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LOW LATENCY AND ENERGY EFFICIENT S-MAC PROTOCOL FOR WSN: MAC PROTOCOL PERSPECTIVE

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Abstract. *In a wireless sensor network (WSN), considerable amount of power is spent in processing information across the sensor nodes (SN) and a high power depletion of the SN can hamper the operation of WSN. Therefore, certain considerations are taken at each layer to reduce the energy consumption of the sensor network. The objective of this paper is to investigate different Medium Access Control (MAC) protocols and to find a suitable protocol that can reduce energy consumption considerably as well as reduce the latency than the others. The authors have found through simulation results that unified scheduling method in S-MAC protocol can improve energy efficiency as well as reduce the latency for larger as well as smaller size networks. The authors also demonstrate that Uni-Scheduling method in S-MAC protocol overcomes the diversified scheduling problem of the Border Nodes between two or more virtual clusters created in WSN.*
Keywords: S-MAC (Sensor-MAC) protocol, SN (Sensor Nodes), Wireless Sensor Network (WSN), Uni-Scheduling packets

1. **Introduction.** The Wireless Sensor Network (WSN) has become known as one of the key technologies of recent times. It has become a hot research issue, which is regarded as one of the ten influencing technologies in the 21st century. The WSNs are composed of low-power radio, embedded processor and battery operated sensor nodes (SN). In recent times a significant amount of research is carried out to reduce the energy consumption of the SN, such as designing suitable network topologies, efficient data processing, or putting the nodes into sleep and listening mode adaptively. A briefing of the key characteristics of the network lifetime can be found in the paper [1].

Sensors nodes are deployed in large number throughout a hostile and unattended environment, making the battery replacement impractical. Therefore, they can only provide small and limited processing capabilities [2]. As a result, energy saving would be the main concern for the design of an effective WSN and the provision of delay is also challenging as most of the periodic monitoring and on-demand traffic applications require low end-to-end delay. Before discussing energy savings mechanism, this paper summarizes the major sources of energy wastage in WSNs.

i. The primary source of energy consumption is idle listening. It occurs when nodes listen to idle channels to receive any possible traffic. In this way, significant proportion of energy are wasted, especially when the traffic load in the network is low.

ii. The second source is collision or corruption of packets. Normally, collisions occur when neighboring nodes transmit packets at the same time and due to lossy channel, the transmitted packets will be corrupted. If one of the above two cases happens, the lost packets will be re-transmitted, which increases the energy consumption of the nodes.

iii. Third one is that overhearing of a node to receive packets that are destined for other nodes reduces the stored energy of the node.

iv. Over emitting can also depreciate the energy level of a node, which is caused by transmission of a message when the destination node is not ready.

v. The last one is the control packet overhead. During data transmission when the control packets are exchanged between sender and receiver some energy is consumed.

Several types of Medium Access Control (MAC) [3] protocols are proposed to reduce the energy consumption of the sensor networks. Whereas, the Sensor-MAC (S-MAC) protocol [4,5] is designed particularly for Wireless Sensor Networks and to some extent it has managed to reduce the energy consumption of the SN.

However, the energy efficiency of S-MAC degrades in the presence of the Border Nodes as they frequently switch to the listen state in proportion to the number of schedules that have adopted. Therefore, designing effective WSN, energy savings issue needs to be considered. In addition to energy efficiency, latency is another crucial factor for time sensitive data, where an event needs to be reported to a sink as soon as it is detected, so that appropriate action can be taken immediately. Adopting our proposed unified scheduling algorithm, we can increase energy efficiency as well as reduce latency. The main contribution of this paper over the previous work [32] is to review the state-of-the-art on energy-aware S-MAC protocol of WSN and to accordingly introduce Uni-Scheduling method in different network topologies on the basis of the mechanism that can affect the delay.

The organization of the paper is as follows. The major sources of energy wastage in WSN are summarized in Section 1. In Section 2 different approaches for energy conservation in WSN have been discussed. An efficient MAC protocol is required for WSN to reduce the energy consumption and low end-to-end delay. In Section 3, a survey of major energy efficient mechanisms in MAC protocols has been presented and Section 4, provides the details of Uni-Scheduling scheme in S-MAC protocol. Simulation results and analysis are given in Section 5. Finally, we draw our conclusion in Section 6.

2. Energy Conservation Approaches in WSN.

Researchers have proposed numerous approaches for energy conservation in WSN and the requirements of different approaches varied according to the application. The main purpose of this section is to present briefly different methods that have been used to increase the energy efficiency. The MAC protocol is one of them and an efficient MAC protocol can reduce the energy consumption as well as end-to-end delay.

2.1. Optimal sink location.

The sensor nodes that are deployed in remote environments are impossible to change or recharge. In such cases it is really essential to place a sink node in optimal location to have an energy efficient WSN [1]. The integrated mobile sink node that moves in a random controlled, predictable, or adaptive manner can also reduce energy consumption.

2.2. Clustering solution.

In WSN, different attributes are executed to increase the energy efficiency of the network such as changing the network size, node density, and topology. These attributes not only increased the efficiency of the network but also improved the latency, bandwidth and network throughput. The sensor networks are usually divided into small clusters in order to reduce the burden of the data traffic. Within the clusters, the SNs are randomly distributed and the node with higher energy will be selected as a cluster head (CH). The CH is responsible for forwarding the information to the sink node [6,7]. One of the most well-known clustering approaches is LEACH (Low-Energy Adaptive Clustering Hierarchy), a self-organized, adaptive protocol. In this protocol, the nodes organize themselves within the clusters, where one node from each clusters acts as a cluster head (CH) [8-10] and all the information is relayed between the CH and sink node. The CH role is rotated periodically among all the nodes in a given cluster. In order to improve the basic LEACH algorithm several approaches are proposed. In [11], the authors introduced an energy factor in the CHs and based on this factor a node with maximum energy becomes a cluster head. In [12] the nodes in a cluster form a chain and send data only to the neighboring node in the chain. The data is collected from the chain nodes and CH sends it to the sink node. In [13], the nodes search the surrounding environment and gather information of the current CH. After collecting the information, the new CH is selected based on the collected information. In [14], a hybrid distributed clustering approach is proposed and the CH is selected based on the energy levels and secondary parameters such as node proximity of the neighboring nodes.

2.3. **Energy-efficient routing schemes.** In a multi-hop WSN, the nodes replay the packets from one neighbor to another for transferring the packets. Thus, while routing an efficient routing algorithm, it can save a significant amount of energy in a network. In WSN, traditional routing methods choose the best routing path in order to minimize the power consumption among the communicating nodes, which is explained in literature [15-18]. However, the neighboring nodes located near a sink node have to handle the maximum load. Thus, any complicated routing algorithm will be unsuitable for low-capacity SN.

One of the earliest routing protocols is Sensor Protocols for Information via Negotiation (SPIN), works by spreading all the information of each node to all the nodes in a network. Simultaneously, each node in the network has the capability to act as a Base Station (BS). Gradient-Based Routing (GBR) is another earliest routing protocol that makes use of the gradient value. The gradient values that are considered are the distance between the nodes and the height of the nodes. The packets will only be forwarded to the nodes that will have the biggest gradient value.

The other routing technique is called SPEED, made use of Stateless Geographic Nondeterministic Forwarding (SNGF), which provides a stateless, localized algorithm to reduce overheads. It also combines the MAC and network layer adaptation to minimize the end-to-end delay in a WSN. In cluster-based network, the whole network is broken down into three-tier architecture. The SN will route the packets based on the hierarchical architecture.

2.4. **Energy-efficient topology scheme.** Another important way to control the energy wastage in a network is to have control on the network topology. Several energy efficient topology structures are discussed for WSN in open literature. Moreover, few proposed methods for power consumptions and building network topology control schemes are also available in literature.

Managing the topology change in WSN is an efficient way to reduce energy loss of the SN by selecting the nodes to forward the data and the remaining nodes turn off their radio for energy conservation. The network topologies can be controlled by maintaining low-cost connectivity among nodes. The mechanism is clearly explained in [22]. Based on the discussions in topology scheme papers, two major areas are identified; the power control and node's sleeping schedules.

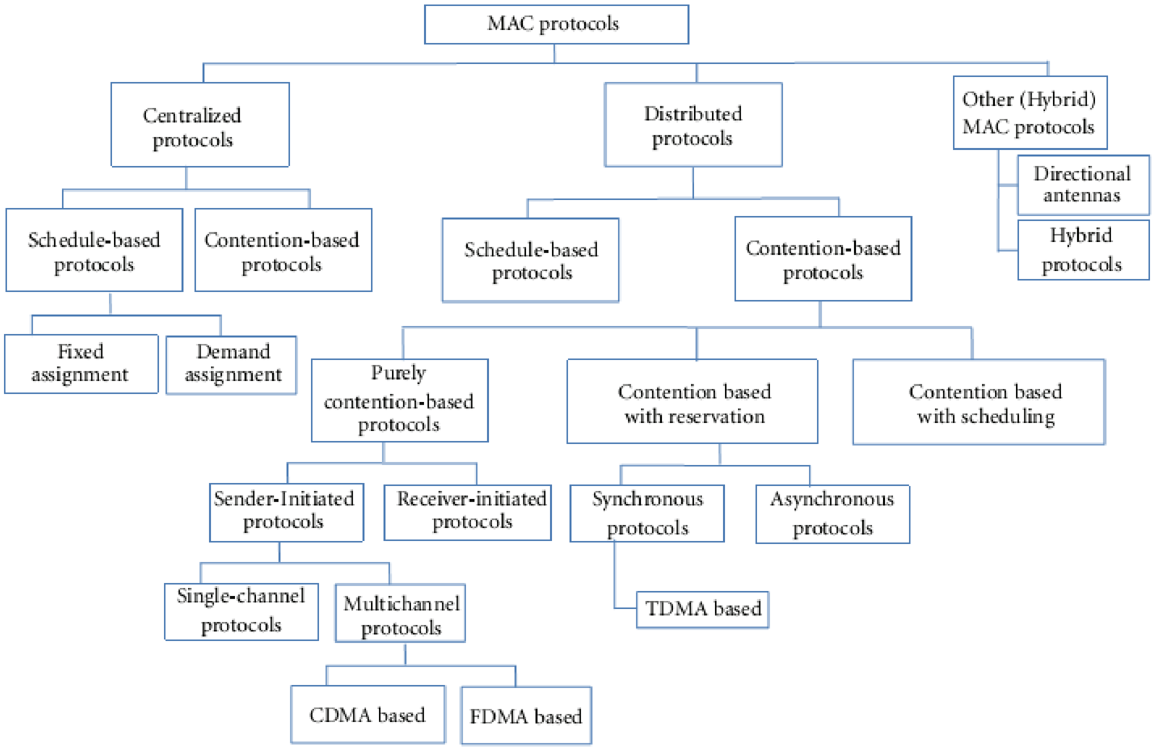


FIGURE 1. The MAC protocols classification tree [22]

2.5. **MAC layer protocols schemes.** In a WSN an efficient MAC protocol is required to support the infrastructure of the network. The MAC protocols that are mostly used in wireless network can be classified into two types: contention-based and contention-free. Moreover, different authors have proposed different classification of these MAC protocols that can be found in [19-21] and that is represented in Figure 1 [22].

Different types of MAC protocols such as T-MAC (Timeout-MAC) [23], S-MAC (Sensor-MAC), DSMAC (Dynamic Sensor-MAC) [24], and Sift [25], that are implemented in WSNs reduce the energy consumptions due to collisions, overhearing and control packets overhead. An overview of the different MAC protocols is given in Table 1.

TABLE 1. Overview of the MAC protocols

MAC Protocol	Mechanism	Adaptability	Energy-Efficient	Synchronization required
B-MAC	CSMA	YES	YES	NO
DSMAC	CSMA/CA	YES	YES	NO
SMAC	CSMA	YES	YES	NO
T-MAC	TDMA/CSMA	YES	YES	NO
WiseMAC	NP-CSMA	YES	YES	NO
X-MAC	CSMA	YES	YES	NO

Although, the MAC protocols show some advantages over the others, the S-MAC (Sensor-MAC) protocol is still widely used in WSNs because it is self-configured and performs periodic sleeping schedules. Since energy efficiency is the primary goal in WSN, we discuss different scheduling mechanisms for energy efficient S-MAC in the following section.

3. **Energy Efficient Mechanisms for S-MAC Protocol.** Several scheduling algorithms were proposed for S-MAC protocol and some of their outcomes are analyzed in this section. Y. Li et al. [26] proposed an algorithm to evaluate the performance of S-MAC protocol by improving the latency and jitter of the network. They achieved the desired results by varying the Duty Cycle of the S-MAC protocol. Although, the protocol showed better performance, it faced some difficulties in initializing the periodic listen and sleep schedules. The problem was overcome by W. Lee et al. [27] using a unified schedule and modified synchronization packet. However, the nodes still incurred delay and went through idle listening time if any collision happened due to the transmission of large packets.

E. M. Shakshaki et al. [28] presented a unified scheduling approach to synchronize network under a single schedule. The scheduling scheme synchronized all the nodes in a network and the lifetime of WSN increased to some extent. However, the Border Nodes situated between the virtual clusters die out quickly as they need to stay in the listening state for longer time period. Thus, the performance of WSN was hugely hampered if the sender and receiver nodes were situated in two different virtual clusters. Then, the data packets were unable to reach the desired destination and efficiency of the network degraded.

T. S. Lee et al. [29] proposed a different approach for unified scheduling in a WSN. Although, all the nodes including the Border Nodes longevity increased to some extent the scheduling scheme was not at all suitable for a larger network size where the nodes engaged in the network at random time. When nodes are included randomly in a large network the collision rate increased to an unacceptable level because the scheduling packets are broadcast to the sink node whenever collisions happened in the network. Y. Yang et al. [30] took account of those problems and performed their scheduling scheme from the sink node. Although, their scheduling approach reduced the collision rate to some extent, the synchronization time of the network increased and more energy was wasted due to idle listening.

In [31] the authors proposed an interesting way for forwarding the data packets. The proposed protocol maintained a color index for the neighboring nodes and based on the color index a node will forward the packets to its neighboring nodes. A major setback with this approach is that a node needed to wake-up more frequent based on the wake-up schedules. Thus, the method is not ideal for an energy-constrained network.

The above limitations are triumphed over by synchronizing the SN under a unified schedule which is explained in the next section. The synchronization schedule will be broadcast periodically from the Border Nodes to the whole sensor network [32]. Thus, all the SN will be synchronized under a single schedule and data communication can take place instantly. In this way, all the nodes in the network can save considerable amount of energy. Our early research work focused on energy-efficiency and not on the latency issue; here we consider both, to have energy-efficient low latency S-MAC protocol for the design of an effective WSN. The following section introduces Uni-Scheduling method for different network topologies.

4. **Uni-Scheduling Method for S-MAC Protocol.** As most WSNs make use of the S-MAC protocol, where the SN periodically switch between the active and sleep state to save energy and this continuous switching of the states will increase the end-to-end delay of the data packets if the sensor node does not have an appropriate scheduling algorithm. In this paper, a scheduling scheme is implemented in S-MAC protocol so that all the SN in a WSN can communicate with each other in a synchronized manner. In order to synchronize the whole network quickly, the algorithm is constructed from the Border

Nodes and the data packets are transferred between different virtual clusters. Before analyzing the algorithm, few assumptions are made: All the nodes are located in their fixed position and without any mobility and have the same Duty Cycle throughout the simulation. The nodes in the WSN are synchronized based on the schedule in the Uni-Scheduling packets. The Uni-Scheduling packets are always broadcast periodically from the Border Nodes. If a node is running under uni-schedule and if it still receives any more Uni-Scheduling packet, it discards all the latter packets.

ALGORITHM-I: UNI-SCHEDULING METHOD

1. **if** (Transition state = = *LISTEN STATE*)
   a. **then**
      i. current state is *LISTEN STATE*
      ii. *Scheduling Timer* activates *D-timer*
   b. **end**
2. **if** (Transition state = = *AWAKE STATE*)
   a. **then**
      i. *Scheduling Timer* activates *B-timer*
      ii. Broadcast *Uni-Scheduling Packets*
      iii. current state is *AWAKE STATE*
3. **else**
   a. *Scheduling Timer* activates *P-timer*
   b. wait to receive *Uni-Scheduling Packets*
   c. no *Uni-Scheduling Packets* received during *P-timer*
   d. back to pervious state *LISTEN STATE*
4. **end**
5. **if** (Transition state = = *RUN STATE* && *rxUniScheduling* = = 1)
   a. **then**
      i. Carrier Sense is performed
      ii. *CheckUniScheduling()*
      iii. Neigbhor node are synchronized & DATA transmission begins
      iv. *rxUniScheduling* = 0
      v. *Scheduling Timer* activates*B-timer*
      vi. Broadcast *Uni-Scheduling Packets*
      vii. current state is *RUN STATE*
6. **else**
7. *Scheduling Timer* activates *P-timer*
8. wait to receive *Uni-Scheduling Packets*
9. no *Uni-Scheduling Packets* received during *P-timer*
10. back to pervious state *AWAKE STATE*
11. **end**

All the SN in the WSN need to synchronize under the schedule included in the Uni-Scheduling packets as mentioned in Algorithm-I and transmission of these packets to all the nodes is done by using three different types of timers. The timers D-timer, B-timer and P-timer are used to change the transition state of the SN. In the actual S-MAC protocol only two modes exist: Listen and Sleep modes. Where else in the proposed algorithm all the nodes have to go through the three different transition states (LISTEN, AWAKE and RUN STATES) before all the nodes are synchronized. The detail explanation of the different transition states and timers are given in the paper [32].

The Scheduling Timer synchronizes the time with the network's virtual clock. The CheckUniScheduling() is a function that is performed by a node to check if the neighboring nodes have received the Uni-scheduling packet. Moreover, the node also monitors if it has received more than one Uni-Scheduling packet. The rxUniScheduling indicates that a node has received the Uni-Scheduling packets.

The Uni-Scheduling packet contains a scheduling time and the packet is broadcast from the constructed Border Nodes to the whole network. According to this signal, the SN reset their timers and set the uni-schedule as their primary schedule in their Schedule Table [32]. After that the data transmission is possible as the network is synchronized under a single schedule.

During the whole synchronization period the nodes will maintain the schedule received from the Uni-Scheduling Packet and data transmission is possible once all the nodes are synchronized.

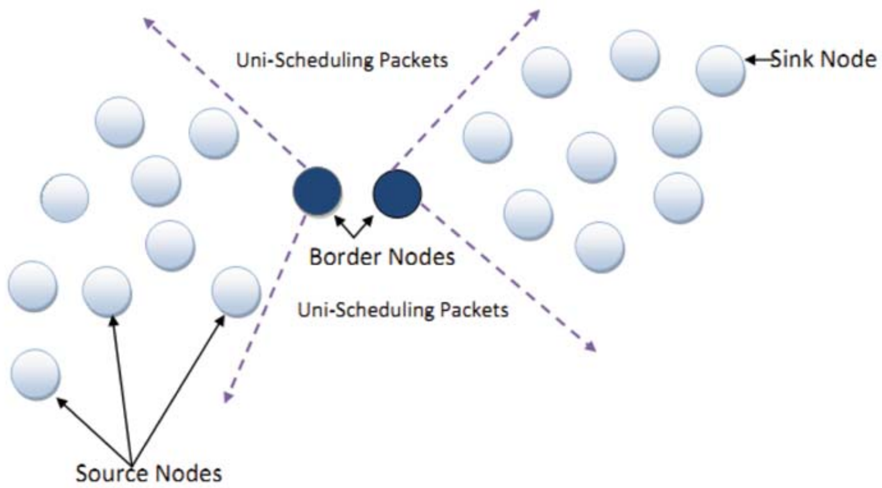
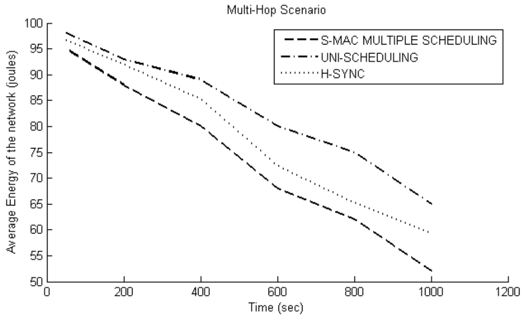


Figure 2. Broadcasting Uni-Scheduling packets to the whole network [32]

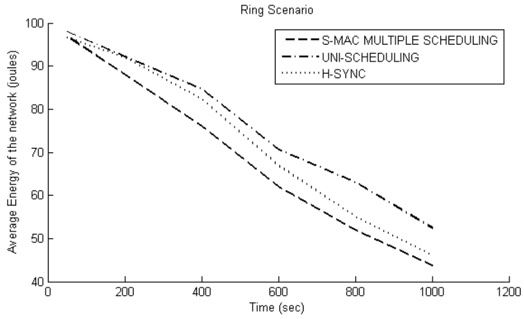
5. **Simulation Results and Analysis.** The proposed scheme is simulated in the Network Simulator-2 (ns-2) platform and this simulator is effective to visualize the SN in a WSN. All the necessary parameters of the wireless network and the energy model are based on the environment in paper [32]. The TCP Sink Agent is attached to the biggest node and TCP Agent is attached to all the remaining nodes in the network. The DSR routing protocol is used because it provides loop-free routing and the updates of the routing table are only sent whenever there are changes in a network topology. The CBR traffic is used for this simulation purpose. The energy model used is already implemented in the ns-2 platform and the energy consumption of the nodes is calculated during the states transition.

The simulation results for four different network topologies such as multi-hop, ring network, grid scenario and random layout are presented. The number of SN used for first two scenarios are 10 nodes and the last two scenarios consist of 50 nodes.

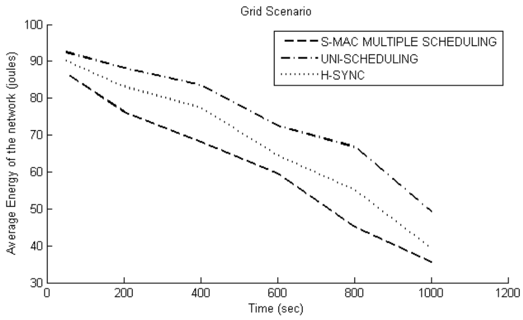
5.1. **Energy consumption.** Figures 3(a), 3(b), 3(c) and 3(d) verified that the presented Uni-Scheduling scheme [32] performed more efficiently when compared with another Unified Scheduling method called H-SYNC [29] and with S-MAC multiple scheduling scheme.



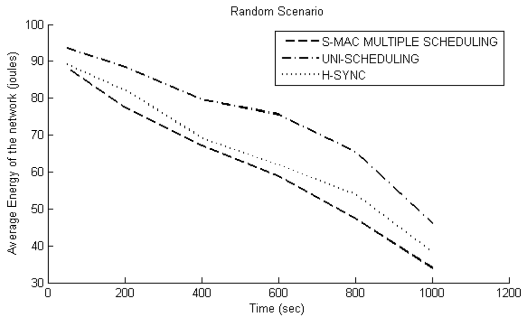
(a) Multi-hop scenario



(b) Ring scenario



(c) Grid scenario



(d) Random scenario

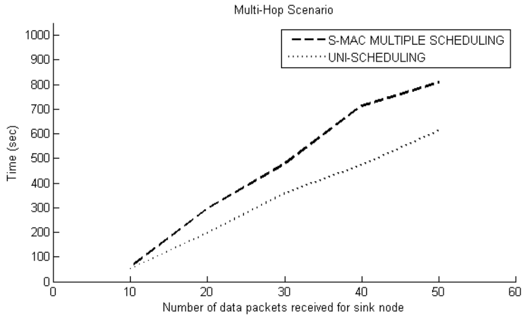
FIGURE 3. Energy consumption of the network

The figures clearly showed that the rate of energy depletion of the network altered at every time interval. This is due to the case that the lost packets are retransmitted and even some of the SN left the network as their energy gradually diminished.

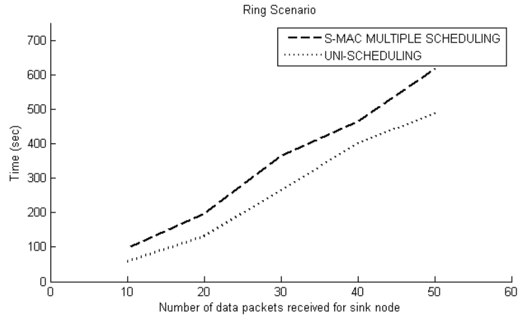
In the cases of Figures 3(c) and 3(d) Uni-Scheduling performed much more efficiently than H-SYNC and S-MAC multiple scheduling scheme, as the rate of energy consumption of the SN is much lower. The outcomes clearly justified that the proposed unified scheduling scheme consumed less energy when compared with the other scheduling methods. In realistic environment like in Figure 3(d) random scenario, the unified scheduling method performed much more effectively than other scheduling methods.

5.2. **Latency.** Another network characteristic that is essential for WSN is end-to-end delay. There are numerous factors that dominate the latency of the network such as transmission delay, propagation delay, and back off. However, we are most concerned about the delay that is brought on by sleep/listen scheduling and from Figure 4, we observed that latency is minimized when the SN adopted Uni-Scheduling scheme. Again, in simple network topologies such as multi-hop and ring the latency is minimal due to minor collisions, overhearing and re-transmission. Thus, Figures 4(a) and 4(b) showed that the latency for Uni-Scheduling and Multi-Scheduling are close to each other. This is because success rate of the data packets of both the scenarios is similar. Where else, in Figures 4(c) and 4(d) the latency is much higher, if the SN is scheduled under Multi-Scheduling when compared to Uni-Scheduling scheme.

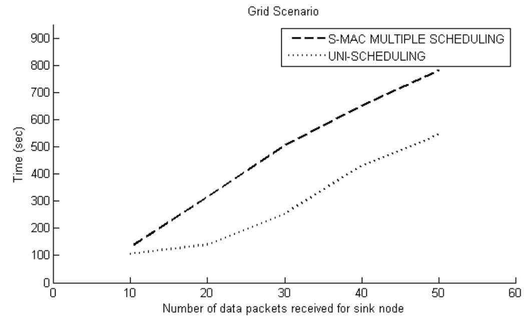
This is because in complex network topologies, traffic congestion increased prior to collisions and re-transmissions of the packets. Although, the network is synchronized under a single schedule, Uni-Scheduling does not completely eliminate the latency, as different listening schedules exist during the construction of the Border Nodes.



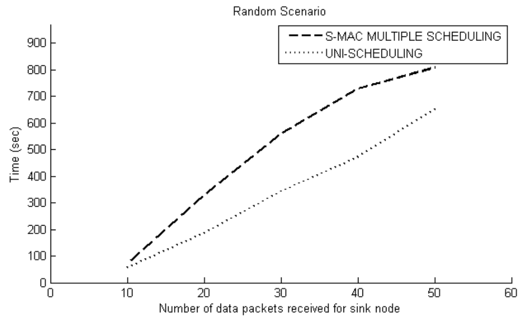
(a) Multi-hop scenario



(b) Ring scenario



(c) Grid scenario



(d) Random scenario

FIGURE 4. Latency of the network

6. **Conclusion.** In this paper, we have presented a scheme which unified the scheduling of the S-MAC protocol to extend energy efficiency of the WSN. It overcomes the handling of the diversified scheduling situation of the Border Nodes by broadcasting Uni-Scheduling packets to all the nodes in the network, which in turn synchronize the whole network under a single schedule. As a result, energy efficiency of the network is maximized in comparison to the existing S-MAC protocol. The paper also discusses S-MAC protocol from the latency point of view and ensures Uni-Scheduling method decreases end-to-end delay.

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