Turkish Journal of Electrical Engineering & Computer Sciences

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

Research Article

Turk J Elec Eng & Comp Sci
(2021) 29: 745 – 755
© TÜBİTAK
doi:10.3906/elk-2003-192

Energy-efficient virtual infrastructure based geo-nested routing protocol for wireless sensor networks

Baranidharan VARADHARAJAN[1,*], **Sivaradje GOPALAKRISHNAN**[2], **Kiruthiga VARADHARAJAN**[3], **Karthikeyan MANI**[3], **Sathishkumar KUTRALINGAM**[1]

[1]Department of Electronics and Communication Engineering, Bannari Amman Institute of Technology, Sathy India
[2]Department of Electronics and Communication Engineering, Pondicherry Engineering College, Puducherry, India
[3]Department of Computer and Information Science, Annamalai University, Chidambaram, India

Received: 03.04.2020 • **Accepted/Published Online:** 22.12.2020 • **Final Version:** 30.03.2021

Abstract: The wireless sensor networks (WSN) are comprised of hundreds to thousands of compact and battery-operated sensor nodes. The deployed sensor nodes are widely used to sense the physical changes in the environment, which collect, aggregate, and transmit the information as data packets or static sink or monitoring station. The data transmission is very challenging under some extreme environments and applications. The efficient way of data transmission is achieved by designing an energy-efficient routing protocol. The position of the sink nodes is broadcasted periodically to all other sensor nodes to forward the sensed data to the monitoring system or sink. The frequent broadcasting of the sink position of the sink will lead to the consumption of more energy and collision in networks. In order to overcome these issues, the new energy-efficient virtual infrastructure based routing protocol has been proposed in this paper. This proposed energy-efficient geo-nested routing protocol with a modified virtual multiring structure is used to update and forward the sensed information. The proposed algorithm comprises of two phases: routing establishment using virtual infrastructure and data forwarding. During the first phase, the geo-nested virtual infrastructure constructed to form a closed-loop structure to identify the effective router nodes to route the data. This stage will minimize the number of hops based on depth threshold values. In the second phase of the algorithm, the links are formed during the last stages are changed dynamically based on the sink mobility and energy levels. This will achieve the energy balance and significantly improves the network lifetime of wireless sensor networks. The simulated results of the proposed routing algorithm show that the energy consumption, impact of sink mobility, and end to end delay metrics are comparatively better than the existing routing protocol algorithms.

Key words: Wireless sensor networks, energy efficient routing protocol, virtual ring based infrastructure, geo-nested routing, performance metrics, energy consumption, end to end delay

1. Introduction

Wireless Sensor Networks (WSN) is a collection of different types of sensors randomly deployed over a region. If any events occur in that environment, the sensor nodes will sense any changes in physical phenomena in the deployed region. The sensed information is transmitted as data packets to the sink or base station. Each sensor nodes are always equipped with battery and radio frequency (RF) modems. These nodes are also having a very limited communication range [1]. Sometimes, the batteries are not replaceable and rechargeable based on their applications or environment. Due to this limitation in the battery, power consumption is another critical issue. In addition, the increased power consumption may lead to decreasing the lifetime of the entire network.

*Correspondence: baranidhar@hotmail.com

In general, the sensor nodes will transmit the data packets to the sink/monitoring stations by a multihop data forwarding fashion. The major disadvantage of the hop by hop routing is that the node, which is very close to the sink must forward the number of data packets (N) to its sink. Hence, the node closer to the sink will die soon or the energy depletion of that node is comparatively higher than the other nodes. So, automatically the remaining nodes could not able to establish the connection with the sink node. This type of problem is otherwise called as a hotspot problem [2]. To overcome this hotspot problem, the mobile sink is used to lead the uniform energy consumption, and data will be collected from all the other nodes in the entire network. But, broadcasting the mobile sink information to all other sensor nodes is a major limitation here [3].

At this stage, the mobile sink node uses a flooding type of algorithms to solve these problems. Earlier, proposed methods suggested that the exact position and ID of the mobile sink are broadcasted to all the deployed sensor nodes in the entire network, and the same will be updated frequently in the network [4].This frequent position transmission will also lead to high energy consumption by all the sensor nodes and increasing the collisions across the entire networks. In order to overcome all the issues, the efficient routing algorithm is needed to be designed to reduce the energy consumption by all the nodes and end to end delay.

In this paper, an energy-efficient modified virtual infrastructure based geo-nested routing algorithm is proposed in a way to address the issues and challenges in the mobile sink. This proposed routing algorithm is used over the existing virtual ring-shaped infrastructure. This modified virtual structure consists of several nested rings with sensor nodes and router nodes. The position of the latest sink node will be saved in its neighbors routing table using the virtual infrastructure. The sinks' latest position will be shared and broadcasted to the nodes within the virtual nested ring rather than transmitting it to all the entire networks. After this process, all the data packets are transmitted from the source to its destination based on the selected suitable shortest path for effective transmission.

The rest of the paper is described as follows: Section 2 explains the literature survey; Section 3 explains the proposed energy-efficient geo-nested routing with modified virtual infrastructure algorithm for WSN; the evaluated performance of the proposed algorithm is explained in Section 4. Finally, Section 5 concludes the paper.

2. Related work

Many routing protocols for wireless sensor networks with mobile sink have been proposed by many researchers. Those routing protocols are categorized as backbone based routing protocol and rendezvous based routing protocol. The classification of these routing protocols is based upon the potential of the nodes to form a virtual infrastructure.

N. Nguyen et al. have proposed this routing scheme, which is based upon the rendezvous localization point, for mobile sensor deployment problem and target coverage problems (ERP-MSV RP) to eradicate the hotspot problems. The rendezvous points are used to solve hotspot problems. The rendezvous points were selected to transmit and store data of the other nodes to the mobile sink. The protocol consists of two stages. First, all the rendezvous point was selected among all the other sensor nodes based upon the energy. The main disadvantages of this routing protocol are to find the optimal routes for data transmission at NP-hard problems [5]. In order to overcome these issues, the heuristic algorithms are used. This algorithm considers several parameters to find the shortest and optimum routers. It assigns the weight for each node based upon the parameters. These weights are used to find the route to the destination nodes. The other disadvantage of these heuristic algorithms is it will increase the end to end delay.

B. Alinia et al. has proposed tree structure based routing algorithm [6] to collect the sensed data packets based on the movable or static sink/monitoring systems and rendezvous points (MQTC RP). This proposed algorithm contains more types of tree-like structures. The rendezvous points are called as a root of that tree structures. The mobile sink is used to move across the link of the trees to collect information from the rendezvous points. The major disadvantage of this routing protocol is that the node has to wait for the sink presence. The nodes will periodically transmit the hello packets and sense the sink node presence to forward the data packets.

Tunca et al. has presented ring routing protocol [7], which is based on the virtually created infrastructure and static or mobile destination node or sink for the wireless sensor networks. This method will build the ring node based infrastructure. The ring nodes are used to store the x and y sink's latest position and sensor nodes' positions. The ring nodes are always responsible for transmitting the sensed information. The nodes send their sensed data as a packet to all the mobile/static sink or the monitoring systems by using the geographic greedy algorithms. The mobile sink changes its position to transfer the information or data packets to the hop by hop method. The major issue is that when the traffic increases, this will increase the collision at the center ring nodes and end to end delay across the network. The energy of the ring nodes will decrease, the nodes will die earlier, and there will be high energy consumption.

The hexagonal cell-based dissemination routing protocols [8] have been proposed by Wang et al. This routing protocol is also based on the virtual infrastructure for the wireless sensor networks. In this routing protocols, the source/transmission sensor nodes are having the positions aware of the stationary nodes. All the sensor nodes deployed area is divided as a grid of all cells throughout the field. This routing algorithm will provide energy-efficient data packet delivery to multiple static/mobile sinks. The entire structure is divided into two tiers: higher and a lower tier. In this routing protocol, at first, the event generated systems, sink or monitoring systems need data, which is query data about the cell size large to discover the nearby dissemination nodes. The main disadvantage of this routing protocol is the flooding of the sinks will lead to reducing the network lifetime.

Alrabea et al. has proposed a task-based model and algorithm for minimizing the WSN energy consumptions. This work is fully based on the sensor operation and energy management model for WSN applications [9]. The energy consumption is minimized by using task modeled on its various energy-consuming parts, sensor operations, parameters, and input-output operations. In this framework, the efficiency and energy consumption is achieved by the weighted reward function. The limitation of this proposed model is that this algorithm is fully based on the nonlinear correlation between the parameters, so it is not suitable for real-world targets. Valerio, et al. have proposed a new data forwarding scheme based on the various relay selection routing algorithms for WSN in underwater scenarios [10–13] . This routing algorithm is always swiftly adapting to the overwhelming dynamic change of the underwater environments. This framework is based on the reinforcement learning-based multipath adaptive routing protocol to optimize the route-long information and improve the packet delivery ratio. The routing protocol is not suitable for nonadaptive environments with less sparsity of the deployed sensor nodes.

Elmonser et al. has proposed a key routing method for large scale wireless sensor networks [14]. The main aim of this proposed energy adaptive clustering routing protocol is to support the scalability substantially and improve the multihop communication to increase the network lifetime of the mobile WSN. The main drawback of this proposed mobile routing algorithm is to support only dynamic and clustering random mobility of WSN. Gheisari et al. proposed a new algorithm for the issues of improving the QoS for the WSN in complex environments [15]. This approach allows to utilize the data routing information effectively, preventing collision of data packets, and distributing the load across the network. This algorithm is improving the residual energy and increases the end to end delay to 10% more than the existing systems.

This [16] work modeled the data routing problem in WSN as an in-zone random process. Haubani et al. proposes the zone-based distributed, randomized, anycast probabilistic routing protocol for WSN. This data forwarding probabilistic distribution is working based on the direction, transmission range, residual energy level, and the perpendicular distance control value based on four energy probabilistic distributions. These four probabilistic distributions are considered as exponential control parameters to improve the network lifetime and reduce the delay across the network. The virtual grid-based routing protocols [17] have been proposed by Sharma et al. for wireless sensor networks based on virtual grid type of infrastructure created over the deployed region. In this proposed algorithm, the entire area is divided into different grid structures equally. This routing protocol is providing the information to define and find the series of nodes, possible and best distribution across the networks. The mobile sink position will be shared and updated periodically with all other sensor nodes. The major disadvantage of these routing protocols [18, 19] is that the deployed sensor nodes of the sink node position is comparatively low in numbering and less proportion with respect to all other normal nodes. This problem will lead to the higher hot spot occurrences in the sensor field.

The authors of [20] and [21] have proposed the new efficient algorithms for secured data transmission in WSN. This algorithm-based solution strongly recommended to prevent the WSN against the malicious attacks from the intruder systems. These algorithms implemented for all the sensor products to limit the resources and avoiding difficulty in implementation. This improves the performance of the WSN under very limited computational resources.

3. Proposed routing protocol

This section gives a detailed explanation of an energy-efficient geo-nested routing with modified virtual infrastructure. The virtual infrastructure construction, sink position node updating of the virtual sink nodes, transfer the information from the source to sink nodes are explained in this section.

3.1. Network characteristics

Considering the WSN, all the sensor nodes and the router nodes are homogeneous in nature. Those sensor nodes are deployed randomly over the entire virtual infrastructure region. The deployed sensor nodes are assumed as global positioning systems (GPS) enabling to know the x and y positions. Depending upon the applications, different types of sensors will be chosen for an implementation. The positions of each sensor node are transmitted to its neighbor nodes by broadcasting the beacon messages periodically [22]. The deployed sensor nodes are assumed to be aware of its position and its length over the entire deployed region. The network contains one sink node for collecting the sensed information from all the other nodes. All the sensor nodes will act as a router node for data forwarding from the source to destination. These sink nodes are freely allowed to move over the entire region [23], which is depicted in the Figure 1.

In this paper, the proposed geo-nested routing algorithm is used to compute the nest based routing for all the possible data transmissions. In these WSNs, each sensor node is assumed to know its x and y positions after receiving the beacon messages. If the node needs to transmit the sensed information as a data packet, the sensor nodes will forward that packets to a suitable neighbor, which is nearer to its destination (i.e. the data packets are routed to its neighbor with the very shortest distance from the sink nodes). The pseudocode of the geographic routing algorithm for selection of short distance neighbor is explained in Algorithm 1.

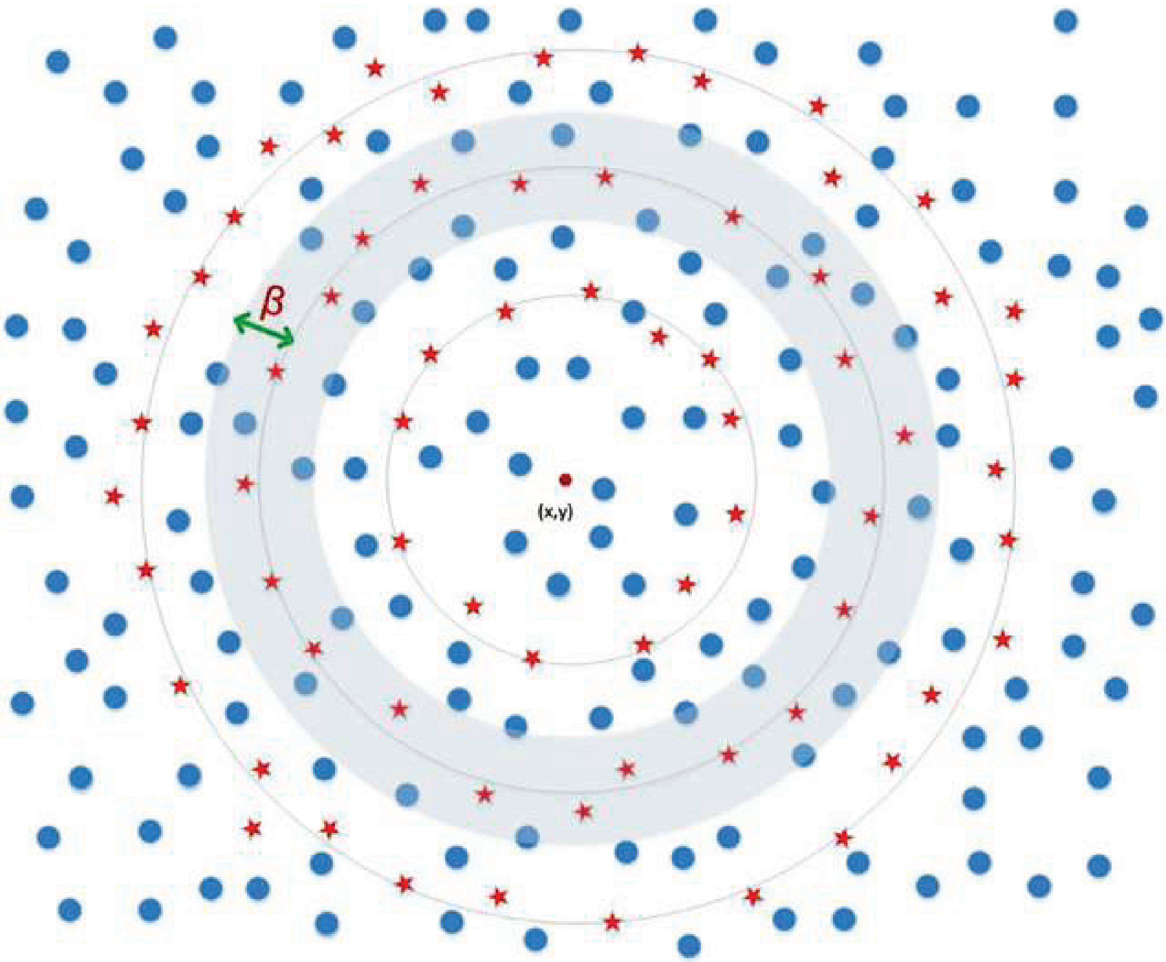

Figure 1. Construction of geo-nested ring structure based on β value.

Algorithm 1 Algorithm for geographic routing

---

procedure PROCEDURE
    Geo-routing(msg)
    Begin
    Dmin= infinite AND Hopnext = Unknown
    if *Each Ni belongs neighbor list do* **then**
        Di $\leftarrow$ *Msg distance*
        Dmin = Distance (Ni, msg, destination)n
        Hopnext=Ni
    end if
    if $\Omega = 0$ **then**
        msg.coordinate$\forall$*neighbour nodes*
    else
        msg.coordinate$\forall$*All nodes*
    end if
end procedure

3.2. Construction of virtual infrastructure for routing protocol

The proposed routing algorithm used a modified virtual infrastructure and mobile sink for data transmission. The sensor nodes are randomly distributed over the entire virtual infrastructure region. The proposed new virtual infrastructure consists of N nested rings from its center over the entire region. The nested rings are not necessarily to be a closed-loop. The virtual infrastructure broadly consists of two types of deployed nodes over the region. The first one is normal sensor nodes, which is widely used to sense the information. The next nodes are router nodes that are used to forward the sensed information to the sink. The number of rings is one of the most important parameter in virtual infrastructure construction. The circumference of the node is 2πr. The transmission range is same in all the directions and its gives circular shape. The distance (D_{min}) between the two nested rings is equal to the communication range of each sensor node. The pseudocode for this geo-nested virtual infrastructure based algorithm is described in Algorithm 2. The notations used in the algorithm is given in the Table 1.

Table 1. Algorithm notations.

Description	**Notation**
Communication range	r
i^{th} node distance	D_i
Next hop node	N_i
Flag value	Ω
Nearest ring of the i^{th} node	NR_i
Distance from nearest ring i^{th} node	D_{NRi}
Coordinates of the sensor nodes	x, y

Let the deployed sensor nodes S=S_1, S_2, S_3, ..., S_N where the value N is the total number of the normal nodes deployed over the entire regions. Among those deployed sensor nodes, S_i is the ith sensed node that will calculate the number of the rings. The S_i will calculate (D_c) the radius of each ring. The node, which is nearer to the ring will become a node nearer to the rings (N_{NR}). After this process, the sensed node S_i will inform its distance between the ring and S_i. This distance is called (N_{DR}). The pseudocode of the position update and data transmission phase is explained in algorithm 3.

After the execution and finding the suitable router nodes, the closed rings are not yet formed. The closed loop formation between the router nodes will lead to the formation of the closed rings. Let the maximum threshold limit to form the number of the rings is β, which is equal to r divided by 2. Based on the β value, the nodes will be allowed to choose at least two suitable neighbors to form a closed loop. Here, the loop does not need to be as ring in shape. It should be a closed loop in any shape.

4. Performance evaluation

The proposed algorithm has been simulated and evaluated by using $NS-2$ simulator platform. The simulation environment is in the size of the $1000m * 1000m$. The normal sensor nodes are deployed in a random manner over the region. The total number of the sensor nodes may vary up to 500. Each and every sensor node are imitated with an energy of 5.0 J. The α values were chosen with the help of the simulations only. The data packet format consists of header (4 Bytes), payload or information (32 Bytes), and trailer (4 Bytes). The header consist of segment number (1 byte), number of segments (1 byte), higher layer packet identifier (1 byte), and

Algorithm 2 Algorithm for virtual structure construction

```
procedure PROCEDURE
    Virtual struct
    Begin
    Ring number = [x/2R]
    Calculate the nearest ring (Ni) and distance (Di)
    Broadcast msg dist (Ri and Ni)
    Dmin = infinite, IDmin = unknown
    if Recieves msg dist then
        if Msg.dist to dist ring < Ring (Ni) then
            Min. dist to Ring = msg. dist. To Ring dist
            Idmin= N(dist_msg), Send ID, X, Y position update
        end if
    end if
end procedure
```

Algorithm 3 Position update and data transmission

```
procedure SINK POSITION UPDATE
    begin
    if msg recieve = Position update(do) then
        if msg type== Normal node(do) then
            delete update position
            return
        end if
    else
        Broadcast msg share postion
    end if
end procedure
procedure DATA TRANSMISSION PHASE
    begin
    if msg.req.position of destination (N) do then
        Save Sink position in msg. data
        Geo routing in Ring(msg. data)
    end if
end procedure
```

source to destination identifier (1 byte). The trailer information consists of parity bits for error control. The various simulation parameters with values are given in the Table 2.

In this paper, the proposed energy-efficient geo-nested routing with modified virtual infrastructure algorithm can be implemented by using simulations using the NS2 platform. This platform will help us to model WSN. This module is widely used to coordinate all the connections between all the other nodes and helps to generate gate creation. This will give the utility information used in the networks. In the first phase, the data packets are routed to all the other nodes. The virtual infrastructure constructed algorithm will be executed in the second phase. In order to evaluate this routing protocol, the simulation results are compared with the given existing routing protocols. There are several types of nested ring structures are evaluated instead of using any structures. The simulated results are evaluated in all the algorithms for the same parameter values. The results of the following sections are explained and analyzed by using the only one mobile sink. The performance metrics are evaluated for the routing protocols.

Table 2. Simulation parameters

Parameters	**Values**
Number of normal nodes deployed	500
Deployment area (m^2)	1000 * 1000
Size of the data packet	40 Bytes
Size of the control packet	100 Bits
Sensor nodes range of communication	80 m
Initial energy of the sensors	5 J
Mobile sink's speed	5 m/s

4.1. Average end to end delay

The average end to end delay is the time taken for the data packets transmitted across the entire networks from the source to the destination. The average delay is measured across all other sensor nodes as 500 has shown in the Figure 2. If the number of nodes increases, the traffic volume and average end to end delay increased exponentially. It is observed that this modified nested based routing protocol has less end to end delay than all the other existing routing protocols. The delay is reduced because of having the capability of transmitting the data packets prior to sink based on the request the sink position which is having the shorter distance. So, the nested rings based on the routing protocols request faster to forward the data packets. The reason for the fluctuation from the average delay is low values in number of the intersections nodes and the traffic volume closer to these nodes is comparatively very high because the traffic is distributed amongst all the nodes.

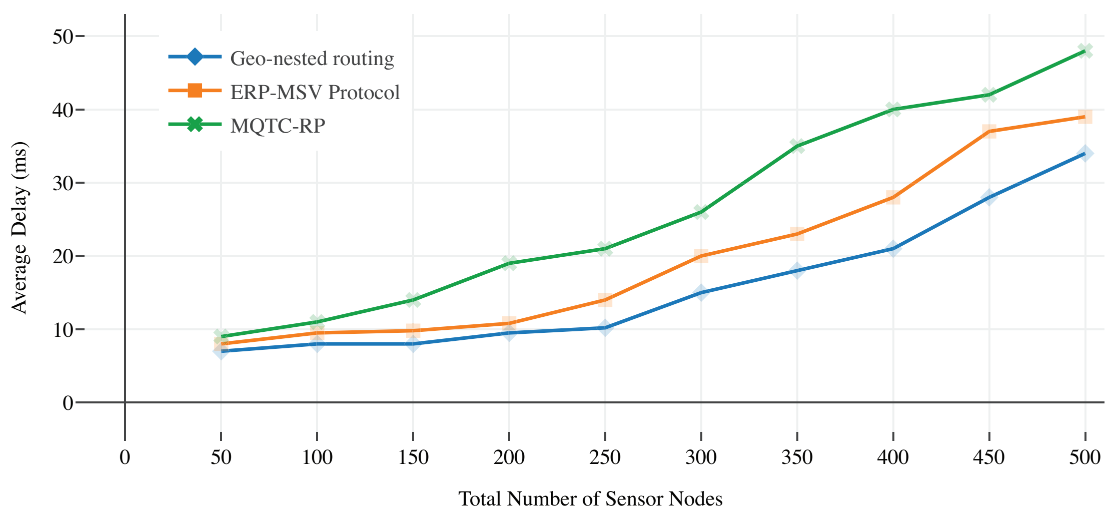

Figure 2. Average end to end delay comparison with various sensor nodes.

4.2. Energy consumption

The total consumed energy of the algorithm is having the both average energy consumption for each and every deployed nodes and the energy consumption in the network. The average energy consumption is defined as the total energy consumed by the each and every node in the network. This algorithm will run for consumed energy of the entire network of all the 500 deployed sensor nodes that are deployed even the first node dies over the network. This proposed routing algorithm consumes the very less energy than the all the other existing routing protocols because its uses only the virtual infrastructure as shown in the Figure 3. This algorithm is having the source nodes, which forward the sensed data packets to sensor node before it is received by its respective mobile sink or destination nodes.

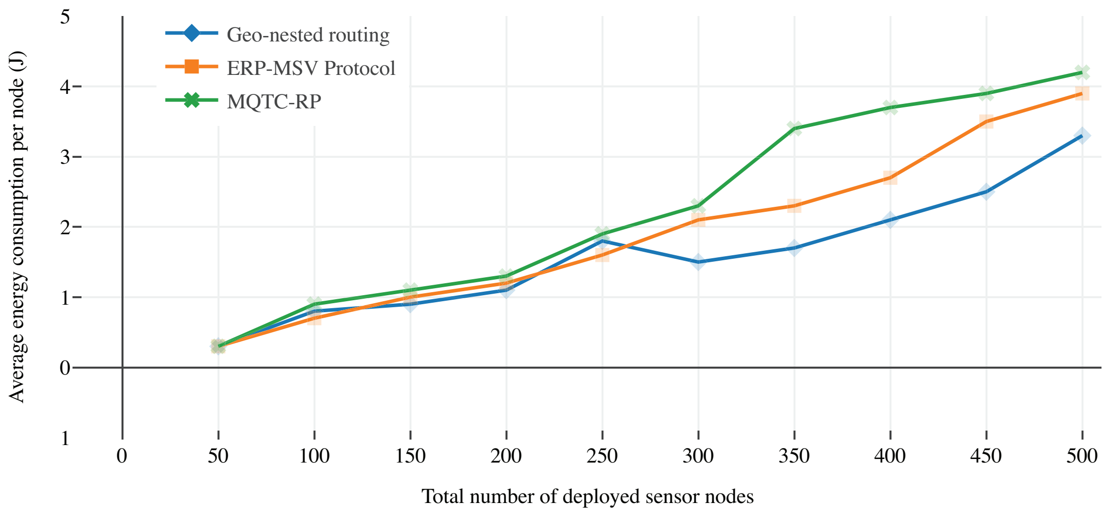

Figure 3. Comparison of average energy consumption with respect to total number of deployed sensor nodes.

4.3. Impact of sink mobility

This proposed routing protocol is evaluating the effect of the sink's mobility speed. The mobile sink may vary, such as 5, 10, 15, 20, 25, and 30 m/s. The mobile sink node speed is 5 m/s. In this simulation, there are 500 normal sensor nodes deployed across in the network, so that the sensor lifetime of the network is the time duration until the 80% of the sensor nodes will die. The Figure 4 shows that the proposed routing protocol is sink's speed changes over the existing routing protocol. The sink moves quickly; the algorithm is generating the more number of the data packages over the entire network for routing updates. If the sink speed increases, the network end to end delay also increases. So, the proposed routing protocols have a very lower delay than that of the other existing routing protocols.

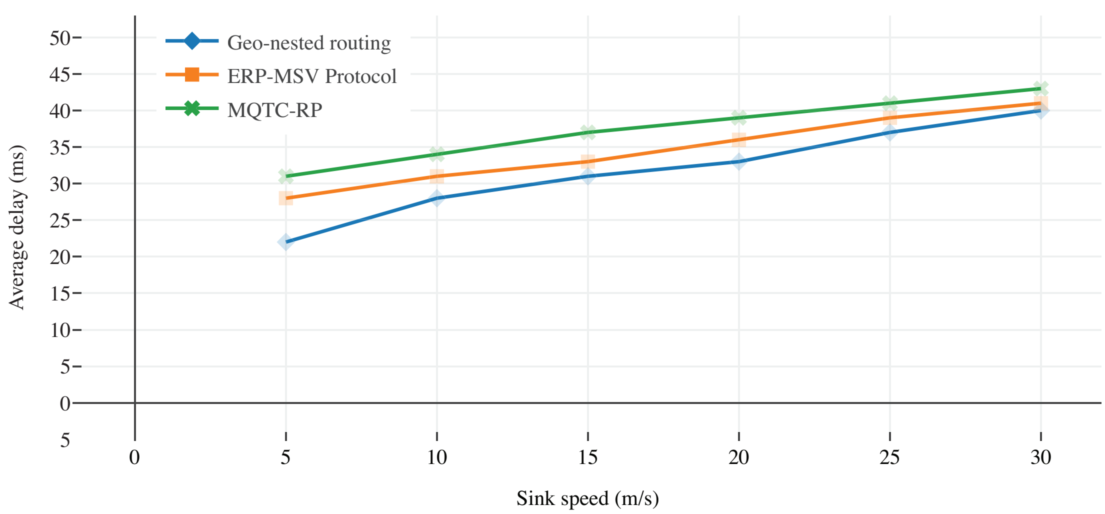

Figure 4. Comparison in terms of the delay at variation with respect speed of the sink.

4.4. Performance metrics comparison with existing system

The proposed energy-efficient geo-nested routing with modified virtual infrastructure is compared with the existing routing protocol in Table 3. It is observed that this proposed geo-nested routing protocol will outperform the existing routing protocols in terms of 24% higher packet delivery ratio, 10.515 ms less latency, 17.23 ms less end to end delay, 673 nJ residual energy saved after simulation, and 25.02% less energy consumption. So, this routing protocols will shed some light on the design of efficient routing protocols for an energy saving and effective bandwidth utilization of WSN.

Table 3. Performance metrics comparison of proposed work with existing systems.

Parameters	MQTC RP	ERP-MSV RP	Geo-nested RP (proposed)
Packet delivery ratio	64.42	78.87	88.73
End to end delay	58.56 ms	47.852 ms	41.332 ms
Throughput	56.2 kbps	58.5 kbps	62.6 kbps
Jitter	36.925 ms	37.828 ms	47.44 ms
Average energy consumption	6.124 J	5.5342 J	4.592 J
Residual energy	6440.7 nJ	6850.11 nJ	7113.14 nJ

5. Conclusion and future scope

To solve the problem of limited energy and short lifetime in WSN, a new energy-efficient geo-nested routing with modified virtual infrastructure has been presented in this paper. The proposed routing algorithm is based on the mobility of the sink and the virtual ring closed formation of loop infrastructure. The algorithm will form the structure of the nested ring with deployed sensor nodes of the entire network. These nested rings will be used to store the data, update the position of mobile nodes/sink, and share the latest sink position to the entire network. The sensor nodes will forward the data and send the packets which are having the sink position request to the entire network. Further, it will transfer the data through the mobile sink to its monitoring systems by the geographic greedy algorithm. This proposed algorithm will select the best relay node and efficient virtual infrastructure will be adjusted based on the energy level and distance. The simulated results show that the proposed routing protocol has a longer network lifetime by improved residual energy, good throughput, and reduced jitter values than the existing systems with different sizes and scales. The future line of work is to improve the fault-tolerant or security-based clustered geographic routing algorithm for wireless sensor networks. In addition, the protocol needs to be designed in a way to identify the faulty nodes and recovers the routing in the networks.

References

[1] Zhang Z, Mehmood A, Shu L, Huo Z, Zhang Y et al. A survey on fault diagnosis in wireless sensor networks. IEEE Access 2018; 6: 11349-11364. doi:10.1109/ACCESS.2018.2794519.

[2] Elhabyan R, Shi W, St-Hilaire M. Coverage protocols for wireless sensor networks: review and future directions. Journal of Communications and Networks 2019; 21 (1): 45-60. doi:10.1109/JCN.2019.000005.

[3] Kanthimathi N, Saranya N, Baranidharan V. A survey on energy-efficient routing protocols with QoS assurances for wireless sensor networks. In: Proceedings of the 2019 International Conference on Advances in Computing and Communication Engineering; Sathyamangalam, India; 2019. pp. 1-5, doi: 10.1109/ICACCE46606.2019.9080007.

[4] Xie H, Yan Z, Yao Z, Atiquzzaman M. Data collection for security measurement in wireless sensor networks: a survey. IEEE Internet of Things Journal 2019; 6 (2): 2205-2224. doi:10.1109/JIOT.2018.2883403

[5] Nguyen N, Liu B. The mobile sensor deployment problem and the target coverage problem in mobile wireless sensor networks are NP-hard. IEEE Systems Journal 2019; 13 (2): 1312-1315. doi:10.1109/JSYST.2018.2828879

[6] Alinia B, Hajiesmaili MH, Khonsari A, Crespi N. Maximum-quality tree construction for deadline-constrained aggregation in WSNs. IEEE Sensors Journal 2017; 17 (12): 3930-3943. doi:10.1109/JSEN.2017.2701552.

[7] Tunca C, Isik S, Donmez MY, Ersoy C. Ring routing: an energy-efficient routing protocol for wireless sensor networks with a mobile sink. IEEE Transactions on Mobile Computing 2015; 14 (9): 1947-1960. doi:10.1109/TMC.2014.2366776.

[8] Wang S, Chang R, Tsai S. Tracking objects using hexagons in sensor networks. IET Wireless Sensor Systems 2012; 2(4): 309-317. doi:10.1049/iet-wss.2011.0127.

[9] Alrabea A, Alzubi OA, Alzubi JA. A task-based model for minimizing energy consumption in WSNs. Energy Systems, 2020: 1-18. doi: 10.1007/s12667-019-00372-w

[10] Valerio VD, Presti FL, Petrioli C, Picari L, Spaccini D et.al. CARMA: channel-aware reinforcement learning-based multi-path adaptive routing for underwater wireless sensor networks. IEEE Journal on Selected Areas in Communications 2019; 37 (11): 2634-2647. doi: 10.1109/JSAC.2019.2933968

[11] Kanthimathi N, Dejey. Void handling using geo-opportunistic routing in underwater wireless sensor networks. Computers and Electrical Engineering 2017; 64: 365-379. doi:10.1016/j.compeleceng.2017.07.016

[12] Varadharajan K. Secure localization using coordinated gradient descent technique for underwater wireless sensor networks. ICTACT Journal on Communication Technology 2018; 9 (1). DOI: 10.21917/ijct.2018.0252

[13] Baranidharan V, Sivaradje G, Varadharajan K, Vignesh S. Clustered geographic-opportunistic routing protocol for underwater wireless sensor networks. Journal of Applied Research and Technology 2020; 18(2): 62- 68. doi: 10.22201/icat.24486736e.2020.18.2.998

[14] Elmonser M, Chikha HB, Attia R. Mobile routing algorithm with dynamic clustering for energy large-scale wireless sensor networks. IET Wireless Sensor Systems 2020; 10 (5): 208-213. doi: 10.1049/iet-wss.2019.0111

[15] Gheisari M, Alzubi J, Zhang X, Kose U, Marmolejo JA et. al. A new algorithm for optimization of quality of service in peer to peer wireless mesh networks. Wireless Networks 2019; 23 (1). doi: 10.1007/s11276-019-01982-z

[16] Hawbani A, Wang X, Abudukelimu A, Kuhlani H, Sharabi Y et.al. Zone probabilistic routing for wireless sensor networks. IEEE Transactions on Mobile Computing 2019; 18 (3): 728-741. doi:10.1109/TMC.2018.2839746

[17] S. Sharma, D. Puthal, S. Tazeen, M. Prasad, A. Y. Zomaya. MSGR: a mode-switched grid-based sustainable routing protocol for wireless sensor networks. IEEE Access 2017; 5: 19864-19875. doi:10.1109/ACCESS.2017.2746676

[18] Baranidharan V, Sathishkumar K, Vignesh S, Poovarasan S. Energy efficient head selection based routing protocol for wireless sensor networks. International Journal of Scientific and Technology Research 2019; 8 (10): 3739-3743.

[19] Baranidharan V, Bharanidharan N, Preethi D. Energy efficient clustered-chain based routing protocol for wireless sensor networks. International Journal of Engineering and Advanced Technology 2018; 8 (2):81-84.

[20] Kim I, Oh D, Yoon MK, Yi K, Ro W. A distributed signature detection method for detecting intrusions in sensor systems. Sensors (Switzerland) 2013; 13 (4): 3998-4016. doi:10.3390/s130403998

[21] Alzubi JA. Bipolar fully recurrent deep structured neural learning based attack detection for securing industrial sensor networks. Transactions on Emerging Telecommunications Technologies 2020; 3 (2): 399-405. doi:10.1002/ett.4069

[22] Abukharis S, Alzubi JA, Alzubi OA, Alamri S, Farrell TO. Packet error rate performance of IEEE802.11g under bluetooth interface. Research Journal of Applied Sciences, Engineering and Technology 2014; 8 (12): 1419-1423.

[23] Yarinezhad R. Reducing delay and prolonging the lifetime of wireless sensor network using efficient routing protocol based on mobile sink and virtual infrastructure. AdHoc Networks 2019; 84: 42-55. doi:10.1016/j.adhoc.2018.09.016