



# Delay-Sensitive, Reliable, Energy-Efficient, Adaptive and Mobility-Aware (DREAM) Routing Protocol for WSNs

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Accepted: 13 April 2021 / Published online: 27 April 2021

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## Abstract

A majority of Wireless Sensor Network (WSN) research at present is focussed on the problems of limited energy supply and its impact on network lifetime. Nevertheless, the plethora of applications conceivable with the help of WSNs often demand for MOO (Multi-Objective Optimization) formulations, where several design goals contend together for the best trade-off solution among them. Therefore, research investigators must also regard other miscellaneous issues in addition to energy efficiency for applicability of WSNs in practical scenarios like Internet of Things. DREAM (Delay-sensitive, Reliable, Energy-Efficient, Adaptive and Mobility-Aware) routing protocol is proposed in the present work, that ameliorates network lifetime (in terms of First Node Death and Last Node Death), throughput (in terms of number of packets sent to Base Station) and latency (average end-to-end delay in seconds) in the network along with enhancing the reliability (in terms of percentage packet loss) of delivered data. The proposed protocol also integrates mobility and heterogeneity of the nodes to cater to the needs of an application-independent general purpose WSN routing protocol, which can be used commercially. Comparative analysis with existing protocols establishes the superiority of the proposed protocol, which is capable of improving the network lifetime by about 3.54% and simultaneously lowering the delay by 35.5%, along with the amelioration of other parameters.

**Keywords** Adaptivity · Energy-efficiency · Heterogeneity · Latency · Mobility · Multi-objective optimization · Network lifetime · Reliability · Throughput · Wireless sensor networks

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## 1 Introduction

Wireless Sensor Networks (WSNs) consist of miniature sensor nodes deployed to gather vital information about an area of interest [1]. The ability of these networks to monitor remote and hostile locations has attracted a significant amount of research over the past decade. As a result of this research, WSNs have found their presence in a variety of versatile applications such as precision agriculture [2], habitat monitoring [3], target monitoring and tracking [4], security applications [5], industrial automation [6], control of nuclear reactors [7], detection of seismic activities [8], healthcare [9], transportation [10] and various others [11]. These networks have ability to operate in human-inaccessible terrains and collect data on an unprecedented scale. However, they experience technical challenges during deployment as well as operation. The nodes in a WSN are generally resource lacking in terms of battery power, storage, computation, and transmission range, with energy resources being the most vital of all resources. Other issues of concern in WSNs are network throughput, latency and reliability [12].

### 1.1 Multi-objective Optimization (MOO)

Further, commercial industry is not able to take full advantage of WSN technology on a large-scale, since no single routing scheme is found suitable for all WSNs applications' requirements. The different schemes being developed by researchers are application-specific, resulting in expensive deployment [13, 14]. The need for energy-efficient routing protocols to prolong lifetime of these networks is very much required. Moreover, operation of sensor nodes in an intimidating environment and presence of error-prone communication links expose these networks to various reliability breaches. Besides energy consumption and reliable packet delivery, latency incurred in network is also crucial in applications demanding real-time data transfer. Practically, all these above-mentioned performance metrics are often conflicting in nature, hence trade-offs are inevitable in the course of optimizing overall performance of WSNs. Therefore, Multi-objective Optimization (MOO) algorithms are fundamentally important to commercially available WSN design [15]. These multiple design goals may be contradictory in nature or may be design independent. Depending upon the nature of application and the environmental scenarios, the character of optimization problem changes. Due to resource constraints of WSNs, it is desirable that the optimization techniques use lesser memory and computational power, and at the same time, deliver appreciable.

### 1.2 Contribution

This work aims to provide an effective solution for minimizing the energy consumption of the sensor nodes, while maintaining appreciable throughput, latency and reliability in the network. To achieve this objective, a cluster-based hierarchical routing protocol, DREAM (Delay-sensitive, Reliable, Energy-Efficient, Adaptive and Mobility-Aware) is proposed that ameliorates network lifetime, throughput and latency in the network along with enhancing the reliability of delivered data. The proposed protocol also integrates mobility and heterogeneity of the nodes to cater to the needs of

an application-independent general purpose WSN routing protocol, which can be used commercially. 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 proposed DREAM routing protocol, followed by the simulation in Sect. 4. Towards the end, in Sect. 5, a brief discussion of results thus obtained in previous section is done, along with the applicability areas of the proposed protocol DREAM. This work is finally concluded in Sect. 6 by presenting a succinct view of the research outcomes, followed by a discourse on future exploratory directions.

## 2 Literature Review

This section focuses on multi-objective network routing protocols for simultaneous optimization of various design goals like network lifetime, latency, throughput, connectivity, coverage, reliability, etc., with special mention of cluster-based routing models. Considering these performance metrics, an exhaustive and systematic analysis of all the recent works has been compared. Ultimately, the literature is concluded by delineating the inferences and research gaps.

Heinzelman et al. [16] have projected the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, which is a homogeneous clustering based protocol that employs Cluster Head (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 a given round if any random number (lying between 0 and 1) chosen by it is lower than a pre-defined threshold ( $T(s)$ ) value of

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

where  $p$  is the probability of selection of a CH and  $G$  is the set of sensors that are qualified to be chosen as a CH in  $r$ th round. In the heterogeneous setting of LEACH, there are two kinds of nodes- normal and advanced. A certain fraction of normal nodes are made 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.

Smaragdakis et al. [17] handled the effect of energy heterogeneity in Stable Election Protocol (SEP). The algorithm is based upon the concept of weighted election probability of nodes to become CHs which considers the remaining amount of energy of each sensor node after every round. Kumar et al. [18] put forward Enhanced Threshold Sensitive SEP (ETSSEP) which performs better in comparison to SEP with respect to 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. Also, ETSSEP considers three-level heterogeneity of the sensor nodes which classifies nodes as normal, intermediate and advanced nodes. The threshold value for  $s^{th}$  sensor node is given as:

$$T(s) = \begin{cases} \frac{p_{opt}}{1-p_{opt} \left( r \cdot \text{mod} \frac{1}{p_{opt}} \right)} * \frac{\text{node's residual energy}}{\text{network's average energy} * K_{opt}} & \text{if } s \in G \\ 0 & \text{otherwise} \end{cases} \quad (2.2)$$

where  $G$  is the set of all sensors eligible to become CHs with optimum probability  $p_{opt}$ ,  $K_{opt}$  is the optimum value of clusters in  $r^{th}$  round.

Another protocol called LEACH-CCH (LEACH-Centered CH) aimed at improving the network lifetime of WSN has been proposed in [19] that considers mobile sensors. It is basically a modified LEACH algorithm. The major cause of performance degradation in LEACH is due to cluster formed in the set-up phase breaks apart in the entire steady state phase of a particular round of communication as the sensors move away from each another. This breaking apart results in an increased energy expenditure. LEACH-CCH tends to modify the existing LEACH protocol for both stationary as well as mobile nodes. It reconstructs the sensor clusters before the start of steady-state phase. The CHs are reselected depending on which sensor is nearest to the centre of cluster, and then the distances of non-CHs to transmit their data are improved. This leads to improved network lifetime and efficient energy expenditure of the WSN.

A hierarchical and cluster based protocol called Energy Efficient and Reliable Routing ( $E^2R^2$ ) protocol for mobility aware WSNs has been formulated in [20]. In this protocol, each cluster contains one CH, two deputy CH nodes (DCH), and some ordinary sensor nodes. The mobility of the nodes comes into picture during the making of routing decisions. The main aim for routing decision making is that the data packets must move through desired path in spite of node mobility and presence of link failures. Therefore alternate paths are made available. The concept of CH panel in this protocol helps in reducing the energy consumption and the re-clustering time. Initially, the Base Station (BS) selects a set of probable CHs to form a CH panel. The communication in this protocol is carries out either directly or through multi hop communication. The simulation results demonstrate improved throughput, energy efficiency and prolonged lifetime.

Considering the benign environment of industrial automation a clustering scheme had been formulated [21] in which the sensor network has been partitioned into non fixed number of non-overlapping clusters according to the measurement distribution as well as network topology. This protocol takes into account both centralised as well as distributed approaches. The protocol has been then tested on a real data set and investigations have been made to perform anomalies detection in industrial production process.

Another protocol as discussed in [22] is Balanced Energy Efficient Circular routing protocol (BEEC) in which the deployment area is assumed to be circular and is divided into ten sub-circular regions which in turn are divided into eight sectors. The transmission of information occurs between the member nodes in each sector and their respective mobile CHs based on their minimum distance from each other. Similar works have been discussed in [23] which is 3R-Reliable Rim Routing consisting of nodes in different rims with different energy levels and in [24] called Multi hop Angular routing protocol. Both of them have been success in achieving improved throughput and stability as compared to traditional protocols.

A lot of research is devoted towards simultaneous optimization of multiple design goals, such as energy-efficiency and throughput as in [25]. In [26], the authors have purported IMOWCA (Improved Multi-Objective Weighted Clustering Algorithm) for achieving trade-off between energy and delay. Similar works are discussed in [27]. In [28], the authors address the issue of building energy-efficient Connected Dominating Sets (CDS) in

WSNs for improving reliability. The problem is simulated as a MOO that simultaneously maximizes reliability and energy-efficiency. In this work, the reliability is modelled as a probabilistic interference due to uncertainty in communication links and topology control is done to achieve the goals. [29] presents a compromise between the energy consumption and source-to-destination delay under reliability constraints. In [30], Energy Efficient Sector based Clustering Protocol (EESCP) for heterogeneous network has been proposed, in which the area of deployment is split into various sectors. The selection of CH is based on maximum remaining energies of sensors. CREEP (Cluster-Head Restricted Energy Efficient Protocol), proposed by Dutt et. al. [31], in order to increase the network lifetime, lowered 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. The authors in [32] propose a routing protocol named Delay Aware and Lifetime Enhanced Sectoring-based (DALES) algorithm for joint optimization of lifetime and delay in a heterogeneous WSN by modifying probability and threshold equations of EESCP and allowing a certain population of nodes closer to the BS to restrain from participating in the clustering process.

### 3 Proposed Protocol DREAM

Till now, the protocols CREEP, EESCP and DALES proposed earlier have to select the final CH from amongst the nodes eligible to become a CH based on the highest residual energy of nodes. However, it may happen that an eligible node having the highest residual energy in a particular round of communication lies far away from the BS. In such a case, there will be a higher delay in the network due to larger distance of CH from BS, as well as higher energy drainage of that particular node.

Therefore, the distance factor also needs to be incorporated in the final CH selection process for further improvement of network lifetime and delay. Keeping this logic in view, the DALES algorithm is further improvised to include distance factor leading to another routing protocol DREAM (Delay-sensitive, Reliable, Energy-efficient, Adaptive and Mobility-aware) In this protocol, a cost factor is associated with each node for final CH selection as follows:

$$cost_i = \begin{cases} \frac{\text{Remaining Energy of node } i}{d_i}, & \text{if } s_i \text{ is normal node} \\ \frac{(\text{Remaining Energy of node } i)^2}{\sqrt{d_i}}, & \text{if } s_i \text{ is advanced node} \end{cases} \quad (3.1)$$

By virtue of above cost factor, instead of considering only the residual energy, a combination of residual energy and its distance from BS has been considered. Since we know that a node which has higher energy and is at a lesser distance from the BS, will last longer as compared to other nodes. Hence, the chosen cost factor is directly proportional to the residual energy of the nodes, and inversely proportional to their distance from the BS. Further, we also want advanced nodes to be selected as CH more often as compared to normal nodes. For this, we can simply increase the cost associated with the advanced nodes by squaring the residual energy in case of advanced nodes and considering the half power of their distances. This factor considerably raises the cost for advanced nodes. So now, in

DREAM, the final CH is chosen from the selected YPCH (Yes Probable CH) nodes on the basis of highest cost.

Another thing while considering DREAM is the fair allotment of CH to nodes. During sectoring, the number of sectors were kept fixed around the BS, as given by equation:

$$Count\_Sectors_r = 10\% \text{ of alive nodes in round } r \tag{3.2}$$

But at times it so happens that there are more number of nodes in one sector as compared to other sectors. Till now, it was being done that there should be only one CH per sector. However, it was not a fair allotment since a CH which was a part of a sector containing higher number of nodes was more burdened as compared to other nodes as depicted in Fig. 1. So, as per DREAM,

$$count \text{ of final CHs in a sector} = \text{floor}(10\% \text{ of total alive nodes in that sector}) \tag{3.3}$$

with at least one CH in each sector. For example, if a sector has 25 alive nodes in a round of communication, then there must be 2 CHs for that sector in that round of communication.

Moreover, in case of DREAM, the CH selection process is not variable in the sense that the probabilities are fixed throughout the operation of the network. The probabilities are defined as:

if  $d_i \leq d_{avg}$  then

$$P_i = \begin{cases} 0.5, & \text{if } s_i \text{ is normal node} \\ 1, & \text{if } s_i \text{ is advanced node} \end{cases} \tag{3.4}$$

and if  $d_i > d_{avg}$  then

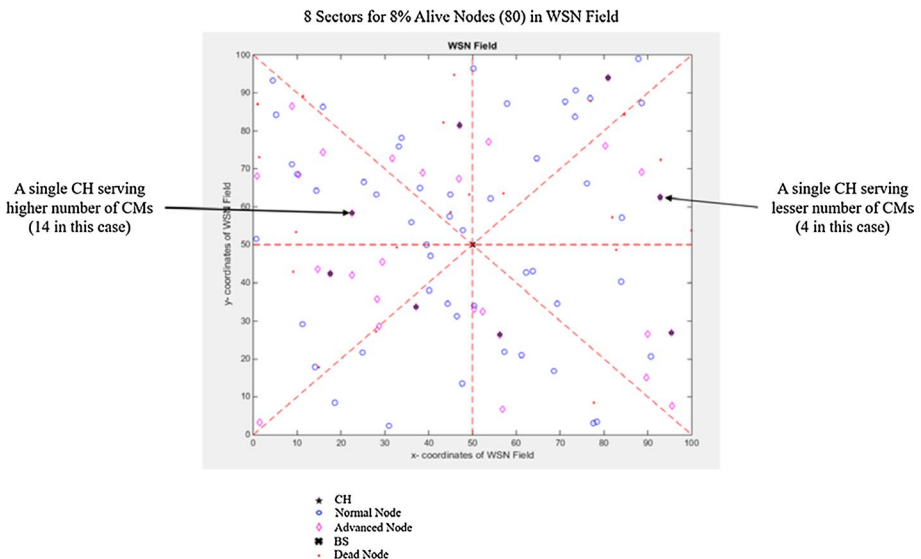


Fig. 1 WSN depicting unfair allotment of CMs to a CH

$$p_i = \begin{cases} 0.25, & \text{if } s_i \text{ is normal node} \\ 1, & \text{if } s_i \text{ is advanced node} \end{cases} \quad (3.5)$$

Selection of such a factor ensures that at any point of time during the network operation, the energy-rich advanced nodes have 100% probability of being selected as CH. The probability of normal nodes, which die out faster, is restrained as compared to the advanced nodes. For the normal nodes that lie closer to the BS, the probability is fixed at half of the advanced nodes, while the normal nodes lying far-away from the BS have one-fourth the probability of advanced nodes to be selected as CH. This guarantees that the far-away nodes are not drained of energy faster.

### 3.1 Algorithm and Flowchart of DREAM

DREAM protocol is suitable for mobile WSN also, in which both the sensor nodes as well as the BS can be mobile. Thus, there can be four different scenarios for DREAM:

- (a) Stationary BS, stationary nodes
- (b) Stationary BS, mobile nodes
- (c) Mobile BS, stationary nodes
- (d) Mobile BS, mobile nodes.

For simplicity, the above four scenarios will be referred to as scenario (a), scenario (b), scenario (c) and scenario (d) respectively, in further discussion.

The Flowchart of DREAM is given in Fig. 2. In DREAM, firstly, all nodes are initialized as NPCH (Non-Probable CH) at start of each round of communication. NPCH nodes are those nodes that cannot become a CH in that particular round. Next, the area of deployment is divided into sectors according to Eq. (3.2). Further, by considering Cartesian coordinates (50, 50) and (100, 50) as reference vector, the angles of all the sensor nodes are calculated in degrees from 0 to 360, with BS at the centre. Based on the angles, sector numbers are assigned to all the nodes.

Next, from each sector, only those nodes that qualify as YPCH (Yes-Probable CH), i.e., they qualify to become probable CHs according to whether they fulfill threshold conditions, are selected. The threshold for CH selection is the same as in EESCP and CREEP and both the probability and threshold equations are used in conjunction to ascertain the YPCH nodes. Once the YPCH nodes are determined, the process is limited to the election of final CHs. In EESCP or DALES, this was based on the YPCH having highest residual energy in a given sector. However, in case of DREAM, the YPCH node having the highest cost factor is chosen as the final CH.

The total number of alive nodes in each sector is determined and with the help of Eq. (3.3), the required number of CHs in each sector are calculated. If there is only one YPCH node in a given sector, that node is automatically designated as the CH node. The rest of the required CHs are chosen from among the NPCH nodes with highest costs. In case of more than one YPCH node in a sector, the YPCH nodes equal to the required number of CHs in that sector with the highest costs are chosen as the CHs. For sectors having no YPCH nodes, all the nodes of that sector contend for CH election and the nodes having highest costs win the competition. After selection of required number of CHs per sector, finally, the usual data communication takes place.

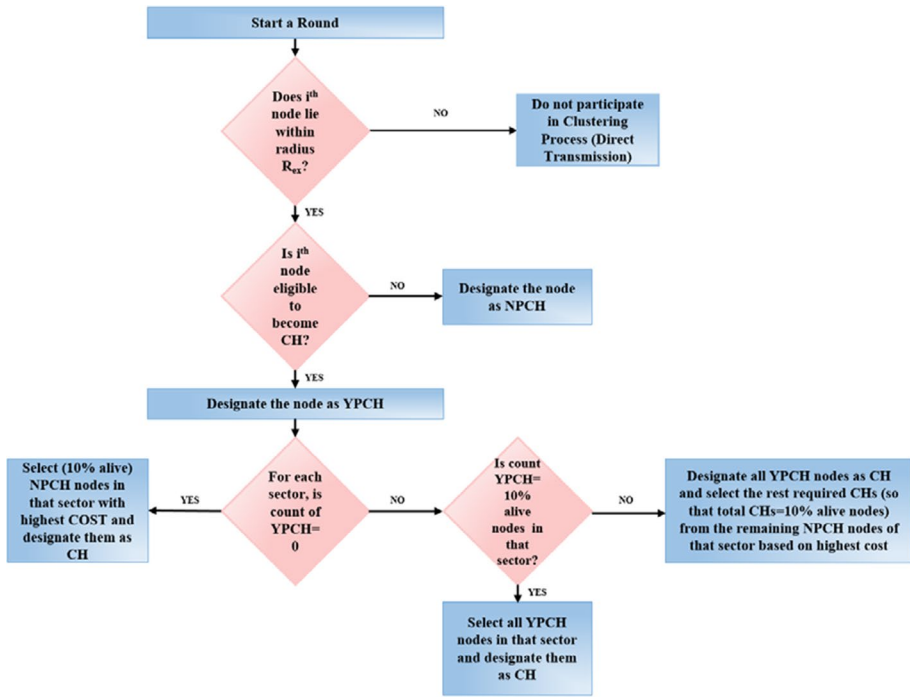


Fig. 2 Flowchart for CH selection in DREAM



The algorithm of DREAM, for all the four scenarios irrespective of their mobilities, is as follows:

**Algorithm for DREAM:**

1. For each node  $s(i)$ 
  - 1.1. If  $s(i)$  lies within distance  $R_{ex}$  from BS, then
    - 1.1.1. Designate  $s(i)$  as Direct Transmission Node.
  - 1.2. Else
    - 1.2.1. Designate  $s(i)$  as Hierarchical Node.
  - 1.3. End if
2. For each node  $s(i)$  designated as hierarchical node,
  - 2.1. Designate as Non-Probable Cluster Head (NPCH).
  - 2.2. Calculate the angle of arrival of each node and assign a Sector Number to it.
  - 2.3. Calculate the probability of CH selection,  $p(i)$ , as well as threshold,  $\text{Threshold}(i)$ .
  - 2.4. Choose a random number,  $\text{rand}(i)$ .
3. For each node  $s(i)$  designated as hierarchical node,
  - 3.1. If  $\text{rand}(i) \leq \text{Threshold}(i)$ , then
    - 3.1.1. Designate node as Yes-Probable Cluster Head (YPCH).
  - 3.2. End if
4. For each sector  $k$ ,
  - 4.1. Calculate total number of YPCH,  $\text{Count}(\text{YPCH})$ .
  - 4.2. If  $\text{Count}(\text{YPCH})=1$ , then
    - 4.2.1. Designate the YPCH node in that sector as CH.
  - 4.3. Elseif  $\text{Count}(\text{YPCH})>1$ , then
    - 4.3.1. Designate the YPCH node having highest residual energy within that sector as CH.
  - 4.4. Elseif  $\text{Count}(\text{YPCH})=0$ , then
    - 4.4.1. Designate the NPCH node having highest residual energy within that sector as CH.
  - 4.5. End if
5. For each node  $s(i)$  designated as hierarchical node & not designated as CH,
  - 5.1. Sense data from environment.
  - 5.2. Send sensed data to the CH in the same sector as node.
6. For each node  $s(i)$  designated as hierarchical node & designated as CH,
  - 6.1. Calculate its distance from BS,  $\text{distance}(i)$ .
  - 6.2. If  $\text{distance}(i) < \text{crossover distance}$ ,
    - 6.2.1. Transmit aggregated data directly to BS.
  - 6.3. Else
    - 6.3.1. Transmit aggregated data to closest CH lying within crossover distance from BS.
7. For each node  $s(i)$  designated as hierarchical node,
  - 7.1. Transmit data directly to BS at the start of each round of communication.

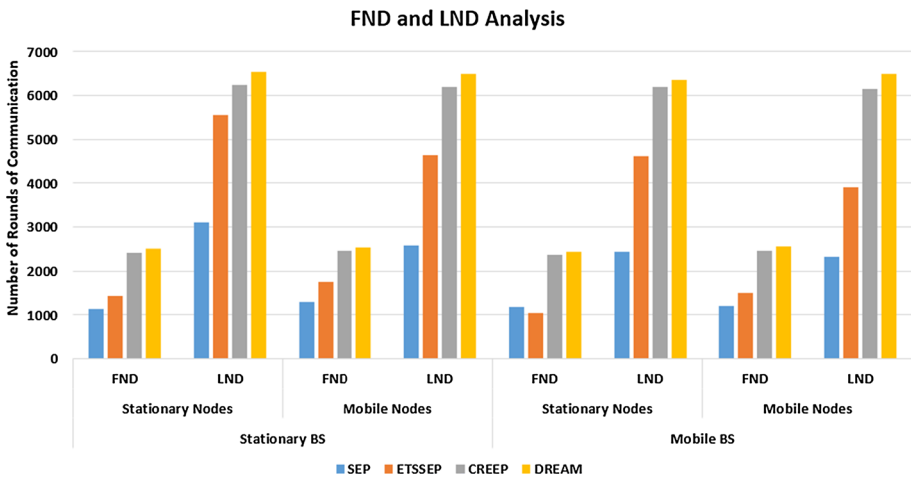
## 4 Results

### 4.1 Network Lifetime Analysis of DREAM

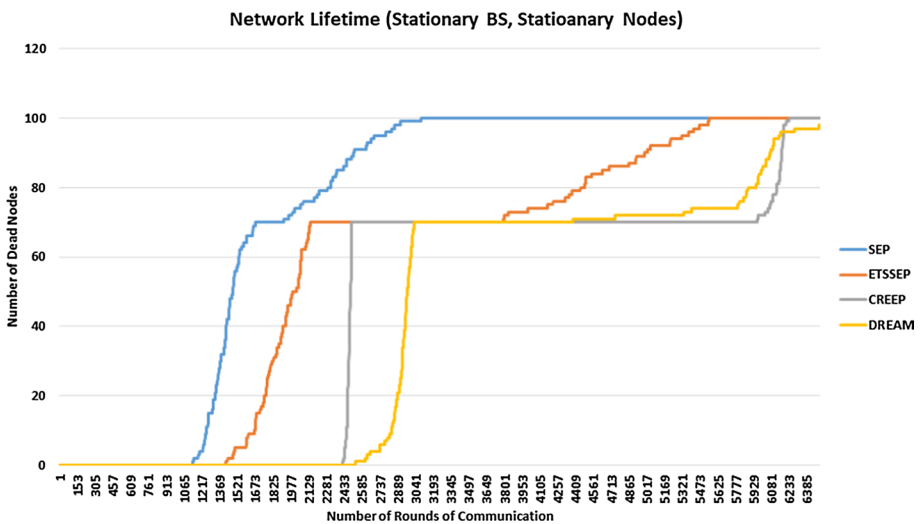
Table 1 and Fig. 3 enumerate the FND and LND for the DREAM protocol in the four scenarios. Figures 4, 5, 6 and 7 show the trend in the number of dead nodes with respect

**Table 1** FND and LND analysis in DREAM

Protocols	Scenario (a)		Scenario (b)		Scenario (c)		Scenario (d)	
	FND	LND	FND	LND	FND	LND	FND	LND
<i>Conventional</i>								
SEP	1142	3092	1303	2573	1170	2439	1191	2314
ETSSEP	1421	5549	1758	4634	1034	4622	1492	3916
<i>Proposed</i>								
CREEP	2421	6233	2455	6187	2369	6199	2458	6148
DREAM	2505	6533	2535	6496	2444	6355	2547	6489



**Fig. 3** Network lifetime comparison of DREAM in terms of FND and LND



**Fig. 4** Network lifetime analysis of scenario (a) DREAM

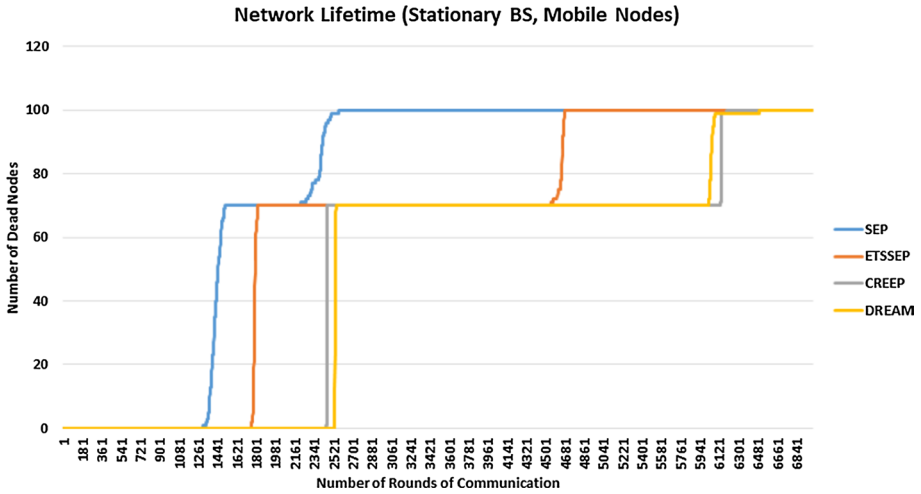


Fig. 5 Network lifetime analysis of scenario (b) DREAM

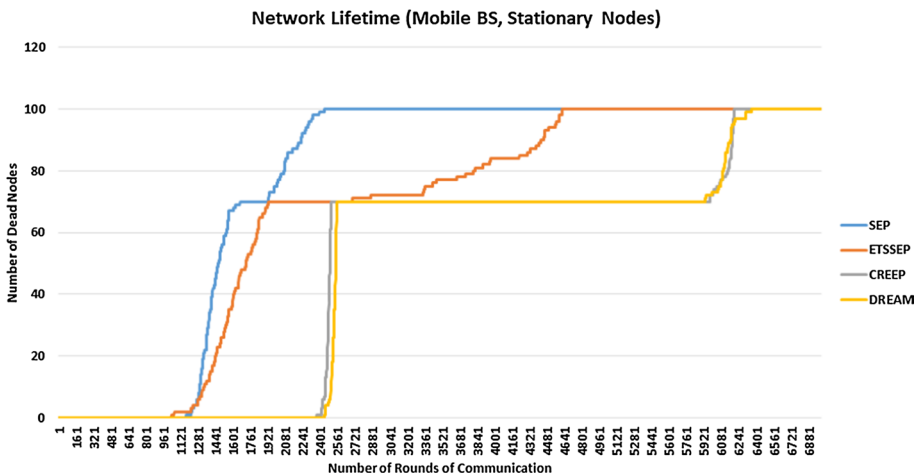


Fig. 6 Network lifetime analysis of scenario (c) DREAM

to the number of rounds of communication. On comparison with CREEP, it is found that the improvement in FND of DREAM is 3.35% in case of scenario (a), 3.15% in case of scenario (b), 3.06% in case of scenario (c) and 3.49% in case of scenario (d). For the case of LND, it is found that the DREAM protocol outperforms CREEP by 4.59% in case of scenario (a), 4.75% in case of scenario (b), 2.45% in case of scenario (c) and 3.525% in case of (d).

The improvement in network lifetime of DREAM may be attributed to the incorporation of a cost factor for CH selection which includes both energy and distance factors, instead of using residual energy alone as the criteria for CH selection as in the

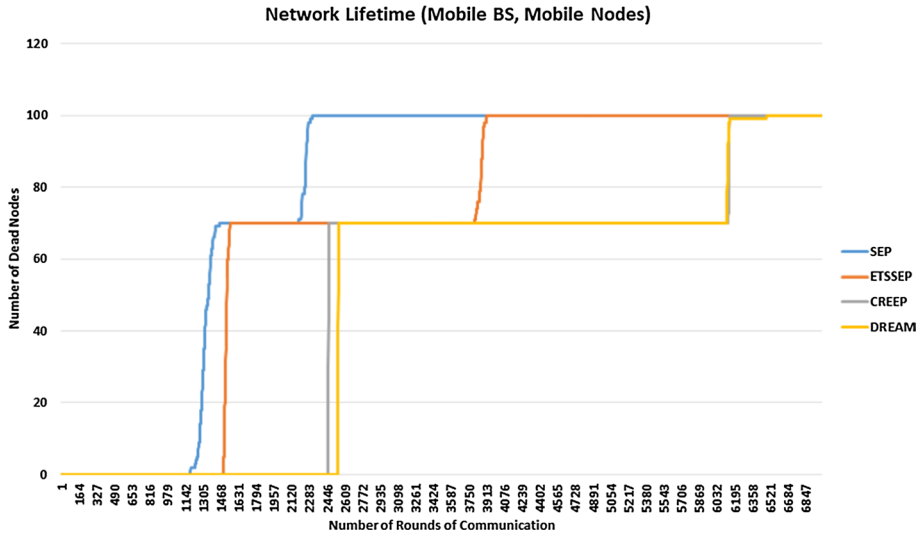


Fig. 7 Network lifetime analysis of scenario (d) DREAM

previously proposed protocols. Further, since there are more number of CHs in one sector, thereby the nodes can communicate with a closer CH, leading to more energy saving.

From these graphs, we can also see that for all these protocols, the normal nodes, which have lesser amount of energy as compared to the advanced nodes, die out first. This is followed by a horizontal portion in the curve. This portion of the curve shows that when all the normal sensors die out, further sensors' death do not occur for some rounds. This is due to the fact that since advanced sensors were equipped with higher initial energies, their energies are not depleted even after all the normal sensors have died. The advanced nodes then start to die after this horizontal region.

## 4.2 Throughput Analysis of DREAM

Figures 8, 9, 10 and 11 show the graphs comparing the proposed protocol DREAM with CREEP, ETSSEP and SEP protocols in terms of the number of data packets received at the BS for all the four scenarios. The graph depicts the number of data packets received at the BS with respect to the number of rounds. As clearly depicted, the proposed protocol DREAM outperforms others here also.

The number of CHs in DREAM is restricted inside a sector, but it is not necessarily 10% of the total alive nodes in the network as in CREEP, EESCP or DALES, Therefore, when taken together, the sum of count of CHs in the network in any round of communication in DREAM may be more than 10% of alive nodes inside the network. We can thus say that the number of CHs in DREAM may be more than that in CREEP. Hence, as expected, more number of packets are now sent to the BS, thereby increasing the throughput in the network in case of DREAM routing protocol.

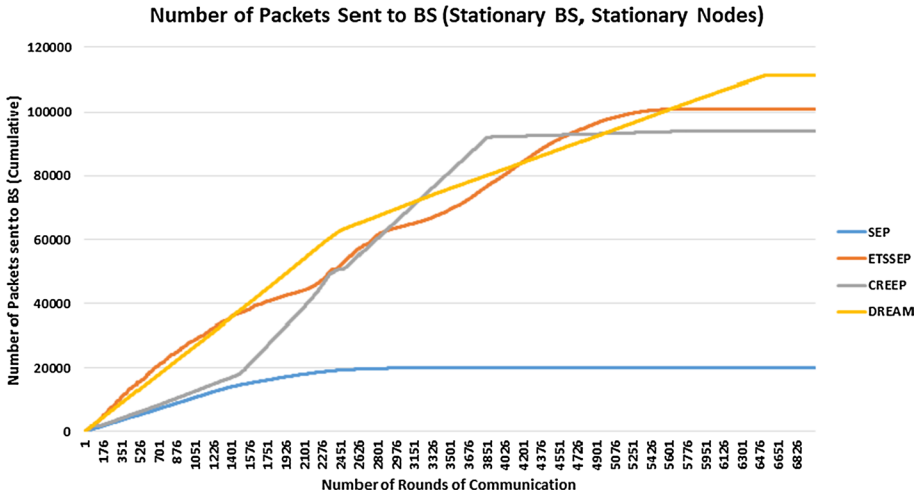


Fig. 8 Throughput analysis of scenario (a) DREAM

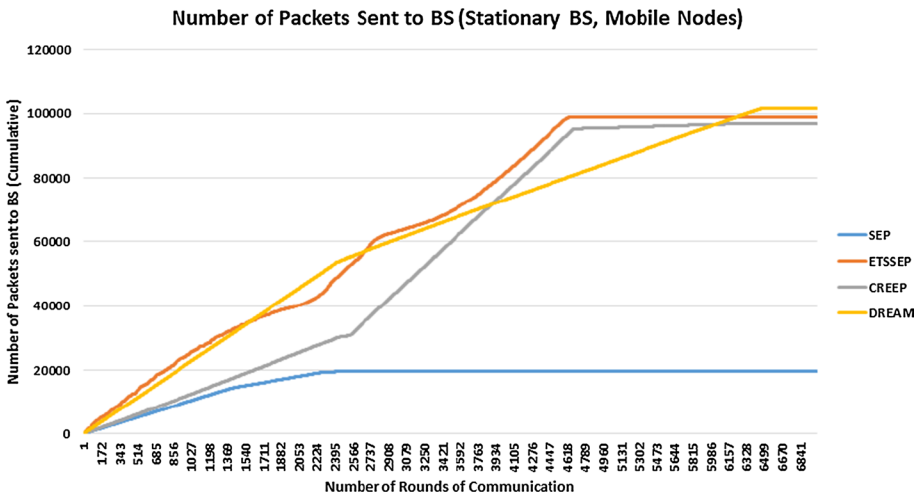


Fig. 9 Throughput analysis of scenario (b) DREAM

### 4.3 Delay Analysis of DREAM

Delay comparison of DREAM is shown in Fig. 12 and corresponding values are listed in Table 2. It is evident from the results that DREAM outperforms SEP, ETSSEP and CREEP in scenario (a) by 8.63%, 96.37% and 40.68% respectively, in scenario (b) by 12.27%, 119.79% and 30.97% respectively, in scenario (c) by 265.76%, 150.20% and 28.85% respectively, and in scenario (d) by 285.07%, 211.22% and 41.74% respectively. Though improvement in lifetime of DREAM is marginal over that in CREEP, but due to a lot of savings in end-to-end delay, it can be deduced that DREAM outperforms CREEP.

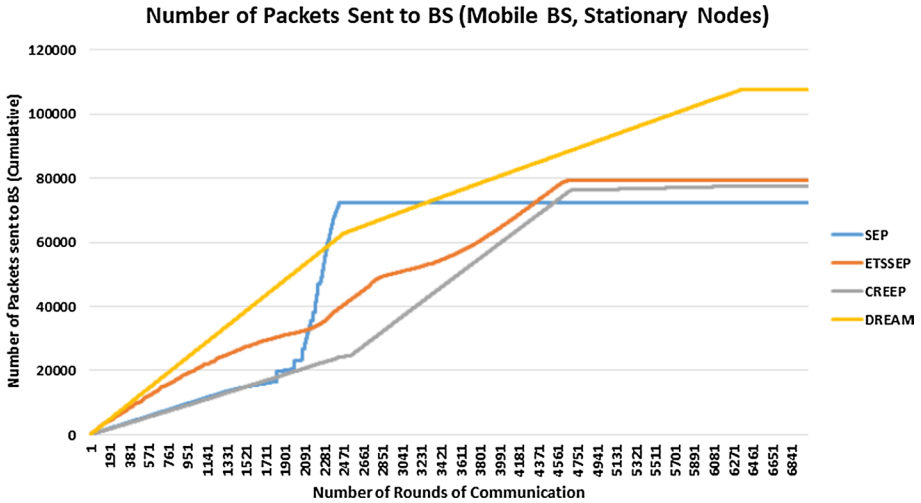


Fig. 10 Throughput analysis of scenario (c) DREAM

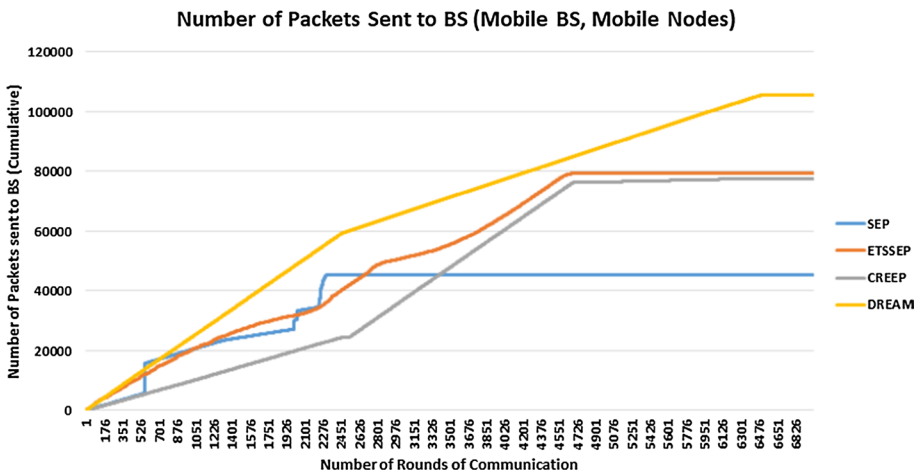


Fig. 11 Throughput analysis of scenario (d) DREAM

By virtue of the cost factor in DREAM, a trade-off between the network lifetime and the delay can be achieved by tweaking the cost factor, depending upon the type of application for which the WSN is to be used. If the application demands for a larger lifetime, a compromise can be made in terms of delay. On the contrary, to achieve a lower delay value, the application has to be satisfied with a lower lifetime. Nonetheless, for an application which demands both higher network lifetime as well as lower delay, DREAM can be implemented in that application.

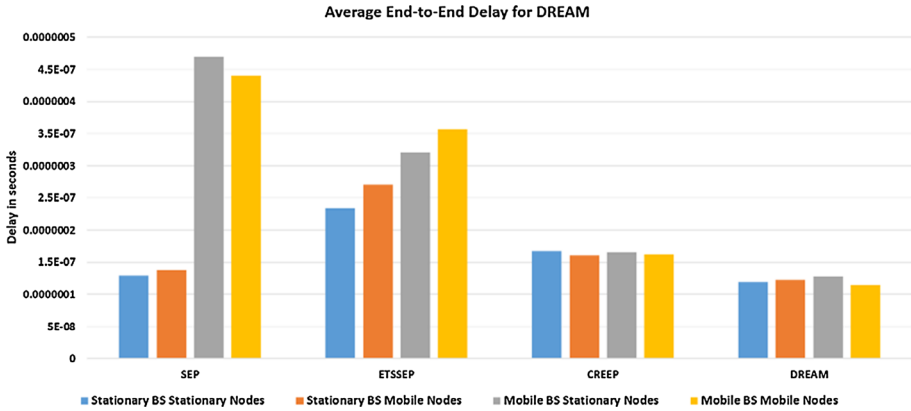


Fig. 12 Delay comparison of existing heterogeneous routing protocols with DREAM

Table 2 Delay in DREAM

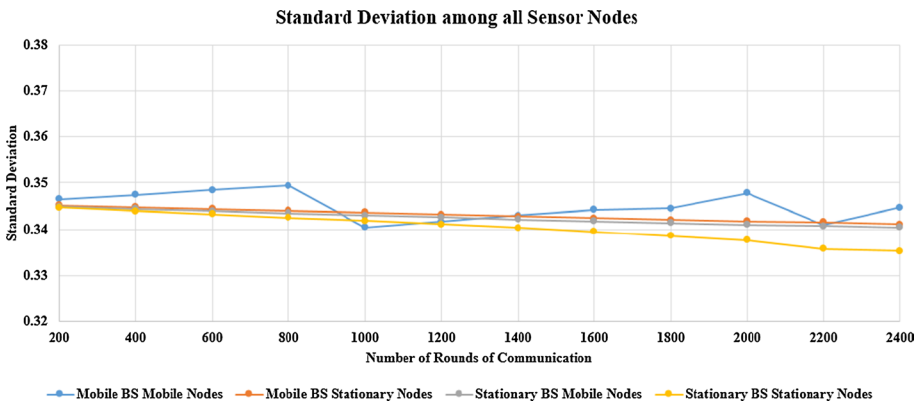
Protocols	Stationary BS		Mobile BS	
	Stationary nodes	Mobile nodes	Stationary nodes	Mobile nodes
<i>Conventional</i>				
SEP	1.29276E-07	1.38212E-07	4.68767E-07	4.40981E-07
ETSSEP	2.33689E-07	2.70566E-07	3.20663E-07	3.56403E-07
<i>Proposed</i>				
CREEP	1.67409E-07	1.61223E-07	1.65133E-07	1.62318E-07
DREAM	1.19002E-07	1.23000E-07	1.28162E-07	1.1452E-07

Table 3 Standard deviation of residual energies of normal and advanced sensor nodes at every 200th round of communication upto FND for DREAM with mobile BS

Round of communication	Mobile BS			
	Mobile nodes		Stationary nodes	
	Normal nodes	Advanced nodes	Normal nodes	Advanced nodes
200	0.000735	0.003859	0.001211	0.001619
400	0.000988	0.007243	0.002036	0.002925
600	0.001135	0.011817	0.002555	0.004098
800	0.001268	0.016372	0.003038	0.005483
1000	0.001506	0.021519	0.003567	0.007255
1200	0.001604	0.028178	0.004139	0.008826
1400	0.001795	0.034869	0.004635	0.010453
1600	0.001875	0.041335	0.005119	0.011891
1800	0.001800	0.047254	0.005278	0.013274
2000	0.001798	0.053469	0.005495	0.014315
2200	0.001865	0.060161	0.006054	0.015999
2400	0.001779	0.067643	0.005067	0.017526

**Table 4** Standard deviation of residual energies of normal and advanced sensor nodes at every 200th round of communication upto FND for DREAM with stationary BS

Round of communication	Stationary BS			
	Mobile nodes		Stationary nodes	
	Normal nodes	Advanced nodes	Normal nodes	Advanced nodes
200	0.000254	0.000529	0.004249	0.005176
400	0.000353	0.000940	0.006849	0.009314
600	0.000385	0.001938	0.009270	0.013280
800	0.000393	0.002753	0.011050	0.017065
1000	0.000386	0.003747	0.012343	0.020519
1200	0.000445	0.004800	0.013884	0.023924
1400	0.000470	0.005808	0.015361	0.027267
1600	0.000500	0.006844	0.016903	0.030736
1800	0.000517	0.007927	0.018358	0.034103
2000	0.000533	0.009033	0.019721	0.037450
2200	0.000564	0.009461	0.016156	0.040651
2400	0.000614	0.009628	0.006365	0.043709



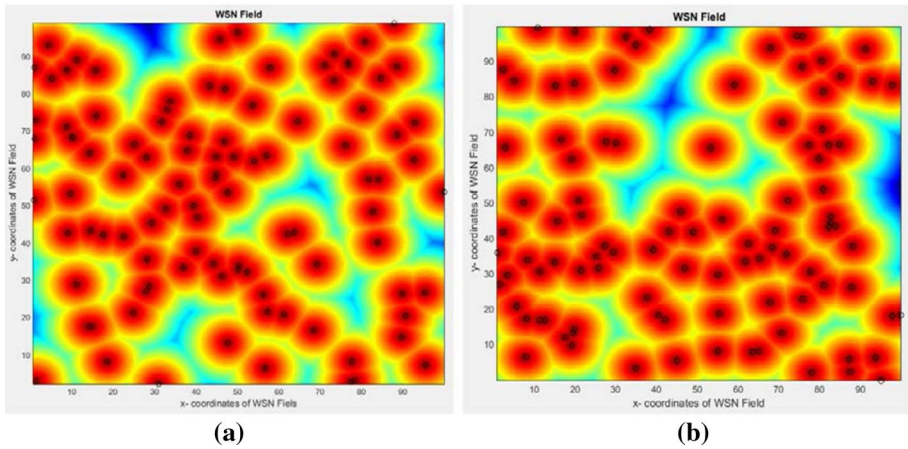
**Fig. 13** Standard deviation of the residual energies of all sensor nodes in DREAM

### 4.4 Energy Consumption and Coverage Analysis of DREAM

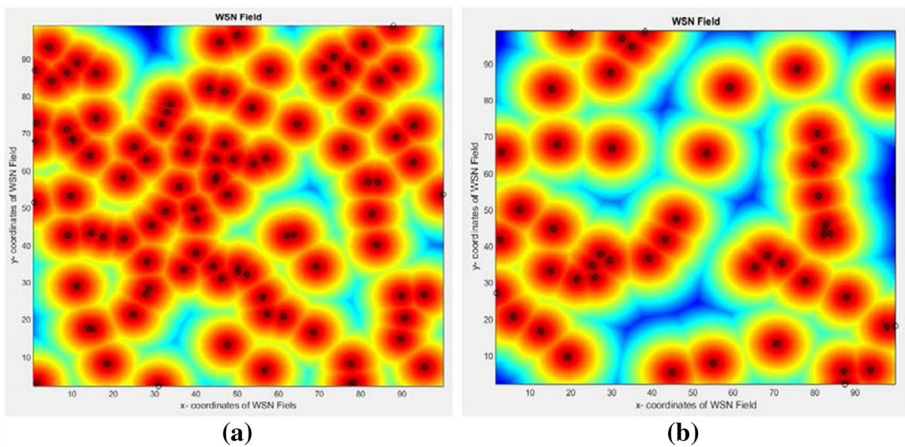
Tables 3 and 4 shows standard deviation of residual energies of normal and advanced sensor nodes at every 200<sup>th</sup> round of communication upto FND for the four scenarios of DREAM. Figure 13 depicts the standard deviation of the residual energies of all sensor nodes taken together.

It is evident from the figure that at any instant, there is very low standard deviation (order 10<sup>-1</sup>) among the sensor nodes, thereby suggesting that the energy consumption is balanced across the network. Moreover, the standard deviation among the nodes is constant upto FND. This helps in improving value of FND leading to more lifetime. Essentially,





**Fig. 14** Heat map at start of WSN for stationary (a) DREAM and (b) CREEP



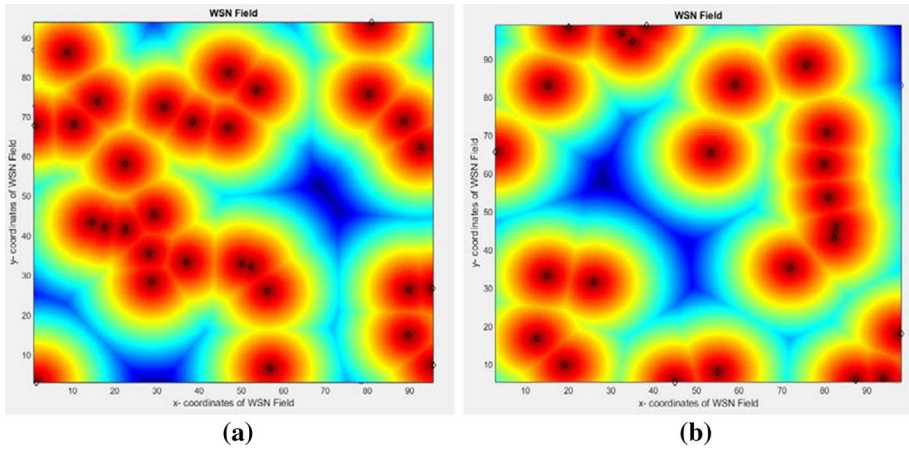
**Fig. 15** Heat Map of WSN at round 2500 for stationary (a) DREAM and (b) CREEP

these point out that in case of both stationary and mobile WSN, there is not much difference in terms of energy variability among all sensor nodes taken together. These graphs, as expected, points towards balanced energy consumption in DREAM.

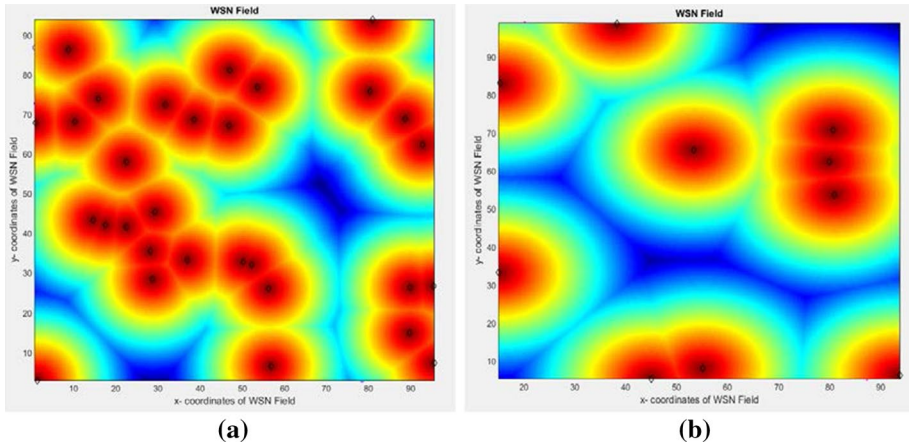
Figures 14, 15, 16 and 17 visually compares the spatial uniformity of nodes over time in case of DREAM (a) and CREEP (b) through heat maps.

The heat maps have been built by considering smallest Euclidean distance between the locations of sensor nodes. In these figures, the sensor locations are shown by their respective symbols. The bright red areas are the regions closest to the sensor node, depicting that the region is fully covered. As the distance from the sensor node increases, so does the coverage decreases. The blue hues indicate the regions on the WSN field that are not covered by any sensor node.

These figures are built for a stationary WSN. It is observed from these figures that DREAM provides the best coverage in the WSN field as the network evolves from its start



**Fig. 16** Heat Map of WSN at round 5000 for stationary (a) DREAM and (b) CREEP



**Fig. 17** Heat Map of WSN at round 6000 for stationary (a) DREAM and (b) CREEP

to the time when it completely runs out of energy. This is due to the fact the DREAM is able to conserve more energy and that too in a more balanced manner as described by the standard deviation curves of DREAM given in the preceding subsection.

#### 4.5 Scalability Analysis

Figure 18 depicts the scalability analysis of DREAM protocol for the stationary node and BS settings. DREAM was run with four different sizes of WSN field as 200\*200 square metres, 300\*300 square metres, 400\*400 square metres, and 500\*500 square metres. The number of sensor nodes in these scenarios was also scaled accordingly to 200, 300, 400 and 500, respectively and their initial energies were kept the same in all four scenarios.

As clearly visible from the figure, the lifetime trend of all the four curves is similar, thereby suggesting that the DREAM protocol is a scalable protocol and provides similar

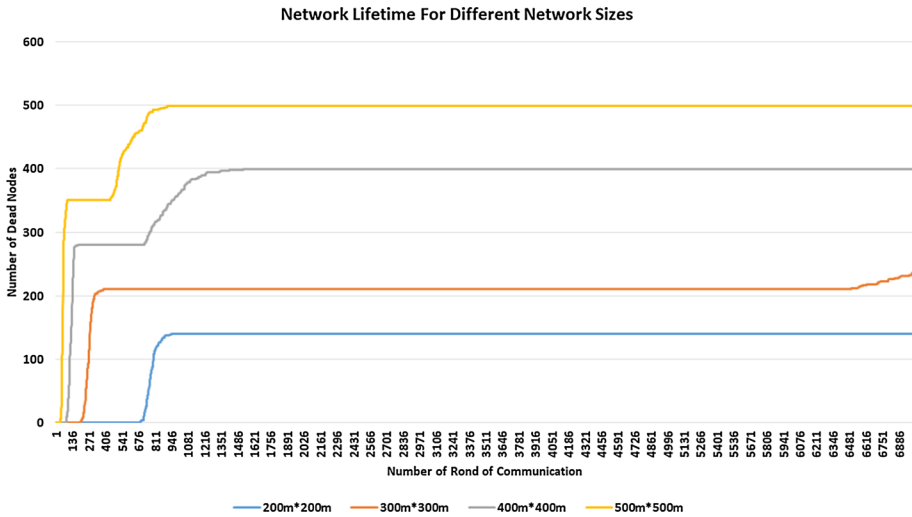


Fig. 18 Network lifetime analysis of scenario (a) DREAM for different network sizes

results in small and large scale fields. The network lifetime of fields of larger size is lower as compared to fields of smaller sizes due to the fact that in larger fields, more energy was expended in data transmission process due to larger distances. However, if accordingly, more initial energies are rendered to nodes in larger-sized fields, the network lifetime would also have been appreciably similar.

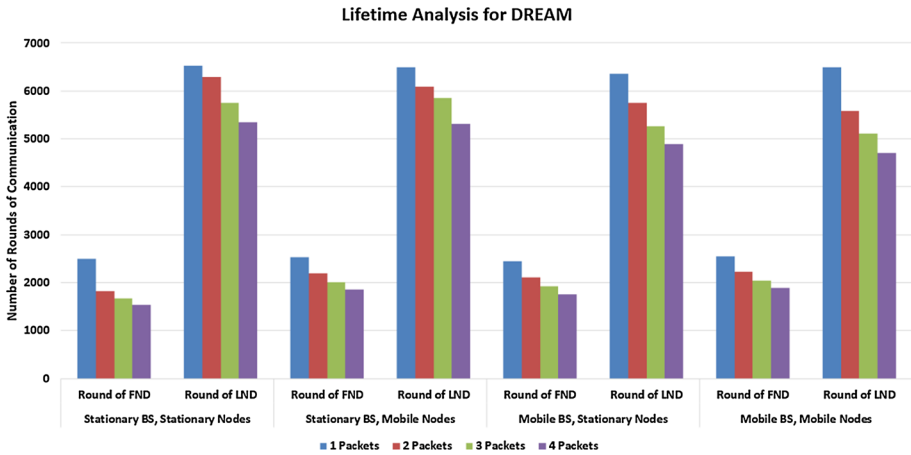
#### 4.6 Performance Analysis of DREAM in Different Types of Traffic

As performed for CREEP in [33], similar experiments were run for DREAM in all its four scenarios. Here also two cases are discussed. In the first case, it is assumed that all sensor nodes in the network transmit at a specified bit rate, which remains same throughout the network lifetime. Four different packet lengths are considered and their impact on performance metrics is analyzed. In the second case, which is the more practical case, it is assumed that the sensor nodes can choose the payload length it will be transmitting at the start of each round. Both the cases are discussed for stationary and mobile sensor nodes.

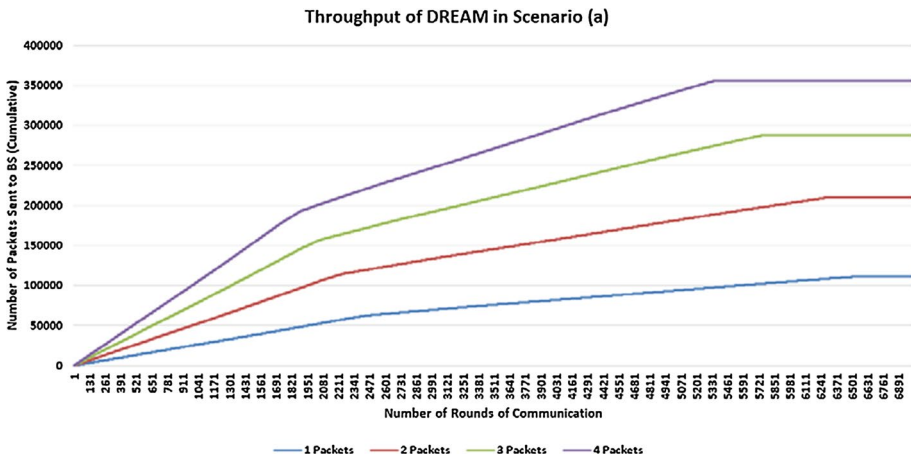
As assumed in earlier simulations, here also a standard data packet is of 4000 bits. Since nodes can allow only a certain number of bit rates, the payload data lengths allowed to be transmitted by them are assumed to be either of 3600 bits, 1800 bits, 1200 bits and 900 bits, according to the different bit rates supported. For any payload size, it is assumed that there is a standard overhead of 400 bits, consisting of addresses and error detection bits. It is further assumed that in each round of communication, a sensor node has to transmit 3600 bits of information. This implies that if a sensor node is working with a lower bit rate, it has to transmit more number of packets to send the same data. For example, if a sensor node is transmitting a maximum payload length of 1800 bits, it will have to send two packets to transfer the complete information in that particular round. The simulation parameters are summarized in Table 5.

**Table 5** Simulation parameters for VBR scenario

Payload length (No. of bits)	No. of overhead bits	Total packet length in bits	No. of packets required for transmission of 3600 bits of data
3600	400	4000	1
1800	400	2200	2
1200	400	1600	3
900	400	1300	4



**Fig. 19** Lifetime (FND and LND) for different bit rates in DREAM



**Fig. 20** Throughput of DREAM for different bit rates in scenario (a)

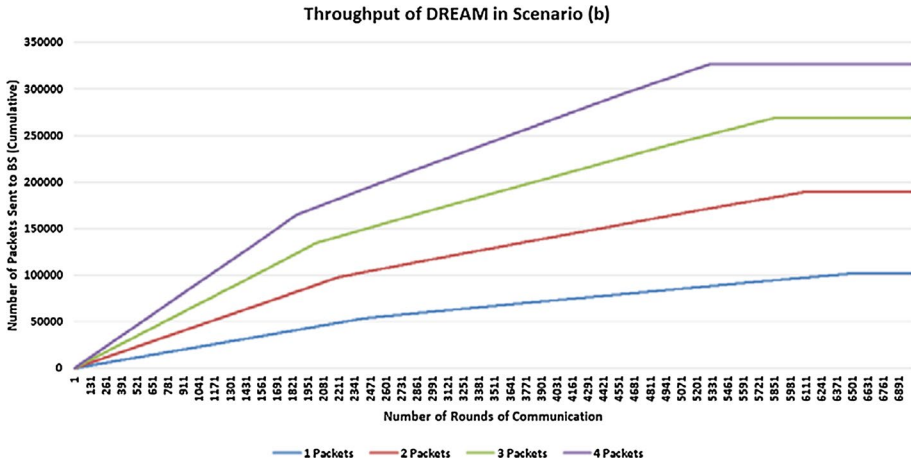


Fig. 21 Throughput of DREAM for different bit rates in scenario (b)

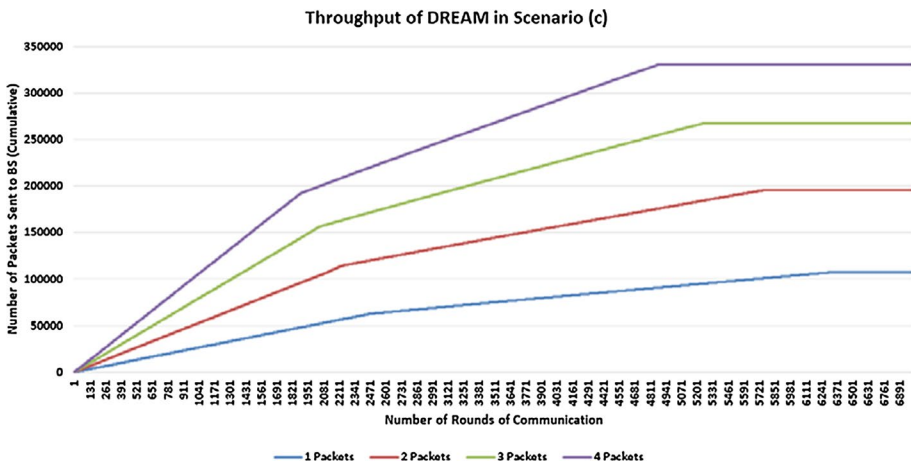


Fig. 22 Throughput of DREAM for different bit rates in scenario (c)

### 4.6.1 Case I: Nodes Having Specified CBR

Figure 19 shows lifetime analysis when all nodes have same bit rates in all four scenarios of DREAM. Unmistakably, when bit rate is high, lifetime is also higher since number of packets to be transmitted are less. It is also observed that difference in lifetime decrease is apparently less in case bit rates are decreased. This is due to the fact that at lower bit rates, the increase in number of packets compensates better with the decrease of packet length. Figures 20, 21, 22 and 23 depict the throughput in terms of the number of packets that are sent to the BS for both the four scenarios of DREAM at different bit rates. As foreseen, the throughput is higher in case of low bit rate scenarios as more number of packets are being transmitted to transfer the same amount of information.

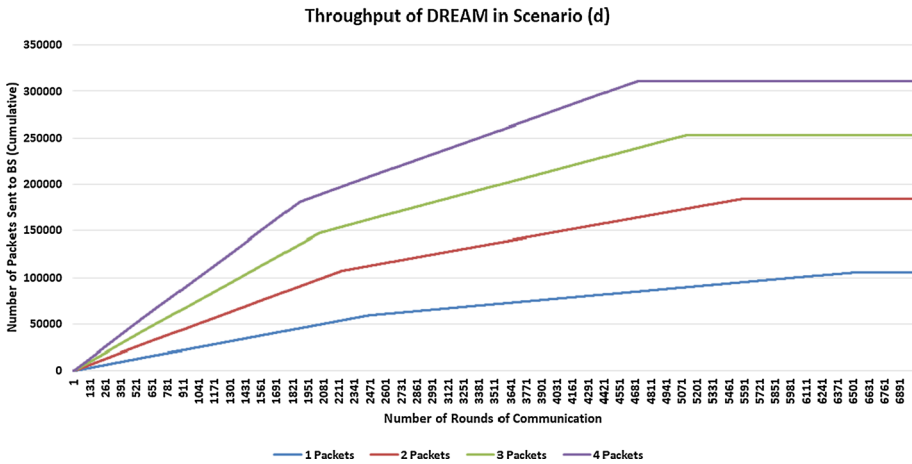


Fig. 23 Throughput of DREAM for different bit rates in scenario (d)

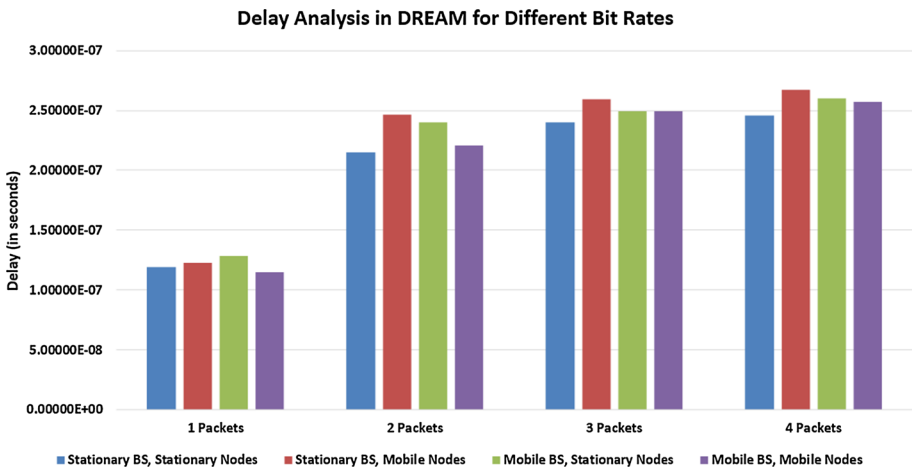


Fig. 24 Delay for different bit rates in DREAM

Figure 24 compares the delay values for all the four scenarios of DREAM at different packet lengths. Consistent to previous observations, the delay is higher in cases where more number of packets have to be transmitted to the BS. This is because of the fact that when more number of packets are to be transmitted, more energy is consumed during data transmission and data aggregation.

#### 4.6.2 Case II: Nodes Having a Dynamically-Changing VBR

Next, lifetime, throughput and delay analysis is performed for the case when all sensor nodes have dynamically changing VBR traffic to be transmitted in different rounds of communication. It is assumed that at the start of each network, a node will decide the

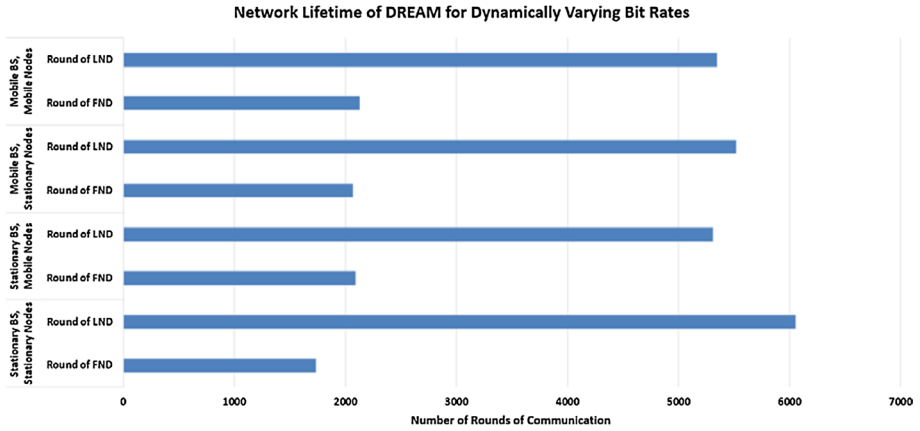


Fig. 25 Lifetime of DREAM for dynamically changing VBR scenario

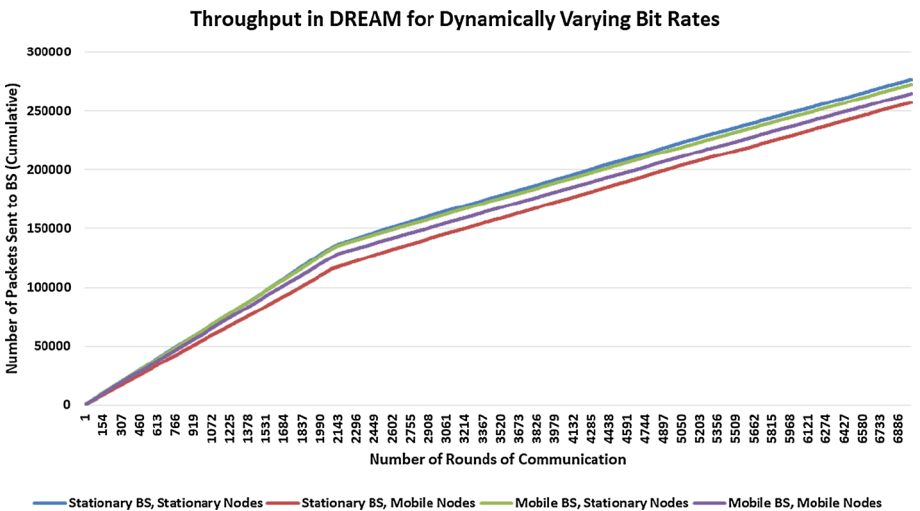


Fig. 26 Throughput of DREAM for dynamically changing VBR scenario

packet length that it will transmit in that particular round. Figure 25 shows the FND and LND in case of VBR data traffic in all four scenarios of DREAM.

When we compare these graphs with the results of the previous case, we observe that in both these cases, the lifetime is roughly the average value of the highest and lowest rounds of node death. Similar average results are obtained in the case of throughput and delay, as shown in Figs. 26 and 27 respectively. From these consequences, we deduct that in case of VBR traffic, the performance of DREAM is roughly the average of its best and worst performances. This is in accordance to what was expected as the performance of the proposed protocol.



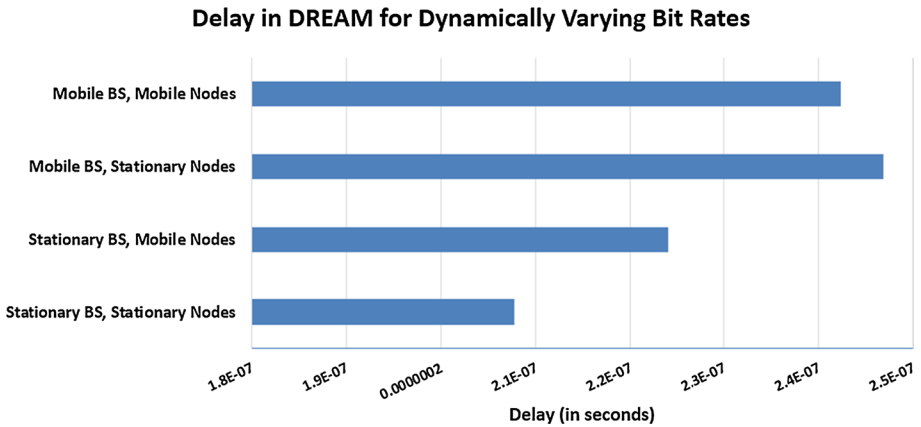


Fig. 27 Delay in DREAM for dynamically changing VBR scenario

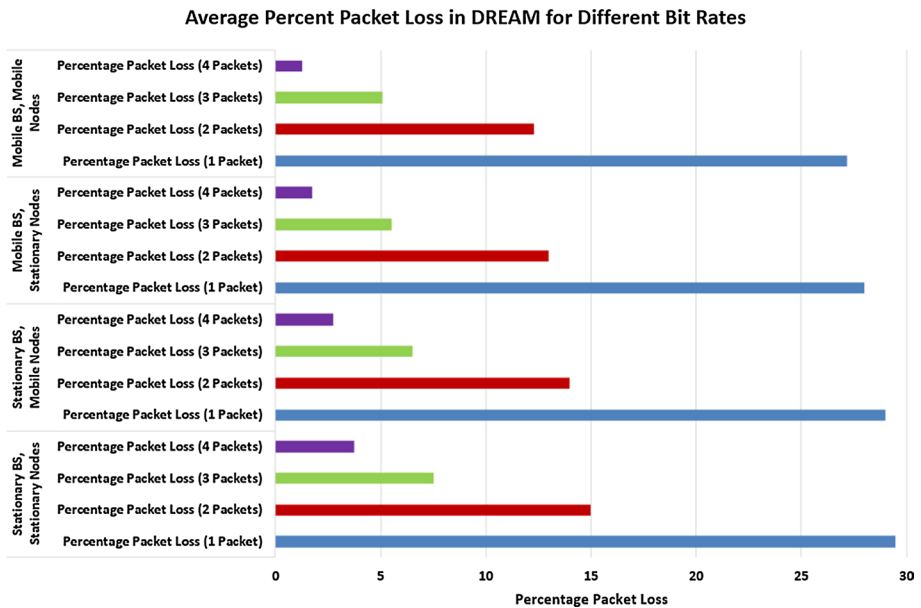


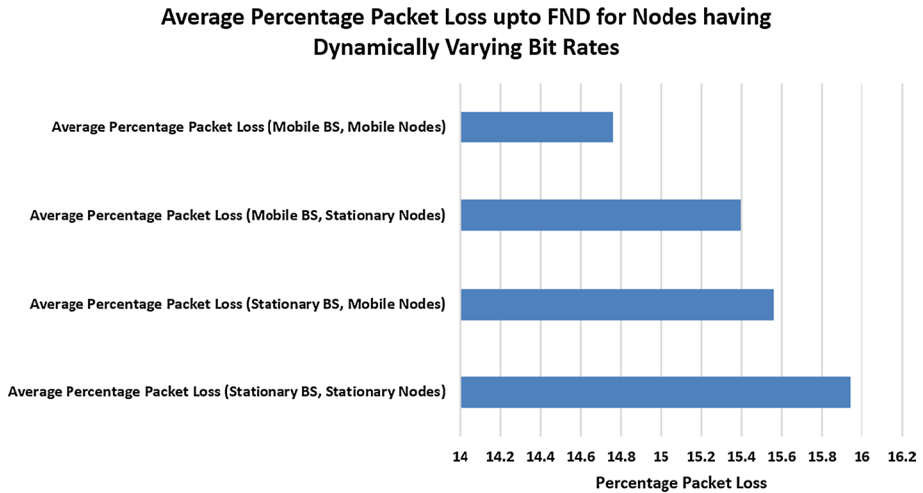
Fig. 28 Reliability analysis of DREAM for different bit rates

### 4.7 Reliability Analysis of DREAM

Whenever packets are sent from source to destination through a wireless channel, some transmitted packets may get dropped due to bad channel conditions. In order to calculate the dropped packets, we use Random Uniformed Model. We then measure the reliability of DREAM in constant and variable bit rates in terms of percentage packet loss.

Figure 28 models the reliability analysis in terms of average percent packet loss for all the four scenarios of DREAM when the nodes' bit rates are varied in the network. The





**Fig. 29** Reliability analysis of DREAM for dynamically changing VBR scenario

graph clearly shows that when the bit rate is low (i.e., when the node has to send more packets to transfer the same amount of information), the packet loss is low and hence the link reliability is high. This is because shorter packets are less affected as compared to longer packets due to the fluctuations and errors in link. As the bit rate is increased, the packet loss increases and the reliability is reduced.

Figure 29 models the reliability analysis in terms of average packet loss for all four scenarios of DREAM when the nodes' bit rates are dynamically changing. As foreseen, the graph clearly shows that the link reliability is high in all the cases of VBR as compared to when all the nodes have a CBR with long packet lengths. It can also be seen that the link reliability is more in case of mobile node scenarios as the random movement of sensors further limit the chances of packet loss due to achievement of better link conditions. On the other hand, a stationary scenario will result in some nodes that are in bad link conditions to remain in such conditions till the link quality improves.

## 5 Discussions and Applicability of the Proposed Protocol DREAM

This section summarizes the results and discusses the applicability of the proposed protocol DREAM to futuristic applications of WSNs that would require multi-objective optimization. The main aim of DREAM was to cater to MOO in different challenging aspects of WSNs. DREAM has incorporated more efficient probability and threshold equations and also used two-hop communication mode instead of single-hop communication mode. The probabilities of becoming a CH in DREAM was also made different for near and far nodes in order to make the far nodes less probable for being selected as a CH, since it would result in more energy wastage. This was achieved by incorporation of a distance based cost factor for CH selection. Four different scenarios were taken into consideration, starting from zero mobility in the network to a fully mobile network. Talking of network lifetime, DREAM out fared the CREEP protocol for WSNs by an average of 3.54% in terms of FND and LND in all four scenarios considered together. The number of packets sent to BS

in all four cases of DREAM were more than one hundred thousand (1,00,000), which is way higher than any other protocol. As compared to marginal energy savings of DREAM over CREEP, the end-to-end delay in DREAM is way lower (average 35.5% lower delay in DREAM). This highlights the fact that DREAM has a lower end-to-end latency. Moreover, the standard deviation calculations in Sect. 4.4 highlighted that DREAM expends its energy in a more balanced manner. Further, coverage analysis of DREAM via the heat maps suggested that DREAM provides the best coverage in the WSN field as the network evolves from its start to the time of LND. Next, the scalability of the proposed protocol DREAM was also verified from the graphs of Sect. 4.5. Lastly, DREAM was also tested for VBR scenario, by exposing it to different kinds of traffic and all the above performance parameters were noted down. It is worth mentioning that DREAM fared well in all scenarios, especially for the reliability parameter. However, in the present work, the nodes were randomly scattered in the network, which is in fact the actual scenario in many WSN applications. But this can result in some nodes lying very close to each other, causing a lot of redundancy in the collected data. This issue has not been catered to in the present work.

Nonetheless, we will now discuss the applicability of the proposed protocol DREAM. A lot of applications demand for a trade-off between network lifetime and throughput, such as asset tracking and management, habitat sensing and monitoring, weather monitoring, etc. In these applications, it is crucial that energy be conserved since the sensor nodes used here cannot be recharged and at the same time, it is mandatory that sufficient data is being sent to the BS at regular intervals of time, thus necessitating the increase of throughput. DREAM can help achieve higher network lifetime and higher throughput simultaneously as compared to the conventional routing protocols. There are other scenarios like detection and tracking of enemy, disaster management and control, etc., which call for minimum delay in interception of relevant data. In order to decrease the delay, energy is consumed in processing and finding the best routes. These applications, however have sensor nodes placed at such terrain, which render the recharging of their batteries infeasible. Thus, in such scenarios, DREAM can help to provide optimal solution for the trade-off between energy and delay metrics. Further, healthcare applications like medical sensing and monitoring, body-worn medical sensing and fitness monitoring require the reliable data transmission to the sink node. This definition of reliability requires that the data packets should be successfully received at the BS. Also, since these applications usually require the sensors to be mounted on the bodies of persons, hence these need to be small in size, which implies smaller batteries and less power resources. This necessitates the reliability in the routing protocol and it has been established that DREAM is able to provide reliable data transmissions. Also, applications such as air traffic control, emergency care and critical patient monitoring, etc., that demand minimum delay as well as high reliability of data transmission simultaneously can also employ DREAM protocol. Thus, it can be said that a general-purpose routing protocol such as DREAM, that can optimize various design objectives simultaneously can bring down the commercial costs of WSN applications.

## 6 Conclusion and Future Scope

Majority of the research at present is directed towards energy efficiency in WSNs. Nevertheless, the plethora of applications conceivable with the help of WSNs often demand for MOO formulations, where several design goals contend together for the best trade-off solution among them. These multiple design goals may be contradictory in nature or may

be design independent. Following these thoughts, this work modified the LEACH protocol in a heterogeneous environment, with an aim to increase the network lifetime, stability period, as well as the number of packets received at the BS, and also to lower the delay and packet loss of the heterogeneous WSN. DREAM aimed at outperforming CREEP in different dimensions, including network lifetime, throughput, delay and reliability. Along with these, the simulation results show that DREAM protocol also proved to be efficient over CREEP in different types of mobility and traffic scenarios in terms of all the performance metrics listed.

Despite the increasing attention that MOO is getting, there are still numerous open areas for future work in case of WSNs. Most of the work pertains to single-hop communication, whereas only limited work has been done for WSNs incorporating multi-hop. The present work tries to follow this and has shown simulations for up to two-hops. Since multi-hop transmissions in resource-constrained networks contributes towards energy conservation, more work by incorporating more than two hops needs to be done in this domain. Also, WSNs are traditionally employed in hostile surroundings, the sensor nodes may be confronted with various kinds of security attacks. Dealing with security concerns while handling failure in WSN nodes is a problematic and unexplored orbit for investigation. Therefore, their security along with MOO requires thorough attention in future research. Existing work also assumes that the WSNs are spread across a 2-D plane, but in reality they are of 3-D nature, whose modelling is extremely challenging. Existing 2-D techniques perform poorly in 3-D deployment scenarios. Work must be done towards implementation of WSNs as a 3-D setup. This work must also be extended to include the data redundancy issues and how to eliminate those.

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