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ECMR: Energy Constrained Mobile Routing for Wireless Sensor Networks

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Abstract

Mobile wireless sensor network (MWSN) has eventual applications in various areas such as health care monitoring, flood and fire detection, wildlife monitoring etc. MWSNs have fascinated much attentiveness from patrons in recent years due to their applications in various fields. MWSNs are resource restraints and demand performance investigation by numerous node mobility patterns. Generally, in MWSN, the routing algorithms have been investigated for predefined mobility. But for real-time applications, it is essential to develop an effective routing algorithm and study the effects of various mobility patterns on routing strategies to give effective outcomes. Therefore, keeping in view of the above issue, we proposed an Energy Constrained Mobile Routing (ECMR) in this paper. Simulations have been performed in MATLAB on diverse parameters to check the efficiency of ECMR and other existing routing protocols. Simulation results show that ECMR gives better performance than the Position-Based Routing (PBR) protocol, which comprises Mobility Aware Routing (MAR) and Geographic Robust Clustering (GRC). ECMR has also shown better performance than Non-Position Based Routing (N-PBR) protocols comprising Distributed Efficient Clustering Approach (DECA) and Distributed Efficient Multi-hop Clustering (DEMC). ECMR reduces the percentage of packet loss 10–12%, increases packet delivery ratio 11–13%, minimizes average end-to-end delay 13–15%, enhances throughput 12–14%, reduces overhead 11–12%, minimizes energy consumption 16–18%, and prolongs network lifetime 15–17% on the mobility of sensor nodes. ECMR performs better with Random Waypoint Mobility (RWPM) model than Pathway mobility (PM) and Random Walk Mobility (RWM) model.

Keywords MWSN · Mobility · Mobility models · Routing protocols · MAR · GRC · DECA · DEMC

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1 Introduction

Wireless sensor networks (WSNs) [1] are mostly used to access information from the physical environment in real time. WSNs made of spatially dispersed tiny sensor nodes (SNs) are used in several areas of engineering. WSN [2] is an essential and very important arena to monitor the physical environment in the real world and find the appropriate control under an emergency. Nowadays, SNs demand has been increased in industries and consumer arcades due to their low cost and easy deployment. Adding mobility as a new parameter in WSN [3, 4] makes it more challenging, especially in some applications. One has to develop a practical/effective approach that could transfer data packets energy-efficiently to the sink. Due to the dynamic topology, a path from the sensor node to the sink node is not assured. Today's applications demand the consistent delivery of data packets in high mobility scenarios, which provides excellent performance and robustness to the network [5]. Many applications such as wildlife, environmental, hospital monitoring, etc. demand traffic patterns in MWSN [6, 7].

Mobile WSN [8] is designed to handle mobility in different forms where either SNs or sink nodes may be mobile. Based on applications and user requirements, other mobility models can be designed and play a vital role based on collected data at a central location. The main reason for introducing mobility in WSN is to decrease the number of hops to deliver data from SNs to the sink node, reducing energy consumption and prolonging network lifetime that ultimately minimizes the delay. The mobility of sensor nodes affects the position of nodes [9]. Thus, it is essential to advance the enactment of routing protocol using the location information of nodes. MWSN has many issues and challenges like data management and security, coverage, energy efficiency, quality of services, and routing. In these issues, the critical problem arises of route stability so that it requires mobility patterns for WSN to improve its performance.

In general, the mobility models in WSNs are categorized into memoryless and memory-based models [10, 11]. Random Walk Mobility, Random Way Point Mobility and Random Direction Mobility [12, 13] were the popular models in the memory-less category. In Random Walk and Random Direction Mobility, the speed can be changed every time, and the new direction can be set from 0 to 360 degrees [8]. In Random Way Point Mobility, speed was distributed uniformly in terms of min and max speed [9]. On the other hand, memory-based models were more energy efficient like geographic-based models, temporal-based models, and spatial-based models [14, 15]. Geographic models were further divided into four categories: Manhattan Mobility, Pathway Mobility, Obstacle Mobility, and Freeway Mobility [16]. Manhattan Mobility provided topology as a grid and applied it in those areas where streets were planned so that the movement could be performed horizontally or vertically [17]. Pathway Mobility restricts the movement of the node in the pathway of the roadmap. The map was defined in the simulation as a random graph model, and it can be randomly generated according to the city. The model graph was a collection of vertices and edges, where vertices show buildings of a city and edges show streets between the buildings. The destination can be achieved by choosing the shortest path through edges [18]. In Obstacle Mobility, the mobile node changes the path to avoid the barrier on the way. This obstacle changes the movement behavior of mobile nodes and impacts the propagation of radio waves [19]. Lastly, Freeway Mobility was used in large-scale vehicles tracking and exchanging traffic information on a freeway. It was based on maps and has different freeways consisting of lanes in direction, namely slow, medium, and fast [20]. Similarly, the Temporal Based Model can be divided into Gauss Markov Mobility and City Section Mobility [12, 21]. Lastly, Spatial Based Models were classified into Reference Point Group Mobility, Column Mobility, Pursue Mobility, and Nomadic Mobility [12, 13, 22–29].

Following are the key research contributions of this paper:

- Identification of node's hop count for data transmission based on priority.
- Development of Energy Constrained Mobile Routing (ECMR) approach taking hop count and priority as the key parameters.
- Enhancement of the overall lifetime of the network.
- The rest of the paper is systematized as follows. Section 2 describes the existing routing protocols. Section 3 elaborates the proposed approach. Section 4 describes the performance assessment of the proposed approach, and finally, Sect. 5 concludes the paper.

2 Related Work

Chaochen et al. [4] proposed a Resource Allocation Technology (RAT) for decreasing the energy consumption and increase throughput of the network by organizing small energy cellular with multi antennas, max system capability and coverage. System model is implemented in this approach as follows:

$$y^m_{[k,n]} = \alpha^m_{[k,n]} \sum_{l=1}^{L} h^m_{[k,n,l]} x^m_{[k,n,l]} + \sum_{i=1}^{N} \sum_{l=1}^{L} \alpha^m_{(i,j)} h^m_{[i,k,l]} x^m_{(i,l)} + \sigma_0 \tag{1}$$

$$y^m_{[k,n]} = \alpha^m_{(k,n)} H^m_{[k,n]} X^m_{[k,n]} + \sum_{i=1}^{N} \alpha^m_{(j,i)} H^m_{[k,i]} X^m_{[j,i]} + \sigma_0 \tag{2}$$

Specific symbols and notations used in Eqs. (1)–(2) are described in [2]. Ant Colony Optimization (ACO) is developed by Kaur et al. [6] which reduces energy utilization and enhances network lifetime. ACO technique is used to create shortest route among existing sink and CHs. ACO is an eminent metaheuristic approach that can discover fines route among a known set of sensor nodes using sink as the endpoint. The chance in the election of principle ant can be calculated as follows:

$$P^i_j = \frac{(\tau_{ij})^\alpha + (\eta_{ij})^\beta}{\sum(\tau_{ij})^\alpha(\eta_{ij})^\beta} \tag{3}$$

The symbols used in Eq. (3) are summarized in [3]. Nagaraju et al. [11] proposed Faster Area Exploration (FAE) technique for the mobile-based localization scheme. FAE is implemented with a hybrid of maximum expansion and cost efficacy-based frontier approach. The utility and maximum expansion approaches can be calculated as follows:

$$U_d = \begin{cases} \left(1 - \frac{dist(CM_k, \alpha_{ij})}{CR_k}\right) & ifdistdist\left(CM_k, \alpha_{ij}\right) < CR_k \\ 0, Otherwise \end{cases} \tag{4}$$

$$U_t\left(a_{ij}\right) = \alpha.UC_b - \sum_{k=1}^{M_k} U_d \tag{5}$$

The specific symbols and notations used in Eqs. (4)–(5) are described in [11]. Spiral Mobility Optimized Clustering (SMOC) was developed by Asad et al. [12], which enhances network lifetime, stability of the network, packet loss ratio, delay, and energy consumption of the network. The receiving and transmission energy in this approach can be calculated as follows:

$$E_{CH_{RX}} = N_i E_{RX}(pl) = plN_i E_{elec} \tag{6}$$

$$E_{CH_{TX}} = \int_{x=0}^{r} \frac{1}{r} E_{TX}(pl, x)dx = pl\left(E_{elec} + \frac{E_{fs} r^p}{p+1}\right) \tag{7}$$

The symbols used in Eqs. (6)–(7) are elaborated in [12]. Alkindi et al. [15] proposed Multipath Grid-based Geographic Routing (MGGR), which reduces energy consumption, delay and increases packet delivery ratio. MGGR is small sensitive to the mobility design of sensor nodes. Furthermore, it attains better performance under various mobility models. This provides the improvement of being appropriate to multiple application areas. Dynamic Directional Routing (DDR) was developed by Almesaeed et al. [17], which enhances network lifetime, packet delivery ratio and reduces energy consumption. DDR offers a directional-based scheme that energetically adjusts the paths to destination according to topology changes due to mobility of sensor nodes. Usually, the info is transmitted in a restricted zone, and only adjacent nodes that exist within the permissible zone are permitted to contribute to the process of routing. The loss path model is used in DDR given as follows:

$$P_r(dBm) = P_t(dBm) - -PL(dB) \tag{8}$$

$$PL(dB) = PL\left(d_0\right) + 10nlog\left(\frac{d}{d_0}\right) + X_0 \tag{9}$$

The symbols and notations used in Eqs. (8)–(9) are described in [17]. Echoukairi et al. [20] proposed Low-Energy Adaptive Clustering Hierarchy and K-Means algorithm (LEACH-C-KMEANS) based on various mobility models which enhances throughput, packet delivery ratio and decreases delay, energy utilization. The key input contains the assessment performance of assimilation an unsupervised algorithm motivated by the K-means approach under different mobility models on the changeable density of movable nodes to introduce a novel cluster approach and discover the optimum clusters. Kaur et al. [21] provide a detailed study of state-of-the-art techniques based on various mobility models to increase network lifetime and reduce energy consumption. An Exponential Ant Lion Whale Optimization (E-ALWO) technique is proposed by Kumar et al. [24], which improves delay, throughput, and remaining energy. The proposed technique achieves the routing procedure using CH so that the election of CH is completed with the ALWO algorithm based on delay and energy. The optimum and protected path used for the info transmitting procedure is calculated using the E-ALWO technique based on fitness measurement. The fitness function reflects delay, trust, distance, and energy factors. Furthermore, the route with the greatest fitness value is recognized as the routing route for transmitting the data. The following fitness functions are used in E-ALWO.

$$F = \frac{1}{2}[J + (1 - L)] \tag{10}$$

$$J = \frac{1}{m \times n} \sum_{k=1}^{m} \sum_{l=1}^{n} J_{mn} \tag{11}$$

$$L = \frac{1}{m \times n \times \eta} \sum_{k=1}^{m} \sum_{l=1}^{n} L_{mn} \tag{12}$$

The specific notations and symbols used in Eqs. (10)–(12) are elaborated in [24]. The performance analysis of existing routing algorithms is given in Table 1.

3 Brief Introduction of Considered Routing Protocols

3.1 Position-Based Routing Protocols (PBR)

PBR protocols are built on location information where GPS is used in every SN. These protocols are able to identify the location of SNs so that based on detachment between two nodes, power utilization can be assessed of all possible paths, and energy-efficient path could be selected. These are further classified into two categories.

Mobility Aware Routing Protocols (MAR) This [25, 29] is a hierarchical PBR protocol where nodes are moved from one zone to another, and a cluster head (CH) is selected, which has low mobility. CH has minimum mobility so that the connectivity between CH and associated nodes could be improved. The major issues with this protocol are the absentia of the energy and location information of the node at the time of CH selection. It provides chances of packet loss in inter-cluster communication.

Geographic Robust Clustering (GRC) This [21, 26] protocol is used to find the node's location at the time of CH selection to be used in an energy-efficient manner. Here, the SN is selected as a CH with high residual energy, close to the center. Each node calculates the weight on behalf of residual energy. Once the selection process of CH is completed, normal nodes send the data to CH in inter-cluster communication. If packets are dropped during transmission, packet recovery strategy is applied using the weight vector, and weight is calculated as follows:

$$\mathrm{Weight} = \mathrm{W}_1 \times \mathrm{E} - \mathrm{W}_2 \times \mathrm{C} \tag{13}$$

where $\sum_{\mathrm{i}=1}^{2} \mathrm{Wi} = 1$ and $\mathrm{W}_1 > \mathrm{W}_2 > 0$.

In Eq. (13), E represents the remaining energy and C is the center-ness of node which is calculated as follows:

$$\mathrm{C} = \left|\mathrm{X_c} - \mathrm{x}\right| + \left|\mathrm{X_c} - \mathrm{y}\right| \tag{14}$$

where *(x, y)* represents the coordinate of mobile sensor node and (X_c, Y_c) represents the approximate center point within the region.

3.2 Non-Position Based Protocols (PBR)

These are location unaware and also divided into two categories.

Distributed Efficient Clustering Approach (DECA) In it [27, 29], each node calculates weight based on residual energy and sends only one message. The process of exchanging

Table 1 Comparative Analysis of Existing Algorithms

References	Proposed Algorithm	Objectives	Limitations
[4]	RAT	Reduces energy consumption, enhances throughput and network lifetime	Network performance degrades on changing network topology frequently
[6]	TESDA	Minimizes energy utilization, enhances network security and maintains reliability of the network	Limited mobility model are implemented
[7]	ACO	Decreases energy consumption, increases network lifetime,	Comprises with network stability on mobile nodes
[11]	FAE	Improves delay, localization error and network lifetime	Unable to route data packets in dynamic topology and need to implement model of dynamic route planning
[12]	SMOC	Improves lifetime of network, delay, packet delivery ratio (PDR), packet loss and stability of network	Need to implement multi-hop technique to improve network stability and lifetime
[15]	MGGR	Enhances PDR, decreases energy utilization and delay	Other mobility model should also be tested to acquire more inclusive results
[17]	DDR	Increases PDR and reduces energy consumption	DDR should be configured dynamically based on system conditions by varying discover angel
[20]	LEACH-C-KMEANS	Advances throughput, reduces delay and energy utilization	Need to implement adaptive traffic initiators, pause time and speed for better performance
[24]	E-ALWO	Minimizes delay, energy consumption and enhances throughput	Other optimization algorithms based on meta-heuristic should be implemented to search route for data transmission
[26]	BOA	Reduces energy utilization and enhances lifetime of network	Performance degrades on high speed of mobile nodes
[27]	KSA-DEEC	Advances network throughput and network lifetime	Nodes of higher energy drain which effects network performance

messages consumes more energy than sensing operations. Each node consists of a neighbors list and communicates with each other by sending a *HELLO* message continuously. All information is maintained in a table that needs high energy and processing. Therefore, DECA does not consider a better approach to maintain a table. CHs move out of range, and packet is lost during inter-cluster communication.

Distributed Efficient Multi-hop Clustering (DEMC) It [28] provides maximum network coverage, and SNs do not send *HELLO* messages continuously, so there is no need to maintain the neighbors list. Therefore, DEMC offers better energy efficiency and less process overhead. At the time of CH selection, each node calculates a weight based on residual energy as follows:

$$\mathrm{Weight} = \mathrm{W}_1 \times \mathrm{E} + \mathrm{W}_2 \times \mathrm{I} \tag{15}$$

where $\sum_{i=1}^{2} \mathrm{Wi} = 1$ and $\mathrm{W}_1 > \mathrm{W}_2 > 0$.

In Eq. (15), *E* represents the remaining energy and I represents the node identifier used to stop tie if two SNs found similar residual energy.

4 The Proposed Approach (ECMR)

In this section, we propose a new routing protocol known as the Energy Constrained Mobile Routing. It uses a blind technique to forward the data to the sink so that a decision to transmit data is made at the receiving node on a hop by hop basis. In other words, when a node communicates, its transmission is overheard by all of its neighbor nodes. The hop count represents a simple metric and is an elementary measurement of the distance in a given network. Therefore, each neighbor starts to compare and count hop delimited in the received packet. Packets are forwarded if node's hop count is smaller or equal to the received hop count. On the other hand, packets are dropped if node's hop count is greater than the received hop count. The transferred packet has a priority bit to indicate the priority status. Received packets by nodes are stored in a queue, and packets are transmitted according to priority in a specific time slot. The priorities determination is as follows:

- If the hop-count of a node is minimum than in the received packet, the packet is transmitted using similar priority as received.
- If the hop-count of a node is greater than in received packet, packets are dropped irrespective of their priority.
- If the hop-count of a node is similar in received packet and packet has the status of priority, then packets are transmitted with variety status.
- If the hop-count of a node is equal as in received packet and the packet has status of variety, then packets are dropped.

Packets having long precedence in the queue will communicate first whereas, the out-of-date packets are dropped from the queue. If other packets from the same source with the same packet IDs are received, these will also be considered out-of-date packets. New packets replace the older ones from the queue and improve end-to-end delay to transmit data.

Mobile nodes are tiny and have a limited amount of energy. This is one of the key challenges observed in energy efficiency to prolong network lifetime. ECMR uses sleep cycles, and the entire network goes into the sleep mode in the absence of no activity or movement of node, and no node transmits packet during this slot. A round contains active cycles shadowed by sleep cycles, such that a portion of sleep to active time can be comprehended. If topology is normal, sleep cycle is activated and beacon packets maintain and save energy, which provides the reliability of the proposed approach. Global-TDMA (GTDMA) is used in the proposed approach. ECMR permits every node to transfer once, which means a single time slot is assigned to the node. This time slot is sufficient for transmitting a single packet. A cycle is the time length for every node to transfer, and time slot is time taken for transferring a single packet. GTDMA provides a collision-free network and diminishes possibilities of packet loss. Subsequently, before the deployment number of nodes and time slot is set, ECMR can be highly adjustable for distinctive optimization of different operations. The prime concern using GTDMA is divergent using of dynamic TDMA, in which central authority allocates time slots dynamically. Because the setup phase at the time of allocating slot needs additional overhead in a high mobile environment, it will require operating regularly. Classic TDMA permits nodes to join and leave the network and takes benefit of unexploited bandwidth. It is unlikely that nodes will need to join or leave the network.

The reliability of GTDMA MAC is one of the apprehensions of latency that nodes will experience to wait for their assigned time slots prior they can transmit. However, end-to-end delay is also retained low, by the absence of advancing node selection, no avoidance of collision strategy, and absence of retransmissions. Moreover, cycle time is kept minimum and packet latency also. GTDMA also produces high-reliability level compare to GTDMA MAC. Subsequently, these are the enthusiasm of using GTDMA in ECMR. Using GTDMA, every node will communicate in a stringent order, and its assurances that when a node is permitted to transfer, it has the chance to overhear other nodes within broadcast range. With the utilizing of GTDMA, ECMR is reliable for effectively communication.

Hop is a real metric, which specifies node's distance from the sink in the hop. Topology data is pooled to uphold hop count at every node, and then hop count is used to transmitting data to the sink. Nodes will frequently need responsiveness of location for position reporting to the sink node; it is also desirable for routing using hop count metric because location information is varied due to topology. Using GTDMA every node gets a chance to transfer once in a cycle. In each slot, nodes transfer packets or a beacon packet if the node has not any data to transmit. A beacon packet has node's ID and hop count. Therefore, every node will have the opportunity to overhear each node's broadcast in the communication range, prior its peculiar time slot emanating around. Subsequently, the node determines its location within the network using topology information, which is considered hop count. In a single cycle, a node will hear all neighbors transfer at least a beacon packet. To overhear broadcasts, a node can define its peculiar hop count, which is the lowest hop count of its neighbors.

ECMR uses a forwarding strategy to transmit data to the sink. Therefore, judgment to transmit data could be primed at receiving node based on the hop by hop. Thus, when a node transfers, its communication is overheard by all its neighbors. Every neighbor can compare hop counts enclosed in the received packets. Hence, if node's hop count < received hop counts, then packets will be transmitted. If node's hop count > received hop count, then packets will be dropped. Subsequently, if received hop count and node's hop count are equal, then the status of packets should be considered. Priorities are considered to rheostat number of routes a packet. Therefore, duplicity could be minimized on enhancing reliability of protocol. Every packet has priority bit, which entitles its status either priority or diversity. The packet status is designated using state of priority bit, which distinguishes priority and diversity packets. When the node receives packets, it stores in a queue, therefore, prior node's time slot it is decided which one packet is to be transmitted. Using of diversity packets is specified to enhance route diversity of protocol without awaiting delay of priority packets. Thus, diversity packets will improve the number of paths to the sink, but priority packets transmitted first. Therefore, the eldest priority packets within the queue will be transferred first, afterward, the diversity packets. The flowchart of ECMR is shown in Fig. 1. This segment covers,

Packet delivery ratio (PDR) measures the quality of ECMR which should be near to one. If delivery ratio is higher than one, there is more chance to deliver duplicate packets. It can be measured from the overall delivered packets.

$$PDR = \frac{P_R \times 100}{\sum_{i=1}^{n} P_{G_i}} \tag{16}$$

where P_R shows packets received by sink, P_{Gi} represents packets produced by the source, and n is the total number of sensor nodes.

Percentage of packets loss It provides the reliability of ECMR protocol. During the data transmission phase if packet lost is low then protocol is more reliable. ECMR reduces packets collision due to its conflict free transmission. Assumed that the network is vigorous defined and connected. Packet loss may be in case of link breakage in packet's path. The average lifetime of link can be calculated as follows

$$L_{avg=}\frac{M_{link}}{\vec{v}} = \frac{4.r}{\pi.v_{\max}} \tag{17}$$

where M_{link} represents distance of link and $\vec{v}$ is the comparative velocity between receiver and transmitter, v_{max}, represents maximum node speed, and r is transmission radius. During this, the created packet is received by the sink; therefore, the probability of link breakage is

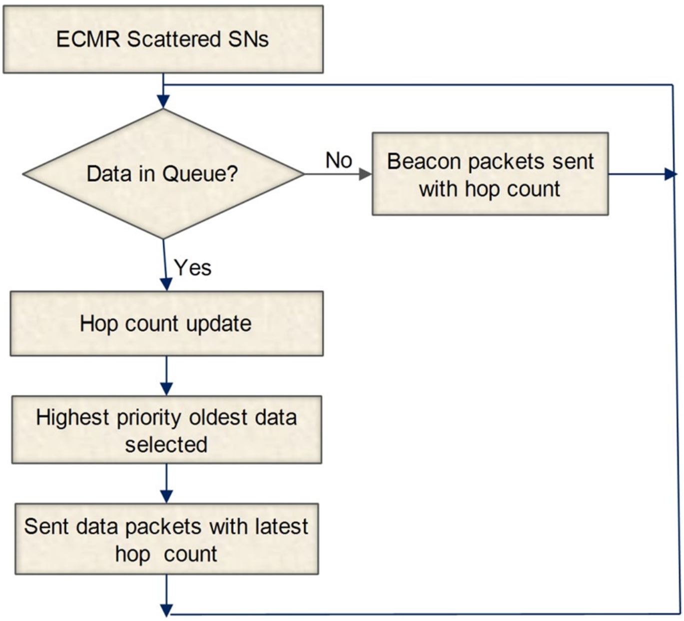

Fig. 1 ECMR flowchart

$$P_{brk} = 1 - \left(1 - \frac{\pi.v_{\max}}{4.r}\right)^{D_{avg}} \tag{18}$$

where D_{avg} shows average end-to-end delay. The broken links is estimated as follows

$$L_{brk} = P_{brk}.\left(\frac{n}{2}\right).\left(\frac{\pi.r^2}{L^2}\right) \tag{19}$$

where L represents distance of four-sided network and *n/2* is the binomial factor.

Link breakage leads packet loss and the percentage of packet loss can be calculated as follows.

$$PPL = 1 - \left(1 - P_{brk}\right)^j \times 100 \tag{20}$$

where j is the average hops between source and base station.

Throughput It shows the data packets delivered per second to the sink node and can be calculated as follows.

$$TH = \frac{L_{data}.P_p.PDR}{D_t} \tag{21}$$

where P_p represents produced packets and D_t is the time of positioning of network. *PDR* indicates packet delivery ratio, and L_{data} symbolizes size of data. Large amount of produced packets provide a great outcome on throughput and enhances the loss of packets.

Overhead It is an essential factor in routing, the huge overhead volume tends to create the delay, and ultimately the packet will be loosed. Two types of overheads are common, known as packet and control overheads. Packet overhead represents segment of bits, not the data of each sensor, while control overhead shows segment of bits of each sensor data packets. Overall overhead can be calculated as follows.

$$OD = \frac{T_{NB}}{L_{data}.P_p.PDR} \tag{22}$$

where T_{NB} represents transmitted number of bits.

Energy Consumption Energy is consumed in transmitting and receiving the data packets. The energy cost for transmission is larger than receiver. In addition to this, other energy costs are also present such as, sensors and peripherals, battery type, and mobility pattern, which are specific for hardware. The energy consumption is calculated as follows.

$$E_C = \left(\frac{V_{battery}}{R_b}\right).\left(\frac{(I_{tx}.T_{NB}) + (I_{rx}.R_{NB})}{n.D_t}\right) \tag{23}$$

where $V_{battery}$ represents battery voltage, I_{tx}, I_{rx} are the transceiver current consumption on transmitting and receiving. R_{NB}, R_b are number of bits received and bit rate.

Average end-to-end delay: The time period measured between the generations of a packet by the node to transmit over the sink. If delay at each node be D_N and h be the number of hopes, then average delay can be estimated as follows.

$$D_{avg} = h.D_N \tag{24}$$

It is assumed that the traffic upcoming rate at every node is μ and service time T_s is continuous at every node enters in to the queue on FCFS basis. If packet creation rate be k_p at the node.

$$\mu = \frac{k_p.(n-1)}{N_n^2} + k_{p\sin k} \tag{25}$$

where k_{psink} represents sink packet creation rate, now, Eq. (25) provides packet creation rate by the network and restricts some nodes to transmit data through a single node. The average delay can be calculated as follows.

$$D_{avg} = \frac{h.T_S.(2-\mu T_S)}{2.(1-\mu T_S)} \tag{26}$$

where T_S is the service time.

Time occupied by every node is based on packet upcoming rate and it takes time to provide service to everyone.

Number of Rounds It provides network lifetime when first node dies. Network lifetime is based on energy consumption of rounds. Minimum energy consumption per round prolongs network lifetime.

Sleep Cycle Sleep cycle provides node's sleep mode in the absence of no activity or movement of node and no node transmits packet during this slot and saves the energy, it can be determined as:

$$S_*^{(n)} = \text{argmin}\left\{ \sum_{i=1}^{n} Del(S_i^{(n)}, S_j^{(n)}) \right\} \tag{27}$$

where $S_*^{(n)}$ represents redundant nodes elected from n nodes and $Del(S_i^{(n)}, S_j^{(n)})$ signifies difference between collected data from node $S_i^{(n)}$ to $S_j^{(n)}$.

Synchronization Synchronization of the mobile nodes is accomplished by transmitting advanced time slots from the base station which initiates the mobile nodes to transmit data packets. It can be calculated as:

$$\eta_\alpha = \left(\frac{(\tau M_t)}{T_f} \right) \left(\frac{(B_u N_u)}{B_w} \right) \tag{28}$$

where:

τ: Time slot duration of data transmitting.

M_t: Total number of time slots/frame.

T_f: Duration of frame.

N_u: Total number of users sharing of similar time slot.

B_u: Individual user's bandwidth during time slot.

B_w: Bandwidth of the system.

Traffic Interference It occurs due to communication medium, transmissions from individual radio interfere with response of adjacent radios subsequent in data loss and low throughput of network. It can be calculated as:

$$\tilde{\rho} = \frac{1}{N_s} \sum_{j=1}^{N_s} F_n \{ I_j > \gamma \} \tag{29}$$

where I_j represents received energy by j^{th} node, F_n denotes indicator function, N_s shows number of measurement samples and γ specifies level of threshold.

Hop-count If hop-count is increased then it increases transmission delay, throughput, packet loss, energy consumption. So, it's better to transmit data packets to nearest hop. Assume the lowest hop-count is h and the distance amid nodes of the i^{th} hop is d_i then the total number of hop-count is estimated as:

$$h_c = \sum_{i=1}^{h} d_i \tag{30}$$

5 Experiments

Simulations of ECMR are performed in MATLAB version 7.8 [29] by diverse parameters and compared with the existing routing protocols like, MAR, GRC, DECA, and DEMC. The number of nodes has been taken 100, which are arbitrarily dispersed in the sensor field of 1000*1000 m^2, and remaining simulation parameters used are given in Table 2.

Different scenarios are shown in Scenarios 1–7 discussed below:

Scenario 1 Packets are dropped due to many reasons such as node's distance, packet broadcasting links, the strength of radio signal, and communication behavior. The simulation outcomes are exposed in Figs. 2, 3, and 4 between percentages of packet loss and node speed, which indicates that the percentage of packet loss increases when node speed

Table 2 Simulation Parameters

Parameters	Values
Simulation Area	1000*1000 m^2
No. of Nodes	100
Number of Zones	16
Packet header size	20 bytes
Node Distribution	Random
Initial Energy	1 Joules
Broadcast Packet Size	20 bytes
Data Packet Size	100 bytes
Radio Model	E_{elec} & E_{amp}
Mobility Model	Random Waypoint, Pathway, Random Walk
Protocols	MAR, GRC, DECA, DEMC, ECMR

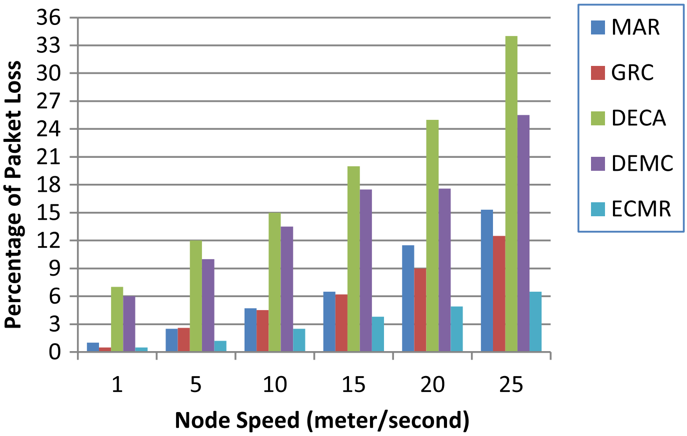

Fig. 2 Percentage of packets loss in RWPM

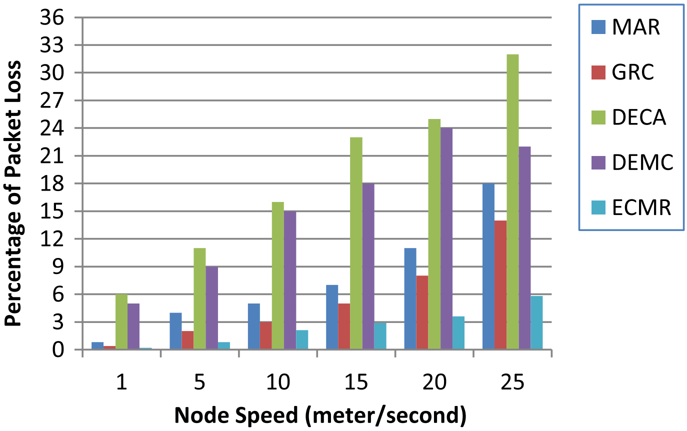

Fig. 3 Percentage of packets loss in PM

increases. Packet loss also increases when sensor nodes send the information to sink node during high speed of mobility and SN moves unexpectedly. Results show that ECMR reduces the percentage of packet loss 10%-12% than PBR and N-PBR protocols.

Scenario 2 Reducing the number of hops enhances the accuracy of packet delivery ratio. The possible number of hops ensures the consequence of fading and traffic interference or network congestion in PDR estimation. Deviations in signal level in sensor link considered across available hops. Figures 5, 6, and 7 shows the comparison results for packet delivery ratio with node speed. Packet delivery ratio is increased by 11–13% in ECMR than considered routing protocols and gives the reliability of data packets to the whole network. ECMR delivers large numbers of packets with low energy consumption, which provides the efficiency of the network.

Scenario 3 The fallouts have connived between numbers of rounds, where the first node dies and the node's mobility are shown in Figs. 8, 9, and 10. If the sensor node dies rapidly, it affects the lifetime of sensor networks. The proposed approach balances

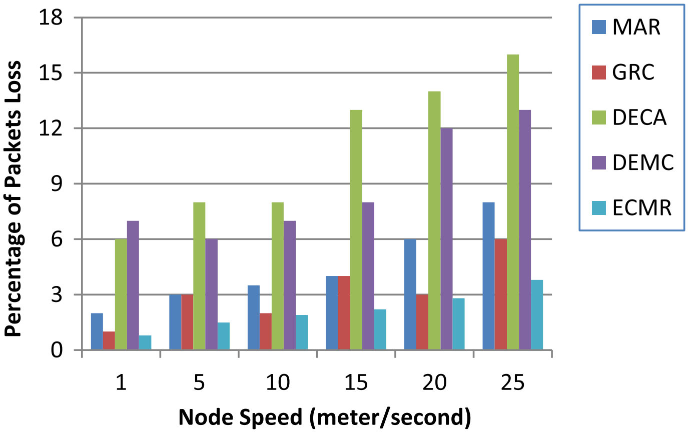

Fig. 4 Percentage of packets loss in RWM

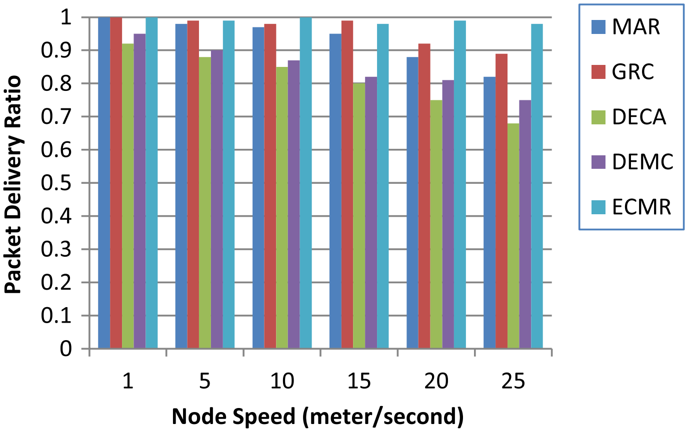

Fig. 5 Packet delivery ratio in RWPM

energy consumption and keeps nodes alive long, so network effectiveness could be improved. Results represent that the network life-time is better of the proposed approach ECMR than position-based MAR, GRC, and non-position-based DECA, DEMC. Node's position is updated rapidly when mobility of node increases and consumes more energy, but ECMR approach balances energy consumption.

Scenario 4 End-to-end delay is estimated middling time, packets are in the queue until received by sink node. Sink data themselves congregate delay. It reduces energy consumption and overhead. End-to-end delay is a key metric to assess the network's performance, and it is also affected by high traffic and node's speed in the network. ECMR selects appropriate hop on a priority basis for the transmission of the data packets and gives reliability to the network. From the simulation, as shown in Figs. 11, 12, and 13, it is clear that ECMR gives better results than MAR, GRC, DECA, and DEMC and minimizes end-to-end delay by 13%-15%.

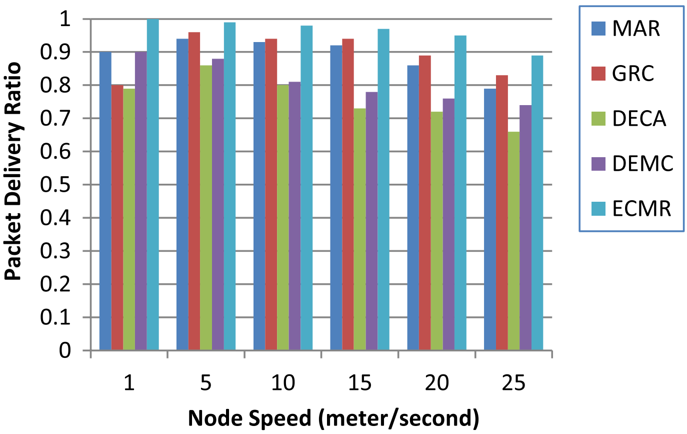

Fig. 6 Packet Delivery Ratio in PM

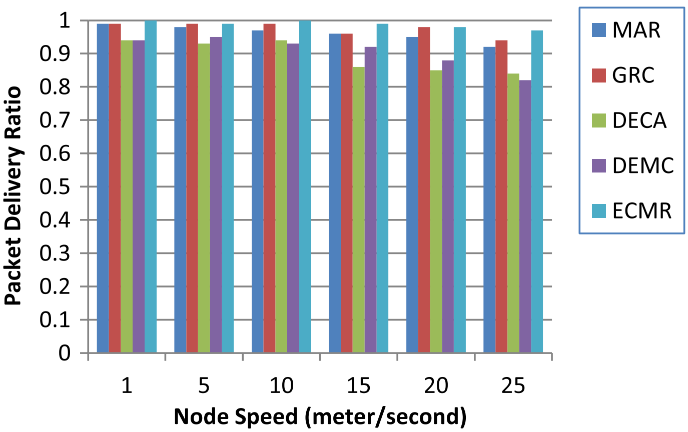

Fig. 7 Packet Delivery Ratio in RWMn

Scenario 5 Throughput is estimated by hop throughput based on capacity of network. In ECMR, the channel capacity is fully utilized and reduces channel error rate and enhances throughput ratio. Data bits are effectively carried to the sink node per second. The evaluation of simulation results from Figs. 14, 15, and 16 represents that the throughput of proposed approach ECMR is increased 12–14% than position and non-position-based routing protocols, and data is delivered frequently which reduces energy consumption and prolongs network lifetime.

Scenario 6 If data is transferred to the nodes that cannot transmit data successfully, retransmission of data packets is needed, increasing the overhead. ECMR approach selects hop counts and transmits data through best hop path. ECMR determines the total number of hops in the path, if path has minimum number of hops then maximum number of data packets are transferred in that way, which reduces overhead 11%-12% in the network. ECMR reduces overhead and works well in most challenging environment and suitable to MWSNs. Low amount of overhead improves delay, packet loss and reduces energy consumption. Therefore,

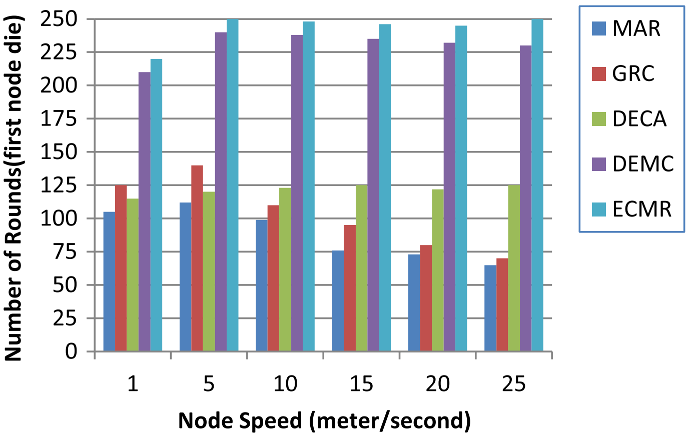

Fig. 8 Number of Rounds in RWPM

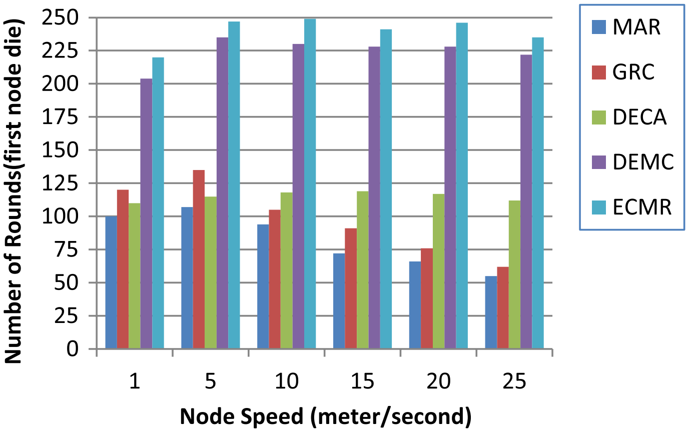

Fig. 9 Number of Rounds in PM

Figs. 17, 18, and 19 show that ECMR performs better than considered routing protocols on varying node's speed.

Scenario 7 Energy consumption is a key challenging in MWSNs which prolongs network lifetime. Energy consumption depends upon packet delivery ratio, overhead, packet loss, throughput and delay. ECMR performs well on these parameters and reduces energy consumption 16%-18%. Nevertheless, simulation results as shown in Figs. 20, 21 and 22 are flawless. The proposed routing approach ECMR performs better than position-based (MAR, GRC) and non-position-based (DECA, DEMC) routing protocols on different mobility patterns and high mobility of sensor nodes.

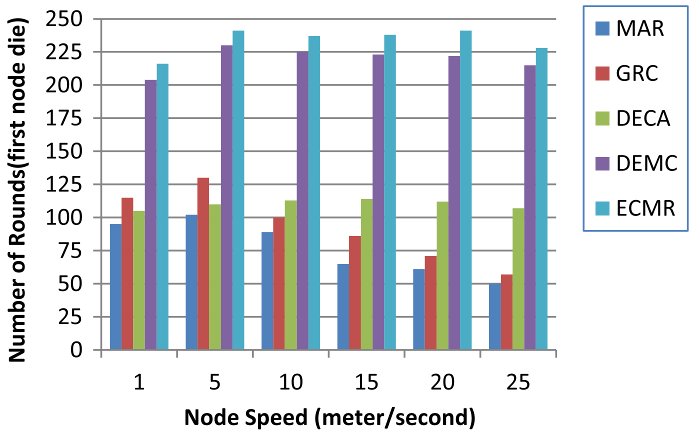

Fig. 10 Number of Rounds (first node die) in RWM

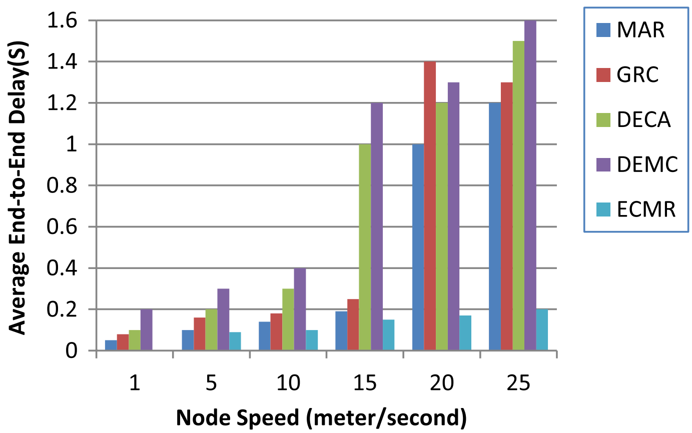

Fig. 11 Average End-to-End Delay (s) in RWPM

6 Conclusions

In this paper, we have proposed Energy Constrained Mobile Routing (ECMR) and compared it with PBR protocols MAR, GRC and N-PBR protocols DECA, DEMC on random waypoint, pathway, and Random Walk mobility models. The logical countenance is given to elaborate ECMR performance at a very high mobility level. After evaluating results, it is clear that ECMR achieves better outcomes than PBR protocol (MAR, GRC) and N-PBR protocols (DECA, DEMC). ECMR reduces the percentage of packet loss by 10–12%, increases packet delivery ratio by 11–13%, minimizes end-to-end delay by 13–15%, enhances throughput by 12–14%, reduces overhead by 11–12%, minimizes energy consumption by 16–18%, and prolongs network life-time by 15–17% on mobility of sensor nodes. If any node moves out of transmission, then packet loss recovery strategy is applied to avoid packet loss. The proposed approach ECMR performs better on the Random waypoint mobility model than the pathway mobility and random walk mobility models. The

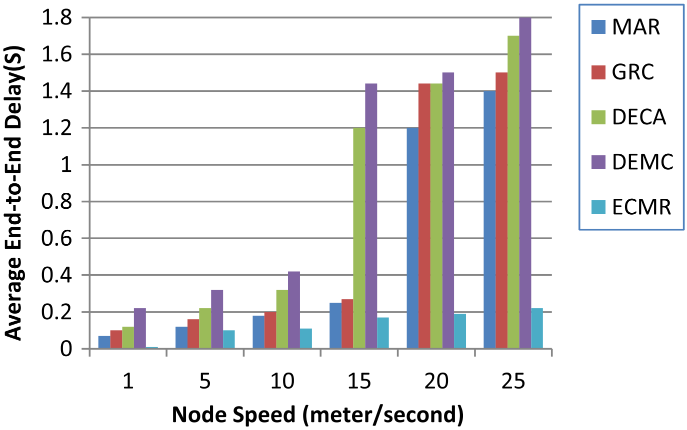

Fig. 12 Average End-to-End Delay (s) in PM

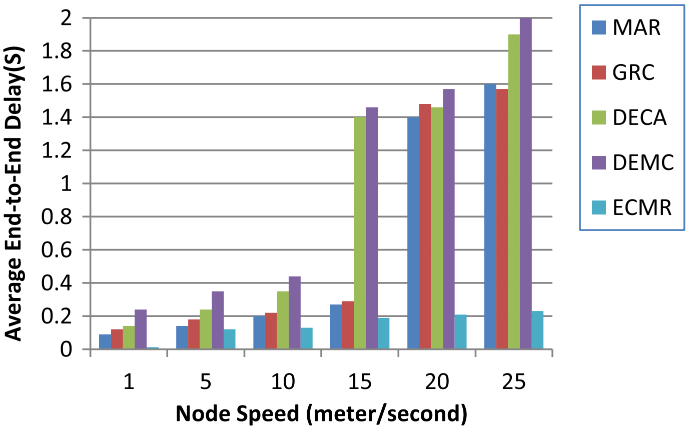

Fig. 13 Average End-to-End Delay (s) in RWM

upcoming work will look to implement ECMR on large networks and various applications [30, 31].

Future work will look at implementing ECMR on a testbed to substantiate its competencies and appropriateness applications further. This work can be extended further on the anvil of energy proficiency to some specific QoS-based applications or be tested for cross-layer design.

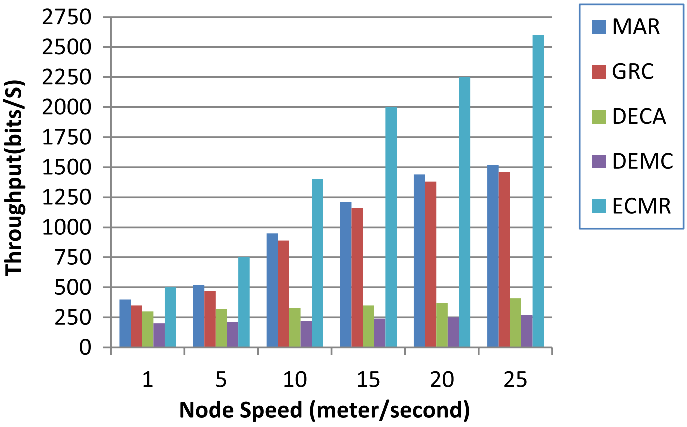

Fig. 14 Throughput (bits/s) in RWPM

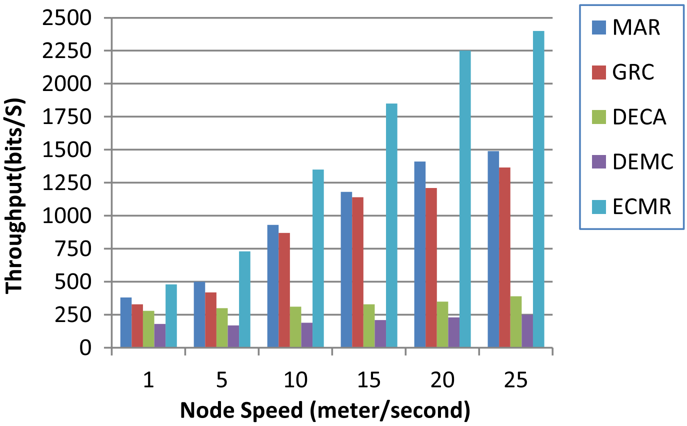

Fig. 15 Throughput (bits/s) in PM

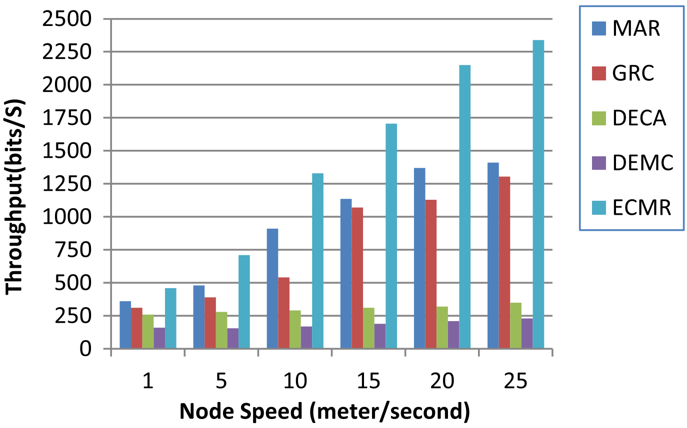

Fig. 16 Throughput (bits/s) in RWM

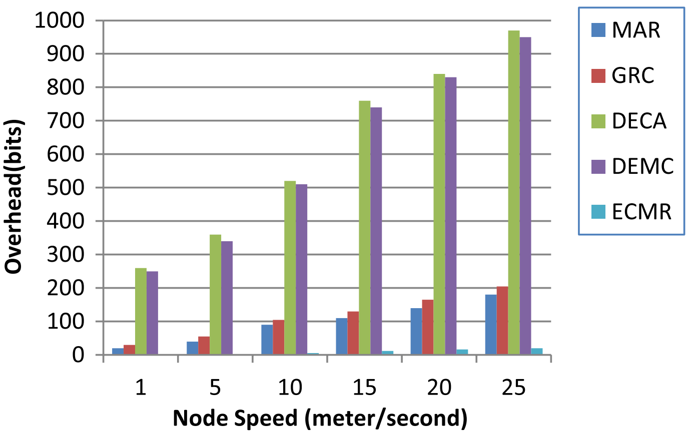

Fig. 17 Overhead (bits) in RWPM

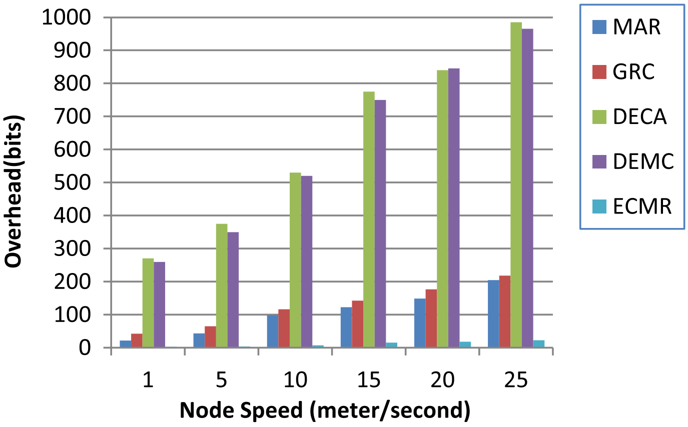

Fig. 18 Overhead (bits) in PM

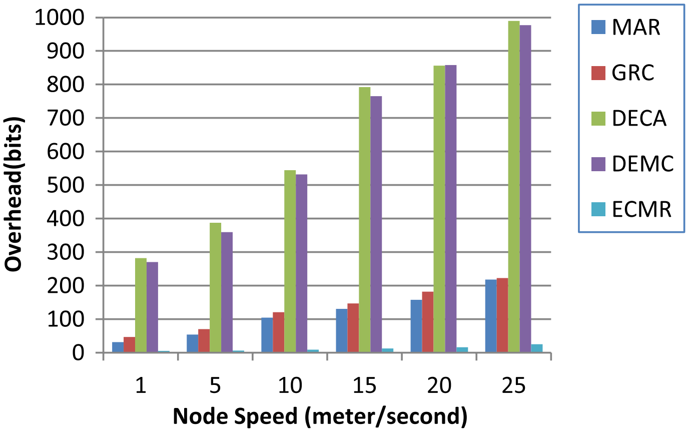

Fig. 19 Overhead (bits) in RWM

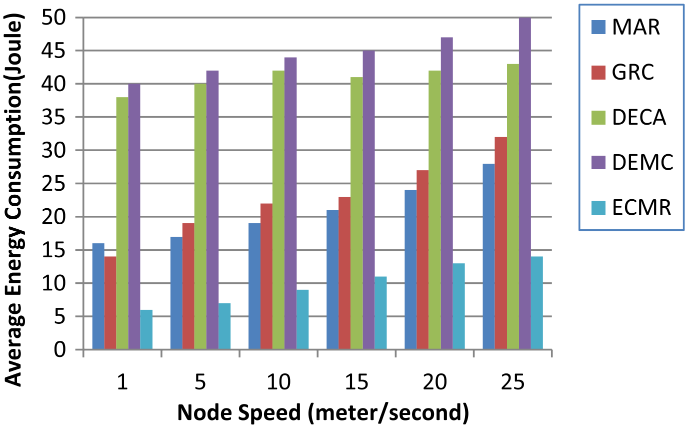

Fig. 20 Average Energy Consumption (joule) in RWPM

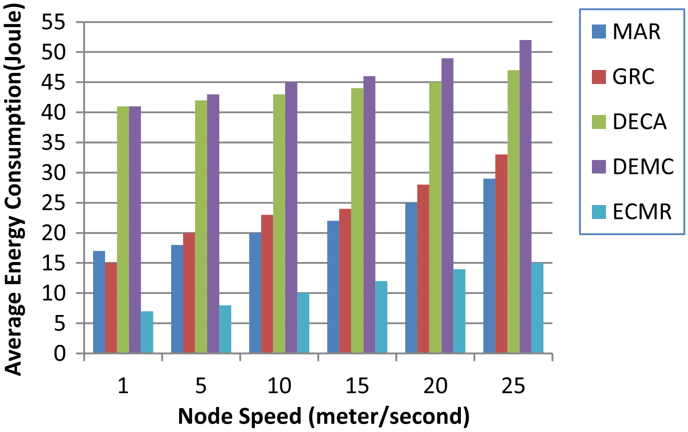

Fig. 21 Average Energy Consumption (joule) in PM

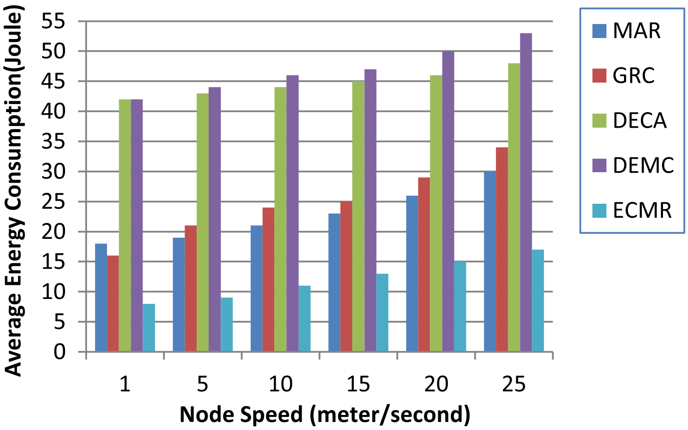

Fig. 22 Average Energy Consumption (joule) in RWM

Appendix 1

See Fig. 23

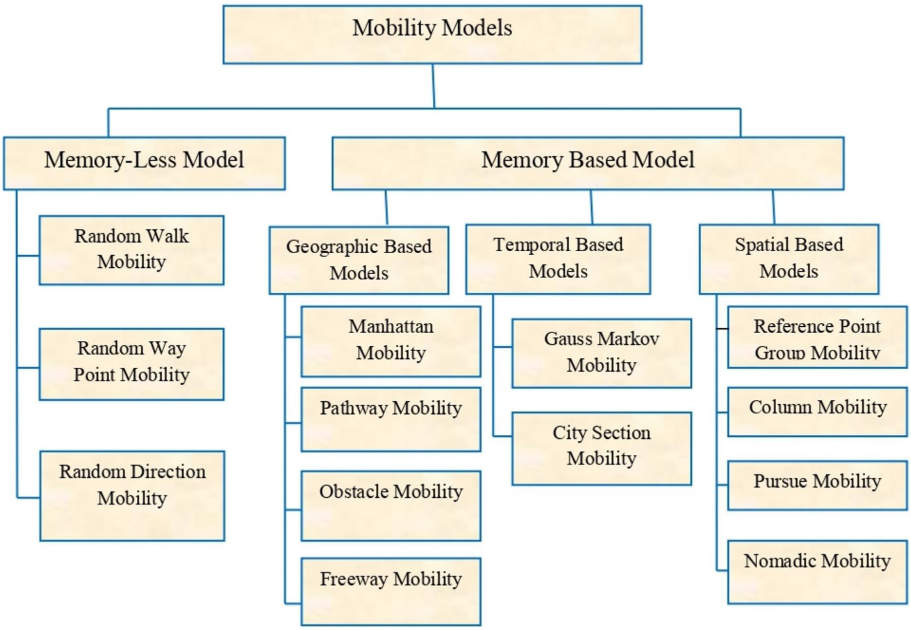

Fig. 23 Classification of Mobility Models

Funding No funding is available.

Availability of data and material Availability of data is not associated.

Code availability We are not providing the code due to privacy because, we are working on some future aspects.

Declarations

Conflicts of interest There is no conflict of interest.

References

1. Hayes, T., & Ali, F. H. (2016). Robust Ad-hoc sensor Routing (RASeR) protocol for mobile wireless sensor networks. *Ad hoc Networks, 50*, 128–144.
2. Bensaleh, M. S., Saida, R., Kacem, Y. H., et al. (2020). Wireless sensor network design methodologies: A survey. *Journal of Sensors, 2020*, 1–13.
3. Gao, Y., Ao, H., Feng, Z., et al. (2018). Mobile Network Security and Privacy in WSN. *Procedia Computer Science, 129*, 324–330.
4. Chaochen, X., Xiaoheng, T., Balginbek, T., et al. (2018). Research of resource allocation technology based on MIMO ultra density heterogeneous network for 5G. *Procedia Computer Science, 131*, 1039–1047.
5. Fu, Y., Lien, T., & Lin, F. (2018). Application association and load balancing to enhance energy efficiency in heterogeneous wireless networks. *Computers & Electrical Engineering, 68*, 348–365.
6. Padmaja, P., & Marutheswar, G. V. (2018). Energy efficient data aggregation in wireless sensor networks. *Procedia Computer Science, 5*, 388–396.
7. Kaur, S., & Mahajan, R. (2018). Hybrid meta-heuristic optimization based energy efficient protocol for wireless sensor networks. *Egyptian Informatics Journal, 7*, 386–398.
8. Zareei, M., Islam, A., & Rosales, C. (2018). Mobility-aware medium access control protocols for wireless sensor networks: A survey. *Journal of Network and Computer Applications, 104*, 21–27.
9. Shahraki, A., Taherkordi, A., Haugen, O., et al. (2020). Clustering objectives in wireless sensor networks: A survey and research direction analysis. *Computer Networks, 180*, 1–75.
10. Ferandis, T., Silvestre, J., Santonja, S., et al. (2018). Deploy&Forget wireless sensor networks for itinerant applications. *Computer Standards & Interfaces, 56*, 27–40.
11. Nagarju, S., Gudino, L. J., Tripathi, N., et al. (2018). Mobility assisted localization for mission critical wireless sensor network applicationsusing hybrid area exploration approach. *JKSU-CIS, 6*, 79–85.
12. Asad, M., Nianmin, Y., & Aslam, M. (2018). Spiral mobility based on optimized clustering for optimal data extraction in WSNs. *MDPI, 35*, 6–36.
13. Ketshabetswe, L. K., Zungeru, A. M., Mangwala, M., et al. (2019). Coomunication protocols for wireless sensor networks: A survey and comparison. *Holiyan, 5*, 1–43.
14. Samiha, M. E., Elsherif, M., & Wahed, M. E. (2018). An enhancement approach for reducing the energy consumption in wireless sensor networks. *JKSU-CIS, 30*, 259–267.
15. Alkindi, Z., Alzeidi, N., Arafehand, B., & Touzene, A. (2018). Performance evaluation of grid based routing for under water wireless sensor networks under different mobility models. *International Journal of Wireless & Mobile Networks (IJWMN), 10*(1), 13–15.
16. Huanga, Y., Wangb, L., Hou, Y., et al. (2018). A prototype IOT based wireless sensor network for traffic information monitoring. *International Journal of Pavement Research and Technology, 11*(2), 146–152.
17. Almesaeed, R., & Jedidi, A. (2021). Dynamic directional routing for mobile wireless sensor networks. *Ad Hoc Networks, 110*, 1–8.
18. Zagrouba, R., & Kardi, A. (2021). Comparative study of energy efficient routing techniques in wireless sensor networks. *Journal of Information, 12*(42), 1–28.
19. Muhtadi, J. A., Qiang, M., Zeb, K., et al. (2018). A critical analysis of mobility management related issues of wireless sensor networks in cyber physical systems. *SAICPS, 8*, 16363–16376.

20. Echoukairi, H., Kada, A., Bourgba, K., et al. (2017). Effect of mobility models on performance of novel centralized clustering approach based on k-means for wireless sensor networks. *IJAER, 12*(10), 2575–2580.
21. Kaur, U., & Sharma, S. (2017). Parmetric analysis of energy aware clustering and routing protocols used in WSN. *International Journal of Advanced Research in Computer Science, 8*(9), 342–350.
22. Shantha, R., Kumari, S., Chitra, A., et al. (2016). Efficient -2 level energy heterogeneity clustering protocols for wireless sensor networks. *Indian Journal of Science and Technology, 9*(3), 1–6.
23. Ramluckun, N., & Bassoo, V. (2018). Energy-efficient chain-cluster based intelligent routing technique for wireless sensor networks. *Applied Computing and Informatics, 7*, 1–12.
24. SureshKumar, K., & Vimala, P. (2021). Energy efficient routing protocol using exponentially-ant lion whale optimization algorithm in wireless sensor networks. *Computer Networks, 197*, 1–12.
25. Lakhotia, J., & Kumar, R. (2014). Fault tolerant and mobility aware routing protocol for mobile wireless sensor network. In *2014 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT)* (pp. 584-590). IEEE
26. Maheshwari, P., Sharma, A. K., & Verma, K. (2021). Energy efficient cluster based routing protocol for WSN using butterfly optimization algorithm and ant colony optimization. *Ad Hoc Networks, 110*, 1–52.
27. Agbehadji, I. E., Millham, R. C., Abayomi, A., et al. (2021). Clustering algorithm based on nature-inspired approach for energy optimization in heterogeneous wireless sensor network. *Applied Soft Computing, 104*, 1–15.
28. Janabi, S. A., Shourbaji, I. A., Shojafar, M., et al. (2017). Survey of main challenges (security and privacy) in wireless body area networks for healthcare applications. *Egyptian Informatics Journal, 18*(2), 113–122.
29. Kumar, S., & Singh, A. K. (2021). A localized algorithm for clustering in cognitive radio networks. *Journal of King Saud University-Computer and Information Sciences, 33*(5), 600–607.
30. Kalaivaani, P. T., & Krishnamoorthy, R. (2018). Performance analysis of various hierarchical routing protocols using spatial correlation. *Journal of Measurement*. https://doi.org/10.1016/j.measurement.2018.11.084
31. Van Khoa, V., & Takayama, S. (2018). Wireless sensor network in landslide monitoring system with remote data management. *Journal of Measurement, 118*, 214–229.

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