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Energy Efficient Protocol for Lifetime Prediction of Wireless Sensor Network using Multivariate Polynomial Regression Model

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The sensor network performs gathering, monitoring, and tracking of objects in the given area. The sensor nodes are normally distributed randomly in the network area for collecting the information. The major issues in Wireless Sensor Networks (WSN) are coverage, energy, and limited resources. Sensor Nodes' (SN) performance depends on so many parameters but normally depends on Residual Energy (RE) and Distance from the base station. The Cluster Head (CH) cooperatively communicates with Base Station (BS) via routing protocols. The proposed Energy Efficient Multilevel Region Based (EEMRB) protocol performs the task by partitioning the entire network area into multiple levels and sub-levels. The sub-levels are partitioned to perform clusters to communicate the sensor via CH (s) using single/multi-hop communication to BS. The proposed protocol is compared with the Stable Election Protocol and shows improvement in network lifetime. Based on the proposed protocol data set, a Multivariate Polynomial Regression (MPR) Model is proposed to predict network lifetime. The model uses packet size and node density as network design parameters. The simulation results show that the size of the packet and network area play a major role in network lifetime. Therefore, the lifetime of the predicted model and EEMRB protocol are close to each other. This prediction model is suitable for the prediction of any network area's lifetime.

Keywords: Base station, Cluster head, Coverage and connectivity, Residual energy, Sensor node density

Introduction

The WSN is widely used in the industry. A set of dedicated sensors is dispersed in various locations to sense multiple parameters such as pressure, vibration, sound, movements, pollution, etc. The information is collected and transmitted to BS. The important application area of WSN is military, health care, combat monitoring, intruder detection, building control monitoring system and monitoring environmental conditions etc. The wireless network does not have a fixed infrastructure. The coverage and connectivity are major issues in the network. The various node deployment techniques are introduced to solve coverage and connectivity problems in the network. In Kannan & Paramasivan[1] authors discussed the limited battery power, connectivity among nodes and complete coverage as a problem in the infrastructure of network. The transmission of packets from node to BS is not directly possible for a long duration of time in the network. The problem is minimized by using a multi-hop routing technique for the transmission of a packet in the network. In Nokhanji & Hanapi[2] authors, discussed a technique to minimize load balancing problems in the network. The network reliability is achieved using multi-hop routing techniques. In Mehmood *et al.*[3] authors discussed various sensor nodes deployment techniques and the zonal-based routing protocol to minimize the network connectivity and coverage problem. In Farsi *et al.*[4] authors discussed cluster-based routing and an efficient CH selection mechanism to improve network performance and enhance network lifetime.

Clustering is an important technique in data-driven applications and its performance is based on the quality of data representation. The linear or non-linear feature transformation is widely used for optimum data representation in the cluster formation process. Cluster-oriented network topology is divided into two categories. Intra-cluster communication takes place between nodes and CH using a single-hop technique. Inter-cluster uses direct or multi-hop routing technique between CH to CH and CH to BS. The coverage deals with the tracking and monitoring of the object(s) in a given area, so the routing protocol is energy-efficient.

The sensor node has a limited battery, computation capability and communication range. The nodes are distributed randomly or in deterministic fashion in the

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network. The deterministic and non-deterministic algorithms determine the performance of the network. Homogenous and heterogeneous nodes are used for performing various tasks in the network, as the infrastructure network has more restrictions than Ad-hoc networks. Thus the network has features like the mobility of nodes, scalability, routing and security.

Coverage is a QoS parameter that measures how long and effectively a sensor node monitors the given target region. The objective of the connectivity is to ensure the existence of a path from the node to the BS. The coverage and connectivity deal with tracking and monitoring the object(s) in a given area. As the node dies, the topology frequently changes in the network, and uncertainty in the sensor network deployment poses the challenge to achieve the connectivity and overall coverage in the network. Therefore, the approaches that aim to improve the lifetime of a network using efficient resource utilization are of greater significance.

In Karthikeyan & Shankar[5] authors proposed an algorithm which uses a multi-hop technique for data transmission in the network. Dual CH selection process is used to minimize the burden of the CH node by maintaining the load between the main and the vice cluster head. In Purkait & Tripathi[6] authors proposed a protocol to minimize hot spot problems. The protocol works in two-phases and multi-hop routing techniques for data transmission to BS. The cluster size is dynamic in the protocol by using the fuzzy logic approach and improved network lifespan.

In Wang *et al.*[7] authors proposed (LEACH-Impt) protocol and follow the multi-hop technique for data transmission in the network. The optimal current path is selected dynamically based on the RE of the SN and route hop count value. The protocol enhanced the survival rate and throughput of the system.

In Faheem *et al.*[8] authors proposed energy efficient event driven hybrid routing protocol consisting of ACNF, ANSA and ANRA algorithms. The protocol minimizes delay, data redundancy and congestion in the network. The ACNF algorithm minimizes the data traffic. The ANSA algorithm minimizes overlapping and data redundancy issues of the active sensor node of each cluster. The ANRA algorithm reduces routing problems for densely deployed nodes using dominating set values of SN.

In Gomathi & Manickam[9] authors proposed energy efficient shortest path routing protocol for deployment of SN in different zones ranging from top to bottom. The limited numbers of SN are involved in the data forwarding task in the network. The zonal CHs transfer the data to the next zone CHs. The protocol reduces delay and improves system performance. In Nivedhitha *et al.*[10] authors proposed a Dynamic multi-hop energy efficient routing protocol. The working protocol is as follows: The network initialization and cluster formation is the first phase. The Super Cluster Head (SCH) requests from more than one node/cluster head(s). The SCH transmit data using a multi-path routing technique. In the second phase, the path reliability rate is achieved. In the third phase, the energy model is used to minimize transmission distance. The protocol improves the system's reliability and performance of the network. In Chen & Shen[11] authors proposed a novel protocol which creates virtual grids in the network. The virtual grids are further divided into several units and use sleep and wake-up technique. The switching nature of SN is alive for a longer time and improves system performance.

In Eiras & Zucchi[12] authors suggested a Monte Carlo Approach using statistical methods. The method estimated the probability of message loss in the network. Some nodes are used to know the number of SN that directly consumes the energy from the central node and other SN work as relay SN in the network. The approach is widely used in the FANETs, border surveillance, highway, etc.

In Sanislav *et al.*[13] authors proposed WEH technology for Internet of Things (IoT) devices. The technology increases the data availability rate and has a significant advantage in the wireless energy harvesting system. In Jaber *et al.*[14] authors discussed various types of redundancy in the WSN. The redundancy is useful in some situations. The Optimization of Energy based on Redundancy (OER) mechanism is used for efficient energy utilization in the network. The OER and Fault Tolerance Mechanism (FTMOS) together shows better performance and enhanced network lifetime. In Mulligan & Ammari[15] the authors discussed the effects of redundant and overlapping nodes on the lifetime of the network. There are some cases where maximum redundant nodes are preferably used in critical health situations and for monitoring purposes. In Fan & Jin[16] authors discussed two important factors which improve network lifetime. The first is to minimize the number of active SN in the network, which minimizes the redundant message problem.

The second is to adjust the transmission radius so that it enhances the network life span.

In Mancilla *et al.*[17] authors discussed distributed and centralized techniques for the wireless sensor network. They also discussed deployment issues, types of nodes, event detection types and significant components to form the sensor network backbone. The centralized approach causes a collision in the network, loss of messages and traffic, etc. The distributed approach is more popular and supports scalability, self-organizing, etc.

In Narayan & Daniel[18] authors proposed a protocol to solve the coverage and connectivity issue in the network. The radius of the nodes and RE are chosen as parameters for complete coverage. The protocol reduces the overlapping problem, and the overlapped SN is utilized to enhance network lifetime by using the sleep and wake-up technique.

In Baranidharan *et al.*[19] authors proposed the hierarchical algorithm based on the unequal clustering concept in the network. The algorithm consists of the following phases. The grid formation, CH selection and data collection Phase. The formation of clusters takes place on the basis of local knowledge and the CH is chosen among them. The phases minimize energy consumption and enhanced system performance.

In Lee *et al.*[20] authors proposed Threshold sensitive Energy Efficient sensor Network (TEEN) protocol. The TEEN protocol transmits the information based on the soft and hard threshold values. If the threshold is not achieved, then SN will not communicate with each other. Therefore, no data will be received from BS. As a result, the BS cannot distinguish between alive and dead nodes in the network.

In Parmar & Pirishothm[21] authors proposed APTEEN Protocol which is similar to the TEEN protocol. The APTEEN protocol consists of proactive and reactive features for performing tasks in the network.

In Pillai & Jain[22] the authors discussed various types of topologies used in the wireless network. The random topology is used for the small network area. The uniform and circular topologies are used for large network areas which improve the network lifetime by 41 and 38% respectively. In Noorikhameneh & Moosavi[23] authors discussed Mobile sink-based routing protocol (MSRP) which is similar to the EEMSRA. The CH performs the data aggregation task when the sink node is nearer to CH in the network. The protocol maintains a constant energy supply and load-balancing tasks in the network. The MSRP technique is only used for delay tolerance applications. Yarienezhad & Hashemi[24] proposed a Virtual Circle Combined Straight Routing (VCCSR) protocol which minimizes the path reconstruction process by continuously changing the BS position. The network area is partitioned into virtual grids, and the backbone is constructed which contains all cell head nodes information. The protocol minimizes the path reconstruction cost and enhanced the network lifetime compared to the VCCSR protocol. In Khan *et al.*[25] authors proposed a Virtual grid-based dynamic routes adjustment (VGDRA) scheme for optimal route selection process to BS. The network area is partitioned into ‘k’ equivalent size cells. The SN close to the cell’s centre is chosen as CH, and only a small group of CH takes part in route readjustment tasks. The protocol minimizes data collision and data retransmission tasks in the network.

In Narayan & Daniel[26] authors proposed a protocol which works in two stages. The new formula for the CH selection process is used in the first stage. The trust function is used in the second stage to obtain accurate data and simultaneously the data fusion process to aggregate all data and transmit it to BS. The protocol enhanced node residual energy, stability period and network lifetime. In Narayan *et al.*[27] authors introduced the EETRB protocol for optimal node deployment in the grid area. The simulation result of the protocol for dynamic data size and fixed network area shows that the lifetime varies as a function of data size in the network. In Narayan & Daniel[28] authors proposed multi-tier cluster-based farming for monitoring animals/objects in the agriculture field. The agricultural area is divided into several sub-regions using distance as a parameter. The CH nodes increase at each level which increases the performance of the network. In Dias *et al.*[29] authors discussed the statistical theorem to determine the effect of the dual prediction technique for the wireless network. The theorem reduces transmissions number and data aggregation tasks so that it enhanced the network system performance.

In Xu & Zhang[30] authors proposed the historical data reconstruction method based on the historical data and the data reconstruction process is used to predict future data value. The method avoids transmission and control delay to know the future values based on certain points.

In Xue *et al.*[31] authors discussed the Linq Quality Prediction (LQP) method to achieve the LQP quality features in the network but the network prediction validity is not achieved. The new LINK- Random Vector Functional Link (LINK-RVFL) method is introduced to overcome the issues. The RVFL method and LQP method are used for prediction purposes for real-life application data in smart grid environments.

In Fathy *et al.*[32] authors proposed an Adaptive filters approach for the data reduction process in the network. The dual prediction method is utilized to predict future value. The method utilizes a convex combination, adaptive filters, and various window sizes to improve system performance. In Samarah[33] authors proposed a data prediction model for the lifetime prediction of the node. The model utilizes optimal data for transmission tasks in the network and enhanced system performance.

Materials and Methods

Stable Election Protocol

The SEP protocol istwo-level architecture and uses Normal Nodes (NN) and Advance Nodes (AN). Fig. 1 shows the flowchart of the SEP protocol. The NN are often deployed far from BS and required more energy for data transmission to BS. The initial energy of AN is 'E_α' time more than the NN. Let us suppose that 'S_N' be the total SN in the network area and the fraction of advance nodes is 'S_A'. The Initial Energy (IE) of NN is 'E_0' and the advance node has $(1 + E_\alpha)$ time more energy compared to NN.

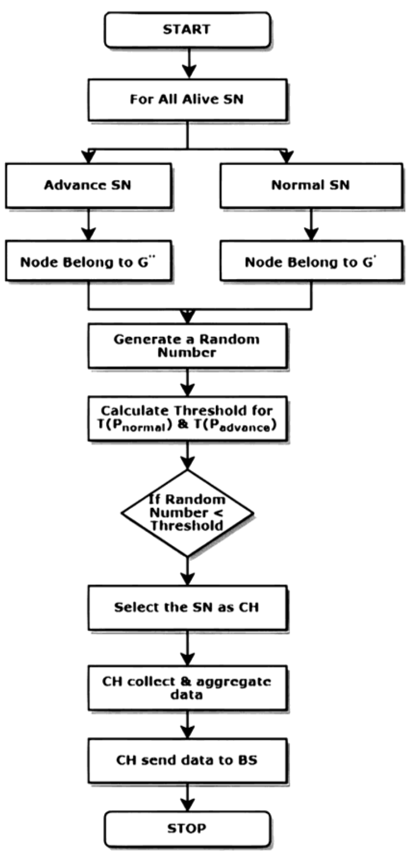

Fig. 1 — Flowchart of SEP

Then the total IE of the heterogeneous network =

$$S_N(1 - S_A)E_0 + S_N S_A E_0(1 + E_\alpha) = S_N E_0(1 + E_\alpha SA \quad \ldots (1)$$

The new heterogeneous network's total energy is improved by $(1 + E_\alpha S_A)$ times. The different probability assignments are used for the CH election process based on the SN energy levels. The data transmission from the cluster(s) to BS is performed by using the Radio energy dissipation model. The CH election probability of the SEP protocol is based on IE. The SEP protocol assigned weight probability for every node. The weighted probability of the normal sensor node is P_{normal} and the advance sensor node is $P_{advance}$ as represented in Eq. (2) & (3):

$$P_{normal} = \frac{P}{1+E_\alpha S_A} \quad \ldots (2)$$

$$P_{advance} = \frac{P}{1+E_\alpha S_A} \times (1 + E_\alpha) \quad \ldots (3)$$

The number is generated and the larger threshold value is chosen as CH for that particular round. The CH aggregates the data and is transmitted to BS. The threshold value for advance ($T_{advance}$) and normal sensor nodes (T_{normal}) is represented in Eq. (4)-(5).[34]

$$T_{normal} = \begin{cases} \frac{P_{normal}}{1-P_{normal}\ (r \bmod \frac{1}{P_{normal}})}, if\ N_{normal} \in G' \\ 0, otherwise \end{cases} \quad \ldots (4)$$

$$T_{advance} = \begin{cases} \frac{P_{advance}}{1-P_{advance}\ (r \bmod \frac{1}{P_{advance}})}, if\ N_{advance} \in G'' \\ 0, otherwise \end{cases} \quad \ldots (5)$$

where, G' and G'' are normal and advanced SN that are not elected as CH for the current round (r).

The limitations of the SEP protocol are as follows:

1. The SEP protocol does not ensure the effective deployment of SN in the network area.
2. The CH election probability in the network is based only on the IE of the SN.
3. The heterogeneity characteristics of SN create an energy imbalance in the network.

These problems are considered and proposed EEMRB protocol to overcome the limitation of SEP. The proposed EEMRB protocol is designed by using multi-level clustering techniques followed by heterogeneous nodes in the network.

Proposed Energy Efficient Multilevel Region Based (EEMRB) Protocol

Network architecture is primarily use to design the sensor-based communication network. The network architecture may include detailed information about various approaches and services delivered through a dedicated communication network. The architecture contains a specification and framework to represent its various physical components, a configuration of the components, how components are functionally organized in the network, operating principles of the components, procedures, and data formats used for data transmission to BS.

The EEMRB Protocol is developed for the military and shopping malls application. The military applications are widely used in combat monitoring, battlefield surveillance, and intruder detection. In battlefield surveillance applications, the SNs are deployed on a battlefield near the enemy force paths. The SN can be spontaneously positioned and can function without continuous maintenance. The EEMRB protocol also reduces energy consumption by monitoring humidity, ventilation, and air conditioning (HVAC) in shopping malls.

The major difference between the SEP and EEMRB protocol are that SEP is a two-level architecture whereas EEMRB is a three-level architecture and the CH selection parameter in SEP protocol is only based on the initial energy of SN whereas in EEMRB protocol it is based on two parameters, minimum distance from BS and maximum residual energy.

The SEP is two level protocol

Assumptions of Proposed EEMRB Protocol

1. The sensor nodes are randomly deployed along with advanced nodes and normal nodes.
2. The nodes are static with heterogeneous characteristics.
3. The data transmission takes place using multi-hop routing among CH(s) nodes.
4. The noise factor and interference of the signal are ignored by designing the system.
5. The 10% of nodes are considered as deployed outside the network area due to dropping from the top. We are only considering effective nodes in the network area such as 100, 200, and so on.

Region Division for Connectivity and Coverage

The sensor nodes are deployed into the M × M dimension area, and BS is placed in the centre of the network area. The three-level architecture is introduced to cover the total area of the network. The area is partitioned into zones, and zones are further partitioned into regions, and regions are partitioned into sub-regions {R_1, R_2… R_n}. They are respectively known as Zonal level, Regional level and Auxiliary level (lowest level). The R_n sub-regions formulate the clusters called Auxiliary Cluster (AC) followed by Auxiliary Cluster Head (ACH). The ACH transmits data to the Regional Cluster Head (RCH) and RCH transmits data to Zonal Cluster Head (ZCH). The CH selection is using minimum node distance from BS and maximum node RE. There are ‘p’ p_1, p_2, …, p_n zone of the given area, then ‘p’ ZCH. There is ‘q’ q_1, q_2, …, q_m regions of zones p_1 then there are ‘q’ RCH. The ‘q_m’ regional formulate cluster of different size based on the node’s number in the region as AC of q_m regional as shown in Fig. 2.

The data is transmitted to ACH to BS using the following logical steps:

1. The ACH aggregates the data from Auxiliary regions clusters set {n_1, n_2, n_3, …, n_n}.
2. The ACH transmits the data to RCH. The RCH aggregates the data that comes from {ACH_1, ACH_2, ACH_3, …, ACH_n} in the given region.
3. The RCH transmits the data to ZCH. The ZCH aggregates the data that comes from {RCH_1, RCH_2, RCH_3, …, RCH_n}.

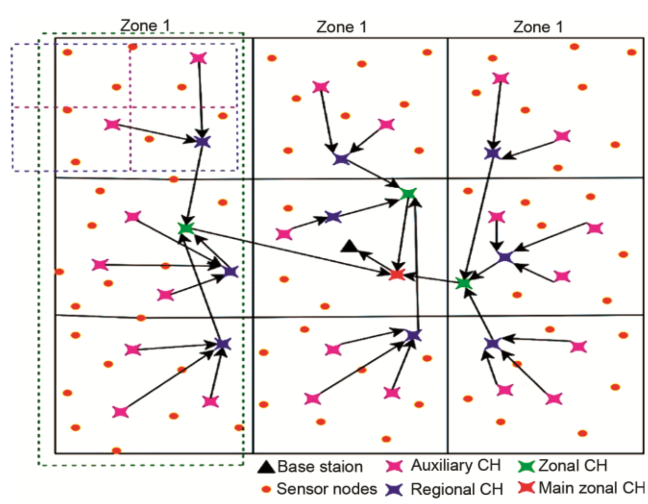

Fig. 2 — Region division

4. The ZCH transmits the data to Z_{MainCH}. The Z_{MainCH} aggregates the data that comes from $\{ZCH_1, ZCH_2, ZCH_3, \ldots, ZCH_n\}$.
5. The Z_{MainCH} finally transmits aggregated data to BS using hybrid routing.

Proposed EEMRB Algorithm

Region Division Algorithm

```
/*Area of Network */
Area = Length × Breadth
Number of Zone = n × m
Let n = m
Z_ij = Zonal Area
P ← m × n
For each i ← 1 to n
For each j ← 1 to m
Z_ij[] ← Area/P
n ← Zone
P_1 ← numbers of region
Zone A_ni ← Area / region n × n
Region A ← Zone A_ni / P_1
Auxiliary Region AP_i ← Region A_i
ACH ← {Set of node n_i, Compute d_i and R_e such that
   [min d_i and max R_e]}
set node n_i ← node ∀{minimumd_i ∧ maximum R_e }
ACH_i ← n_i
ACH ← {Set of node, Compute d_i and R_e with each node}
ACH← node {min (d_i) ∧ max (R_e) at Node level}
RCH← node {min (d_i) ∧ max (R_e) at Regional level}
ZCH← node {min (d_i) ∧ max (R_e) at Zone level}
Do while not end node
Begin
for i ← 1 to n
/* send data to Auxiliary Cluster Head*/
ACH_i← {node n_i, n_2, …, n_p}
/* send data after aggregation to Regional Cluster
   Head*/
RCH_i← {ACH_i, ACH_2, …, ACH_n }
/*send data after aggregation to Zonal Custer Head*/
c) ZCH_i ← {RCH_i, RCH_2, …, RCH_n }
/ * send data after aggregation to Main Zone Cluster
   Head by using hybrid routing */
Z_MainCH ← {ZCH_i, ZCH_2, …, ZCH_n }
BS ← Z_Main CH
End For
End
End do
```

Simulation Parameter

The simulation of EEMRB and SEP protocol is performed in MATLAB under two case studies. The EEMRB protocol was designed to overcome the limitation of the SEP protocol.

Case 1: The nodes started from 100 to 1000 nodes and varied in the incremental step of 100 nodes in 100 × 100 m^2 network area for different packet sizes 2000, 3000, and 4000 bits.

Case 2: The nodes started from 100 nodes to 1000 nodes and varied in the incremental step of 100 nodes for various packet sizes 2000, 3000, and 4000 bits in a 200 × 200 m^2 network area.

The simulation parameters used are shown in Table 1. The 20% of nodes are AN, and the rest are NN in the network.

Case – 1: ***The Lifetime of SEP and EEMRB Protocol for 100 × 100 m^2 area***

The simulation results of SEP and the proposed EEMRB protocol for 100 nodes deployed in a network area of 100 × 100 m^2 for a different packet size of 2000, 3000, and 4000 bits, respectively are shown in Figs 3(a), 3(b), and 3(c). The performance of the proposed EEMRB protocol shows the enhancement in network lifetime compared to SEP.

The simulation analysis of 100 nodes to 1000 nodes in the incremental step of 100 nodes in the network area of 100 × 100 m^2 for packet sizes as 2000, 3000, and 4000 bits are shown in Table 2.

Table 1 — Key parameters

Parameters	Values
Sensor Area	Case 1: (100 × 100) m^2 Case 2: (200 × 200) m^2
Nodes	Vary from 100–1000.
Packet Sizes	2000, 3000, and 4000 bits
Initial Energy	0.5 J
Initial Energy of Advanced Nodes	$E_0 (1 + E_\alpha)$.
Energy Factor α	1
Transmit, receiving energy consumption per bit $\boldsymbol{E}_{elec}$	50 nJ/bit
Amplifier power consumption $E_{fs}(d<d_0)$	10 pJ/bit//m^2
Amplifier energy consumption $E_{mp}(d \geq d_0)$	0.0013 pJ/bit/m^4

Table 2 — Lifetime of SEP and proposed EEMRB protocol

Nodes	2000 bits		3000 bits		4000 bits	
	SEP	EEMRB	SEP	EEMRB	SEP	EEMRB
100	4485	7200	3270	4895	1849	3775
200	4892	7351	2938	5022	2388	3877
300	5001	7451	2952	5264	3098	4004
400	4303	7555	3007	5396	2321	4189
500	4499	7623	3088	5510	2310	4098
600	4367	7489	3200	5300	2356	3892
700	4544	7351	3235	5100	2172	3701
800	4304	7189	2903	5000	2275	3555
900	4001	7001	2959	4862	2160	3347
1000	4304	6900	2903	4700	2273	3216

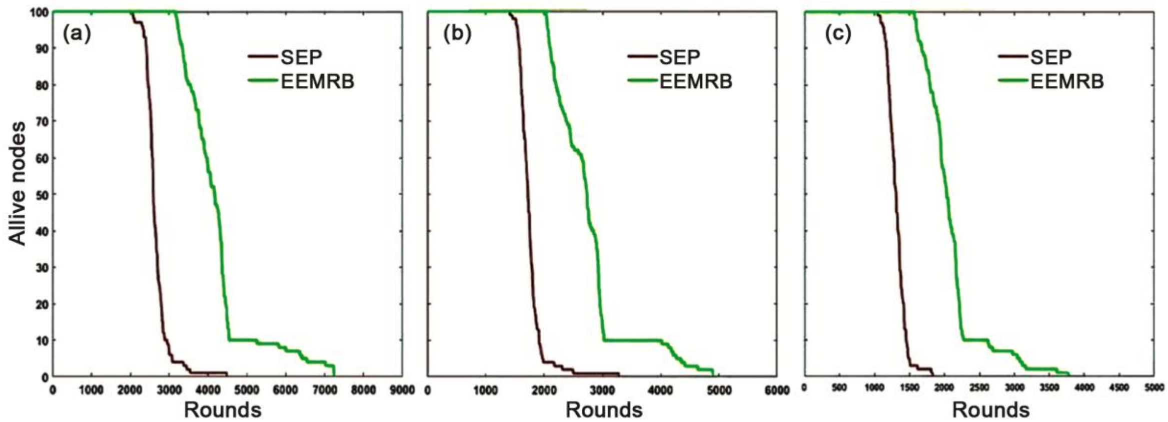

Fig. 3 — SEP and EEMRB protocol network lifetime for packet size (a) 2000, (b) 3000, and (c) 4000 bits

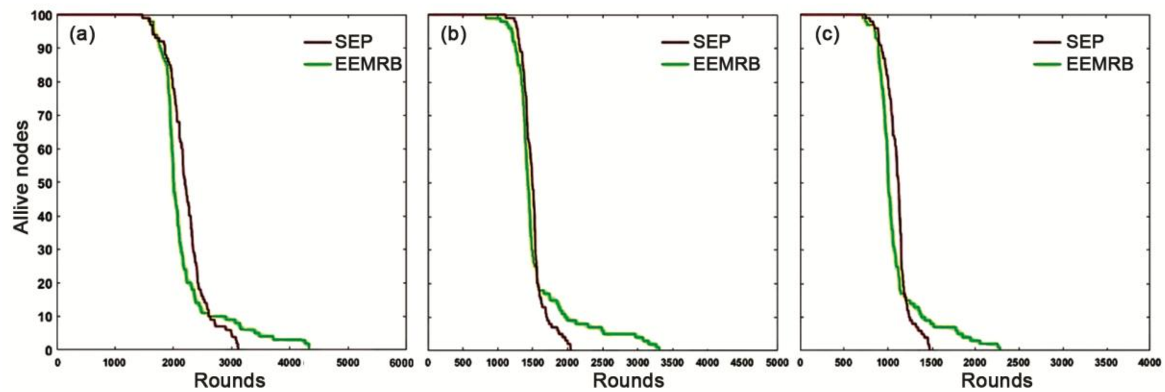

Fig. 4— SEP and EEMRB protocol network lifetime for packet size (a) 2000, (b) 3000, and (c) 4000 bits

The performance analysis of Table 2 shows that with the increase in packet size for a given network area, the network lifetime decreases. The network lifetime increases up to 400 nodes for a packet size of 4000 bits, 500 nodes for a packet size of 3000 bits, and 2000 bits for the EEMRB protocol. Afterwards, it starts decreasing exponentially because of congestion or delay in the network.

Case 2: The Lifetime of SEP and EEMRB Protocol for 200 × 200 m² Area.

The simulation results of SEP and the proposed EEMRB protocol for 100 nodes deployed in a network area of 200 × 200 m^2 for a different packet size of 2000, 3000, and 4000 bits respectively are shown in Figs 4(a), 4(b), and 4(c). The performance of the proposed EEMRB protocol shows an improvement in network lifetime compared to SEP.

The simulation analysis of 100 nodes to 1000 nodes in the incremental step of 100 nodes in the network area of 200 × 200 m^2 for distinct packet sizes as 2000, 3000, and 4000 bits is given in Table 3.

Table 3 — Lifetime of SEP and proposed EEMRB protocol

Nodes	2000 bits		3000 bits		4000 bits	
	SEP	EEMRB	SEP	EEMRB	SEP	EEMRB
100	3182	4402	2089	3301	1492	2300
200	3292	4629	2523	3690	1528	2451
300	4031	4896	2869	3800	1749	2580
400	4461	5021	2539	3951	1903	2681
500	4085	5343	2952	4100	2150	2700
600	4168	5177	2557	3982	2191	2710
700	3712	5164	2537	3744	1929	2651
800	4044	5039	2551	3599	1921	2554
900	3518	5011	2523	3406	2012	2501
1000	4000	5060	2620	3256	1915	2401

The performance analysis of Table 3 shows that with the increase in packet size for a given network area, the network lifetime decreases. The network lifetime increases up to 600 nodes for a packet size of 4000 bits, 500 nodes for packet size of 3000 bits and 2000 bits for the EEMRB protocol. Afterwards, it starts decreasing exponentially because of congestion or delay in the network. Most of the research in sensor networks focuses on resolving the deployment issue for monitoring enemy troops' movement in battlefield surveillance. The proposed EEMRB protocol use optimal number of SN for maximum coverage in the given network area.

Proposed Multivariate Polynomial Regression (MPR) Model

The MPR model is trained with three variables (x_1, x_2, y). The independent variables are packet size (x_1) and the number of nodes (x_2). The dependent variable is a lifetime (y). A, B, C, D, E, F, and ε are the six coefficients in the MPR model as shown in Fig. 5. The MPR Model predicts the lifetime of the network corresponding to the independent variables for the EEMRB protocol data set. Thus, the prediction helps to replace the sensor nodes easily with less human effort and maintenance cost is also reduced.

Sometimes a linear line is incapable of apprehending the sample, which is an illustration of under-fitting. In such a scenario, the complexity of the model will escalate. The increasing complexity will generate a quadratic equation. The equation for the Linear Regression Model is given below:

$$y = A + Bx + \varepsilon \quad \dots (6)$$

where, the independent variable is ‘x’ and the dependent variable is ‘y’, the intercept of ‘y’ is A, the slope for variable ‘x’ is B and ε is the error rate of the model. Under Polynomial Regression Model, Sagar *et al.*[35] created a link between multiple independent variables and one dependent variable. The Polynomial Regression Model of the n^{th} degree equation is shown below.

$$y = A + Bx + Cx^2 + Dx^3 + \dots + Nx^n + \varepsilon \quad \dots (7)$$

But when there are two independent variables, the Multivariate Polynomial Regression (MPR) Model is represented below.

$$y = A + Bx_1 + Cx_1^2 + Dx_2 + Ex_2^2 + Fx_1x_2 + \varepsilon \quad \dots (8)$$

where ‘x_1’,‘x_2’, and ‘y’ are two independent and one dependent variables respectively, the intercept of ‘y’ is A, B is the slope for ‘x_1’, C is the slope for ‘x_1^2’, D is the slope for x_2, E is the slope for ‘x_2^2’, F is the slope for ‘x_1x_2’, ‘ε’ is the model error rate.[36] The coefficients A, B, C, D, E, and F are termed as MPR model parameters. The error rate is calculated as given below.

$$\varepsilon = y - A - Bx1 - Cx12 - Dx2 - Ex22 - Fx1x2 \quad \dots (9)$$

We are calculating the error rate for the i^{th} sample in ‘n’ number of samples.

$$\sum_{i=1}^{n} \varepsilon_i = \sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{1i}x_{2i}\right) \quad \dots (10)$$

Squaring both sides, we get

$$\sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{i1}x_{2i}\right)^2 \quad \dots (11)$$

The MPR model parameters are calculated by minimizing the equation (i.e., the sum of squares of errors (SSE)) as given below.

$$SSE = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{1i}x_{2i}\right)^2 \quad \dots (12)$$

For minimizing Eq. (12), the equation(s)’ partial derivative is calculated with respect to each model parameter.

$$\partial SSE/\partial A = 2\sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{1i}x_{2i}\right)^2 (-1) \quad \dots (13)$$

$$\partial SSE/\partial B = 2\sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{1i}x_{2i}\right)^2 (-x_{1i}) \quad \dots (14)$$

$$\partial SSE/\partial C = 2\sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{1i}x_{2i}\right)^2 (-x_{1i}^2) \quad \dots (15)$$

$$\partial SSE/\partial D = 2\sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{1i}x_{2i}\right)^2 (-x_{2i}) \quad \dots (16)$$

$$\partial SSE/\partial E = 2\sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{1i}x_{2i}\right)^2 (-x_{2i}^2) \quad \dots (17)$$

$$\partial SSE/\partial F = 2\sum_{i=1}^{n}\left(y_i - A - Bx_{1i} - Cx_{1i}^2 - Dx_{2i} - Ex_{2i}^2 - Fx_{1i}x_{2i}\right)^2 (-x_1x_2) \quad \dots (18)$$

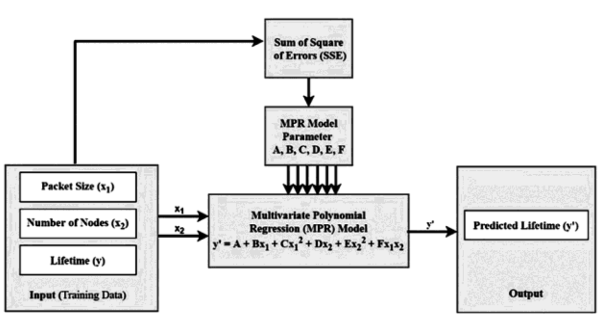

Fig. 5 — MPR Model

Now, the partial derivative is set to zero and resulting linear equations are solved simultaneously to achieve the MPR model parameter value.

$$\partial SSE/\partial A = 0 \quad \dots (19)$$

$$\sum_{i=1}^{n} y_i = nA + B\sum_{i=1}^{n} x_{1i} + C\sum_{i=1}^{n} x_{1i}^2 + D\sum_{i=1}^{n} x_{2i} + E\sum_{i=1}^{n} x_{2i}^2 + F\sum_{i=1}^{n} x_{1i}x_{2i} \quad \dots (20)$$

$$\partial SSE/\partial B = 0 \quad \dots (21)$$

$$\sum_{i=1}^{n} x_{1i}y_i = A\sum_{i=1}^{n} x_{1i} + B\sum_{i=1}^{n} x_{1i}^2 + C\sum_{i=1}^{n} x_{1i}^3 + D\sum_{i=1}^{n} x_{1i}x_{2i} + E\sum_{i=1}^{n} x_{1i}x_{2i}^2 + F\sum_{i=1}^{n} x_{1i}^2 x_{2i} \quad \dots (22)$$

$$\partial SSE/\partial C = 0 \quad \dots (23)$$

$$\sum_{i=1}^{n} x_{1i}^2 y_i = A\sum_{i=1}^{n} x_{1i}^2 + B\sum_{i=1}^{n} x_{1i}^3 + C\sum_{i=1}^{n} x_{1i}^4 + D\sum_{i=1}^{n} x_{1i}^2 x_{2i} + E\sum_{i=1}^{n} x_{1i}^2 x_{2i}^2 + F\sum_{i=1}^{n} x_{1i}^3 x_{2i} \quad \dots (24)$$

$$\partial SSE/\partial D = 0 \quad \dots (25)$$

$$\sum_{i=1}^{n} x_{2i}y_i = A\sum_{i=1}^{n} x_{2i} + B\sum_{i=1}^{n} x_{1i}x_{2i} + C\sum_{i=1}^{n} x_{1i}^2 x_{2i} + D\sum_{i=1}^{n} x_{2i}^2 + E\sum_{i=1}^{n} x_{2i}^3 + F\sum_{i=1}^{n} x_{1i}x_{2i}^2 \quad \dots (26)$$

$$\partial SSE/\partial E = 0 \quad \dots (27)$$

$$\sum_{i=1}^{n} x_{2i}^2 y_i = A\sum_{i=1}^{n} x_{2i}^2 + B\sum_{i=1}^{n} x_{1i}x_{2i}^2 + C\sum_{i=1}^{n} x_{1i}^2 x_{2i}^2 + D\sum_{i=1}^{n} x_{2i}^3 + E\sum_{i=1}^{n} x_{2i}^4 + F\sum_{i=1}^{n} x_{1i}x_{2i}^3 \quad \dots (28)$$

$$\partial SSE/\partial F = 0 \quad \dots (29)$$

$$\sum_{i=1}^{n} x_{1i}x_{2i}y_i = A\sum_{i=1}^{n} x_{1i}x_{2i} + B\sum_{i=1}^{n} x_{1i}^2 x_{2i} + C\sum_{i=1}^{n} x_{1i}^3 x_{2i} + D\sum_{i=1}^{n} x_{1i}x_{2i}^2 + E\sum_{i=1}^{n} x_{1i}x_{2i}^3 + F\sum_{i=1}^{n} x_{1i}^2 x_{2i}^2 \quad \dots (30)$$

The linear Eqs (20), (22), (24), (26), (28), and (30) are solved either with the help of matrix notation or with the help of algorithm 1. The matrix notation for the model is discussed here. The linear equation is solved with the help of three matrices [a], [p], [d].

$$[a] \times [p] = [d]$$

where, matrix[a] is a k × k coefficient matrix where μ_{x_1} represents the summation of x_{1i}, $\mu_{x_1^2}$ represents the summation of x_{1i}^2 and so on. The matrix[p] is a column matrix with k entries of the model parameter. The matrix[d] is a column matrix with k entries of values present on the left side of Eqs (20), (22), (24), (26), (28), (30), and k is the total count of the MPR model parameter.

$$\begin{bmatrix} n & \mu_{x_1} & \mu_{x_1^2} & \mu_{x_2} & \mu_{x_2^2} & \mu_{x_1x_2} \\ \mu_{x_1} & \mu_{x_1^2} & \mu_{x_1^3} & \mu_{x_1x_2} & \mu_{x_1x_2^2} & \mu_{x_1^2x_2} \\ \mu_{x_1^2} & \mu_{x_1^3} & \mu_{x_1^4} & \mu_{x_1^2x_2} & \mu_{x_1^2x_2^2} & \mu_{x_1^3x_2} \\ \mu_{x_2} & \mu_{x_1x_2} & \mu_{x_1^2x_2} & \mu_{x_2^2} & \mu_{x_2^3} & \mu_{x_1x_2^2} \\ \mu_{x_2^2} & \mu_{x_1x_2^2} & \mu_{x_1^2x_2^2} & \mu_{x_2^3} & \mu_{x_2^4} & \mu_{x_1x_2^3} \\ \mu_{x_1x_2} & \mu_{x_1^2x_2} & \mu_{x_1^3x_2} & \mu_{x_1x_2^2} & \mu_{x_1x_2^3} & \mu_{x_1^2x_2^2} \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \end{bmatrix} = [a] \times [p] \quad \dots (31)$$

$$\begin{bmatrix} \mu_y \\ \mu_{x_1y} \\ \mu_{x_1^2y} \\ \mu_{x_2y} \\ \mu_{x_2^2y} \\ \mu_{x_1x_2y} \end{bmatrix} = [d] \quad \dots (32)$$

$$[a] \times [p] = [d] \quad \dots (33)$$

$$[a] \times [a]^{-1} \times [p] = [a]^{-1} \times [d] \quad \dots (34)$$

$$[p] = [a]^{-1} \times [d] \quad \dots (35)$$

The values of the model parameter are solved using matrix notations in Eq. (35). The proposed Multivariate Polynomial Regression model is divided into three steps:

The first step is to prepare training data. The training data are Packet Size, Number of Nodes and Lifetime obtained from the EEMRB protocol.[37,38] The input variables are Packet Size and Number of Nodes whereas the output variable is Lifetime. The second step is to fit the MPR model into the training data. This is achieved by passing all the prepared training data to a learning algorithm. Algorithm 1 (i.e., MPR Model) figures out the mapping between the input variable and the output variable. MPR Model also generates the equations obtained by SSE, i.e. Eqs (20), (22), (24), (26), (28), and (30) then calculates the value of coefficients A, B, C, D, E, and F with help of the previously generated equations. The sym function is used to create symbolic variables.

Algorithm 1: MPR Model

Input: p_n, n_n, l_n, r, X[], Y[], Z[], E[][]

Initialization: p_n= Count of Packet Size, n_n = Count of Nodes for each Packet, l_n= Count of Lifetime for each Packet, r = Count of no. Nodes for each Packet (rows), len = number of column, X[] = Array of Packet, Y[] = Array of number of Nodes, Z[] = Lifetime for the respective Nodes, E[][] = computing different features, S[] = Summation of columns of matrix E[][], L= Variable to solve the equations.

Output: A, B, C, D, E, F
MPR Model (p_n, n_n, l_n, X[],Y[],Z[])
size ← $p_n \times n_n$
for i ← 0…r do
$E_{i0} = X_i * X_i$;
$E_{i1} = Y_i * Y_i$;
$E_{i2} = X_i * X_i * X_i$;
$E_{i3} = X_i * Z_i$;
$E_{i4} = Y_i * Y_i * Y_i$;
$E_{i5} = Y_i * Y_i * Y_i * Y_i$;
$E_{i6} = Y_i * Z_i$;
$E_{i7} = X_i * X_i * X_i * X_i$;
$E_{i8} = Y_i * Y_i * Z_i$;
$E_{i9} = X_i * Y_i$;
$E_{i10} = X_i * Y_i * Z_i$;
$E_{i11} = X_i * Y_i * Y_i$;
$E_{i12} = X_i * X_i * Y_i$;
$E_{i13} = X_i * X_i * X_i * Y_i$;
$E_{i14} = X_i * X_i * Y_i * Y_i$;
$E_{i15} = X_i * Y_i * Y_i * Y_i$;
$E_{i16} = Y_i * Y_i * Y_i * Y_i$;
end for
for i ← 0…len do
for j ← 0…size do
sum ← sum + E_{ji}
end for
S[i]← sum
end for
Eqn←S[i]
syms A B C D E F
L ← solve (Eqn)
L.A
L.B
L.C
L.D
L.E
L.F
return A,B,C,D,E,F
end function

The third step is to connect the prediction with the input variable to the MPR model. Algorithm 2 (i.e. Prediction Model) takes the Number of Nodes (Y[]) and Packet size(X[]) as input and predicts the network lifetime.

Algorithm 2: Prediction Model

Input: Y[], X[], A, B, C, D, E, F
Initialization: Y[]= Array of number of Nodes, X[] = Array of packet, lp[] = Array of Predicted Lifetime for the respective Node.
Output: lp[]
PREDICTIONMODEL (X[], A, B, C, D, E, F, Y[])
for i ← 0… size do
lp[i] ← $A+(B\times X_i)+(C\times X_i\times X_i)+(D\times Y_i)+(E\times Y_i\times Y_i)+(F\times X_i\times Y_i)$
end for
return lp[]
end function

Results and Discussion

The proposed MPR model predicts the lifetime of the SN. In the prediction model, each node is trained according to data points. The proposed EEMRB protocol and proposed MPR model values are taken to estimate the leading and lagging delay (compensation factor) and the MPR model performance. The leading delay is the positive value, and the lagging delay is the negative value shows in Tables 4 and 5.

CASE 1

The data given in Table 2 is used to train the proposed MPR model of 100×100 m^2 network area. The multiple independent variables, x_1(packet size) and x_2(sensor nodes) and dependent variable y (lifetime), are used as input parameter for the model. The predicted value is calculated by usingthe matrix[a] and matrix[d] (according to Eqs (31) & (32)). The matrix [p] is calculated by solving the linear equation simultaneously in MATLAB.

Table 4 — Performance analysis of the proposed EEMRB protocol and MPR model for 100×100 m^2

Nodes	2000 bits			3000 bits			4000 bits		
	EEMRB	MPR	LD (%)	EEMRB	MPR	LD (%)	EEMRB	MPR	LD (%)
100	7200	7226	0.36	4895	4989	1.91	3775	3829	1.43
200	7351	7361	0.13	5022	5107	1.69	3877	3931	1.39
300	7451	7452	0.02	5264	5182	1.56	4004	3989	0.37
400	7555	7500	0.73	5396	5213	3.39	4189	4004	4.42
500	7623	7504	1.56	5510	5201	5.61	4098	3975	2.99
600	7489	7465	0.32	5300	5145	2.92	3892	3903	0.29
700	7351	7383	0.43	5100	5046	1.05	3701	3788	2.34
800	7189	7257	0.94	5000	4904	1.93	3555	3629	2.07
900	7001	7087	1.23	4862	4718	2.97	3347	3426	2.36
1000	6900	6874	0.37	4700	4488	4.51	3216	3180	1.12

Table 5 — Performance analysis of the proposed EEMRB protocol and MPR model for 200 × 200 m^2

Nodes	2000 bits			3000 bits			4000 bits		
	EEMRB	MPR	LD (%)	EEMRB	MPR	LD (%)	EEMRB	MPR	LD(%)
100	4402	4489	1.98	3301	3314	0.39	2300	2300	0.01
200	4629	4735	2.28	3690	3534	4.24	2451	2494	1.76
300	4896	4929	0.66	3800	3702	2.58	2580	2636	2.19
400	5021	5071	0.99	3951	3818	3.36	2681	2727	1.71
500	5343	5161	3.40	4100	3883	5.29	2700	2766	2.44
600	5177	5200	0.45	3982	3896	2.16	2710	2753	1.59
700	5164	5188	0.46	3744	3858	3.03	2651	2689	1.42
800	5039	5123	1.67	3599	3767	4.68	2554	2573	0.73
900	5011	5007	0.08	3406	3625	6.44	2501	2405	3.84
1000	5060	4839	4.36	3256	3432	5.40	2401	2186	8.97

a =

$$\begin{bmatrix} 30 & 9.00E+04 & 2.90E+08 & 1.65E+04 & 1.16E+07 & 4.95E+07 \\ 9.00E+04 & 2.90E+08 & 9.90E+11 & 4.95E+07 & 3.47E+10 & 1.60E+11 \\ 2.90E+08 & 9.90E+11 & 3.53E+15 & 1.60E+11 & 1.12E+14 & 5.45E+14 \\ 1.65E+04 & 4.95E+07 & 1.60E+11 & 1.16E+07 & 9.08E+09 & 3.47E+10 \\ 1.16E+07 & 3.47E+10 & 1.12E+14 & 9.08E+09 & 7.60E+12 & 2.72E+13 \\ 4.95E+07 & 1.60E+11 & 5.45E+14 & 3.47E+10 & 2.72E+13 & 1.12E+14 \end{bmatrix}$$

$$d = \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \end{bmatrix} = \begin{bmatrix} 1.62E+05 \\ 4.50E+08 \\ 1.35E+12 \\ 8.77E+07 \\ 6.05E+10 \\ 2.43E+11 \end{bmatrix}$$

For 100 × 100 m^2 the model parameter [p] are:

$$p = \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \end{bmatrix} = \begin{bmatrix} 1.47E+04 \\ -4.92E+00 \\ 5.39E-04 \\ 2.33E+00 \\ -2.17E-03 \\ -1.65E-04 \end{bmatrix}$$

Hence, substituting the value of the model parameter matrix[p] in Eq. (8), the MPR model lifetime is calculated. Leading and Lagging delay of MPR (LD%) are calculated using Eq. (36) for 100 × 100 m^2 network area as shown in Table 4. We consider an absolute function that indicates the positive value of Lagging delay.

Leading and Lagging delay of MPR (LD %)

$$= \left(\frac{\text{abs (Lagging Delay)}}{\text{actual value (y)}} \times 100\right)\%$$

$$= \left(\frac{\text{abs}\left(\text{predicted value } (y') - \text{actual value } (y)\right)}{\text{actual value } (y)} \times 100\right)\% \quad \ldots (36)$$

For example, if the input parameter x_1 is 2000, x_2 is 100, y is 7200, and model coefficients A, B, C, D, E, F are given above in matrix[p] then the predicted lifetime is 7226, and the Leading and Lagging delay of the MPR (LD%) is 0.36%. The performance analysis of the MPR model varies in terms of the leading and lagging of nodes due to system constraints.

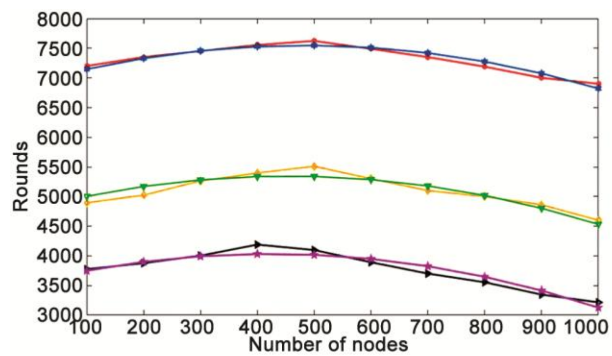

Fig. 6 — Comparison of EEMRB protocol and MPR model for 100 × 100 m^2 network lifetime for packet size 2000, 3000 & 4000 bits

Similarly, for 100 nodes to 1000 nodes in the interval of 100 nodes over the 100 × 100 m^2 area for the different packet sizes as 2000, 3000, and 4000 bits respectively are simulated and the simulation result are shown in Table 4 for the lifetime of the MPR model to EEMRB protocol.

The simulation result of the proposed MPR model and proposed EEMRB protocol for 100 nodes in the network area of 100 × 100 m^2 for packet sizes 2000, 3000, and 4000 bits are shown in Fig. 6.

The simulation performance of the EEMRB protocol for packet size 2000 bits and deployed 100 sensor nodes in the 100 × 100 m^2 area is 7200 rounds and the MPR model has 7226 rounds. Similarly, for packet sizes 3000, and 4000 bits the network lifetime for EEMRB is 4895 rounds, and 3775 rounds and for the MPR model is 4889 rounds, and 3829 rounds, respectively.

Under the MPR model simulation result, maximum closeness is 99.98% and minimum closeness is 98.44% for packet size 2000 bits, maximum closeness is 98.95% and minimum closeness is 94.39% for packet size 3000 bits and maximum closeness is 99.71% and minimum closeness is 95.58% for packet size 4000 bits from EEMRB protocol.

CASE 2

The data given in Table 3 is used to train the proposed MPR model for 200 × 200 m^2 network area. The predicted value is calculated by using matrix[d], matrix[p], and matrix[a]. The matrix[d], matrix[p] are computed by using algorithm 1, whereas matrix[a] remains the same.

$$p = \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \end{bmatrix} d = \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \end{bmatrix} = \begin{bmatrix} 1.12E+05 \\ 3.12E+08 \\ 9.39E+11 \\ 6.20E+07 \\ 4.31E+10 \\ 1.72E+11 \end{bmatrix}$$

For 200 × 200 m^2 area, the model parameter [p] are:

$$p = \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \end{bmatrix} = \begin{bmatrix} 6.97E+03 \\ -1.55E+00 \\ 8.07E-05 \\ 3.75E+00 \\ -2.58E-03 \\ -2.58E-04 \end{bmatrix}$$

Hence, using Eq. (8), the lifetime of the MPR model is calculated. The Leading and Lagging delay of MPR is calculated using Eq. (36) for 200 × 200 m^2 having 100 to 1000 nodes in the interval of 100 nodes for packet size 2000, 3000, and 4000 bits respectively are simulated and the simulation result is shown in Table 5.

The simulation result of the proposed MPR model and proposed EEMRB protocol for 100 nodes in the network area of 200 × 200 m^2 for packet sizes 2000, 3000, and 4000 bits are shown in Fig. 7.

The simulation performance of the EEMRB protocol for packet size 2000 bits and deployed 100 sensor nodes in the network area of 200 × 200 m^2 is 4402 rounds, and the MPR model has 4489 rounds.

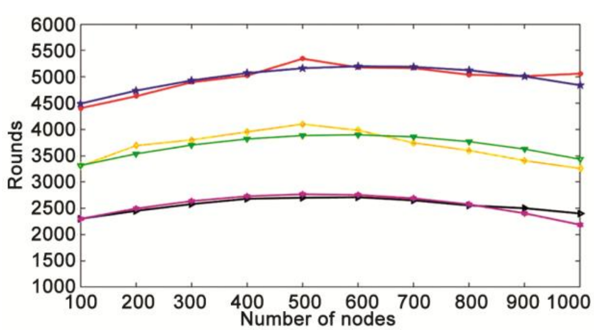

Fig. 7 — Comparison of EEMRB protocol and MPR model for 200 × 200 m^2 network lifetime for packet size 2000, 3000 & 4000 bits

Similarly, for packet size 3000, and 4000 bits, EEMRB is 3301 and 2300 rounds and the MPR model is 3314, and 2300 rounds respectively during the network lifetime.

The MPR model simulation result has shown maximum closeness as 99.92% and minimum closeness as 95.64% for packet size 2000 bits, maximum closeness as 99.61% and minimum closeness as 93.56% for packet size 3000 bits, and maximum closeness as 99.99% and minimum closeness as 91.03% for packet size 4000 bits from EEMRB protocol.

Conclusions

The performance of the predicted Multivariate Polynomial Regression (MPR) model and the proposed Energy Efficient Multilevel Region Based (EEMRB) protocol are very close to the real data set. The packet size of 2000, 3000, and 4000 bits for 100 × 100 m^2 area coverage show closeness of 99.98%, 98.95%, 99.71% and for 200 × 200 m^2 area coverage have the closeness of 99.92%, 99.61%, 99.99%. The simulation results show that node density and packet size play an important role in determining the optimal number of nodes for the maximum lifetime of the network. The future objective is to calculate the optimal number of active sensor nodes essential for total coverage and overlapping regions. The assumption here is that nodes are static in nature after deployment. In the future, this work can extend to the large network area coverage supported by relay nodes and consider other important factors such as throughput, delay and number of discarded packets.

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