EEM-MAC: Enhanced Energy Efficient Mobility aware MAC protocol for Mobile Internet of Things

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EEM-MAC: Enhanced Energy Efficient Mobility aware MAC protocol for Mobile Internet of Things

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Abstract: Mobile wireless sensor networks (MWSNs) have become a foremost solution in many emerging applications both in industry and academia. Moreover, considering the mobile node in WSN is a challenging task to designing efficient communication protocols, specifically at a medium access control (MAC) layer. Most of the existing protocols consider only for static and slow mobility. To meet with future MIoT applications, in this paper we propose Enhanced Energy Efficient Mobility aware MAC (EMM-MAC) protocol. Our EMM-MAC protocol consists of 3 contributions i) static synchronization and mobility handling phase to support both environments, ii) By using queue length-based channel access priority for static nodes, and iii) the combined highest signal strength and node status-based channel access priority for mobile nodes without any control packet overhead. The simulation results verify that EMM-MAC yields a notable improvement in the average power consumption, packet latency, and packet delivery ratio performances against the well-known mobility-aware MAC protocols under different mobility models and environments.

Keywords: *MWSN, MAC, IEEE 802.15.4, adaptive duty cycle, Energy Efficient and IoT.*

1. Introduction

The latest development of wireless sensor networks (WSNs) becomes a leading network technology for next-generation smart wireless networks. The global market is dynamically changing and it forecast that connected IoT devices are estimated to 75.44 billion worldwide by 2025 [1] and the global IoT market worldwide is expected to raise 1.6 trillion by 2025 [2,3]. This network during the last years coming out of a new paradigm called Mobile Internet of Things (MIoT) consist of a large number of tiny nodes that can Connect both living things and inanimate, sensors for raw data collection and communication over an IP Network through multi-hop fashion. In such MIoT applications, the usage of mobile nodes plays a vital role has broadened their application both in academia, industry, and areas such as wildlife, habitat & patient monitoring, tracking enemy movements, and many other network applications [4-6]. Under mobile-based applications packet transmission extremely important when connection established, because dynamic nature, changes in topology, and accessing channel for a long time leads to minimizing the sensor battery lifetime. Hence packet transmission to the preferred device (i.e.) sink is more important before losing the connection. To find a suitable solution and reliable communication between nodes Medium Access Control (MAC) layer plays a vital role, this makes a challenging role to enhance MAC under mobile environment for future mobile WSN.

Over a year many WSN based MAC protocols have been designed, such as S-MAC [7], T-MAC [8], and B-MAC [9], and provide solutions for low power energy consumption and duty cycle scheduling mechanism, etc., under static environment, where a topology remains fixed meanwhile depending on the physical medium may change (i.e) energy hole problem. Previous research works have been addressed towards static to the mobile environment of which some of the prominent reviews are presented in [10-13] [7-10]. The survey in [10] [12] presents various mobility models, estimation, and detection techniques concerning the challenges in the design of mobility MAC protocols in MWSNs. In [11] presents key aspects of mobility support at the MAC, network layers. Under mobility, the node's position changes dynamically may impact high processor computing, unwanted radio wake up and decrease in network lifetime. To overcome this, they come with a proposal called Network of Proxies (NoP), to competent of managing low processing, energy, and less time-consuming. In [13] mobility MAC protocols are classified into two groups namely synchronous and asynchronous schemes in MWSNs. Based on this the major challenges and protocol design for future consideration they addressees. However, to the best of our knowledge, very few observe the vital role in mobile IoT applications of dynamic nature.

Mobility MAC protocol still endures three problems. The first problem is a classification of stationary node (SN) and mobile node (MN) and secondly under routes reconstruction may cause packet loss (i.e., remaining (n-1) packets that a node contains in it transmit buffer) when MN moves from the virtual region (VR) to other. Lastly, duty-cycle medium access control (MAC) protocols allow the neighboring nodes to be synchronized effectively under static and struggle to handle under dynamic. In this paper, we design an enhanced Mobility Based queue aware Mac protocol called EEM-MAC to reduce the above state problems. To achieve EEM-MAC focus on low power short and long preamble based on queue length MAC mainly due to the dynamic’s nature induced by mobile nodes in a network. Consequently, the static node can provide known information about the radio (e.g., buffer length, power, and Radio Signal Strength Indication) module. By using this information, we adopt a short preamble-based duty cycle mechanism for quick and efficient data transmission under normal mode. We further introduce a long preamble-based mechanism under the mobile node that can be stimulated to allow seamless handover to the neighboring node to make the radio receive packets till the ongoing data transmission on the respective channel in a network. Similar to the existing X-MAC [14] EEM-MAC is an asynchronous MAC protocol, data transmission from sender to receiver based on buffer length. When a sender attempts to transmit the packet to the receiver, once the sender receives the link-layer acknowledgment it broadcast the queue length to neighboring nodes in the respective network region. Hence by knowing wake-up time allows the neighboring node to adjust their radio goes to sleep state. Hence EEM-MAC increases its sleep time to save energy by reducing the unwanted wake-up time (i.e.) ideal mode.

The contributions presented in this paper are threefold:

- After a detailed study of existing mobility-aware MAC protocols for WSNs, we propose an asynchronous duty cycling mobility MAC protocol, called EEM-MAC, which adopts a two-phase: data transfer and mobility handling. To achieve this, we embedded S-static and M-mobility flags (2-bit) in the reserved field in IEEE 802.15.4 MAC header [15].
- In the data transfer phase, a sender transmits data to the receiver based on queue length information and the respective sender will broadcast to use queue length of a neighbor node to adjust the data transmission to go to a sleep state until the ongoing transmission on the channel. Therefore, EEM-MAC behaves like static MAC but improves the energy efficiency and increases the network lifetime.
- In the mobility handling phase, node movement is realized by using obtainable information from the radio module (e.g., RSSI, position). By predicting the node mobility, it will set mobility flag, if the flag is perceived, the mobile node will choose

the preferred node and extent the long preamble time. By adopting a long preamble time receiver or potential next-hop node will remain inactive state and the non-targeted node will not affect the channel and go back to sleep mode and. Hence EEM-MAC provides fast discovery, good packet reception, and minimum delay under mobility and static environment.

- Finally, to determine the performance of EEM-MAC, we perform our proposed protocol in Contiki OS (top of COOJA) on well-known WSN platforms (Z mote). In addition, we evaluate our protocol design comparing it with existing mobility MAC protocols in two different mobility models and scenarios.

The remainder of this paper is structured as follows: we provide a detailed summary of the most pertinent related works and problem formulation in section 2. In section 3, we present the system model and detailed analysis and design of the EEM-MAC protocol. Section 4 describes the performance evaluation of the EEM-MAC protocol against well-known MAC on top of the Contiki OS. Finally, section 5 provides conclusions and potential suggestions for future work.

2. Motivation

2.1. Related works:

During the previous decade, quality in WSNs was improved of which MAC protocols play a vital role because they directly access the medium. Many solutions were designed related to mobility-aware MAC in MWSNs. However, they are categorized into scheduling, preamble duty cycle, synchronous, asynchronous, and hybrid. Hereafter, our studies focus on recent and relevant approaches towards mobility-aware preamble-based MAC protocols for MWSN to our investigation.

In [16] author proposed mobility aware medium access control protocol called MA-MAC that is extended from X-MAC [14]. To support mobility MA-MAC defines two thresholds: the first threshold is to enable the handover initialization and the second threshold is used to activate the intermediate node (next hop distance) and inform to receive data from the mobile node. Under static mode data transmission is based on a preamble-based mechanism, when the node completes the data it transmits ACK once receive goes to sleep state. On other hand during mobility, the sender will embed the handover bit and broadcast during ongoing packet transmission. During this first potential receiver will receive the bit and the mobile node transmit the data to the region. After a random interval remaining receiver will wake up and receive the handover bit followed by the first. Thus the mobile node can perform uninterrupted transmission in a structured mechanism.

Limitations of the protocol: a) when a mobile node broadcasts the handover bit during mobility the first potential receiver will receive data and if the adjacent/next hop receiver fails to wake up makes the mobile node decrease in throughput. b) Author highlights preamble cycle it holds perfect for static mode by adopting the random wakeup interval time at the same time under mobility mode random wakeup interval makes non targeted node/ targeted node will be in between active/ideal state leads to more energy consumption and decrease in network lifetime.

In MT-MAC [17] is an extended version of T-MAC [8]. MT-MAC resolves high packet drop and can balance tradeoffs between energy, latency. To solve the connection problem with the mobile node they use RSSI and LQI (Link Quality Indicator) values in the SYNC packet. During mobility when MN moves to a new region and respective MN must wait for t time to choose sink in the respective region, this makes low throughput and high packet drop. Thus MT-MAC adopts 1. Scheduling phase 2. Mobility handling phase. Before start transmission, it adopts three different identifier flag styles namely border node, cluster head, stationary node, and the mobile node. At the scheduling phase, nodes start to exchange the SYNC control packets. After exchanging SYNC packets, they are categorized into three types: first when the node does not receive SYNC packet from a neighbor in the network region and it will independently schedule a frame and broadcast intern act as cluster head node type. Secondly, when the node adopts the frame schedule with the neighboring node it sets node type as a stationary node. Finally, if the node has a different frame schedule it sets node type as border node (BN). Hence data transmission under static (SN flag is set) environment is scheduled within the virtual region (VR) and if the node travels from one VR to another it identifies based on the RSSI and LQI threshold values. once the threshold varies the respective flag from SN changes to mobility phase (MN flag is set). To achieve smooth handover MT-MAC uses a handover bit along with a SYNC packet. Once it broadcast neighboring nodes and border node adopt a new schedule for smooth communication without delay.

Limitations of the protocol: a) Data transmission based on identifier flags (overhead) and are suitable for the targeted node or sink if the non-targeted node pursues the same schedule makes the node in the wake-up state leads to the dead node. Hence MT-MAC is well-matched for non-energy-constrained applications. b) Under mobility, the interaction between MN and BN makes BNs node consume more energy and further unwanted wakeup (active and ideal state) between neighboring nodes build packet loss due to its less network lifetime.

In [18], the authors present the MS-SMAC protocol which is inherited from S-MAC [7]. The probability of network disconnection and packet loss occurs during mobility for both mobile and neighboring nodes. To overcome this MS-SMAC adopt MSYNC and MACK in the SYNC packet. MSYNC examine the speed of the mobile node in the respective communication range and broadcast to the receiver. On another hand, the MACK control packet involves 1) determines when to transmit the MSYNC packet. 2) Two sleep Times (1and 2). SleepTime1 schedule for sender node in respective cluster region similarly sleepTime2 schedule for new cluster region under mobility. Hence mobility prediction is calculated based on RSSI values of mobile nodes in a cluster. When the mobile node enters from one region to another it will inform its position, next to sleep time, next interval, and speed. The border node will receive this up-to-date information so that the mobile node will ensure better connectivity.

Limitations of the protocol: a) overhead involves computation towards sleep time, interval time, node speed, and position. b) Control packet (MSYNC and MACK) is flooded in-network particularly for mobile node but in some situation, if more mobile nodes in network the synchronization between static, neighboring, and border node may fail due to complex computation. This leads to high packet drop and high energy consumption due to an unwanted wakeup state.

In [19] Ba et al. present the MOX-MAC as an extension of the X-MAC protocol [14] which uses a preamble-based data transfer mechanism for both static and mobility conduction. Under the static condition when a static node is attempting to transmit data it checks the channel is free or not. Once it receives the preamble it will communicate to the respective node with backoff time. Similarly, under mobility, when the mobile node is attempting to transmit the data it will sense the medium to receive the ACK control packet from the respective static node. But mobile node will wait for some time till the ongoing transmission from the respective static node, once the node becomes free subsequently it sends the data packet to the receiver static node. One major problem is that when the static node has long ongoing transmission in such case the mobile node must keep their radio ON and leads to makes unnecessary energy consumption and high packet drop. Fig. 1 shows when the mobile node wants to transfer the data it waits for the random interval to make the connection establishment to receiver static/ sink node. In such cases when the collision or channel access to some other nodes make more packet loss and high energy consumption. Similarly, if the ACK also fails leads to unwanted wakeup and introduces a long delay in a network.

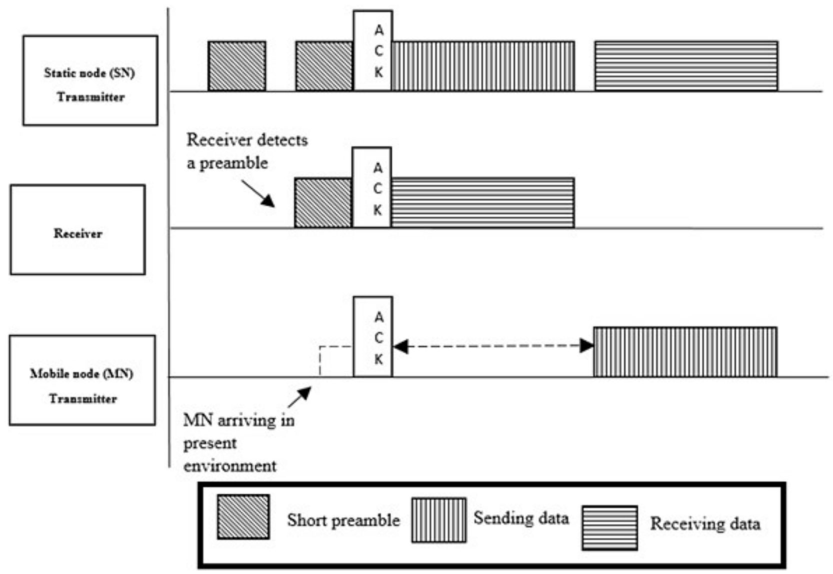


Figure. 1 MoX-MAC data transmission between the static and mobile node

Papadopoulos, G. Z et al. presented the M-ContikiMac [21] which is based on ContikiMac [20] which is a default MAC protocol in ContikOS [26]. ContikiMac is an asynchronous preamble-based protocol designed for static domains. For mobility, they adopt the burst mode transmission in a network. When a node decides to transmit data first it informs the receiver by setting the flag (UniByte). On the monitor, this flag the receiver make the node keep their radio in ON state to receive the n packets from the mobile node until the ongoing transmission.

Fig 2. Shows the M-ContikiMAC procedure, initially, the sender S wants to transmit data under burst transmission. However, to transmit data sender must discover the potential static node in its network region before moving to a new region. Thus it adopts anycast transmission method so that it places the destination address in the packet. Initially, the first packet incorporates an additional UniByte flag (flag=0) and it continuously transmits to find the static neighboring nodes. Meanwhile, R1 checks the flag makes the radio wake up, and starts receiving the packets of static nature. Under Mobility, the mobile node receives ACK it enables the UniByte flag (flag=1) and transmits the remaining packets to R1 before disconnection. If network disconnected once it identified again makes UniByte is 0 and repeat the same process to find the next receiver static node say R2 to avoid disconnection and the detailed data transmission and reconnection process are illustrated as shown in Fig. Limitations of the protocol: a) when two or more node wake up simultaneously may arise the collision may cause the packet drop. In addition, when the mobile node transmits the packet if the ACK loses this results in high energy consumption because both mobile and neighboring node keeps the radio inactive state.

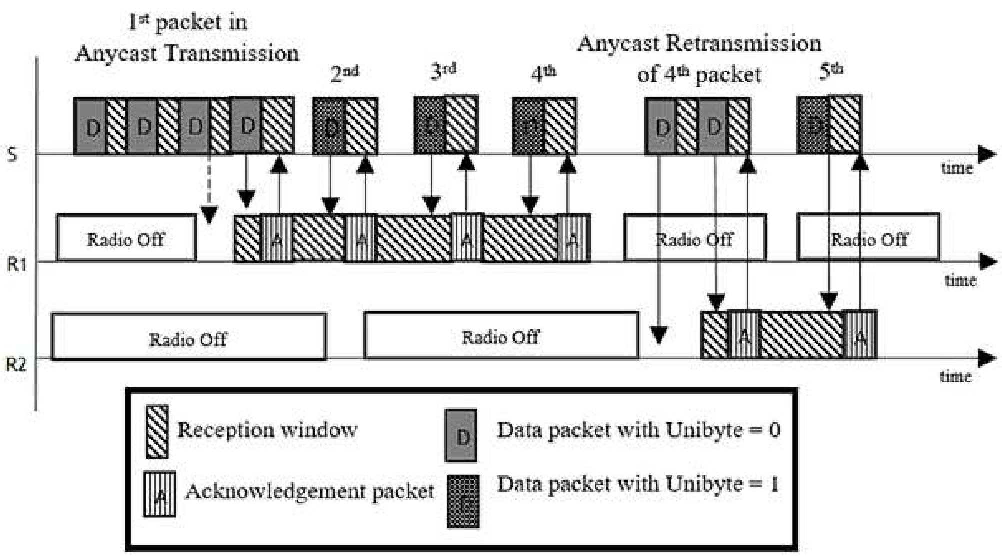


Figure. 2 M-ContikiMAC procedure for the sender and mobile node

Set back in M-ContikiMac protocol leads to design ME-ContikiMac [22]. To avoid packet duplication at the mobile node it adopts the control packet. In ME-ContikiMac when a mobile node begins the transmission it does not accept the ACK packet but it will adjourn the ongoing preamble cycle according to n packets. First data transfer is the same as a previous mechanism [21] under static nature, on the other hand when two static node S2, S3 sample the medium and receive the control packet the ACK and transmit under collision when the on two static nodes S2 and S3 receive the control packet from M at the same time ACK packet retransmission results in a collision. To avoid packet collision, it will postpone some time and follow the same discovery procedure and transmit to the potential static receiver node S4. The detailed working process is illustrated as shown in Fig 3. Hence packet duplication, collision, and delay are reduced and makes smooth packet forwarding towards sender/sink in a network is improved. One of the major problems faced by the mobile node at the time of transmission because it follows the next duty cycle for data transmission so that the node keeps the radio ON for a long time this leads to more energy consumption and packet loss.

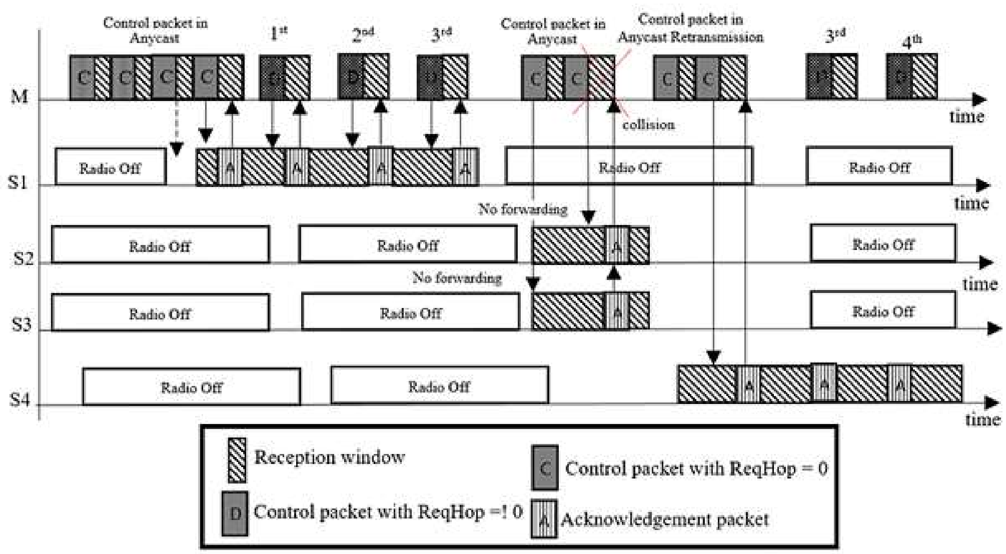


Figure. 3 ME-ContikiMAC procedure for the sender and mobile node

Table. 1 Comparison of different mobility aware protocols concerning mode (S-synchronous, A- Asynchronous), derived from, throughput, latency, mobility detection, and comments

Protocol	**Mode**	**Derived from**	**Throughput**	**Latency**	**Mobility detection**	**Other comments**
MA-MAC [16]	A	X-MAC [14]	High	High	Low	✓ Implemented in a real

						testbed environment and it has overheads. ✓ Different mobility models to be analyzed.
MT-MAC [17]	S	T-MAC [8]	High	Medium	Moderate	✓ If more node wakeup concurrently collision occur in the work. ✓ Handover problem occurs.
MS-SMAC [18]	S	S-MAC [7]	Moderate	Moderate	Moderate	✓ More overhead and if SYNC packet collides results in the wrong prediction to

						the mobile node.
MOX-MAC [19]	A	X-MAC [14]	High	Low	Low	✓ Mobile node adopts random interval during data transmission under mobility. ✓ If congestion occurs mobile node suffers reconnection problems both in static and mobility.
M-ContikiMac [21]	A	ContikiMac [20]	Low	Low	Low	✓ Anycast mode leads to many duplications of packets. ✓ Decrease in network lifetime because of

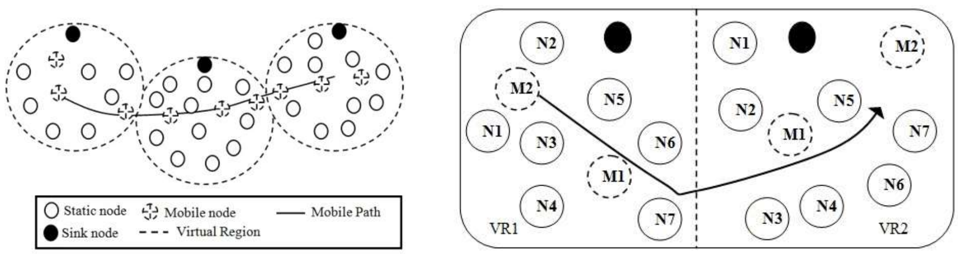
						unwanted wakeup. ✓ When multiple nodes make priority classification is not considered.
ME-ContikiMac [22]	A	ContikiMac [20]	High	Moderate	Moderate	✓ When two or more mobile nodes in the same region MN will attempt many reconnections between MN and sender/sink node. ✓ Increase in ideal listening and packet loss.

						✓ It was suitable only for selected applications.

2.2. challenges

In WSNs either in designing protocols or applications they focus on static networks, here the topology remains fixed. As shown in Fig 3 (a) under mobile scenario topology may changes rapidly in such case if we face some major problems in the network are packet loss, connection termination, reconnection, rapid node classification, unwanted radio wakeup by the neighbouring sensor nodes. From the literature, we identify that additional improvement is needed for both static and mobile nodes in a dynamic environment. Fig 3 (b) illustrates those potential challenges. At the beginning sensor are deployed randomly and after some time nodes will be aware that either SN or MN, when a mobile node initiates the data transmission first it will discover and choose the receiver static node to transmit the data. In the coverage region of mobile node M1 along with three nodes say N4, N7, and N6. Hence MN will transfer data towards the sink with any of the receiver static nodes. At this juncture, MN has to continuously transfer packets on the same ongoing duty cycle without any loss and disconnection. No assurance remaining static nodes wake up and make unwanted wakeup and channel contention in the network.

In the existing survey once common drawbacks we identified that when MN select the static node based on first received ACK. Meanwhile, we also observed that when two or more MN in the same network or region it fails to classify because if the ongoing duty cycle expires then the next cycle all the nodes wake up leads to a collision, delay, and more energy consumption. Consider the same scenario as shown in Fig 3(b) in the virtual region (VR1) there are two mobile nodes M1, M2. Before link disconnection, M1 moves from VR1 to VR2 and has to transmit the remaining n packets to the receiver static node in VR1 on the same duty cycle. Here the problem arises that once the ongoing transmission complete with MN and the next cycle begins nodes wake up and start schedule for data transmission this, in turn, causes handover delays in the remaining mobile node (M2). Hence the challenges reveal that there is a demand for MAC protocol under mobile IoT environment that should be suitable for large and heavy traffic applications.



(a) (b)

Figure. 3 (a) Mobile sensor node movement through different VRs (b) Mobile handover process in VR

3. DESIGN of EEM-MAC

Mostly either in designing protocols or applications they focus on static networks, here the topology remains fixed. To enhance both static and mobility we have come up with enhancing energy-efficient mobility-aware MAC protocol called EEM-MAC to tackle with ideal listing time, channel contention, and minimize multiple reconnections for a mobile node during handoff. In this section deliberate the energy model, mobility model, and the proposed algorithm respectively.

3.1. Energy Model

The ultimate intent of the energy model is to accurately measure the battery power consumption of the sensor node during the different operating states. A sensor node comprises a transceiver module, microcontroller, a memory element, analog-to-digital converter (ADC), battery, and sensing units. Among the sensor sub-components, the transceiver unit consumes a significant source of battery energy due to the transmission and reception of data packets between sensor nodes. The total energy required by the transmitter (E_{tx}) to forward q-bits of data over a distance $'r'$ is expressed as

$$E_{tx} = E_{micro}(q) + ET_{amp}(q, r) \tag{1}$$

Where $E_{micro}(q)$ is the energy consumed by the microcontroller unit and $ET_{amp}(q, r)$ is the energy consumed by the amplifier to transmit q-bits over a distance $'r'$. Equation (1) is modified and rewritten concerning propagation coefficients as follows

$$E_{tx} = \begin{matrix} q(E_{micro} + \varepsilon_{fs} r^2)\ r < r_0 \\ q(E_{micro} + \varepsilon_{tr} r^4)\ r \geq r_0 \end{matrix} \tag{2}$$

Where ξ_{fs} and ξ_{tr} are free space and two ray propagation coefficients, $'r$ is the distance between transmitter and receiver nodes, and $'r'_0$ is the reference distance. Total energy consumed during the reception (E_{rx}) of q bits of data packets can be represented as

$$E_{rx}(q, r) = q[ER_{amp} + ER_{DC}] \tag{3}$$

Where ER_{amp} is the energy consumed by the sensor node to receive packets and ERDC is energy dissipated during the data acquisition and compression process. Total energy dissipated E_{idle} by the sensor node during the idle listening time can be represented as

$$E_{idle} = T_{wait*}\, q * (E_{tx\_rx} + E_{micro} + E_{mem}) \tag{4}$$

Where T_{wait} is the idle waiting period, E_{tx_rx} is the energy consumed by the transceiver module to remain in the idle wake-up mode, and E_{mem} is the energy consumed by the memory element to hold the packets. It is widely proven [23] that the energy consumption during T_{wait} is equivalent to that of E_{tx} or E_{rx} process. Thus, minimizing E_{idle} is crucial to improve the battery efficiency of the sensor node.

3.2. Mobility Model

In this section, the mobility model describes the pattern of the mobile node and predicting their localization, direction, and speed concerning time. Since the mobility model play an essential role to determine the significant performance of mobility MAC in MWSN [24]. The main objective to study mobility patterns is used to relate to real-life applications realistically. Consider two nodes (p_i, q_i) situated at (u_i, v_i) and (u_j, v_j) such that $s^i \in (u_i, v_i)$; $s^j \epsilon (u_j, v_j)$.The node p and q move in a particular direction with variable rate making an angle α_1 α_2 i.e. node p_i moves a distance $d1$ and node q_i moves a distance d2 in interval T = 0 to t. At initial time t, the nodes located at a distance $p_i(u_j, v_i)$ and $q_i(u_j, v_i)$ is given as,

$$D_{(uv,0)} = \sqrt{\left|u_i - u_j\right|^2 + \left|v_i - v_j\right|^2} \tag{5}$$

Let the node p_i and q_i moves with the variable rate V_{pi} and V_{qj} making an angle α_1 and α_2, the node distance D_1 and D_2 in a particular time t is given as,

$$D_1 = v_{pi} \times t \text{ and } D_2 = v_{qj} \times t \tag{6}$$

After some time, $T = t$, mobility of the node moves to a new position and the updated position reach by node P_i is given as

$$u_{i,new} = u_{i,old} + v_{pi} \times t \times Cos\phi \tag{7}$$

$$v_{i,new} = u_{i,old} + v_{pi} \times t \times Cos\phi$$

Similarly, after some time $T = t$, mobility of the node moves to a new position and the updated position reach by node q_i is given as

$$u_{j,new} = u_{j,old} + v_{qj} \times t \times Cos\phi \tag{8}$$

$$v_{j,new} = u_{j,old} + v_{qj} \times t \times Cos\phi$$

Once the mobile node reaches the new position, the updated distance between the nodes p_i and q_j is given as

$$D_{(p_{new}\,q_{new},t)} = \sqrt{\left|u_{i_{new}} - u_{j_{new}}\right|^2 + \left|v_{i_{new}} - v_{j_{new}}\right|^2} \tag{9}$$

3.3. Dynamic Agile Mobile Node (DAMN) Prediction with EEM-MAC

In general IEEE 802.15.4 standard has 2 consecutive CCA checks in an interval along with the back-off period. The main role for consecutive CCA checks is for signal detection in the wireless medium [25]. Generally, sensor mote will wake up their transceiver radio module from its sleep state when double CCA checks operation. Once the radio wakes up it checks the channel availability, if the channel is free it will start data transmission towards the sink by placing the radio module inactive state. The obtained value (channel condition, RSSI) received at the beginning is applicable only for the ideal and no interference conditions. Next, if interference occurs the RSSI and channel condition may not be valid and leads to misdirection for neighbouring nodes in a dynamic network. At last, CCA struggles to sustain its precision when congestion and false wakeup by nodes. To predict effectively under dynamic nature, we introduce DAMN mode which further reduces the false prediction, false scheduling mechanism between sender and receiver node in a network. Initially before starts sending data, it waits for T_{ws} seconds to collect the node information (RSSI, queue length, and position). At this time DAMN further extends the Channel Check Rate (CCR) to get better RSSI threshold values set over the noise floor to detect sender signals. The subsequent steps are as follows:

- ❖ Initialize the NETSTACK_RADIO once wake up and start sampling to channel to get the average RSSI value
- ❖ Assign the RSSI threshold value to as previous obtained RSSI.
- ❖ Increase the transmission radio power and assign the threshold value to the obtained signal level energy

❖ Again sample the channel and update value based on a recent CCR interval check. The detailed flow diagram of DAMN mode is shown in Fig 4.

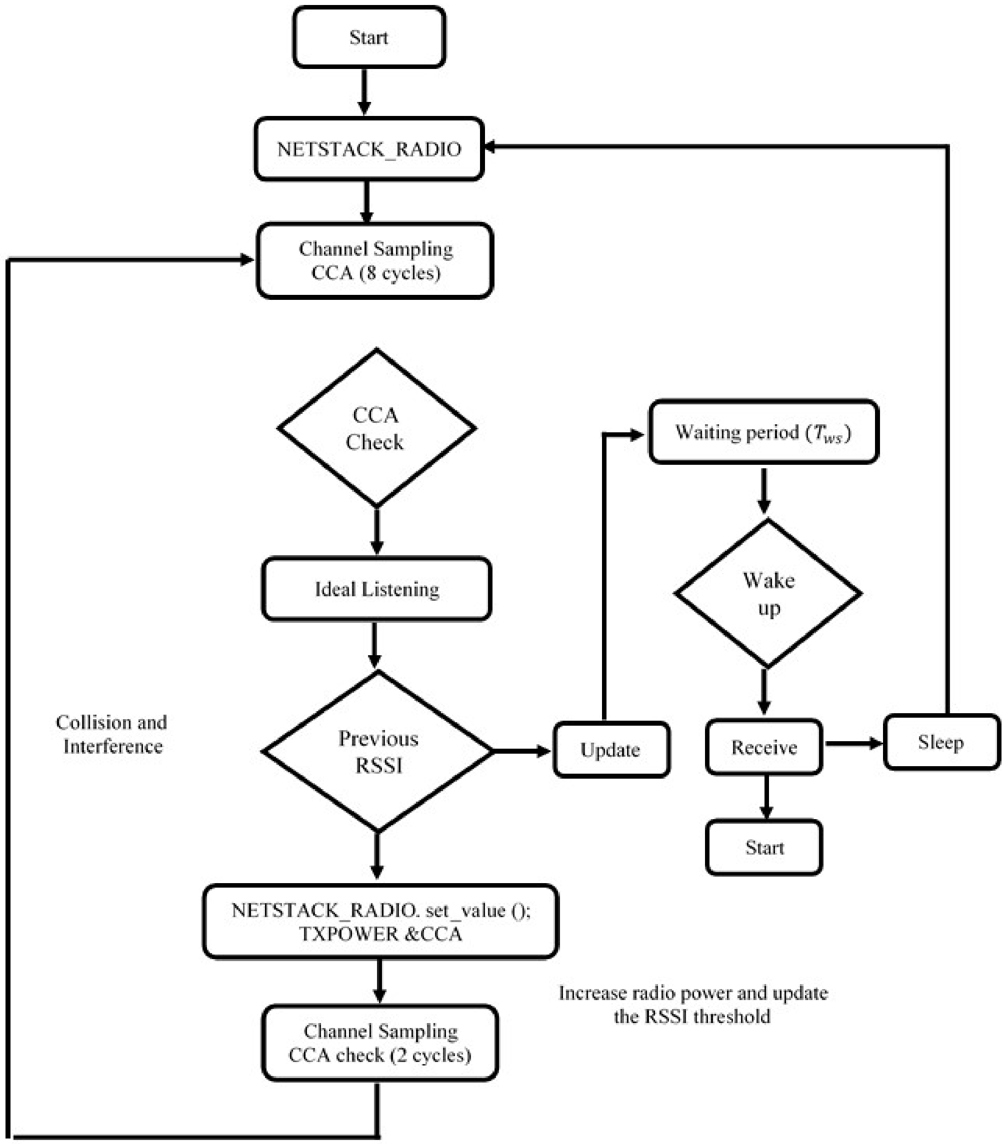


Figure. 4 Flow diagram of the DAMN mode

3.4. Static synchronization phase with EEM-MAC

The proposed EEM-MAC implements a channel access priority mechanism combined with a receiver coordinated radio sleep scheduling approach among the competing sensor nodes under each VR. The EEM-MAC implements distinct channel access strategies for static and mobile sensor nodes. In the static node scenario, the receiver node 'R' collects the queue length information and received signal strength (RSS) of all participating sensor nodes in the VR during the synchronization process of T_{ws} seconds. The receiver ‘R’ grants access priority to the sensor node ‘Si’ with the highest packet count in the queue with the short preamble and broadcast the sleep message among the competing neighbouring sensor nodes. On reception of the radio sleep message, competing sensor nodes remain in the sleep state until the data transmission of the current sender-receiver process. Adopting the queue length-based access strategy and receiver coordinated sleep scheduling avoids channel contention and minimizes the idle wake-up time of the neighbouring nodes under static conditions. The timing diagram of the proposed EEM-MAC access mechanism for the static condition is represented in Fig. 5.

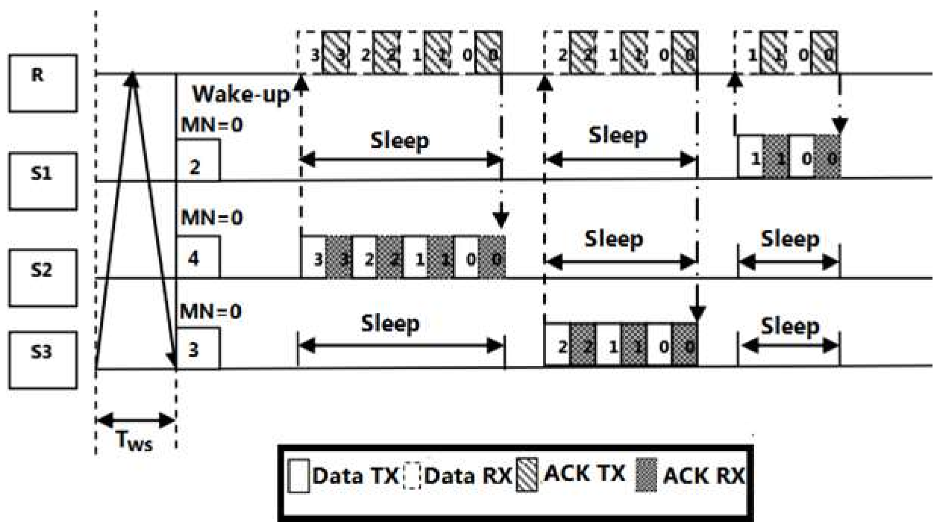


Figure. 5 Sender and receiver data transfer in static condition

As shown in Fig. 5, sensor nodes ‘S1’, ‘S2’, and ‘S3’ advertise their queue length with the receiver ‘R’ during the static synchronization process. The receiver ‘R’ initiates the access priority to the node ‘S2’ with a short preamble based on the packet count in the buffer and broadcast sleep message among the competing neighboring nodes ‘S1’ and ‘S3’. The neighbouring nodes remain in the sleep state until the data transmission between ‘S2’ and ‘R’. Let TSD is the time interval for successful packet transmission, QL is the queue length information of the current node, Tack is the successful acknowledgment duration and T_{sleep}, D

is the competing nodes sleep duration to save the battery energy. The T_{sleep}, D duration of the static nodes are represented as

$$T_{sleep}, D = Q_L T_{SD} + T_{ack} \tag{10}$$

3.5. Mobility handling phase with EEM-MAC

In the node mobility handling phase, the EEM-MAC is designed to attain the following objectives i) maximize the data transfer with minimum loss probability and ii) minimize the idle listening time of the competing neighboring nodes. EEM-MAC implements the following strategies to achieve the objectives, i) access priority based on RSS and node status field, ii) long preamble based data transfer between the mobile node and receiver static/sink node, and iii) receiver coordinated power-saving mode (sleep state) among the competing neighboring sensor node. During the periodic wake-up interval, the receiver node 'R' obtains the node status (static or mobile) information and the RSS value of each sensor node in the VR. The node status information is obtained from the newly added mobile node (MN) field in the IEEE 802.15.4 MAC header [15] as shown in Fig. 6.

Bits 0-2	3	4	5	6	7-9	10-11	12	13	14-15
Frame Type	Security Enabled	Frame Pending	ACK Request	PAN ID Compression	Reserved	Destination Addressing Mode	Mobile Node (0/1)	Reserved	Source Addressing Mode

Figure. 6 IEEE 802.15.4 MAC header with MN field

The receiver node 'R' initiates access priority to a mobile sensor node with the highest RSS value and adopts a long preamble mechanism to ensure high data transfer with minimum loss probability during the node movement between the VRs. When the RSS value of the existing mobile sensor node falls below the minimum sensitivity value, the receiver node 'R' dissociates with the node. Conversely, the competing neighbor nodes remain in the sleep state based on the receiver coordinated sleep message. The timing diagram of the proposed EEM-MAC access mechanism for the node mobility condition is represented in Fig. 7

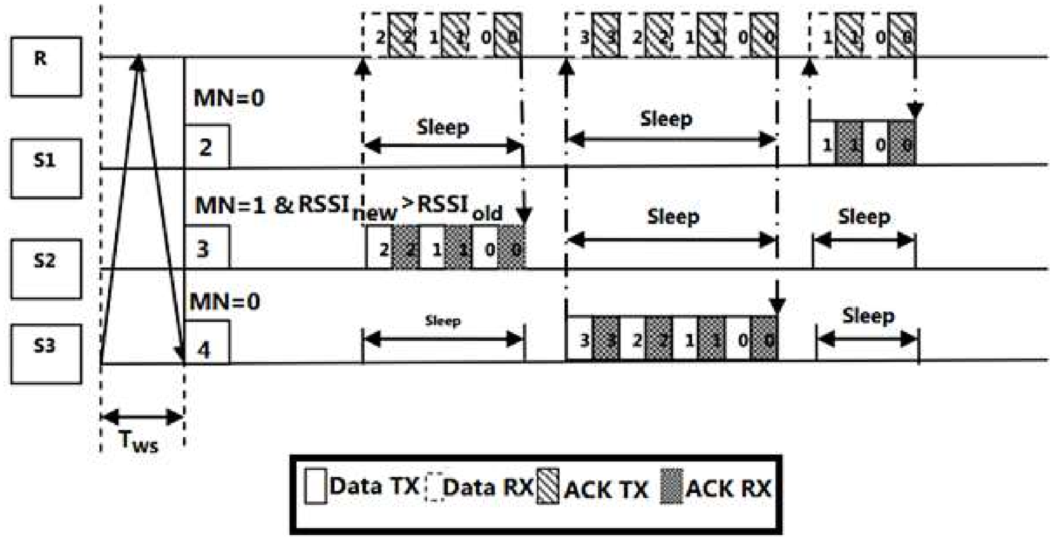


Figure. 7 Sender and receiver data transfer under node mobility conditions

As shown in Fig. 7, sensor nodes 'S1', 'S2', and 'S3' advertise their mobility state and queue length information during the synchronization process. The receiver 'R' initiates the access priority to the mobile node 'S2' and adopts a long preamble mechanism for elongated data transfer during node movement. The mobile node long preamble duration $T_{MN,D}$ is represented as

$$T_{MN,D} = (S_{(i=1)} + T_{ack})Q_L \tag{11}$$

Meanwhile, the receiver 'R' broadcasts sleep messages to the competing 'Si-1' neighbour nodes 'S1' and 'S3' that allow them to remain in the sleep state until the preamble period. The controlled sleep by the competing 'Si-1' nodes substantially minimizes the idle radio listening time, and channel contention that results in minimum packet latency and reduced battery power consumption. By considering the following description, the detailed procedure of EEM-MAC protocol is presented in Algorithm I.

R → Receiver

Ni	→	node
Ni .T	→	Neighbouring node type
SYNC	→	synchronization packet
Schdlp	→	current schedule
Schdln	→	new schedule
SN	→	stationary-node
MN	→	Mobile-node
RSSIn	→	RSSI new values
RSSIo	→	RSSI old values
QL	→	Current Queue Length
TQL	→	Queue Length Timer
TWS	→	Waiting Timer
ch	→	Channel
TXp	→	TX power
Nei	→	Neighbouring set of Ni

```
Functionality of the proposed EEM-MAC protocol
1  Begin
2    when Ni starts checking ch and CCA status then
3      then sample the channel for 5 symbols period for Tws time
4      Increase the TXp and set RSSI threshold
5      Again sample the ch and update recent CCR check then
6      if Ni starts listening for SYNC then
7        at Tws time R will collect Nei information (Q_L RSSI)
8          else if  Ni receives SYNC from Nei then
9            Ni adopt to Schdlp && broadcast  Q_L to Nei
10           Broadcast the queue length ( Q_L) to Nei
11           Set  Ni .T = 0 /* stationary node*/
12           Keep the radio ON till the (Q_L --1) packet
13           T_QL = Q_L
14         else
15           Keep the radio OFF
16         end
17         T_QL --
18         if T_QL =0 then
19           Goto line 2
20         end
21     end
22     else if RSSIo ≠ RSSIn || (Schdlp ≠ Schdln) then
23       goto line 2
24       else if  Ni .T = 1 then
25         broadcast the queue length (Q_L) to Nei
26         Set  Ni .T = 1 /* Mobile node*/
27         Keep the radio ON till the (QL--1) packet
28         T_QL ++    /* long preamble time */
29         if T_QL = 0 then
30           Set  Ni .T = 0
31           GOTO line 2
32         elseif   Ni .T = 1 then
33           sample the channel for 2 symbols
34           if Schdln then
35             adopt the Schdln & Broadcast
36           end
37           else
38             goto line 23
39         enpd
40       end
41     end
42   end
43 end
```

4. Simulation results and discussion

In this section, we discuss and evaluate the performance of our proposed enhanced mobility aware EEM-MAC protocol as compared it with well-known protocols, i.e., M-ContikiMac [21], ME-ContikiMac [22], and MoX-MAC[19]. To validate, we use ContikiOS [26] an open-source real-time simulator, and also an emulator to support hardware platform in WSN. The accessible sensor mote in Cooja, Sky (radio CC2420 chip at 2.4 GHz) motes are used in a network topology for mobile clients and sink respectively. BonnMotion mobility tool

[27] was utilized to generate the sensor node mobility models to generate mobility in the network. Moreover, our network simulation is chosen 250 meters × 250 meters with 40 static nodes including one sink and 10 mobile nodes which are deployed indoor (grid) and outdoor (random) environment. Further, 10 mobile nodes travel by utilizing the random waypoint mobility model. More specifically mobile nodes travel with an average velocity of 2m/s to 12 m /s; this replicates a typical human walk or jog.

EEM-MAC performs better node classification (SN and MN) by adopting a reserved flag in the MAC header. Further, it adopts short preamble (static node) and long preamble (mobile node) based duty cycle by using queue length information without any overhead. This makes the EEM-MAC maximizes the sleep time and reduces the collision between the nodes in a network. Additionally, for sake of precision, we further introduced DAMN mode to reduce false prediction and false scheduling in a dynamic network. The entire simulation duration of 1800 seconds of two different scenarios (Grid, Random) is shown in Fig 8, and the parameters performed in simulations are detailed in Table 2. Finally, the average battery power consumption, the packet delivery ratio (PDR), and end-to-end packet latency metrics were chosen to validate EEM-MAC performance under different node velocities. The evaluation metrics were calculated as follows:

Table. 2 The simulation parameters

Simulation parameters	**Value**
Topology	Random, Grid
Nodes	50 (40 static , 10 mobile) including 1 sink
Mobility model	Random Walk, random waypoint
Velocity	(2, 5, 10, 15) m/s
Sensor mote	Tmote Sky

Radio model	Unit disk graph model
Hardware parameters	**value**
Radio	CC2420
Radio propagation	2.4 GHz
Transmission power	−10 dBm
Antenna gain	5 dB

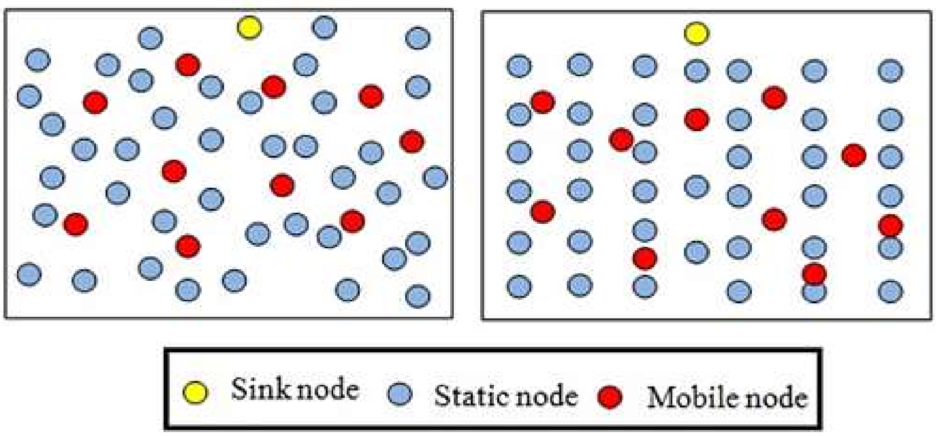


Figure. 8 MWSN of the grid and random scenarios (both static and mobile sensors)

- Packet delivery ratio (PDR) is calculated as the total packets received successfully by the receiver node to the packets received by the sender.
- End to End delay is the time taken by the data packet to reach from source to sink node with acknowledgment. Energy consumption is equal to per-packet energy dissipation of sensor node when a microcontroller is an active mode as described in section 3.1. In ContikiOS, an inbuilt power trace module is available to calculate per packet energy consumption of the respective mote. Generally, when a radio module is in an OFF state, the sensor is in low-power mode (LPM) mode and the energy consumption is 20µA. when the radio is switching from OFF to ON state it is considered to be in CPU/Ideal

state. Meanwhile, energy consumption also depends on transmission current (Tx) and reception current (Rx). The formula to calculate energy consumption for each packet as follows:

$$Energy\ consumption = \frac{\sum Consumed\ energest\ value\ of\ node \times current \times voltage}{RTIMER\_SECOND} \quad (12)$$

By considering Table 3. The consumed energest value of node is calculated in simulation models by equation (13).

$$\begin{aligned} Energest\ value\ of\ node = \sum LPM \times 0.020 \times \frac{3}{32768} \\ + \sum CPU \times 0.426 \times 3/32768 \\ + \sum T_x \times 17.4 \times 3/32768 \\ + \sum R_x \times 18.8 \times 3/32768 \end{aligned} \quad (13)$$

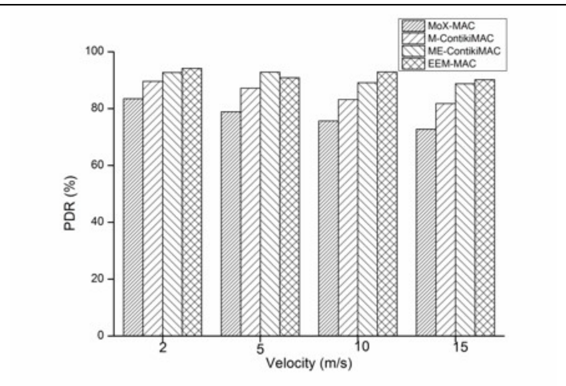
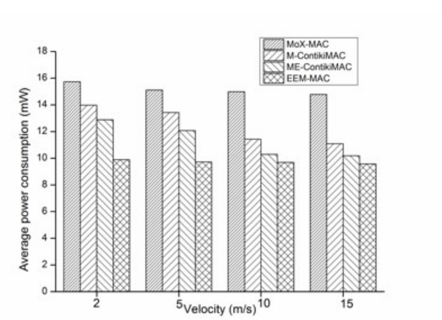
Table. 3 CC2420 Radio Current Consumption parameters

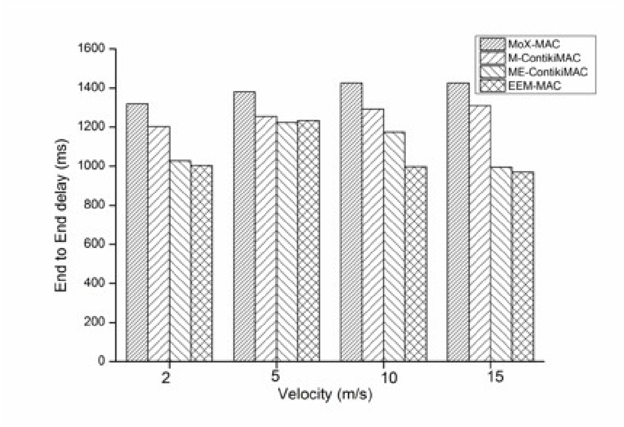
Mode	**Current Consumption**
Idle	426 µA
Sleep	20µA
Transmit	17.4 mA
Receiver	18.8 mA
Active	8.65mA
Power save mode	250µA

The performance of EEM-MAC compared against MoX-MAC, M-ContikiMac, and ME-ContikiMac concerning varying with four different velocities such as normal (0-2 m/s), low (2-5 m/s), medium (5-10 m/s), and high (10-15 m/s) speed. Here the normal speed is considered as an ordinary walk inside a room/building and low speed represents a human walk in the ground/outdoor, medium speed represents running/jogging and high speed represents cycling. Based on the application we analyze our speed in two different mobility models namely the Random waypoint (RWP) and Random walk (RW) model. In this analysis, the static node transmits 1 packet per 30 seconds whereas the mobile node transmits (n-1) packets continuously before moving to another region. So that under mobility mobile node adopts a long preamble mechanism based on queue length with the smooth handoff.

Figure 9 shows the impact of speed in grid topologies under the RWP mobility model. Here results were obtained for MoX-MAC, M-ContikiMac, ME-ContikiMac, and EEM-MAC by varying between normal to high speed ((i.e.) 2m/s to 15m/s). Fig 9a shows an impact of varying speed on PDR over grid topologies under the RWP model respectively The average PDR in grid topology was found to be 23.87% improvement for the EEM-MAC as compared to MoX-MAC, 10.24% improvement for the EEM-MAC as compared to M-ContikiMac and 1.69 % improvement for the EEM-MAC as compared to ME-ContikiMac. Figure 9b shows the end-to-end delay and it observed that EEM-MAC performs better and reaches the sink faster by an average of 31.9% as compared to MoX-MAC and an average of 25.89% as compared to M-ContikiMac and 2.47% as compared to ME-ContikiMac by varying speed of the MNs. As shown in Fig. 9c, it is found that proposed EEM-MAC consumes on an average 54.44% less power as compared to MoX-MAC, on an average 15.88% less power as compared to M-ContikiMac and on an average 6.47% less power as compared to M-ContikiMac in the grid topology.

As the MoX-MAC uses random wakeup timing and poor synchronization between mobile nodes makes less performance in a network. In M-ContikiMac protocol adopt anycast method transmission which leads to more duplicate packets and poor reconnection in a network. In the case of ME-ContikiMac, by introducing packet duplication and delay enhancement mechanism perform better under normal and low speed but it underperforms at high speed. In ME-ContikiMac one major limitation is that when multiple MN under mobility, before completing the ongoing burst transmission MN changes its potential sink/static receiver node several times due to poor reconnection/collision. For this reason, many reconnections during mobility result in high energy consumption, unwanted wakeup (ideal state), handover delay, and packet loss. By contrast, EEM-MAC reduces reconnection and handover delay by adopting a long preamble priority-based duty cycle without affecting any schedule. Once the ongoing transmission is completed it will select the next-hop based on the node length information. To validate the precision under mobility environment DAMN mode makes the better improvement in all conditions (channel contention and collision) in an MWSN environment.

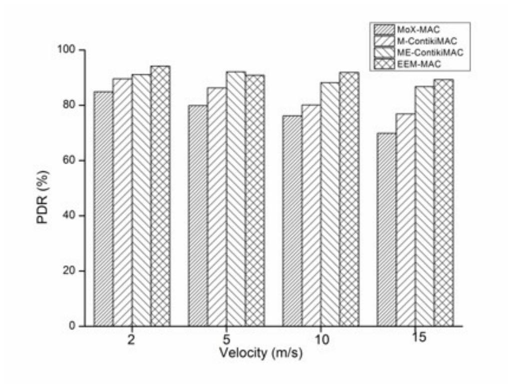
	
(a)	**(b)**



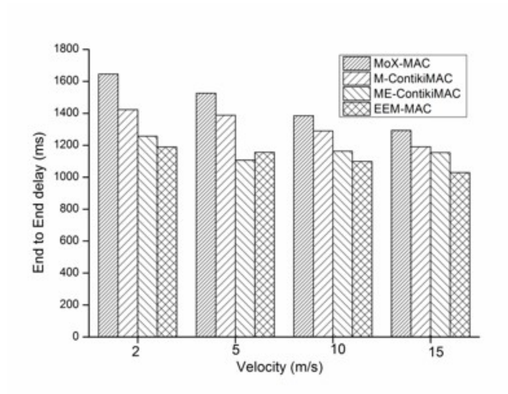
(c)

Figure. 9 Impact of speed on (a) PDR (b) End to End delay and (c) Energy consumption used in grid topology under RWP mobility model

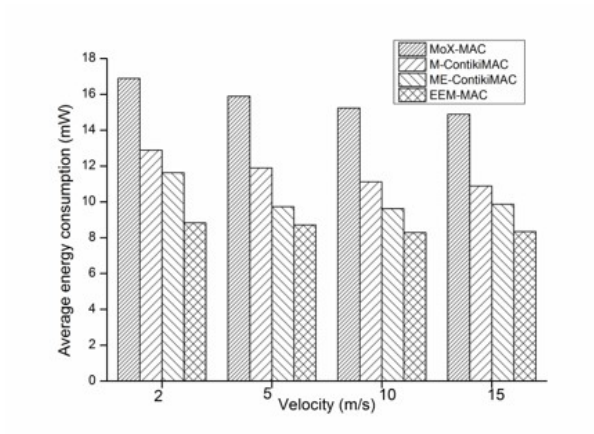
Figure 10 shows the impact on varying speed in random topologies under the RWP mobility model which is sub-categorized concerning PDR, end-to-end delay, and energy consumption. Fig.10a shows the performance concerning PDR. It is observed that the average PDR in the random topology is found to be 27.7% improvement for the EEM-MAC as compared to MoX-MAC, 16.10% improvement in the EEM-MAC against M-ContikiMac, 2.86% improvement in the EEM-MAC against ME-ContikiMac. From Fig. 10b, it is found that EEM-MAC packets reach the sink/potential static node faster than MoX-MAC by an average of 25.55%, an average of 15.53% as compared to M-ContikiMac, and an average of 12.05% as compared to ME-ContikiMac in random topology. As illustrated in Fig. 10c, shows the average power consumption of the node. In EEM-MAC power consumption is less and it was found to be 8.35 mW; on an average 43.92% less power as compared to MoX-MAC, on an average 23.33% less power as compared to M-ContikiMac, and on an average 15.40% less power as compared to ME-ContikiMac in the random topology. This is because of the dynamic preamble duty cycle mechanism once the nodes access the channel for data transmission it informs the neighboring node to go to sleep state based on the queue length of the ongoing node. This makes an EEM-MAC achieve maximum lifetime and reduce collision.



(a)



(b)

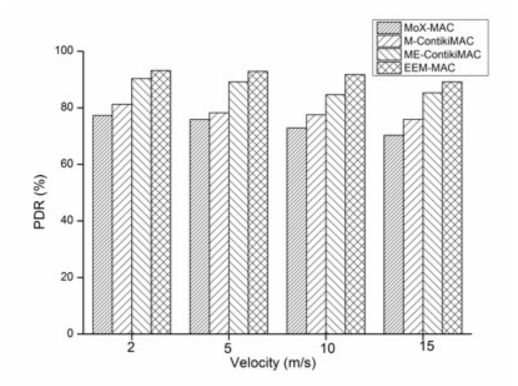


(c)

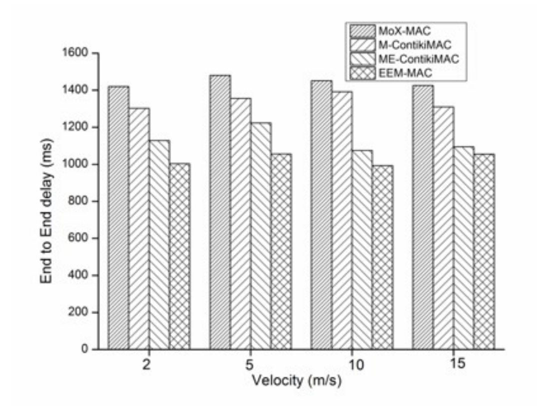
Figure. 10 Impact of speed on (a) PDR (b) End to End delay and (c) Energy consumption used in random topology under RWP mobility model

Figure 11 shows the impact of varying speed in grid topologies under the RW mobility model. The average PDR in the grid topology was found to be 26.86% improvement for the EEM-MAC as compared to MoX-MAC, and 17.52% improvement for the EEM-MAC against M-ContikiMac and 4.54% improvement for the EEM-MAC against ME-ContikiMac as shown in Fig 11a. Fig. 11b, it was found that EEM-MAC has a quick response by an average of

35.09% as compared to MoX-MAC, an average of 24.13% as compared to M-ContikiMac, and an average of 3.73% as compared to ME-ContikiMac by varying speed. Figure 11c, showing the average power consumption of the node, in the MoX-MAC it was 15.55 mW; in the case of M-ContikiMac, it was 14.83 mW and the ME-ContikiMac consumed an average of 12.69 mW, whereas, in the EEM-MAC, it was 9.43 mW for the transmission of the packets in a network. The reason behind this is that EEM-MAC reduces the unwanted wakeup and several reconnections under mobility.



(a)



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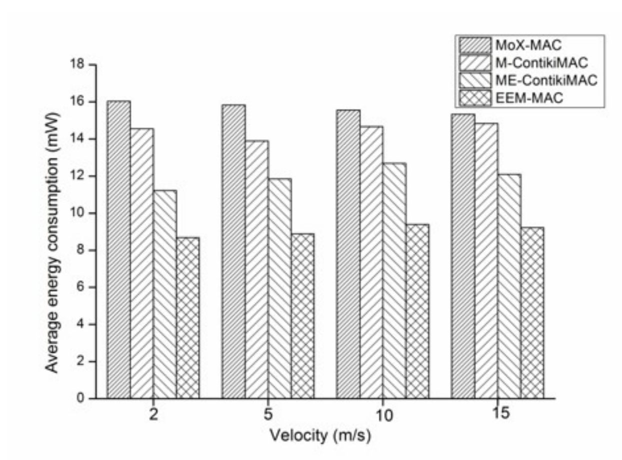
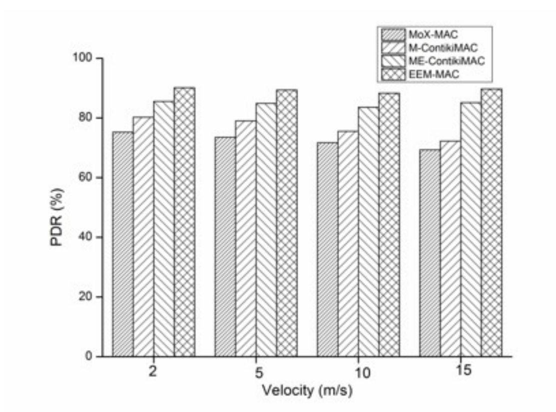


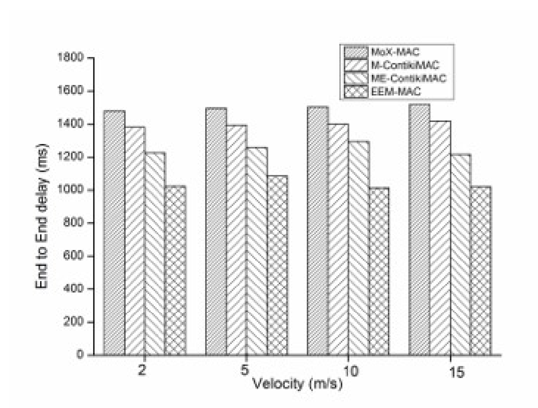
(c)

Figure. 11 Impact of speed on (a) PDR (b) End to End delay and (c) Energy consumption used in random topology under RW mobility model

Figure 12 shows the impact of varying speed in random topologies under the RW mobility model. Figure 12a shows the performance concerning the PDR. The average PDR in the grid topology was found to be 29.44% improvement for the EEM-MAC as compared to MoX-MAC, and 24.18% improvement for the EEM-MAC against M-ContikiMac and 5.38% improvement for the EEM-MAC against ME-ContikiMac. In Fig. 12b, it was found that EEM-MAC packets reach the destination quickly by an average of 32.90% as compared to MoX-MAC, an average of 39.28% as compared to M-ContikiMac, and an average of 16.33% as compared to ME-ContikiMac by varying normal to high speed. As shown in Fig.12c, it can be observed that the proposed EEM-MAC protocol consumes less energy consumption when compared to all protocols this is achieved by minimizing reconnection and reduced unwanted wakeup under mobility.



(a)



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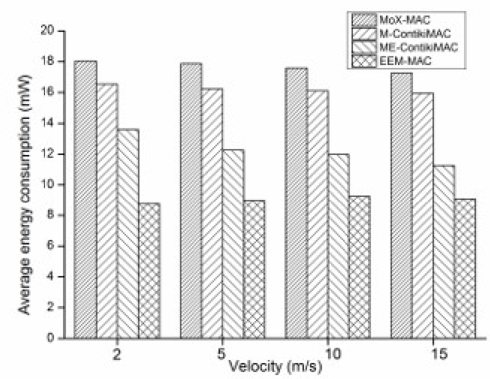

(c)

Figure. 12 Impact of speed on (a) PDR (b) End to End delay and (c) Energy consumption used in random topology under RW mobility model

5. Conclusion and future work

In this paper, we introduced EEM-MAC intended to improve the battery life of a sensor node by minimizing the idle radio listening time and channel contention under both static and mobility conditions. Here the proposed mobility aware EEM-MAC protocol has two-phase namely static synchronization and mobility handling phase to improve packet reception, delay, and duty cycle performance under heavy traffic. EEM-MAC implements a queue length-based access priority for static nodes, and RSS assisted long preamble-based access priority for mobile nodes without any control packet overhead. Furthermore, under heavy traffic, the initial node information may fail due to collision and interference. To overcome this, we introduced DAMN mode for accurate precision, and low-cost mobility detection this enables smooth handovers in both static and mobile networks in MWSNs.

Furthermore, EEM-MAC implements a receiver coordinated power-saving mode or sleep state among the competing neighboring nodes that significantly reduces the channel contention and idle radio listening time. Simulation results reveal that the proposed EEM-MAC attains a considerable reduction in average power consumption, packet latency, and improvement in PDR performance against the existing MoX-MAC, M-ContikiMac, ME-ContikiMac under two different scenarios and mobility model. The proposed EEM-MAC algorithm extremely suitable for delay-sensitive mobile IoT applications and future work focused on customizing EEM-MAC for complex high-speed vehicular IoT environments.

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