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ZEMDC: Zone based Energy efficient Mobile Data Collector in Wireless Sensor Networks

Praveen Kumar Kenkere Vijay[1*] Moodkonaje Krishnappa Banga[2] Udaya Rani Vinayakamurthy[1]
Ballekatte Mallikarjunappa Thippeswamy[3]

[1]*Department of Computer Science and Engineering, REVA University, Bangalore 560 064, India*
[2]*Department of Computer Science and Engineering, Dayanandasagar University, Bangalore, India*
[3]*Department of Computer Science, Adama Science & Technology University, Adama, Ethiopia*
* Corresponding author's Email: Praveenkv_mtech@yahoo.com

Abstract: The primary objective of wireless sensor networks (WSNs) is to collect data from physical environment. Transmission of data to longer distance consumes more energy, increases the interference and that minimizes the network life time and throughput. In order to overcome this problem we proposed zone based energy efficient mobile data collector for WSN. This technique maintains energy variance level minimum among all nodes by selecting precise and equal sized hop length. Here all nodes transmit data up to specified optimal hop length distance. In proposed algorithm each node requires constant power for transmission and energy discharge is uniform that enhances the network life time. This technique involves zone head and associate zone head in which, the zone head uploads data to mobile data collector, in turn associate zone head acts as zone head and collects data form sensor nodes. Our simulation results shows that ZEMDC provides better performance when compare with other state of art works.

Keywords: Associate zone head, Energy efficient, Mobile data collector, Optimal hop length, Zone head.

1. Introduction

Advanced research effort in Wireless Sensor Network (WSN) focused on prolonging the network life time by routing the data packets to sink node using different energy efficient techniques. Advanced data communication techniques such as clustering, data aggregation, multi hop relaying and mobile data gathering have been used to improve the network life time. All these techniques have their own advantages in different applications of WSN. Hence these can be integrated to a single protocol to further optimizing the network performance.

In cluster routing approach there are several works proposed to form a cluster, based on event or geographical area. Cluster head aggregates data from all cluster members and transmit to sink node. This approach effectively balancing energy locally but network life time reduces due to early drain of energy at cluster heads because of continuous collection of data from all members and transmits to distant sink node [1]. Global synchronization is required among all cluster heads to transmit data to sink which limits the network size.

In multi hop relay routing approach selects the reliable intermediate relay nodes based on some specific criteria to transmit data to sink node. It considerably balance the energy levels among the network but challenge is in guaranteed delivery of sensed data in presence of relay node failure, interruptions in communication and holes in the network [2]. This approach minimizes the network life time due to over burden to relay nodes nearer to sink node [3].

In mobile data collection approach [4][5] mobile node or collector traverse in the network area to collect data from each nodes. This technique alleviates traffic flow congestion near sink node. Many advancements in this technique focus on finding optimal travelling path to minimize the latency and energy consumptions [6]. These techniques balance the energy consumptions, increases the network life time and reliable data transmission considerably, but at the same time data collection latency also increases.

The main objective of the proposed work ZEMDC is to enhance the sensor network life time by balancing the energy. In this approach sensed data from each node is transmitting to base station using multi hop technique by determining optimal hop length for selecting intermediate relay node. Nodes transmit data with optimal hop length makes energy discharge uniform among all the nodes. It also uses zone head and associate zone head to balance the energy and to minimize the packet drops. Mobile Data Collector traverse to each zone heads to collect data, it enhances the network life time significantly compare to recent state of art works.

This paper is organized in 6 sections. Section 1 provides introduction, motivation and contribution. Section 2 describes the literature survey. Problem formulation and system design presented in section 3 and 4 respectively. Section 5 describes simulation and performance analysis. Finally section 6 concludes the paper based on results and analysis.

1.1 Motivation

To maintain the minimum energy variance level among all the nodes is one of the significant issues to prolong the network lifetime. Energy required to transmit data is proportional to square of the distance in normal propagation model because path loss coefficient is 2. Even in the cluster environment energy consumption is depends on the distance, farthest nodes consume more energy to transmit data to cluster head. To minimize the energy consumption, it is required to find the optimal hop length which consume unit amount of energy. Every node transmits data with optimal hop length in multi hop fashion inside the cluster, leads to uniform discharge of energy among all nodes. This minimizes the energy variance level and enhances the network lifetime. In cluster environment cluster head plays an important role of receiving data from all cluster members and transmit to base station leads to drain of cluster head sooner [7]. To maintain the minimum energy variance level among all nodes and to enhance the network lifetime it is required to design an algorithm with optimal hop length to transmit data to zone head from each zone members and mobile data collector to collect data from each zone heads [8, 9].

1.2 Contribution

The major contributions of this work are as follows

1. To find the optimal hop length in the network, so that all the nodes inside the zone consume uniform or constant (optimal) power to transmit data that balance the common power level in all the nodes of network.
2. Zone Head (ZH) and Associate Zone Head (AZH) are used to balance power level with all zone members. It avoids packet drops during each zone head is uploading data to Mobile data collector (MDC).
3. It uses the virtual zones; zone size can be varied with area of deployment.

Mobile data collector traverse in a specified path to collects data from each ZH and upload to Base Station (BS) which minimizes the latency.

2. Literature survey

Recent research works, adapts different advanced techniques in different categories of routing such as multi hop relay routing, cluster based routing, mobile data collection etc. Advanced techniques are used to enhance network lifetime, throughput, reliable data transfer and to minimizes energy consumption and data latency.

Lalith et al., [10] proposed the LEACH Low Energy Adaptive Cluster Hierarchical forms a cluster and selects cluster head stochastically in each round. Cluster head aggregates data and directly transmit to sink node. This algorithm performance well for smaller network but consume more energy with increase in network size and minimize network lifetime.

Nakamura et al., [11] presented INFRA Information Fusion base Role Assignment forms a cluster, based on the event. It builds the shortest path tree to maximize information fusion. When the new event arises, it must be flooded throughout the network which consumes more energy and minimizes the scalability.

Stephanie et al., [12] proposed an idea of Power-Efficient Gathering in Sensor Information Systems (PEGASIS). It is based on near optimal chain-based protocol. It constructs chain based path from source to destination with optimal number of chain leaders. In each transmission the chain leaders are frequently changed based on the energy level. Frequent change of chain leaders consumes more energy.

Praveen Kumar et al., [13] presented the Energy Efficient Routing using Dynamic clustering approach (EERDC). It uses the data aggregation in cluster based environment using shortest path for transmitting data to sink node. It uses the efficient cluster head selection and dynamic route selection technique for reliable data transmission. Hotspot nodes near to sink node drain out sooner due to transmission overload which minimizes the network lifetime.

Villas et al., [14] proposed Data Routing In Network Aggregation (DRINA) algorithm. It uses the efficient overlapping of relay path, it increases the data aggregation rate and provides reliable data transmission. This algorithm fallows the static shortest route increases the transmission overload on relay nodes that leads earlier network partition.

Holland et al., [15] proposed Optimizing Physical Layer Parameters for Wireless Sensor Networks, it consider the energy efficient data transmission over noisy channel and consider the physical layer parameters. This work finds the optimal hop to transmit the data bits.

Ma et al., [16] proposed a single-hop data collection technique using mobile data collector to provide uniform energy consumption among sensor nodes. Mobile collector is made to stop at some polling position for collection of data from nearby sensor via single-hop. Nodes away from polling position drain sooner due to amplify data signal for longer distance. This minimizes the network lifetime.

Miao et al., [17] presented the mobile data gathering using load balancing and dual data uploading methods using three layers techniques. The physical layer forms the cluster with randomly deployed nodes. Cluster head layer performs intra cluster communication and SenCar layer determines the travelling path. Cluster members away from cluster head drain out sooner as the energy required to transmit data is based on the distance.

In this paper we enhanced previous work [10, 13, 17] by considering energy as primary performance matrix using optimal hop length, mobile data collector and zone heads.

3. Problem formulation

In a given WSN, consists of N number of sensor nodes S = {S_1, S_2, S_3, …, S_n} are randomly deployed in a sensing area (SA). SA is virtually partitioned in to four square zones Zi. Zone Head (ZH) transmit distance message Md with constant transmission power PT, so that it can reach up to optimal hop length HL (discussed in section 4.1). All the nodes receiving these messages update information about minimum number of hop to reach the ZH and first node address in the shortest path towards the ZH. In turn these nodes further forward modified Md message based on their timestamp till all the nodes update information of minimum hop and first node in the shortest path.

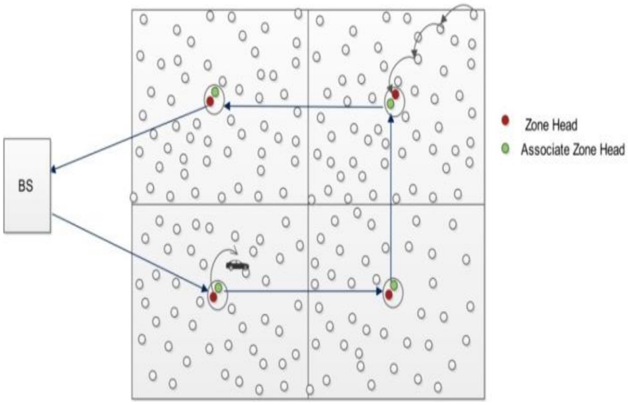

Figure.1 System architecture

Further nodes transfer the sensed data to ZH through multi hop relay nodes with m number of hops using constant optimal power PT for each hop. When MDC approaches to ZH, it uploads the data to MDC. While ZH is uploading data to MDC, AZH collects data form zone members (Z_m). After MDC collects data from all ZHs it uploads data to BS.

4. System design

System architecture is illustrated in Fig.1. The network consists of *N* number of static sensors deployed randomly in sensing area denoted as SA. This SA is partitioned into four square virtual zones. Zone Head and Associate Zone Head are selected from the centre of the zone with radius *r* and maximum residual energy.

In this protocol each nodes uses the constant, appropriate transmission power P_T, to transmit data from Z_m to ZH. All Z_m's transmit data with same constant power so power dissipation is uniform. MDC is equipped with adequate number of battery on shelf, to perform more complex computation, transmission, reception of data without any energy issues. This work focus only on sensor nodes to elongate the network life time. All Z_m transmit their sensed data to ZH in multi hop fashion and when MDC approaches ZH, it uploads data to MDC. After collects data from each ZH, it uploads data to BS.

4.1 Energy model

In direct transmission, nodes situated near centre of the zone require less energy to transmit data as compare to farthest nodes in the zone. As the frequency of transmission increases farthest node

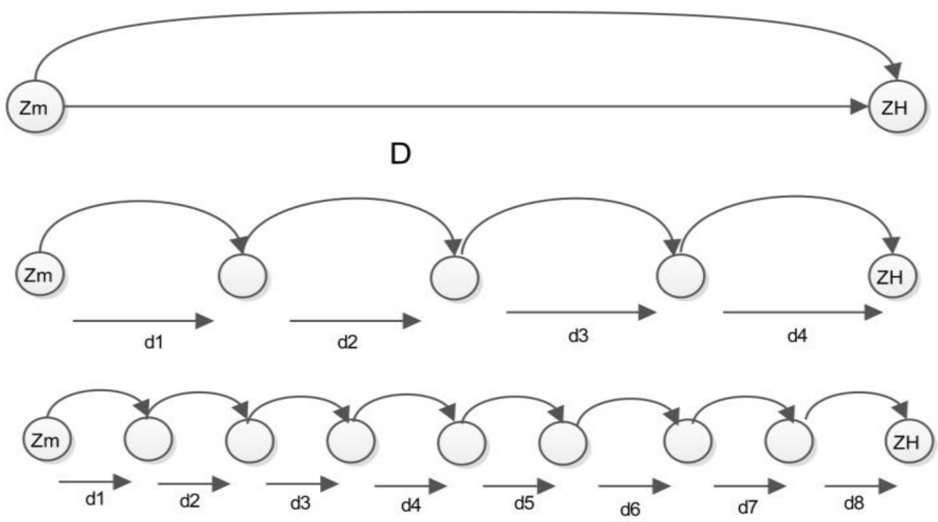

Figure.2 Categories of hop lengths

inside the zone drains sooner compare to the nodes nearer to ZH. For uniform energy discharge, proposed algorithm makes all the nodes to transmit data up to optimal hop length. Due to this technique all nodes consume uniform constant energy. Nodes in the zone use multi hop transmission to send data to ZH with optimal hop length H_L. Fig. 2 illustrates the different categories of hop length. Z_m directly transmit to distant ZH requires more power for amplify the signal. If hop length is too small then number of hops increases and consumes more energy for running transmitter and receiving circuitry in each node. Hence it is required to determine the optimal length of the hop so energy discharge is uniform.

4.1.1. Optimal Power and Hop Length calculation

Energy required to transmit data is based on the summation of energy required for running the transmitter, receiver and amplifier circuitry. For running the transmitter and receiver circuit require constant energy and it is independent of the distance. Energy required for amplification is based on the distance and propagation model.

Power required to transmit data P_T from Z_m to ZH depends on the number of hops and power required to transmit for each hop. Let D be the total distance from Z_m to ZH, H_L be the hop length and P_{HL} is the power required to transmit for single hop.

$$P_T = \frac{D}{H_L} \times P_{HL} \tag{1}$$

Power required transmit data up to H_L is the summation of power required for running transmitter, receiver and amplifier circuitry.

$$P_{HL} = P_{\mathrm{TX}} + P_{\mathrm{RX}} + P_{\mathrm{AMP}} \tag{2}$$

Power required running the transmitter circuitry P_{TX} and receiver circuitry P_{RX} are constant and independent of the distance and consider as P_c. P_{AMP} can be written in terms of $P_{\min}$ is the minimum energy required to receive data by nearest node, n is the path loss coefficient and α is scalar coefficient.

$$P_{HL} = 2P_c + \alpha P_{\min} {H_L}^n \tag{3}$$

By substitute Eq. (3) in Eq. (1) results the following equation.

$$P_T = \frac{D}{H_L} \times (2P_c + \alpha P_{min} {H_L}^n) \tag{4}$$

Eq. (4) can be rewritten as Eq. (5)

$$P_{\mathrm{T}} = D\left(2P_c {H_L}^{-1} + \alpha P_{\min} d {H_L}^{n-1}\right) \tag{5}$$

By taking the derivative of total power w.r.t hop distance H_L and setting this derivative to zero gives Eq. (6).

$$P'_{\mathrm{T}} = D\left(-2P_c {H_L}^{-2} + \alpha(n-1) P_{\min} {H_L}^{n-2}\right) \tag{6}$$

Optimal hop length H_L can be written as in Eq. (7).

$$H_L = \sqrt[n]{\frac{2P_c}{\alpha(n-1)}} \tag{7}$$

So optimal energy consumed for optimal Hop distance is given by Eq. (8).

Algorithm 1 : Zone Head and Associate Zone Head Selection

input: S_i – nodes present in the zone with radius r from the centre of the zone
// Nodes present within the radius r, arrange them in
//descending order based on their residual energy.
Begin
For each node i $\in S_i$
If node i with in radius r from centre of zone Then
Output[]=Arrange_Descend($E_R(i)$)
End if
End for
// selection of zone head *ZH and AZH*
ZH=Output[0];
AZH=Output[1]
End

$$P_T = \frac{D}{\sqrt[n]{\frac{2P_c}{\alpha(n-1)}}} \times (2P_c + \alpha P_{min} d^n) \qquad (8)$$

P_T is the optimal power required to transmit data to the optimal hop distance H_L.

4.2 Initialization

This section explains the initialization of sensor nodes. All the sensors are deployed randomly over sensing area SA. It is divided in to four logical square zones Z_i. This protocol uses zone_id and Node_id to uniquely identify a node. It assumes the availability of Global Positioning System GPS to locate the position of the nodes which in turn provides the zone_id. Further it initializes all the nodes with the values of hop count H_c to infinity and first node in the shortest path SF_id to its own node_id.

4.3 ZH and AZH selection

This section describes the selection of ZH and AZH. This algorithm selects set of nodes form the centre of the zone and arranges them in descending order of their residual energy. First two nodes will be selected as the ZH and AZH. If the nodes are not available within the radius r, it increases the value of r. Algorithm 1 presents the selection of ZH and AZH from the centre of the zone.

4.4 Path finding and routing of data

This phase determines the optimal path from ZH to each sensor nodes in the network using the Eqn 8. Each node maintains shortest hop distance H_c to ZH and first hop node_id in the shortest path SF_id.

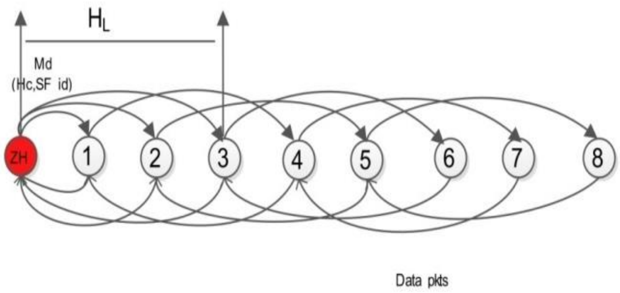

Figure.3 Distance message and data transmission

Initially each node contains shortest hop distance as infinity and first hop node_id as its own node_id. ZH broadcast the distance message M_d that includes SF_id and hop count H_c. While ZH broadcast the Md, hop count value H_c = 0 and SF_id= ZH_id. On receiving M_d message nodes check whether H_c of M_d is less than its own H_c then it modify its H_c with H_c of M_d and SF_id with node_id of broadcasted node. These intermediate nodes further forward M_d message by changing value of H_c and SF_id with its H_c+1 and its own node_id respectively. This process continues till all nodes contain shortest H_c and first node_id in the shortest path. Function for shortest path calculation is presented in algorithm 2.

For routing the sensed data, each sensor transmit to its next node specified as first node in the shortest path SF_id towards ZH in their time slot. Intermediate nodes aggregate the data and transmit to its first node in the shortest path SF_id, this process continues till all data reaches to ZH. Fig. 3 illustrates the transmission of distance message M_d and data packets. Initially ZH transmit M_d massage up to optimal hop length H_L.

Algorithm 2: Shortest Path Finding

Input: M_d - broadcast message with H_c =0, SF_id= ZH_id;
// set ZH with minimum time stamp
For each node $N_i \in |Z|$ && Min(Timestamp(N_i)) do
Broadcast(N_i ,M_d); // M is the set of nodes
//consists of more than one node N_i that
//receives the broadcast message M_d
For each $N_i \in |M|$ do
If (N_i (H_c) > M_d (H_c) && First_recieve (N_i)) then
Set_TimeStamp(N_i)
N_i (SF_id) ‹- M_d (SF_id) ;
N_i (H_c) ‹- M_d (H_c) +1;
M_d(SF_id) ‹- N_i (SF_id)
M_d (H_c) ‹- N_i (H_c) ;
Else
Node N_i discards the received message M_d
End If
End For
End For

Table 1. Comparison value of energy consumption

Simulation Time in (Sec)	Avg. Energy Consumption (in joules)			
	EERDC	**LEACH**	**SenCar DDU_LBC**	**ZEMDC**
5	0.5	0.4	0.3	0.2
10	1.0	0.8	0.5	0.3
15	1.5	1.1	0.7	0.4
20	2.0	1.4	1.0	0.5
25	2.5	1.8	1.3	0.7
30	3.2	2.3	1.6	0.8
35	3.8	2.5	2.0	1.0
40	4.5	2.9	2.2	1.2

The nodes 1, 2 and 3 receive the M_d message and update the shortest distance H_c as 1 and next hop node in the shortest path as ZH_id. As the timestamp of node 1 is minimum so it transmit M_d message further with H_c=H_c+1 and SF_id as its node_id. Even though node 2 and 3 receives M_d message from node 1, they discord it because their H_c values is less then H_c of M_d message sent by node 1. Node 4 receives and proceeds further, till all the nodes updates shortest hop and first node in the shortest path. When farthest node (8) senses the data to transmit, it finds next hop node in the shortest path store in it and transmit to that node (5). Similarly nodes intern forward data towards ZH by finding their first node in the shortest path and transmits, this process continue till data reaches to ZH.

5. Simulation and performance analysis

The ZEMDC protocol is implemented using NS-2 simulator. Here 400 sensor nodes are randomly deployed over 400m x 400m geographical area. We set travelling speed of Mobile Data Collector to 20 Mtrs/Sec and data transmission bandwidth to 100 kbps. This protocol assumes line of sight path without any obstacles, it uses the free space propagation model. Simulation results are illustrated in terms of average energy consumption, network throughput, packet drops and Data Latency. For evaluation of performance of our protocol we consider EERDC: Energy Efficient Routing using Dynamic Clustering Approach [13], LEACH: Low Energy Adaptive Clustering Hierarchy in Wireless Sensor Network [10] and LBC_DDU: Mobile Data Gathering with Load Balanced Clustering and Dual Data Uploading in Wireless Sensor Networks [17] algorithms. We also assume that all the above stated protocols used for comparison are implemented using common scheme and strategy in all layers of network. Transmission range of nodes varied based on the Eq.(8).

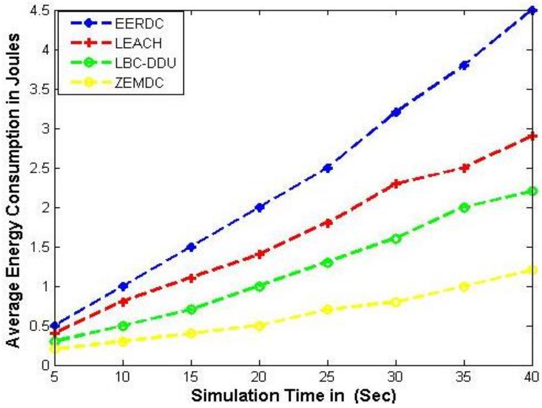

Figure.4 Graph for energy efficiency

5.1 Energy consumption

In this section we discuss the performance in terms of average energy consumption with observed simulation results. We conducted simulation about 40 Sec and tabulate the values of average energy consumption of each protocol for every 5 Sec interval. Table 1. Illustrate the comparison values of average energy consumption of above stated protocol. Fig. 4 shows the graph of energy efficiency and result illustrate that ZEMDC achieves over 73%, 58% and 45% energy efficient compare with EERDC, LEACH and LBC_DDU protocols respectively. This better performance is due to each node transmits data to optimal constant hop length distance hence it minimizes energy consumption. Even ZH not transmit data to distant BS, MDC traverse to each ZH to collects data and uploads to BS this minimizes the energy consumption in ZHs.

5.2 Throughput

This section illustrates the performance of throughput. To compare the throughput, we simulate the protocols about 5 to 40 seconds and tabulate the number of data packets (in Kb) received at the base station. Initially till 10 seconds EERDC and LEACH perform better due to minimum relay or direct

Table 2. Comparison value for throughput

Simulation Time in (Sec)	Throughput (in Kb)			
	EERDC	LEACH	SenCar DDU_LBC	ZEMDC
5	20	15	0	0
10	38	28	45	45
15	55	43	45	45
20	72	58	90	90
25	90	72	90	135
30	110	85	135	175
35	125	95	135	175
40	140	108	180	220

Table 3. Comparison value for packet drops

Number of Packet Transmitted	Packet Drops (No of Packets)			
	EERDC	LEACH	SenCar DDU_LBC	ZEMDC
500	15	11	5	3
1000	28	21	10	5
1500	42	30	13	6
2000	57	39	18	8
2500	70	48	24	10
3000	83	56	29	12
3500	95	64	34	15
4000	110	75	45	18

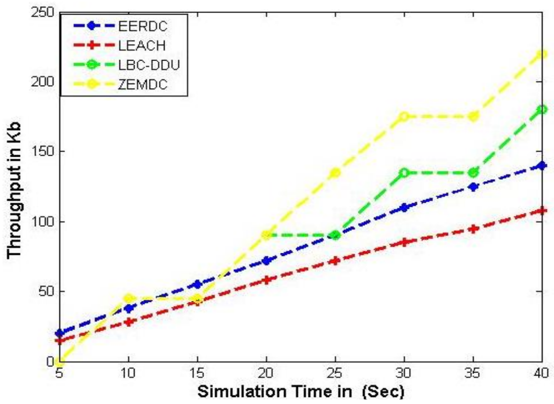

Figure.5 Graph for throughput

transmission of data to base station. Initial poor performance in ZEMDC and DDU_LBC is due to traversing and sojourn time of MDC. As the simulation time increases our protocol perform better due shortest travelling path and MDC collects data continuously from ZH. Table. 2 illustrate the comparison values of throughput of different protocol. Fig. 5 shows the graph of throughput and results illustrate that ZEMDC provides better throughput over 36% 50% and 18% as compare with EERDC, LEACH and LBC_DDU protocols. This better performance of ZEMDC is due to shortest travelling path of MDC. Minimum packet drops and interference are due to optimal hop length distance for data transmission. ZEMDC protocol provides better performance as network size increases as compare to other protocols.

5.3 Packet drop analyses

Reliability of on algorithm is evaluated based on the packet drop ratio. To analyze the packet drop ratio, we conducted the extensive simulation by transmitting 500 packets to 4000 packets and tabulate the observed packet drops of each protocol. Table 3 depicts the observed values of our protocol with other well-known protocols. The ZEMDC protocol exhibit better performance by minimize the packet collision due to less interference. This is due to transmission of data packets using fixed optimal hop length distance. While ZH transmitting data to MDC, AZH act as ZH to collects data from all the zone members. This reduces packet drops. Fig. 5 shows graph of packet drops for various protocols and it is observed that ZEMDC protocol minimizes the packet drops by 83% 76% and 60% as compare to EERDC, LEACH and LBC_DDU respectively. Packet drops in EERDC and LEACH protocol increases with size of the network and data significantly. Though LBC_DDU protocol uses the SenCar to collect data, in absence of optimal transmission distance packet drops increases.

5.4 Latency of data transmission

To evaluate the latency of data transmission of

Table 4. Comparison value for latency

Number of nodes	Latency required in (Sec)			
	EERDC	LEACH	SenCar DDU_LBC	ZEMDC
100	25	25	75	65
200	50	45	82	70
300	70	65	90	73
400	90	80	98	78
500	105	95	104	82
600	122	105	109	87
700	135	115	114	92
800	150	125	118	98

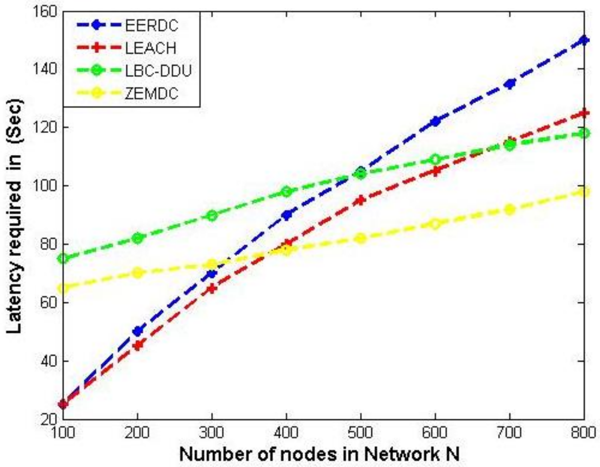

Figure.6 Graph for latency

ZEMDC with other protocols, we simulated the algorithm with 400m x 400m area and number of nodes varies from 100 to 800. When nodes are less than 100, EERDC unable to provide better stable network connection due to unavailability of intermediate relay nodes. In connected network EERDC and LEACH perform well with limited number of nodes. As the number of nodes increases performance degrades. Comparative values of latencies of all protocols are depicted in table 4. In EERDC protocol, farthest nodes consumes more latency due to more number of hop and time coordination. In LEACH protocol, number of cluster or cluster size increases with increase in number of nodes and lack of global synchronization leads to excess latency. Fig. 6 shows the graph of latency for different protocols. From the result it is observed that ZEMDC protocol minimizes the latency by 53%, 27%, and 20% as compare with EERDC, LEACH and LBC_DDU respectively. This performance is due to minimum travelling path and ZH continuously uploads data to MDC while AZH collecting data from Zone members.

6. Conclusion

In this paper we proposed the ZEMDC protocol for data collection in WSNs. It calculates the optimal hop length and energy to transmit data from zone member's to Zone Head in multi hop fashion. Zone size may vary in accordance with deployment area and mobile data collector traverse in the specified path to collect the data. Energy is balanced uniformly in this protocol due to each node transmitting data with constant optimal energy. This protocol is more reliable due to less interference, associate zone head feature and mobile data collector. When ZH uploads data to mobile data collector, AZH will become ZH to collects data from zone members. It provide better throughput for large area networks and bulk data transmission. The ZEMDC protocol provides better performance over 45%, 18%, 60% and 20% in terms of energy efficiency, throughput, reliability and latency respectively in compare with LBC_DDU protocol. Further this work can be extended to latency optimization by tradeoffs between size of the zone and travelling distance of MDC.

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