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Cluster-Head Restricted Energy Efficient Protocol (CREEP) for Routing in Heterogeneous Wireless Sensor Networks

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Abstract A magnanimous number of collaborative sensor nodes make up a Wireless Sensor Network (WSN). These sensor nodes are outfitted with low-cost and low-power sensors. The routing protocols are responsible for ensuring communications while considering the energy constraints of the system. Achieving a higher network lifetime is the need of the hour in WSNs. Currently, many network layer protocols are considering a heterogeneous WSN, wherein a certain number of the sensors are rendered higher energy as compared to the rest of the nodes. In this paper, we have critically analysed the various stationary heterogeneous clustering algorithms and assessed their lifetime and throughput performance in mobile node settings also. Although many newer variants of Distributed Energy-Efficiency Clustering (DEEC) scheme execute proficiently in terms of energy efficiency, they suffer from high system complexity due to computation and selection of large number of Cluster Heads (CHs). A protocol in form of Cluster-head Restricted Energy Efficient Protocol (CREEP) has been proposed to overcome this limitation and to further improve the network lifetime by modifying the CH selection thresholds in a two-level heterogeneous WSN. Simulation results establish that proposed solution ameliorates in terms of network lifetime as compared to others in stationary as well as mobile WSN scenarios.

Keywords Clustering · Heterogeneity · Lifetime · Routing · Throughput · Wireless sensor network

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1 Introduction

Communication engineering has encountered an uninterrupted development in various fields, including that in Wireless Sensor Networks (WSN). A Sensor Network [1] can essentially sense an environment using sensors, perform computations via embedded processors, and communicate the information wirelessly to end users, enabling them measure a physical parameter and carry out actions accordingly. WSNs are highly distributed networks of sensors nodes and each node has three major functional parts [2]:

- environmental sensors, which perform the sensing operations,
- data processors, which perform computations on the sensed data, and,
- communicators, which perform information exchange among the sensor nodes.

WSNs have completely revolutionized the wireless communication scenario since it can enable instrumentation in environments where wired sensors are impractical. It has thus generated paramount stakes among the researchers. WSNs can be deployed in a vast range of applications, which include healthcare and medical telemetry [3, 4], habitat and environmental monitoring applications [5, 6], surveillance/target tracking applications [7, 8], military and security [9], traffic control domains [10], and, home and industrial automation [11, 12]. WSN research is increasingly evident in many practical applications. The "Smart Dust" Project of Berkeley being carried out at University of California, USA, [13] established the viability to incorporate a huge amount of invisible wireless dust nodes. Many other plans are being envisioned that are grounded on the principles on WSNs. Examples include the CitySense project, which aimed at spanning an entire city [14]. Another forthcoming practical use of WSN is being employed to determine the permafrost in Swiss Alps (PermaSense) [15]. Harvard University has developed the Code Blue project [16], which is being utilized for remote-location medical aid and catastrophe management. It can be aptly said that the applications of WSN are eternal and restricted only by a man's imagination.

WSNs can be classified as either homogeneous or Heterogeneous WSNs. Homogeneous WSNs essentially comprise of similar sensor nodes in all aspects such as radio range, processing capabilities, power levels etc. Low-Energy Adaptive Clustering Hierarchy (LEACH) [17] is considered to be the primeval routing protocol for a homogeneous environment. The heterogeneous WSNs consist of dissimilar sensors having different abilities in terms of sensing, power levels, processing and communication capabilities [18]. Mostly an energy-heterogeneity scenario is implemented by assuming two-level, three-level or multi-level energy heterogeneity. In two-level heterogeneity, a certain population of the nodes are designated as advance nodes (the rest being normal nodes), whose energy exceed that of normal nodes. Likewise, we can have many levels of heterogeneity, with nodes in each level having higher energy than the nodes in previous level.

1.1 Cardinal Issues and Challenges of WSN Designs

For an efficient operation of WSNs, the following issues are of prime importance over all other issues [19, 20]:

- Sensor nodes are battery-operated and hence energy-saving or maximizing the network lifetime is one of the most crucial design parameter.
  - Also as sensor nodes die out, maintaining the sensing coverage is of grave concern [21].

- Since nodes are battery operated and communications are based on radio, the sensor nodes are more prone to failures [22].
- Sensor network should also be able to efficiently share the communication resources. It should provide a minimum guaranteed QoS (Quality of Service). There must be an efficient congestion control mechanism employed at transport and MAC layers [23].
- A major number of WSNs employ sensor nodes that are equipped with Global Positioning System (GPS) to obtain their positions. However, facilitating all nodes with GPS can turn out to be a very costly deployment scenario. Therefore, localization, or estimating the locations of sensors with unknown location information by use of an algorithmic procedure, is also crucial to sensor network design [24, 25].

1.2 Energy Conservation in WSN and Routing Protocols

We know that the WSNs consist of massively distributed small devices that have restrained sensing, processing, and communication abilities. All these bounded abilities give rise to the need for a robust wireless communication protocol with low power consumption. Due to the ever-changing physical topology of sensor networks, enduring an energy-efficient protocol stack is a tremendously ambitious task [26]. Higher energy-efficiency is being achieved at various layers of the OSI (Open Systems Interconnection) protocol model by different researchers: data link layer [27], network layer [28] and transport layer [29]. The current work is relevant to the network layer.

The hierarchical (cluster-based) network layer protocols group the sensor nodes into clusters [30]. The sensors then communicate only with the leader of their associated cluster, which is referred to as a Cluster Head (CH). These CHs then conglomerate the data of their respective cluster members and disseminate it to the Base Station (BS), i.e., the sink node. Cluster-based routing significantly cuts down the energy dissipation of the network due to the incorporation of a multi-hop communication architecture. LEACH [17] is an excellent illustration of a clustering protocol in a homogeneous scenario. Other protocols that utilize clustering for achieving energy-efficiency in network layer include but are not limited to EDACH (Energy-Driven Adaptive Clustering Hierarchy) [31] and EEUC (an Energy-Efficient Unequal Clustering Mechanism) [32], EADC (Energy Aware Distributed Clustering) [33] and DHCR (Decentralized Energy-efficient Hierarchical Cluster-Based Routing) [34]. Different researchers act according to different objectives while planning clusters in a WSN. The primary clustering objectives [35, 36] include maximizing the network lifetime, achieving a balanced load, ensuring fault-tolerance, reducing the data delivery latency and achieving network security.

1.3 Contribution

In this paper, some representative WSN routing protocols for heterogeneous environment are discussed. These well-established protocols assume stationary setting of sensor nodes. The chief contributions of the current work are listed below:

(1) The paper selects out some typical stationary heterogeneous WSN routing protocols that aim towards enhancement of network lifetime and throughput.
(2) It presents a comparative analysis of the above mentioned routing protocols in heterogeneous WSNs, considering both cases of stationary and mobile sensor nodes and compare their performance in terms of network lifetime and throughput.

(3) It highlights the system's weakness in terms of complexity and provides solution for the same in the form of protocol CREEP (Cluster-head Restricted Energy-Efficient Protocol).
(4) This paper also focuses on the design challenges and future research directions.

The remainder of the paper is orchestrated as follows: Sect. 2 discourses the related work done in heterogeneous WSNs. Section 3 explicates the limitations of these well-established existing routing protocols in a mobile environment and puts forward a modification, followed by the simulation and discussion of results thus obtained.

2 Related Literature

We focus on a two-tier architecture for WSNs. There are three types of nodes in the network, namely, (1) basic sensor nodes, (2) aggregation and forwarding nodes, or the CHs, and (3) a BS. The non-CH nodes, or the basic sensor nodes, constitute the lower-tier of the network. They are deployed in groups or clusters for various sensing applications and are responsible for sending the sensed data directly to its local CH, which are elected from amongst all the nodes on the basis of selection probabilities and thresholds. It is assumed that communication in a WSN happens in rounds. The basic sensor nodes sense and transmit data only once in a round. The CHs aggregate this data and forward it to the BS in the same round. The BS is the sink node for data generated at all CHs in the network.

Heinzelman et al. [17] have projected the LEACH protocol, which is a homogeneous clustering based protocol that employs CH rotation process in each round of communication in order to evenly conserve the energy in the network. All the nodes have equal initial energies as well as an equal probability (p) of being selected as a CH. The node will be elected as a CH in any given round if a random number (between 0 and 1) chosen by it is less than a pre-defined threshold ($T(s)$) value of

$$T(s) = \begin{cases} \dfrac{p}{1 - p\left(r \bmod \dfrac{1}{p}\right)} & if \quad s \in G \\ 0 & otherwise \end{cases} \tag{2.1}$$

where p is the probability of selection of a CH and G is the set of nodes that are eligible to become a CH in rth round.

In the heterogeneous setting of LEACH, there are two types of nodes—normal and advanced. A certain fraction of normal nodes are made as advanced nodes, whose initial energies exceed that of normal nodes, but their probability to be selected as CH are same. The threshold value for CH selection also remains equal for both types of nodes. For example, if there are total n nodes in the network, and a fraction m of the total nodes constitute the advanced nodes, $n * m$ nodes will be advanced nodes and the rest $n * (1 - m)$ nodes will be normal nodes. The energy of normal nodes is E_o and the energy of advanced nodes is $E_o(1 + a)$. Thus total energy of network is given by:

$$E_{total} = n(1 - m) * E_o + nmE_o(1 + a) = nE_o(1 + am) \tag{2.2}$$

Qing et al. [37] have proposed a Heterogeneity-aware Distributed Energy-Efficient Clustering (DEEC) scheme. The main feature of DEEC is probability-based selection of CHs by employing the factors of remainder energy of nodes and average energy of network in its probability equation. The probabilities of normal and advanced nodes, with p_{opt} being the optimal probability, are:

$$p_i = \begin{cases} \dfrac{p_{opt} * Residual\,Energy\,of\,a\,node}{(1+am) * Average\,Energy\,of\,a\,network} & if\ s_i\ is\,normal\,node \\ \dfrac{p_{opt} * (1+a) * Residual\,Energy\,of\,a\,node}{(1+am) * Average\,Energy\,of\,a\,network} & if\ s_i\ is\,advanced\,node \end{cases} \tag{2.3}$$

where m is the fraction of advanced nodes among normal nodes and a is the factor by which the energy of advanced nodes exceed that of normal nodes. The threshold value is same as in LEACH, with probability p being replaced by probability p_i for each node as described in Eq. 2.3.

Smaragdakis et al. [38] addressed the impact of energy heterogeneity in Stable Election Protocol (SEP). The threshold value for rth round is same as in DEEC. The probabilities of normal and advanced nodes are essentially the same as in DEEC, sans the energy factors of average and residual energies. Threshold Distributed Energy-Efficient Clustering (TDEEC) [39] employs essentially similar procedure of CH selection as in DEEC. The threshold value is the value of DEEC, multiplied by k_{opt}, which is the optimal number of clusters. The probabilities values are same as in DEEC.

Kaur et al. [40] proposed Enhanced-Critical Heterogeneous Adaptive Threshold Sensitive SEP (E-CHATSEP) that takes into account energy and distance factors for deciding the CH selection threshold values. The algorithm computes optimum count of CHs as given by Eq. 2.4:

$$k = \frac{\sqrt{3} * M}{2 * r^2 * \pi^2} \tag{2.4}$$

where k denotes the optimum count of CHs for a WSN field of area M and r is the node communication radius. The threshold value for CH selection is then given as in Eq. 2.5:

$$T(n) = \frac{E_i * k}{E_{tot} + D} \tag{2.5}$$

where E_i refers to the residual energy of node i, k denotes the optimum count of CHs, E_{tot} denotes the total sum of energies of all nodes and D is the average distance between ith node and all other nodes. The simulation outcomes establish improvement over SEP in terms of network lifetime and throughput.

Kumar et al. [41] put forward Enhanced Threshold Sensitive SEP (ETSSEP) which performs better in comparison to SEP in terms of network lifetime and stability. It is based on dynamically changing CH selection probability. It elects CHs on the basis of residual energies of nodes and minimum number of clusters per round of communication. ITDEEC [42] attained better results over TDEEC by excluding the nodes closer to the BS while forming clusters.

All the protocols discussed above assume a stationary setting of sensor nodes as well as BS. In literature, some protocols are designed with a mobile sink to reduce the energy consumption [43]. There are many applications which require mobility of sensor nodes also, such as when sensors are tethered to animals or shipping containers [44, 45]. Heterogeneous routing protocols incorporating node-mobility have not been developed much as compared to the protocols involving sink-mobility, which is the primary motivation behind the present work.

3 Limitations of Existing Heterogeneous Routing Protocols and Proposed Solution

3.1 Comparative Analysis

This paper compares the different well-established protocols: heterogeneous-LEACH, DEEC, SEP, TDEEC, ETSSEP, ECHATSEP and ITDEEC protocols in terms of network lifetime and throughput. All these protocols originally assume stationary sensor nodes. However as discussed earlier, a lot of applications require mobile sensor nodes also. Therefore, two different scenarios are being considered, first, in which the sensor nodes are always fixed in position, and second, in which the sensor nodes are mobile.

3.1.1 Network Topology

The network topology assumes that there is a set of N heterogeneous sensor nodes, $V = v_1, v_2, \ldots\ldots\ldots v_N$, distributed randomly over a 2-D field of area A, with BS (node v_0) at the center of the field. Each node operates with same range R and wireless links represent direct communication between sensors and BS within radio range in the form of a multi-level star topology, with ordinary nodes having a direct link with their CHs and CHs having a direct link to the BS.

3.1.2 Network and Path Loss Models

When a signal is sent from a transmitter to a receiver circuitry, the path loss is expressed as the ratio of the power of transmitted signal to the power of the received signal. This estimation is always a function of the propagation distance d between the transmitter and receiver. The two kinds of path loss model used in this work are same as in existing literatures for clustered WSN [17, 35–40]: multi-path fading and Friis free space models depending on node distances (d). The former is used to estimate longer transmission range e.g. transmission from CHs to BS, while the latter is used for shorter transmission from cluster members to their respective CHs. In the free-space model, there is a line-of-sight connection between transmitter and receiver nodes. In a multipath model, a radio signal travels through multiple paths due to reflection, refraction and deflection through various obstacles. With the free space model, the energy loss due to channel transmission is proportional to the square distance separation of the transmitter–receiver circuitry. The multi-path model estimates this channel transmission loss as fourth power of distance d.

This work considers the same radio energy dissipation model as used in [17] and shown in Fig. 1. In this simple first order radio model, the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics. The energy dissipated during the idle time of the processors has been ignored for simplicity, since the idle times will be same for all sensor nodes as the nodes will actively sense and transmit data only once in a round of communication and will be in idle state for the remaining time of the round.

To transmit an L-bit message, the energy dissipated, $E_{TX}(L,d)$, is [17]:

$$E_{TX}(L,d) = \begin{cases} L * E_{elec} + L * E_{fs} * d^2 & if\, d < d_o \\ L * E_{elec} + L * E_{amp} * d^4 & if\, d \geq d_o \end{cases} \tag{3.1}$$

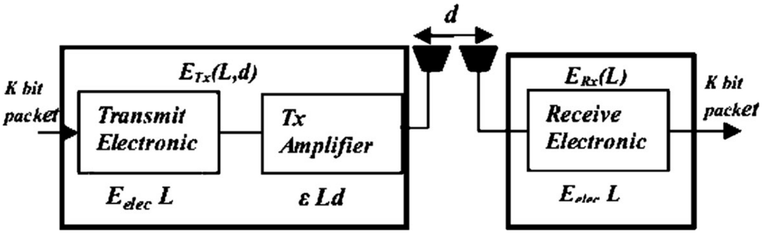

Fig. 1 Radio energy dissipation model

where E_{elec} is the electronics energy and d_o is the distance threshold for swapping between the free space loss and multipath fading models (also known as cross-over distance), which is calculated as:

$$d_o = \sqrt{\frac{E_{fs}}{E_{amp}}} \tag{3.2}$$

where E_{fs} is the loss due to the free space path loss model and E_{amp} is the amplifier loss due to the multipath loss model. The electronics energy, E_{elec}, depends on factors such as the digital coding, modulation, filtering, and spreading of the signal, whereas the amplifier energies, $E_{fs} * d^2$ or $E_{amp} * d^4$, depend on the distance to the receiver and the acceptable bit-error rate.

To receive a L-bit message, the radio will dissipate [17]:

$$E_{RX}(L) = E_{elec} * L \tag{3.3}$$

It is further assumed that the radio channel is symmetric i.e., the same amount of energy is required to transmit a L-bit message from node A to B and vice versa.

3.1.3 Simulation Settings

The following assumptions are made in respect to the analytical work:

- 100 heterogeneous sensor nodes are arbitrarily dispersed in a 2-dimensional square field of dimensions 100 × 100 square metres (Cartesian Coordinates).
- There exists only one stationary BS at the centre of the square field.
- All the sensor nodes are assumed to be pre-equipped with a GPS, and hence their distances to BS and CHs are known a priori.
- The sensor nodes are heterogeneous in nature, with two types of nodes: normal and advanced, with advanced nodes having higher initial energy as compared to normal nodes.
- The energy of sensor nodes cannot be recharged. The BS is not energy limited in comparison with the energy of other nodes.
- All sensor nodes are able to communicate with the BS.
- The data links chosen are Constant Bit Rate (CBR) links where the data sent is assumed to have constant rate of packet delivery.
- Nodes sense the environment at a fixed rate and always have data to transmit.
- For the scenario of mobile sensor nodes, it is assumed that the sensor nodes do not expend any energy during their movement (e.g. when sensor nodes are attached to humans or animals) and that their movement is totally random.

For the purpose of analysis, MATLAB is used to implement the simulation. The network parameters are summarized in Tables 1 and 2.

3.1.4 Definitions of Performance Metrics

- *Network Lifetime* Lifetime is typically specified as the total time for which the network is fully operational and functional and is able to execute the dedicated task(s). The moment up to which the network is considered to be functional is application-dependent. For some applications, it may be the time until the first sensor node or some percentage of sensor nodes run out of energy. The node is considered to be dead when it dissipates all of its energy. The time at which the first node dies is the widely assumed definition of network lifetime because losing a sensor node means that the network could lose some functionality. Alternately, lifetime may also be defined as the time at which the last node runs out of energy. In the present work, both the first node death and last node death will be together considered as two definitions of network lifetime.

  Applications which adhere to the first definition include critical applications like battlefield surveillance, critical patient monitoring, etc. For monitoring of non-friendly forces, like border area surveillance across two nations at war, sensors are laid out across the length of the border to sense any kind of activity. Death of any particular sensor will result in loss of crucial coverage at a particular area, whose consequences can be ominous. Similarly, for the health monitoring of a critically ill patient, several sensors like oxygen rate monitor, heart rate sensor, blood pressure monitor, ECG (Electrocardiogram), temperature sensor, etc., can be placed on the body of the patient. Failure of any one of these sensors can lead to delivery of partial information to the doctors regarding the vitals of the patient. This situation can be life-endangering for the patient. Hence for these situations and other such urgent applications, the sensor network is considered functional up to the point of first node death.

  For other applications, like agriculture, habitat monitoring, etc., lifetime is taken to be the death of the last node in the network. For example, sensor nodes deployed inside a greenhouse to measure air temperature, the loss of nodes do not affect the measurement process since the air temperature is relatively same at every point inside the greenhouse. Hence, as long as there is one node left to measure the air temperature, the network can be considered functional as it is still able to provide sufficient information to the farmers.

Table 1 Parameter settings

Parameters	Value
Network area (square metres), A	100×100
Location of BS (metres)	(50, 50)
Number of nodes, N	100
Data packet length (bits)	4000
Threshold distance, d_o(metres)	70
Transmitter/receiver electronics energy	50 nJ/bit
Data aggregation energy	5 nJ/bit
Transmit amplifier energy, E_{fs}, if $d_{toBS} \leq d_o$	10 pJ/bit/m^2
Transmit amplifier energy, E_{amp}, if $d_{toBS} \geq d_o$	0.0013 pJ/bit/m^4
Optimal probability	0.1

Table 2 Two-level heterogeneity parameters

Parameters	Value
Proportion of advanced nodes, *m*	0.3
Energy factor for advanced nodes, *a*	1.5
Initial energy of normal nodes (Joules)	0.5

- *Throughput* It is defined differently in different literature but its inherent meaning remains the same. In the present work, throughput is specified as the total number of bits transmitted to BS, which is the most widely accepted definition among the researchers.

3.1.5 Analysis of Experiment

We first present a primary comparison of the lifetime of the selected heterogeneous routing protocols. The network lifetime results are shown in the form of graphs in Figs. 2 and 3. Tables 3 and 4 show the first node and last node death metrics in case of stationary and mobile sensor nodes respectively. For simplicity, all the protocol names have been appended with '–S' and '–M' to signify their stationary and mobile node settings respectively.

It is evident that ECHATSEP protocol outperforms the remaining protocols in terms of network lifetime in the both scenarios, with protocols like ITDEEC and TDEEC following its leads. Figures 4 and 5 depict the network throughput in terms of the number of packets that are being sent to the BS for the stationary and mobile node settings respectively. As clear from the figures, the protocol TDEEC outperforms all other protocols in terms of the throughput.

3.2 Limitations

Though the findings revealed that ECHATSEP, ITDEEC and TDEEC protocols outperformed the other protocols in terms of network lifetime and throughput in case of both stationary and mobile nodes, there seems to be a limitation in terms of the number of nodes being selected as CH. Table 5 shows the highest number of CHs being selected in any

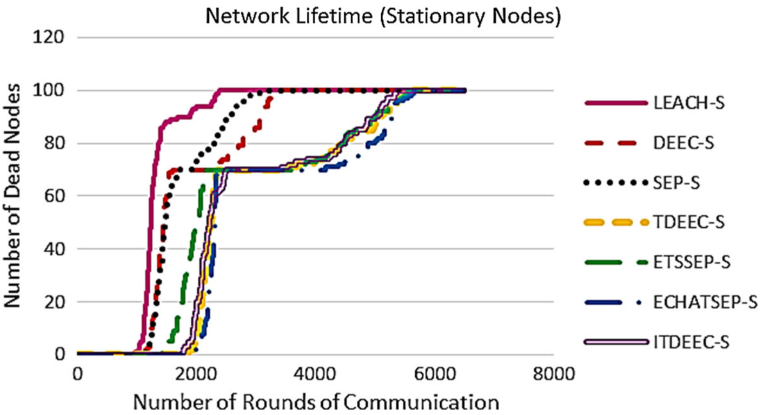

Fig. 2 Network lifetime in case of stationary sensor nodes

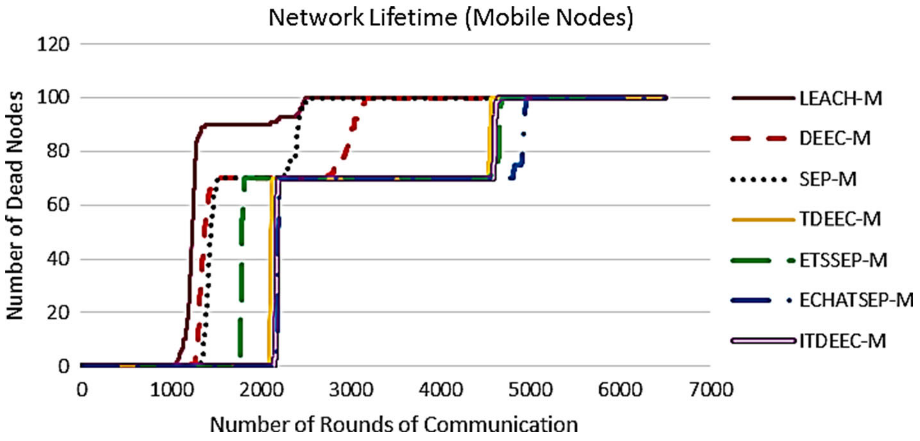

Fig. 3 Network lifetime in case of mobile sensor nodes

Table 3 First node death and last node death in case of stationary sensor nodes

	First node death	Last node death
LEACH-S	969	2376
DEEC-S	1115	3294
SEP-S	1142	3092
TDEEC-S	1786	5563
ETSSEP-S	1421	5549
ECHATSEP-S	1947	5657
ITDEEC-S	1860	5372

Table 4 First node death and last node death in case of mobile sensor nodes

	First node death	Last node death
LEACH-M	1051	2491
DEEC-M	1217	3156
SEP-M	1303	2753
TDEEC-M	2089	4565
ETSSEP-M	1758	4684
ECHATSEP-M	2169	4955
ITDEEC-M	2107	4641

round of communication for all the protocols discussed for both the scenarios of stationary and mobile nodes. Table 6 shows the average percentage of the number of CHs selected on the interval up to first node death as well as for the entire network lifetime in case of stationary nodes.

On analysing the number of CHs selected in each round in these protocols, it is found that there are many rounds of communication during which the number of CHs is large and some rounds in which very few CHs exist. Higher the percentage of alive nodes designated as CHs, higher is the system complexity, pointing towards higher complexities of better performing protocols like TDEEC, ECHATSEP and ITDEEC. Also, when the number of

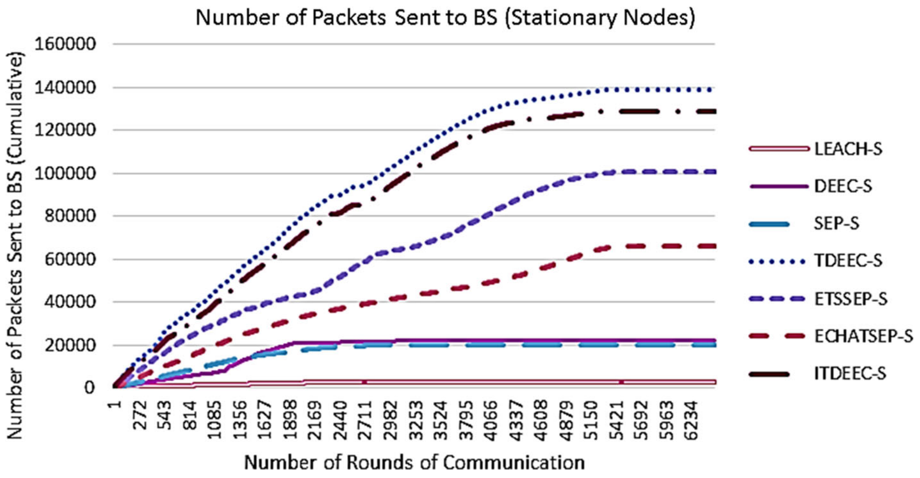

Fig. 4 Comparison of throughput in case of stationary sensor nodes

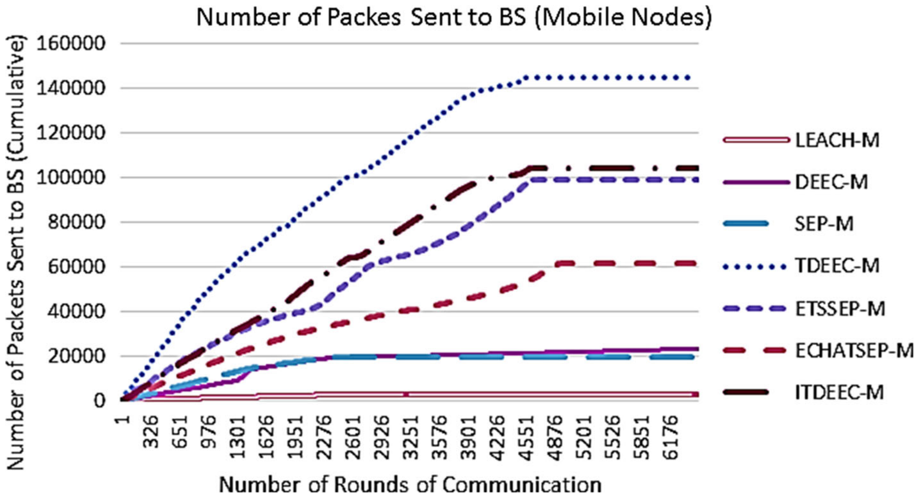

Fig. 5 Comparison of throughput in case of stationary sensor nodes

Table 5 Highest count of CHs in any round of communication for stationary and mobile sensor nodes

	Highest count of CHs	
	Stationary WSN	Mobile WSN
LEACH	23	20
DEEC	32	32
SEP	23	22
TDEEC	99	100
ETSSEP	51	59
ECHATSEP	43	41
ITDEEC	90	80

Table 6 Average percentage of nodes selected as CHs up to first and last node deaths for stationary sensor nodes

	Average percentage of selected CHs	
	Up to first node death (%)	Up to last node death (%)
LEACH-S	9.99	9.56
DEEC-S	7.56	7.12
SEP-S	10.15	9.46
TDEEC-S	28.42	16.62
ETSSEP-S	2.76	4.56
ECHATSEP-S	15.39	7.82
ITDEEC-S	27.18	20.77

nodes being selected as CH on an average is very low as in ETSSEP, the protocol performs inferior in terms of network lifetime.

At this point, we can say that there is a certain impact of the number of CHs selected in a round of communication on the performance of WSN. To keep the number of CHs in control in order to reduce the system complexity, and at the same time, maintaining appreciable network lifetime, a new protocol has been developed, that has a fixed number of nodes as CH. The new protocol is aptly termed as CREEP, i.e. Cluster-Head Restricted Energy Efficient Protocol.

3.3 Cluster-Head Restricted Energy Efficient Protocol (CREEP)

In CREEP, it is assumed that initially the total number of nodes are *n*, out of which a few nodes are advanced nodes and the rest are normal nodes, having lesser initial energy as compared to normal nodes.

3.3.1 Threshold and Probability for CH Selection

The threshold value for CH selection is given by:

$$T(s) = \frac{p_i}{1 - p_i\left(r\,mod\frac{1}{p_i}\right)} * \frac{Remaining\,Energy\,of\,node\,i}{Initial\,energy\,of\,node\,i} \tag{3.4}$$

where the probability p_i is different for different types of i nodes. In order to increase energy saving in these nodes, a distance component is introduced in the equation of probability. This ensures that the nodes far-away from the BS get lesser chance of becoming a CH. The probabilities of normal and advanced nodes are given by the following equations:

$$if\ d_i \leq d_{avg}\ then$$

$$p_i = \begin{cases} \dfrac{p_{opt} * Remaining\,Energy\,of\,node\,i * d_i}{(1+am) * Average\,Energy\,of\,network * \,d_{avg}} & if\ s_i\ is\ normal\ node \\ \dfrac{p_{opt} * (1+a) * Residual\,Energy\,of\,node\,i * d_i}{(1+am) * Average\,Energy\,of\,network * \,d_{avg}} & if\ s_i\ is\ advanced\ node \end{cases} \tag{3.5}$$

and *if* $d_i > d_{avg}$ then the factor of (d_i/d_{avg}) is not multiplied in the above equation.

In the above equations, d_i is the actual distance of an *ith* node from the BS and d_{avg} is the average distance from any node to the BS as shown in Fig. 6, given by the equation

$$d_{avg} = d_{toCH} + d_{toBS} \tag{3.6}$$

where d_{toCH} is the average distance between the CH and the cluster members, and d_{toBS} is the average distance between the CHs and the BS, given by:

$$d_{toCH} = \frac{M}{\sqrt{2\pi k}} \tag{3.7}$$

$$d_{toBS} = \frac{0.765 * M}{2} \tag{3.8}$$

where $M * M$ are the dimensions of the sensor field, and k is the number of clusters given by:

$$k = \frac{\sqrt{n}}{\sqrt{2\pi}} * \sqrt{\frac{E_{fs}}{E_{amp}}} * \frac{M}{d_{toBS}^2} \tag{3.9}$$

3.3.2 Dual Hopping

Also in CREEP, the concept of multiple-hopping is applied. In single-hop mode, the sensors located farther away from the BS die out faster due to the long-distance communication. In order to extenuate this problem, dual-hop communication is being employed between the CHs. CREEP approximates the square WSN field as a circular field and considers a disc of radius R with BS at its centre as shown in Fig. 7. Any CH which is

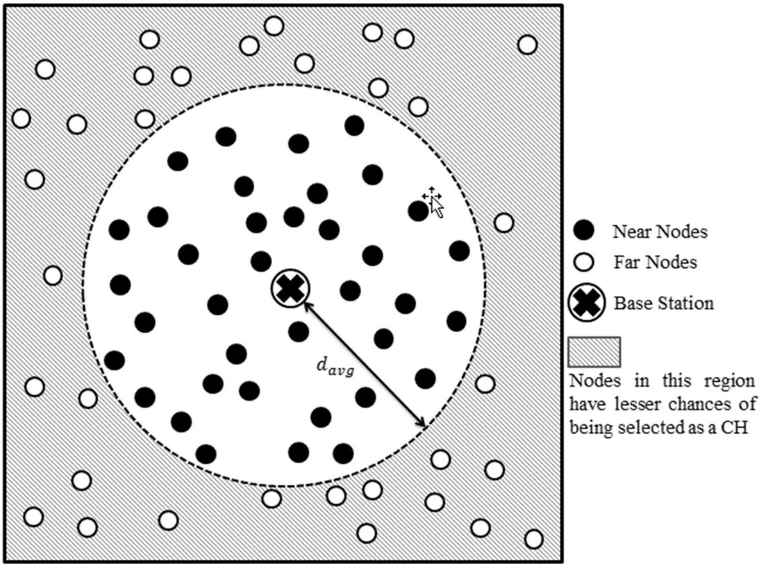

Fig. 6 Probability modification according to distance of near nodes and far nodes

lying within this disc transmits its aggregated data directly to the BS in one single hop. However, for CHs lying outside this disc, dual hop communication is required between the CHs. The CHs lying at a distance greater than R transmit their aggregated data to a CH that lies within the distance R of BS and not directly to the BS. In this manner, the energy of the far-away CHs is saved. The communication process flowchart is being depicted in Fig. 8.

3.3.3 Restricted Number of CHs

In each round of communication, the total number of alive nodes are calculated and no more than k% of alive nodes are selected as CHs, thereby putting a limit on the total number of CHs. It is considered that all the nodes of the network which qualify to be selected as a CH (by satisfying the threshold conditions) are assigned a status of ‘probable CH’. Out of these probable CHs, ‘CH_set’ is formed which has a count of k% of alive nodes. The nodes constituting the CH_set are the nodes having the highest remaining out of probable CH nodes. No other criteria is employed for final CH selection. Those probable CH nodes that fail to be a part of the CH_set are designated as non-CH nodes. Figure 9 shows a part of the CREEP protocol, highlighting the CH selection process.

3.4 Analysis of Optimal Number of CHs

As discussed earlier, the relationship between the number of selected CHs and the performance of WSN (in terms of network lifetime) has to be explored. In order to observe this behaviour, the total number of selected CHs (CH_set) were varied in CREEP protocol according the following different cases for both stationary and mobile nodes:

(1) CH_set having not more than 5% of the total alive nodes in a round of communication
(2) CH_set having not more than 10% of the total alive nodes in a round of communication (original CREEP)

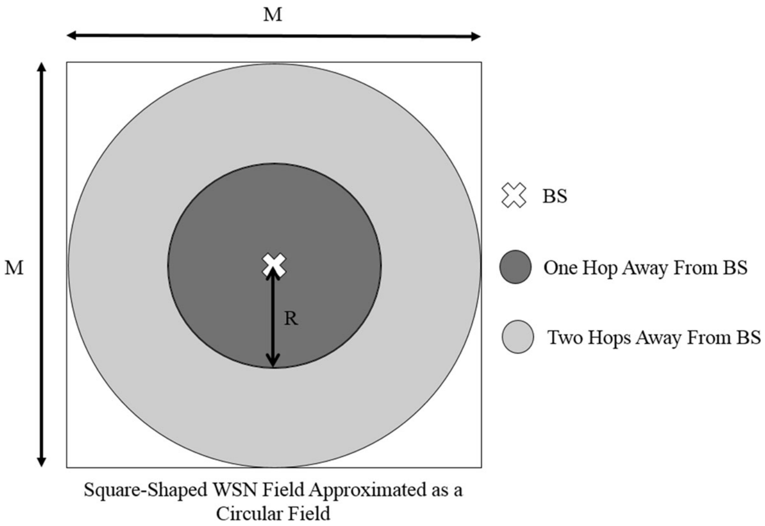

Fig. 7 Dual-Hop in CREEP

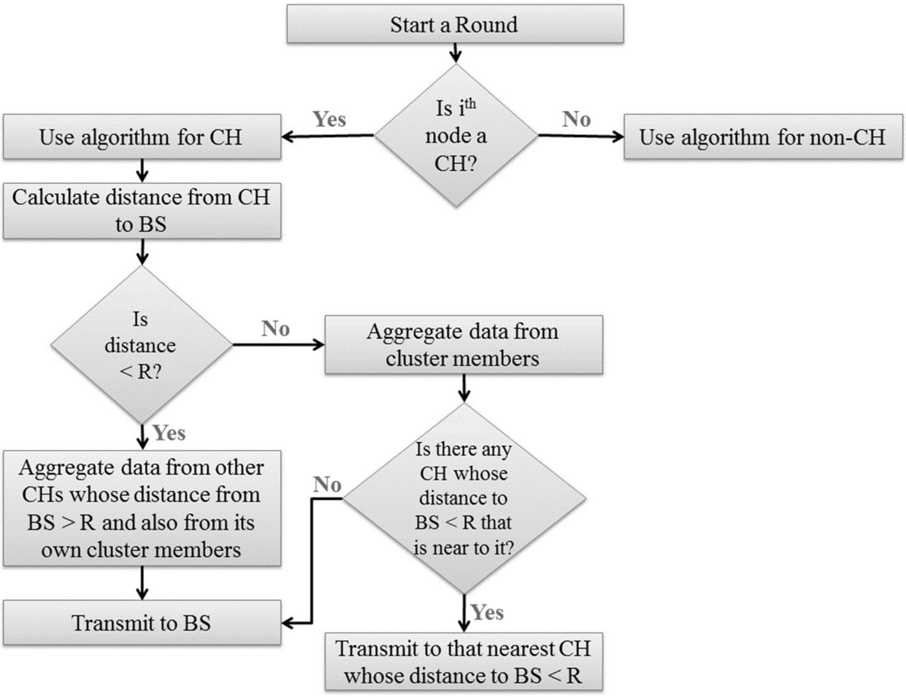

Fig. 8 Communication process flowchart

(3) CH_set having not more than 20% of the total alive nodes in a round of communication
(4) CH_set having not more than 30% of the total alive nodes in a round of communication
(5) No limit on the number of CHs in a round of communication.

Tables 7 and 8 show the network lifetime in case of stationary and mobile sensor nodes respectively for the above cases.

It can be observed from the tables that when we start restricting the number of nodes selected as CH, the lifetime of WSN increases and this trend continues up to 10% of alive nodes selected as CH. Beyond this, on further limiting the number of CHs, the lifetime starts to degrade. Hence, it can be observed that keeping only 10% of the total alive nodes as CH will result in optimum lifetime in case of both stationary and mobile sensor nodes and will have the least system complexity at the BS since the number of CHs are less.

Evidently from the observations of Tables 3, 4, 7 and 8, it can be deduced that CREEP with 10% of alive nodes as CH outperforms ECHATSEP and ITDEEC in terms of network lifetime by 24.3 and 30.1% respectively in the stationary node settings. The performance of CREEP is similar for mobile node settings.

With less number of CHs, we can expect a reduction in the number of packets being sent to CH, since the CHs send the packets to the BS (the individual nodes attach themselves to a CH and send their packets to CH instead of the BS). Therefore, restricting the number of CHs may impact the throughput negatively. To explore this, the throughput analysis is also done. Figures 10 and 11 depict the number of packets sent to BS with respect to the

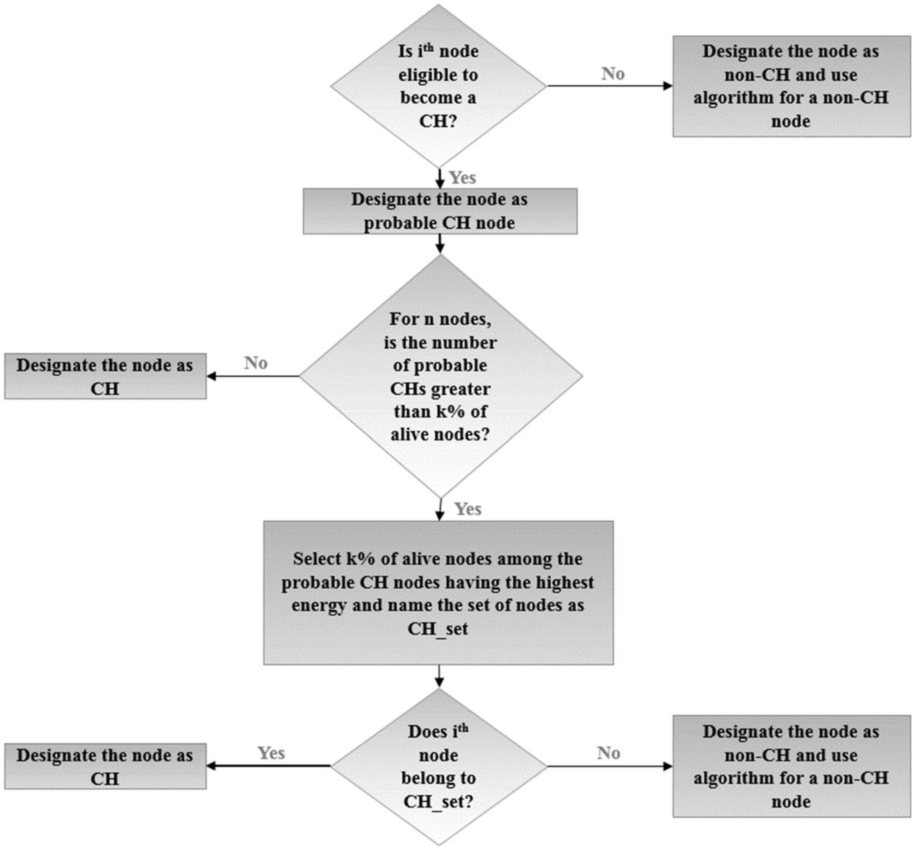

Fig. 9 Portion of the flowchart of CREEP highlighting CH selection process

Table 7 CREEP: first node death and last node death in case of stationary sensor nodes

Limit on number of CH	First node death	Last node death
No limit	2190	5874
30%	2362	6232
20%	2398	6221
10%	2421	6233
5%	1630	5801

Table 8 CREEP: first node death and last node death in case of mobile sensor nodes

Limit on number of CH	First node death	Last node death
No limit	2315	5060
30%	2356	6190
20%	2423	6187
10%	2455	6187
5%	2206	5928

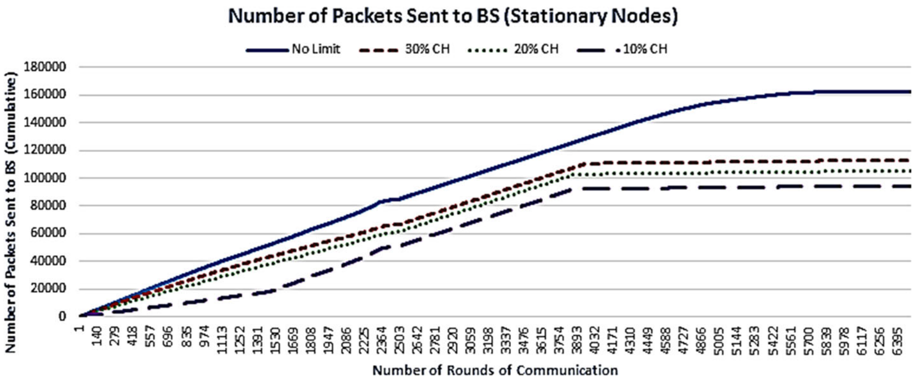

Fig. 10 CREEP: comparison of throughput in case of stationary sensor nodes

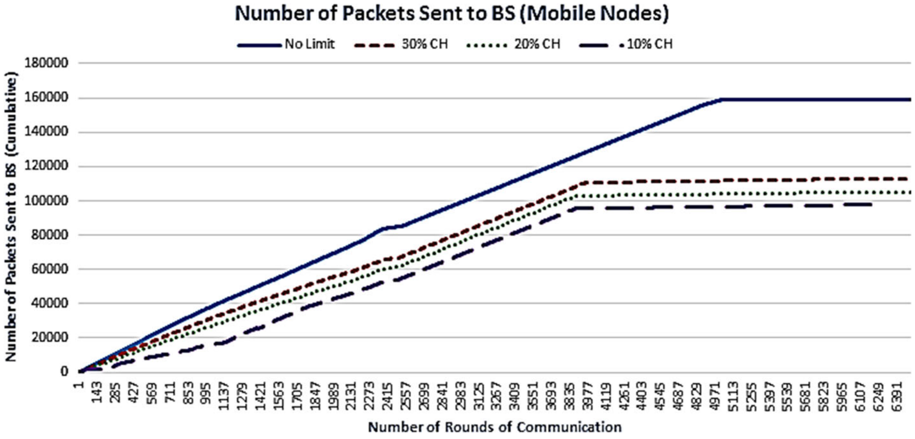

Fig. 11 CREEP: comparison of throughput in case of mobile sensor nodes

number of rounds of communication for the two cases of stationary and mobile nodes respectively.

For both the cases, it is observed that the number of packets sent to BS for the case of 10% alive nodes as CH is less than that of CREEP protocol with no CH restriction (since the CHs send the packets to BS and the number of CHs are limited). It is deduced that although the case of 10% alive nodes as CH result in the highest lifetime, the same is not true in case of throughput. Hence there needs to be a trade-off between the network lifetime and the number of packets sent to BS depending upon the type of application for which the WSN is to be used. If the application demands for a larger lifetime, the number of CHs need to be restricted. On the contrary, to achieve better throughput, there should not be any limit on the number of CHs being selected in each round of communication. Also, on comparing the various throughput graphs, it can be deduced that CREEP outperforms ECHATSEP, TDEEC and ITDEEC protocols in terms of the number of packets being sent to BS. Thus, it can be generalized that CREEP surpasses all the discussed protocols in terms of network lifetime and throughput.

4 Conclusion and Future Research Direction

Many investigators have tapped extension of the network lifetime of heterogeneous WSNs, but there is still a great deal to be achieved. Moving towards this direction, this work critically analysed the well-established stationary heterogeneous routing protocols for mobile scenarios and developed a modified protocol, CREEP, in order to increase the network lifetime. The need for this modification was the system complexity arising due to the large number of nodes being selected as CHs. The simulation results show that by restricting the number of CHs, the CREEP performs better as compared to the other protocols in heterogeneous environment for both stationary and mobile WSNs. However, there needs to be a trade-off between higher lifetime and throughput.

At present the CHs are limited in count by selecting only those nodes having the highest remaining energy. Algorithm can be improved by considering the spatial distribution of the nodes also during CH selection process. The scheme can also be extended for more than two-levels of heterogeneity. Since the network area is assumed to be small in the present protocol, two-hopping has been adopted to improve energy efficiency. The algorithm can also be tested for scalable performance by introducing multiple hopping. Constant Bit Rate (CBR) traffic is being considered for analysis purpose in the present work. Due to the evolution of multimedia systems, there is a need to design protocols that support Variable Bit Rate (VBR) traffic that consists of bursty packets. The impact of restricting the number of CHs on other WSN parameters like latency and reliability can also be studied in future.

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