

Traffic-Aware Reliability Enhanced Cluster Head Selection Based Routing for Heterogeneous WSNs

S.Tamilselvi, S.Rizwana



Abstract: One of the most important challenges for Wireless Sensor Networks (WSNs) is improving the lifespan of the network. This is tackled by the clustering technique that simplifies the routing in WSNs. The clustering strategy only takes into account a small number of nodes randomly selected as Cluster Heads (CHs). CH's main task is to collect the sensed data from their member nodes, aggregate it and transmit it to the sink or Base Station (BS). Several clustering strategies are proposed to significantly increase energy efficiency and lifespan of the network. Among those, Reliability-based Enhanced Technique for Ordering of Preference by Similarity-Ideal-Solution (RE-TOPSIS) using fuzzy logic model promotes effective CHs selection and network lifespan with the consideration of five different criteria like remaining power, distance between neighboring nodes, distance between the sink and CHs, energy efficiency and availability of adjacent nodes. This algorithm is only appropriate for energy heterogeneity scenarios. Conversely, under multi-level traffic heterogeneities, routing is not successful due to the considered criteria. For WSNs with heterogeneity scenarios, considering traffic as well as energy heterogeneities is the most important to maximize the network's lifespan. Hence, a Traffic-Aware RE-TOPSIS (TARE-TOPSIS) for an effective CH selection protocol is proposed in this article which considers the traffic of nodes along with their initial and residual power. This protocol provides the framework for selecting CH under multi-level traffic and energy heterogeneities. This considers the node's initial energy, traffic load including five criteria in RE-TOPSIS to efficiently choose the CH during each cycle. At last, simulation outcomes exhibit that the proposed technique outperforms the RE-TOPSIS technique in terms of network lifespan, average energy consumption, throughput and Packet Delivery Ratio (PDR).

Keywords: Wireless sensor network, Heterogeneity, Clustering, Network lifetime, Energy efficiency, RE-TOPSIS

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of many wireless sensor nodes that communicate with their surroundings via wireless channels to gather and transmit the necessary environmental information to the Base Station (BS). Such nodes are usually built with a densely distributed battery, processor, memory and radio in the given region for a particular purpose. WSN's emerging applications are military, farming, weather forecasting, monitoring of healthcare, smart transportation, and home automation.

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* Correspondence Author

S.Tamilselvi*, Research Scholar, Department of Computer Science, Erode Arts and Science College, Erode.

S.Rizwana, Assistant Professor & Head, Department of Computer Science[SF], Erode Arts and Science College, Erode.

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There are two features of the sensor network: homogeneous and heterogeneous WSNs.

All sensor nodes are equipped with the same capacity hardware in the homogeneous WSN,

whereas in heterogeneous WSN, only advanced nodes need more hardware. Heterogeneous WSNs are well-known and prevalent in real-time applications to extend the life and performance of the network. Efficient routing becomes an

important problem in such networks due to the constraints on power, transmission bandwidth and storage capacity. Typically, routing is a process of finding a path from the origin node to the destination node [1].

Most recent energy-efficient routing protocols designed for heterogeneous WSNs are based on clustering techniques that are efficient in scalability and energy conservation for WSNs. A cluster-based routing is an energy-efficient method in which nodes with a high energy level are randomly chosen for processing and transmitting data while nodes with a lower energy level are used to sensing and transmit data to the Cluster Heads (CHs). This cluster-based routing protocol property results in scalability, lifetime maximization and power minimization. Such protocols play a key role in achieving specific goals for implementation. Low-Efficiency Adaptive Clustering Hierarchical (LEACH) protocol is the most well-known cluster-based routing protocol that has the benefit of simple implementation and effectively manages network loads [2]. For many subsequent clustering protocols, the basic concept of the LEACH protocol was an inspiration.

LEACH's functionality is divided into several rounds where each round is divided into two phases: the phase of set-up and the phase of the station. The clusters are organized in the set-up phase, while the data is delivered to the base station in the steady-state phase. Each node determines whether or not to become a CH for the current round during the set-up process. This decision is based on the network's recommended percentage of CHs and the number of times the node has so far been a CH. It transmits an advertisement message to the other nodes when a node is successfully selected by CH. Other nodes will determine which cluster they will join for this round based on the advertisement's of Received Signal Strength Indicator (RSSI) and send a membership message to their CH. Besides, CH rotation is performed at each round to disperse the energy load equally between sensor nodes through the generation of a new phase of ads. Sensor nodes sense the information in the steady-state phase and send it to the CH. The CH compresses the data coming from the nodes belonging to the respective cluster and directly transmits to the base station an aggregated or fused packet.

This protocol also uses Time-Division Multiple Access (TDMA) to reduce inter-cluster and intra-cluster collisions. The network returns to the set-up process after a certain time and begins another round of CH selection. This requires single-hop communication, however, and can therefore not be used in large-scale networks. CHs are also selected based on probability; thus, uniform distribution cannot be assured and load balancing cannot also be accomplished. Many

clustering-based routing protocols have been developed for WSN over the past decades to optimize the lifespan of the network and reduce energy consumption. Among those, Murugaanandam & Ganapathy [3] proposed a Reliability-based Enhanced Technique for Ordering of Preference by Similarity-Ideal-Solution (RE-TOPSIS) using fuzzy logic which employs Multi-Criteria-Decision-Making (MCDM) methodology to promote effective CHs selection. Based on the RE-TOPSIS rank index value, the LEACH protocol was used to allow one-time scheduling in each cluster. CH selection process necessity in each round of the setup state phase of LEACH has been removed. Different criteria have been considered, such as remaining power, distances between neighboring nodes, energy efficiency, availability of adjacent nodes, distances between CHs and member nodes including distances between the sink and CHs. However, under multi-heterogeneity WSNs, this set of criteria cannot provide more effective routing.

Hence in this article, a TARE-TOPSIS protocol for CH selection is proposed which considers the node's traffic along with its initial energy and residual energy. This protocol provides the method for selecting CH in a multi-heterogeneity scenario like energy and traffic heterogeneities. It considers nodes' initial energy, residual energy, traffic load along with the average energy consumption of the network during CH selection. The probability of becoming CH for a node during each round is formulated based on criteria in RE-TOPSIS with a traffic heterogeneity factor. Thus, the network lifetime is increased and the energy consumption is reduced efficiently.

The rest of the article is structured as follows: Section II discusses the related work on protocols for energy-efficient CH election in WSNs. Section III discusses the suggested TARE-TOPSIS protocol mechanism. Section IV presents the simulation outcomes of the TARE-TOPSIS protocol compared to the state-of-the-art protocols. The research work is completed in Section V.

II. LITERATURE SURVEY

El Alami & Najid [4] proposed a Stable Election using three Fuzzy Parameters (SEFP) to increase the network lifetime and stability time. This method was focused only on three fuzzy parameters like the remaining power of nodes, distance to the BS and the total of nearness between two nodes. But, this method does not consider the sink distance from each cluster and reliability as a significant parameter. Lee & Kao [5] proposed a semi-distributed clustering method by considering a hybrid of centralized gridding for the upper-level CH selection and distributed clustering for the lower-level CH selection. But, this method has no reliability and integrity for choosing CH to deliver the data.

Saidu et al. [6] proposed an enhanced cluster-based routing algorithm by considering the remaining power of nodes in the network when maintaining the optimal number of CHs throughout the network lifetime. The network was split into the optimal number of clusters with CH. At each cycle, each CH chooses the node with the highest remaining power in the cluster as vice CH. The CH switches the vice CH to sleep for the current cycle and the vice CH becomes the CH in the consecutive cycle.

However, it considers only the residual power of the nodes whereas the other significant parameters were not taken into account for the CH election.

Khan et al. [7] proposed a Fuzzy-TOPSIS method based on the multiple criteria decision making for selecting CH and maximizing the network lifetime. Five criteria were considered such as residual power, power consumption, amount of neighboring nodes, the mean distance between adjacent nodes and distance from the sink.

A threshold-based intra-cluster and inter-cluster multi-hop transmission schemes were utilized for minimizing power consumption. Moreover, predictable mobility with an octagonal trajectory was projected for improving the accurate traffic allocation and reducing the mean latency based on the time-critical applications in WSNs. However, an improvement was needed to further enhance the ability to deal with fuzziness in this method.

Vançin & Erdem [8] proposed a Threshold Balanced Sampled Distributed Energy Efficient Clustering (TBSDEEC) protocol.

In this protocol, a balanced rate named Threshold Balanced Sample Energy (TBSE) was proposed and contributed to the computation of the threshold value. The threshold value was changed and the CH election was made quickly to reduce the energy consumption. However, the average latency was still high.

Haseeb et al. [9] proposed a Reliable Cluster-based Energy-aware Routing (RCER) protocol to improve the network lifetime and reduce the routing cost. Initially, the network was split into the geographical clusters for creating the network more power-efficient. Then, RCER was applied as optimum routing to improve the next-hop election by accounting the remaining power, hop-count and weighted value of Round Trip Time (RTT). Also, the routing paths were adjusted based on the network measurements to support the network reliability. However, route lifetime and average network throughput were less.

Hamzah et al. [10] proposed the Fuzzy Logic-based Energy-Efficient Clustering for WSNs based on the minimum partition Distance (FL-EEC/D) enforcement between CHs.

In this protocol, the Gini index was considered for measuring the clustering algorithm's energy efficiency in terms of their ability to balance the allocation of power via sensor nodes. At last, the locality suitability was computed through the mean of the local consumed power for the adjacent nodes. However, the other significant parameters such as traffic, delay, etc., were not considered during the CH election.

III. PROPOSED METHODOLOGY

In this section, the TARE-TOPSIS protocol for the CH selection technique in a multi-heterogeneity scenario is briefly explained. The sensor nodes will be new and unused while the WSN is being set up for the first time; thus, have initial values for the respective parameters used to pick CHs. At first, only the distances from the sink node allocate CH status. Just 5-10% of the nodes will become CHs while using the LEACH protocol. In this technique, the sensor nodes including the CHs must activate from the initialization after a time interval T for having different CH selection criteria values.

The following attributes can be used to assess the understanding of factors such as energy and traffic preservation and network reliability:

- Node's initial energy (F_1)
- Remaining energy (F_2)
- Average distance between neighboring nodes (F_3)
- Distance between the sink and CHs (F_4)
- Average energy consumption (dissipation) rate (F_5)
- Availability of adjacent nodes (F_6)
- Traffic load i.e., packet length (F_7)

Consider the TARE-TOPSIS protocol with N heterogeneous nodes uniformly distributed in a communication region ($R \times R$). The BS or sink is placed at the centre of the region and all the nodes are within a range of distance d_0 from the BS. The nodes transmit their information to their respective CH which aggregates the member node's information and transmits the aggregated information to the BS. The initial energies of the nodes are randomly distributed over $[E_0, E_0(1 + \alpha_{eh})]$ for representing a realistic energy heterogeneous scenario, where E_0 denotes the lower bound and α_{eh} denotes the energy heterogeneity factor that controls the upper bound. The overall initial energy of the network is denoted by,

$$E_{To} = \sum_{i=1}^N E_0(1 + \alpha_{eh_i}) \quad (1)$$

In Eq. (1), α_{eh_i} represents the energy heterogeneity factor for node i. Moreover, the packet length of the node i with the traffic heterogeneity factor α_{th_i} for supporting heterogeneous in terms of traffic is provided by $m_i = m_0(1 + \alpha_{th_i})$ which is randomly distributed over $[m_0, m_0(1 + \alpha_{th})]$, where m_0 denotes the lower bound and α_{th} denotes the traffic heterogeneity factor that controls the upper bound. It is supposed to meet the requirements for bandwidth to allow such heterogeneity.

For uniformly distributed nodes, the mean distance between the cluster member nodes and the CH (d_{toCH}) and the mean distance between the CHs and the BS (d_{toBS}) are represented by,

$$d_{toCH} = \frac{R}{\sqrt{2\pi k}} \quad (2)$$

$$d_{toBS} = 0.765 \frac{R}{2} \quad (3)$$

In Eq. (2), k denotes the number of clusters. The total energy dissipated in one round is given by,

$$E_{Round} = k \left(E_{CH} + \left(\frac{N}{k} - 1 \right) E_{non-CH} \right) \quad (4)$$

In Eq. (4), E_{CH} and E_{non-CH} denote the energies dissipated in a CH node and a non-CH node, respectively. The power dissipated in N non-CH nodes in a round is as:

$$\begin{aligned} N \cdot E_{non-CH} &= \sum_{i=1}^N (m_i \cdot E_{ele} + m_i \cdot \epsilon_{fs} \cdot d_{toCH}^2) \\ &= m_0 (E_{ele} + \epsilon_{fs} \cdot d_{toCH}^2) (N + \sum_{i=1}^N \alpha_{th_i}) \end{aligned} \quad (5)$$

Where E_{ele} denotes the electronic circuit's per bit energy dissipation of the transmitter or the receiver and ϵ_{fs} denotes the per bit energy dissipation in the transmitter amplifier. By considering (2), (5) and $\alpha_{Tot} = \sum_{i=1}^N \alpha_{th_i}$,

$$N \cdot E_{non-CH} = m_0 \left(E_{ele} + \epsilon_{fs} \frac{R^2}{2\pi k} \right) (N + \alpha_{Tot}) \quad (6)$$

Considering the CH aggregated data which is transmitted from any CH to the BS is $m_{max} = m_0(1 + \alpha_{th})$ bits long. The power dissipated in the k CH nodes in one round in delivering N - k member nodes information, aggregating the data and transmitting k CHs information to the BS is given by,

$$\begin{aligned} k \cdot E_{CH} &= \sum_{i=1}^{N-k} (m_i \cdot E_{ele}) + \sum_{i=1}^N (m_i \cdot E_{DA}) + \sum_{i=N-k}^N (m_{max} \cdot E_{ele} + \\ & \quad m_{max} \cdot \epsilon_{fs} \cdot d_{toBS}^2) \end{aligned} \quad (7)$$

In Eq. (7), E_{DA} denotes per bit energy spent in data aggregation. Considering $\sum_{i=1}^{N-k} \alpha_{th_i} \approx \frac{N-k}{N} \sum_{i=1}^N \alpha_{th_i} \approx \frac{N-k}{N} \alpha_{Tot}$,

$$\begin{aligned} k \cdot E_{CH} &= \frac{N-k}{N} m_0 (N + \alpha_{Tot}) E_{ele} + m_0 (N + \alpha_{Tot}) E_{DA} + \\ & \quad k \cdot m_0 (1 + \alpha_{th}) E_{ele} + k \cdot m_0 (1 + \alpha_{th}) \epsilon_{fs} \cdot d_{toBS}^2 + \\ & \quad m_0 (N + \alpha_{Tot}) \left(E_{ele} + \epsilon_{fs} \frac{R^2}{2\pi k} \right) \end{aligned} \quad (8)$$

Also, the average energy of the round (r) is as:

$$E_{Avg}(r) = \frac{1}{N} E_{Tot} \left(1 - \frac{r}{R} \right); R = \frac{E_{Tot}}{E_{Round}} \quad (9)$$

In Eq. (9), R stands for the estimated value of network lifespan in terms of the number of rounds based on uniform energy drainage in each round. Initially, F_3 and F_6 in the Hello packets are unfilled as they do not have any relevant information.

Once the node-ID and location meta-data are distributed with their adjacent nodes, each node can pervasively compute the considered metrics and exchange them with the successive Hello packets. The member nodes within the vicinity of a cluster will receive the subsequent Hello packets with the updated data. After acknowledging Hello packets from adjacent nodes, a sensor node revises its neighborhood table with the neighboring node’s ID. Based on this, a decision matrix using seven attributes i.e., $F_1 - F_7$ is formed as:

$$F_k = \begin{bmatrix} \varphi_{1,1} & \varphi_{1,2} & \varphi_{1,3} & \varphi_{1,4} & \varphi_{1,5} & \varphi_{1,6} & \varphi_{1,7} \\ \varphi_{2,1} & \varphi_{2,2} & \varphi_{2,3} & \varphi_{2,4} & \varphi_{2,5} & \varphi_{2,6} & \varphi_{2,7} \\ & & & \vdots & & & \\ \varphi_{n,1} & \varphi_{n,2} & \varphi_{n,3} & \varphi_{n,4} & \varphi_{n,5} & \varphi_{n,6} & \varphi_{n,7} \end{bmatrix} \quad (10)$$

These values are converted into fuzzy values by utilizing the fuzzy membership functions as shown in Table 1.

Table.1 Membership Functions using Fuzzy Values

Rank	Membership Function
Extremely Low (EL)	(0.00,0.10,0.15,0.20)
Low (L)	(0.15,0.20,0.25,0.30)
Average (A)	(0.25,0.30,0.45,0.60)
High (H)	(0.45,0.60,0.75,0.80)
Extremely High (EH)	(0.75,0.80,0.90,1.00)

RE-TOPSIS Process:

- By using the decision matrix, the normalized decision matrix is constructed which gives the relative information and computed as:

$$R_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (11)$$

In Eq. (11), $i = 1, 2, \dots, m; j = 1, 2, \dots, n$, where m is the alternatives and n is the attributes.

- Filtering is performed for which a weighted decision matrix (D_k) is designed by multiplying each element of the normalized matrix by a random weight. The weighted decision matrix is formed by multiplying each element of the normalized decision matrix by a random weight matrix D_k i.e.,

$$D_k = D_{ij} = W_j \times R_{ij} \quad (12)$$

This can be rewritten as:

$$D_k = \begin{bmatrix} X_{1,1} & X_{1,2} & X_{1,3} & X_{1,4} & X_{1,5} & X_{1,6} & X_{1,7} \\ X_{2,1} & X_{2,2} & X_{2,3} & X_{2,4} & X_{2,5} & X_{2,6} & X_{2,7} \\ & & & \vdots & & & \\ X_{n,1} & X_{n,2} & X_{n,3} & X_{n,4} & X_{n,5} & X_{n,6} & X_{n,7} \end{bmatrix} \quad (13)$$

- The alternative is identified based on the optimal distance between Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) as follows:

$$PIS = (X_1^+, X_2^+, \dots, X_n^+) = [(max_i X_{ij} | i = 1, \dots, m, j = 1, \dots, n) \quad (14)$$

$$NIS = (X_1^-, X_2^-, \dots, X_n^-) = [(min_i X_{ij} | i = 1, \dots, m, j = 1, \dots, n) \quad (15)$$

Where X^+ is related to the valuable attributes in a column matrix and X^- is related to the non-valuable attributes in the column matrix. On the other hand, the optimal distance from the PIS and the maximal distance from the NIS can create the most appropriate solution.

- Distances are computed for each alternative between PIS and NIS as:

$$D_j^+ = \sum_{i=1}^7 \sqrt{\sum_{j=1}^n (X_{ij} - X_j^+)^2} \quad (16)$$

$$D_j^- = \sum_{i=1}^7 \sqrt{\sum_{j=1}^n (X_{ij} - X_j^-)^2} \quad (17)$$

- Then, the Rank Index (RI) is computed as:

$$RI = \frac{D_j^-}{D_j^+ + D_j^-} \quad (18)$$

The node with the highest RI value transmits its status as the CH in that area. Other nodes within the region with the minimum distances transmit joint requests to the closet CH and act as member nodes of that cluster. The CH receives joint request messages from the adjacent nodes and acknowledges all of its member nodes. Regarding this, the whole network is heterogeneously split into several clusters and internally, the member node with the highest remaining energy and the lowest traffic load is chosen as the CH. This process goes on successively and CHs are hence selected by clusters. Once clusters are created with CHs, all member nodes in each cluster start independent data transfer with their corresponding CHs. Thus, both energy and traffic heterogeneity in WSN routing is efficiently solved to increase the network lifespan and energy efficiency.

IV. SIMULATION RESULTS

In this section, the performance of the TARE-TOPSIS protocol is evaluated and compared with the RE-TOPSIS and LEACH protocols by using Network Simulator (NS2.35). The comparison analysis is prepared in terms of network lifespan, average energy consumption, network throughput and PDR. The simulation parameters are given in Table 1.



Table.1 Simulation Parameters

Parameters	Value
Simulation area	100×100m ²
Number of nodes	100
Sink position	(50,50)
Initial energy	0.5J
Transmission range	20m
Packet size	500bytes
Hello packet size	25bytes
Aggregation energy consumption	50pJ/bit
Transmission energy	100nJ/bit
Reception energy	50nJ/bit
Transmitter amplifier energy	100pJ/bit/m ²

4.1 Network Lifespan

It refers to the maximum time taken from the start of the operation till the last node dies.

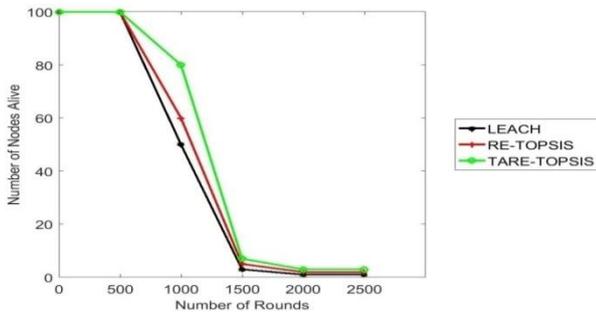


Figure.1 Number of Nodes Alive vs. Number of Rounds

Figure 1 shows the network lifespan (in terms of the number of nodes alive) of TARE-TOPSIS, RE-TOPSIS and LEACH protocols with the number of rounds. It shows that the number of rounds is 1000, the number of nodes alive of TARE-TOPSIS is 80 whereas the number of nodes alive for RE-TOPSIS and LEACH protocols is 60 and 50, respectively which is less than the TARE-TOPSIS protocol. Thus, it is proved that the TARE-TOPSIS achieves maximum network lifespan than the LEACH and RE-TOPSIS protocols.

4.2 Average Energy Consumption

It defines the total amount of energy dissipated by the network during data transmission and computed by (9).

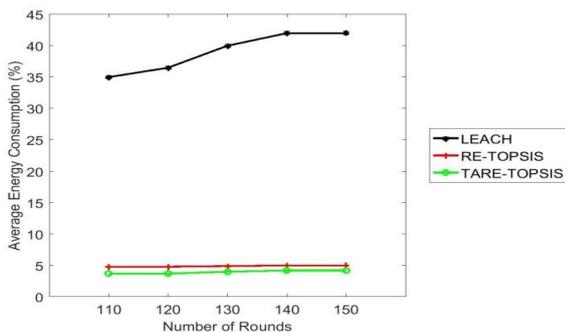


Figure.2 Average Energy Consumption vs. Number of Rounds

Figure 2 shows the average energy consumption (in terms of %) of TARE-TOPSIS, RE-TOPSIS and LEACH protocols with the number of rounds. It shows that the number of rounds is 110, the average energy consumption of TARE-TOPSIS is 22.92% less than RE-TOPSIS and 89.43% less than LEACH protocols. Thus, it is proved that the TARE-TOPSIS achieves minimum energy consumption than the LEACH and RE-TOPSIS protocols.

4.3 Throughput

It refers to the number of bits delivered to the BS within a given interval.

$$\text{Throughput} = \frac{\text{Total number of bits delivered to the BS}}{\text{Time period}}$$

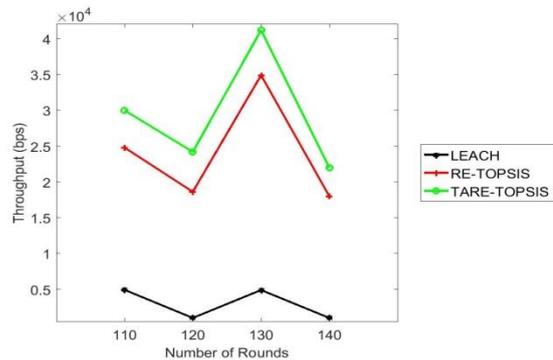


Figure.3 Throughput vs. Number of Rounds

Figure 3 shows the throughput (in terms of bps) of TARE-TOPSIS, RE-TOPSIS and LEACH protocols with the number of rounds. It shows that the number of rounds is 130, the throughput of TARE-TOPSIS is 42000bps which is higher than RE-TOPSIS and LEACH protocols whose throughput values are 34900bps and 4900bps, respectively. Thus, it is proved that the TARE-TOPSIS achieves higher throughput than the LEACH and RE-TOPSIS protocols.

4.4 Packet Delivery Ratio

It defines the percentage of the sum amount of packets delivered to the sum amount of packets sent via the wireless channel.

$$PDR = \frac{\text{Sum amount of packets delivered}}{\text{Sum amount of packets sent}}$$

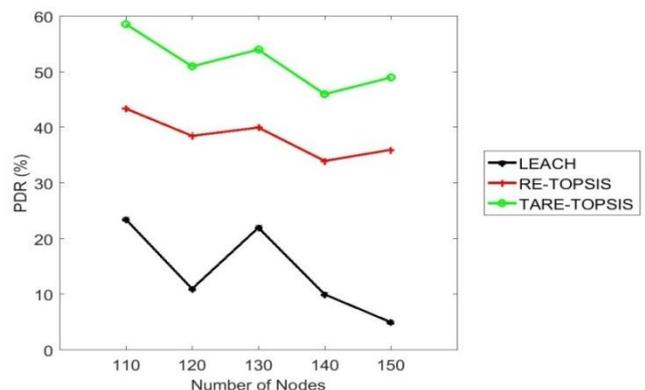


Figure.4 PDR vs. Number of Nodes

Figure 4 shows the PDR (in terms of %) of TARE-TOPSIS, RE-TOPSIS and LEACH protocols with the number of nodes. It shows that the number of nodes is 110, the PDR of TARE-TOPSIS is 58.6% which is higher than RE-TOPSIS and LEACH protocols whose PDR values are 43.4% and 23.5%, respectively. Hence, it is proved that the TARE-TOPSIS achieves higher PDR than the other CH selection protocols.

V. CONCLUSION

A TARE-TOPSIS based CH election protocol is proposed in this article that takes into account the traffic of the node along with its initial energy and residual energy. This protocol provides the method for selecting CH in energy and traffic multi-heterogeneity scenarios. It considers the initial power, residual energy and the traffic load of nodes during CH selection along with the average network energy consumption. The likelihood of becoming CH for a node during each round is formulated with the traffic heterogeneity factor in RE-TOPSIS based on criteria. This increases the lifetime of the network and efficiently reduces energy consumption. Finally, the simulation results show that the proposed technique is superior to the RE-TOPSIS technique in terms of network lifespan, average energy consumption, throughput and PDR.

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