Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2018) 26: 1444 – 1452

doi:10.3906/elk-1706-226

Virtual force-based intelligent clustering for energy-efficient routing in mobile wireless sensor networks

Selvi MUNUSWAMY[1,*], Jothi Muneeswari SARAVANAKUMAR[1], Ganapathy SANNASI[2], Khanna Nehemiah HARICHANDRAN[3], Kannan ARPUTHARAJ[1]

[1]Department of Information Science & Technology, Faculty of Information & Communication Engineering, Anna University, Chennai, India

[2]School of Computing Science and Engineering, VIT University-Chennai Campus, Chennai, India

[3]Ramanujan Computing Centre, Faculty of Information & Communication Engineering, Anna University, Chennai, India

Received: 20.06.2017 • **Accepted/Published Online:** 16.11.2017 • **Final Version:** ..201

Abstract: A mobile wireless sensor network (MWSN) consists of many sensor nodes, which can move from one position to another and gather data from the environment, and such nodes are coordinated with the support of a sink node. In recent years, the mobility behavior of sensor nodes present in wireless sensor networks is used to form effective clustering and to perform cluster-based routing. Virtual force is an important phenomenon in sensor nodes, which is used to model the mobility behavior. Production rules that use spatiotemporal constraints are able to make more accurate decisions on mobility speed, mobility area, and the required time. Routing in MWSNs under the mobility scenario will provide better performance if virtual force-based mobility modeling is used to form clusters. In this paper, an intelligent routing algorithm called virtual force-based intelligent clustering for energy-efficient routing in MWSNs has been proposed for effective and energy-efficient cluster-based routing of data packets collected by mobile sensor nodes in a MWSN. This algorithm uses attractive and repulsive forces for finding the cluster members. Moreover, spatiotemporal constraints are used in the form of rules for clustering, reclustering, and cluster head election and to perform routing through the cluster heads using intelligent rules. The main advantage of the proposed algorithm is that it increases the network lifetime and packet delivery ratio. Moreover, it reduces the delay and the energy consumption.

Key words: Mobile wireless sensor network, virtual force-based clustering, spatiotemporal constraints, Allen's interval algebra, mobile sensor node deployment, target coverage, network connectivity

1. Introduction

Mobile wireless sensor networks (MWSNs) are nothing but wireless sensor networks in which there are some sensor nodes that are mobile and they are coordinated by a sink node. In recent years, the mobility of sensor nodes is studied using mobile node mobility modeling in which the force of attraction and force of repulsion are considered. In such a scenario, the deployment of mobile nodes is a challenging issue since it is necessary to predict the collisions in advance and to prevent them before they occur. Another challenging issue in the design of MWSNs is energy optimization. This can be achieved by dividing the nodes into active nodes and sleeping nodes by applying intelligent rules. Cluster-based routing is an important technique used to perform energy efficient routing. Moreover, clustering reduces the energy consumption for routing the data from sensor nodes to the sink node if the clustering process, cluster head selection, and cluster-based routing are performed

*Correspondence: arpudhaselvi123@gmail.com

more systematically. The use of spatial and temporal constraints is not only helpful to form dynamic clusters but also useful for maintaining energy efficiency, mobility modeling, and optimal routing.

The major issues in the design of MWSNs include the mobile sensor node distribution problem, which concerns two issues, namely the target coverage and the network connectivity problems. In the target coverage problem, given m different targets with known locations in which n mobile sensors are to be deployed randomly in the given sensing area, it is necessary to move the sensor to new and suitable positions in such a way that all the targets for routing are covered with minimum distance, minimum mobility, and optimal energy. The network connectivity problem deals with the coverage problem in which, for a given sink node, it is necessary to find the set of coverage member sensor nodes and the remaining mobile sensor nodes that are left without joining any group. According to this problem, the deployment of the remaining mobile sensor nodes is a challenging issue since it has to connect with suitable coverage sensors and also the sink node minimum movement. Moreover, the target coverage problem tries to cover all the specified locations of interest within the deployment region of MWSNs. In such a scenario, network connectivity is necessary by proving links to the sink node for the sensor nodes in the MWSNs to gather the data effectively and to send them to the sink node. Thus, this paper proposes a new routing algorithm for performing cluster-based routing in which virtual force-based rules are used to form clusters and to perform cluster head election for routing the data packets through the cluster heads. Therefore, the deployment of sensor nodes has been done in this work in such a way that the maximum number of hops is always below a threshold.

The new intelligent cluster-based routing algorithm called virtual force-based intelligent clustering for energy-efficient routing (VFICEER) in MWSNs proposed in this paper uses the virtual force between the sensor nodes, which is balanced by considering the attractive and repulsive forces effectively using rules and constants. Moreover, the existing k-means clustering algorithm [1] is used in this work for performing the initial clustering of the nodes. In this algorithm, k nodes are chosen arbitrarily to form the initial cluster heads. Under each cluster head, members are added by selecting members from the nearest distance using the k-means clustering algorithm in which members are added by comparing the distances from the nodes to the cluster heads. This procedure is repeated until all nodes are attached to a cluster head that is close to the node. This proposed cluster-based routing protocol takes care of the target coverage problem and the network connectivity problem by applying spatiotemporal constraints and rules in order to provide energy-efficient routing in MWSNs. Thus, the proposed algorithm focuses on increasing the network lifetime extension by performing energy optimization by solving the target coverage and network connectivity problems more effectively. The major advantages of the proposed algorithm are its capability in significantly extending the network lifetime and by managing the mobility optimally. From the experiments conducted in this work, it is observed that quality of service (QoS) metrics including packet delivery ratio, delay, and reliability of communication are taken care of in the proposed algorithm by the application of the clustering technique using virtual force, energy-efficient routing using spatiotemporal constraints, and optimal mobile node deployment. The remainder of this paper is organized as follows: Section 2 describes the related works in this area. Section 3 explains the proposed algorithm in detail. Section 4 provides the experimental results obtained from this work with relevant discussions. Section 5 gives the conclusion of this work and proposes some possible future works.

2. Related works

There are many works available in the literature that discuss clustering, cluster-based routing, sensor node deployment, and the use of rules for decision making [2–4]. Moreover, Chamam and Pierre [5] developed a new centralized algorithm for solving the near-optimal state assignment problem in wireless sensor networks. Their model is based on a tabu search algorithm that is useful for computing a near-optimal network configuration. Nikolaos et al. [6] developed a survey paper on WSNs and they explained the use of energy-efficient protocols that have been developed for WSNs. They classified WSNs into different categories, namely flat networks, hierarchical sensor networks with coherent and nonlocation-based nodes, mobile agent-based routing, and QoS-based design, in their survey. They also discussed the advantages and disadvantages of these protocols. Fang [7] proposed a new distributed and effective routing protocol for MWSNs based on node cooperation. That study compared the energy efficiency of cooperative and noncooperative routing through analysis and simulation. Tunca et al. [8] provided a complete review of the existing distributed mobile sink routing protocols available in the literature. They also provided accurate classification of protocols and discussed the advantages and limitations of their system. Al-Jemeli and Hussin [9] proposed a new and effective cross-layer network operational model for the design of MWSNs. Their network model focuses on two major mechanisms, namely controlling the amount of control packets and the transmission power control, which are dependent on the node locations. Abo-Zahhad et al. [10] proposed a new clustering protocol called mobile sink-based adaptive immune energy-efficient clustering protocol for solving the energy hole problem, which also improves the network lifetime and the stability period of the WSNs. Suh and Berber [11] proposed a new data-forwarding strategy for WSNs with a mobile sink that visits rendezvous points to gather data from sensor nodes. Selvi et al. [12] proposed an energy-efficient routing algorithm for wireless sensor networks using fuzzy rules. Lu et al. [13] proposed new distributed deployment strategies for mobile sensor networks where the coverage priorities of different points in the field are specified by special functions developed by them. Wang and Tseng [14] proposed an effective competition- and pattern-based scheme for WSNs to solve the k-coverage placement problem using connectivity of graphs. Mahboubi et al. [15] proposed an efficient sensor deployment algorithm in order to improve the coverage area in the target field of wireless sensor networks. Their algorithm calculates the position of the sensors iteratively by using statistical information on nodes and coverage holes in the target field for enhancing the network performance. Younis and Fahmy [16] developed a new cluster-based routing algorithm called the hybrid energy-efficient distributed clustering approach for effective routing in ad hoc sensor networks. It is an important contribution for energy-efficient routing in sensor networks. However, the energy consumption is high due to the ad hoc nature of this network. Logambigai and Kannan [17] proposed a fuzzy-based unequal clustering (FBUC) approach for effective routing in wireless sensor networks. The main advantages of their model include increase in packet delivery ratio and network lifetime and decrease in delay. In spite of all these works, many limitations are still present in the design of MWSNs. This is due to the fact that most of the existing works focused on the design of static sensor nodes. However, mobile sensor nodes are necessary to increase the coverage area and performance. Therefore, an intelligent cluster-based energy-efficient routing algorithm scheme in which clusters are formed using distances, energy, and virtual force is proposed in this paper. The proposed algorithm is capable of solving the low-energy problem and the coverage problem and hence it enhances the QoS in MWSNs.

3. Proposed work

This section explains in detail the proposed routing algorithm developed in this research work for enhancing the communication reliability, energy efficiency, QoS, and network lifetime of MWSNs.

3.1. Virtual force and rule-constrained cluster-based routing algorithm

In the field of robotics, virtual forces are used to consider the field strength based on attractive and repulsive forces. In this work, a new routing algorithm is proposed in which virtual forces along with spatiotemporal rules are considered for initial deployment of nodes and to form suitable clusters. For performing initial clustering and to support the reclustering, the existing k-means clustering [1] algorithm is enhanced with virtual forces and rules for satisfying the spatiotemporal constraints in this work. Therefore, K number of clusters are formed by partitioning the N nodes from the set of nodes D using a distance measure. Later, reclustering is performed by using a combined metric with minimum force, minimum distance from the sink, maximum energy, and minimum mobility. The steps of the algorithm are as follows:

3.1.1. Algorithm for virtual force-based energy-efficient cluster-based intelligent routing

Algorithm name: Virtual force-based intelligent clustering for energy-efficient routing (VFICEER).

Step 1: Deploy (nodes) for each sink i = 1...4.

Step 2: Compute entropy using the formula entropy(S) $= -\ln \frac{\sum u,v \in S, u \neq v N(u,v)}{\frac{|S|(|S|-1)}{2}}$, where u and v are any two nodes from S, the set of nodes, and N indicates the probability density function of the normal distribution given by $N(u,v) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{d(u,v)}{2\sigma^2}}$, and find the threshold value Th.

Step 3: Measure the distance of nodes from the nearest sink using $d(u,v) = |u,v|$, where d indicates the Euclidian distance between node u and sink v.

Step 4: Compute the virtual forces and virtual links using $VF(C,D) = MaxDist - d(CD)$ and $VF(vl,D) = VF(C,D)$, respectively.

Step 5: Compute the attractive and repulsive forces by computing the sign and magnitudes of forces using the formula $F_g = \frac{Gm_1m_2}{d_2}$, where m_1 and m_2 are the moving sensor nodes, d is the distance between them, and G is a constant.

Step 6: Apply the location constraints for each node deployed using the maximum number of hops using the formula $MaxHopCount = MinHopCount + \log_2\left(\frac{1}{r}\right)$

Step 7: Apply the temporal constraints to check the valid time interval [t_1, t_2] for data gathering and communication without overlapping intervals by applying Allen's interval algebra operators [18] as follows:

If $(t_2 < t_3)$ then $[t_1, t_2]$ = before $([t_3, t_4])$

Else If $(t_1 > t_4)$ then $[t_1, t_2]$ = after $([\ t_3, t_4])$

Else If $(t_1 < t_3$ and $t_2 > t_4)$ then $[t_1, t_2]$ = during $[\ t_3, t_4]$

Else If $(t_1 = t_3$ and $t_2 = t_4)$ then $[t_1, t_2] = [t_3, t_4]$

Else If $(t_1 < t_4$ and $t_3 < t_2)$ then $[t_1, t_2]$ overlaps $[\ t_3, t_4]$

Else

Apply spatial constraints S_1, $S_2 \ldots$Sn.

Step 8: Compute the mobility speed of mobile nodes using the formula

$$\vec{F_{ij}} = T_{ij}(aRF - bAF)d_{ij},$$

where T_{ij} is a constant that affects the total force strength, while a and b are constants that control the individual magnitude forces of mobile nodes. RF is the repulsive force and AF is the attraction force. d_{ij} is the distance between the two position vectors of the two mobile nodes m_1 and m_2.

Step 9 : Call k-means (K, N) // k-means clustering algorithm to form initial clusters.

Step 10: Check (energy (N_1, N_2,... N_m)) // the energy levels of members.

Step 11: Select cluster heads based on energy, distance, and force using the formula $CH = \frac{w_1 * e + w_2 * d + w_3 * F_{ij}}{(w_1 + w_2 + w_3)}, CH \geq Th$ where Th is the threshold value.

Step 12: Call route-discovery (source, destination).

Step 13: Route (packets (P_1, P_2,...,P_j)).

Step 14: Measure mobility and energy levels for nodes.

Step 15: Call reclustering (N_1, N_2,...,N_m)

Step 16: Call best-node (nodes, mobility, energy, force) // conduct cluster head election based on mobility, energy and force.

Step 17: Call rules (S, T) // apply spatiotemporal rules to check the coverage and network connectivity using Allen's interval algebra to check overlap in space and time.

Step 18: Call route-discovery (N_1, N_2,...N_m) // new routes based on current cluster heads.

Step 19: if hop count $\leq$ MaxHopCount then call route (packets).

Step 20: If data = {} then stop.

This algorithm assumes that all nodes are in active mode initially. It also assumes that all nodes are cooperative in nature. Whenever the energy drains, the node will send this information to the cluster head. Cluster head failures are avoided by rotating the cluster head by keeping the nodes with high energy as cluster heads.

4. Simulation results

The proposed work has been simulated using network simulator ns-2.35. For this purpose, 36 nodes and one sink node per cluster were deployed as shown in Figure 1 in the first experiment. It was later enhanced to work with 100 nodes, 200 nodes, and up to 500 nodes. These nodes were deployed in an area of 100 m $\times$ 100 m. Moreover, theoretical analysis has been carried out to compare the time complexity of this algorithm with other cluster-based routing algorithms including LEACH and HEED. In these algorithms, a k-means clustering algorithm is used, the time complexity of which is O(NKI), where N is the number of nodes, K is the number of clusters, and I is the number of iterations needed for the algorithm to converge. In the proposed algorithm, the initial complexity is O(NKI), and then it forms K clusters using virtual force and hence the overall complexity is O(NKI) + O(NK), leading to an overall complexity of O(NKI). Therefore, theoretically, the proposed algorithm provides the same complexity and better results. Moreover, the work is proved through simulations also with a maximum of 500 sensor nodes. The packets were routed from a source node to a destination node using the LEACH algorithm [19] and also with the proposed intelligent routing algorithm. The performance of the network was measured based on energy consumption, packet delivery ratio, delay, and network lifetime, which shows the reliability. The Table shows the simulation parameters used in this work for carrying out the experiments.

Figure 2 shows the comparative analysis of the energy consumption between the proposed protocol and the existing protocols, namely the HEED [16], FBUC [17], and LEACH [19] protocols.

From Figure 2, it can be observed that the proposed energy-efficient routing protocol reduces the energy consumption of the wireless sensor network in comparison with the existing protocols, namely LEACH, HEED, and FBUC. This improvement in performance is due to the use of virtual force for making effective decisions in cluster formation, cluster head selection, and reclustering.

Figure 3 shows the comparison of packet delivery ratio between the proposed protocol and the existing protocols, namely LEACH, HEED, and FBUC, for different numbers of nodes. From Figure 3, it is observed

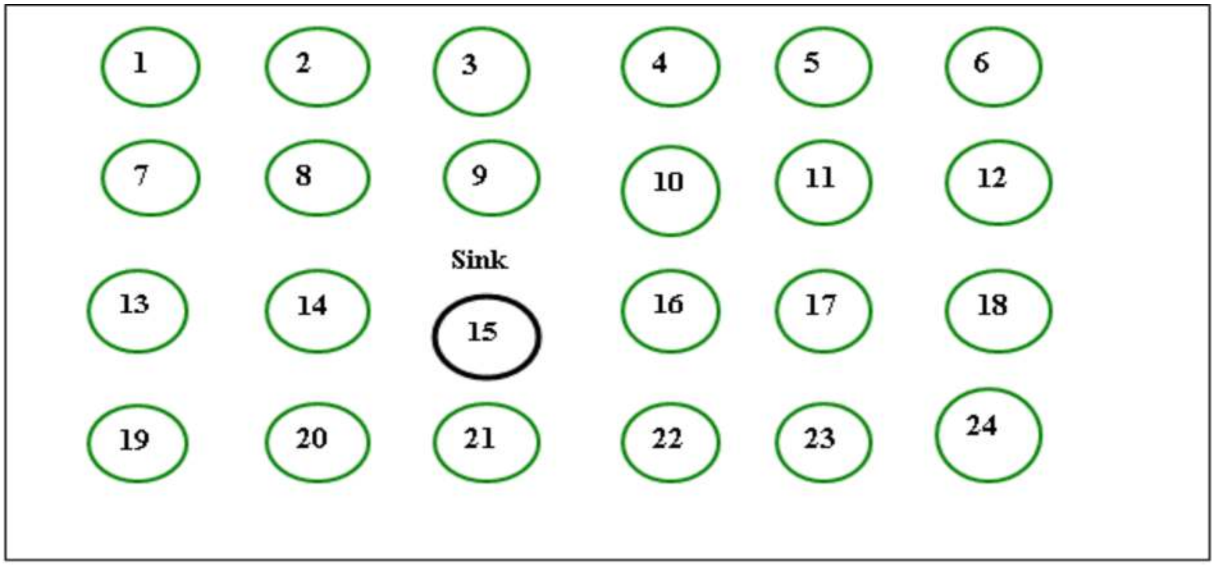

Figure 1. Initial deployment of sensor nodes with data gathering.

Table. Simulation parameters.

Simulation parameters	
Parameter	Value
Communication area (m^2)	100 m × 100 m
No. of sensor nodes	10–500
No. of clusters	5–30
Clustering protocol	Virtual force-based clustering algorithm
Localization	Based on rules and combined metrics
Mobility model	Random waypoint mobility
Mobility speed	10 m/s to 100 m/s
Routing protocol	VFICEER
Initial energy of nodes	2 J
Packet size	4000 bits
Energy consumption rate	0.01 J

that the packet delivery ratio of the proposed protocol is higher than those of LEACH, HEED, and FBUC. This increase in packet delivery ratio is due to the use of virtual force in cluster formation and rules in decision making with respect to routing.

Figure 4 shows the delay analysis comparison between the proposed energy-efficient routing algorithm and LEACH, HEED, and FBUC for routing the packets from the data-gathering points to the base station. From Figure 4, it can be observed that the proposed protocol reduces the delay in routing packets to the base station when it is compared with LEACH, HEED, and FBUC.

Figure 5 shows the comparison of network lifetime between the proposed protocol and the LEACH, HEED, and FBUC protocols. From Figure 5, it can be observed that the proposed protocol increases the network lifetime when it is compared with LEACH, HEED, and FBUC. This is due to the fact that the proposed protocol uses rules and virtual force for cluster formation, cluster head rotation, and routing.

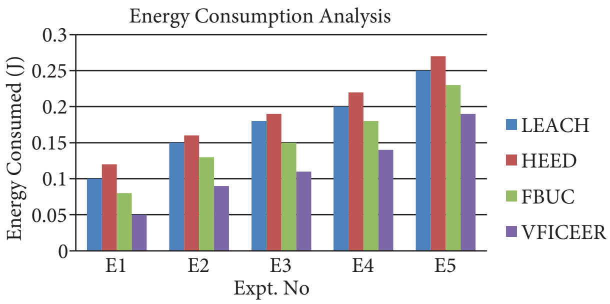

Figure 2. Energy consumption analysis.

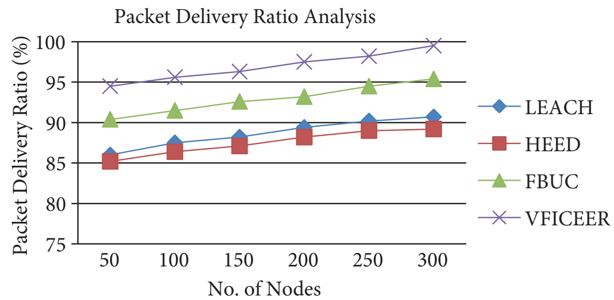

Figure 3. Packet delivery ratio analysis.

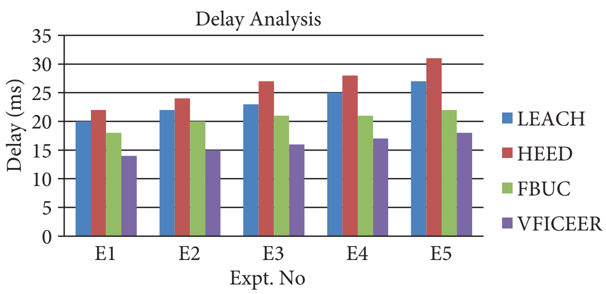

Figure 4. Delay analysis.

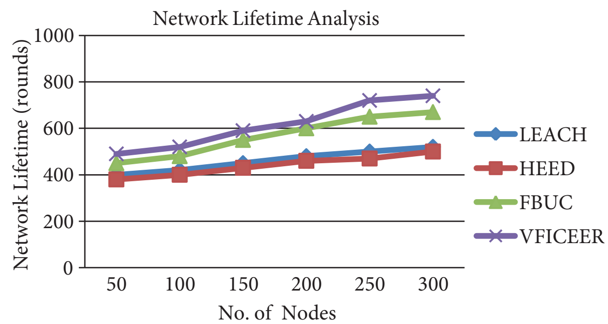

Figure 5. Network lifetime analysis.

Figure 6 shows the comparative analysis of clustering accuracy by the four clustering algorithms, namely k-means, c-means [1], FBUC, and VFICEER. From Figure 6, it is observed that the clustering model used in fuzzy-based unequal clustering called FBUC provides better clustering accuracy than the k-means clustering and c-means clustering algorithms under node mobility in wireless sensor networks. Moreover, the proposed virtual force-based clustering algorithm used in the proposed VFICEER algorithm provides better performance than the k-means clustering, c-means clustering, and FBUC algorithms. This improvement in accuracy is due to the use of virtual forces for modeling the mobility, which is not considered in the other three algorithms.

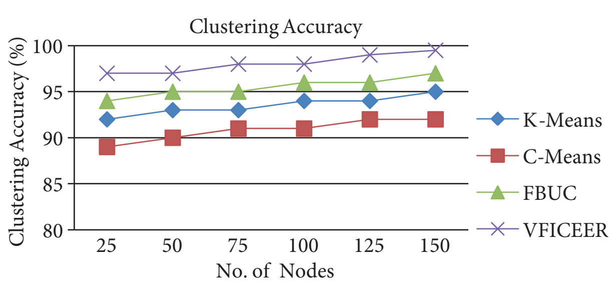

Figure 6. Clustering accuracy analysis.

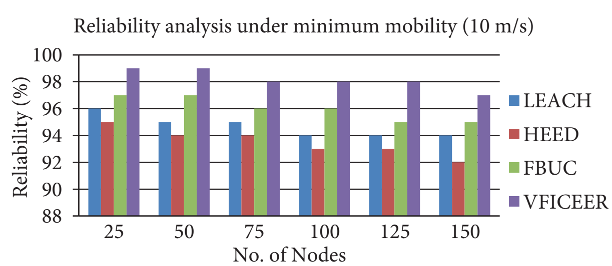

Figure 7. Reliability analysis under minimum mobility (10 m/s).

Figure 7 shows the reliability comparison between the existing LEACH, HEED, and FBUC routing algorithms and the proposed VFICEER algorithm with a mobility speed of 10 m/s that is used as the minimum mobility speed for carrying out the experiments. From Figure 7 it can be observed that the reliability of the proposed model is high when it is compared with LEACH, HEED, and FBUC under minimum mobility speed of 10 m/s. This improvement in reliability is due to the use of rules and a combined metric for making routing decisions in the proposed VFICEER algorithm.

Figure 8 shows the reliability comparison between the existing LEACH, HEED, and FBUC routing algorithms and the proposed VFICEER algorithm with a mobility speed of 100 m/s that is used as the maximum mobility speed for carrying out the experiments in the proposed work. From Figure 8, it can be observed that the reliability of the proposed model is high when it is compared with LEACH, HEED, and FBUC under maximum mobility speed of 100 m/s. This improvement in reliability is due to the use of rules and a combined metric for making routing decisions in the proposed VFICEER algorithm. Moreover, in the existing algorithms, the increase in mobility speed leads to reduction in reliability of communication. However, in the proposed algorithm, the reliability is not affected significantly even under high mobility. This performance improvement is achieved by the use of a combined decision parameter for forming clusters and to perform cluster-based routing.

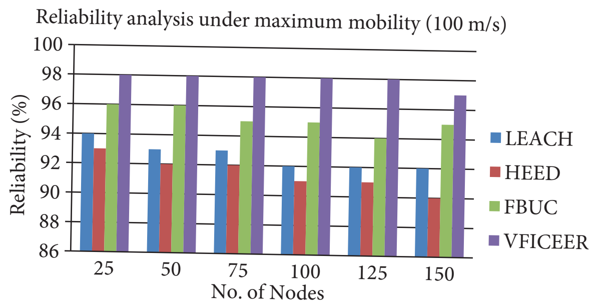

Figure 8. Reliability analysis under maximum mobility (100 m/s).

5. Conclusion and future work

In this paper, a new virtual force and spatiotemporal rule-constrained energy-efficient cluster-based routing algorithm has been proposed for reducing energy consumption, increasing the packet delivery ratio, reducing the delay, and improving the network lifetime in MWSNs. This algorithm reduces the number of hops in routing and uses the Euclidian distance with the probability density function of normal distribution to fix the threshold for clustering, which is used to make effective decisions about routing. The experimental results show that the performance of the proposed intelligent energy-efficient cluster-based routing algorithm in terms of the QoS metrics of packet delivery rate, delay, and reliability of communication is improved in MWSNs due to the use of virtual force, spatial constraints, and temporal constraints. Moreover, the proposed routing algorithm is able to overcome the issues of target coverage and network connectivity in MWSNs and increases the network lifetime. Future works could be the use of fuzzy logics to make decisions about the routing process.

References

[1] Han J, Kamber M. Data Mining: Concepts and Techniques. 2nd ed. San Francisco, CA, USA: Morgan Kaufmann Publishers, 2006.

[2] Yang CC, Wen JH. A hybrid local virtual force algorithm for sensing deployment in wireless sensor network. In: IMIS 2013 Seventh International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing; 3–5 July 2013; Taichung, Taiwan. New York, NY, USA: IEEE. pp. 617-621.

[3] Liu C, Wu J. Virtual-force-based geometric routing protocol in MANETs. IEEE T Parall Distr 2009; 20: 433-445.

[4] Mahboubi H, Moezzi K, Aghdam AG, Sayrafian-Pour K, Marbukh V. Self-deployment algorithms for coverage problem in a network of mobile sensors with un-identical sensing. In: IEEE Globecom 2010 IEEE Global Telecommunications Conference; 6–10 December 2010; Miami, FL, USA. New York, NY, USA: IEEE. pp. 1-6.

[5] Chamam A, Pierre S. On the planning of wireless sensor networks: energy-efficient clustering under the joint routing and coverage constraint. IEEE T Mobile Comput 2009; 8: 1077-1086.

[6] Nikolaos AP, Stefanos AN, Dimitrios DV. Energy-efficient routing protocols in wireless sensor networks: a survey. IEEE Commun Surv Tut 2013; 15: 551-591.

[7] Fang W. Comment on robust cooperative routing protocol in mobile wireless sensor networks. IEEE T Wirel Commun 2013; 12: 4222-4223.

[8] Tunca C, Isik S, Donmez MY, Ersoy C. Distributed mobile sink routing for wireless sensor networks: a survey. IEEE Commun Surv Tut 2014; 16: 877-897.

[9] Al-Jemeli M, Hussin FA. An energy efficient cross-layer network operation model for IEEE 802.15.4-based mobile wireless sensor networks. IEEE Sens J 2015; 15: 684-692.

[10] Abo-Zahhad M, Sabah MA, Sabor N, Sasaki S. Mobile sink-based adaptive immune energy-efficient clustering protocol for improving the lifetime and stability period of wireless sensor networks. IEEE Sens J 2015; 15: 4576-4586.

[11] Suh B, Berber S. Rendezvous points and routing path selection strategies for wireless sensor networks with mobile sink. Electron Lett 2016; 52: 167-169.

[12] Selvi M, Logambigai R, Ganapathy S, Ramesh LS, Nehemiah HK, Kannan A. Fuzzy temporal approach for energy efficient routing in WSN. In: ICIA 2016 ACM International Conference on Informatics and Analytics; 25–26 August 2016; Pondicherry, India. New York, NY, USA: ACM. pp. 1-5.

[13] Lu M, Li M, Wu J, Cardei M. Energy-efficient connected coverage of discrete targets in wireless sensor networks. In: WiMob 2005 International Conference on Computer Network and Mobile Computing; 2–4 August 2005; Zhangjiajie, China. pp. 43-52.

[14] Wang YC, Tseng YC. Distributed deployment schemes for mobile wireless sensor networks to ensure multi-level coverage. IEEE T Parall Distr 2008; 19: 1280-1294.

[15] Mahboubi H, Habibi J, Amir G. Distributed deployment strategies for improved coverage in a network of mobile sensors with prioritized sensing field IEEE T Ind Inform 2013; 9: 451-461.

[16] Younis O, Fahmy S. HEED: A hybrid energy-efficient, distributed clustering approach for ad hoc sensor networks. IEEE T Mobile Comput 2004; 3: 366-379.

[17] Logambigai R, Kannan A. Fuzzy logic based unequal clustering for wireless sensor networks. Wirel Netw 2016; 22: 945-957.

[18] Allen JF. Maintaining knowledge about temporal intervals. Commun ACM 1983; 26: 832-843.

[19] Heinzelman WR, Chandrakasan A, Balakrishnan H. Energy-efficient communication protocol for wireless micro sensor networks. In: HICSS 2000 33rd IEEE Annual Hawaii International Conference on System Sciences; 7 January 2000; Maui, HI, USA. New York, NY, USA: IEEE. pp. 1-10.