Iraqi Journal for Computer Science and Mathematics

Journal Homepage: http://journal.esj.edu.iq/index.php/IJCM
e-ISSN: 2788-7421 p-ISSN: 2958-0544

SEEK Mobility Adaptive Protocol Destination Seeker Media Access Control Protocol for Mobile WSNs

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DOI: https://doi.org/10.52866/ijcsm.2023.01.01.0011
Received Sebtember 2022; Accepted December 2022; Available January 2023

ABSTRACT: The mobile wireless sensor network (WSN) is an emerging field as it widens the scope of applications where sensor networks can be applied. Generally, mobility in wireless communications degrades how well each pair of nodes communicate with one another. In WSN, the effect is higher because nodes have limited communication and computational capabilities. Those limitations create a challenging environment for the operation of sensor node communications. This paper proposes an energy-efficient media access control (MAC) protocol with mobility adaptive throughput based on a carrier-sense multiple access with collision avoidance MAC mechanism called the SEEK-mobility adaptive protocol (SEEK-MADP). SEEK-MADP uses a unique control packet operation to transfer data packets through as many nodes as possible in one duty cycle. The control packets, SYNC and RTS, are merged into one packet (SEEK). SEEK is then transferred to the downstream nodes to establish a connection between a stream of nodes in a duty cycle. This process minimizes the energy consumed by the handshaking process between the connected nodes. To increase throughput, the data period is adaptive to minimize/maximize the data packets according to the movement speed of the sender/receiver nodes. The proposed algorithm is assessed via extensive simulations in mobile scenarios using Network Simulator version 2. The final results show that the SEEK-MADP outperforms MAC protocols, sensor MAC (S-MAC), and SMAC with adaptive listening, which have shown good performance in mobile scenarios. The performance of the proposed algorithm is better than that of IEEE 802.15.4 standard MAC mechanism at mobile scenarios.

Keywords: Adaptive, Energy, SEEK, MAC, Mobile, Wireless Sensor Network.

1. INTRODUCTION

Wireless sensor networks (WSNs) are resource-constrained devices with computation and communication capabilities [1]. Developing operation frameworks and protocols is a challenge because of their limited capabilities [2, 3]. Mobility in WSNs is an important feature; the application list of sensor networks expands from static environment monitoring/controlling to mobile sensors roaming around the environment to collect relevant data for end users [4]. Applications such as swarm-bots [5, 6] and elder people monitoring systems are only a few examples of applications where mobile WSNs (MWSNs) can be used.

However, mobility has its toll on WSN operation [7]. Controlled and infrequent mobility has less effect on network operation than frequent and strong mobility [8]. Media access control (MAC) protocols proposed for WSNs mainly focus on stationary deployed sensor nodes [8]. For example, sensor MAC (S-MAC) [9], timeout MAC (T-MAC) [1], and Berkeley MAC [10] protocols are aimed for stationary networks with or without weak mobility [8]. In frequent mobility scenarios, the nodes in the network change their locations rapidly. The change in topology leads to disjoining and rejoining processes between the nodes, thereby worsening the network operation. Frequent mobility can be defined as the deliberate movement of an object that the sensor nodes are attached to. Swarm-bot applications are mobile because mobile nodes seek for objects that need to be addressed throughout the deployment area [11]. Biomedical applications

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have frequent mobility because their nodes are attached to nurses and patients to locate and monitor their activities [8]. Frequent mobility can introduce the following issues in a network:

- Mobility affects the connections between the nodes in the networks, which deteriorates the net links affecting the overall execution of a network.
- Mobility changes a net route, which results in higher delays in packet deliveries.
- Mobile nodes cannot start transmission unless they discover one another. This operation consumes time.
- Contention-based MAC protocols can suffer from high collisions in mobile scenarios. Contention-free MAC protocols can suffer from assigning/reassigning connection slots between the nodes because of the join/disjoin effects that occur in the network.

This paper proposes a MAC protocol called SEEK-mobility adaptive protocol (SEEK-MADP) for MWSNs. SEEK-MADP is energy-efficient and mobility-aware, and has adaptive packet throughput and end-to-end (E2E) delays lower than conventional WSN/MAC protocols. SEEK-MADP has been evaluated using extensive simulations implemented in the Network Simulator version 2 (NS2). SEEK-MADP has been compared with S-MAC [9], S-MAC with adaptive listening (S-MAC-ADP) [1], and IEEE 802.15.4 [12] protocols. Results indicated that SEEK-MADP consumes less energy for each packet transmission, increases the system throughput significantly, and achieves E2E delays lower than S-MAC and S-MAC-ADP.

2. RELATED WORKS

When considering the OSI model, the MAC layer follows the physical layer. The fundamental objective of the MAC protocol is to coordinate the transmissions and receptions of the nodes' network interface. Efficiency in terms of power consumption and latency in packet delivery can be increased by controlling and improving the functions of a MAC protocol [13].

Multiple concepts for MAC protocols in WSNs have been created in response to the issue of application dependency. Recommended protocols must strike a compromise between low-power consumption and high throughput to promote system reliability [13, 14].

A key characteristic of wireless media is that it is a public medium. Therefore, MAC protocols must utilize the medium effectively for stable connections between nodes. When building MAC protocols for WSNs, power consumption must be considered. Classical MAC protocols are established to minimize lag and maximize data flow. The issue of power conservation is critical for WSNs [15]. By improving the scheduling of channel access, MAC protocols can improve the energy efficiency of the system. Utilizing sleep scheduling can frequently increase long-term channel access. Comparable to the strategies used to shut down a central processing unit is sleep scheduling. In wireless communications, sleep scheduling is studied in an effort to balance energy usage and reaction time. Transmission latency and system throughput are metrics of reaction time.

The effect of mobility on the functions of a MAC protocol has a direct bearing on transmission range. Reestablishing a link once a mobile node has gone out of range is cumbersome for the rest of the network's nodes.

The study of MAC protocols for WSNs is an active and expansive subject of study. MAC protocols proposed for WSNs fall into two broad classes [16]:

1. Priority-based MAC protocols (carrier sense multiple access (CSMA)). In this scenario, wireless nodes fight for access to the connection medium (the wireless medium in WSNs), with the winner reserving the medium until the end of its operation. IEEE 802.11 and its derivatives, such as S-MAC [9], T-MAC [17], and routing-enhanced MAC (R-MAC) [18], are examples of such protocols.
2. Time-division multiple access (TDMA) is the basis for the second class of MAC protocols. Here, the medium is divided into several temporal intervals. Each node has a predetermined window of opportunity to access the medium and perform its job. The ALOHA [19] MAC protocol is frequently utilized in WSNs due to its TDMA foundation.

With contention-based MAC protocols, a network can oversee more users than with TDMA-based protocols. TDMA-based protocols must arrange connections at times when adjacent nodes are available. The slotting technique may reduce the scalability efficiency when installing multiple nodes simultaneously. The following are examples of works in the field of contention-based MAC protocols for WSNs:

IEEE 802.11 is widely utilized as a contention-based MAC protocol for WSNs. Current Wi-Fi network interfaces and WLAN applications are required to comply with this standard. IEEE 802.11 is a tried-and-tested MAC protocol for WSNs. However, given its idle/listening operation modes, MAC protocols are deemed unsuitable for such applications. Studies have demonstrated that WSNs spend the same amount of energy in their idle state as they do when actively receiving data, making them a poor choice for these networks [9].

Ye et al. [9] proposed S-MAC as a MAC technique for WSNs. The major objective of S-MAC is to reduce the demand on the power supply of each sensor node. As a result of its CSMA with collision avoidance (CSMA/CA) base, the protocol is easily scalable to meet expanding networks. In addition, the technique may aid in avoiding collisions. Timing the listening and sleeping stages reduces energy use. By synchronizing the sleep cycles of numerous nodes, the protocol facilitates the development of virtual clusters. The protocol employs the same technique as IEEE 802.11 to address the difficulties of overhearing and disguised channel. However, the issues with S-latency MAC arise from the protocol's periodic sleeping and listening mechanism. The periodic pattern of the machine is determined by its duty cycle. The adaptability to the mobility of the S-MAC protocol has been proven by testing in a mobile sensor node environment [8].

The operation of WSN applications is distinguished by a few unique properties, including low message rate and insensitivity to delay [1]. These properties have the potential to be utilized in energy-saving techniques, such as active/sleep modes. The T-MAC proposed in [17] can accommodate an adjustable duty cycle by gracefully shutting down during the inactive section of the cycle. This approach increases efficiency by minimizing the amount of time nodes spend "simply listening" or waiting for a message that may or may not arrive while maintaining a constant throughput. T-MAC transmits a task-aware (TA) packet to halt the active phase if no data can send or receive on the node. In view of the concept of burst data transmission being more energy-efficient, the protocol finds a compromise between latency-efficient throughput and energy-efficient usage.

The system of periodic listen and sleep has been examined [20]. Therefore, traffic-aware, energy-efficient MAC (TEEM), a new MAC protocol that builds on the S-MAC standard, has been suggested. It utilizes each sensor node's traffic information, thereby enabling efficient operation while minimizing energy consumption.

The medium can be prepared for potential data traffic events, allowing nodes to go to sleep earlier. To achieve these objectives, two significant modifications have been made to S-MAC. First, the node is now disabled when no data or traffic is expected. Second, the request to send (RTS) control packet is no longer transmitted separately whenever data transmission is anticipated. TEEM is ineffective at reducing energy use due to packet latency.

In [21], the potential for a cross-layer repair was investigated. As a solution, TA-MAC protocol was proposed. The protocol determines the channel access based on the relative loads of the two endpoints. By minimizing collisions that are not strictly necessary, the TA-MAC protocol conserves energy while enhancing the throughput. The TA-MAC architecture can be used or implemented with several MAC protocols (e.g., S-MAC). The TA-MAC protocol, which differs from earlier MAC protocols for WSNs, focuses primarily on estimating the channel access probability.

An example of a cross-layer approach examined in [18] is the RMAC, which uses routing data to provide minimal power usage and predictable latency. The R-MAC can transport a packet over many hops in a single duty cycle. If the upstream node is ready to transfer the data packet, then the relay node will be awoken during the R-MAC sleep time. The relay node can replicate the packet and forward it to the subsequent node in the chain. Pioneer is the name of the control packet that communicates the current transmission status to all nodes. The downstream nodes get the Pioneer packet and utilize it to synchronize their rest and work cycles to successfully receive the data packet.

In [22], on the basis of the current S-MAC protocol, simple energy-aware MAC (SEA-MAC) was proposed to reduce power consumption during habitat monitoring. Given the nature of the protocol, the only network node responsible for setting the synchronization schedule is the base station. The system conserves energy because sensor nodes are only active when they detect anything of interest (an event sensed). The duty cycles to meet the needs of the detected event period. The TONE packet, which has a shorter duration than the Synchronization packet used by S-MAC, is used to initiate the flow of important data when SEA-MAC is in operation.

Despite the advantages of TDMA scheduling in terms of connection assurance, research has demonstrated that WSN applications cannot adopt this strategy due to the time slotting overhead. As the number of sensor nodes increases, the time slotting technique is more likely to generate erroneous results. The energy and rate (ER)-MAC was proposed in [23]. ER-MAC has the following benefits. Given that each participant in a two-way connection runs on its own timetable, collision-related packet loss is decreased (or eliminated) in this case. Additional causes of packet loss include poor network quality, interference, and signal loss. A wireless medium contention mechanism is no longer required when time slots are removed. Consequently, contention control can be managed without control packets.

ER-MAC is similar to S-MAC in that it employs the periodic listen-and-sleep principle, but it operates differently. The sensor node enters the sleep mode only when it is in control of its own time slot and has nothing to communicate. To receive packets, the radio interface must be active for its whole time slot, even if the surrounding node(s) have nothing to send.

Real-time MAC (RT-MAC) [] is an additional instance of a MAC protocol based on TDMA. The allocation of time slots in TDMA-based MAC protocols causes considerable delays due to the large number of sensor nodes. The RT-MAC protocol resolves this issue by reusing the link channel between two consecutive channel requests from a sensor node. With RT-MAC, sensors can save energy by hibernating. Even though it resolves the delay guarantee issue, the RT-MAC protocol exerts a large computing burden on the sensor node, rendering it inapplicable in cases such as the clock drift problem.

Other studies on the design of MAC protocols based on the TDMA scheme [25, 26] share the difficulties in time slot assignment, which is not the case for all of them.

In the literature, MAC protocols with emphasis on mobility scenarios have been introduced [8]. Mobility-aware MAC (MS-MAC) protocol [27] is an extension method for the S-MAC protocol that accounts for mobility. The MAC protocol uses the duty cycle action to schedule neighboring nodes. By using the fluctuations in RSSI values, the sending node can make an educated prediction regarding the mobility of the neighboring node. Synchronization packets are utilized to record values as they are transferred. The nodes alter their duty cycle to seem to operate properly alongside surrounding nodes whose mobility have also changed. Given how frequently the synchronization mechanism must occur, MS-MAC consumes a great deal of energy whenever there exist numerous network activities.

A mobility-adaptive, collision-free MAC protocol was implemented in [102] to increase the mobility of the TRAMA MAC layer [11]. The MAC employs the same method as the TRAMA MAC layer, but its frame time can be dynamically adjusted to accommodate mobile nodes. The AR-1 model is used to estimate the mobility of the nodes. The primary disadvantage of takes is that it is based on the computationally intensive TRAMA process.

M-TDMA, another TDMA-based mobility extension strategy, was presented in [7]. FLOC is a technique utilized by M-TDMA to build clusters that do not overlap [104]. Each cluster is assigned a “head,” and all nodes linked to that head are assigned unique identities. The protocol splits round operations into a control segment responsible for mobility adaptability and a data component responsible for the transmission of actual data. M-TDMA operates based on a series of rigorous assumptions. A circumstance in which the heads of the cluster do not communicate with the nodes for more than one cycle of activities should not occur. The nodes are expected to be absent from the network for two consecutive phases.

MobiSense [28] is a mobile-efficient cross-layer MAC technique that uses routing layer data. The system is divided by MobiSense. Cluster leaders stay in crucial places, while mobility nodes move between them. The goal is to simplify network administration for administrators. MobiSense involves expensive channel resource management and a multichannel compliant receiver architecture, both of which depend on previously planned static nodes having multichannel operating clusters nearby.

Recently, MAC protocols for WSNs were reviewed in [10]. The survey delved deeper into the concerns with each type of MAC protocols, highlighting the practical difficulties that arise. In [1], an exhaustive review of routing protocol in general was conducted. The study examined the practical application of CSMA, TDMA, and their offshoots, as well as other generic approaches applied to MAC protocols.

IEEE 802.15.4 is the de facto MAC standard for ZigBee networks [2, 29]. In IEEE 802.15.4, the time and connections between nodes are regulated by a coordinator node. The protocol functions halfway between TDMA and CSMA/CA. The coordinator allots time intervals for connecting to the coordinator. Once a node arrives at its designated time, it competes for the connection, such as the coordinating node will not be disrupted if data packets are still being received. The protocol proposed for use in WSNs may be implemented anywhere.

3. SEEK-MADP OPERATION AND MODEL

The MAC protocols proposed ARE based on the operation of the S-MAC protocol. The S-MAC protocol works on the bases of a periodic listen (active) and sleep operation, thereby optimizing and increasing the resources in the system (Figure 1).

FIGURE 1. Listen/sleep cycle of the S-MAC occurring at regular intervals.

S-MAC works prevent data packets from having to be resend due to lack of connectivity, as discussed as follows. The transmitting node coordinates its sleep cycles with the receiving node. The source node sends an RTS packet to a receiver node when it is ready to deliver data and wants to ensure that the receiver is not connected to another source. The receiving node will respond with a clear to Send (CTS) packet to inform the available sending node. Then, Node A begins sending data packets to Node B. When the transmission of a data packet is complete, the receiving node sends an acknowledgment packet (ACK) to the transmitting node(s). Figure 2 demonstrates this relationship.

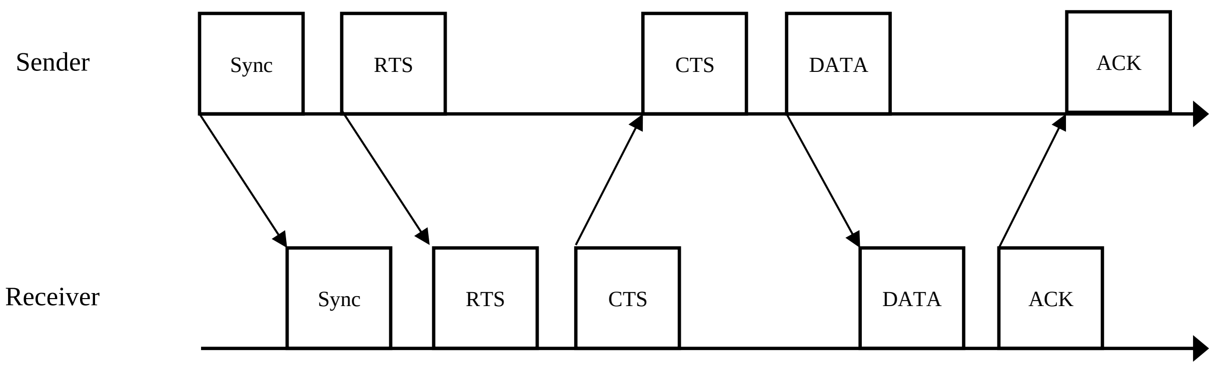

FIGURE 2. Sending and receiving nodes in S-MAC.

However, the proposed MAC employs an innovative technique to perform the control packet function, resulting in decreased power consumption and accelerated packet delivery. The proposed protocol operates as follows.

During network activation, a brief neighbor discovery (ND) broadcast packet is transmitted between nodes to promote ND. ND packets simply contain the address of the node from which they originated. After the neighbor's table(s) has been established, a particular control packet that combines a function of the SYNC packet, as well as an RTS packet, is broadcasted to the next position. An incorporation of these features into a single packet minimizes the control packet overhead and eliminates the need to send a second packet. This packet is called SEEK.

Given the dynamic nature of a network's nodes, an adaptive data transmission strategy is used to divide the sending window into three independent time periods. The adaptive operation benefits nodes that are regularly out of range of the network's connections because it minimizes the likelihood of data loss at such nodes. When nodes send and receive SEEK and CTS packets, they select the appropriate time period. In packets, the mobility speed indicator field consists of two bits (Table 1).

Table 1. Transforming mobility types into time series.

Bit config	Transforming mobility	Time series
(0, 0)	Fixed	Full time series
(0, 1)	Making an intrusion	3/4 time series
(1, 0)	1 > Speed < Maximum transforming speed	1/2 time series
(1, 1)	Speed = Maximum transforming speed	1/4 time series

To determine whether SEEK and CTS packets should be handled, the receiving node looks at the mobility indication field, as shown in Table 1. Subsequently, the node decides which time period to use for the data depending on the category that has the best performance. It ensures that all nodes in the network will transmit data at the same rate. This tactic reduces the amount of time needed to process the data if the nodes are moving at a high pace, which improves the transmission process.

The system's throughput is increased by sending a SEEK packet to higher-level nodes before sending a CTS signal to those nodes (Figure 3). As a result, the data packet can travel through the network and arrive at the BS (or the required destination node). In view of this process, the upstream node will be idle for a considerable period of time as it waits for the data packet(s) to be sent. This period of inactivity can be expressed as follows:

$$\rho = \frac{\vec{E}}{J_C(T=\text{const.})\cdot\left(P\cdot\left(\frac{\vec{E}}{E_C}\right)^m+(1-P)\right)}, \tag{1}$$

Where m is the number of relay nodes in the data stream. Given that the data were obtained from the primary node, the SEEK receiver node i, i will check the amount of time to avoid the increase of *t_idle(i)* time. The nodes will enter the sleep mode for a duration equal to the time stamp of receiving the SEEK packet, plus the difference between the expected reception time of data and the time stamp of receiving the SEEK packet if the data clock time exceeds twice the time required to generate a SEEK and CTS packet in succession (Figure 4).

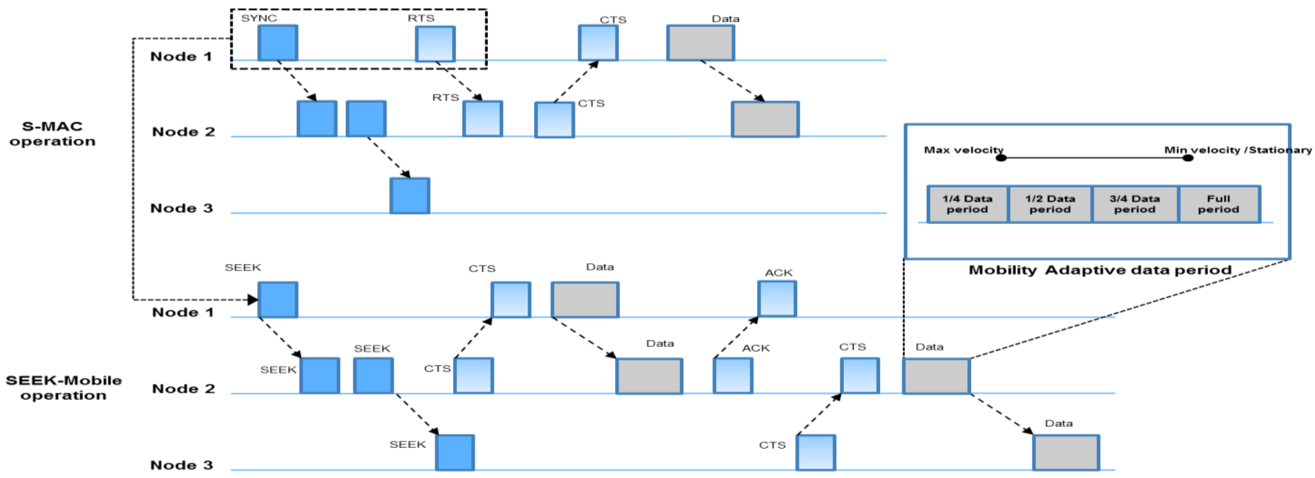

FIGURE 3. Node 1 (sender) and Node 2 (receiver) exchange using SEEK-MADP control packets (Node 3).

Algorithm

$t_{idle(i)}$ Period time check algorithm
Node rotation receives SEEK Duration stamp = SEEK packet timestamp Duration data = Potential time for sending data packet Duration seek = Time asked to create SEEK packet Duration CTS = Time asked to create CTS packet Duration sleep = Sleep period Condition = If (Time data more than (2 * Time seek + Time CTS)) And duration sleep = (Time data − (Time stamp + Time CTS)) Back to Sleep

3.1 Forecasting Energy Use

To assess how much energy the SEEK MAC protocol consumes, a simplified three-node scenario (Figure 4) is provided to investigate the connection among the nodes when the MAC protocol is active. This analysis is based on the following hypotheses:

1. Any of the intermediary nodes can be used to send a packet.
2. Nodes 1 and 3 are the source and destination for the packets, respectively.
3. Neither Node 2 nor 3 can eavesdrop on Node 1.
4. A collision between nodes is impossible (assuming that carrier sense is successful in each start of transmission).
5. Data packet can travel from one node to the next without stopping.
6. Sizes of control packets are always predetermined.
7. The time it takes to collect data depends on how fast the nodes in question are moving. Generally, the shorter the data period is, the higher the mobility speed will be. The longer the allotted data time is, the slower the connection speed will be.
8. During a data period, one data packet is the smallest possible unit of measurement.

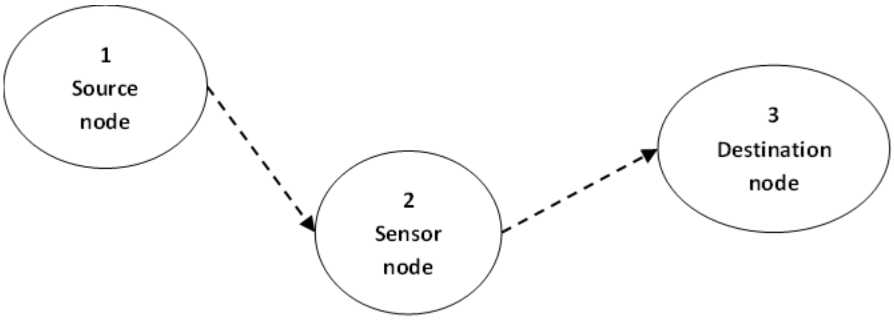

FIGURE 4. Analysis of potential future events. Node 1 is the origin; it holds the pertinent data and intends to convey it to Nodes 2 and 3.

The study starts by separating every node's energy consumption evaluation during the activity for the specified scenario. Beginning with Node 1 (sender node),

$$\mathrm{E_{Node2}} = \mathrm{E_{rcvSEEK}(t_{SEEK})} + \mathrm{E_{SEEK}(t_{SEEK})} + \mathrm{E_{CTS}(t_{CTS})} + \mathrm{E_{rcvDATA}\big(t_{DATA}(MobCat)\big)} + \mathrm{E_{ACK}(t_{ACK})} E_{Node1} = E_{SEEK}(t_S) + E_{CTS}(t_{CTS}) + E_{DATA}(t_{DATA}(MobCat)) + E_{rcvACK}(t_{ACK}). \quad (2)$$

where t_{SEEK} represents the time required to transmit a SEEK packet; t_{CTS} is the CTS packet time duration; $t_{DATA}(MobCat)$ is the data bundle time length function, which is a feature of node(s) movement speed; and $MobCat$ denotes the mobility speed in the categories of the node(s). Following the same trend in Node 1, the energy consumption trend in Node 2 can be expressed as follows. The preceding equation makes use of the following variables: t_{SEEK}, which is the time needed to communicate a SEEK packet; t_{CTS}, which is the time length of a CTS packet; and $t_{DATA}(MobCat)$, which is the time length of a data packet as a function of the speed at which the nodes are moving. $MobCat$ is short for "node mobility category," which describes how fast nodes can move. Similar to the trend shown in Node 1, the energy consumption trend of Node 2 can be represented as

$$E_{Node2} = E_{rcvSEEK}(t_{SEEK}) + E_{SEEK}(t_{SEEK}) + E_{CTS}(t_{CTS}) + E_{rcvDATA}\big(t_{DATA}(MobCat)\big) + E_{ACK}(t_{ACK}). \quad (3)$$

The energy use trend of Node 3 can be expressed as follows:

$$E_{Node3} = E_{rcvSEEK}(t_{SEEK}) + E_{CTS}(t_{CTS}) + E_{rcvDATA}\big(t_{DATA}(MobCat)\big) + E_{ACK}(t_{ACK}). \quad (4)$$

When all the nodes' energy consumption are considered, the following resulting equation can be utilized to characterize the overall energy usage trend of the system:

$$E_s = E_{Node1} + E_{Node2} + E_{Node3}, \quad (5)$$

where E_s is the power used via analysis system when a SEEK MAC protocol is active. The energy consumed via every node in an S-MAC network can be expressed as follows:

$$E_{SMAC} = E_{SYNC}(t_{SYNC}) + E_{RTS}(t_{RTS}) + E_{CTS}(t_{CTS}) + E_{DATA}(t_{DATA}) + E_{ACK}(t_{ACK}). \quad (6)$$

Using Equation (7) and the configuration depicted in Figure 4, the system energy utilization can be described as follows:

$$E_s = \sum_{i=0}^{N} E_{SMAC}(i), \quad (7)$$

where N represents the number of nodes in the data stream, and i represents the node identifier.

4. SEEK-MADP ESTIMATION

The SEEK-MADP has been evaluated against S-MAC, S-MAC-ADP, and IEEE 802.15.4 protocols. The simulation setups are presented below followed by the implementation results. The results are initially illustrated with the reporting of the behavior of each mechanism evaluated. The concluding section provides the analysis of the recorded results.

4.1 Simulation Setup

The suggested MAC protocol technique relies on MAC and CSMA (also known as CSMA/CA) as its primary building blocks. The MAC layer is an essential component of every communication network. The fundamental responsibility of a MAC protocol is to exercise authority over the medium of transmission and reception used by a network interface card. The SEEK-MADP, which is a proposed architecture for a MAC protocol, is evaluated using five NS2 simulation situations [30]. The S-MAC protocol, S-MAC-ADP, and IEEE 802.15.4 standard are compared using the SEEK-MADP. In addition to the findings, a confidence interval with a value of 95% is provided. The nodes are dispersed in a manner that is completely arbitrary in an area measuring 100 m × 100 m. The sink node, which is always present, is located in the deployment zone. Every node can travel at a random speed ranging from 1 m/s to 3 m/s. The parameters of the simulated scenario are listed in Table 2, which include the beginning node energy, the propagation model, and the simulation length. The Dumba Gent protocol is used as the routing technique to investigate how well different protocols serve mobile devices.

Table 2. Parameters and values for simulation.

Simulation parameters	Parameter values
No. of nodes	2, 5, 10, 15, 20
Initial energy (Joules)	1000
Mobility	1–3 m/s
Model of propagation	2 ray ground
Power of N transmission	35 mW
Power of node reception	31 mW
Range of transmission	40 m
Power of N idle	712 µW
Power of N sleep	144 nW

Time of simulation	500 s
Pauses of mobility	0 s, 50 s

The following factors are used to assess the effectiveness of the proposed MAC protocol.

Energy per packet: The energy efficiency of the operating model in the network can be represented by the measure of energy usage per packet. Calculating the energy consumption of a single packet involves dividing the total energy consumption of the network by the total number of successfully transmitted packets. Each operational model and equivalent technique can be calculated, as well as the amount of energy that is consumed per packet when operating under the identical hardware/physical layer specification.

$$E_{Packet} = \frac{E_{Network}}{Number\ of\ packets\ transmitted} \quad (8)$$

System throughput: During network functioning, throughput indicates how efficiently the system transfers data. System throughput is measured by the amount of data sent from a sender to a destination throughout a specific time interval.

$$Throughput = \frac{Number\ of\ packets\ received}{Network\ operation\ time} \quad (9)$$

Packet delivery ratio (PDR): It is the proportion of successfully delivered packets to the total packets produced.

$$PDR(\%) = \frac{Number\ of\ received\ packets}{Numberof\ generated\ packets} \quad (10)$$

E2E delay: The E2E latency metric counts the amount of time it takes for a packet to travel from its source node to its destination node. To calculate E2E latency, the delays of each successfully sent packet are added, and the sum is divided via the total number of packets.

$$E - E_{Delay} = \frac{\sum_{i=0}^{n} E - E_{delay_i}}{n}, \quad (11)$$

where n is the total number of received packets, and i is the ID of a received packet.

4.2 Results of Energy

The proposed MAC protocol strategy intends to enable energy-efficient network operation in various scenarios, including those involving mobile or stationary nodes. When selecting simulation scenarios, the scalability of the network and the influence of mobility on its performance are considered. Figures 5 and 6 depict the average amount of residual energy remaining after the deployment of a network in each simulated scenario. In comparison with other protocols, SEEK-MADP consumes the least amount of energy per packet, as indicated by the data.

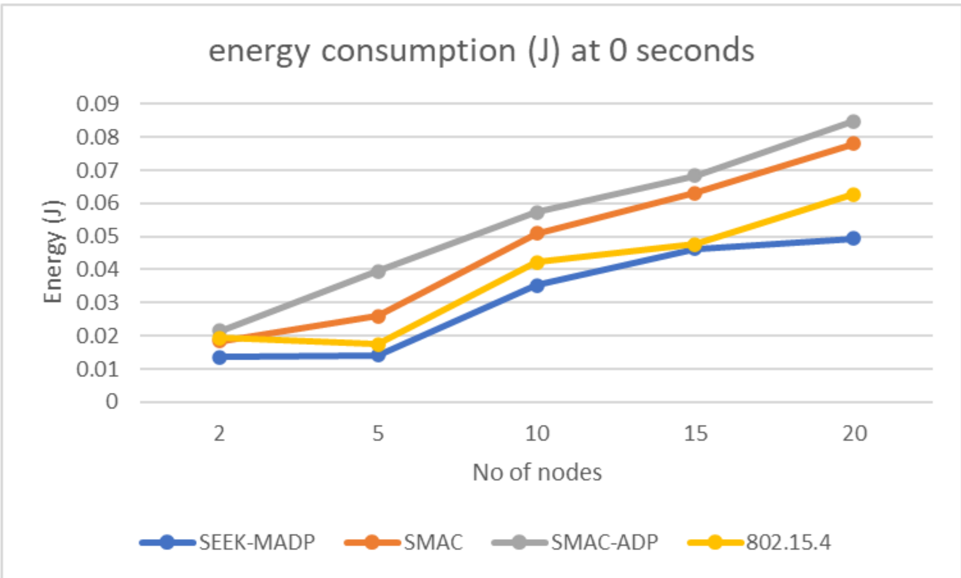

FIGURE 5. Energy utilization (J) at 0 s.

The mobility halt of 0 s results in the maximum packet energy usage. When no pause time exists, the nodes are in constant motion. This is performed to replicate a scenario in which the nodes are extremely mobile.

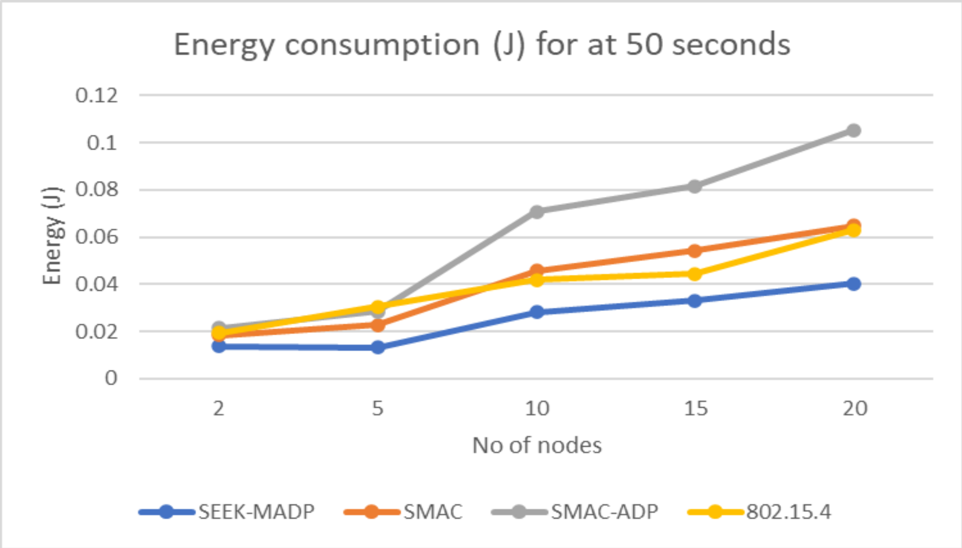

FIGURE 6. Energy utilization (J) at 50 s.

4.3 Throughput Results

The tests on throughput are evaluated and compared depending on the total number of packets sent and received during the designated operating (simulation) time period. Figures 7 and 8 show the results. Every graph presents the outcomes of the several simulations that were run. Figures 9 and 10 illustrate the typical size of a received packet for each MAC protocol.

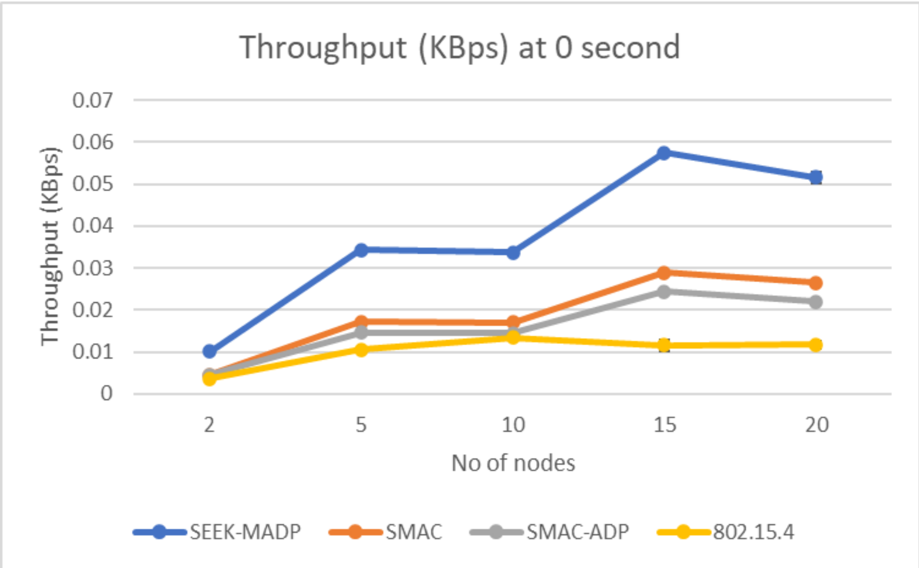

FIGURE 7. Energy utilization (J) at 50 s.

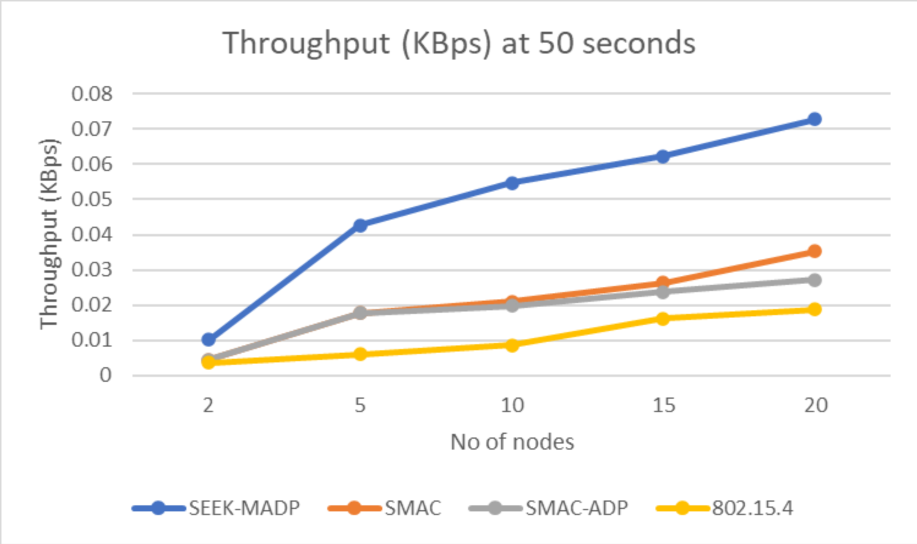

FIGURE 8. **Fluency of the system at 50 s.**

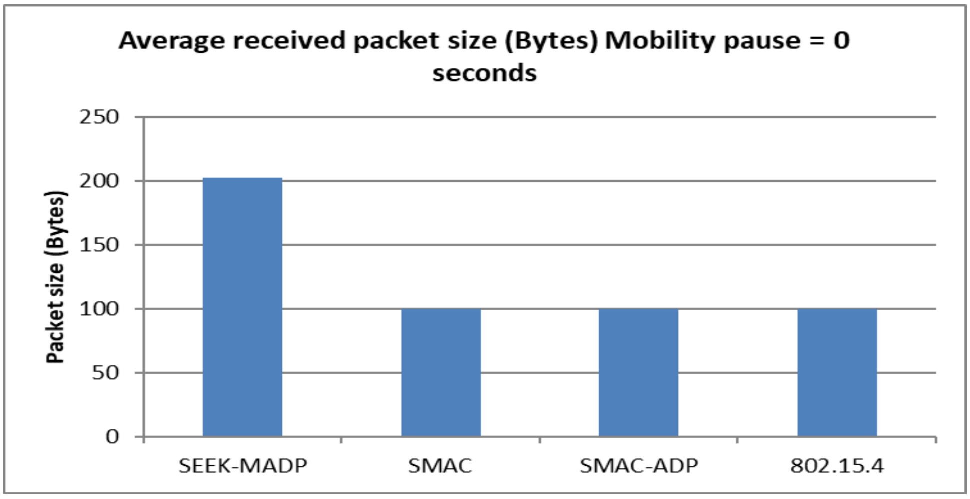

FIGURE 9. **Average packet size transferred or received throughout a 0-s mobility pause.**

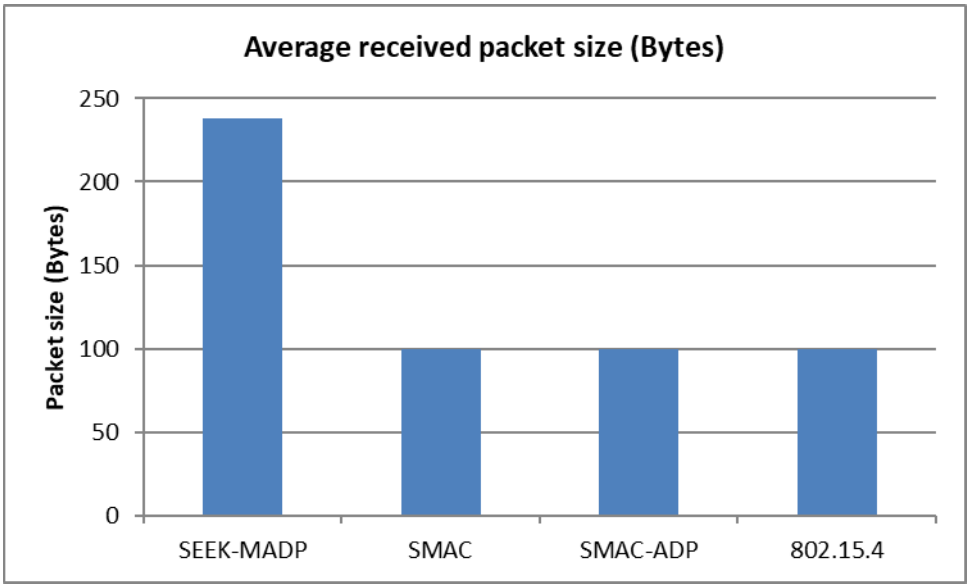

FIGURE 10. **PDR for mobility delay of 0 s.**

4.4 PDR Results

Figures 11 and 12 illustrate the PDR results. The SEEK-MADP has the same behavior as the S-MAC algorithm when evaluating PDR data. Different from IEEE 802.15.4, S-MAC-PDR ADP drops steadily as the number of deployed nodes increases.

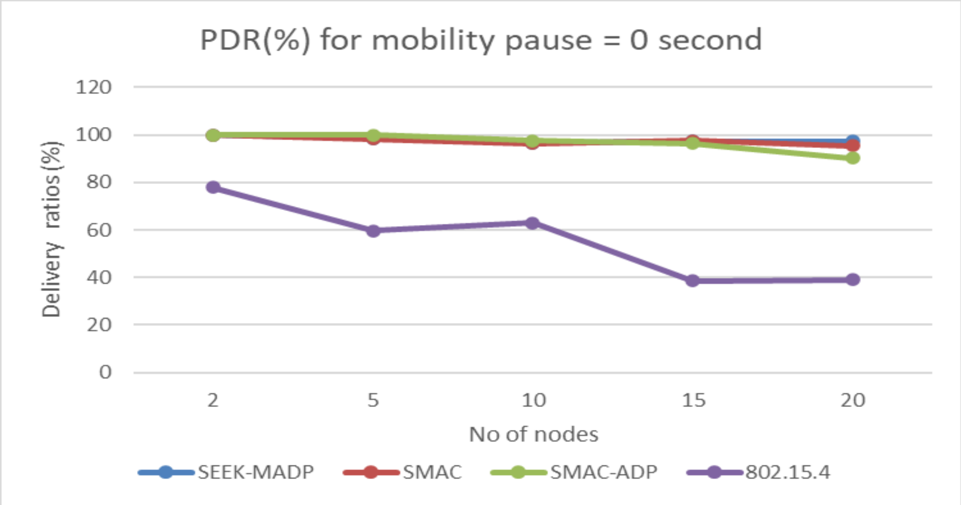

FIGURE 11. PDR for mobility delay of 0 s.

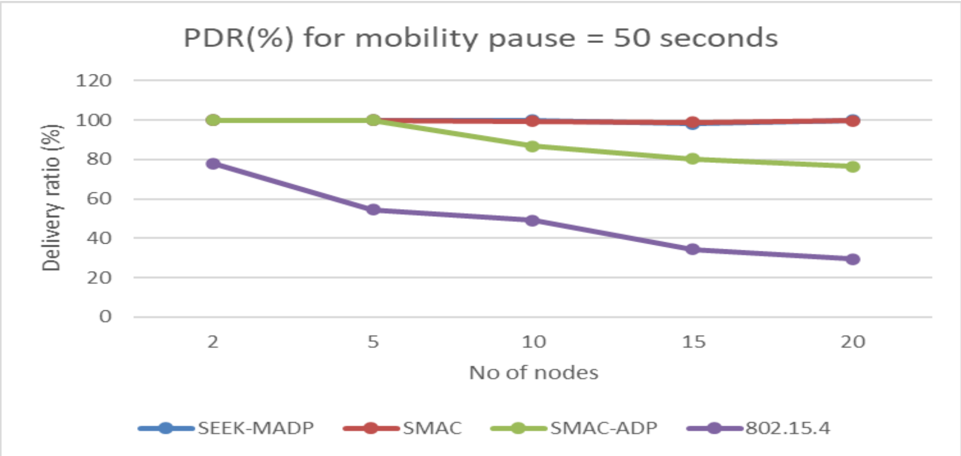

FIGURE 12. PDR for mobility delay of 50 s.

4.5 E2E Delay Results

The E2E delay results allows to understand the message transmission delay in the context of the total network operation. Figures 13 and 14 present the findings. From the figures, the SEEK-MADP has shorter E2E latency than S-MAC and S-MAC-ADP. The IEEE 802.15.4 has the lowest latency from start to finish. The SEEK-MADP modifies the time of data transmission based on the pace of node mobility (Figures 15 and 16).

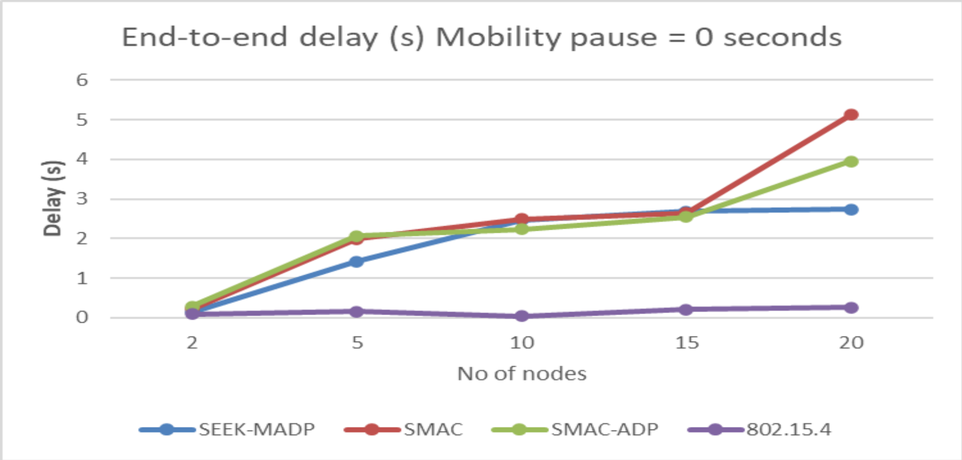

FIGURE 13. **Mobility delay of 0 s; E2E delay per byte.**

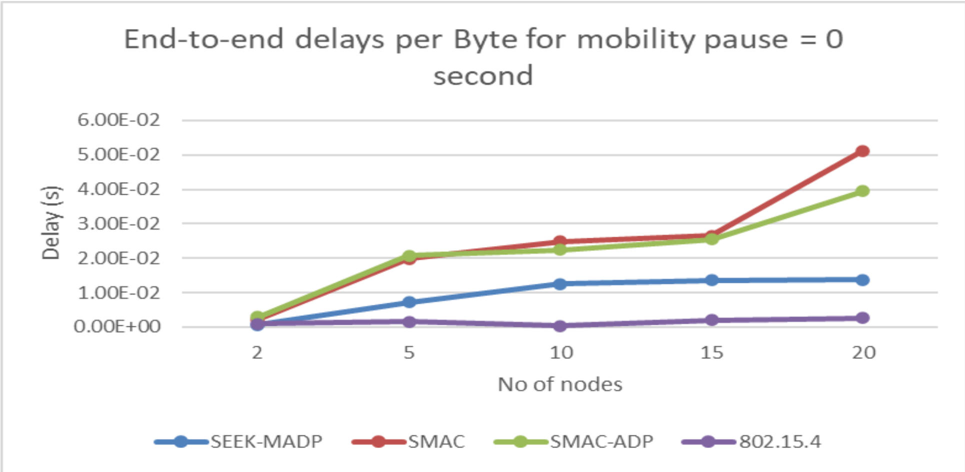

FIGURE 14. **Mobility delay of 0 s; E2E delay per byte.**

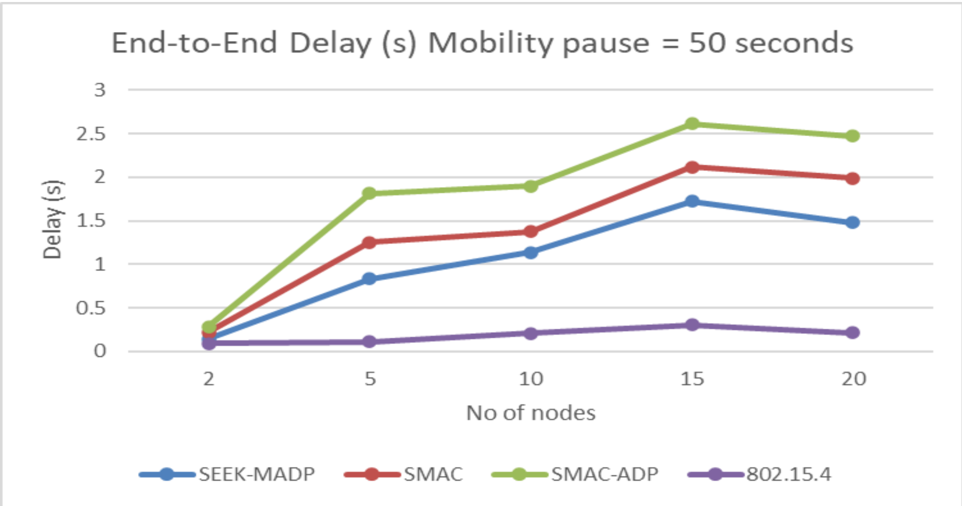

FIGURE 15. **Mobility delay of 50 s; E2E delay per byte.**

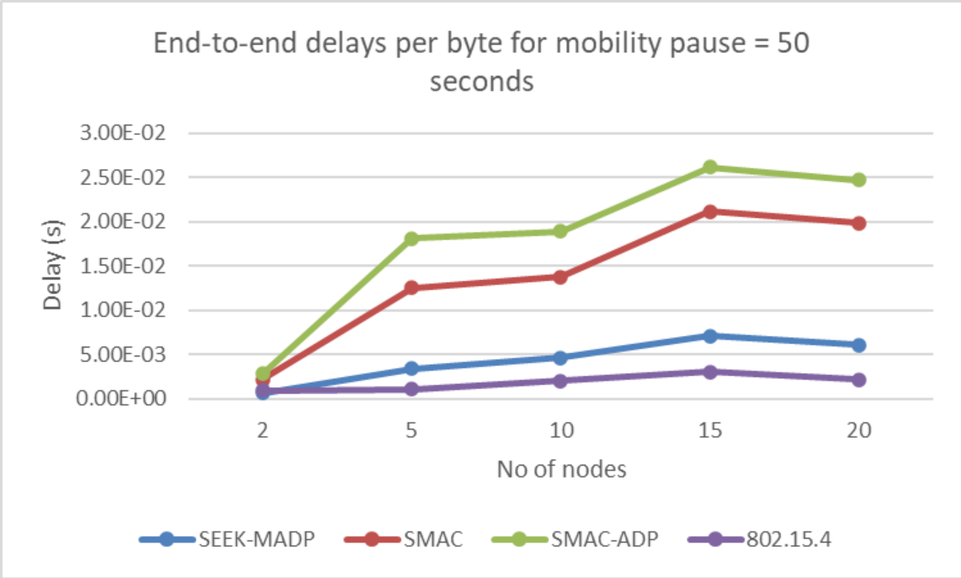

FIGURE 16. Mobility delay of 50 s; E2E delay per byte.

4.6 Analyses and Discussions of Results

From the perspective of packet energy consumption, throughput, PDR, and E2E delay, the SEEK-MADP MAC protocol surpasses S-MAC and S-MAC-ADP. SEEK-MAC has longer E2E latency than IEEE 802.15.4.

Different from S-MAC, S-MAC-ADP, and SEEK-MADP, the IEEE 802.15.4 MAC address protocol does not include the RTS/CTS method [31], which causes messages to be delayed due to the handshake phase. However, as the number of nodes in an IEEE 802.15.4 network increases, the protocol's lack of an RTS/CTS mechanism diminishes the PDR results. The IEEE 802.15.4 begins to encounter reliability concerns as the number of nodes in the operation increases [2]. In IEEE 802.15.4, the network performance degrades when a sink node attempts to manage many connections simultaneously.

Given that the SEEK-MADP transmits on average larger packets, it has the maximum throughput. The data period of SEEK-MADP is dependent on users' mobility. In comparison with S-MAC, which uses a similar process but is limited in the size of the packets it can send, which results in a reduced throughput, the transfer of data is used efficiently without compromising the node's duty cycle, thereby yielding a high throughput and a low power consumption. The listening duration for S-MAC-ADP can be adjusted. For this method to function, the data packet size must be larger than the node's duty cycle. If a data packet's size exceeds a node's duty cycle, then the packet will be divided into smaller pieces. As shown in Figures 10 and 11, the SEEK-MADP approach seeks to lower the average packet size in contexts where many nodes are extremely mobile. An average packet size transmitted in the SEEK-MADP instance increases as a node's mobility decreases (has pauses).

The SEEK-MADP is superior to S-MAC and S-MAC-ADP because it minimizes E2E latency by decreasing the length of control packets required for MAC address operation. Using this strategy, a SEEK-MADP MAC address protocol decreases the nodes' power consumption.

4.7 Mobility Effect on MAC Address Protocols

Mobility can affect the network operation. To show how each protocol performs when the nodes are fully mobile or have pauses, the influence of mobility is presented by normalizing the values of the energy per packet, E2E delays per byte, throughput, and PDR results against the protocol that performs best in each particular parameter listed above. The normalization method followed is the feature scaling method [32]. This method is used for values between 0 and 1. Assume a set of values {m} for each metric to each compared MAC address protocol. The normalization equation is

$$Normalized(m) = m - M_{min}/(M_{max} - M_{min}),$$

$$If\ (M_{max} - M_{min} = 0)\ \rightarrow m\ =\ 0.5,$$

where m represents the value to be normalized to the scale of 0–1, M_{min} is the minimum value of the set of values for each method, and M_{max} is the maximum value of the set. Figures 17 and 18 illustrate the results of this operation for mobility pauses of 50 s and 0 s, respectively. The results indicate that changing the mobility pace from mobility with pauses of 50 s to fully mobile nodes does not influence the performance of SEEK-MADP. The SEEK-MADP has the lowest energy consumption for every packet. The protocol scores the highest throughput, highest PDR, and second-lowest E2E delays.

The S-MAC has the second-best throughput. The results of the S-MAC PDR are close to those of the SEEK-MADP. The S-MAC-ADP ranks third in terms of throughput. The S-MAC-ADP has the highest energy per packet. S-MAC and S-MAC-ADP have the highest E2E delays. The IEEE 802.15.4 has the lowest PDR, throughput, and E2E delays; their energy per packet results, while not the highest, are higher than those of the SEEK-MADP.

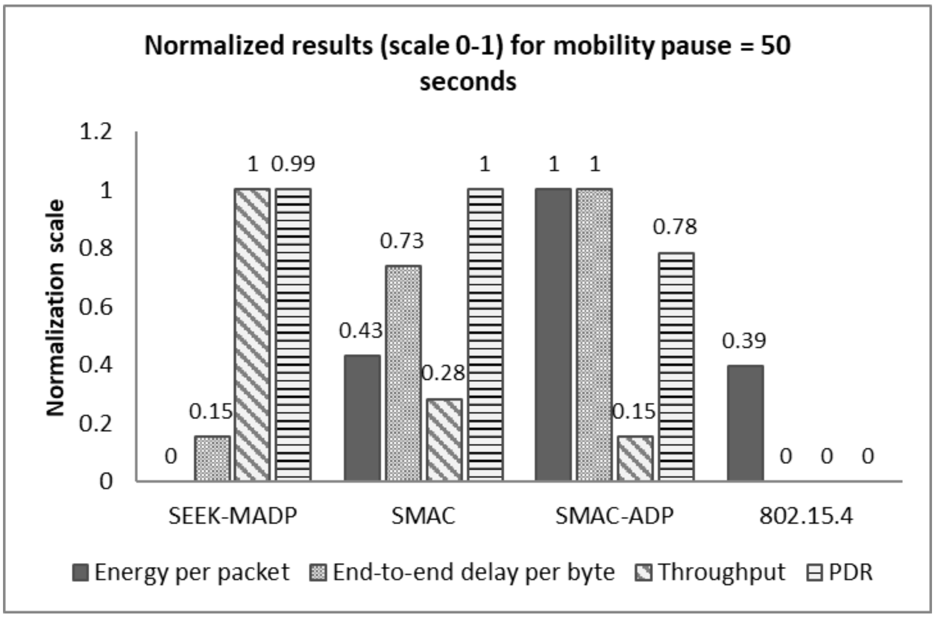

FIGURE 17. **Normalized values of measurement metrics for mobility pauses of 50 s. A 0 value represents that the MAC address protocol scores the lowest output for the measurement metric (energy per packet, E2E delay per byte, throughput, and PDR).**

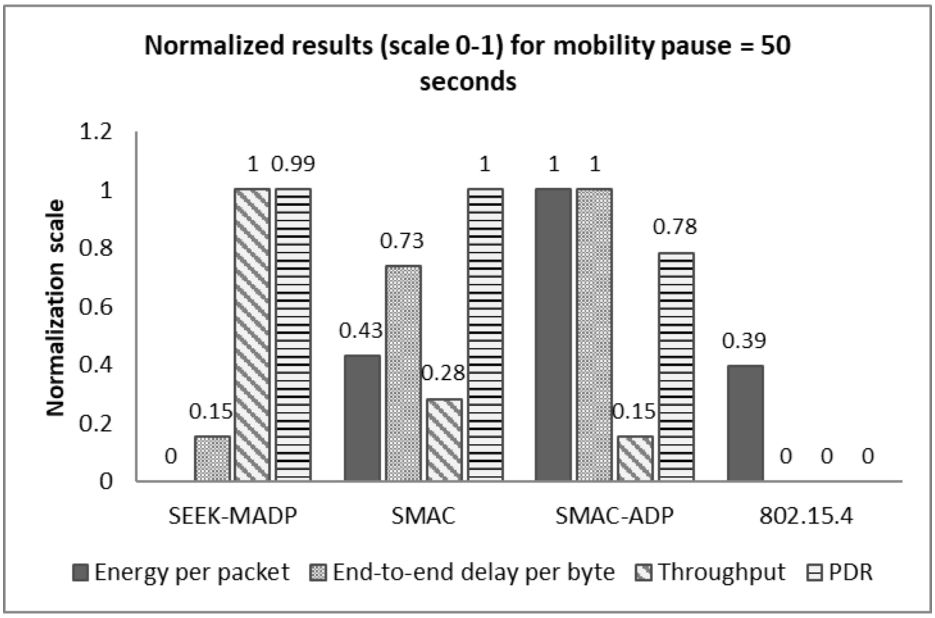

FIGURE 18. **Adapted metric values for 0-s rest times during mobility.**

The SEEK-MADP performs better than S-MAC and S-MAC-ADP in terms of E2E delays because it has less control packets and thus a shorter data handshaking period. The SEEK-MADP has better throughput because the mechanism scales the data period to accommodate a higher packet size in the same duty cycle. This mechanism also improves the energy consumption, because the protocol produces more output at the same data period scale for the other protocols. The S-MAC does not have such a mechanism, nor the S-MAC-ADP because the adaptive listening in S-MAC-ADP affects the energy consumption due to the increase in the period of listening to the medium.

Zen et al. [29] reported that the IEEE 802.15.4 suffers from an irregular operation in random mobility scenarios. This irregularity is associated with the coordinator's association of the mobile nodes. When the nodes have random mobility, the coordinator node cannot cope with the nodes that are associated to it to achieve successful connection slotting times. E2E delays decrease immensely, and throughput improves by a margin. The results of the normalization process show that the SEEK-MADP is the most energy-efficient, stable PDR and has the highest throughput when changing the mobility pace of the network.

5. Conclusions

This paper has presented the SEEK-MADP, an energy-efficient, high-throughput, and mobility-aware MAC address protocol for MWSNs. The protocol is evaluated in terms of frequent mobility and frequent mobility with random pauses. The results show that the SEEK-MADP has better energy consumption for each packet, better system throughput, a stable PDR performance, and lower E2E delays than S-MAC and S-MAC-ADP. The combination of RTS and SYNC packets into one packet (SEEK) improves the energy consumption of a protocol, as well as the E2E delays. The SEEK-MADP provides high throughput because it utilizes the data period efficiently to embed more data packets in a single transmission. The lowest recorded E2E delays are for IEEE 802.15.4, because it uses a different handshaking process with fewer control packets. However, the IEEE 802.15.4 has the lowest PDR results and throughput, and it shows highly inconsistent performance when several deployed nodes increase. The SEEK-MADP has higher E2E delays than IEEE 802.15.4 mainly because of the duty cycle scheduling process. A shorter and adaptive duty cycle solution can improve the performance of the SEEK-MADP considering delays. A cross-layer approach between the routing layer and the MAC address layer can be implemented to minimize the control packet overhead, which originates from broadcasting ND packet(s) to maintain the neighbor nodes. The cross-layer approach can use the neighbor nodes' maintenance mechanism, such as HELLO packets in the AODV routing protocol instead of ND packets.

ACKNOWLEDGEMENTS

The authors would like to thank Editors and reviewers.

CONFLICT OF INTEREST:

Author declare no conflict of interest

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