A Novel Routing Technique For Mobile Ad Hoc Networks (Manet)

Kirtikumar K. Patel[1] and Dhadesugoor.R.Vaman[2]

Prairie View A & M University
Prairie View, TX-77446
[1]Doctoral Candidate; Electrical and Computer Engineering Department
[2] Texas A&M University System Regents Professor, Electrical and Computer Engineering Department

ABSTRACT

Actual network size depends on the application and the protocols developed for the routing for this kind of networks should be scalable and efficient. Each routing protocol should support small as well as large scale networks very efficiently. As the number of node increase, it increases the management functionality of the network. Graph theoretic approach traditionally was applied to networks where nodes are static or fixed. In this paper, we have applied the graph theoretic routing to MANET where nodes are mobile. Here, we designed all identical nodes in the cluster except the cluster head and this criterion reduces the management burden on the network. Each cluster supports a few nodes with a cluster head. The intra-cluster connectivity amongst the nodes within the cluster is supported by multi-hop connectivity to ensure handling mobility in such a way that no service disruption can occur. The inter-cluster connectivity is also achieved by multi-hop connectivity. However, for inter-cluster communications, only cluster heads are connected. This paper demonstrates graph theoretic approach produces an optimum multi-hop connectivity path based on cumulative minimum degree that minimizes the contention and scheduling delay end-to-end. It is applied to both intra-cluster communications as well as inter-cluster communications. The performance shows that having a multi-hop connectivity for intra-cluster communications is more power efficient compared to broadcast of information with maximum power coverage. We also showed the total number of required intermediate nodes in the transmission from source to destination. However, dynamic behavior of the nodes requires greater understanding of the node degree and mobility at each instance of time in order to maintain end-to-end QoS for multi-service provisioning. Our simulation results show that the proposed graph theoretic routing approach will reduce the overall delay and improves the physical layer data frame transmission.

KEYWORDS

Dynamic networks, Graph Theory, routing algorithm, Cluster, MANET

INTRODUCTION

Mobile Ad Hoc Network (MANET) [1] is often characterized as infrastructure-less as it does not use towers or base stations. It can be defined as a system of autonomous mobile (Dynamic) nodes that communicate over wireless links without any preinstalled infrastructure [2]. The network deployment is easy. The network is both power and bandwidth constrained and yet it is expected to provide multi-service provisioning with end-to-end Quality of Service (QoS) provisioning to

DOI : 10.5121/ijngn.2014.6101

end users. MANET doesn't have any dedicated routers to do routing (define a path for packet to transmit from source to destination), Thus each node can work as a relay in the communication path. Each node is able to send and receive data from other nodes in the network [3]. When a node wants to send data to another node which is outside the coverage area (or in a different cluster), then the source node will forward this data to an intermediate node. The intermediate node will forward the data to the next hop or destination node. As long as the cumulative power for multi-hop path is less than the broadcast power, it is feasible to achieve power efficiency [4]. This method also achieves overall throughput efficiency and end-to-end response time. However, since the nodes move freely, maintaining continuous path connectivity imposes additional complexity. MANETs rely on all participating nodes to share the task of routing and forwarding peer traffic. Thus, it is very necessary to develop a routing algorithm which can be efficient in terms of power and bandwidth usage as well as it can improve the overall efficiency of the network to provide quality of service (QoS) assurance for the required application. QoS in MANET is defined as the collective effect of service performance with constraints on delay, jitter, system buffer, network bandwidth, number of hops, power at each node, node mobility in MANET, and packet loss. Also, the performance efficiency achieved with a small set of nodes must be scalable for large set of nodes. Furthermore, in MANET, fast and unpredictable topology changes due to nodes mobility, and channel capacity vary due to environmental effects. Thus, it is more prone to errors compared with that of wired networks. These factors reduce the overall network throughput than equivalent wired network. Thus, supporting media applications such as "video streaming" over MANET is challenging. As infrastructures need to be quickly deployable in applications such as battlefield and homeland security theaters [5, 6, 7, 8, 9]. MANET architectures are still attractive even if complexity to handle mobility is higher.

This paper is organized as follows. Section II described background research. Section III describes the system model followed by simulation performance in section IV followed by conclusion in Section V.

2. BACKGROUND

A routing protocol is needed to deliver packet from a source to destination based on distance and power availability of the nodes in the network. It selects a path for each source and destination pair based on the system constraints which are extracted from the application needs. There are many routing algorithms have been developed by researchers [10, 11, 12 13 14 15, 16]. We had discussed many routing protocols with their advantages and limitations in our previous paper and these limitations prohibit them to be useful for deployment in a scalable MANET. Most of these algorithms which have evolved over years for INTERNET are not suitable for scalable MANET application. In our previous research [17] we developed a graph theory based intra-cluster routing algorithm for dynamic networks which shows multi-hop route saves transmission power at each intermediate node and increase the network lifetime and in this paper we extended the same concept to inter-cluster routing algorithm with validation of modified M/D/1 queuing system with original M/D/1 queuing system and we also simulated the processing power of each node. We propose an efficient routing algorithm based on graph theoretic approach specifically for MANET architecture that provides:

- Less delay in packet transmission.
- Power saving at each intermediate node.
- Pre-emptive action to provide better QoS.
- Better utilization of bandwidth.

Here, we summarize the previous discussion which concludes the requirement of new routing protocol. Reactive routing protocols [18-24] use flooding technique to find the new route if an existing route breaks and thus it will direct to more packet loss in deciding the on-demand routing algorithm. It uses much network overhead in finding the new route and ad-hoc networks have very limited resources therefore it's not adequate idea to use more resources to find new route even if there is no guarantee that new selected route will be more effective than previous one. In comparison, proactive routing protocols [25-39] provide higher routing efficiency in scattered traffic pattern and high mobility network. It maintains all the routes periodically thus it is very feasible to change the route at any point. It avoids finding of new route on demand. This technique does not use flooding technique and therefore it doesn't add any extra overhead to packet and saves available bandwidth usage accordingly. These existing routing algorithms are either scalable or power and bandwidth efficient. In wireless communication, link quality is proportional to the transmission power and therefore, for long distance communication we need multi-hop connectivity to save power at each intermediate node. Many researchers provide their multi-hop connectivity based on shortest path and minimum power. Most of researchers considered only the power constraint in developing routing scheme but no one considered the congestion at each node due to receiving packets from different nodes to forward to related destination.

As per author's knowledge, there is no research proposed to date, which is scalable, power and bandwidth efficient to provide QoS assurance for multi-service application based on traffic consideration at each node. In this paper, a novel idea of graph theoretic routing approach is presented, which is efficient in terms of power dissipation, bandwidth usage, and QoS guarantee. Presented idea is also scalable and it can works for large number of nodes to provide video streaming in dynamic network as explained in Section III.

SYSTEM MODEL

The MANET Architecture for the proposed research is explained in our previous paper [17] and is shown in fig.1 as below. The proposed scheme considers congestion at each node to develop routing path from source to destination node and this newly developed routing algorithm will reduces the scheduling time at each node by selecting the least congested node first in routing path, consequently this reduces the overall delay and accomplish the targeted QoS for the application. In addition, it is proactive routing and it saves bandwidth and power at each intermediate node consequently to increase efficiency of the MANET. In this section we describe the procedure to select a Cluster Head as well as how the inter-cluster and intra-cluster routing algorithm differs from each other with the validation of M/D/1 queuing system.

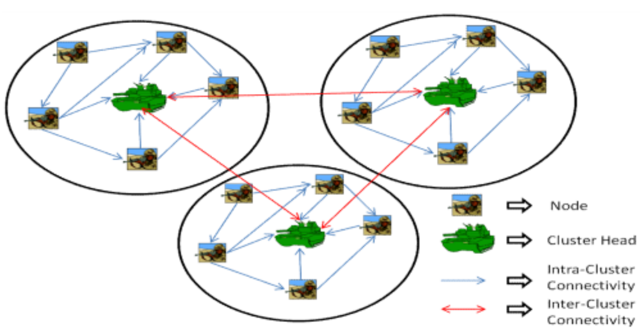

Figure 1. MANET Architecture

3.1. Cluster Head Selection Algorithm

There are numerous techniques available for selection and update of cluster head based on clustering algorithm for ad hoc network. Clustering algorithm should be selected according to the application associated with the ad hoc network. Ad hoc networks are mainly used in battlefield and homeland security application and therefore, this kind of networks are mobile and they don't have any fixed base station. Nodes can come and join the existing cluster and leave it after finishing the task. These kind of available clustering algorithms are explained briefly as below.

- Lowest ID Clustering Algorithm

As we stated before, each node is assigned with a unique ID and it can be used to identify the malicious and friendly nodes in the network [41, 42]. According to lowest ID clustering algorithm, each node broadcast their own ID within the cluster and each node receives other node's ID as well as it has its own node ID and it compare all the IDs from available list and select the node with minimum node ID (lowest ID) as a Cluster head for that cluster and other nodes works as cluster members [43]. Here, it is assumed that each CH has high backbone bandwidth and larger amount of power available with compare to other cluster members.

- The Highest Degree Clustering Algorithm

This algorithm has been developed in order to minimize the number of clusters and increase the number of nodes in each cluster [44]. By adding more nodes in one cluster, it will increase the degree of connectivity of each node. Thus, the node which has higher degree will be selected as a cluster head. In contrast, it will increase traffic at each node and it will delay the packet transmission from source to destination. Higher degree of connectivity also increases the number of collision which reduces the efficiency of the whole network and packet transmission.

- Weighted Clustering Algorithm

Weighted clustering algorithm consider an ideal degree of connectivity for each node and then it compare other design factors like, available battery life, transmission power, mobility [45]. The node which has higher amount of these factors available then it will select as a Cluster head for the whole cluster and takes the responsibility to handle whole network and detect malicious nodes for security concern. In this algorithm, nodes have to update their power and battery life with all other nodes in the network and it will increase more traffic and waste the resources.

By comparing all the major available clustering algorithms, we have selected a lowest ID clustering algorithm. Thus, after deploying cluster, node with lowest ID will be selected as a Cluster head and other node will work as cluster members. In addition, all nodes and cluster head will have the same node ID for the entire setup for a period of time and therefore, it is an easy idea to manage the cluster. Whole network is separated in 4 clusters and their nodes are shown in Fig.1.All nodes are placed randomly and each node has their own individual node ID. According to lowest ID algorithm, node with lowest ID has been picked up to perform as a Cluster Head and it is shown in different color than the cluster members in the Fig.1. Node 5 will work as a CH for Cluster A, and in the same way node 3, 1, 4 will work as CH for Cluster B, C and D respectively.

3.2. Intra-Cluster Routing Algorithm

A network has multiple clusters and each cluster has a number of nodes. In a particular cluster, some nodes which tend to communicate with the other nodes in the same cluster or in the different cluster. In case, when a node wants to send packet to a node within the cluster then it will follow the intra-cluster connectivity. In this routing algorithm, each source node selects a multi-hop path based on available degree at each node. This route discovery and route maintenance is explained in detail in our previous research. This routing algorithm will select the minimum cumulative degree path in order to provide very efficient route to destination. If the congestion increases or the node moves out from the path, then source will use route maintenance algorithm in order to setup new path and provide preemptive solution.

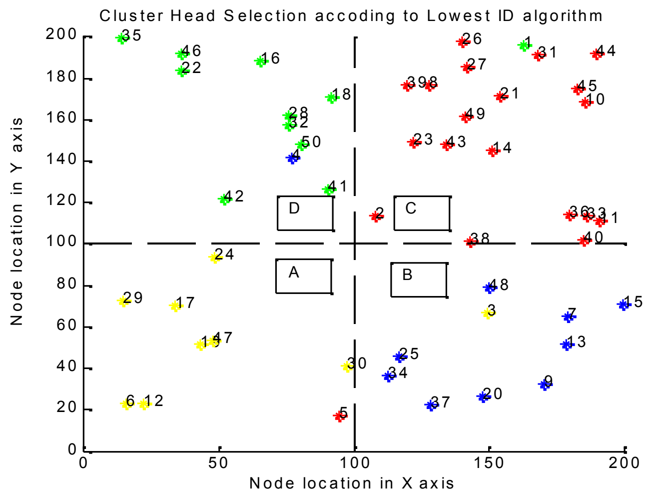

Figure 2. Cluster Head Selection according to lowest ID algorithm

3.3. Inter-Cluster Routing Algorithm

A node in the cluster is not capable to communicate with other node in different cluster and therefore, in this kind of communication cluster head performs a main role in forwarding the incoming packet to destination node in the different cluster. Thus, when two nodes in the different cluster communicate with each other via cluster head, then it is called inter-cluster communication. Inter-Cluster communications occurs between a cluster head and another cluster head. It can also have a direct connectivity or through multi-hop path connectivity between cluster heads. Here we assumed that each cluster head has high backbone bandwidth and more power with compared to other node members.

3.4. Determination of number of intermediate nodes

In the digital communication, power is consumed for processing and transmitting a packet. Ad hoc networks are power and bandwidth limited networks and therefore, power saving is an important issue in developing any routing algorithm for mobile ad hoc network. In our designed routing scheme, we developed a multi-hop routing scheme to save power at each intermediate node. To achieve this power saving within the individual cluster, a source node determines the location of the destination node. In addition, a source node develops three power circles around it. Based on the location of the destination in any of the power circles, source node determines the number of required intermediate nodes for successful packet transmission. These intermediate nodes can be selected using the minimum degree algorithm as described in our previous research [17].

4. SIMULATION RESULTS

4.1. Inter-Cluster Routing Algorithm

We developed an inter-cluster routing algorithm along with intra-cluster routing for Ad hoc network. As we defined our graph theoretic routing algorithm for inter-cluster communication and here we simulated the same algorithm using the matlab software. According to the algorithm, if the source node and destination nodes are in the separate clusters then source node cannot communicate with the destination node directly because of their power and bandwidth limitations and therefore it has to find some other proper way. Source node will send a packet to the cluster head of its own cluster and this cluster head will forward the received packet to the destination cluster head and then it will be delivered to the destination node. Figure 3 demonstrates that the node 35 is the source node and node 32 is the destination node. Therefore, in this case, node 35 will send packet to node 4 which is the cluster head and it will send packet to node 1 to deliver packet at node 32. Blue dotted lines in the fig. shows that all the cluster heads are internally connected and they have higher backbone bandwidth for deliver packet to listed destination.

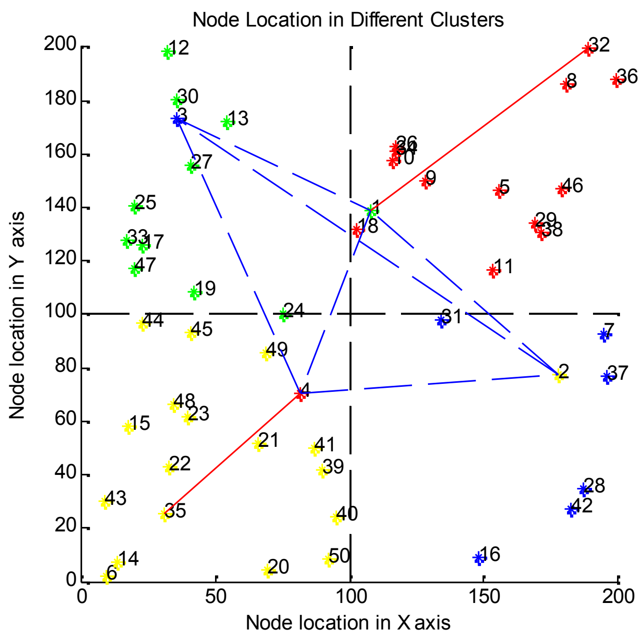

Figure 3. Inter cluster Communication

To perform simulation, we used MATLAB as a simulation tool and created MANET with random distribution of nodes in the 200 x 200 meters area and set the random mobility for each node. Figure 4 shows the random distribution of nodes in the whole network.

Table 1. SIMULATION PARAMETERS

Parameter	Values
Area	200*200 meters
Number of Nodes	50
Node Placement Strategy	Random
Mobility	Random

4.2. Intra-Cluster Routing Algorithm

Source and destination nodes are changing during each simulation. But here we showed one set of simulation in which source node is 5 and destination node is 12 as shown in Fig. 5. Node 12 is in the third circle from node 5 therefore, node 5 selects the intermediate node from middle circle. During the initial conditions, node 5 sends its packets via node 18 because node 18 has less degree than other nodes which are near to it. Node 5 selects node 18 as intermediate node and send packet to it to forward it to node 12. Fig 6 shows the direct path with blue line as well as multi-hop path via node 18 via black line. It will also shows that by using less degree node as intermediate node, the algorithm will save time for scheduling and forwarding the incoming packet to destination. It also shows that direct transmission require more amount of power than multi-hop connectivity. Furthermore, Fig. 6 shows that the node 18 moves from its original place and therefore the routing connection breaks, but our algorithm will select the next available path before the existing path breaks. Thus, it selects node 8 as intermediate node which has less degree and source node 5 will send packet to destination node 12 via this intermediate node 8.

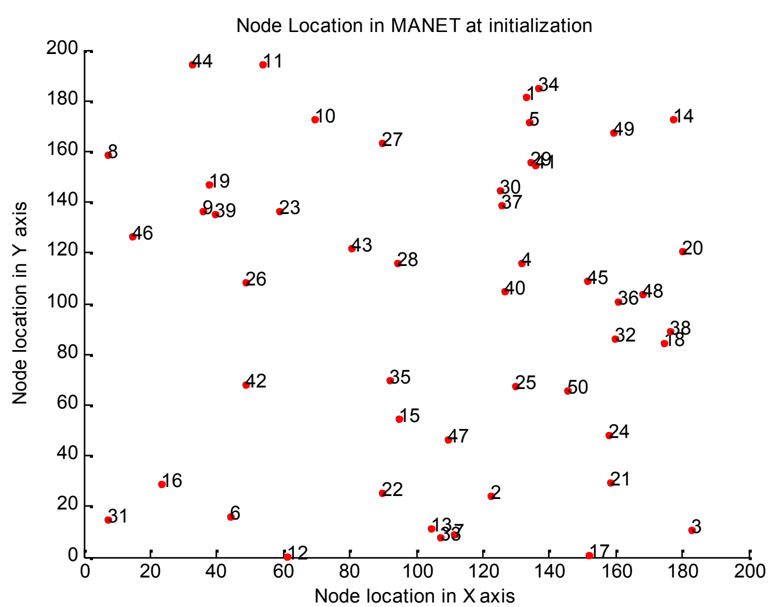

Figure 4. Random Placements of Nodes in MANET

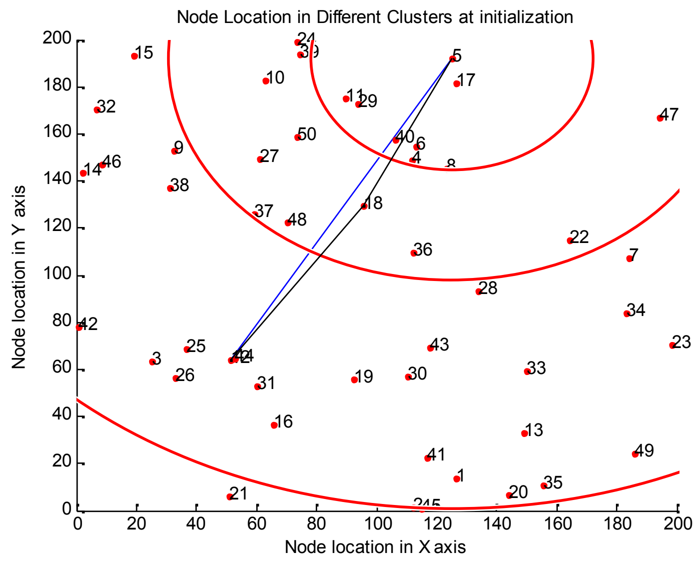

Figure 5. Node position at the time of MANET Initialization

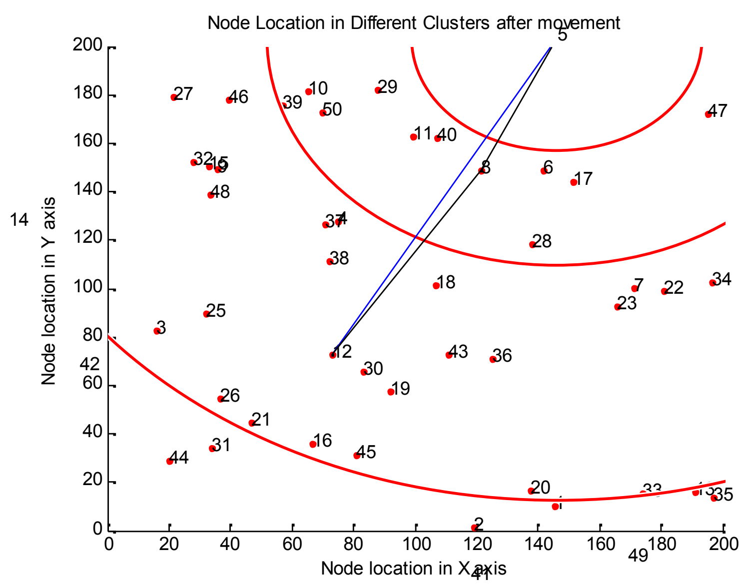

Figure 6. Node positions of all nodes after Movement for the same Source - Destination pair via different intermediate node.

4.3. Determination of number of intermediate nodes

In the simulation, there are three circles developed with source node selected as a center of each circle, as shown in Fig. 7 and source node will select the number of intermediate nodes based on the location of destination node. If destination node and source node both are in the same circle, then there is no need to select any other node to work as intermediate node as shown in Fig. 8. In case, if destination node is in the second circle and source node is in the first circle, then source node will select an intermediate node from its own circle and then forward the packet to destination node. This case has been shown in Fig. 9. In the last case, as indicated in fig. 10 if the destination node is in the third circle, then source node will select two intermediate nodes from first circle and second circle respectively. If the destination node is outside the third circle, then according to our algorithm source node will select three intermediate nodes from each circle. Thus the method of dividing the cluster into circles helps to determine the number of intermediate nodes based on destination node's location. According to the derived algorithm to select the intermediate node, we can develop multi-hop route for the packet transmission.

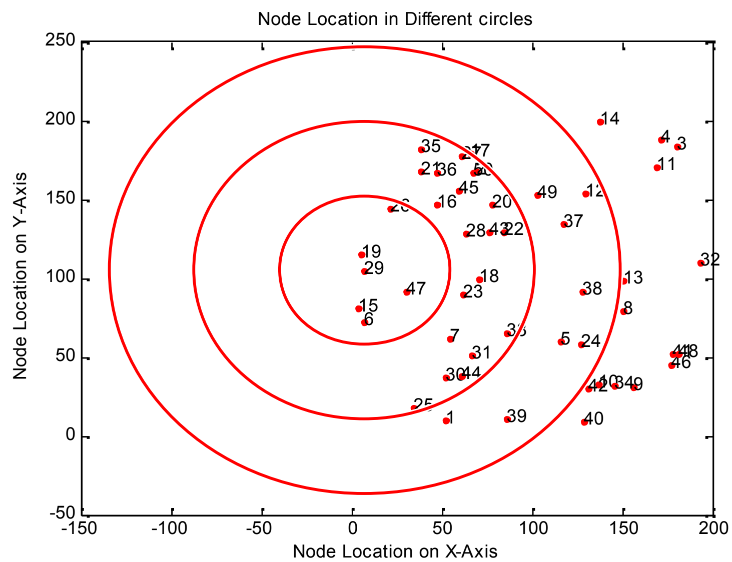

Figure 7. Node location in Different circles according to their Location

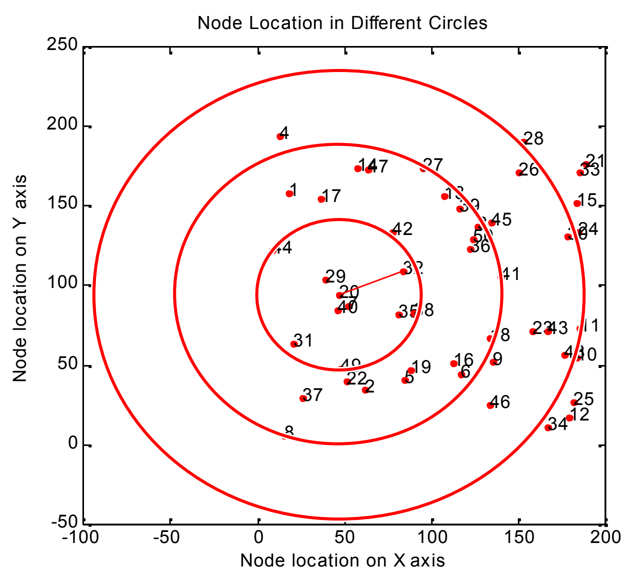

Figure 8. Source and Destination both are in the same circle

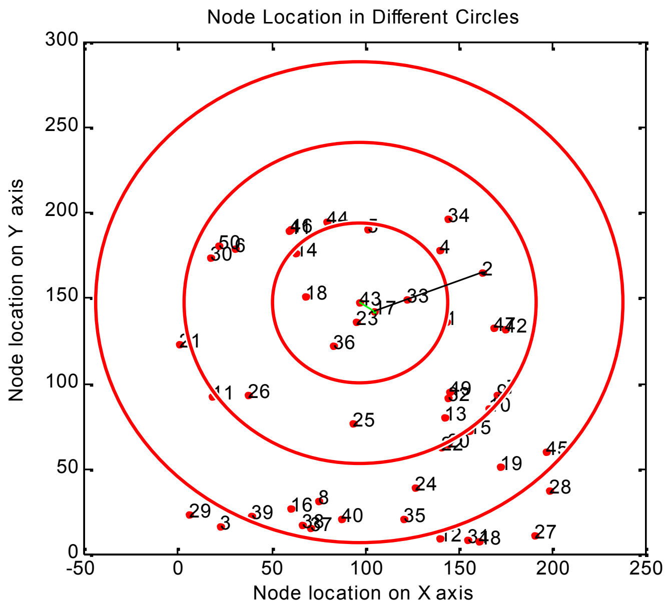

Figure 9. Destination node is in the second circle

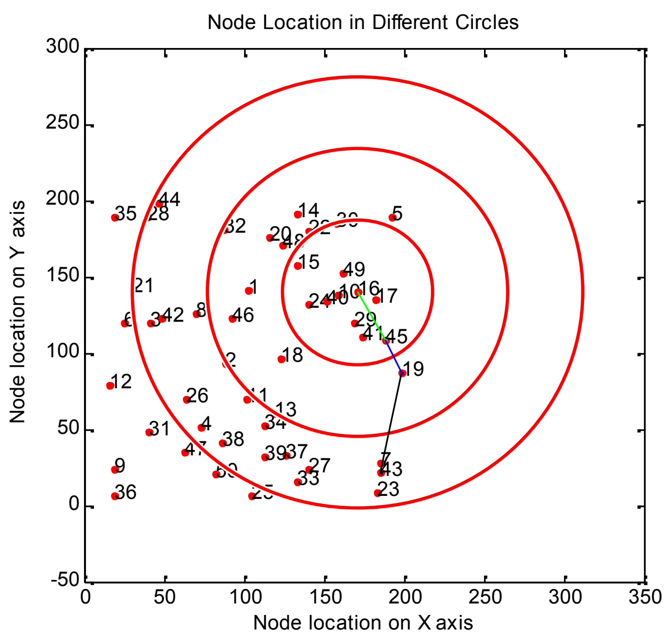

Figure 10. Destination node is in the Third Circle

4.4. M/D/1 queuing Validation

To validate our modified M/D/1 with original M/D/1 queuing system [49], we have developed a simulation setup for 50 nodes with their random movement. Each node has degree 1. Here, in the original M/D/1 queuing system each node has buffer and therefore, incoming packets have higher waiting time in queue before transmission, while we considered modified M/D/1 queuing system for the MANET and node doesn't have buffer in the ad hoc network. Thus, we didn't consider a buffer for arriving packets and therefore, a node will have less read/write cycles to forward incoming packet and it can lead the node to save energy for future use and increase lifetime of the network. Here we compared the power required for read/write cycle of the node with buffer and node without buffer. According to Fig. 11, we can say that average power associated with processing of packets at node with buffer is higher than the node without buffer. We also have to consider the decay of power when the node is in idle state. A node loses small amount of power in its idle state and it can affect the node's lifetime and consequently network lifetime. This power decay will remain same in both cases as described in Fig. 11 as well as there is more research going on to save this power decay at each node. Furthermore, when packets arrive simultaneously, there are more chances to be dropped and each node has little amount of variation for the delays. In addition, mean delay for the whole network with modified M/D/1 queuing system with 50 nodes is almost same as the original M/D/1 queuing system. As a validation point of view, from Fig. 12, we observed 0 ms delay in original M/D/1 queuing system while we observed some 0.0189 ms delay for our modified M/D/1 queuing system for sending packet to next node. We can conclude that each node has their own packet to send and therefore they have to schedule the incoming packet as well as own packet. From Fig. 13, we can observe that delay increases with the degree of node and therefore, node with less degree will provide higher throughput.

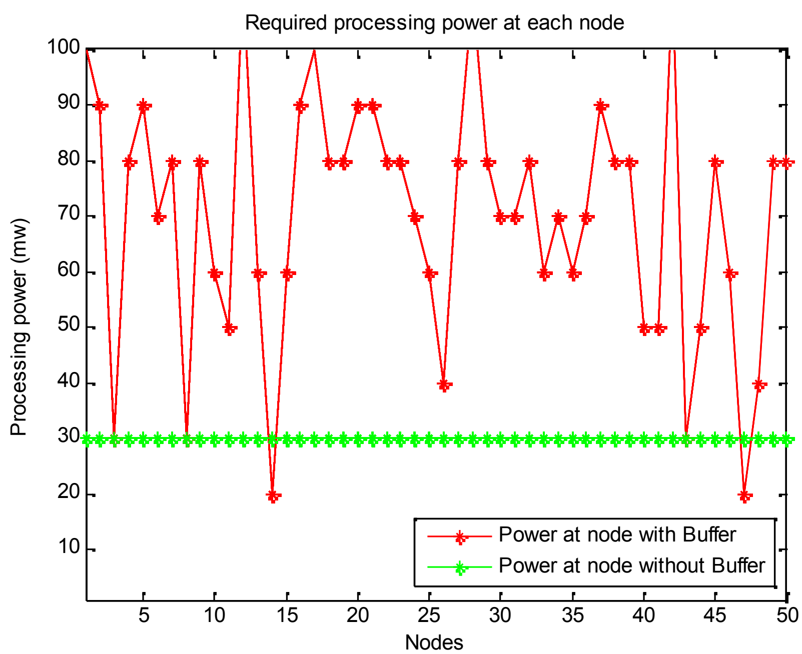

Figure 11. Required processing power for each node

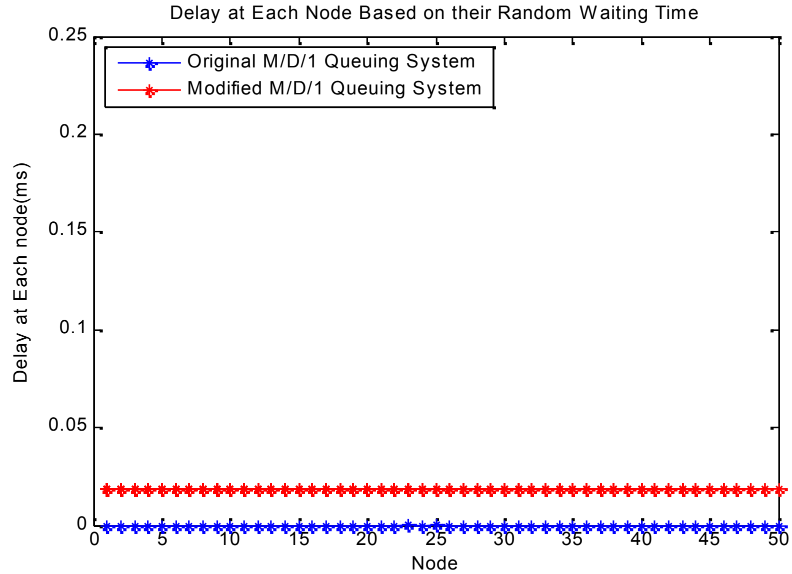

Figure 12. Delay at each node having Degree = 1

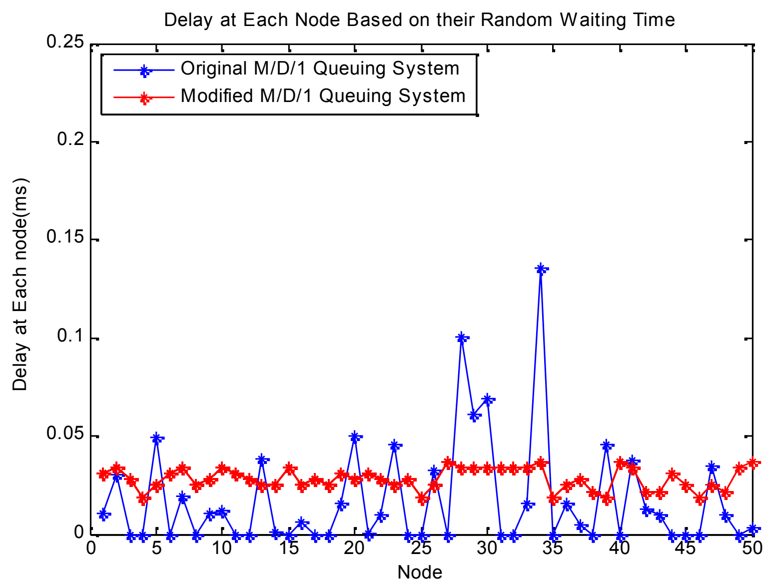

Figure 13. Delay at Each node with Random Degrees

CONCLUSION

MANET is a dynamic network and therefore, it is a critical to route packet in this kind of network. Here, we developed a graph theoretic routing algorithm for inter-cluster as well as intra-cluster network. We designed all identical nodes except cluster head and thus we reduced management overhead in order to provide highly efficient routing for the packets to deliver at destination. By simplifying and using the minimum cumulative degree path as a preferred route to destination, we can minimize the overall delay and increase the throughput as well as network life by using multi-hop connectivity to save power at each intermediate node. In addition, our simulation results proves that the average processing power required at nodes with buffer is higher as compared to node without buffer in ad hoc network. Also, this routing algorithm is scalable and provides preemptive action which reduces the overall packet loss and able to provide efficient packet transmission.

ACKNOWLEDGEMENTS

This research work is supported in part by the National Science Foundation NSF 0931679. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the National Science Foundation or the U. S. Government.

REFERENCES

[1] http://datatracker.ietf.org/wg/manet/charter/
[2] K. Srinivas and A. A. Chari, “Cross layer congestion control in MANETs and current state of art,” International Journal of Computer Applications, vol. 29, no. 6, pp. 28-35, September 2011
[3] Ad Hoc Networking, edited by C. E. Perkins, Addison Wesley, 2001.
[4] R. Wattenhofer, L. Li, P. Bahl, and Y. Wang. Distributed topology control for power efficient operation in multihop wireless ad hoc networks. In IEEE INFOCOM 2001, April 2001.
[5] Dow, C.R.; Lin, P.J.; Chen, S.C.; Lin, J.H.; Hwang, S.F.; , "A study of recent research trends and experimental guidelines in mobile ad-hoc network," Advanced Information Networking and Applications, 2005. AINA 2005. 19th International Conference on , vol.1, no., pp. 72- 77 vol.1, 28-30 March 2005
[6] G. Aggelou, R. Tafazolli, RDMAR: a bandwidth-efficient routing protocol for mobile ad hoc networks, in: ACM International Workshop on Wireless Mobile Multimedia (WoWMoM), 1999, pp. 26–33.
[7] C-Y. Chong, S.P. Kumar Sensor networks: evolution, opportunities, and challenges Proceedings of the IEEE, 91 (8) (2003), pp. 1247–1256
[8] Oh, S.Y.; Lau, D.; Gerla, M.; , "Content Centric Networking in tactical and emergency MANETs," Wireless Days (WD), 2010 IFIP , vol., no., pp.1-5, 20-22 Oct. 2010
[9] D. R. Vaman, “Complexities of ad hoc wireless network architectures and their dual use capabilities for Multi-service QoS assured applications”, Proceedings of IEEE Conference on Enabling Technologies for Smart Appliances, Vol. 1 Key Session ETMA, January 12-14, 2005, Hyderabad, India (Invited Paper)
[10] Abolhasan, M., Wysocki, T., & Dutkiewicz, E. (2004). A review of routing protocols for mobile ad hoc networks. Ad hoc networks, 2(1), 1-22.
[11] S. R. Das, R. Castaneda and J. Yan, “Simulation Based Performance Evaluation of Mobile, Ad Hoc Network Routing Protocols,” ACM/Baltzer Mobile Networks and Applications (MONET) Journal, July 2000, pages 179-189.
[12] J. Broch, D.A. Maltz, D.B. Johnson, Y.-C. Hu, and J. Jetcheva, “A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols,” in Proceedings of ACM/IEEE MOBICOM’98, Dallas, TX, Oct. 1998, pp. 85-97.
[13] M. Royer and C.-K. Toh, ”A Review of Current Routing Protocols for Ad-Hoc Mobile Wireless Networks”, IEEE Personal Communications Magazine, April 1999, pp. 46-55.
[14] Iwata, C.-C. Chiang, G. Pei, M. Gerla, and T.-W. Chen, ”Scalable Routing Strategies for Ad-hoc Wireless Networks,” IEEE Journal on Selected Areas in Communications, Aug. 1999, pp. 1369-1379.
[15] S.-J. Lee, C.-K. Toh, and M. Gerla, ”Performance Evaluation of Table- Driven and On-Demand Ad Hoc Routing Protocols,” in Proceedings of IEEE PIMRC’99, Osaka, Japan, Sep. 1999, pp. 297-301.
[16] Bellman-Ford: R.E. Bellman, Dynamic Programming, Princeton University Press, Princeton, NJ, 1957.

[17] K. Patel, D.R.Vaman," Graph Theoretic Routing Algorithm (GTRA) For Mobile Ad-Hoc Networks (MANET)", International Journal on Applications of Graph Theory in Wireless Ad hoc Networks and Sensor Networks (GRAPH-HOC), Vol 5, No. 4, ,December 2013
[18] E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," in Proc. IEEE Workshop on Mobile Comp. Sys.and Apps., Feb. 1999, pp. 90-100.
[19] B. Johnson and D. A. Maltz, "Dynamic source routing in ad hoc wireless networks," in Mobile Computing, 1996, pp. 153-181.
[20] C.-K. Toh, "Associativity-Based Routing For Ad Hoc Mobile Networks," Wireless Personal Communications Journal, Special Issue on Mobile Networking and Computing Systems, Kluwer Academic Publishers, vol. 4, no. 2, Mar. 1997, pp. 103-139.
[21] Park V. and S. Corson, 2001. Temporary-ordered Routing Algorithm (TORA). Internet Draft, draft-ietf-manettora-spec-04.txt.
[22] Y. Ko and N. H. Vaidya, "Location-aided routing (LAR) in mobile ad hoc networks," Wireless Networks, 6(4), July 2000, pp. 307-321.
[23] J. Raju, J. Garcia-Luna-Aceves, A new approach to on demand loop-free multipath routing, in: Proceedings of the 8th Annual IEEE International Conference on Computer Communications and Networks (ICCCN), Boston, MA, October 1999, pp. 522–527.
[24] MALEKI, M., DANTU, K., AND PEDRAM, M. 2003. Lifetime prediction routing in mobile ad hoc networks. In Wireless Communication and Networking Conference. New Orleans, LA. USA
[25] G. Pei, M. Gerla, and T.-W. Chen,"Fisheye State Routing: A Routing Scheme for Ad Hoc Wireless Networks," in Proceedings of ICC 2000, New Orleans, LA, Jun. 2000
[26] P. Jacquet, P. Muhlethaler, A. Qayyum, A. Laouiti, L. Viennot and T. Clausen, "Optimized Link State Routing Protocol," draft-ietf-manet-olsr- 05.txt, Internet Draft, IETF MANET Working Group, Nov. 2000.
[27] T. Clausen and P. Jacquet. Optimized Link State Routing Protocol (OLSR). IETF, October 2003. RFC 3626.
[28] R. G. Ogier, F. L. Templin, B. Bellur and M. G. Lewis, "Topology Broadcast based on Reverse-Path Forwarding (TBRPF)," draft-ietf-manettbrpf 05.txt, INTERNET-DRAFT, MANET Working Group, Mar. 2002.
[29] B. Bellur, R.G. Ogier, F.L Templin, Topology broadcast based on reverse-path forwarding routing protocol (tbrpf), in: Internet Draft, draft-ietf-manet-tbrpf-06.txt, work in progress, 2003.
[30] Neumann, C. Aichele, M. Lindner, and S. Wunderlich, Better Approach To Mobile Ad-hoc Networking (B.A.T.M.A.N.), Internet-Draft, pages 1-24, 2008. Network Working Group.
[31] E. Perkins and P. Bhagwat, "Highly dynamic destination sequenced distance-vector routing (DSDV) for mobile computers", Computer Communications Review, pp. 234-244, Oct.1994.
[32] K.K. Kasera, R. Ramanathan, A location management protocol for hierarchically organised multihop mobile wireless networks, in: Proceedings of the IEEE ICUPC_97, San Diego, CA, October 1997, pp. 158–162.
[33] C.-C. Chiang, Routing in clustered multihop mobile wireless networks with fading channel, in: Proceedings of IEEE SICON, April 1997, pp. 197–211.
[34] G. Pei, M. Gerla, X. Hong, and C. -C. Chiang, "A Wireless Hierarchical Routing Protocol with Group Mobility," in Proceedings of IEEE WCNC'99, New Orleans, LA, Sept. 1999.
[35] T.-W. Chen, M. Gerla, Global state routing: a new routing scheme for ad-hoc wireless networks, in: Proceedings of the IEEE ICC, 1998.
[36] J. Garcia-Luna-Aceves, C. Marcelo Spohn, Source-tree routing in wireless networks, in: Proceedings of the Seventh Annual International Conference on Network Protocols Toronto, Canada, October 1999, p. 273
[37] S. Basagni, I. Chlamtac, V. R. Syrotiuk, and B. A. Woodward, "A distance routing effect algorithm for mobility (DREAM)," in ACM/IEEE International Conference on Mobile Computing and Networking (Mobicom98), 1998,pages 76 - 84.
[38] M. A. Rajan, M. G. Chandra, L. C. Reddy and P. Hiremath, "Concepts of Graph Theory Relevant to Ad-hoc Networks". International Journal of Computers, Communications & Control, Vol. 3, No.Suppl, pp. 465-469, 2008.
[39] Meghanathan, Natarajan, "Applications of Graph Theory Algorithms in Mobile Ad hoc Networks".

[40] Z.J. Haas and M.R. Pearlman, "The Performance of Query Control Schemes for the Zone Routing Protocol," ACM/IEEE Transactions on Networking, vol. 9, no. 4, August 2001, pp. 427-438.

[41] D.R. Vaman, N. Shakhakarmi, "Integrated Key based Strict Friendliness Verification of Neighbors in MANET, IEEE International Conference On Security Science and Technology, Jan 22, ICSST 2011.

[42] N. Shakhakarmi, D. R. Vaman, "Distributed Position Localization and Tracking (DPLT) of Malicious Nodes in Cluster Based Mobile Ad hoc Networks (MANET)", WSEAS Transactions in Communications, ISSN: 1109-2742, Issue 11, Volume 9, November 2010.

[43] C. R. Lin and M. Gerla, "Adaptive Clustering for Mobile Wireless Networks", Journal on Selected Areas in Communication, Vol. 15 pp. 1265-1275, September 1997.

[44]M. Gerla and J.T.-C. Tsai, Multicluster, mobile, multimedia radio network, Wireless Networks 1(3) (1995) 255–265

[45] M. Chatterjee, S. K. Das, and D. Turgut, "WCA: A Weighted Clustering Algorithm for Mobile Ad hoc Networks", Journal of Cluster Computing, Special issue on Mobile Ad hoc Networking, No. 5, 2002, pp. 193-204.

[46] Lih-Hsing Hsu , Cheng-Kuan Lin, Graph Theory and Interconnection Networks, CRC Press, Inc., Boca Raton, FL, 2009

[47] Jean-Claude Fournier, Graph Theory and Applications with exercises and problems, ISBN: 9781848210707,Feb'09.

[48] Marks, R.J.; Das, A.K.; El-Sharkawi, M.; Arabshahi, P.; Gray, A., "Minimum power broadcast trees for wireless networks: optimizing using the viability lemma," Circuits and Systems, 2002. ISCAS 2002. IEEE International Symposium on , vol.1, no., pp.I-273,I-276 vol.1, 2002

[49] Kleinrock, Leonard (1975). Queuing Systems Volume 1: Theory.

Authors

Kirtikumar K. Patel received the B.S. degree in Electronics and Communication Engineering from Hemchandracharya North Gujarat University, India, and M.S. degree in Electrical Engineering from Lamar University, United States of America in 2006 and 2008, respectively. He is currently working towards his PhD. degree in the Department of Electrical and Computer Engineering at the Prairie View A&M University, a member of the Texas A&M University System. His current research interests include mobile ad hoc network, routing algorithms, Communication and signal processing as well as graph theory applications and contention resolution algorithms.

Dhadesugoor R. Vaman is Texas Instrument Endowed Chair Professor and Founding Director of ARO Center for Battlefield Communications (CeBCom) Research, ECE Department, Prairie View A&M University (PVAMU). He has more than 38 years of research experience in telecommunications and networking area. Currently, he has been working on the control based mobile ad hoc and sensor networks with emphasis on achieving bandwidth efficiency using KV transform coding; integrated power control, scheduling and routing in cluster based network architecture; QoS assurance for multi-service applications; and efficient network management. Prior to joining PVAMU, Dr. Vaman was the CEO of Megaxess (now restructured as MXC) which developed a business ISP product to offer differentiated QoS assured multi-services with dynamic bandwidth management and successfully deployed in several ISPs. Prior to being a CEO, Dr. Vaman was a Professor of EECS and founding Director of Advanced Telecommunications Institute, Stevens Institute of Technology (1984-1998); Member, Technology Staff in COMSAT (Currently Lockheed Martin) Laboratories (1981-84) and Network Analysis Corporation (CONTEL)(1979-81); Research Associate in Communications Laboratory, The City College of New York (1974-79); and Systems Engineer in Space Applications Center (Indian Space Research Organization) (1971-1974). He was also the Chairman of IEEE 802.9 ISLAN Standards Committee and made numerous technical contributions and produced 4 standards. Dr. Vaman has published over 200 papers in journals and conferences; widely lectured nationally and internationally; has been a key note speaker in many IEEE and other conferences, and industry forums. He has received numerous awards and patents, and many of his innovations have been successfully transferred to industry for developing commercial products.