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RESEARCH ARTICLE

Mobility Induced Multi-Hop LEACH Protocol in Heterogeneous Mobile Network

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ABSTRACT Heterogeneous mobile networks are a vital cue for Internet of Things (IoT) networks and their applications. Therefore, an optimal routing protocol is essential for the heterogeneous network to realize energy efficiency and robustness. However, designing an optimal routing protocol is more complex due to uneven energy depletion and dynamic event generation. The complexity further increases with the node mobility. In this context, the multi-hop routing approach with a controlled mobility pattern provides an energy efficient network by improving memory and storage utilization. This work proposes a new energy-efficient model for heterogeneous network, considering the effect of mobility and residual energy of nodes for cluster head selection in multi-hop-LEACH (M-LEACH). The performance of the proposed mobility induced multi-hop LEACH (Mob M-LEACH) protocol is further compared with existing baseline methods. The robustness of the network is evaluated considering static and dynamic environments for multiple network technologies. The simulation results show that the proposed method reduces network latency by 25% and enhances the throughput by 75%, improving energy consumption and network lifetime when compared with the state-of-art methods.

INDEX TERMS Energy consumption, heterogeneous mobile network, Internet of Things, M-LEACH, network convergence indicator.

I. INTRODUCTION

Internet of things (IoT) connects various heterogeneous devices for immediate access of information with high efficiency. It is programmed with embedded technology, which senses and controls the communication among the devices to form an intelligent network. IoT can be realized as a unified infrastructure to support a diverse set of applications for urban and semi-urban development, which uses advanced communication technologies. With the increase in the number of intelligent devices in the networks, efficient energy and memory utilization have become the critical network development requirement. Moreover, scalability, low latency, high throughput, better device heterogeneity, and proper resource management are some of the prime paradigms for an efficient IoT network development with improved quality of service (QoS) [1]. The most common wireless networks use IEEE 802.15.4 standard or Zigbee, WiFi network with standard IEEE 802.11 and S-MAC protocols in radio access set up for cloud access in IoT. Further, challenges for implementing IoT applications involve node density, hardware requirements, mode of communication, power utilization, and computational cost [2].

Above mentioned issues can be addressed by adopting primitive technological changes in routing protocol to enable QoS requirements. In [3], a routing algorithm is developed to achieve high data delivery with less energy consumption, but it cannot be applicable to IoT applications. The multi-hop heterogeneous network, the building block for the IoT application, is illustrated in Figure 1, comprising of sensing devices of various kind. All the devices are interconnected to each other and finally connected to a centralized

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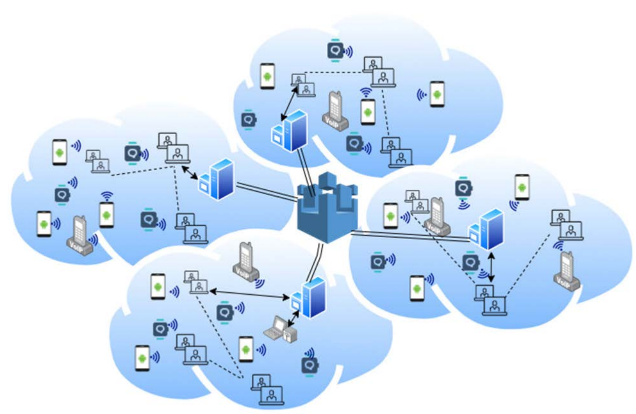

FIGURE 1. Illustration of a multi-hop heterogeneous network.

TABLE 1. Acronyms.

Acronym	Full Form
CH	Cluster Head
CI	Convergence Indicator
IoT	Internet of Things
LEACH	Low-energy adaptive clustering hierarchy
MAC	Medium Access Control
$M-LEACH$	Multihop Low-energy adaptive clustering hierarchy
Mob MLEACH	Mobility induced Multihop Low-energy adaptive clustering hierarchy
NS3	Network Simulator version 3
PRR	Packet Reception Rate
QoS	Quality of Service
RSSI	Received Signal Strength Indicator
SMAC	Sensor-MAC protocol
TDMA	Time Division Multiple Access
TDMA	Time Division Multiple Access
TCP	Transmission Control Protocol
UDP	User datagram Protocol
WiFi	Wireless Fidelity
ZHLS	Zone Based Hierarchical Link State Routing Protocol
ZSEP	Zonal-Stable Election Protocol

server. The devices are unique in terms of their functionality, operating frequency, data transmission rate, and energy utilization, which leads to a heterogeneous network [4]. On the contrary, for homogeneous network the development of the routing algorithms is unambiguous for remote sensing applications [5]. However, algorithms for energy efficient heterogeneous networks suffer from faster data delivery [6]. Therefore, wireless communication and networking include sensing, rate control, routing, MAC, and wireless signal processing. The network, as mentioned earlier, characteristics are essential in designing an efficient and robust network [7].

Mobile sensors induce random mobility patterns, which involve the movement of one or more sensing nodes for accessible and faster data communication with the main challenges in such a network control overhead and efficient energy utilization [8]. The mobility of sensor nodes does not guarantee that all nodes expend energy with same rate. But with proper design and selection of the node mobility, the network overhead is reduced [9]. Therefore, the parameters like energy consumption, latency, network lifetime needs prior attention during the development of the routing protocol for heterogeneous networks.

TABLE 2. Symbols and notations.

Variables	Meaning
P_t and P_r	Transmitter and Receiver Power
G_t and G_r	Gain of transmitter and Receiver antenna Gain
h_t and h_r	Height of Transmitter and Receiver Antenna
E_C	Energy consumed in the network
E_c^i	Energy consumption of i^{th} node
E_{LP}^i	Energy consumed in listen period for i^{th} node
E_{SP}^i	Energy consumed in sleep period for i^{th} node
E_{TX}^i	Energy consumed in transmit period for i^{th} node
E_{RX}^i	Energy consumed in receive period for i^{th} node
k	Number of bits
N	Number of nodes
EDA	Corresponding Interval at Transmitter and Receiver level
I_{LP} and I_{SP}	
t_{LP} and t_{SP}	Corresponding Time at Transmitter and Receiver level
E_{elec}	Energy utilized per packet
E_{DA}	Energy spent due to Data Aggregation for one bit packet
ϵ_{fs}	Free space path loss factor
ϵ_{mp}	multipath loss factor, amplifier characteristics constant.
E_{nn}, E_{an}, E_{sn},	Normalized Energies of Normal node, Advanced Node and Super node Respectively.
α and β	% of advanced and super nodes
γ^a and γ^s	% of energy allocated for advanced and super nodes
d_0	Distance Threshold
E_{mob}	Energy of mobile node
E_{grp}^l	Energy of cluster for lth iteration
E_{net}	Network energy of a group after the selection of the optimum CH.
E_{ch}	Energy associated with the selected CH
E_{nch}	Total energy of the cluster excluding the CH.
E_{tot}	Total Energy in the group due to all nodes along with sleep and listen state
d_{to_CH}	Distance between the node and the CH
d_{to_sn}	Distance between the CH and super node.
E_{res}	Residual energy in each group
E_{avg}	Average energy dissipated in the group
E_{nnc}	Energy consumption by Normal node
E_{anc}	Energy consumption by Advanced node
E_{snc}	Energy consumption by Super node
E_{EC}	Base Station Energy Consumed

A. NOTATIONS

Table 1 is associated with the Acronyms used and its full form used throughout the paper., Similarly Table 2 represents the list of symbols along with their meaning as indicated in the paper.

TABLE 3. Comparison of our contribution to the literature.

Related Literature	Features					
	Heterogeneity	Node Mobility	Energy Efficiency	Network Lifetime	Optimization	IoT Applications
[10]			✓	✓		✓
[11]	✓					✓
[12]			✓	✓		✓
[14]	✓				✓	
[15]	✓		✓	✓		✓
[18]	✓		✓	✓	✓	
[20]	✓		✓	✓	✓	✓
[21]			✓			✓
[26]	✓	✓	✓	✓		
[27]	✓	✓	✓			✓
[28]	✓	✓	✓		✓	
[32]	✓		✓	✓	✓	✓
[33]			✓	✓	✓	
[34]			✓	✓	✓	
Proposed (Mob M-LEACH)	✓	✓	✓	✓	✓	✓

1) MOTIVATION AND CONTRIBUTION

One of the major constraints of smart IoT applications is energy efficiency. Various multi hop based heterogeneous network resolves it up to some extent; however, creating the hotspot problem near sink node. It leads to implement mobile heterogeneous nodes as and when required. The major motivation behind this work is to develop an energy efficient mobility induced routing protocol suitable for smart IoT based heterogeneous network such as smart automation system, smart home appliances, smart agriculture system etc. We have implemented and evaluated the system model for a heterogeneous mobile network over LEACH Routing protocol and analyzed its performance with some state-of-the-art protocols. The system model proposed is introduced to resolve the challenges like energy efficiency and network longevity for which it offers better solution than MLEACH and ZHLS. This paper is based on the following aspects

- To offer a tier-based architecture based on how energy is distributed among the nodes, simulating the various node types that make up an IoT network, including normal nodes, advanced nodes, and super nodes.
- To give such scalable and highly available infrastructure and services that emphasis on service content cluster-based support.
- To offer seamless mobility as needed to the advanced nodes within a clustered group and the overall heterogeneous network.
- To offer a productive sleep schedule-based channel assignment technique that, by leveraging infrastructure computation, enables such devices advanced features.

The main contributions of our proposed model are explicitly obtained from the literature review as discussed in next section and at glance being cited in Table 3.

2) ORGANIZATION

The rest of the paper is structured as follows. Section II gives a brief overview of the related literature in the development of routing protocols. The system model is detailed in Section III. Section IV describes the proposed mobility induced multi-hop routing protocol for heterogeneous network. The performance of the proposed protocol is evaluated and compared with the state-of-art protocols in Section V. Section VI concludes the paper with the future scope.

II. RELATED WORKS

The significant challenges of IoT are to maintain the database, which contains information such as energy utilization, cost, lifetime, and maintenance about the massive sensors of different categories deployed at various geographical locations [10]. This leads to a heterogeneous network, where the nodes are unique in terms of their functionality and energy profile. In such a scenario, energy management plays a crucial role in network lifetime and maintenance. In this context, various mechanisms are developed which are suitable for different IoT applications [11]. The power management aspects of IoT devices for increasing efficiency are discussed in [12]. Improvement in spectral efficiency, scalability, economy, and network lifetime are essential factors that lead to the initialization of heterogeneous networks over homogeneous counterparts. The dynamic simulation of adaptive modulation and coding is used for resource allocation and the signal to noise ratio gives the estimated throughput [13].

The primary goal of any sensor network is to route the packets through the proper channel and gateway towards the server, leading to various routing protocol initiation. However, depending on different routing protocol strategies, good optimization instead of energy utilization and shortest path coverage are a prime focus area for researchers [14]. However, the performance of these techniques decreases in the heterogeneous network. Due to direct transmission of data towards the sink, the nodes nearby it dies out more quickly, creating hotspots [15]. Shakkottai et al. quantified the degrading consequences of such pattern and used these parameters as sufficient and necessary criteria in terms of adaptive sensing basis of heterogeneous ad hoc networks [16]. Moreover, the sensing coverage and network connectivity is an NP-complete sub problem that ensures the transmission range is at least twice the sensing range. Further, machine learning-based approaches have been adopted to address the challenges in the WSN network [17], but the training complexity of such approach limits the practical implementation.

Fang et al. [18] introduced an energy harvesting formula for next generations multiple access systems. They exploit a pair of sleep scheduling policies with multiple access techniques searching for an optimal solution using linear search-based algorithm. The multiple vacation and startup threshold policy reduced the power consumption but it is to static networks. The authors have investigated the peak age of information in underwater sensor networks using the sleep scheduling technique. The active queue management policy compresses the packets with large waiting time [19]. Although, it analyzed the energy cost of network but mobility is not assigned to the nodes. Thair et al. [20] have introduced a dynamic hybrid MAC protocol for high density IoT communications with IEEE 802.15.4. However, they utilized the traditional Markov model with TDMA technique which is not energy efficient.

To maintain the IoT standard, various researchers have focused on device energy conservation methods in the form of clustering, which involves cluster head (CH) selection criteria as discussed in [21]. The heterogeneous network model also emphasizes multiple access strategy, propagation effects, routing, and mobility pattern criteria for a better quality of service. Out of these available models, the heterogeneous network model is based on leveled architecture. However, such network architecture assumes the network to be flat and static [22]. The node heterogeneity on the basis of computation, communication, and link connectivity is addressed in various literature. The level of node heterogeneity decides the variants of Sensor Nodes to be deployed in the network field [23]. Parallelly, non-CH based methods are developed for both homogeneous and heterogeneous networks. In this context, a non-CH based routing protocol is designed [24], but this protocol is applicable only for the homogeneous network without considering node mobility. Further, the categorization of sensor nodes based on performance metrics along with node heterogeneity has been extended by the author in [25]. In the context of heterogeneous WSN, Zonal-Stable Election Protocol (ZSEP) protocol has been developed. ZSEP is a hybrid protocol that transmits the data either directly to the base station or through the CH [26]. Enhanced multipath LEACH (M-LEACH) protocol has been developed for efficient selection of the CH and the optimum path selection for the data transfer [27]. In [28] a zone-based hierarchical link-state (ZHLS) has been proposed where the data transfer does not restrict by the cluster head selection. The whole network is divided into non-overlapping zones. The nodes are connected to within in the zone and the zones are connected as a whole.

The CH selection, as discussed in several papers, is based on uniform and no uniform energy selection as in ZSEP [26] and ZHLS [28]. Sharma et al. [29] have expressed the CH selection criteria in a mobile ad hoc network where the routing is selected from some specific nodes within a zone with certain mobility. But it is not so energy efficient in that aspect. Some energy-efficient homogeneous network like M-LEACH [27] involves the movement of non-cluster head nodes with remaining energy in the group helps in selecting the appropriate cluster head. But it lacks the tiered model for network design which makes the network unstable quickly. Even though a better stable CH selection protocol is claimed by [30]. However, this protocol has two ways of communication in direct mode and via advanced node that makes the model inappropriate in the presence of node mobility which restricts the network's throughput [31]. Furthermore, the significant contributions made by various researcher provides a key insight on the techniques and models required to implement an energy efficient clustered heterogeneous network.

Chang et. al [32] discussed on the dynamic hierarchical protocol based on optimization to balance the energy consumption of sensor nodes and improve network lifetime. However, the authors have analyzed for a limited network size for limited frequency band. Various performance metrics as discussed in [33] provides a survey on optimization strategies. In this work we have analyzed network size, energy consumptions, latency and lifetime as the basic criteria for comparison of our proposed model with other routing models. Although various topology control strategies proposed by authors in [34]., but the optimization rule is applied to static network. However, we have considered mobile model.

The primary motivation behind this work is to exploit the heterogeneity in energy utilization to develop an energy-efficient protocol for IoT applications. The significant contribution of this proposed work is summarized as follows. The paper aims to resolve the issue of energy consumption, latency, and network lifetime of heterogeneous mobile networks. The higher tier heterogeneous nodes divide the network into multiple partitions to resolve the unreachable route problem. A system model for level based heterogeneous mobile network is proposed that signifies a better QoS. In this context, a three-tier heterogeneous network model has been proposed. Based on the energy, the nodes are categorized as normal, advanced, and super nodes. From the set of advanced nodes, the CH is selected, leading to a robust new protocol in terms of stability and throughput. The energy and node mobility criteria are imposed as constraints in the heterogeneous network to calculate the threshold and received signal strength indicator. The optimum threshold is obtained considering the simultaneous effect of mobility and energy on the heterogeneous network. The performance of the proposed routing protocol is evaluated by varying the node density using metrics such as end-to-end delay, energy consumption, and throughput. The proposed routing protocol is compared with other routing protocols of tier-based heterogeneous networks under the stationary and dynamic condition of regular nodes with respect to stationary and mobility induced M-LEACH implementation.

III. SYSTEM MODEL

An IoT Network model is based on an internet protocol model with five layers of implementation. The system model is considered to design and implement an IoT architecture, with each layer having a specific approach. The proposed model, as shown in Figure 2 indicates the parameter specification model of each layer required to develop an IoT network.

The characteristic models of different layers are described in the subsequent sub-sections.

Following assumptions are made for node deployment and link establishment in the network.

(i) The nodes are deployed in the network maintaining heterogeneity in the energy, i.e., the nodes are distinct in terms of the energy contained.

(ii) Based on the energy levels, the nodes are classified as super, advanced, and normal nodes. The super node is unique and has maximum energy. It is most likely to be at the geometric center of the network.

(iii) The advance nodes have less energy than the super nodes and are deployed such that the clusters will contain at least one of them.

The links between two nodes (with the same or different energy levels) are identical and symmetric.

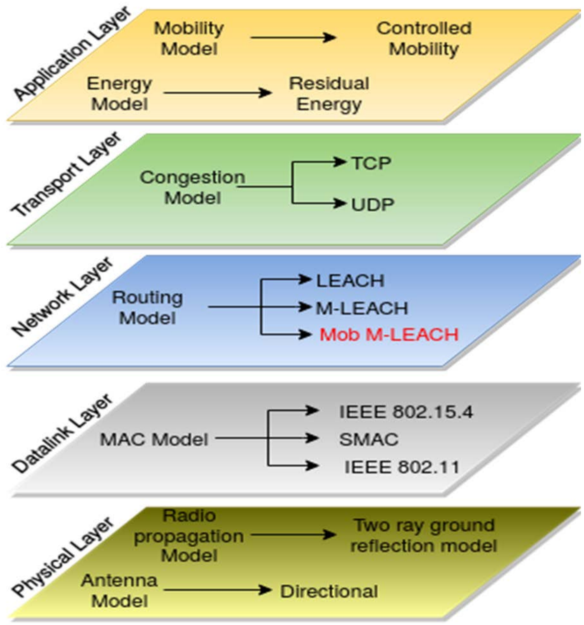

FIGURE 2. Block diagram representation of system model for IoT devices.

A. RADIO PROPAGATION MODEL

The connections between the entities are established based on the channel estimation strategy using the radio propagation model, which depicts the physical aspect of the IoT network. In this context, a two-ray ground reflection model is chosen to improve the probability of accurate prediction of the received power. Since the IoT network operates at a high signal frequency, the two-ray ground reflection model does not depend on the frequency. Further, when a significant distance separates the nodes, the operating frequency doesn't affect the received power and path loss. The received power P_r describes the received signal strength indicator (RSSI) and is expressed as [35]

$$P_r = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} = \frac{P_t}{L} \quad (1)$$

where, P_t represents the transmitted signal power, G_t and G_r represent the gain of the transmitter and the receiver antenna when placed at a height of h_t and h_r respectively. The distance between the nodes is denoted by d and $L = \frac{d^4}{G_t G_r h_t^2 h_r^2}$ being the path loss.

B. MAC MODEL

Efficient resource management is highly essential for the implementation of the MAC model. In this context, sleep-active time schedule, energy saving, synchronization, and correct management of heterogeneous information are managed in implementing the MAC model. This approach is implemented by assigning different medium access priorities to each information.

To enable low power, low cost, and low data rate communication, the narrow-band IoT gives the LTE design with

TABLE 4. MAC Protocols for various wireless standard.

Standards	WiFi	S-MAC	Zigbee
Frequency	20-40MHz	1GHz	915MHz, 868MHz, 2.4GHz
Data rate	650 Kbps	500Kbps	250Kbps
Average frame size	600bits	127bytes	127 bytes
Slot Response	Reservation scheme	Sleep-awake scheme	GTS scheme
Slot time	52 μsec	106 μsec	192 μsec

changes in resource scheduling in Medium Access Control (MAC) layer [36]. The future heterogeneous wireless network for 5G communication involves the combination of WiFi (IEEE 802.11), SMAC, Zigbee (IEEE 802.15.4) as standard building blocks [37]. The standards used are characterized in Table 4 to indicate resource utilization with network lifetime improvement.

C. ROUTING MODEL

An optimal routing model is required for efficient inter node communication in the heterogeneous multi-hop network. This routing model is constrained by packet loss, bandwidth, and packet transmission delay. These metrics are considered for optimal path selection between nodes to CH and from CH to Sink [38]. Further, the CH is selected by imposing a threshold on the advanced nodes for implementation of the routing model [39]. In this work, a new CH selection algorithm is proposed and compared with the existing stationary and mobility induced heterogeneous routing models.

D. CONGESTION MODEL

The heterogeneity restricts the performance of the transport layer protocols (TCP and UDP) in the application layer and mobility in the heterogeneous IoT network. TCP designed with fair sharing and overload protection of available resources made suitable to apply congestion control and allowed the Internet to scale up from tens to several millions of hosts [40]. Therefore, some flexibility with minor receiver-based modifications to TCP protocol is implemented for well-functioning congestion control in IoT networks. The scheduling constraints and virtual queue concept ensure system stability with congestion control in heterogeneous network [41].

E. ENERGY MODEL

Heterogeneous networks incorporate different energy levels depending on the node's deployment. The energy model is based on the network's total energy, including the resource utilized by cluster head or advanced node and non-cluster head or normal nodes. The radio energy model as depicted in Figure 3 describes the energy distribution within a node that consumes energy E_C.

The energy consumed in the network is represented as $E_C = \sum_{\forall i \in N} E_c^i$, and

$$E_c^i = E_{LP}^i + E_{TX}^i + E_{RX}^i + E_{SP}^i$$

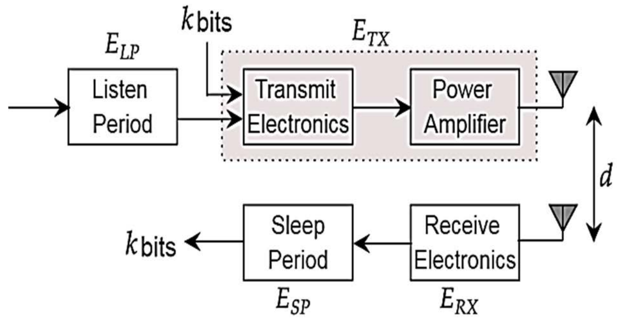

FIGURE 3. Energy model for the sensor nodes.

$$= k \left(I_{LP}^i t_{LP} + E_{TX}^i + E_{RX}^i + I_{SP}^i t_{SP} \right) \quad (2)$$

where, E_c^i represents the energy consumption of i^{th} node, which is obtained by combining the corresponding energy consumption in the listen period E_{LP}^i, sleep period E_{SP}^i, the energy consumption due to transmit E_{TX}^i, and consumption in the receiver E_{RX}^i. Further, the transmitting and receiving energy is derived from the energy consumption in by the electronics devices in the T_X/R_X unit. The packet length is denoted by k bits. The periodic interval of the listen and sleep period is represented as I_{LP} and I_{SP} respectively. The corresponding time for the listen and sleep period is denoted as t_{LP} and t_{SP}. Defining the E_{elec} as the energy per packet within the E_{TX} and E_{RX} at a distance d is expressed as

$$E_{TX} = \begin{cases} kE_{elec} + k\epsilon_{fs}d^2, & d \le d_o \\ kE_{elec} + k\epsilon_{mp}d^4, & d > d_o \end{cases} \quad (3)$$

$$E_{RX} = kE_{elec} + kE_{DA} \quad (4)$$

where, E_{DA} is data aggregation energy for one-bit packet. The distance between transmitter and receiver d depends on distance threshold $d_0 = \sqrt{\epsilon_{fs}/\epsilon_{mp}}$. ϵ_{fs} represents free space path loss factor and ϵ_{mp} represents multipath loss factor, amplifier characteristics constant. The normalized energies associated with normal node is E_{nn}, advanced node is E_{an} and super node is E_{sn}, and are defined as

$$E_{nn} = E_o; E_{an} = E_o \left(1 + \alpha\gamma^a\right); E_{sn} = E_o \left(1 + \beta\gamma^s\right) \quad (5)$$

where, E_0 refers to the initial energy allocated for the normal node. α and β represents the percentage of advanced and super nodes, whereas γ^a and γ^s are the percentage of energy allocated for advanced and super nodes respectively.

F. MOBILITY MODEL

The node mobility in a heterogeneous mobile network is monitored by the Received Signal Strength Indicator (RSSI) and Packet Reception Rate (PRR). The mobility pattern of an advanced node is then determined based on the energy consumption. In this work, we have considered a controlled mobility pattern for an advanced node whose RSSI level is below threshold level [42]. The topology management of mobile nodes is achieved such that the data from the clustered (advanced) node is delivered faster than the standard improving throughput and energy efficiency [27].

IV. PROPOSED SCHEME

The routing schemes like ZSEP [26] and ZHLS [28] involves zone based clustering method and M-LEACH [27] use a threshold parameter based clustering approach to design the network. However, to achieve proper resource utilization, improve network lifetime, and better QoS, the proposed scheme requires modification in internet protocol layer models. With the aid of mobility management and resource allocation, we presented a 3-tier energy efficient mobility induced heterogeneous routing scheme designated as Mob M-LEACH (Mobility Induced Multi-hop- LEACH) with essential modification in M-LEACH.

The objective of the proposed routing protocol is to improve the network lifetime. The routing algorithm is developed based on the clusters in the network herein. The data are routed through the concern CH. In the proposed method the CH selection is determined by the residual energy and node mobility. It is essential to obtain the optimal number of clusters and corresponding cluster heads in developing the energy-efficient, dynamic and stable protocol. This work selects the cluster head from the set of advanced nodes.

The selected cluster heads within a clustered group (combination of normal, advanced and super node) can be static or mobile depending on distance between CH and Super node. The network is dynamic, i.e., the cluster selection is dynamic based on advanced node mobility. Later considering the arrangement of the clusters and the presence of the super node, the network is further classified to cluster group as shown in Figure 4. The mobility in the network helps generate the well-connected network and manages the energy consumption by avoiding formation of hot spots near super node.

The CH is selected from the set of advanced nodes S_{an}. The advanced nodes are deployed in the network with predefined criteria, i.e., every cluster has at least one advanced node. The criteria also impact on energy and mobility. Furthermore, the mobility is decided from the advanced nodes' received signal strength indicator (RSSI). With a controlled mobility model of fixed velocity, the node becomes mobile if the node position is not suitable to obtain the required RSSI. The controlled mobility model for relay node is summarized as follows

(i) Each node acquires the information of the new position it has to reach when the reply of the request is received. The new position is on the straight line between the source and destination and each nodes will be positioned in an evenly distributed fashion. (ii) Each node that received a reply packet moves towards new position. Therefore, the network energy is also affected by the power consumption due to individual mobile nodes [43]. The energy dissipated by the mobile node (moving advanced node) is expressed as

$$E_{mob} = qd + \frac{1}{2}mv^2 \tag{6}$$

where q is the continuous friction loss in J/m due to the node movement, d is the distance travelled by the node in meters,

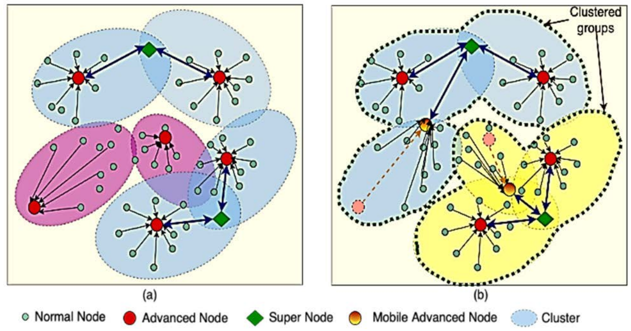

FIGURE 4. Schematic representation of (a) the heterogeneous network (b) grouping and clustering based on movement of advanced node.

v is the velocity of the mobile node, and m is the weight of the moving node. In every iteration the energy of a group E_{grp} is the sum of energy of the cluster E_C, energy of the super node E_{sn}, and the energy required for movement of the CH E_{mob}. For the l^{th} iteration the energy of the group is defined as

$$E^l_{grp} = E^l_C + E^l_{mob} + E^l_{sn} \tag{7}$$

The network energy of a group E_{net} after the selection of the optimum CH is expressed as

$$E_{net} = \sum_{l=1}^{L} E^l_{grp} = \sum_{l=1}^{L} E^l_C + E^l_{mob} + E^l_{sn} \tag{8}$$

where, L is the total number of iterations required to select the optimal CH. Considering p as the selection probability of an advanced node as CH, the energy of the cluster is expressed as

$$E_C \approx pE_{ch} + p\frac{N(1-\alpha-\beta)}{l}E_{nch} \quad \forall l = 1, 2, \ldots L \tag{9}$$

where, E_{ch} is the energy associated with the selected CH and E_{nch} is the total energy of the cluster excluding the CH. l represents the number of iterations required to find the optimum number of cluster head. α and β remain the same as in (5). Furthermore, E_{ch} and E_{nch} are defined as in [44].

$$E_{ch} = \begin{cases} kE_{elec}\left(\frac{\alpha N}{l} - 1\right) + kE_{DA}\frac{N}{l} + k\epsilon_{fs}d^2_{to\_CH}, & d \le d_o \\ kE_{elec}\left(\frac{\alpha N}{l} - 1\right) + kE_{DA}\frac{N}{l} + k\epsilon_{mp}d^4_{to\_sn}, & d > d_o \end{cases} \tag{10}$$

and

$$E_{nch} = kE_{elec} + k\epsilon_{fs}d^2_{to\_CH} \tag{11}$$

where, d_{to_CH} is the distance between the node and the CH and d_{to_sn} is the distance between the CH and super node. Further, the total energy E_{tot} in the group due to all nodes along with sleep and listen state is expressed as

$$E_{tot} = E_{LP} + E_{net} + E_{SP} \tag{12}$$

The number of clusters depends on the E_{tot} and the cluster probability p. The optimal number of clusters is obtained by differentiating E_{tot} with respect to l and equating to 0 and given as

$$l^* = \sqrt{N/0.765} \tag{13}$$

Using, the optimal probability obtained for the proposed model for computing threshold from the set of advanced nodes S_{an} in the network is expressed as

$$p^* = \frac{l^*}{N}(1+\gamma^a) \tag{14}$$

The new threshold value for Mob M-LEACH is calculated as

$$T = \begin{cases} \frac{p^*}{1-p^*\left(r mod\left(\frac{1}{p^*}\right)\right)} \frac{E_{res}-E_{avg}}{E_{avg}} & if\ CH \in S_{an} \\ 0 & Otherwise \end{cases} \tag{15}$$

where E_{res} is the residual energy in each group and E_{avg} is the average energy dissipated in the group. For each group the residual energy E_{res} and average energy E_{avg} are defined as

$$E_{res} = E_{an} - E_{tot} \tag{16}$$

$$E_{avg} = \frac{1}{\alpha N}\sum_{\forall S_{an}} E_{tot} \tag{17}$$

The network lifetime depends on the total energy consumption of the entire network, which ultimately depends on energy consumption due to nodes (normal, advanced, and super node) as well as Base Station energy consumed now defined using the following expressions.

$$E_{nnc} = \sum_{i=1}^{N(1-\alpha-\beta)} E_{nn}^{i} - E_{TX_{nn}} - E_{RX_{nn}} \tag{18}$$

$$E_{anc} = \sum_{i=1}^{\alpha N}(E_{an}^{i} - E_{TX_{an}} - E_{RX_{an}}) - \sum_{j=1}^{L} E_{tot}^{ij} \tag{19}$$

$$E_{snc} = \sum_{i=1}^{\beta N} E_{sn}^{i} - E_{TX_{sn}} - E_{RX_{sn}} \tag{20}$$

$$E_{EC} = E_{nnc} + E_{anc} + E_{snc} \tag{21}$$

In the proposed scheme, mobility plays a key role in the selection of the CH and enhances the performance of the M-LEACH routing protocol in the heterogeneous network. Hence it is named as mobility induced M-LEACH (Mob M-LEACH) routing protocol. The various steps involved in the implementation of Mob M-LEACH routing protocol for heterogeneous networks are presented in the Algorithm 1.

Algorithm 1 Implementation of Mob M-LEACH Routing Protocol

Require:
N : Number of Nodes
α : No. of advance nodes regulating parameter
β: Number of super nodes regulating parameter
m : % of energy level for advance nodes
$m1$: % of energy level for super nodes
E_0: Initial Energy of the network
Ensure:
$d_{N_{an}}$..: Distance between AN and NN
E_{mob} : Energy of mobile nodes
E_{res} : Residual energy of the network
E_{tot} : Total energy of the network
$N_{an:}$ Number of alive Nodes
k: Packets Received in bits
Initialization:
$E_{nn} = E_0$, $N_{an} = \alpha N$, $N_{sn} = \beta N$, r_{max}
$E_{an} = E_0(1 + \alpha m)$ and $E_{sn} = E_0(1 + \beta m1)$
for $r = 1$: r_{max} **do**
  for $i = 1$: N_{an} **do**
    if $d_{N_{an}} < RSSI$ **then**
      Calculate E_{mob}
      Calculate E_c *using* Ech, E_{nch}
    end if
    Calculate E_{grp}, E_{net}
end for
  Calculate E_{res}, E_{avg}
  Compute l^*, p^*, T
  if T (CH_i) =highest **then**
  Select $CH = N_{an}(i)$
  end if
end for
for $i = 1$: N **do**
  for $j = 1$: L **do**
  Calculate E_{tot} of Nij
  end for
end for
Calculate *Ennc, Eanc, Esnc*
Compute $E_{EC} = Ennc + Eanc + Esnc$

V. EXPERIMENTAL ANALYSIS

In this section, the performance of Mob M-LEACH is accessed by comparing it with other heterogeneous protocols using NS3 simulator [45]. The proposed work is carried out in Ubuntu 14.04 with 64-bit operating system and Intel(R) Core (TM) i5-8250U CPU @ 1.80GHz with more than 10000 simulations. The analysis is carried out with simulation of protocols with stationary and mobile nodes considering the simulation parameters as mentioned in Table 5. The performance metrics used for evaluation are end-to-end delay, throughput, energy consumption as discussed in [46].

The convergence indicator (CI) parameter measures the balanced energy consumption that determines the network convergence. Higher the CI better is the energy utilization in the network and it is expressed as

$$CI = \frac{LND - HND}{HND - FND} \tag{22}$$

where LND is the last node dead indicator, HND is the half node dead indicator and FND is the first node dead indicator. The network implementation is carried out with 20% of total nodes as advanced nodes and 10% of total nodes as super

TABLE 5. Simulation Parameters.

Parameters	Value
Number of nodes (N)	10,50,100,200,400,600,800,1000
Topography	$1000X1000\ m^2$
Communication range(d_0)	87 m
Simulation time	300s
No. of rounds(r)	10000
Initial energy of normal node (E_0)	1J
Packet Length	500 bits, 127 bytes
Mobility model	Controlled with velocity 10 *m/s*
E_{TX} (*nJ/bit*)	50
E_{RX} (*nJ/bit*)	50
E_{elec} (*nJ/bit*)	50
E_{DA} (*nJ/bit/frame*)	5
ϵ_{fs} ($pJ/bit/m^2$)	10
ϵ_{mp} ($pJ/bit/m^4$)	0.0013

TABLE 6. Average computation time (in seconds).

Network Size	ZSEP	M-LEACH	ZHLS	Mob M-LEACH
10	15.20	13.45	8.34	4.25
50	34.23	23.17	15.22	9.87
100	45.34	35.76	25.98	16.22
150	54.45	42.10	32.72	23.12
200	67.32	52.65	40.21	32.44
400	82.14	72.45	62.10	40.12
600	93.12	87.91	60.21	64.71
800	130.2	122.10	101.87	84.66
1000	165.2	145.29	125.20	92.20

nodes, rest as normal nodes. Similarly, the E_o is 20% high for advanced nodes and 30% high for super nodes. All the sensor nodes remain alive until their energy gets exhausted

A. END TO END DELAY ANALYSIS

A comparison among different heterogeneous protocols under static and mobile scenarios is shown in Figure 5 for the standard IEEE 802.11 (WiFi), S-MAC, and IEEE 802.15.4 (Zigbee), respectively. Figure 5(a) illustrates the protocol performance for IEEE 802.11, and it is observed that the heterogeneous stationary network exhibits more delay than its mobile counterpart. The variation is less for fewer nodes, but it becomes significant as the number of nodes increases.

At the same time, the control overhead also increases with an increase in node numbers. However, Mob M-LEACH gives a better performance than ZHLS [47] due to its CH movement criteria. Similarly, the performance of SMAC and IEEE 802.15.4 standards are shown in Figure 5(b) and (c), giving better performances under a mobile condition in the network. Mob M-LEACH outperforms in Zigbee standard with fewer delay variations than others. The proposed Mob M-LEACH protocol provides a low end-to-end delay in all the scenarios by varying the node density from sparse (10 nodes) to dense (1000 nodes) deployment. From these observations it can be summarized that for Mob M-LEACH routing protocol, the delay is minimized w.r.t state-of-art methods in all the

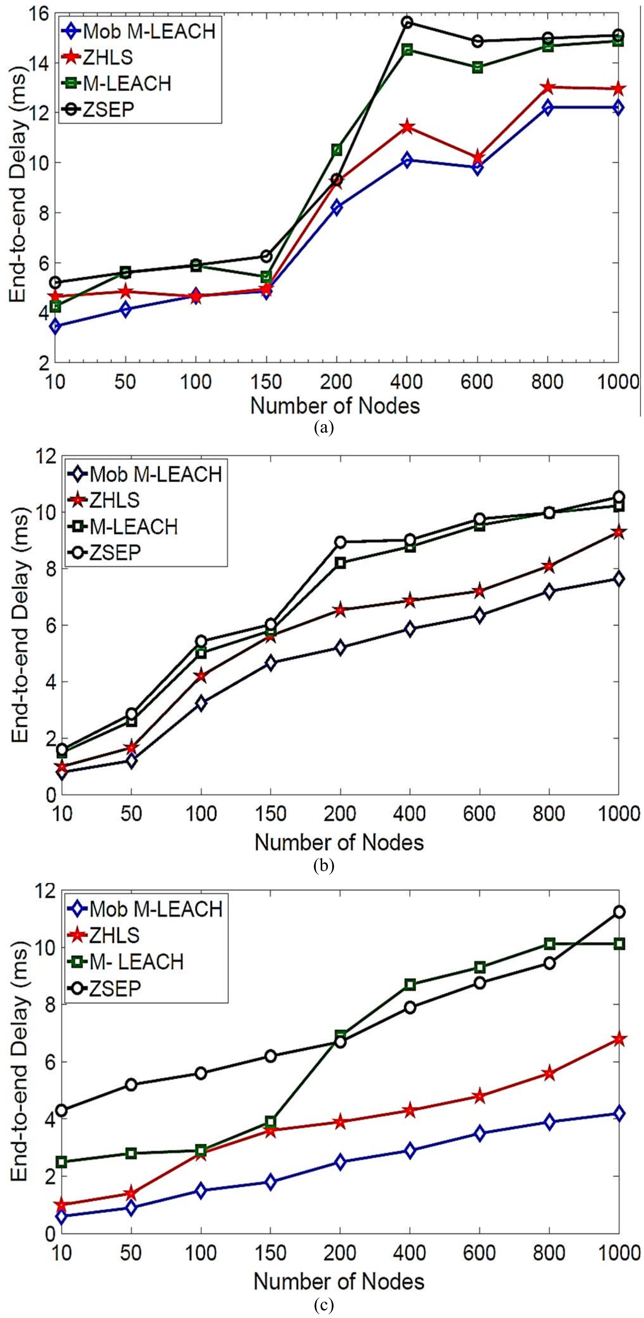

FIGURE 5. Analysis of End-to-end Delay (in ms) by varying the number of nodes in heterogeneous network for (a) WiFi, (b) S-MAC, and (c) IEEE 802.15.4 (Zigbee).

wireless standards. The computational complexity is based on the time required to execute the protocol as discussed in Table 6. From the table it is observed that the time required by the data to flow from target towards the sink is less in our Proposed Protocol than other state of art protocols. The mobility of the nodes makes faster delivery of data towards sink.

B. ENERGY CONSUMPTION ANALYSIS

The residual energy of nodes decides the lifetime of the heterogeneous network, making energy consumption analysis

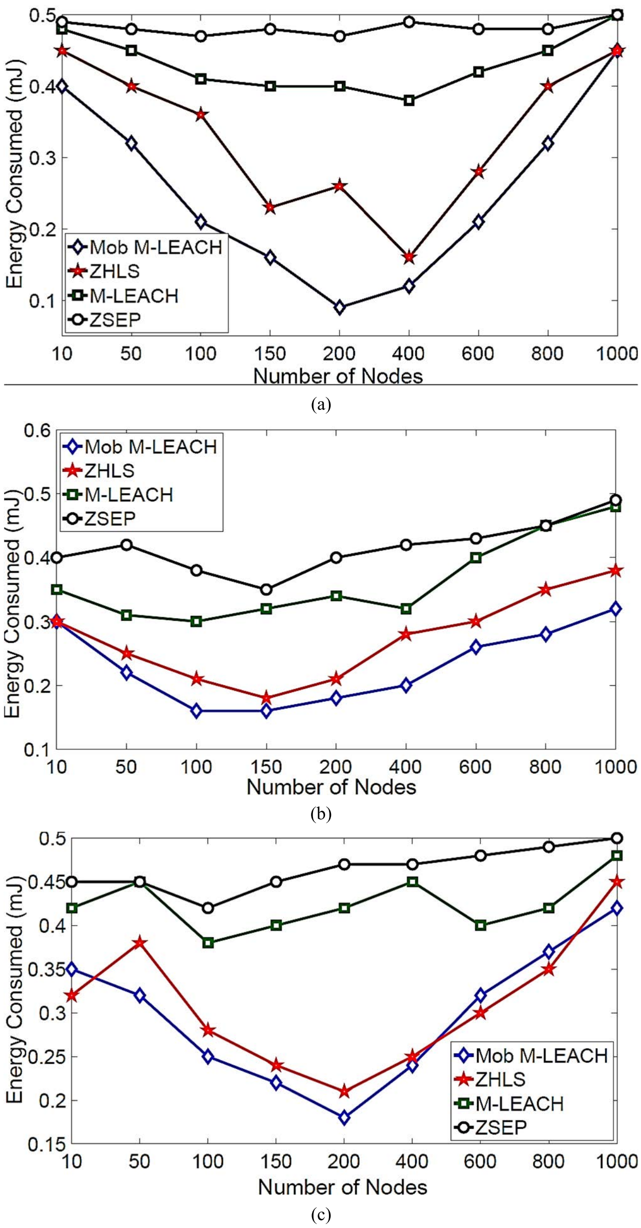

FIGURE 6. Analysis of Energy Consumption (in mJ) by varying the number of nodes in heterogeneous network for (a) WiFi, (b) S-MAC, and (c) IEEE 802.15.4 (Zigbee).

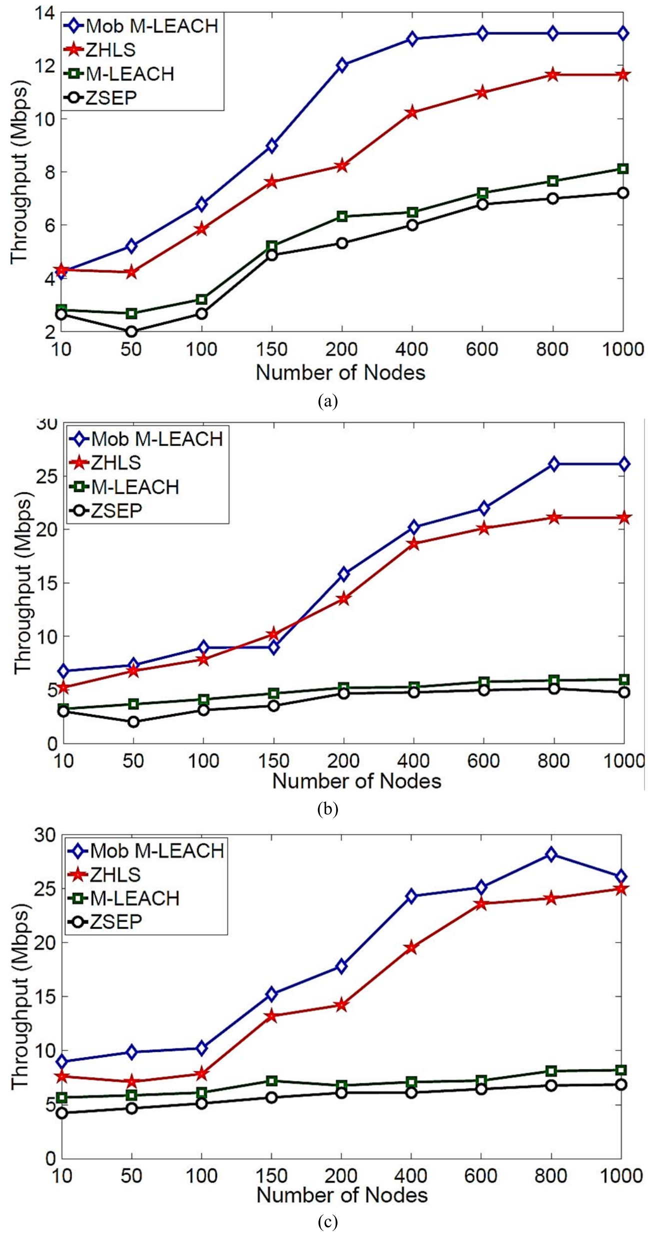

FIGURE 7. Analysis of Throughput (in Mbps) by varying the number of nodes in heterogeneous network for (a) WiFi, (b) S-MAC, and (c) IEEE 802.15.4 (Zigbee).

important. Figure 6 shows the energy consumption by the nodes in different scenarios. Less is the energy consumption; more is the residual energy and also increases the network lifetime. As shown in Figure 6 the energy consumed by the network decreases up to 200 nodes and then increases when the number of nodes is more than 200. It is due to the fact that at a smaller number of nodes, the reachability is less, so searching for an appropriate forwarding node takes more energy. The Energy consumption for the routing protocol depends on the energy due to clusters and non-clusters as described in the algorithm. However due to heterogeneous level for advanced and normal node the energy consumed is different for normal, advanced and sink nodes.

Similarly, a higher number of nodes require more control overhead consuming more energy. Considering Figure 6(b), the SMAC model gives the lowest energy utilization due to the sleep awake principle. The proposed algorithm consumes less energy than ZHLS and other protocols for S-MAC and WiFi even if number of nodes is less. But, in Zigbee for 10 number of nodes ZHLS performs better than others. As the network density increases.Mob-MLEACH protocol consumes the least energy that outperforms than other protocols. The proposed protocol consumes less energy for all network scenarios than the ZHLS, M-LEACH, and ZSEP protocols. Therefore, it can be concluded that Mob M-LEACH provides a better lifetime.

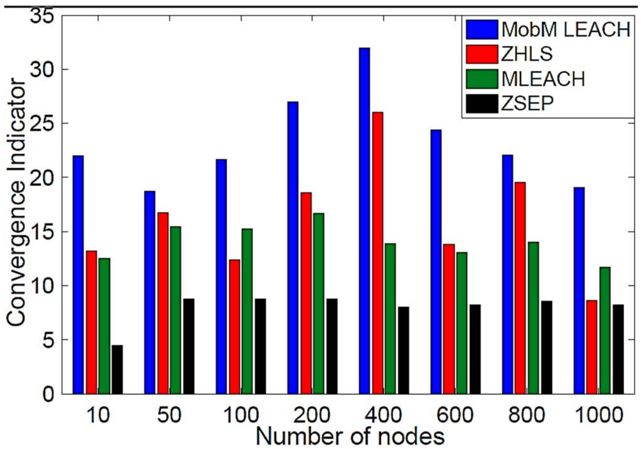

FIGURE 8. Illustration of Convergence Indicator with respect to the number of nodes.

TABLE 7. Analysis of network lifetime.

No. of Nodes	Z-SEP			M-LEACH			ZHLS			Mob MLEACH		
	FND	HND	LND	FND	HND	LND	FND	HND	LND	FND	HND	LND
10	3787	4808	5853	1523	1623	9001	1798	1961	7033	1643	1900	9210
50	1525	1965	5839	863	1256	7343	1087	1345	8089	1110	1543	8788
100	1548	2036	6330	971	1232	8591	1146	1363	4056	1090	1576	8800
200	1542	2035	6357	984	1248	9001	1072	1364	5428	998	1453	7655
400	1538	2077	6413	983	1239	6228	1142	1363	7109	995	1440	7505
600	1516	2050	6430	1007	1237	6000	1021	1366	6127	997	1450	7500
800	1523	2037	6430	1009	1239	5310	1084	1358	7719	998	1454	6987
1000	1519	2039	6329	1012	1240	5990	1050	1363	4059	989	1400	7100

C. THROUGHPUT ANALYSIS

The adequate data delivered at the sink node over time describes the throughput of the network. The throughput for the different protocols is obtained and shown in Figure 7. Figure 7(a) shows the overall throughput of the network and observed that variation in throughput is minimum after 200 nodes. For fewer nodes, the throughput is small and variation is minimal for all protocols. Figure 7(c) shows that the standard with IEEE 802.15.4 has better throughput than other standards. Again, the heterogeneous mobile-based protocols like Mob M-LEACH and ZHLS give higher throughput than static networks. This is because in the static network, the overhead control increases delay, decreasing the throughput; however, better throughput is observed with more nodes. The proposed Mob M-LEACH protocol outperforms the other protocols in terms of providing a better throughput making the network more suitable for IoT applications.

D. CONVERGENCE INDICATOR

The convergence indicator deals with the development of technology and demand, which allows service providers to adopt innovative services and new models suitable for IoT applications. These simulation parameters provide an insight on network lifetime [48] as indicated in Figure 8. The heterogeneous mobile network has a better network convergence factor than its stationary counterpart. From Table 5, it can be observed that the proposed Mob M-LEACH outperforms as the first node dead (FND) point is obtained at a higher number of rounds than other protocols as well as the last dead node dead round. However, it is observed that the ZSEP protocol [26] has a convergence indicator with a range of 4 to 10, whereas the M-LEACH has a network convergence of more than 12 factors. It justifies our proposed protocol suitable for IoT models.

VI. CONCLUSION

The heterogeneous network used in IoT applications requires high throughput, low bandwidth, and low energy consumption model. In order to improve the performance, the smart devices deployment and its implementation are of prime concern. Since in IoT variants of nodes with different energy levels are implemented, a basic comparison of channel access schemes like WiFi, SMAC, and Zigbee has prime importance. In this work, a three-tier heterogeneous network with different node densities is implemented and the performance is analyzed for different channel access scenarios with the static and mobile conditions. As observed from the results, Mob M-LEACH protocol for heterogeneous mobile model outperforms other static and mobile tiered heterogeneous networks in terms of throughput, end-to-end delay, and energy consumption factor. The convergence indicator of Mob M-LEACH indicates prolonging of the network for which more smart devices can be included in service-based platform of IoT. In future, the routing model can be further extended with a random mobility pattern to include different categories of smart devices under dynamic environments for smart IoT applications.

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