhearing, which occurs when a sensor node receives packets that are destined for other nodes.

The fourth is caused by control packet overheads, which are required to regulate access to the transmission channel. Sending and receiving control packets consumes energy too, and less useful data packets can be transmitted.

The fifth source is over-emitting where the destination node is not ready to receive during the transmission procedure, and hence the packet is not correctly received.

Finally, the transition between different operation modes, such as sleep, idle, receive and transmit, can result in significant energy consumption. Limiting the number of transitions between sleep and active modes leads to a considerable energy saving.

2.1 Related Approaches

For wireless sensor networks the literature provided a lot of protocols and divided it into two major categories (Shukur et al, 2009):

1. **Contention Based MAC Protocols (CSMA carrier sense multiple access)**. The wireless nodes here contend to enter the medium of connectivity (which is the wireless medium in case of WSNs) and the winner node reserves the medium to itself until it finishes its operation. Examples for this kind of protocols are: IEEE 802.11, S-MAC (Ye et al, 2001), T-MAC (Van Dam, Longendean, 2003), R-MAC (Du et al, 2007) and others.
2. **TDMA (time division multiple access) Based MAC Protocols**. The medium here is divided into time slots each node knows its time slot when to enter the medium and do its operation. One popular TDMA based MAC protocol for WSNs is ALOHA (PARK et al, 2006).

Contention based MAC protocols offers a more scalability approach over TDMA based approaches because of the nature of TDMA approaches that requires slotting the time into slots to each node which is improper when deploying a large number of nodes. To list dome of the works in this area of research, follows are some approaches regarding CSMA based MAC protocols:

A popular contention based MAC protocol for wireless networks is the IEEE 802.11 which is the standard for WLAN applications. IEEE 802.11 performs well in terms of latency and throughput but it is not efficient in terms of energy consumption because of the idle listening problem. It has been shown that when the node is in idle listening state it consumes energy equivalent to the receiving energy and that is why this protocol is not suitable for WSNs applications (Ye et al, 2001).

Sensor-MAC, S-MAC is a contention based MAC protocol designed explicitly for wireless sensor networks proposed by (Ye et al, 2001). While reducing energy consumption is the primary goal of this design, the protocol also has good scalability and collision avoidance capability. It achieves good scalability and collision avoidance by utilizing a combined scheduling and contention scheme. It also achieves efficient energy consumption by using a scheme of periodic listening and sleeping which reduces energy consumption. In addition, it uses synchronization to form virtual clusters of nodes on the same sleep schedule. These schedules coordinate nodes to minimize additional latency. The protocol also uses the same mechanism to avoid the overhearing problem and hidden channel problem that is used in IEEE 802.11. But the S-MAC has a problem of latency because of periodic listen and sleep scheme which is dependent on the duty cycle.

WSNs applications have some unique operation characteristics, for example, low message rate, insensitivity to latency. These characteristics can be exploited to reduce energy consumption by introducing an active/sleep duty cycle. To handle load variations in time and location, (Van Dam, Langendeon, 2003) proposed the Timeout MAC T-MAC protocol. T-MAC can handle an adaptive duty cycle in a novel way: by dynamically ending the active part of it. This reduces the amount of energy wasted on idle listening, in which nodes wait for potentially incoming messages, while still maintaining a reasonable throughput. T-MAC uses *TA* (time out) packet to end the active part when there is no data to send/receive on the node. The protocol balances between energy efficient consumption and latency efficient throughput due to the scheme of burst data sending more effective in terms of energy consumption.

The concept of periodic listen and sleep approach was explored by (Suh, Ko, 2005). They proposed a novel MAC scheme named as TEEM (Traffic aware, Energy Efficient MAC) protocol. The proposed TEEM is based on the often cited contention-based MAC protocol S-MAC. The protocol achieves energy efficient consumption by utilizing 'traffic information' of each sensor node.

Thus, Suh and Ko show that the listen time of nodes can be reduced by putting them into sleep state earlier when they expect no data traffic to occur. In this method, they made two important modifications to the S-MAC protocol: the first modification was to make all nodes turn off the radio interface much earlier when no data packet transfer is expected to occur in the networks, and secondly eliminating communication of a separate RTS control packet even when data traffic is likely to occur. However, it lacks on latency efficiency to conserve energy.

The cross-layer approach protocol was investigated by (Pack et al, 2006) . They proposed a task aware MAC protocol for WSNs. The TA-MAC protocol determines the channel access probability depending on a node's and its neighbor nodes' traffic loads through the interaction with the data dissemination protocol. In this approach the TA-MAC protocol can reduce energy consumption and improve the throughput by eliminating unnecessary collisions. The TA-MAC protocol is feasible because it can be integrated with other energy efficient MAC protocol example, SMAC. The TA-MAC protocol focuses on the determination of channel access probability that is orthogonal to the previous MAC protocols for WSNs.

Another work that explores the cross-layer approach was presented by (Du et al, 2007) . The proposed scheme called Routing-enhanced MAC protocol (RMAC), exploits cross-layer routing information in order provide delay guarantee without sacrificing energy efficiency. Most importantly, RMAC can deliver a data packet *multiple* hops in a single operational cycle. During the SLEEP period in RMAC, a relaying node for a data packet goes to sleep and then wake up when its upstream node has the data packet ready to transmit to it. After the data packet is received by this relaying node, it can also immediately forward the packet to its next downstream node, as that node has just woken up and is ready to receive the data packet. The mechanism is implemented using a packet called Pioneer. This packet travels to all sensors in down-stream to synchronize the duty-cycles of the nodes to guarantee a multi-hop packet delivery. In this way the protocol achieved latency efficient operation.

(Erazo, Qain, 2007) developed the S-MAC to SEA-MAC, a protocol which aims for energy efficient operation for WSNs for environment monitoring. The protocol assumes only the base station node has the time synchronization schedule. Sensor nodes are active only when there is a sample to be taken from the environment which decreases the duty-cycle of the node and preserves energy. The packet which is responsible for initiating important data delivery in SEA-MAC is called TONE packet which is shorter in period than SYNC packet in S-MAC.

The literature trawl has revealed that few protocols use TDMA-based scheduling because of the overhead of time slot scheduling as sensor network deployment usually includes large number of sensors. A protocol that uses TDMA-based scheduling is the Energy and Rate (ER) proposed by (Kannan et al, 2003). The ER_MAC protocol has the ability of avoiding extra energy wastage.

The main advantages of ER-MAC are:

- packet loss due to collisions is absent because two nodes do not transmit in the same slot. Although packet loss may occur due to other reasons like interference, loss of signal strength etc.
- no contention mechanism is required for a node to start sensing its packets since the slots are pre-assigned to each node. No extra control overhead packets for contention are required.

ER-MAC uses the concept of periodic listen and sleep. A sensor node switches off its radio and goes into a sleep mode only when it is in its own time slot and does not have anything to transmit. It has to keep the radio awake in the slots assigned to its neighbors in order to receive packets from them even if the node with current slot has nothing to transmit.

Real-Time MAC (RT-MAC) proposed by (Sahoo, Baronia, 2007) is another TDMA-based MAC protocol that can provide delay guarantee. TDMA based MAC protocols suffers from latency caused by the assigning of time slots which takes up a lot of time because of the number of sensor nodes deployed. RT-MAC overcomes this problem by reutilizing the connection channel between two successive channel accesses of a sensor node. RT-MAC also allows sensors to go to sleep which preserves energy. Although it provides delay guarantee, the RT-MAC protocol requires a lot of computation that exhaust the sensor node itself in some cases like clock drifting problem.

There are other works on design of MAC protocol based on TDMA scheme (Ganeriwal et al, 2003; Egea-L'opez et al, 2006); they all share the same complexity in time slot assigning.

To summarize the investigated literature, we devised a table that illustrates the categories of MAC protocols proposed for WSNs showing their advantages and disadvantages. Refer to Table 2:

MAC Protocol	Category	Main Advantage	Main Disadvantage
IEEE 802.11	CSMA/CA	The Highest system throughput	Inefficient energy consumption
S-MAC	CSMA/CA	Scalable, energy efficient due to the sleep/listen scheme	Suffers from Latency issues
T-MAC	CSMA/CA	Energy efficient, Reasonable throughput	Requires extended control packet to achieve efficient operation
TEEM	CSMA/CA	Energy efficient due to the eliminating the use of RTS packet	Suffers from Latency issues
TA-MAC	CSMA/CA	Cross-Layer approach	Suffers from latency issues
R-MAC	CSMA/CA	Enhanced throughput	Control Packet Delivery overhead
SEA-MAC	CSMA/CA	Energy efficient operation	Suffers from Latency issues
ER-MAC	TDMA	Collision free environment	Scalability and latency issues
RT-MAC	TDMA	Increased the system throughput	Excessive calculation and clock drifting problems

Table 1. Summary of the related approaches for MAC Protocols.

3. Proposed solution and the methodology behind it

In this section we ill discuss our proposed solution and describe the operation on the protocol. It also discusses how it manages control packets and data packets exchanges between the network nodes. Energy consumption and packet exchange delay analysis are also discussed. To prove the method proposed we devised simulation experiments using the most common tool to simulate networking systems the Network Simulator 2 (NS2) (Issariyakul, Hossain, 2008). The analysis equations were based on the theory of S-MAC.

3.1 The Network Simulator 2 (NS2)

NS2 is the most widely used tool in researches involved in general networking systems analysis and wireless networking systems includes Mobile networking, Satellite networking, Wireless Sensor Networks, LAN networks and other network technologies. NS2 is built using C++ language and uses OTcl (Object Oriented Tcl) language as an interface with the simulator. The network topology is built using OTcl and the packet operation protocol is written in C++ (Issariyakul, Hossain, 2008).

3.1.2 Mobile Networking In NS2

The wireless model essentially consists of the MobileNode at the core, with additional supporting features that allows simulations of multi-hop ad-hoc networks, wireless LANs etc. A MobileNode thus is the basic Node object with added functionalities of a wireless and mobile node like ability to move within a given topology, ability to receive and transmit signals to and from a wireless channel.

3.1.3 Routing and MAC protocols provided in NS2

Two MAC layer protocols are implemented for mobile networks, which are IEEE 802.11 and TDMA, while S-MAC was added to NS2 as a Patch by (Ye et al,2001). The four different ad-hoc routing protocols currently implemented for mobile networking in NS2 are dsdv, dsr, aodv and tora.

3.2 The Proposed Scheme

The proposed scheme (Shukur, Yap, 2009, a; Shukur, Yap, 2009, b) considers the following:

1. Combining the functionality of SYNC packet with RTS packet will provide both energy and latency efficient operation which will eliminate the need of sending two packets and decrease control packet overhead. This packet from now on would be referred to as SEEK.
2. To increase the throughput of the system (SEEK) packet will be sent all the way to the down stream nodes before sending CTS packet to the upper stream node. This will open the way to DATA packet to move through the stream of nodes until DATA packet reaches the base station node. Figure 2 Describes the approach mentioned above.

3.2.1 Energy Consumption analysis

The first step is to analyze the proposed approach energy consumption for three nodes operation. The following assumptions are made for the analysis (using the scenario shown in Figure 3-3 below:

1. All nodes in the way are by all means available for any packet transmission.
2. The packet delivery direction is from node 1 to node 3.
3. No collision happens between nodes (assuming that Carrier Sense is successful in each transmission start).
4. SEEK packet follow this rule (SYNC<SEEK<SYNC+RTS).
5. DATA packet could be transmitted in one hop.
6. All control packets are fixed in size.
7. In a more realistic scenario upper-layer routing information provides the shortest route to the destination.
8. DATA packet can be transferred in one hop.
9. If the next node in the way is in sleep mode (SEEK) works as the signal that wakes up the node.

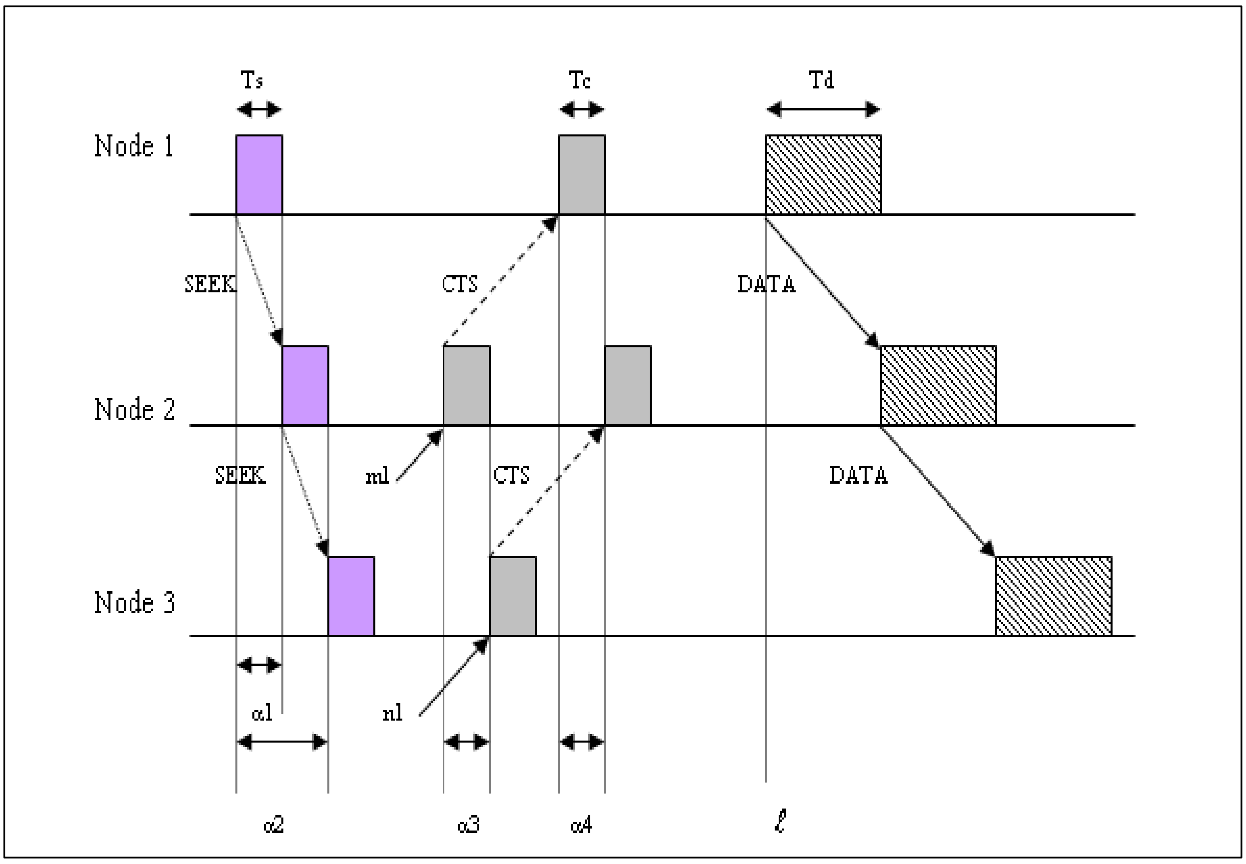

Fig. 2. Proposed Scheme operation for Synchronization in MAC layer Protocol.

The analysis scenario is described in Figure 3:

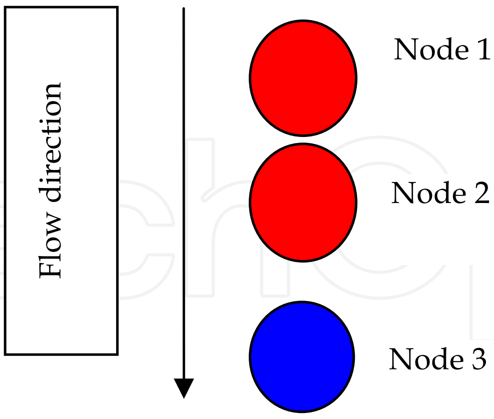

Fig. 3. Analysis Scenario.

Each Node operation is represented by a formula following the devised Synchronization timeline which is described in figure 2 above. Starting with the operation of Node (1) form

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the Scenario above (figure 3) the formula of Energy consumption can be represented as follow:

$$S_1(t) = X(t) + Y(t-\alpha_3) + Xd(t) \ldots\ldots(1)$$

$$S_1(t) = P_t \times \mathrm{rect}\left(\frac{t}{T_s}\right) + P \times \mathrm{rect}\left(\frac{(t-\alpha_3-m_1)}{T_c}\right) + P \times \mathrm{rect}\left(\frac{(t-\ell)}{T_d}\right)$$

Where:
T_s: SEEK packet time length.
T_c : CTS packet time length.
T_d : DATA packet time length.
α : the delay in each state of transmitting SEEK packet and receiving CTS packet.
P_t : Transmission Power.
P : Reception Power.
X(t): rectangular function of delay for SEEK packet.
Y(t): rectangular function of delay for CTS packet out from the exact node.
Z(t): rectangular function of delay for CTS packet received from the down stream node.
X_d(t): rectangular function of delay for DATA packet.

Node (2) energy consumption is equal to the following equation:

$$S_2(t) = X(t-\alpha_1) + Y(t) + Z(t-\alpha_4) + Xd(t-\alpha_4) \ldots\ldots(2)$$

$$S_2(t) = \begin{array}{l} \left[P_t \times \mathrm{rect}\left(\frac{(t-\alpha_1)}{T_s}\right) + P_t \times \mathrm{rect}\left(\frac{(t-m_1)}{T_c}\right) + P \times \mathrm{rect}\left(\frac{(t-\alpha_4)}{T_c}\right)\right] + \\ \left[P \times \mathrm{rect}\left(\frac{(t-\alpha_4)}{T_c}\right) + P \times \mathrm{rect}\left(\frac{(t-\ell-\alpha_4)}{T_d}\right)\right] \end{array}$$

Finally Node (3) energy consumption:

$$S_3(t) = X(t-\alpha_2) + Y(t) + Z(t) + X_d(t-\alpha_4) \ldots\ldots(3)$$

$$S_3(t) = P_t \times \mathrm{rect}\left(\frac{(t-\alpha_2)}{T_s}\right) + P_t \times \mathrm{rect}\left(\frac{(t-n_1)}{T_c}\right) + P \times \left(\frac{(t-\ell-\alpha_4)}{T_d}\right)$$

From Equation (1,2 and 3) we can compute the energy consumed by following equation (4):

$$E_s = S_1(t) + S_2(t) + S_3(t) \ldots\ldots(4)$$

Where (E_s) represents the energy consumed by the proposed analysis system in Figure (3-3). Substitute equations (1, 2 & 3) into (4) results in:

$$
\begin{aligned}
E_s(t) = {} & \left[P_t * \mathrm{rect}\left(\frac{t}{T_s}\right) + P * \mathrm{rect}\left(\frac{t - \alpha_3 - m_1}{T_c}\right) + P * \mathrm{rect}\left(\frac{t - l}{T_d}\right) \right] + \\
& \left[P_t * \mathrm{rect}\left(\frac{t - \alpha_1}{T_s}\right) + P_t * \mathrm{rect}\left(\frac{t - m_1}{T_c}\right) + P * \mathrm{rect}\left(\frac{t - \alpha_4}{T_c}\right) + P * \mathrm{rect}\left(\frac{t - l - \alpha_4}{T_d}\right) \right] + \\
& \left[P \times \mathrm{rect}\left(\frac{(t - \alpha_4)}{T_c}\right) + P \times \mathrm{rect}\left(\frac{(t - \ell - \alpha_4)}{T_d}\right) \right] + \\
& \left[P_t \times \mathrm{rect}\left(\frac{(t - \alpha_2)}{T_s}\right) + P_t \times \mathrm{rect}\left(\frac{(t - n_1)}{T_c}\right) + P \times \left(\frac{(t - \ell - \alpha_4)}{T_d}\right) \right]
\end{aligned}
$$

3.2.2 System Delay analysis

The proposed scheme deals with more that one node in a duty-cycle because of the concurrent (SEEK) packet transmission so the packet delay will only be counted as (extra SEEK packet) and (extra CTS packet) in the middle nodes, Below is the mathematical delay approach of the proposed scheme following the same parameters and the same assumptions made for energy consumption:

Node 1 delay:

$$D_1(t) = T_s + T_c + T_d \ldots\ldots\ldots\ldots (5)$$

Node 2 delay:

$$D_2(t) = \alpha + T_s + 2 * T_c + T_d \ldots\ldots\ldots\ldots (6)$$

Node 3 delay:

$$D_3(t) = T_s + T_c + T_d \ldots\ldots\ldots\ldots (7)$$

From (5, 6 and 7) above a system delay equation can be derived:

$$D_s(t) = \sum_{1}^{N-2} \alpha * T_s + T_c \ldots\ldots\ldots\ldots (9)$$

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N: the number of nodes in the system.

While for S-MAC (Ye et al, 2001), because each node have to go through the same operation to send the data packet it is possible to describe S-MAC delay operation for the same system as:

$SYNC_t$: time length for SYNC packet.
RTS_t: time length for RTS packet.
CTS_t: time length for CTS packet.
$DATA_t$: time length for DATA packet.

Node 1 delay (S-MAC):

$$D_1\ (t) = SYNC_t + RTS_t + CTS_t + DATA_t. \ldots\ldots\ldots\ldots (10)$$

Node 2 delay (S-MAC):

$$D_2\ (t) = D_1\ (t) + SYNC_t + RTS_t + CTS_t + DATA_t. \ldots\ldots\ldots\ldots (11)$$

Node 3 delay (S-MAC):

$$D_3\ (t) = D_2\ (t) + SYNC_t + RTS_t + CTS_t + DATA_t. \ldots\ldots\ldots\ldots (12)$$

From (10, 11 and 12) we can reach to a system delay equation using S-MAC:

$$D_{S\text{-}MAC}\ (t) = \sum_{1}^{N} D(N-1)(t) + SYNC_t + RTS_t + CTS_t + DATA_t \ \ldots\ldots\ldots(13)$$

4. Implementation of the proposed solution

This section will discuss the implementaiton of the methodology and the simulation parameters used. Two simulation scenarios are devised and simulation parameters with a range of duty-cycles from (5% - 25%) for the first scenario and from (5%-40%) for the second scenario in three steps to cover most of operation environment that can a WSN suffer. The first simulation scenario (Figure 3) is represented by a straight line of nodes deployment .:

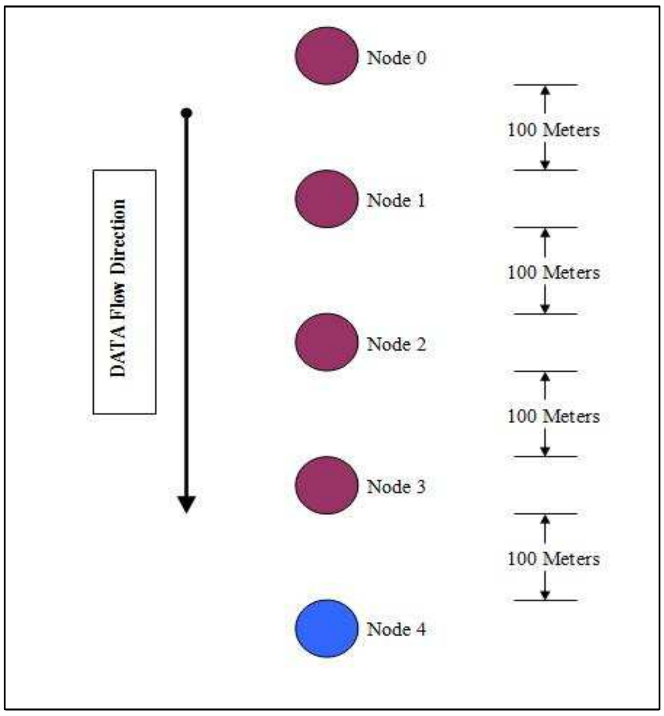

Fig. 3.a: A straight node deplyment used as the first simultion scene.

The simulation environment was built and made using NS2 version 2.33, the scenario consists of five nodes in one row Starts from node 0 to node 4 considering node 4 as the destination node in the simulation. Our main revals during where S-MAC protocol (as it is considered the base protocol to propose the Sleep-Listen Theory) and SEA-MAC because it is an inprovment over S-MAC in terms of the control packets handling. The proposed approach will be referred as Proposed Protocol (PP-) before or after any protocol name.

below is a table of the parameters that where allocated for the scenarion above:

Parameter	**Amplitude**
Simulation time	700 second
Duty-Cycle	5%, 10%, 25%
Routing Protocol	None
Node Idle power	100 mW
Node Rx Power	100 mW
Node Tx Power	100 mW
Node Sleep Power	1 mW
Transition Power	20 mW
Transition time	5 ms
Energy model	NS2 Energy model
Propogation model	TwoRayGround
Initial Energy for each node	1000 mJ

Table 3. the simulation parameters for the first scene

The second simulation (Figure 4) scenario consist of ten nodes. nine nodes 0-8 formed a square deployment and one node 9 was separated from the other as a base node. The simulations are conducted on a wide range of duty cycles from 5% - 40% in three steps (5, 25 and 40).

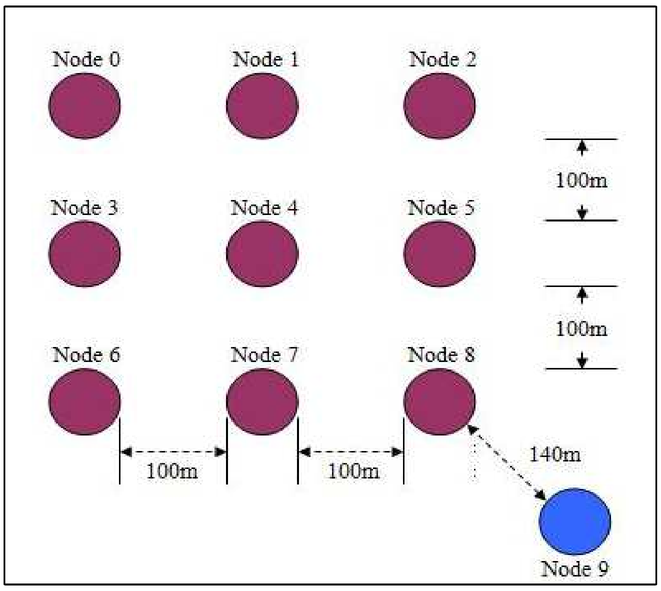

Fig. 4. square shape node deployment to simulate the second scene.

The Simulation parameters where allocated to this sceneario as in table 4 below:

Parameter	Amplitude
Simulation time	7000 seconds
Duty-Cycle	5%, 25%, 40%
Routing Protocol	DSR
Node Idle power	100 mW
Node Rx Power	100 mW
Node Tx Power	100 mW
Node Sleep Power	1 mW
Transition Power	20 mW
Transition time	5 ms
Energy model	NS2 Energy model
Propogation model	TwoRayGround
Initial Energy for each node	100000mJ

Table 4. the simulation parameters for the second scene.

The next section will discuss the results of the simulation and the effect of the proposed scheme on the operation of the MAC protocols and the Network itself.

4.1 First Scenario Results

To show the effect of the solution we propose we have to issue a comparison between our rivals S-MAC and SEA-MAC. Our criteria of comparison are Energy consumption, the number of collisions and the delay of packet transmission. Figure 5 shows the protocols operation in a 5% duty-cycle:

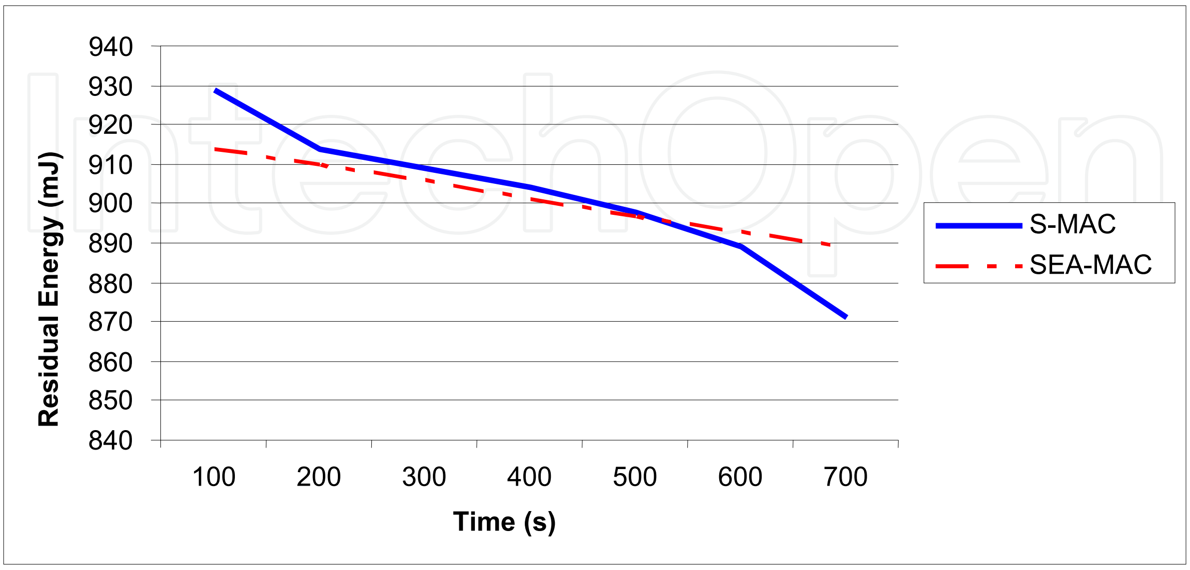

Fig. 5. S-MAC vs. SEA-MAC at 5% Duty-Cycle.

S-MAC operation is more prone to lose energy than SEA-MAC as it uses much more for (SYNC) packet than in SEA-MAC (TONE) packet. Figure 6-A shows the collisions occurance for both protocols. Figure 6-B show the delay effecincy of each protocol:

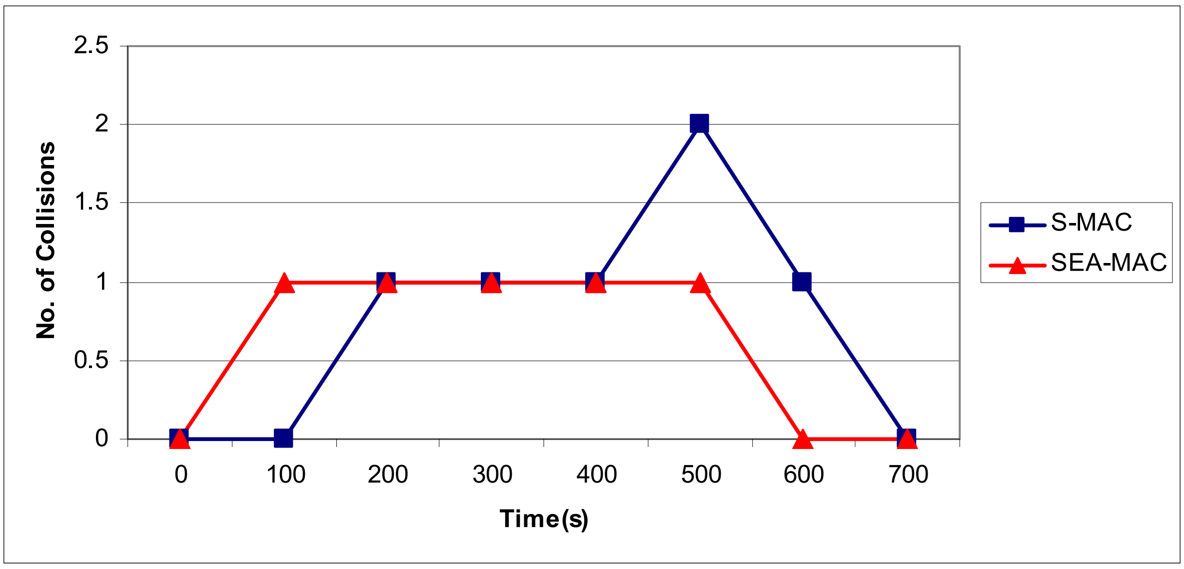

Fig. 6-A: S-MAC vs. SEA-Mac in terms of collision occurance at 5% Duty-Cycle

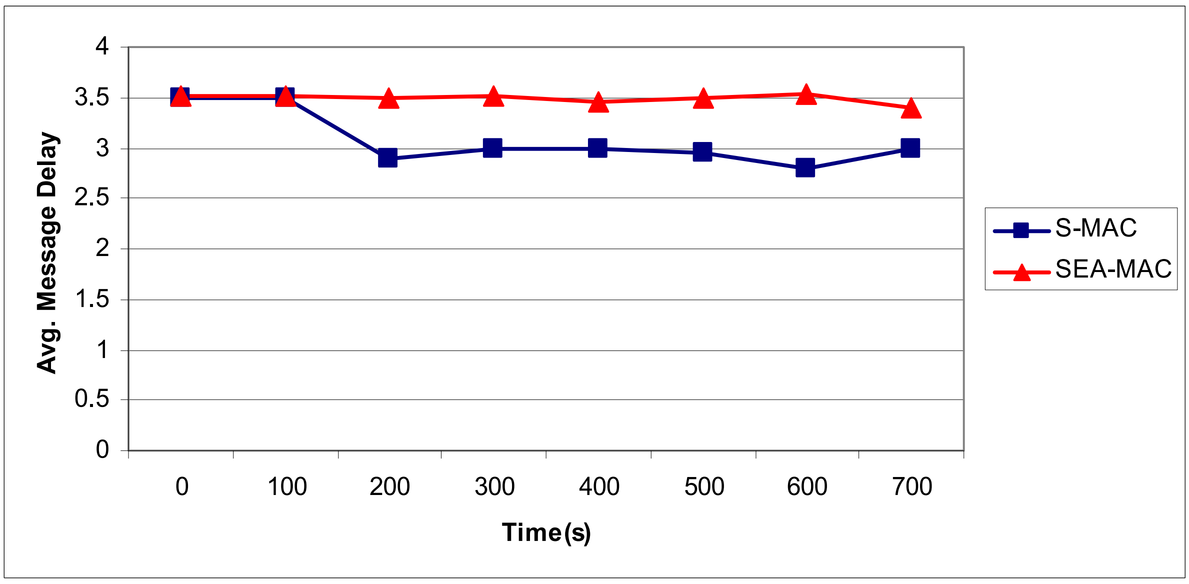

Fig. 6-B: S-MAC vs. SEA-MAC in terms of Message Delay at 5% Duty-Cycle

Overall, S-MAC offers better delay than SEA-MAC, if we increase the operation Duty-Cycle to 25%, we will observe that S-MAC a better performance in terms of Delay and collisions (Figure 7-A & B). But SEA-MAC offers better energy consumption over S-MAC because it uses a shorter activating packet called (TONE). Figure 8 shows the energy consumption effect.

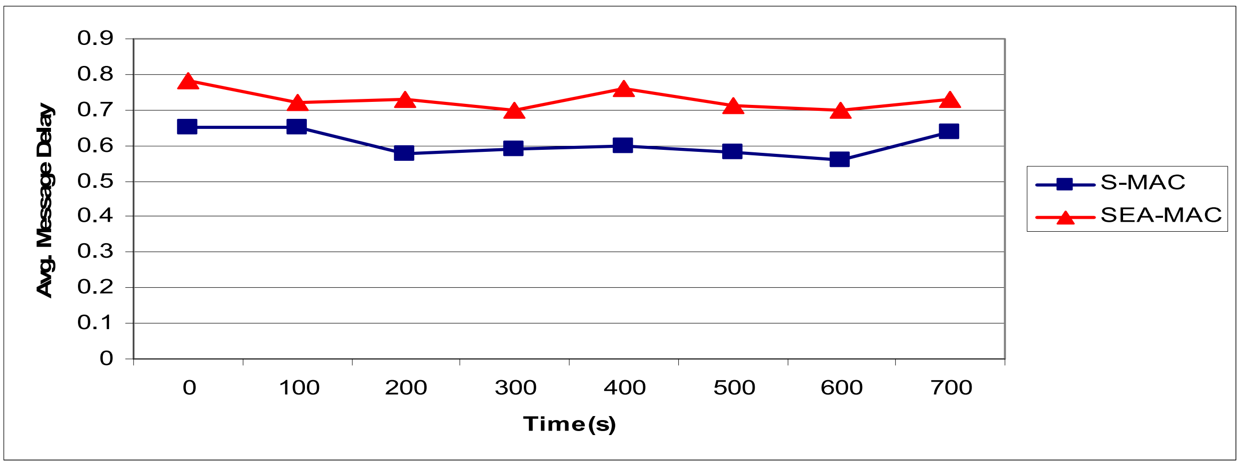

Fig. 7-A: S-MAC vs. SEA-MAC Message Delay at 25% operation Duty-Cycle.

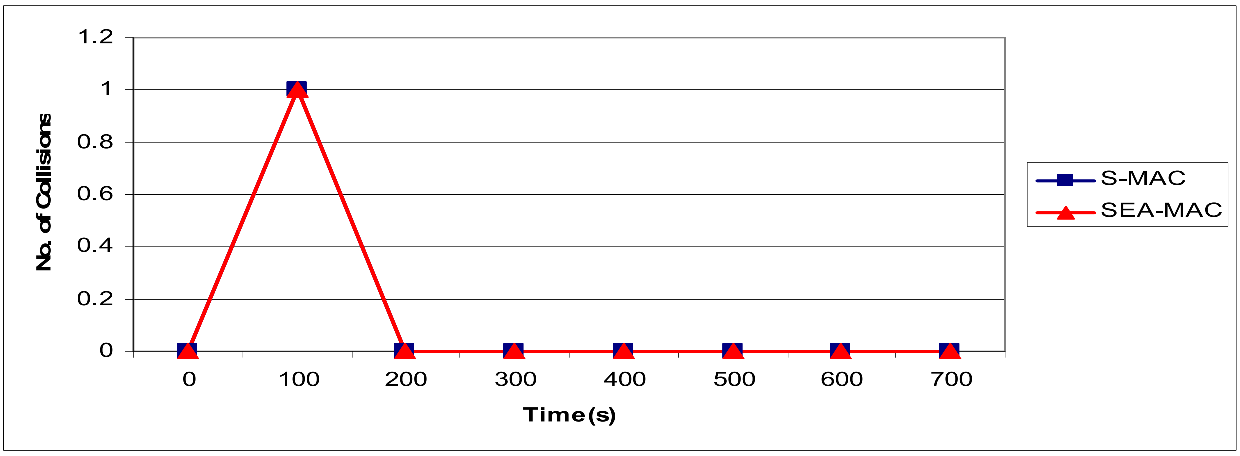

Fig. 7-B: S-MAC vs. SEA-MAC Collision Effect at 25% Duty-Cycle.

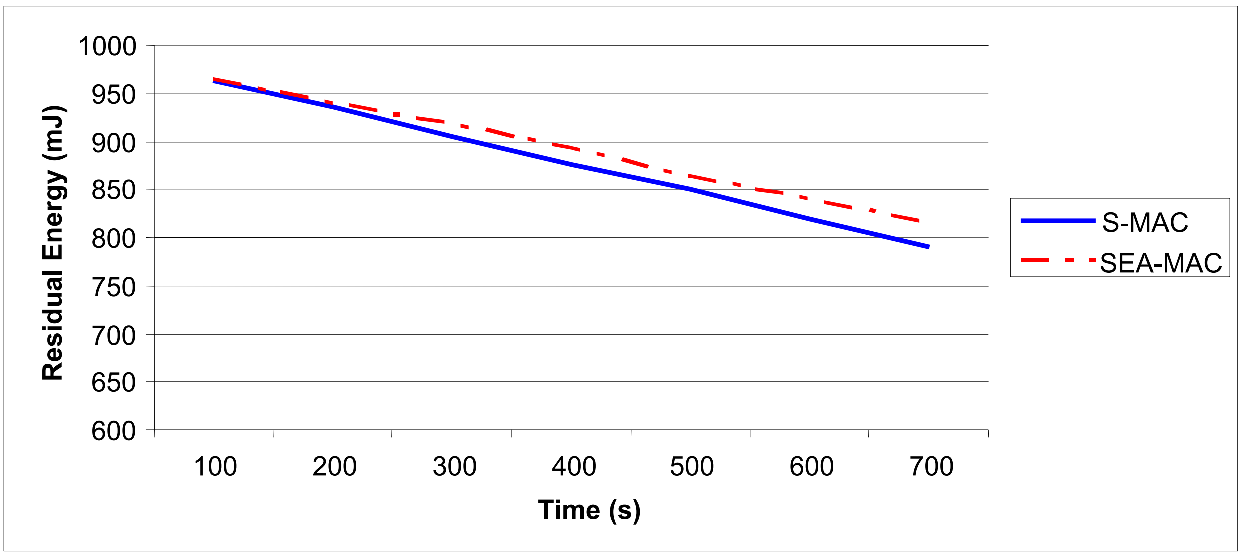

Fig. 8: S-MAC vs. SEA-MAC Energy consumption at 25% Duty-Cycle.

After impl;ementing our theory on both protocols (indicated by adding (PP-) before or after the protocol's name), S-MAC started to perform better than SEA-MAC in terms of energy consumption at low duty-cycle. While SEA-MAC kept the energy consumption better at higher Duty-Cycles. And to mention that both protocols after improvments provided Zero-collisions in the straight line simulation scenario. Figure 9-A,B,C&D shows the energy consumption and delay efficency at 5% & 25% duty-cycles.

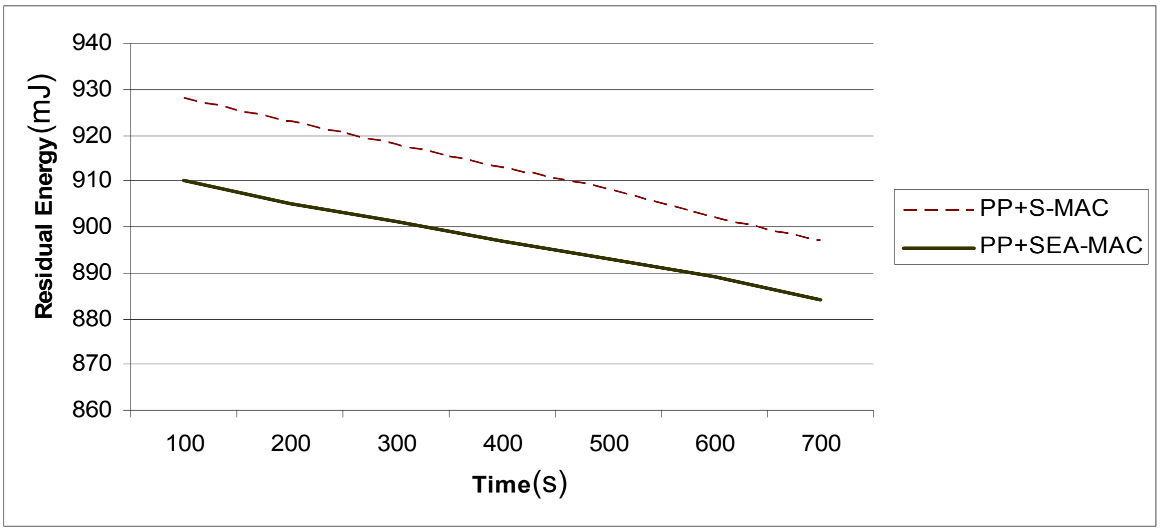

Fig. 9-A: PP+S-MAC vs. PP+SEA-MAC energy consumption at 5% Duty-Cycle.

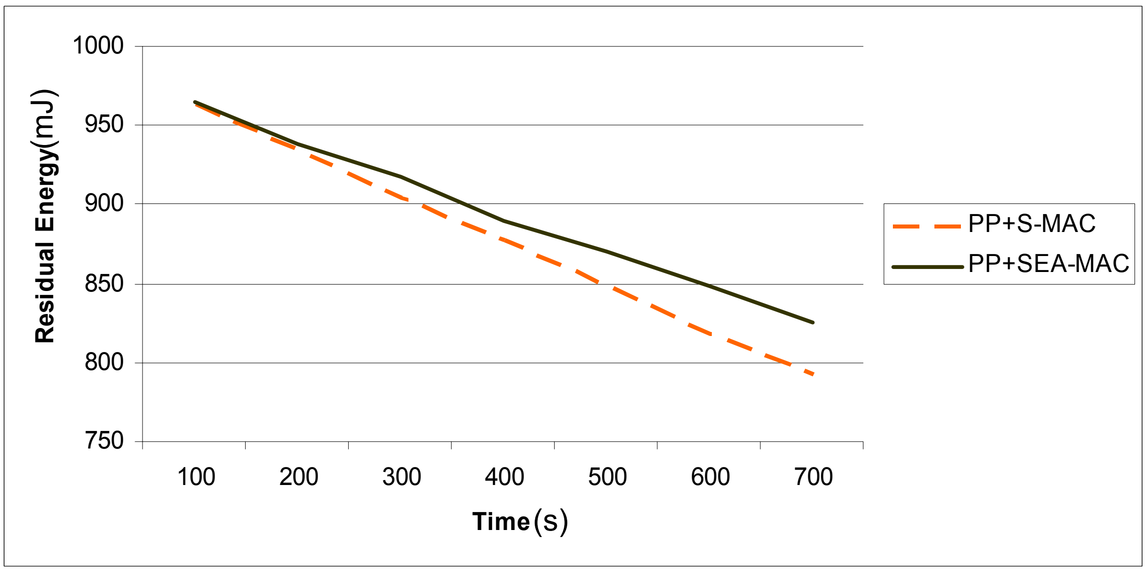

Fig. 9-B: PP+S-MAC vs. PP+SEA-MAC energy consumption at 25% Duty-Cycle.

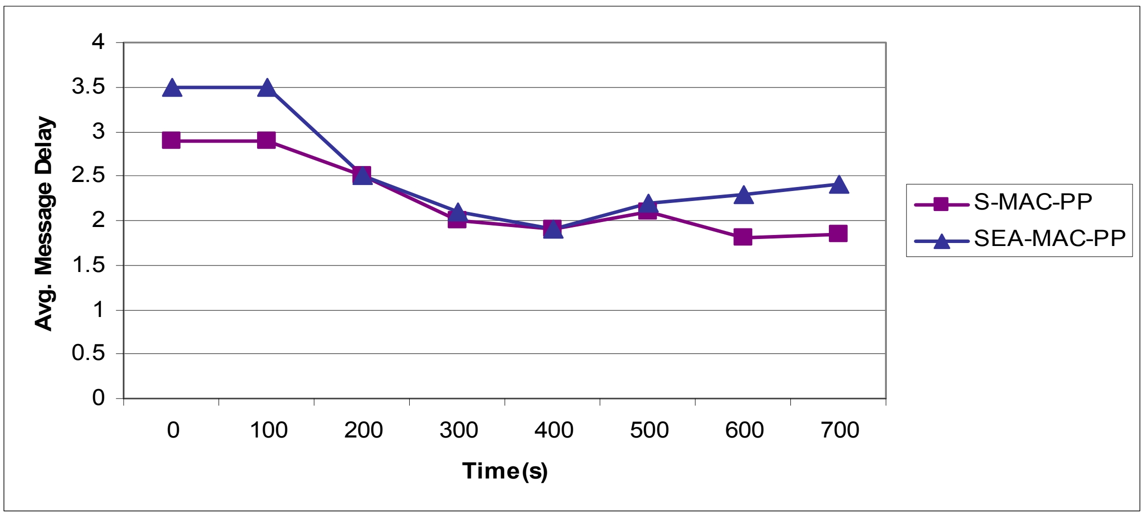

Fig. 9-C: PP+S-MAC vs. PP+SEA-MAC Delay effeciny at 5% Duty-Cycle.

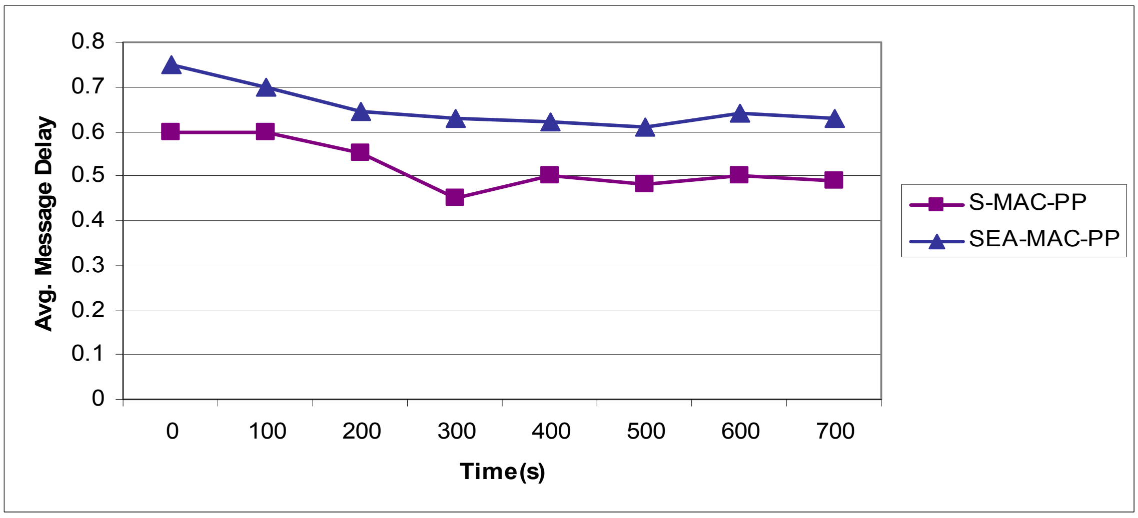

Fig. 9-D: PP+S-MAC vs. PP+SEA-MAC Delay comparison at 25% Duty-Cycle.

To summerize the result show above, The proposed scheme gave the effect on S-MAC and made the consumption in terms of energy at low Duty-Cycle operation better than the original scheme of S-MAC.
The proposed approach provided better operation in terms of energy consumption at high Duty-Cycle operation than the original SEA-MAC scheme.
Both protocols provided better throughput for most of the scenarios after adding the proposed scheme to the original scheme of the protocols.

4.2 The proposed Scheme effect for the second scenario

The second scenario has a new factor that gave an effect on the operation of both protocols S-MAC and SEA-MAC (with or without the implementation of the proposed theory). This is represented by the number of the deployed nodes. Increasing the number of the nodes can give a positive effect on the network operation as it will help to conduct the inquiry collection of the phenomena in a more fast paced operation. Figure 10-A,B &C shows the energy consumption, Delay and collisions occurrences. This effect is observed in Figure 10-A, where we can see the gap of consumption between SEA-MAC and S-MAC.

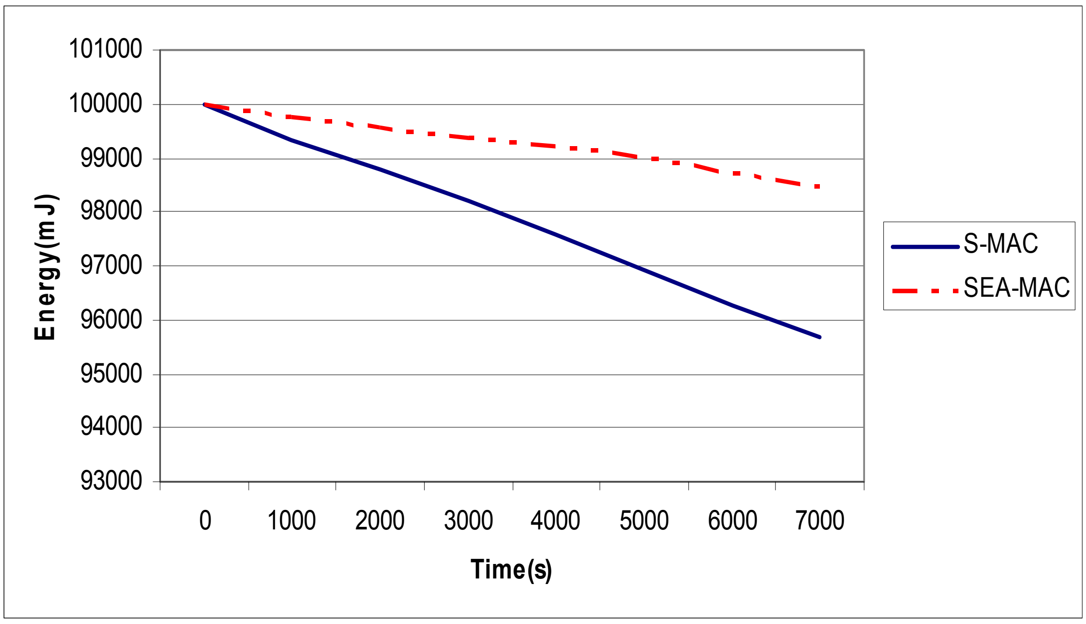

Fig. 10-A: S-MAC vs. SEA-MAC energy consumption at 5% Duty-Cycle.

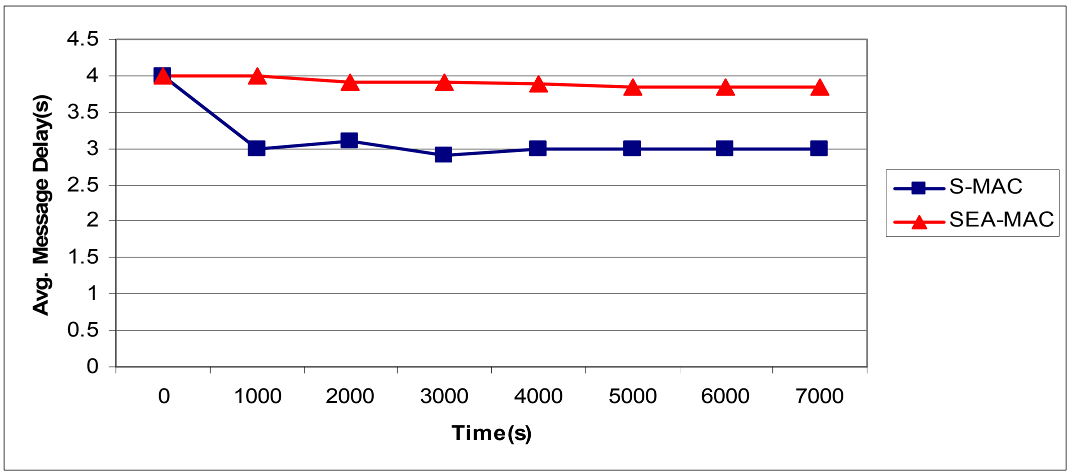

Fig. 10-B: S-MAC vs. SEA-MAC Delay average at 5% Duty-Cycle.

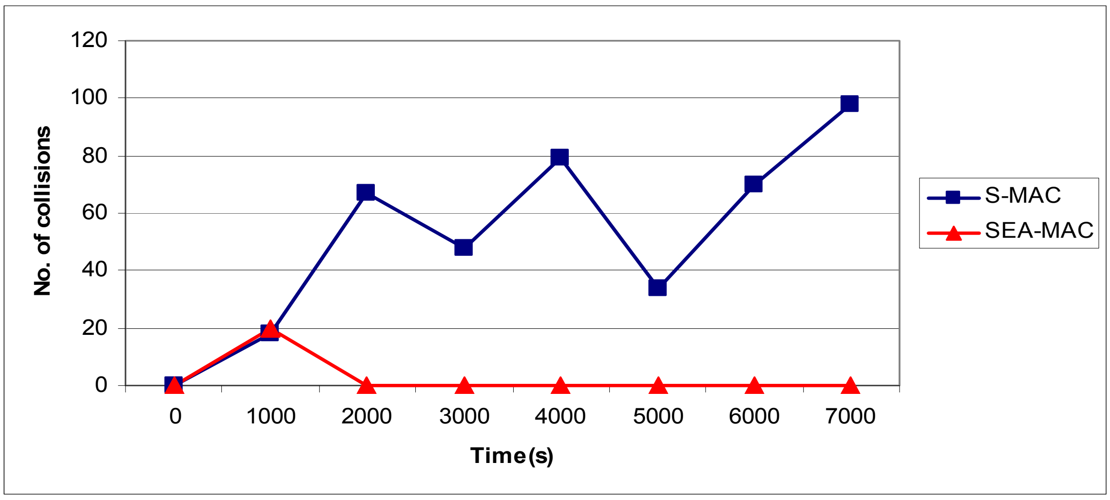

Fig. 10-C: S-MAC vs. SEA-MAC collisions ocurrances at 5% Duty-Cycle.

Adding the proposed approach to both protocols resulted in a different operation than the original ones. Figure 11-A,B&C shows that, it is observed that S-MAC was improved over SEA-MAC operation at low Duty-Cycle. This is due to the fact that S-MAC goes through four stages of operation (SYNC+RTS+CST+ACK) while SEA-MAC has (TONE+SYNC+RTS+CTS+ACK) which leads to a longer operation even with the compression of two control packets (SYNC&RTS), SEA-MAC has longer operation time than S-MAC at shorter duty-cycle.

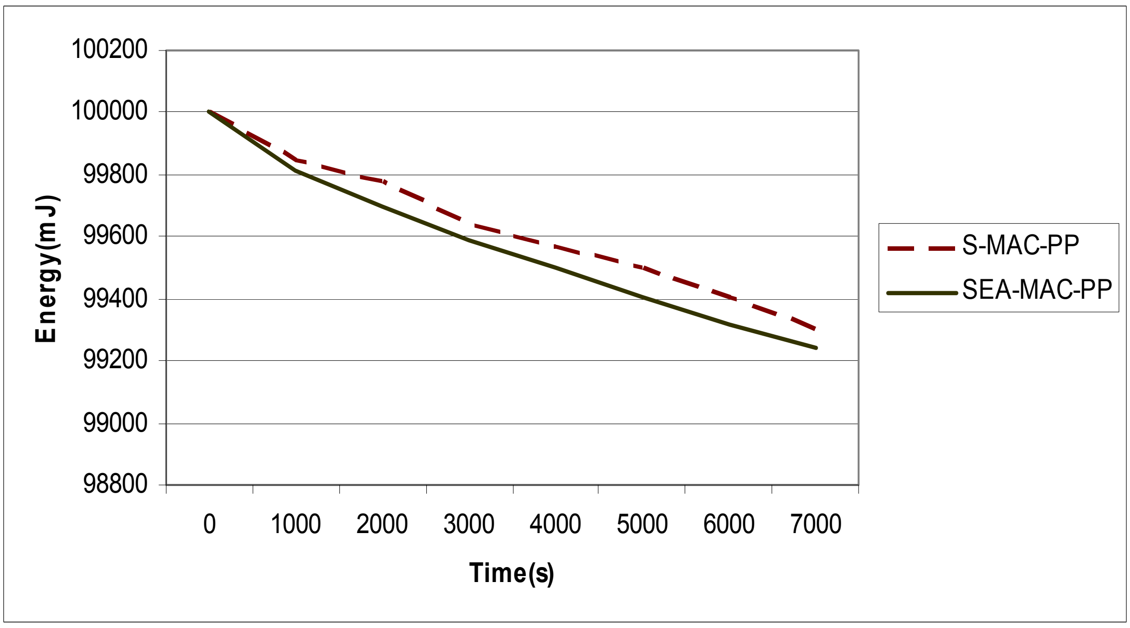

Fig. 11-A: PP+S-MAC vs. PP+SEA-MAC energy consumption at 5% Duty-Cycle.

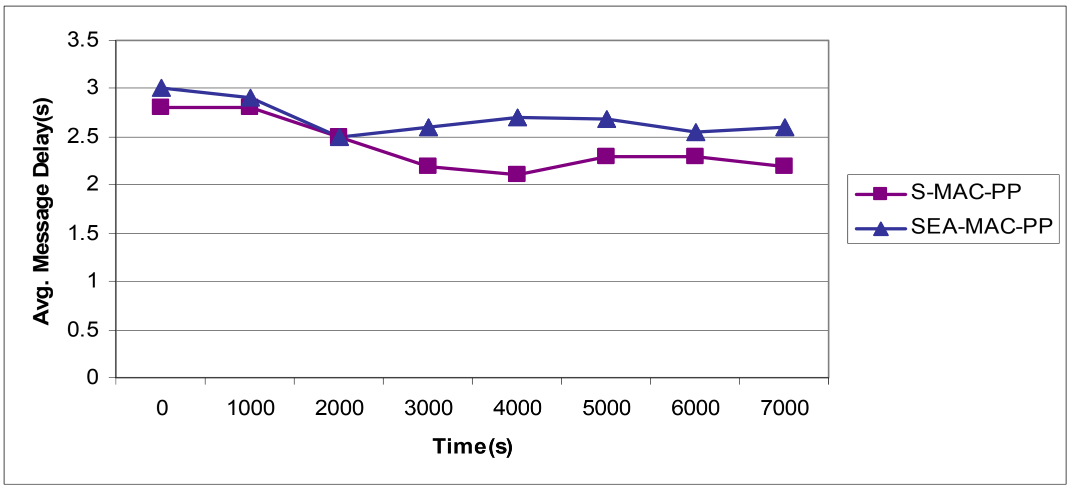

Fig. 11-B: S-MAC-PP vs. SEA-MAC-PP average Delay at 5% Duty-Cycle.

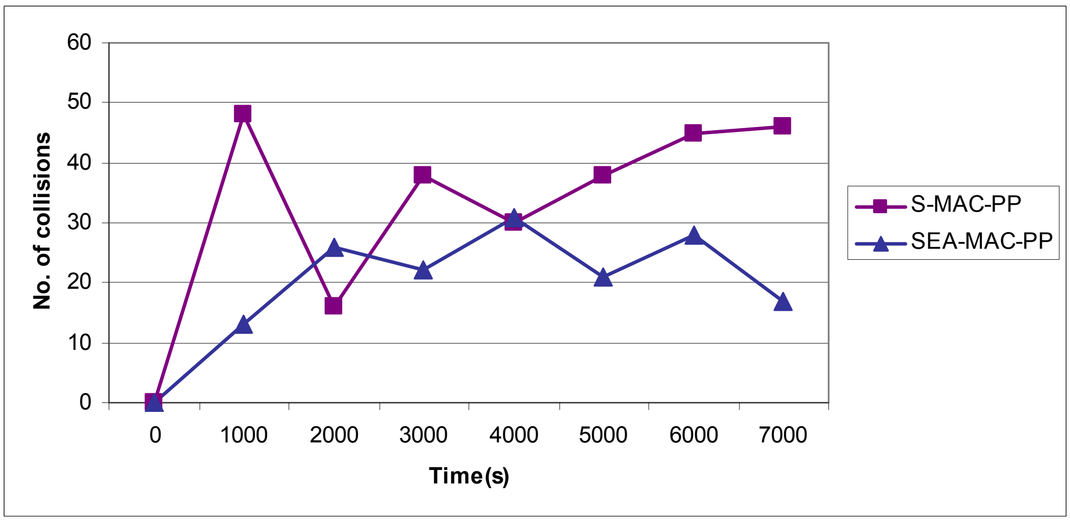

Fig. 11-C: S-MAC-PP vs. SEA-MAC-PP collisions at 5% Duty-Cycles.

4.3 Pros and Cons of the proposed theory

Overall, the proposed approached satisfied the quest as it does improve the operation of both protocols at different ranges of duty-cycle (we must note SEA-MAC with the proposed approach offered better energy consumption and delay operation at higher duty-cycles than S-MAC also implemented with the approach). Increasing the number of nodes result in collision occurance rather than the situation with the straight line deployment. Overall message delay is in favor of S-MAC at shorter duty-cycles and the advantage is to SEA-MAC at longer duty-cycle.

In the next section we will discuss breifly the mobility issues in WSN as it is considered an important part of this research area.

5. Mobility in WSN

Wireless sensor networks (WSN) offers a wide range of applications and it is also an intense area of research. However, current research in wireless sensor networks focuses on

stationary WSN where they are deployed in a stationary position providing the base station with information about the subject under observation. However, a mobile sensor network is a collection of WSN nodes. Each of these nodes is capable of sensing, communication and moving around. It is the mobility capabilities that distinguish a mobile sensor network from the conventional 'fixed' WSN (Motari'c et al, 2002).
Mobile sensor networks offer many opportunities for research as these sensors involves: the estimate location of the node in a movement scenario, an efficient DATA and information processing schemes that can cope with the mobility measurements and requirements (this includes the routing theory and the potential MAC Protocol Used).
Most of the discussed approaches interms of routing theory, MAC and also allocation the location of the sensors are ment for stationary sensor nodes. Mobile sensor networks requiers extra care when it comes to design and implementing a network related protocols the conserns includes ad not exclusive to: energy consumption, message delay, location estimation accuracy and scurity of information traveled between the nodes to the base station.
To list some of the aspects that effects on designing an operapable Mobile sensor networks, the next sections will give a brief explination about routing theory, MAC approaches and Localaization scheme aimed for mobility applications.

5.1 Routing theory

Routing protocols are protocols aimed to offer transmitting the DATA through the network by utilizing the best available routes (not always the shortest ones) to the destination. When it comes to design routing protocols for mobile Sensor nodes, extra care should be taken in terms of timing the transportation between the nodes. Most of the routing protocol that are used and implemented for Wireless sensor networks (e.g. Ad hoc on demand Distance Vector (AODV) and Dynamic Source Routing (DSR)) are originally designed and optimized for ad hoc networks which utilizes devices like (Laptop computers and mobile phones) which has much powerful energy sources than the ones available in sensor nodes. And to the power issue mobility make the task even tougher.

5.2 MAC approaches

Even the approach discussed in this chapter does not satisfy the mobility issues in MAC protocols aimed for mobile sensor networks. The results from the current work suggest that the CSMA based MAC protocols has a better chance in overcoming this issue than TDMA based MAC protocols because of the time slotting issues that comes along with TDMA based systems. IEEE802.15.4 or best known as (Zigbee) is a MAC layer standard provided by IEEE organization aimed for low power miniatures. Still, it cannot be considered yet as a standard MAC protocols for mobile sensor networks as it is still in the development stages for such applications.

5.3 Localization Issues

Locating the sensor is an important task in WSN as it provides information about the phenomena monitored and what action should be taken at the occurrence of an action. Proposed localization schemes are aimed manly for stationary networks and partially for mobile networks. Some of the examples of localization techniques are (Boukerche et al, 2007):

RSSI: Received Signal Strength Indicator, which is the cheapest technique to establish a node location as the medium used is wireless medium and most of the wireless adapter are capable of capturing such information. The disadvantage of such approach is the accuracy of the information calculated by such approach.

GPS: Geo- Positioning System, the most used approach mobile nodes application and in some cases considered the easiest. The disadvantage of GPS systems is that it adds extra cost to systems in terms of financial cost and energy consumption costs and also accuracy issues.

TOA: Time On Arrival systems, the most accurate approach to achieve the location of the nodes. However there are some cons for this technique: first of all the cost is higher than GPS systems. Second the accuracy issue is dependent on how violent the environment being applied on as it requires a line-of-sight connection to capture the required information. And the last issue, because it is a mounted platform so it will consume energy like the issue with the GPS systems.

6. Future Research goals

The future research goal is to devise a template Network Model aimed for Mobile Wireless Sensor Networks. The template will take in consideration the concerns discussed in section five of this chapter. It is envisage that the proposed approach provided in this chapter can assist to devise a MAC approach that can be applied for various applications in WSN. The proposed template is designed for Habitat monitoring applications as they share some similarities in terms of the configurations and crucial guarantees. Future work would to utilize a Signal – to – noise Ratio estimator (Kamel, Jeoti, 2007) as a metric to define which route is the best to chose and on which nodes signal can estimate the location of the node. Cross-layer approach a definite approach and consideration that we aim utilize in our template.

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Wireless Sensor Networks: Application-Centric Design

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Over the past decade, there has been a prolific increase in the research, development and commercialisation of Wireless Sensor Networks (WSNs) and their associated technologies. WSNs have found application in a vast range of different domains, scenarios and disciplines. These have included healthcare, defence and security, environmental monitoring and building/structural health monitoring. However, as a result of the broad array of pertinent applications, WSN researchers have also realised the application specificity of the domain; it is incredibly difficult, if not impossible, to find an application-independent solution to most WSN problems. Hence, research into WSNs dictates the adoption of an application-centric design process. This book is not intended to be a comprehensive review of all WSN applications and deployments to date. Instead, it is a collection of state-of-the-art research papers discussing current applications and deployment experiences, but also the communication and data processing technologies that are fundamental in further developing solutions to applications. Whilst a common foundation is retained through all chapters, this book contains a broad array of often differing interpretations, configurations and limitations of WSNs, and this highlights the diversity of this ever-changing research area. The chapters have been categorised into three distinct sections: applications and case studies, communication and networking, and information and data processing. The readership of this book is intended to be postgraduate/postdoctoral researchers and professional engineers, though some of the chapters may be of relevance to interested masterâ€™s level students.

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