An environment-adaptive distributed node joining approach and a secure cluster-based architecture for MANET

Serin V. Simpson* and G. Nagarajan

Department of Computer Science and Engineering,
Sathyabama Institute of Science and Technology,
Jeppiaar Nagar, Chennai, India
Email: serinsimpson@gmail.com
Email: nagarajanme@yahoo.co.in
*Corresponding author

Abstract: The increased popularity of mobile ad hoc networks (MANETs) is only due to their unique characteristics. It requires highly efficient mechanisms, in order to cope with the dynamically changing topologies. The environmental changes in turn increase the complexities of algorithms used to maintain the topology. A keen analysis of network scenarios is required to maintain a balanced network in all aspects. A centralised monitoring system can address this issue up to a tolerable level. But, that in turn increases the risk of one point failure as well as the problems due to unavailability. The main goal of this work is to propose a secure, environment-adaptive distributed node joining approach for MANET. It uses a cluster-based network model. This approach reduces the risk factors at the time of node joining as well as it can maintain the network in a balanced manner. The aim of this work is mainly focused on the problems of the MANET due to the dynamically changing topologies.

Keywords: MANET; environment-adaptive distributed clustering technique; EDCT; cluster-based architecture; secure routing; node joining algorithm.

Reference to this paper should be made as follows: Simpson, S.V. and Nagarajan, G. (2022) ‘An environment-adaptive distributed node joining approach and a secure cluster-based architecture for MANET’, *Int. J. Enterprise Network Management*, Vol. 13, No. 1, pp.3–18.

Biographical notes: Serin V. Simpson received his BTech in Information Technology from University of Calicut in 2012. He received his MTech in Computer Science and Engineering from University of Calicut in 2015. Currently, he is doing his PhD Program in Computer Science and Engineering in Sathyabama Institute of Science and Technology. His research areas are wireless communications and computer networks. He has one year of industrial experience and five years of teaching experience. Currently, he is working as an Assistant Professor in the Department of Computer Science and Engineering in Thejus Engineering College, affiliated to APJ Abdul Kalam Technological University. He has published papers in the research areas of mobile ad hoc networks, network security and cluster-based communication.

G. Nagarajan received his Diploma in Electronic and Communication Engineering from Directorate of Technical Education in 1997. He received his BE in Electrical and Electronic Engineering from Manonmaniam Sundaranar University in 2000. He received his ME in Applied Electronic Engineering from Anna University in 2005. He also received his ME in Computer Science

Engineering from Sathyabama Institute of Science and Technology in 2007. He obtained his PhD in Computer Science Engineering from Sathyabama Institute of Science and Technology in 2015. He has 19 year of teaching experience. Currently, he is working as a Professor in Department of CSE in Sathyabama Institute of Science and Technology. He has published more than 40 papers in the research area of wireless sensor network.

1 Introduction

Mobile ad hoc network (MANET) is always vulnerable to attacks. It had been designed without considering any security in mind. It was developed to satisfy the communication needs. After getting enough popularity, attackers found the beneficiary area inside MANET. Today, the main challenge that the developer faces is the security issues related to the developed protocols. This paper address only the one point failure attack on MANET and the proposed method mainly focused on the communication scenarios happening in the network. This paper proposes a clustering approach. The clustering process in turn increases the distributed nature of MANET. The most challenging task in a cluster-based communication is the proper maintenance of communication. All communication in a clustered network can happen only in the controlled manner. In the clustered architecture, it is easy to utilise the communication link among the cluster head (CH) nodes for the fastest discovery of nodes. That will increase the communication speed in a tremendous manner.

A sudden collapse of a single cluster may affect the entire network. It is possible to reduce such chances by proper cluster maintenance. It is not possible to predict the existence of any node in the network due to mobility. A stable node may lose the connectivity due to the mobility of another node. Thus, it is really hard to maintain a communication without any interruptions. It is possible to manage the communication only with the help of some stable communication entities. The proposed method makes use of the nodes situated at the intersecting areas of more than two clusters for managing the communication. Such nodes will have more stable connectivity than other nodes. Only those nodes can withstand from an immediate collapse of the cluster. This proposed framework makes use of a set of possible methods for improving the performance of the network (Popli and Garg, 2016; Kulkarni and Yuvaraju, 2015; Li and Yang, 2015; Zhou and Zhang, 2015; Mehta and Kashyap, 2017; Rekha and Muthukumarasamy, 2016; Yang and Li, 2015; Devarajan and Padmathilagam, 2015; Ali and Salim, 2015; Alinci and Spaho, 2015; AlMheiri and AlQamzi, 2015; Gomathi and Parvathavarthini, 2015; Guizani et al., 2015; Gavhale and Pranay, 2015; Kaur and Singh, 2015; Sreevatsan and Thomas, 2016; Piyalikar and Kar, 2016; Ma, 2011; Liu et al., 2013; Selvakumar and Seethalakshmi, 2018; Murthy and Manoj, 2007; Simpson and John, 2015; John and Samuel, 2017; Ahamed et al., 2017; Lalitha and Devi, 2014).

2 Related work

Aftab and Zhang (2017) have proposed a self-organising-based clustering in MANET using zone-based group mobility. This paper proposes bio-inspired clustering architecture based on bird flocking. The clustering scheme is self-organised and it uses zone-based group mobility. The method increases the stability and scalability of the network (Aftab and Zhang, 2017).

Drugan and Plagemann (2014) proposed a dynamic clustering scheme for sparse MANET. This work gives a solution towards the lack of dynamic nature of existing networks. The proposed clustering technique helps to adapt the existing network towards a high responsive network whenever it needs. It works even without the presence of CH. The nodes extract the topology information from the local routing table. This scheme does not affect the existing routing protocols and other scenarios (Drugan and Plagemann, 2014).

Ahmad and Hameed (2019) have analysed the objectives and challenges in designing a cluster scheme for MANET. The paper mainly focused on the topology changes due to mobility. It also discusses the possibilities to reduce the size of routing table by using cluster-based schemes (Ahmad and Hameed, 2019).

Jabbar and Saad (2018) proposed multi-criteria-based hybrid multipath protocol for QoS aware data routing in MANET. This paper focused on the effective data routing among IoT devices. The main challenge in the area or IoT is the heterogeneity of network nodes. This work also proposes a node rank with respect to multi-criteria node rank metric (Jabbar and Saad, 2018).

Cai and Li (2018) have proposed an evolutionary self-cooperative trust scheme against routing disruptions in MANETs. This work offers a self-cooperative trust scheme for MANET. The nodes in the network self-assess their trustworthiness by calculating the trust value. Malicious node isolation is also done based on the trust value. That in turn increases the routing effectiveness and scalability of the network (Cai and Li, 2018).

Vaseer and Ghai (2018) proposed a neighbour trust-based mechanism to protect mobile networks. This paper presents an algorithm to prevent various attacks in the network. The method reduces the packet drop by isolating the malicious nodes based on their malicious nature. The malicious nature is determined by the accusations from the neighbouring nodes (Vaseer and Ghai, 2018).

3 Proposed architecture

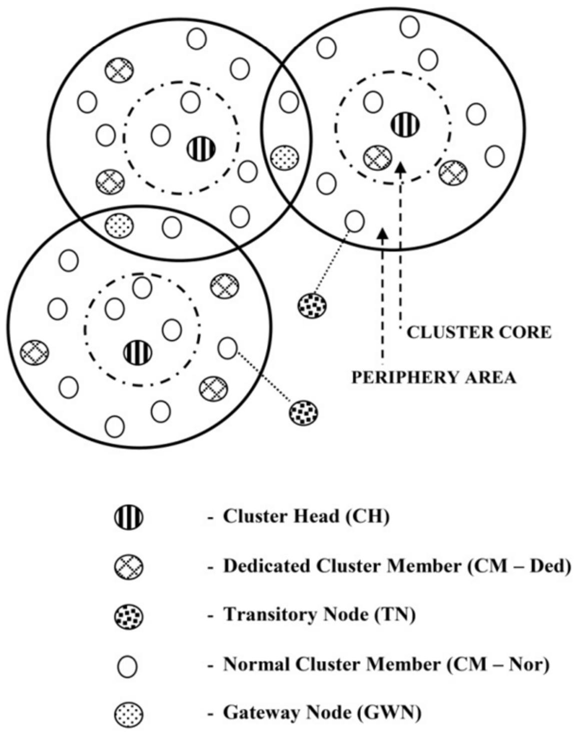
This paper proposes an environment-adaptive distributed clustering technique (EDCT) for MANET. EDCT approach mainly addresses the problems due to the momentary changes happening in the MANET due to mobility. A proper CH selection is required to keep the sustainability of the network. CHs are always vulnerable to one point attack. The communication among CH nodes is also important in cluster architecture. The cluster maintenance is also an integral part of keeping the network stable in mobile environment.

In order to maintain the communication link among the CH nodes, EDCT proposes *gateway nodes* (GWNs), chosen from the intersecting periphery area of two clusters. The CH must be active at all time to manage the cluster and the communication. The stability of CH is an important factor while considering the overall stability of the network. Thus, EDCT proposes a *weight-based CH selection* approach for the long run of the network. It also proposes a *random shift approach* on CH node, for preventing the one point failure attack on network. The cluster maintenance is required mainly due to the mobility of nodes in MANETs. EDCT proposes two significant approaches for cluster maintenance due to mobility. The GWNs are assigned to calculate *cluster sustainable value* of their occupying clusters based on some known parameters. The non-sustainable clusters will be dispersed based on the cluster sustainable value. Another method for cluster maintenance *is re-clustering* approach. EDCT proposes a re-clustering, while a cluster continues with less than sufficient number of nodes. It happens due to the mobility of nodes.

3.1 Cluster architecture

The architecture consists of CH, dedicated CM (CM – Ded), transitory nodes (TNs), normal CM (CM – Nor) and GWN. Figure 1 shows the proposed architecture.

Figure 1 Architecture of EDCT

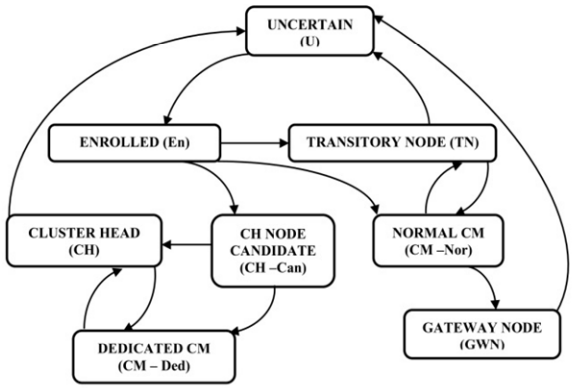


A set of nodes are considered for assigning the duties of a CH. Those nodes are called CH – node candidates (CH – Can). The selection criteria for CH – Can nodes will be discussed later in this paper. One node among the CH – Can nodes will be randomly selected for becoming CH node. A random shift approach will also be applied among CH – Can nodes. All nodes in CH – Can set other than CH node will join the network as CM – Ded nodes. GWNs are responsible for the communication among the CH nodes of various clusters. Nodes failed to find a CH node among its K-hop neighbours will join the network as TN under any of its immediate neighbouring node. All other nodes, having at least a CH node in the range of their K-hop neighbours will join the network as CM – Nor nodes, under an available CH node.

3.2 Roles and responsibilities

The nodes in the network have different roles for maintaining the cluster architecture. Figure 2 shows the state transition of nodes during their tenure in the network.

Figure 2 State transition diagram



All new nodes in the network will be in UNCERTAIN state while waiting to join the network. The nodes will fall into this stage during the following conditions:

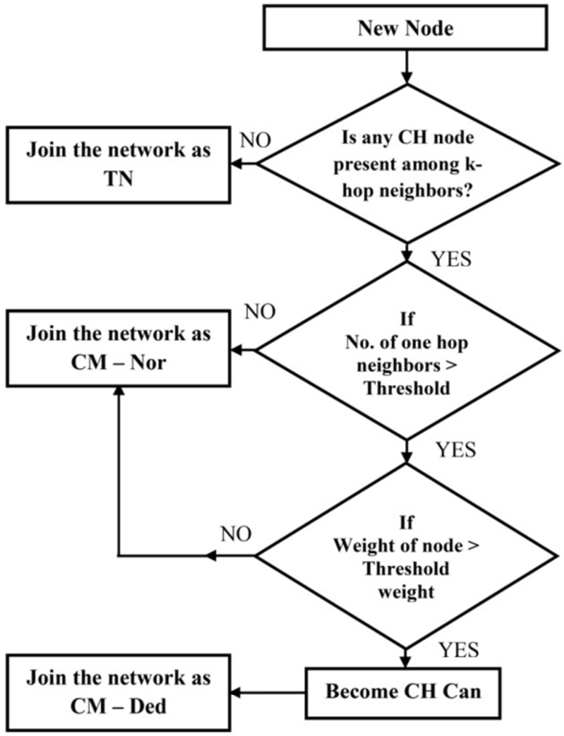
- When a new member joins the network.
- At the time of re-clustering due to the lack of cluster sustainability value.
- CH, cluster members and GWNs will fall into this state when it loses the connectivity due to mobility.
- At the time of re-clustering due to the lack of sufficient numbers of cluster members in the existing cluster.

All nodes entering to the UNCERTAIN state will send a node joining request to its K-hop neighbour nodes. The nodes, which initiated this process, will be considered as in ENROLLED state. The cluster formation approach is also designed to address the scalability issues present in the network. Each node will be assigned a role, even before joining the network. This pattern will help the network to cluster the nodes whenever a re-clustering is necessary. Here, the cluster members are categorised to different levels for handling the tremendous increase in the number of nodes. The proposed clustering approach is also capable to address the issues happening due to mobility. The categorisation of nodes in turn helps to handle the dynamic changes.

3.3 CH selection

All the nodes that are entering in to the network as well as the nodes in the existing clusters will be regularly checked for their ability to become the CH node candidate. Figure 3 illustrates the conditions which are needed to be verified before nominating a node to CH – Can set.

Figure 3 CH candidate selection



Nodes having sufficient one-hop neighbours and at least one CH node among its K-hop neighbours are initially considered for CH – Can list. Also, CH – candidate node must have weight greater than the threshold. Such nodes will join the network as CM – Ded nodes.

The weight of the node is calculated by using the following equation with the following assumptions:

$$W_i = w_1 H_i + W_2 \frac{1}{V_i} + w_3 E_i \tag{1}$$

where $w_1 + w_2 + w_3 = 1$

H_i number of one hop neighbours

V_i velocity of the node

E_i remaining energy of node in %.

Assumption: The velocity of a node cannot be zero, i.e., there is no static node in the network. The velocity of the nodes in static condition will be approximated to 1 km/h. The value of parameters are fixed to, $w_1 = 0.6$, $w_2 = 0.33$ and $w_3 = 0.07$.

Case 1 Ideal condition

A static node can perform well in a particular area for a long time ($V_i = 1$ km/h). Also, a node with a maximum one hop neighbouring count will have good connectivity (H_i = 15). 100% battery power can be assumed for the ideal case (E_i = 100%).

Case 2 Worst condition

A node with minimum number of satisfying one hop neighbours will be the worst case (H_i = 5). A minimum of 20% battery power is required to be considered for becoming CH (E_i = 20%). Also, the nodes with 60 km/h velocity can be considered for the worst case scenario (V_i = 60 km/h).

Case 3 Moderate condition

The following condition is considered as a moderate case for considering the nodes as CH candidates (H_i = 8, V_i = 30 km/h and E_i = 50%).

Table 1 gives the weight value for the all three specified cases. The weight is calculated using equation (1). The threshold of node's weight is fixed almost equal to the moderate condition (W_i = 8).

Table 1 Weight calculation

Values	*Ideal*	*Worst*	*Moderate*
H_i	15	5	8
V_i	1	60	30
E_i	100	20	50
W_i	16.33	4.4055	8.311

Nodes having higher weight than the threshold will be considered as CH – Can nodes. Initially, a node among CH – Can nodes will become CH. In order to increase the security of the network, a random shift will be applied among CH – Can nodes in regular interval of time for handling the duties of CH node. That in turn prevents the network from one point failure. The remaining CH – Can nodes other than selected CH node will remain in the network as dedicated CM nodes.

3.4 Node joining algorithm

Step 1 A node that wants to join the network is considered in UNCERTAIN state.

Step 2 Nodes in UNCERTAIN state will send node joining requests to their K-hop neighbours. At this stage, the nodes will be considered as in ENROLLED state.

Step 3 CH nodes receiving the node joining request will respond to the same.

Step 4 If the newly entered node could not find any existing CH nodes among their K-hop neighbours, than that node will join the network as TN under any of its neighbour.

Step 5 After receiving the reply for node joining request, the node will be assessed with the requirements to become CH candidate node.

Step 6 All nodes which satisfied the preliminary conditions to become CH – candidate nodes will be held to calculate the weight factor.

Step 7 Nodes having weight value higher than the threshold value will join the network as dedicated CM nodes.

Step 8 All other nodes will join the network as normal cluster members.

Note: TN can join the network as a normal cluster member at any time, if it could find a CH among its K-hop neighbours. All existing nodes in the network have the chance to fall into UNCERTAIN state at any time due to the reasons mentioned in the roles and responsibility section of this paper. Such nodes need to execute the node joining algorithm again to join the network.

3.5 Cluster maintenance

GWNs are responsible for the smooth functioning of the network. It ensures the connectivity among the CH nodes. Only the normal CM nodes will be considered to become the GWN nodes. Those nodes have to satisfy the following conditions:

- Those nodes must be situated at the periphery of the cluster.
- Those nodes must be situated at the intersecting portions of at least two clusters.
- Those nodes must be capable to find at least two CH nodes among its K-hop neighbours.

Thus, the GWNs will not lose the connectivity to the network due to problems associated with a single cluster. That is, the main reason for assigning the cluster maintenance duty to GWNs.

Mainly, two methods are proposed in EDCT for the cluster maintenance.

1 cluster sustainability value

2 re-clustering approach.

3.5.1 Cluster sustainability value

A cluster must be capable to handle the communications happening among the cluster members. The CH as well as all other members are equally responsible for the same. The main aim of calculating the cluster sustainability value is for preventing the network from the effects of an immediate collapse of a cluster. That in turn may affect the whole network in an uncontrolled manner.

The sustainability value of each cluster can be calculated as follows:

$$\text{Sustainability value} = w_1 * AE + w_2 * AV + w_3 * k + w_4 * H_{CH} + w_5 * R + w_6 * AD \quad (2)$$

where $w_1 + w_2 + w_3 + w_4 + w_5 + w_6 = 1$

AE average energy of CH – Can nodes

AV average velocity of CH – Can nodes

k total number of nodes in the cluster

H_{CH} number of one-hop neighbours of the current CH

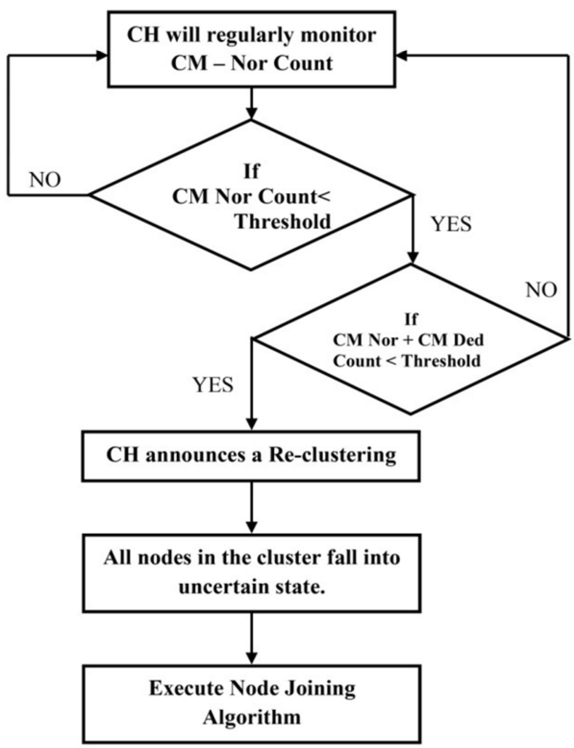
R the ratio between the total number of CM – Nor nodes to the total number of CM – Ded nodes present in the cluster

AD average of distances between current CH node and the nodes present in the periphery of the clusters

The cluster sustainability value is calculated by GWNs. The cluster sustainability value will be calculated immediately after the formation of a new cluster. Afterwards, the GWNs will check the value periodically. After calculating the sustainability value of all present clusters, the GWN select an ideal sustainability value among the obtained results. GWNs will fix the threshold value depending on the obtained ideal sustainability value. Based on that threshold value, GWN suggests re-clustering.

The GWN is responsible for the calculation of cluster sustainability value. Based on the sustainability value, GWN suggests and executes the re-clustering. All the nodes will be explicitly notified about the re-clustering by GWNs. GWNs have communication links with more than one clusters, thus it can ensure the reachability of re-clustering notification to all the intended nodes.

Figure 4 Re-clustering approach



3.5.2 Re-clustering approach

EDCT limits the minimum number of nodes required to form a cluster in to a threshold. The clusters in the network will form only after verifying this threshold value. But at any time, the number of cluster members may fall down to a lesser value than the threshold, due to mobility. GWNs are responsible for observing the member count of a cluster periodically. At any time, when the GWN finds a value lower than threshold, then GWN suggests a re-clustering. CH node will disperse the cluster. All nodes other than GWNs will immediately fall to UNCERTAIN state. Then, each node has to execute the node joining algorithm separately.

4 Result and discussion

In this section, the proposed EDCT is compared with the cluster head gateway switch routing (CGSR) protocol (Murthy and Manoj, 2007). The performance of both methods is analysed based on the simulation results obtained in NS 2.35 network simulator. The comparison mainly focused on the clustering approach as well as the overall results. The impact of new method is analysed by measuring the overhead and the delivery ratio of the network in different number of nodes.

IEEE 802.11 is used as physical and MAC layer for the experiments done for the analysis. All simulation parameters are listed in Table 2.

Table 2 Simulation parameters

Simulation time	2,000 seconds
Bandwidth	2 Mb/s
Mobility model	Random way-point
Average speed	3 m/s
Pause time	10 s
Transmission range – TR	250 m
Network density	40 nodes/TR surface

The proposed EDCT is analysed and compared with CGSR, on the basis of following five performance metrics:

- Average life time of clusters

  It is the average life time of formed clusters in the network with respect to the number of nodes.

- Number of role changes

  It is the total number of CH role changes excluding the periodic random shift applied by EDCT with respect to the number of nodes.

- Average number of clusters

  It is the total number of clusters formed with respect to the number of nodes.

- Packet drop

  It is the total number of packet loss happened during the communications. It can be calculated by, packet drop = total number of packets send – total number of packets received.

- Routing overhead

  It is the total number of control packets used rather than the data packets.

- Packet delivery ratio

  It is the ratio between the total number of packets received and total numbers of packets send.

Figure 5 shows the average life time of clusters with different number of nodes. As per the simulation results, EDCT has higher cluster life than CGSR. EDCT shows this performance improvement due to the technical enhancements achieved by the environment-adaptive scheme. EDCT prevents the one point failure by applying a random shift among the CH – Can nodes for the role of CH. Random shift also prevents the cluster collapse due to the low energy of CH. That in turn increases the life time of clusters. In EDCT, nodes without a CH node among its K-hop neighbours are not allowed to join any cluster as a cluster member. So, the cluster sustainability value is calculated depending only on the genuine cluster members. Thus, the proper cluster maintenance is possible based on the cluster sustainability value. This also helps to increase the life time of cluster. CH candidate selection is depending on the velocity and remaining energy of nodes. Thus, the chances of cluster collapse are also minimal.

Figure 5 Average life time of clusters

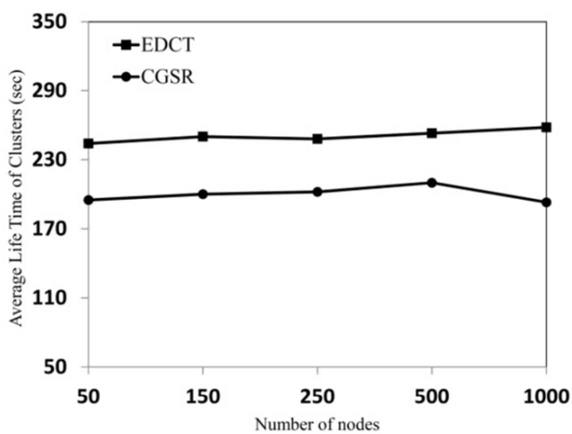


Figure 6 shows the number of CH role changes with respect to the number of nodes. It happens mainly due to the connection loss due to mobility. The simulation count excludes the CH role changes due to periodic random change applied by EDCT. The simulation result shows that, EDCT has minimum count than CGSR. The main reason for this improvement is only because EDCT is capable to predict the cluster behaviour of the cluster earlier than a cluster collapse by using the cluster sustainability value. EDCT suggests a re-clustering, if the value goes beyond the threshold. Also, EDCT suggests re-clustering based on the lower count of cluster members. These techniques increase the stability of network and reduce the need of role change.

Figure 6 Number of role changes

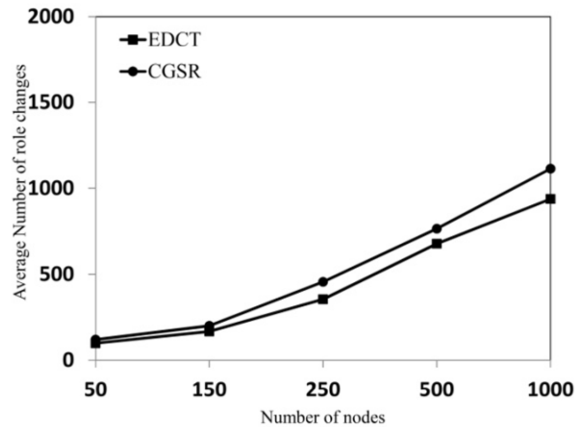


Figure 7 presents the average number of clusters formed with respect to the number of nodes. The communication becomes more faster with the small number of clusters. As per the simulation results, EDCT has lower number of cluster formations while comparing with CGSR. This is achieved by proper cluster maintenance and re-clustering approach. Also, EDCT does not allow any node to join the network, without having CH node present among their K-hop neighbours. That also avoids unwanted clusters formation.

Figure 7 Average number of clusters

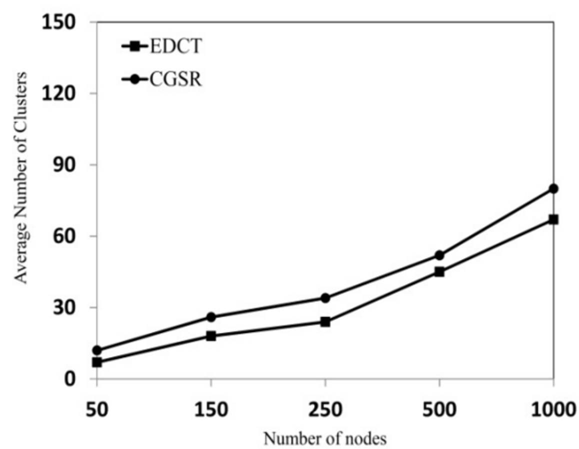


Figure 8 shows the packet drop happened during the simulations done with different number of nodes. The packet loss is less in EDCT while comparing with CGSR. In EDCT, cluster sustainability value-based cluster dispersion eliminates the risk of unpredicted cluster collapse. Thus, the communication links present in the network will be stable in almost all conditions. That in turn reduces the packet drop. GWNs can handle the unpredicted link failure by re-routing the packets through another path dynamically. That also reduces the risk of packet drop.

Figure 8 Packet drop

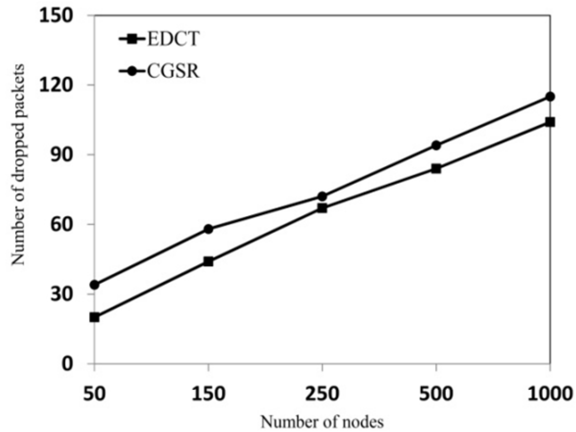


Figure 9 shows the count of routing overhead in both EDCT and CGSR. The overhead is the total number of control packets used for the communication. In EDCT, inter cluster communication is limited among the network of CH nodes with the help of GWNs. GWNs also help for the faster discovery of intended recipient. It works in a distributed manner. So a complete broadcast of messages from a centralised authority for a negligible/genuine reason can also be avoided. Reducing the complexities also reduce the overhead.

Figure 9 Routing overhead

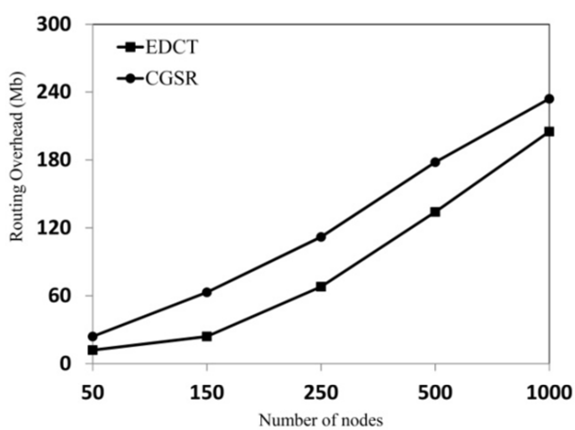
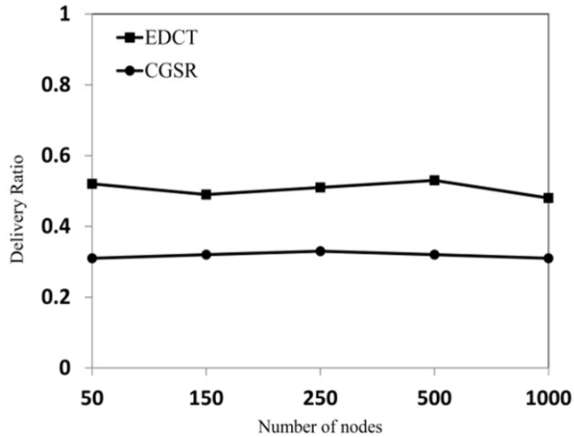


Figure 10 shows the packet delivery ratio with respect to the increasing number of nodes. The packet delivery ratio is high in EDCT. Based on the simulation results, it is clear that, EDCT has high cluster stability than CGSR. Packet delivery ration will be high if the stability of network is good.

Figure 10 Packet delivery ratio



5 Conclusions

The main goal of this work is to develop an environment-adaptive distributive clustering technique. The main hurdle present in the network is the issues related to the mobility of nodes. It is not possible to insist a static condition in mobile environment as a solution to the above mentioned problem. In order to cope with these issues, EDCT proposes a novel approach towards the improvement of cluster stability. Random approach on CH nodes reduces the one point failure of network and the cluster sustainability value-based re-clustering approach in turn increases the stability of the network. A keen monitoring on the network nodes reduces the chances of immediate cluster collapse due to the mobility and also due to the lack of enough number of cluster members. This work can also be considered as a predictive approach for the cluster maintenance. A properly maintained cluster performs better than the one with normal scenarios. The simulation results show that, the proposed work fulfil the aim up to an acceptable level.

References

Aftab, F. and Zhang, Z. (2017) 'Self-organization based clustering in MANETs using zone based group mobility', *IEEE Access*, November, Vol. 5, No. 1, pp.27464–27476.

Ahamed, A.M.U., Eswaran, C. and Kannan, R. (2017) 'CBIR system based on prediction errors', *J. Inf. Sci. Eng.*, Vol. 33, No. 2, pp.347–365.

Ahmad, M. and Hameed, A. (2019) 'State-of-the-art clustering schemes in mobile ad hoc networks: objectives, challenges and future directions', *IEEE Access*, February, Vol. 7, No. 1, pp.17067–17081.

Ali, M. and Salim, B.M. (2015) 'Self-stabilizing clustering algorithm in mobile ad hoc networks', *SAI Intelligent Systems Conference*, November.

Alinci, M. and Spaho, E. (2015) 'Clustering algorithms in MANETs: a review', *Ninth International Conference on Complex, Intelligent, and Software Intensive Systems*, August.

AlMheiri, S.M. and AlQamzi, H.S. (2015) 'MANETs and VANETs clustering algorithms: a survey', *Proceedings of the 8th IEEE GCC Conference and Exhibition*, February.

Cai, R.J. and Li, X.J. (2018) 'An evolutionary self-cooperative trust scheme against routing disruptions in MANETs', *IEEE Transactions on Mobile Computing*, April, Vol. 8, No. 1, pp.42–55.

Devarajan, K. and Padmathilagam, V. (2015) 'An enhanced cluster gateway switch routing protocol (ECGSR) for congestion control using AODV algorithm in MANET', *International Journal of Computer Applications*, August, Vol. 123, No. 3, pp.37–42.

Drugan, O.V. and Plagemann, T. (2014) 'Dynamic clustering in sparse MANETs', *IEEE Computer Communications*, December, Vol. 59, No. 1, pp.84–97.

Gavhale, M. and Pranay, D. (2015) 'Survey on algorithms for efficient cluster formation and cluster head selection in MANET', *International Conference on Information Security & Privacy*, December.

Gomathi, K. and Parvathavarthini, B. (2015) 'A secure clustering in MANET through direct trust evaluation technique', *2015 International Conference on Cloud Computing (ICCC)*, April.

Guizani, B., Ayeb, B. and Koukam, A. (2015) 'A stable K-hop clustering algorithm for routing in mobile ad hoc networks', *2015 International Wireless Communications and Mobile Computing Conference (IWCMC)*, August.

Jabbar, W.A. and Saad, W.K. (2018) 'MEQSA-OLSRv2: a multicriteria-based hybrid multipath protocol for energy-efficient and QoS-aware data routing in MANET-WSN convergence scenarios of IoT', *IEEE Access*, November, Vol. 6, No. 1, pp.76546–76572.

John, S.P. and Samuel, P. (2017) 'Trust prediction model for certificate exchange and revocation in MANET', *Int. J. Networking and Virtual Organisations*, Vol. 17, Nos. 2/3, pp.268–289.

Kaur, K. and Singh, J. (2015) 'Weightage based secure energy efficient clustering algorithm in MANET', *International Conference on Advances in Computing, Communications and Informatics*.

Kulkarni, S.B. and Yuvaraju, B.N. (2015) 'Node connectivity, energy and bandwidth aware clustering routing algorithm for real-time traffic multicasting in MANET', *IEEE International Advance Computing Conference (IACC)*, June.

Lalitha, T. and Devi, A.J. (2014) 'Security in wireless sensor networks: key management module in EECBKM', in *2014 World Congress on Computing and Communication Technologies*, IEEE, pp.306–308.

Li, Y. and Yang, S. (2015) 'Research on cluster head selection algorithm based on QoS constraints in mobile ad hoc networks', *10th International Conference on Broadband and Wireless Computing, Communication and Applications*, November.

Liu, W., Nishiyama, H., Ansari, N., Yang, J. and Kato, N. (2013) 'Cluster-based certificate revocation with vindication capability for mobile ad hoc networks', *IEEE Trans. on Parallel and Distributed Systems*, February, Vol. 24, No. 2, pp.239–249.

Ma, X. (2011) 'A K-hop cluster maintaining mechanism for mobile ad hoc networks', *2011 7th International Conference on Wireless Communications, Networking and Mobile Computing*, October.

Mehta, D. and Kashyap, I. (2017) 'Random cluster head selection based routing approach for energy enrichment in MANET', *Proceeding International Conference on Recent Innovations is Signal Processing and Embedded Systems*, October.

Murthy, C.S.R. and Manoj, B.S. (2007) *Ad Hoc Wireless Networks*, Chapter 7, Pearson, India.

Piyalikar and Kar, P. (2016) 'Forecast weighted clustering in MANET', *Twelfth International Multi-conference on Information Processing*.

Popli, R. and Garg, K. (2016) 'SECHAM: secure and efficient cluster head selection algorithm for MANET', *2016 International Conference on Computing for Sustainable Global Development (INDIACom)*, March.

Rekha, S.B. and Muthukumarasamy, S. (2016) 'Balanced clustering in mobile ad hoc networks using route cluster', *International Conference on Information Communication and Embedded System*, July.

Selvakumar, K. and Seethalakshmi, N. (2018) 'Secure group key management protocol for mobile ad hoc networks', *Cluster Computing*, Vol. 22, No. 5, pp.11989–11995, Springer Nature.

Simpson, S.V. and John, S.P. (2015) 'Security aware cluster based architecture for MANET', *Proceedings of the International Conference on Emerging Trends in Engineering & Technology (ICETET-2015)*, pp.89–96.

Sreevatsan, A.P. and Thomas, D. (2016) 'An optimal weighted cluster based routing protocol for MANET', *2016 International Conference on Data Mining and Advanced Computing (SAPIENCE)*, March.

Vaseer, G. and Ghai, G. (2018) 'A neighbor trust-based mechanism to protect mobile networks', *IEEE Potentials*, December, Vol. 38, No. 1, pp.20–25.

Yang, H. and Li, Z. (2015) 'A clustering optimization algorithm based on WCA in MANET', *6th International Conference on Computing Communication and Networking Technologies*, July.

Zhou, H. and Zhang, J. (2015) 'An efficient clustering algorithm for MANET based on weighted parameters', *8th International Symposium on Computational Intelligence and Design*, December, Vol. 1.