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Enhanced Longevity of MANETs using ACO based Balanced Network Monitoring and Routing Model (BNMR)

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Abstract

Routing for Mobile Ad Hoc Networks is a challenge, as several criteria needs to be considered before selecting the next hop. This paper discusses the issues in MANET and proposes a Balanced Network Monitoring and Routing (BNMR) model that enhances the lifetime of the network by providing balanced selection of nodes during the routing process. The network is clustered and cluster heads are selected, which serve as communication points within the network. The selection of cluster heads and effective transmission of information within the network is performed using modified ACO incorporated with SA to reduce local optima. Cluster monitoring and maintenance modules performs effective load balancing, hence maintaining altruism in the network. Experiments were conducted on 30, 50 and 100 nodes and comparisons performed with FASER indicates that BNMR exhibits 2X times better route selection levels and 26 times faster route selection times. Node usage levels and levels of randomization in the path selection component were also observed to exhibit effective performances.

Keywords: Routing; MANET; Ant colony optimization; Simulated Annealing; Clustering; Altruism; Load balancing

1. INTRODUCTION

Mobile Ad Hoc Networks (MANET) are wireless networks created using independent mobile devices. The mobility associated with them imbibes certain properties in their operational model and performance. This includes dynamic changes in topology, mobility in nodes, resource scarcity due to usage of battery and lack of central control [1]. Nodes in MANETs are not just simple nodes, instead, they are a combination of nodes and routers [2]. Hence all nodes in a MANET require energy for both processing and transmitting their information and also to forward packets from neighbors. Practically, in a MANET, energy spent by a node on routing is higher compared to energy spent for its own packet transmission.

Routing is the process of identifying the next hop to which the packet is to be transmitted for it to reach its destination. Routing protocols are broadly classified into proactive and reactive methods. Proactive methods tend to maintain updated routing tables, while reactive models identify the routes when demand arises [3]. Usual routing models consider distance between nodes as the basic criterion for routing. However, in MANETs, utilizing this criteria alone is not sufficient. Energy being the major constraint of MANETs needs to be considered as the major aspect during the routing process [4].

Nodes in MANET spend their energy for their own transmissions and for forwarding packets from neighbor nodes [4,5]. This results in spending their charge during several instances, not related to their transmissions. Hence, when the energy levels of nodes reduces below a defined threshold, as a backup mechanism the node turns selfish. Selfish nodes avoid packet forwarding and concentrates only on their transmissions. This property keeps the component nodes live, such that lifetime of the network is extended. However, the node does not participate in routing, leading to a route block. Hence routing mechanisms proposed for MANETs should incorporate load balancing such that the nodes do not turn selfish. Further, MANET routing methods must also concentrate in achieving dynamicity and low failure levels such that retransmissions are avoided.

This paper proposes an effective modified ACO based node selection and routing model to incorporate energy efficiency and to provide balanced routing in-order to avoid selfishness in the nodes. This paper modifies the existing ACO model by incorporating Simulated Annealing into its working process to provide a modified ACO node selection technique. The network nodes are clusters and cluster heads are chosen based on the proposed modified ACO technique. Transmissions are performed using the cluster heads, hence enabling lower hop counts and effective energy savings.

2. RELATED WORKS

This section reviews some of the recent contributions in the area of routing in MANET. Discussions are divided into three major sections namely studies dealing with energy efficiency in routing, multi-path routing mechanisms and swarm based routing methods.

A communication framework designed for addressing routing issues and energy drainage issues in MANET was proposed by Joshi et al. in [6]. This model discards the conventional mechanisms of routing, to provide a novel routing protocol that resists routing overhead and features to maximize data delivery probability. Evaluation in terms of routing overhead, packet delivery ratio and energy consumption levels exhibits that this model excels several proactive and reactive routing models. A zone based routing with parallel collision guided broadcasting protocol (ZCG) was proposed by Basurra et al. in [7]. This model performs distributed broadcasting to reduce redundant broadcasting and to accelerate the path discovery process. This mode of operation also aids in reducing the energy consumption levels. A one hop clustering algorithm is used to split the network and cluster based communication is performed. The major downside of this approach is that it utilizes static leaders, leading to high resource depletion in the leader nodes. A similar clustering based routing model E_2FNC was proposed by Sivaraj et al. in [8]. The energy levels are balanced by creating two level clusters. K-means clustering was used for the grouping process. The cluster heads with depleted energy levels are provided with local remedies for energy compensation. An extension to this approach was proposed in [9] and was named ELDCA. This model extends E_2FNC by creating congruent grids and creating clusters at the inner crossing points. ELDCA was extended by incorporating independent neighbor sets in [10], to provide better and enhanced results. A routing model that incorporates quality of the channel, link quality and remnant node energy for routing was proposed by Malathi et al. in [11]. This model has its major aim to ensure reliable communication. An effective algorithm to handle cluster head failures was proposed by Selvi et aln in [12]. This model restricts failures effectively to provide reliable routing.

Scheduled multicast routing mechanism was proposed by Abdulwahid et al. in [13]. Dynamic nature of MANETs proves to be the challenging aspect of routing in MANET. This issue is handled in [13] by proposing a scheduled-links multicast routing protocol (SLMRP). Mobility prediction acts as the major component of this model. A triangle routing mechanism with its major concentration on energy reduction was proposed by Jiang et al. in [14]. The proposed low-overhead reactive routing protocol reduces message redundancies, hence conserving energy. A stochastic multi-path routing model utilizing game theoretic approaches for multipath routing was proposed by Sarkar et al. in [15]. This model is based on the reinforcement learning model to enhance security of the network.

An intelligence based routing model that operates on the basis of interaction between the mobile nodes was proposed by Chavhan et al. in [16]. This model operates on the basis of collaborated group intelligence in the routing process. An ACO based random node selection routing model was proposed by Singh et al. in [17]. This model is based on probabilistic selection of solutions by ants. This model uses the basic ACO model for processing, hence has the issue of getting struck in the local optimal solutions. A similar ACO based on-demand routing technique was proposed by Batt et al. in [18]. This technique uses the basic ACO named ACODeRA to perform routing. Bat algorithm used as a node selection mechanism was proposed by Prabha et al. in [19]. A similar node selection mechanism exhibiting energy efficient routing was proposed by Upendran et al. in [20]. This technique utilizes Firefly algorithm for processing and is evaluated based on selection overhead and node trust levels.

3. BALANCED NETWORK MONITORING AND ROUTING (BNMR)

The proposed ACO based Balanced Network Monitoring and Routing (BNMR) model aims to improve the life-time of the network by maintaining the altruism levels of the network nodes. The process of routing is simplified by clustering the network into independent components and assigning a cluster head node for each of the cluster groups. The cluster heads aid in communication, hence energy levels of cluster nodes are preserved, leading to improved altruism in the network. The cluster head monitoring phase aids in effective replacement of cluster heads at appropriate energy levels. The cluster member maintenance module aids in keeping track of the nodes in a cluster, while the routing tables for cluster heads are maintained by the route table maintenance module. The proposed modules are combined into two major components in the proposed BNMR model, namely; Network Monitoring and Routing modules.

3.1. Network Monitoring

Network formation results in the set of nodes grouping themselves together to form a single entity, thereby enabling communication. Communication within this single group might result in selection of several intermediate nodes, leading to additional data transfer resulting in energy loss. In-order to reduce additional communication overheads, BNMR approach proposes a cluster based communication. The cluster creation module groups the networks into multiple clusters and communications are performed between nodes entitled as cluster heads. No other node in the cluster is provided the additional burden of data transmission. This leads to energy depletion in the node selected as the cluster head. Hence a periodic energy based cluster head modification mechanism has also been proposed to maintain a balanced network. The network monitoring module performs three basic functionalities, which includes; creation of clusters, cluster head selection and cluster monitoring. The operational process of network monitoring is shown in figure 1.

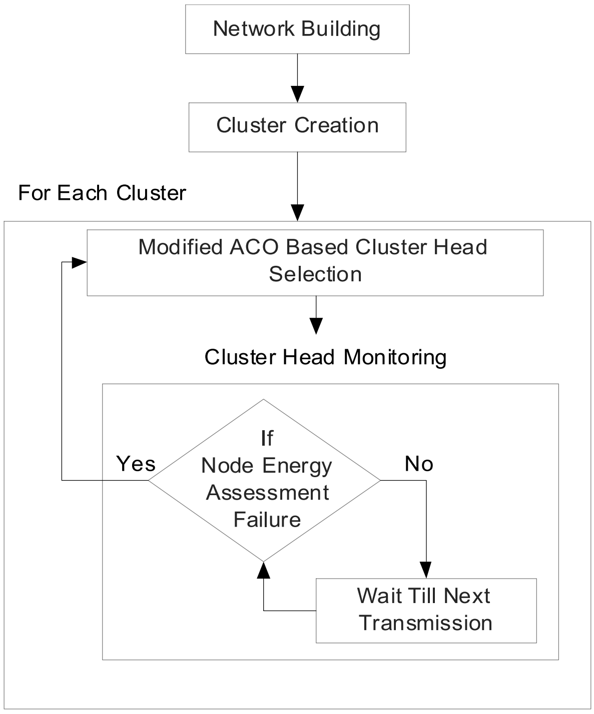

Figure 1: Network Monitoring

3.1.1. Cluster Creation

The cluster creation module aids in grouping nodes in the network so as to aid in faster communication. A sensitivity analysis was performed on networks ranging from 30 to 100 nodes to identify the number of clusters to be created from a network.

Let n be the number of nodes in the network, then the number of proposed clusters k is given by,

$$k = n * 0.15 \qquad (1)$$

The major objective of this module is to minimize the objective function, given by,

$$\arg\min_{c} \sum_{i=1}^{k} \sum_{X \in c_i} \|X - \mu_i\|^2 \qquad (2)$$

Where c_i is the *(x,y)* co-ordinate of node i and μ_i is the mean of points in cluster i.

Initial μ_i is set to k random nodes for each i using the Forgy method [21], and the nodes closest to each of the μ_i nodes is grouped into the cluster c_i, given by,

$$c_i = \{j : d(X_j, \mu_i) \le d(X_j, \mu_l), l \ne i, j = 1, \dots, n\} \qquad (3)$$

Where *d(x,y)* is the Euclidean distance between two points *x* and *y.*

The value of μ_i is modified according to the current nodes in the cluster c_i, and is given by

$$\mu_i = \frac{1}{|c_i|} \sum_{j \in c_i} X_j, \forall i \qquad (4)$$

This process is repeated until the value of μ_i remains unchanged for three consecutive iterations.

3.1.2. Modified ACO based Cluster Head Selection

The next phase selects cluster head nodes for each of the cluster. A cluster head node serves as an entry into the cluster. These nodes takes care of the transmissions by sending and receiving packets inside and between clusters. A node geographically centered in a cluster would be considered a best choice for a head node. However, in MANET, it is also essential to maintain the energy levels of each node, such that no node is completely depleted of its charge. The criterion for a node to be selected as a cluster head is given by

$$CH_i = \begin{cases} 1 & if\ \varepsilon_i > \varphi \\ 0 & Otherwise \end{cases} \quad \forall\ i\ \in n \qquad (5)$$

Where ε_i is the energy level of node *i* and φ is the average charge of the cluster with *m* nodes, and is given by

$$\varphi = \frac{1}{m} \sum_{i=1}^{m} \varepsilon_i \qquad (6)$$

However, several nodes in the cluster can satisfy this criteria, hence an optimal selection mechanism is required for effective selection of the cluster head. Node energy levels and the distance of the node from the cluster end nodes serves as the major criterion for selection of nodes.

This paper proposes a modified Ant Colony Optimization (ACO) model for optimal selection of cluster head from the set of available cluster nodes. ACO is the optimization model proposed by Dorigo et al. in [22, 23]. The major advantage of ACO is its possibility to incorporate multiple criterion in their decision making process. However, it involves probability based decision making, leading to the issue of local optima. This is eliminated by incorporating simulated annealing into the local selection mechanism, hence creating a modified ACO.

The operational process of the proposed modified ACO begins by dispersing the ants on the search space, which composed of the nodes in the cluster. The major objective of ACO is to identify the optimal node exhibiting the highest charge and moderate distance to the end points of the cluster, with higher preference provided to the charge component. The ants begin selecting nodes based on this criteria.

The probability of selecting a node is given by

$$p_{ij}(t) = \frac{[\tau_{ij}(t)]^{\alpha}.[\eta_j]^{\beta}.[\varepsilon_j]^{\gamma}}{\sum_{j=1}^{n}[\tau_{ij}(t)]^{\alpha}.[\eta_j]^{\beta}.[\varepsilon_j]^{\gamma}} \quad (7)$$

where τ_{ij} is the pheromone intensity in the edge ij and η_j is the average distance of the node j from the cluster edge nodes, ε_j is the charge contained in node j, α, β and γ are the weights provided to the pheromone trial, distance measure and charge component respectively.

Completion of a single iteration is marked by every ant selecting an appropriate node as the best candidate. The second level selection is performed by identifying the optimal node from the set of nodes selected by the ants. The proposed model utilizes Simulated Annealing for this process. Simulated Annealing is a metaheuristic optimization technique, proposed by Kirkpatrik et al. in [24], which is a probability based optimization technique used to perform global optimization. The nodes selected by ants in the initial iteration is passed to the Simulated Annealing module to identify the optimal solution.

This process is repeated until the stagnation condition is met. The node obtained after the stagnation is considered as the cluster head. This process is repeated for each of the clusters and their corresponding cluster head nodes are selected. This stage marks the beginning of the transmission process in the network.

3.1.3. Cluster Head Monitoring

Cluster head selection is not a single-time process. In-order to prolong the network's lifetime, it is necessary to maintain sufficient charge in all the nodes. Using a single node as a cluster head leads to faster power depletion in the node [25]. Hence it becomes mandatory to periodically alternate the component nodes as the cluster head. This process is performed by the cluster head monitoring module. A periodic energy assessment of the node is performed and a failure in eq (5) triggers the cluster head selection process.

3.2. Routing

Cluster formation and cluster head selection is followed by data transmissions in the network. On transmission initiation, the packets are constructed and passed to the cluster head, which than determines the next-hop using the entries from its routing table. The operational process of routing is shown in figure 2.

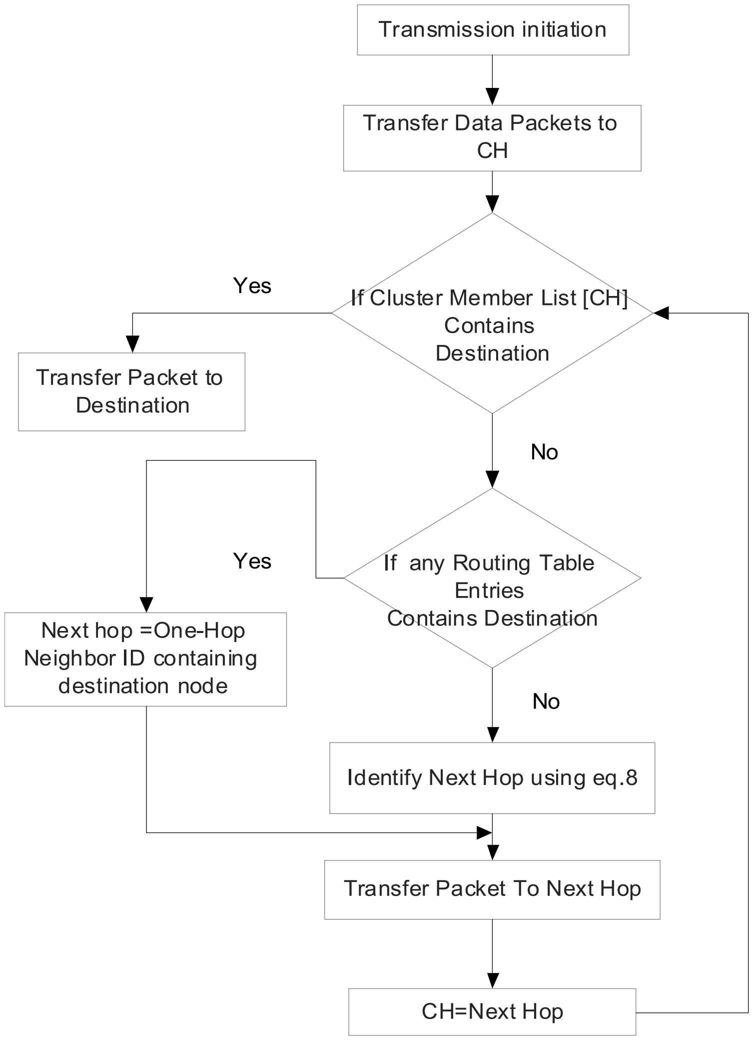

Figure 2: Routing Process

3.2.1. Data Transmission

Data transmission in the network is based on clusters and cluster heads. A transmission initiation, if performed by a node, is directed towards its corresponding cluster head. The required packets are constructed with data and details of destination node, and passed to the cluster head. The cluster head node identifies the destination cluster head node from its routing table and transmits the packets to the next hop. The next hop to which the packet is transferred is a cluster head node. Transmissions are performed within the cluster head nodes until the destination cluster head node is reached. The destination cluster head node then transfers the packet to its corresponding destination node.

A major advantage of the proposed BNMR model is that clustering reduces the transmissions to a huge extent, as only the cluster heads are involved in the transmission process. Hence selection of the next hop is determined by the energy level cluster head node and its distance with the current node. This is given by,

$$NextHop = \max\left(\frac{\varepsilon_j}{d(i,j)}\right) \forall j \in n \wedge j \neq i \quad (8)$$

Where i is the current node, ε_j is the energy level of node j and $d(i,j)$ is the Euclidean distance between nodes i and j.

The next hop selection also becomes an optimization issue due to the involvement of multiple parameters (energy level and distance). This issue is exaggerated if the network is sufficiently large with several cluster heads. Hence the proposed modified ACO utilizing SA as the local optimizer is used for the next hop selection. The proposed routing mechanism is a reactive one-hop routing model, hence every node identifies only its next-hop for transmission. This mechanism deals with effectively handling the dynamicity of MANETs.

3.2.2. Cluster Member Maintenance

Effective routing requires appropriate maintenance of cluster members. This is performed as soon as the cluster is created. After the cluster creation and cluster head selection, the cluster member table is created. This table is maintained by the cluster head and it contains details of the cluster members, with a *CH* (Cluster Head) flag set to 1 for the cluster head. The unstable nature of MANET might lead to movement of certain nodes. Hence periodic heartbeat signals are passed from cluster nodes to the cluster head. These signals ensure the presence of nodes within the range of the cluster. Missing two consecutive heartbeats leads to elimination of the node from the cluster. Change in cluster head is reflected by copying the cluster member table to the cluster head and changing the *CH* flag of the cluster head to 1 and all others to 0.

3.2.3. Routing Table Maintenance

Creation of clusters and selection of cluster heads is followed by creation of the routing table. The usual routing tables in networks maintain details of all the nodes in the network. The proposed BNMR model simplifies this process by maintaining details about only the cluster heads. Transmissions are performed only to the cluster heads. Hence the node selection process is simplified to a large extent. The cluster table stores details about its one-hop neighbor cluster nodes and the component nodes in the cluster. The contents of routing table are shown in figure 3.

Cluster ID	1-Hop Neighbor ID	Energy Level	Location Coordinate	Cluster Member List

Figure 3: Routing Table

Updates within clusters requires modifications in the routing table of all of its 1-hop neighbors. The cluster head monitoring module triggers the route table maintenance module after every cluster head change. A single route table entry broadcast is passed to all its 1-hop neighbor cluster heads enabling appropriate update of cluster entries.

4. RESULTS AND DISCUSSION

The proposed BNMR based routing model is implemented and is compared with FASER [20], a firefly based route selection model. A distance based comparison and time based comparison was performed on a network with 30 nodes.

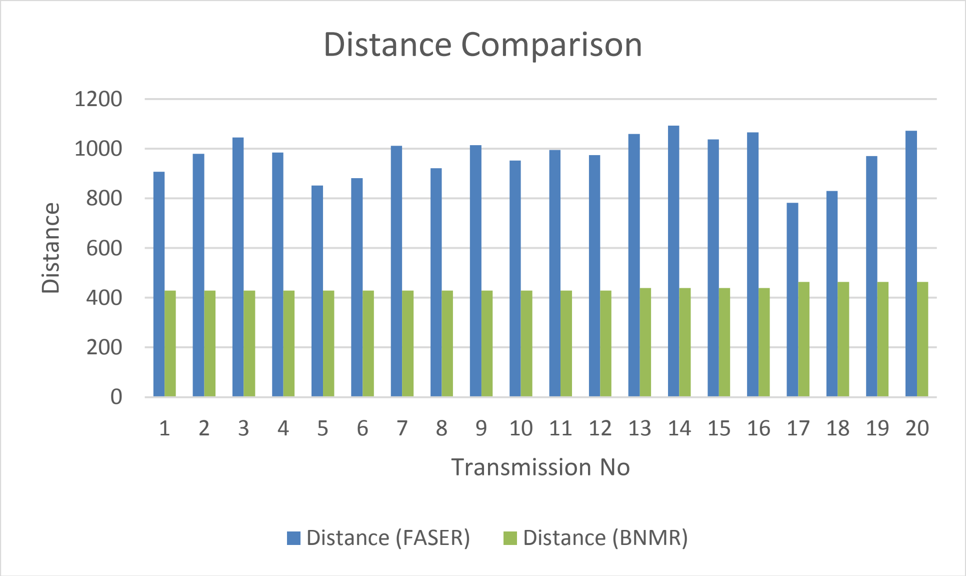

Figure 4: Distance Comparison

Distance comparison is performed by identifying the distance travelled to cover all the nodes in the network and shown in figure. The optimal distance was identified to be 424. It could be observed from the figure 4 that the proposed BNMR based routing model performs effectively, with distance levels ranging from 428 to 464, while FASER exhibits very high distance levels ranging from 782 to 1066. Very low variance level from the optimal results makes the proposed model most effective in terms of route identification.

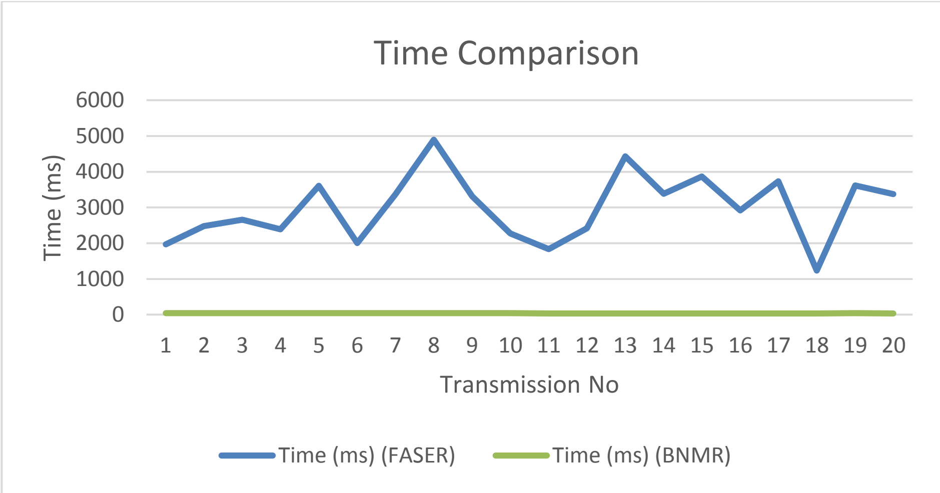

Figure 5: Time Comparison

Time taken for identifying the path is measured in terms of milliseconds and the comparison is shown in figure 5. It could be observed that the proposed BNMR based routing model exhibits a time requirement of 31ms to 45ms, while the requirements of FASER ranges from 1200ms to 4800ms. The proposed BNMR model exhibits 26.6 to 106 times faster route detections exhibiting efficiency of the model.

The randomness levels, path and node usage levels are analyzed by using networks with 30, 50 and 100 nodes. The randomness levels exhibited by the proposed model is shown in figure 6. It could be observed that periodic 100% randomness due to the cluster head rotation mechanism. Proceeding which the randomness levels are reduced to zero and spikes up again when the cluster heads are changed.

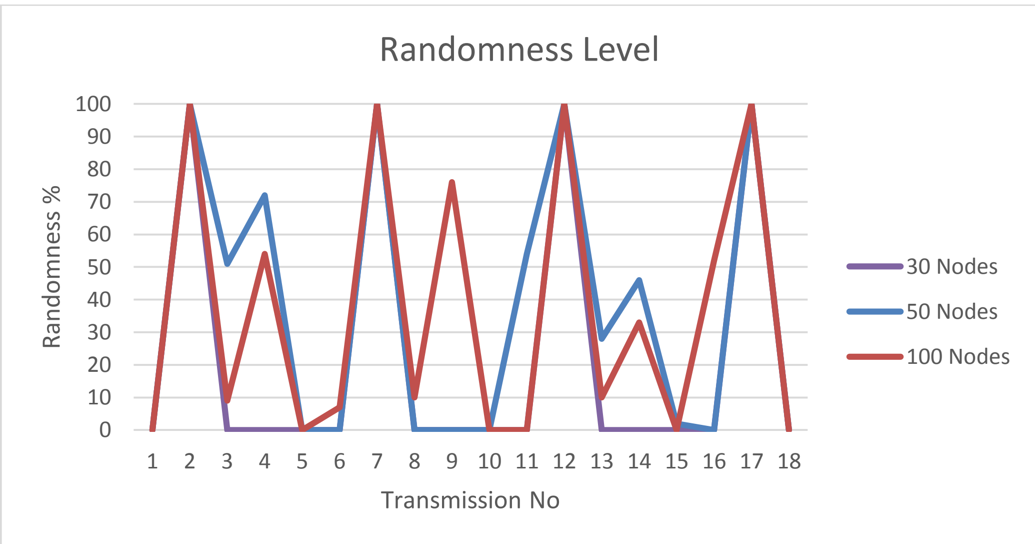

Figure 6: Randomness Level

The path and node usage levels of the proposed BNMR model is shown in figures 7 and 8. It could be observed that for most of the transmissions, the path reuse levels in figure 7 remain low, while certain transactions exhibit spiked reuse levels. Hence it could be concluded that the proposed model exhibits sufficient randomness in the path reuse levels.

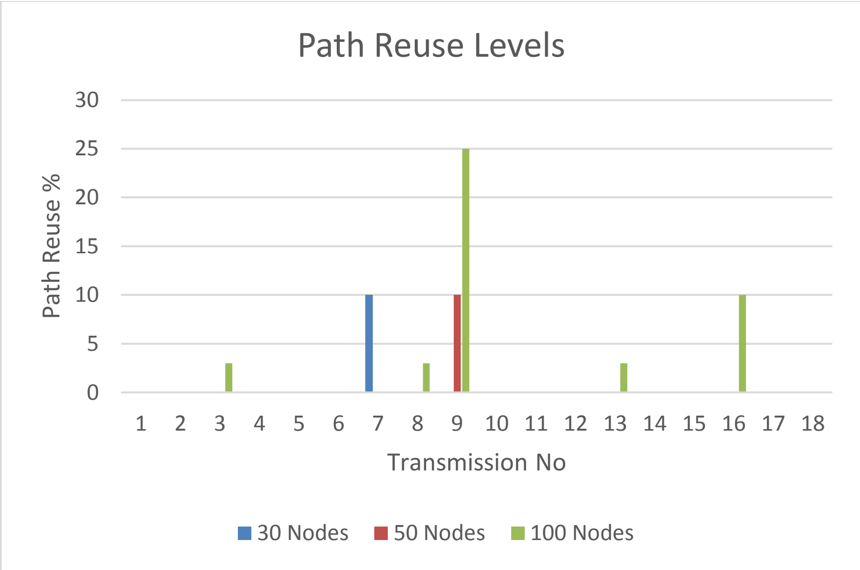

Figure 7: Path Reuse Levels

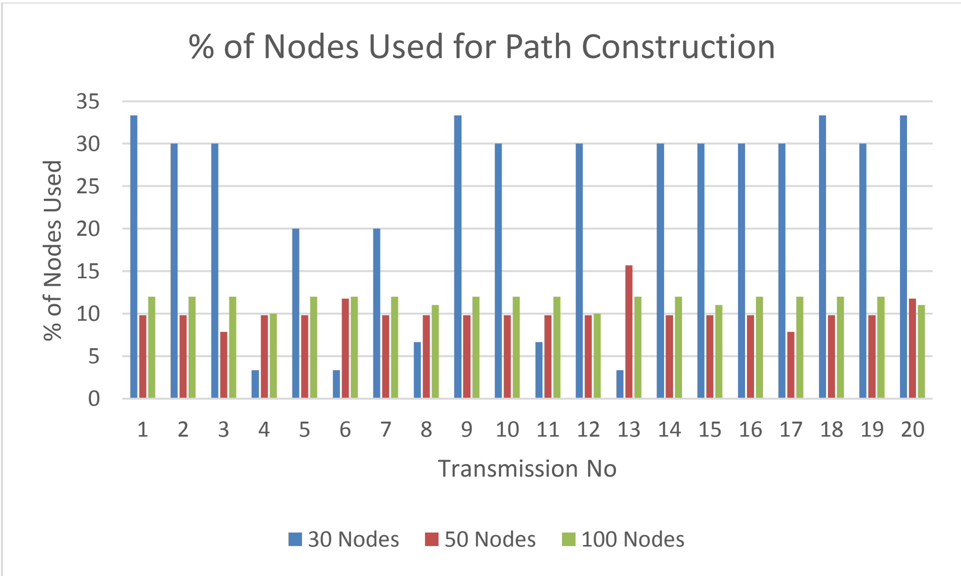

Figure 8: % of Nodes Used for Path Construction

Node usage levels for path construction is shown in figure 8. It could be observed that the network with 30 nodes have the highest usage levels. This is attributed to the low node usage levels, while the network with 50 and 100 nodes exhibit node usage levels ranging from 9% to 13%, exhibiting effective performances.

5. CONCLUSION

Effective network routing and balancing node energy levels is one of the major issues faced by MANETs. This paper proposes an effective swarm intelligence based model BNMR, to effectively perform routing with minimal energy loss. The major advantage of BNMR is that the routing tables are maintained by the cluster heads, which avoids additional storage overhead in the nodes. These routing tables maintain information about the cluster heads alone, hence results in shorter tables. The proposed model is scalable, as only the cluster heads are involved in communication. Even a huge increase in the network size will lead to an addition of a few cluster heads, hence improving the scalability levels of the proposed model. Dynamism in routing is enabled by the reactive routing strategy. Future enhancements of the proposed model can be incorporated by enabling trust based node selection mechanisms, which can effectively reduce retransmission levels.

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