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Metaheuristic Technique for Dynamic and Energy Efficient Routing (METDEER) in MANET

S. Beski Prabaharan, Saira Banu, Monika Sethi

***Abstract** - The Metaheuristic Technique in Mobile Ad-hoc Network (MANET) is an experiment based model for improving lifetime of the MANET. This contribution proposes a Balanced Network Monitoring and Routing-Based on Ant Colony Optimization Technique (BNMR-ACOT) that enhances the lifetime of the network by providing a balanced selection of nodes during the routing process. Experiments were conducted with various parameters – packet delivery ratio, energy consumption of node and total overhead were compared with existing models with BNMR, which exhibits two times better route selection levels and twenty times faster route selection times. Node usage levels and randomization levels in the path selection component were observed to exhibit effective performances.*

***Keywords-** MANET, Packet delivery ratio, Energy consumption, Routing, Network Monitoring, Randomization.*

I. INTRODUCTION

Routing for Mobile Ad Hoc Networks is a challenge as the several criteria need to be considered before selecting the next hop neighbor for effective data dissemination. This contribution discusses the issues in the MANET and proposes a Balanced Network Monitoring and Routing-Based on Ant Colony Optimization Technique (BNMR-ACOT) that enhances the lifetime of the network by providing a 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. To reduce local optima, used modified ACO for the selection of cluster heads and effective transmission of information within the network. Cluster monitoring and maintenance modules perform effective load balancing, hence maintaining altruism in the network.

II. ENHANCED LONGEVITY OF MANETS USING BNMR-ACOT

Balanced Network Monitoring and Routing (BNMR) model is proposed ACO based model aims to improve the lifetime 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 the cluster nodes are preserved, leading to improved altruism in the network.

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***** Correspondence Author
Dr. S. Beski Prabaharan*, Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India
Dr. Saira Banu, Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India
Ms. Monika Sethi, Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India

The cluster head monitoring phase aids in effective replacement of cluster head 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, namely; Network Monitoring and Routing modules.

A. Network Monitoring

Single entity should be formed by the set of nodes grouping themselves together, thereby enabling communication. Energy loss should be occur by communication within this single group might result in selection of several intermediate nodes, leading to additional data transfer. BNMR approach proposes a cluster based communication, in-order to reduce additional communication overheads. 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. Cluster head is selected to reduce energy depletion in all other nodes. To maintain a balanced network, a periodic energy based cluster head modification mechanism has also been proposed. The network monitoring module performs three basic functionalities, which includes; creation of clusters, cluster head selection and cluster monitoring. The operating process of network monitoring is shown in Fig.1.

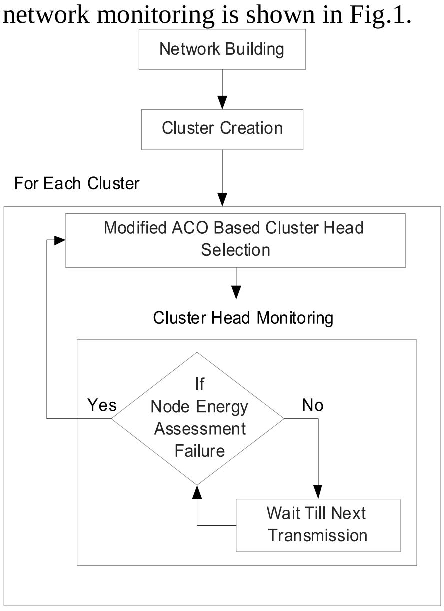

Fig. 1. Network Monitoring Process of BNMR-ACOT

B. Cluster Creation

The cluster creation module aids in groups of 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,

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

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

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

where 'i' is the *(x, y)* coordinates 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 [4], and the nodes closest to each of the μ_i nodes am grouped into the cluster c_i, given by,

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

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

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

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

C. Modified ACO based Cluster Head Selection

The next phase selects cluster head nodes for each of the clusters. To enter into the cluster, a cluster head node serves as an entry. These nodes take care of the transmissions by sending and receiving packets inside and between clusters. A node geographically centered on a cluster would be considered a good choice for a head node. 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

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

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

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

Several nodes in the cluster can satisfy this criterion; 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 section proposes a modified Ant Colony Optimization (ACO) model for optimal selection of cluster head from the set of available cluster nodes.

ACO is the optimal model proposed by Dorigo et al. in [5], [6] and [7]. The major advantage of ACO is, its possibility to incorporate multiple criterion in their decision making process. It involves probability based decision making, leading to the issue of local optima. This is eliminated by including 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 two main 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 these 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 at the edge *in* and j_{ob} 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 trail, distance measure and charge component respectively.

Named a best candidate ant could be selected by completion of a single iteration is marked by every ant. 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 [8], which are the probability based optimization technique used to perform global optimization. The nodes selected by ants in the initial iteration are 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.

D. Cluster Head Monitoring

Cluster head (CH) 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 [9]. Hence it is important that 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 Equation (5) triggers the cluster head selection process.

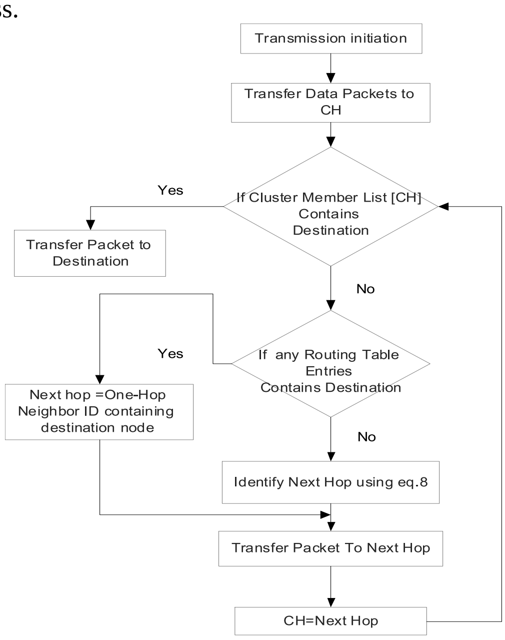

Fig.2. Routing Process for BNMR-ACOT

First, cluster formation and then 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 then determines the next-hop using the entries from its routing table. The operating process of routing is shown in Fig. 2.

E. 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 the 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. 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.

Proposed BNMR model major advantage is that clustering reduces the transmissions to a huge extent, as only the cluster heads are involved in the transmission process. Hence the 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,

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

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

The next hop selection 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. The SA is used as the local optimizer for the next hop selection, which is proposed in modified ACO. 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.

F. 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 leads 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 lead 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.

G. Routing Table Maintenance

Creation of clusters and selection of cluster heads are followed by the creation of the routing table. The usual routing tables in networks, maintain details of all the nodes in the network. By maintaining only details about the cluster heads, the proposed BNMR model simplifies this process. 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 Fig. 3.

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

Fig.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 its entire 1-hop neighbor cluster heads enabling appropriate update of cluster entries.

III. METHODOLOGY

In this section, the overall framework proposed for integrating all the four proposed swarm intelligence-based meta-heuristic schemes are described based on Fig. 4 and Fig. 5 respectively.

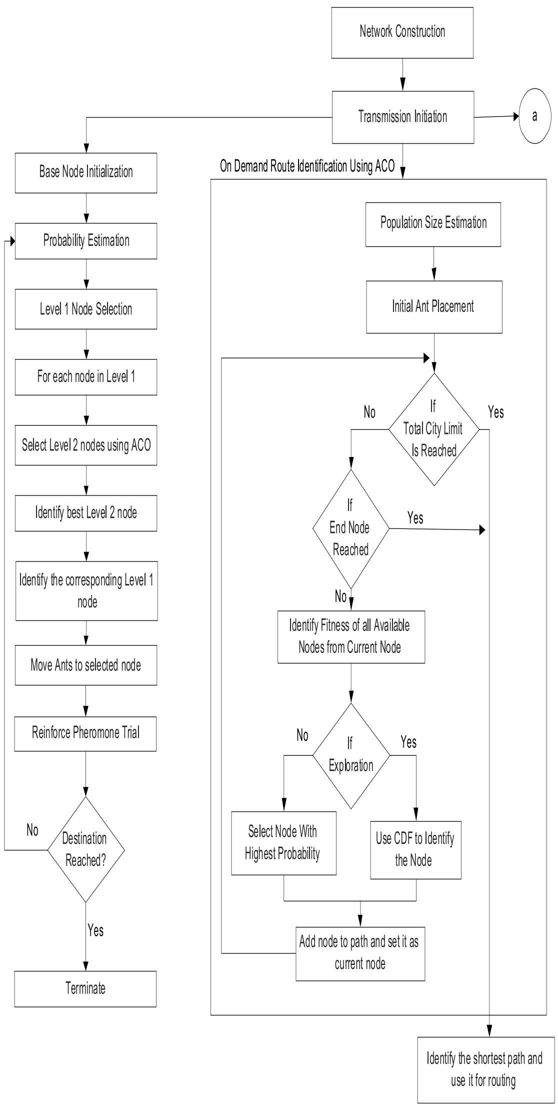

Fig.4. Overall Architecture (Part 1)

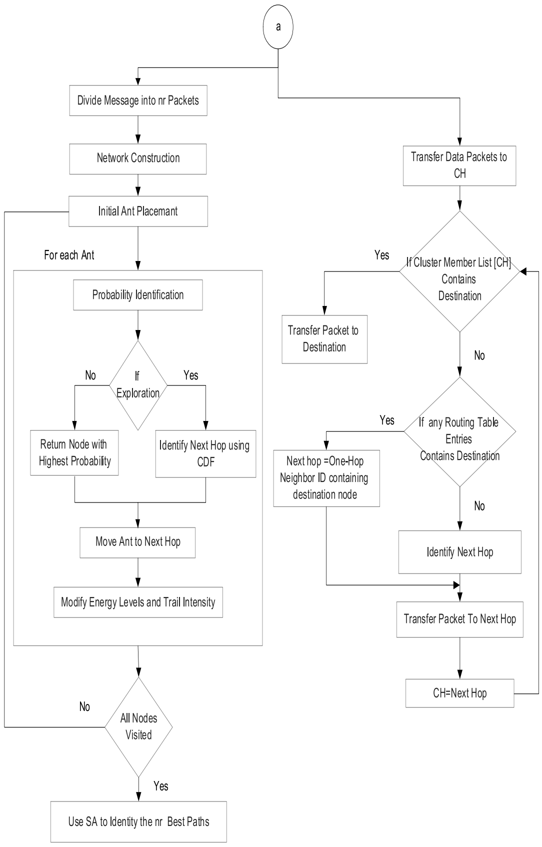

Fig. 5. Overall Architecture (Part 2)

The first and second contributions of the proposed architecture are shown in Fig. 4 and Fig. 5. The initial contribution [1] deals with providing an effective routing model to provide highest trust levels. It employs hybrid ACO in the routing process to perform fast and dynamic node selection. The operating process is modeled such that the best second level node is used to identify the first level node. This makes the selection process more effective and reliable. The second contribution [2] concentrates on energy levels of the node to present an energy aware routing model using ACO. The proposed architecture incorporates an on-demand route selection process, such that the best route is identified only one requirement, rather than a priori path determination. This model of operation makes the proposed model immune towards sudden network traffic and sudden node failures. The third and fourth contributions of the proposed architecture are shown in Fig. 5. The third contribution [3] deals with generating dynamic multipath routes in the routing process using a modified form of ACO.

The proposed model performs route selection based on ACO. Several routes are determined and Simulated Annealing is used to identify the best route from the list of available routes determined by ACO. This enables faster results, hence providing a huge reduction in terms of processing time. The final contribution 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 contribution 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 clustered 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.

IV. SIMULATION RESULTS AND DISCUSSION OF BNMR-ACOT SCHEME

The simulation experiments of the proposed BNMR-ACOT scheme are also conducted using the network simulator (NS-2.34). This simulation setup used for implementing the proposed BNMR-ACOT method comprises of the network terrain area of 1500x1500 with 250 mobile nodes under the random motion in the network. The simulation parameters used for the deployment of the proposed BNMR-ACOT method is tabulated in Table 1.

Table 1- BNMR-ACOT method -Simulation Setup Parameters

Parameter	Value
Mobile nodes	250
Antenna type	Omni Antenna
Mobility model	Random Way Point
Model of Radio Propagation	Two Ray Ground
Traffic model	Constant Bit Rate (CBR)
Time for Simulation	300 secs
Transmission Range	250m
Type of MAC	802.11
Type of Network Interface	Wireless Phy Channel

Initially, the performance of the proposed BNMR-ACOT method is studied using evaluation metrics such as Packet Delivery Ratio (PDR), total overhead and energy consumptions by varying the number of source and destination pairs. Fig. 6 and Fig. 7 unveils the potential plots of PDR and total overhead of the proposed BNMR-ACOT method compared to LS-SA-EA-ACOT, EA-ACOT and THACOS techniques. The PDR of BNMR-ACOT method is identified to be potential over the compared LS-SA-EA-ACOT[3], EA-ACOT[2] and THACOS[1] techniques since they use categorical ordering for classifying the mobile node in the network as benevolent or malicious. Hence, the PDR of BNMR-ACOT method is enhanced by 12%, 16% and 19% predominant to the compared LS-SA-EA-ACOT, EA-ACOT and THACOS techniques. Likewise, the total overhead of the proposed BNMR-ACOT method is estimated to be reduced by an excellent margin of 10%, 12% and 17% optimal to the compared LS-SA-EA-ACOT, EA-ACOT and THACOS techniques.

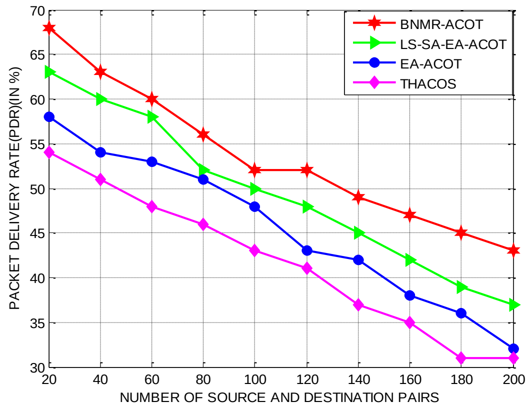

Fig. 6- BNMR-ACOT–PDR-Source and destination pairs

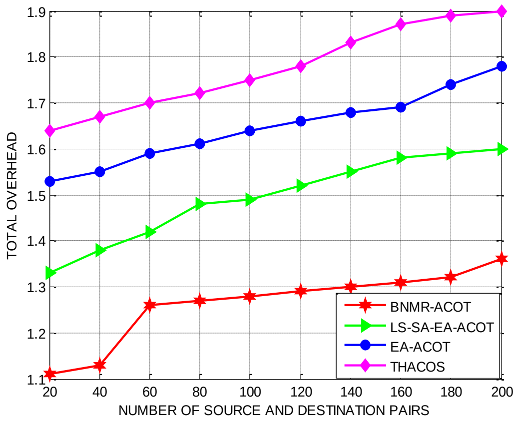

Fig. 7- BNMR-ACOT-Total overhead-Source and destination pairs

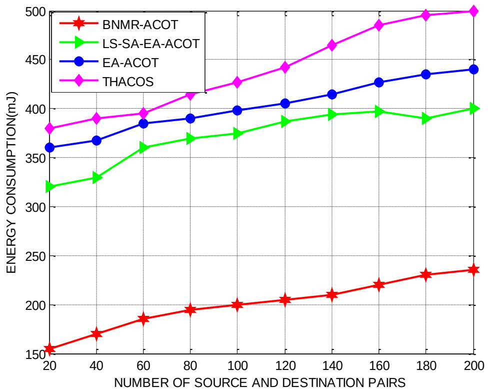

Fig. 8- BNMR-ACOT-energy consumptions-Source and destination pairs

Fig. 8 spotlights the performance BNMR-ACOT mechanism using packet drop rate and energy consumptions evaluated under a different number of malicious adversaries. The packet drop rate and the energy consumptions of the proposed BNMR-ACOT method is superior to the comparable LS-SA-EA-ACOT, EA-ACOT and THACOS techniques since they utilize a balanced factor derived through an adaptive ant colony optimization scheme that is capable of improving the rate of detection by using the concept of
ordering categorical multiple rating factor.

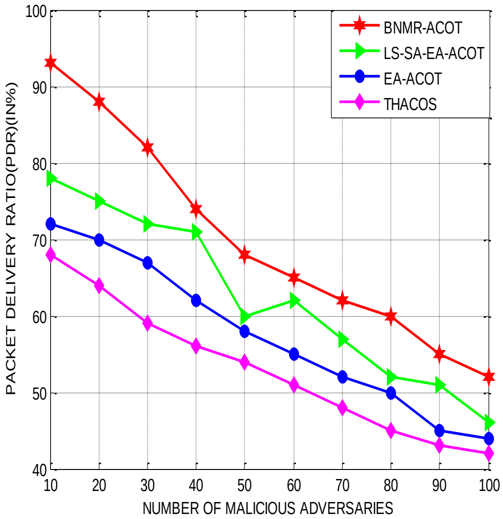

Fig. 9-BNMR-ACOT -PDR-Malicious adversaries

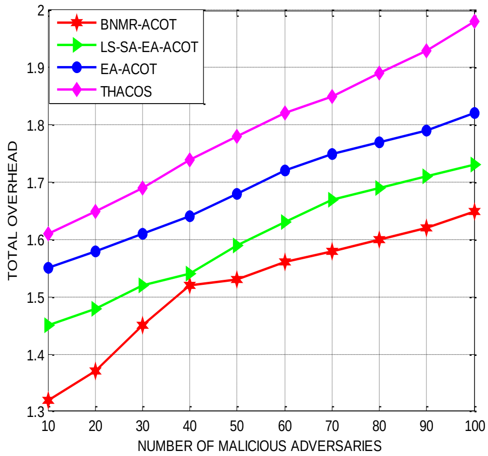

Fig.10-BNMR-ACOT-total overhead-Malicious adversaries

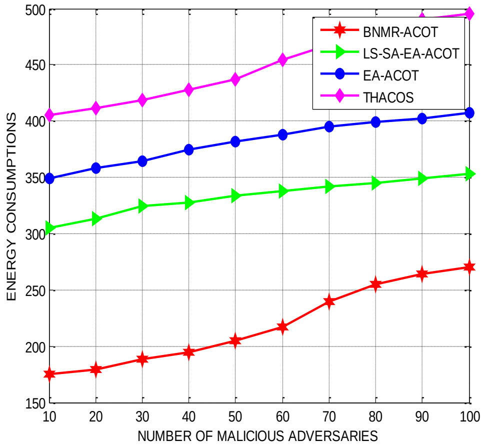

Fig. 11-BNMR-ACOT-energy consumptions-Malicious adversaries

Thus the packet drop rate of BNMR-ACOT method is determined to be minimized by 12%, 16% and 21% compared to LS-SA-EA-ACOT, EA-ACOT and THACOS techniques. Similarly, the energy consumptions of the proposed BNMR-ACOT technique is also inferred to drastically reduced by 10%, 14% and 19% compared to the baseline LS-SA-EA-ACOT , EA-ACOT and THACOS techniques. Furthermore, the suitability of the proposed BNMR-ACOT mechanism is studied using PDR, total overhead and energy consumptions by varying the pause time of simulation. Fig. 9 and Fig. 10 glorifies the performance of BNMR-ACOT method using PDR and total overhead analyzed based on different amounts of pause time. The PDR of BNMR-ACOT mechanism under different pause time is proving to be predominant than the baseline LS-SA-EA-ACOT, EA-ACOT and THACOS techniques since it is potential of sustaining the rate of detection. Thus PDR of BNMR-ACOT mechanism under different pause time is confirmed to be improved by 9%, 11% and 16% compared to the existing LS-SA-EA-ACOT, EA-ACOT and THACOS techniques. The total overhead of BNMR-ACOT is also remarkable by a considerable margin of 12%, 16% and 21% compared to LS-SA-EA-ACOT, EA-ACOT and THACOS techniques. In Fig. 11-BNMR-ACOT-energy consumptions-Malicious adversaries are displayed and in Fig. 12-BNMR-ACOT-PDR-pause time are plotted.

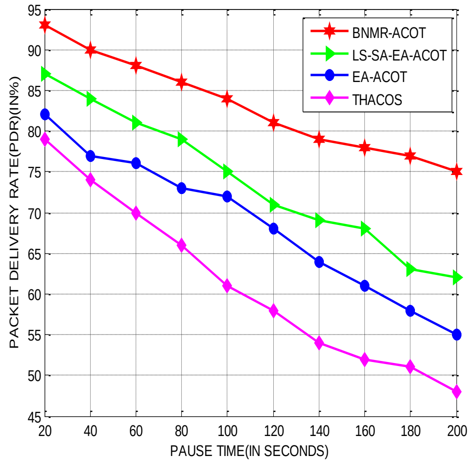

Fig. 12-BNMR-ACOT-PDR-pause time

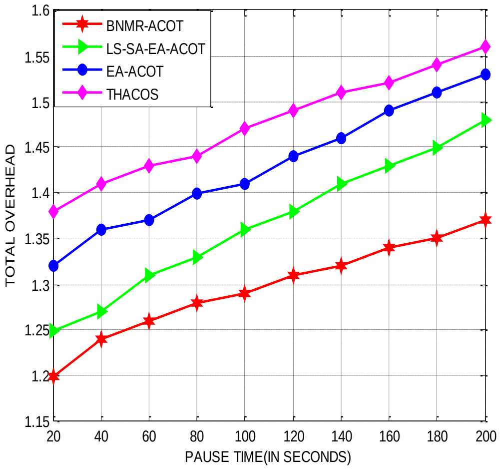

Fig. 13-BNMR-ACOT-total overhead- pause time

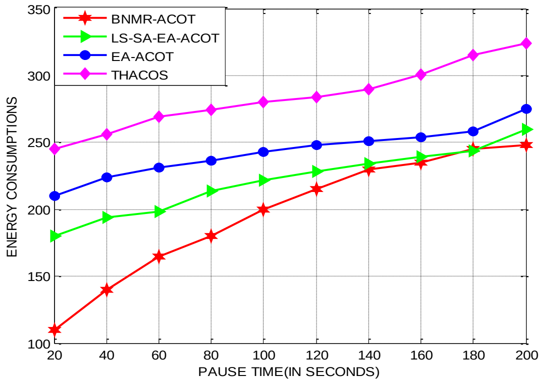

Fig. 14-BNMR-ACOT-energy consumptions-pause time

Likewise, Fig. 13 and Fig. 14 highlights the performance of BNMR-ACOT mechanism using packet drop rate and energy consumptions evaluated under a different pause time. The packet drop rate of BNMR-ACOT method is considerably reduced by 10%, 12% and 15% compared to LS-SA-EA-ACOT, EA-ACOT and THACOS techniques. Similarly, the energy consumptions of the proposed BNMR-ACOT technique is also inferred to drastically reduce by 7%, 10% and 14% better to the compared efficient routing schemes.

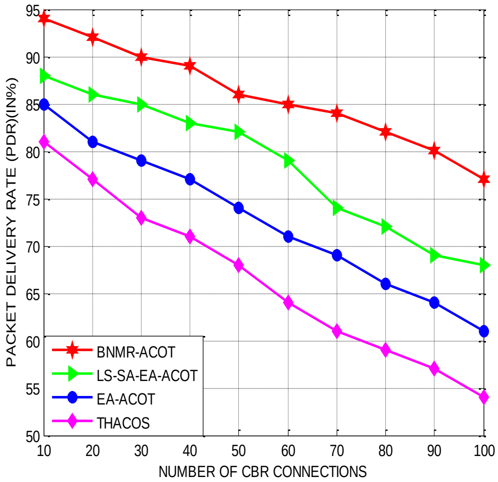

Fig. 15-BNMR-ACOT-PDR-number of CBR connections

Finally, the proposed BNMR-ACOT mechanism is analyzed using PDR, total overhead and energy consumptions by varying the number of CBR connections. Fig. 16 and Fig. 17 highlights the PDR and total overhead plot of BNMR-ACOT method analyzed based on different amounts of CBR connections. The PDR of BNMR-ACOT under different CBR connections is determined to be enhanced by 15%, 19% and 23% compared to the existing LS-SA-EA-ACOT, EA-ACOT and THACOS techniques. The total overhead of BNMR-ACOT is reduced by a degree of 10%, 13% and 18% better to the benchmarked schemes. Also explains the performance of the proposed BNMR-ACOT mechanism using packet drop rate and energy consumptions evaluated under different numbers of CBR connections. The packet drop rate of BNMR-ACOT method is reduced by 8%, 10% and 14% compared to LS-SA-EA-ACOT, EA-ACOT and THACOS techniques. Similarly, the energy consumptions of the proposed BNMR-ACOT technique is also inferred to drastically reduced by 10%, 13% and 16% better to the compared detection schemes.

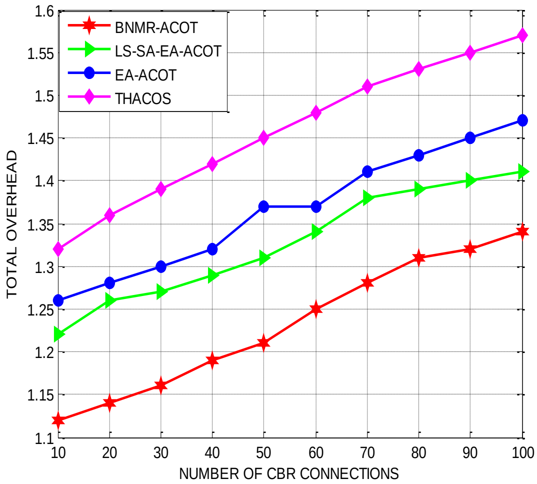

Fig. 16-BNMR-ACOT-total overhead- number of CBR connections

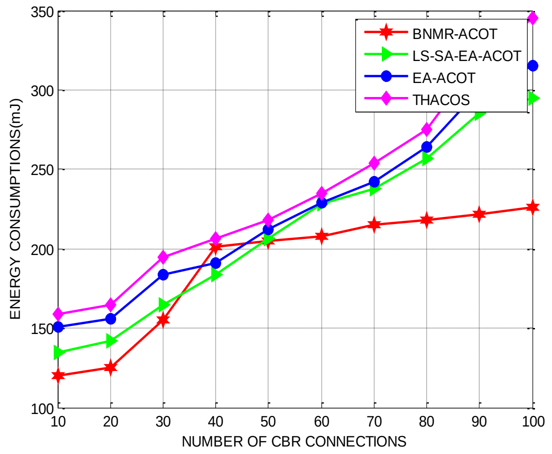

Fig. 17-BNMR-ACOT-energy consumptions- number of CBR connections

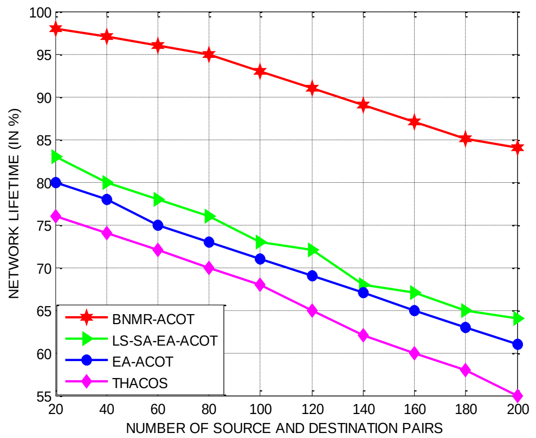

Fig. 18- BNMR-ACOT-Network Lifetime under varying source and destination pairs

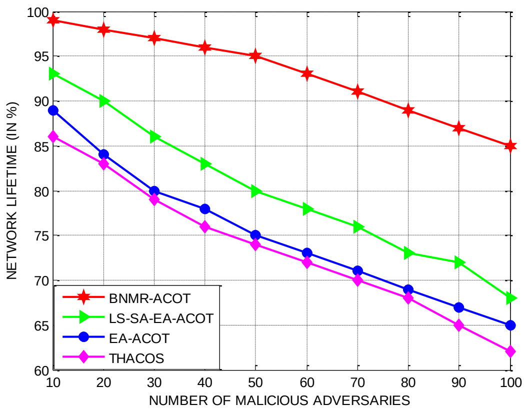

Fig. 19- BNMR-ACOT-Network Lifetime under varying malicious adversaries

Finally, Fig. 18 and Fig. 19 exemplars the predominance of the proposed BNMR-ACOT investigated using network lifetime (in percentage) with the baseline LS-SA-EA-ACOT, EA-ACOT and THACOS approaches under a different number of source and destination pairs and malicious adversaries of the network. The network lifetime of the network of the proposed BNMR-ACOT was improved by 13%, 11% and 9% superior to the baseline LS-SA-EA-ACOT, EA-ACOT and THACOS approaches during its investigation under varying number of source and destination pairs. The network lifetime of the network of the proposed BNMR-ACOT was improved by 16%, 14% and 11% superior to the baseline LS-SA-EA-ACOT, EA-ACOT and THACOS approaches during its investigation under varying number of malicious adversaries. Thus, the network lifetime was estimated to be enhanced independent to the number of malicious adversaries and, source and destination pairs of the network, since they are capable of exploring trustworthy nodes during routing.

V. CONCLUSION

This contribution emphasizes that effective network routing and balancing node energy levels are of the major issues faced by MANETs. It has presented an effective swarm intelligence based BNMR-ACOT model to effectively perform routing with minimal energy loss. The major advantage of BNMR-ACOT model 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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AUTHORS PROFILE

Dr. Beski Prabaharan completed Master of Technology (M.Tech) in Information Technology from Bharathidasan University and Doctor of Philosophy (Ph.D), Bharathiar University, Coimbatore, India.

Currently he is working as Professor (Associate) in the Department of Computer Science and Engineering, Chitkara University, Punjab, India. He has published more than twenty papers in national and International Journals in Wireless Sensor Networking, Mobile Computing and Mobile Ad-hoc Networks.

Dr. Saira Banu Atham (RRN. 1186223) is a native of Chennai, Tamil Nadu, India. She received herB.E., degree in Computer Science and Engineering from Madras University, Chennai. She received her h her M. M.E., degree in Computer Science and Engineering from Anna University, Chennai. She is currently working as an Associate Professor in the R & D Department of Chitkara University, Punjab. She has got 15 years of teaching experience. Her area of Research is VOIP. She has contributed many papers for enhancing the performance of Voice over using the VOIP. Her email id is saira.atham@gmail.com and her contact number is: 91 9884127780.

Ms. Monika Sethi, completed GraduGraduation in Electronics and
Communications Engineering from Institute of Engineers and PG in Computer Science and Engineering from NIT, Hamirpur. She has more than ten years of teaching experiences in the field of Computer Science and Engineering in Chitkara University, Punjab. She did her Post Graduate project in Routing protocols in WSN. Her area of research Interest is in Wireless sensor Network (WSN).