Minimizing Routing Broadcast and Packet Loss in Wireless Ad-hoc Networks with a Cluster-Based Self-Organized Algorithm as MAC protocol

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***Abstract*—One of the main issues of routing protocols on wireless ad-hoc networks is the energy consumed by the traffic generated in the route discovery and routing table construction and maintenance. To reduce such of amount messages, we propose to use a backbone structure which would control the network traffic flow in an energy-efficient manner. This paper proposes the implementation of the energy-efficient self-organized algorithm (EESOA) as Medium Access Control (MAC) protocol. Also, we extended the algorithm to address network segmentation by handling inter clusters connectivity. EESOA as MAC provide a backbone structure for wireless ad-hoc networks due to their cluster-based capabilities and robustness to topology changes. The encapsulation of EESOA on MAC provides a cross layer solution, agnostic to the routing protocol and wireless technology. To show the performance of this cross-layer solution, an implementation of a wireless ad-hoc network with AODV and EESOA as MAC protocol in the NS3 simulator is used. This simulation allows evaluating the performance of the AODV routing protocol over EESOA as MAC protocol compared against normal Ad-hoc MAC. Therefore, the use of routing protocol over a self-organized algorithm can obtain better results, in packet loss, network connectivity and node reachability.**

***Index Terms*—AODV, self-organization, EESOA, ad-hoc network, clustering, emergent behavior, stigmergy, WSON.**

I. Introduction

Wireless networks can be categorized in infrastructure-based and infrastructure-less wireless networks, also called wireless ad-hoc networks. Wireless ad-hoc network consists on two or more wireless devices able to communicate with each other without any centralized administrator. Each node works as both a host and a router although they have less computational capabilities [1]. The network topology is dynamic because the connectivity among nodes vary with time due to node mobility, node departures and new node arrivals [2].

Ad-hoc networks are decentralized, nodes are connected in heterogeneous manner using wireless links [3]. Ad-hoc network introduces terms such as distributed, resource-constrained, self-organized and infrastructure-less [4]. Resource constrains distinct ad-hoc networks on hardware and energy limitations when compared with wired networks. The ability to reach inhospitable terrains and reduced cost for physical implementation against wired networks offers a wide range of applications. For example, sensor monitoring of cropping zones and farming, emergency response tasks, health care monitoring, environmental sampling, surveillance and security applications [5]. However, such applications requires protocols that make possible the communication between the devices. Routing protocols require to construct routing tables by sending messages through the network performing several broadcast messages until the shortest path to all different nodes are discovered. These processes are energy consuming since they flood the network with a large amount of messages.

In this work, we propose a cross-layer approach which consists of implementing a routing protocol over a clustered-based algorithm as MAC. The algorithm is able to construct a backbone which is a logical structure that connects all nodes of the network through a subset of nodes with the best quality. The backbone establishes the rules of how the nodes communicate with its neighbors in order to reduce the amount of messages. Routing tables construction and maintenance will be directly affected by the backbone, once is constructed, controlling which nodes will be visible to the routing protocol as well as the intra nodes communication, therefore minimizing the messages and thus the energy. The problem of constructing a backbone structure on wireless ad-hoc networks has been widely researched. Cluster-based algorithms address the backbone construction and maintenance due to their self-organized nature. This work chose the Energy-Efficient Self-Organized Algorithm (EESOA), since it construct and maintain a backbone structure.

In this paper we present an extension of the EESOA algorithm which addresses network segmentation. The extended EESOA encapsulated by the MAC layer provides a novel cross-layer solution approach which is agnostic to the routing protocol, i.e., any other routing protocol can be used without significant modification. Additionally we describe how to implement such approach in the Network Simulator 3 (NS3). Finally we compare the simulation results of network traffic with AODV over ESSOA as MAC and ad-hoc MAC.

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The rest of this work is organized as follows: Sections II and III introduces cluster-based and routing algorithms for wireless networks. Section IV introduces an improvement of EESOA and its implementation as MAC protocol. Section V defines the testbed for the Network Simulator 3 on which AODV will run over EESOA as MAC protocol. Section VI shows the NS3 simulation results of AODV with EESOA and with normal Ad-hoc MAC, presenting a performance comparison between both scenarios. Section VII concludes this work. Finally Section VIII presents future work of this research.

II. Cluster-based Algorithms in Wireless Ad-hoc Networks

Routing in wireless ad-hoc networks requires special management. Providing a virtual infrastructure such as the virtual backbone is of high importance [6]. The backbone structure will have a critical effect on the network traffic efficiency and therefore in the energy consumption. Lifetime of the network depends on the residual energy of the system [7], hence clustering schemes plays an important role in the energy-efficiency performance for routing algorithms by providing an efficient route for forwarding the packet in the network. Cluster-based algorithms on ad-hoc networks has become a hot research field in recent years [1], [3], [4], [8]–[11].

Network-efficient protocol design is a cross-layer issue which spans the network and MAC layer [12]. Routing layer aims to choose routes which balance network traffic among nodes while MAC layer will impact on the routing protocol, specifically on routing tables. Therefore, combining routing and cluster-based algorithms as MAC protocol is appropriate for such network-efficient protocol. We will discuss the role of cluster-based algorithms in the remainder of this section.

As shown by [13], cluster-based schemes address the problem of construction and maintenance of virtual backbone in wireless ad-hoc networks. Clustering schemes takes into account ad-hoc networks limitations, i.e., nodes in the network only have local information of the neighbors within one hop. Self-organized clustering schemes achieve a global pattern in the system to emerge from the numerous individual interactions of the lower-level components of the system which is consistent with the stigmergy principle.

An approach to Cluster Head (CH) selection is the Mobility-based Clustering technique (MOBIC) [14], nevertheless is not energy oriented on its Weighted Clustering Algorithm (WCA), besides, the control overhead messages are too high. Energy Efficient Clustering (EEC) [15], address the battery limitations on its WCA, taking into account the node's degree and bandwidth for the CH selection, but has the drawback of cluster overlapping. [16], proposes the Max Heap Algorithm (Max-Heap) which for CH selection chooses the node with highest energy levels, but also do not address the overlap of clusters. The Load Balancing Clustering Mechanism (LBCM) [17] address the problem of cluster overlapping at cost of using a genetic algorithm, which is costly. Combined-Metrics Based Clustering (CMBC) [18], by using the Score Based Algorithm (SCBA) is proposed as an alternative.

With the aforementioned, we conclude that clustering schemes which considers combined metrics shows more promise, Adaptive On-demand Weighting clustering algorithm (AOW) [19] serves as a good example of the aforesaid in Wireless Self-Organized Networks (WSON). We reviewed several energy-efficient clustering protocols such as DE-MAC [20], EEMAC [12], EA-TDMA MAC [21], WEAC [22] and EESOA [23], for the scope of this work EESOA was chosen as the clustering algorithm to be implemented as MAC protocol.

III. Routing Algorithms for Wireless Ad hoc Network Simulation

A. Routing Protocols Taxonomy

Routing algorithms can be classified in 3 different types in wireless ad hoc networks [24]: Proactive, Reactive and Hybrid routing protocols. The proactive approach constantly updates the routing tables contrary to reactive protocols which updates the routing tables only if it is required. Hybrid protocols mix these two protocols depending on the context. On proactive protocols you can find Distance-Sequenced Distance Vector (DSDV) and Optimized State Link State (OLSR), on the reactive side we can find Dynamic Source Routing (DSR) and Ad hoc On Demand Distance Vector (AODV), finally on the Hybrid approach, most common protocols are Zone Routing Protocol (ZRP) and Wireless Ad hoc Routing Protocol WARP.

Surveys comparing the performance of network simulators can be found at [24]–[30]. On [24], a performance comparison between the aforementioned routing schemes on open source simulators shown that most of the surveys chooses AODV [31], [32] as routing protocol for their simulations due to the pre-availability in the network simulators being compared and because it maintains a time-based state as part of its protocol. Thus, for the aforementioned, for simulation purposes AODV was chosen as the routing protocol to use EESOA as MAC.

IV. EESOA reviewed

A. EESOA Summary

EESOA is a clustering algorithm which builds a virtual backbone through the formation based on 4 hierarchies. It consists in a set of rules on which each node self assigns a hierarchy based on local information of their neighbors within one hop. The best node in a cluster according to quality criteria defined at [23] will have the leader role and will start to inhibit its neighbors with periodic hello broadcast messages. A gateway is a node inhibited by two or more leaders. A member is an inhibited node by a single leader. A bridge is an inhibited node connected to another node inhibited by a leader from another cluster. Bridges will exists as long as no gateway or other bridge is detected to being already connecting the same clusters. The leader along with it's inhibited nodes will form a cluster, this can be observed at the EESOA-MAC layer shown on Fig. 2. EESOA, through its simple rules, will adapt to the dynamic topology of wireless ad hoc networks by re-clustering due to its distributed self-organized nature. EESOA is described in detail in [23].

Algorithm 1 Network Segmentation Managing Algorithm Overview for node u

L_w is the set Leaders of neighbors gateways of node u
C_T is the set of group Ids of neighbors of node u whom are Members or Bridges with different GroupId
C_N is the set of all Id Connects of the Bridge neighbors
C_u = C_T - C_N - L_w
if $C_u \neq \emptyset$ **then**
    $Role_u$ = Bridge
    C_u = C_T
end if

Algorithm 2 Network Segmentation Managing Algorithm

$|X(u)| = 1$ **if** $role_u = (Member \vee Bridge)$
$X(u) = \{id_{best}\}$ $id_{best} = BestLeader$
function TREAT_BRIDGES
    if $\exists v \in N(u) \mid role_v = Gateway$ **then**
        $L_w = L_w \cup X(v)$
    end if
    if $\exists v \in N(u) \mid role_v = (Member \vee Bridge), X(v) \cap X(u) = \emptyset$ **then**
        $C_T = C_T \cup X(v)$
    end if
    if $\exists v \in N(u) \mid role_v = Bridge, X(v) \cap X(u) \neq \emptyset$ **then**
        $C_N = C_N \cup C_v$
    end if
    $C_u = C_T - C_N - Lw$
    if $C_u \neq \emptyset$ **then**
        $role_u = bridge$
        $C_u = C_T$
    end if
end function

B. EESOA extended

Although EESOA's bridge role designation aid inter-cluster communication, an extension to EESOA algorithm which addresses network segmentation is proposed in this work. After a node self assigns the bridge role when performing the EESOA [23], a new sub-algorithm is proposed to be performed, `TREAT_BRIDGES`. A key element in this algorithm is the set of other clusters `group_Ids` observed by the neighbors of the potential bridge node, such set is defined as `Id_connects`. The high level description of the `TREAT_BRIDGES` is shown in Algorithm 1, the detailed definition of the `TREAT_BRIDGES` algorithm is described in Algorithm 2. The novelty EESOA's extension relies in determine if a member is connected to a bridge or member of a different cluster and no other backbone neighbor is connected to it. In such case the member becomes a bridge.

The processes shown in algorithm 2 consist on filling the sets L_w, C_N which are all cluster ids connected to the gateways and clusters ids of neighbors of node u respectively. All clusters' Ids are in fact leaders' Ids, denoted by $X(u)$, the leaders of node u. On the other hand C_T indicates all clusters the node u is connected with. Therefore, if the difference between C_T and $L_w + C_N$ is not empty, means that node u is connected to a cluster that no other of its neighbors (bridges and gateways), thus u becomes a bridge. Finally, C_u is the connect set of node u meaning all different clusters u can see, so it will be equal to C_T in case that node u become a bridge. Thus, the new Bridge designation scheme address the network segmentation problem which can be observed at Fig. 1.

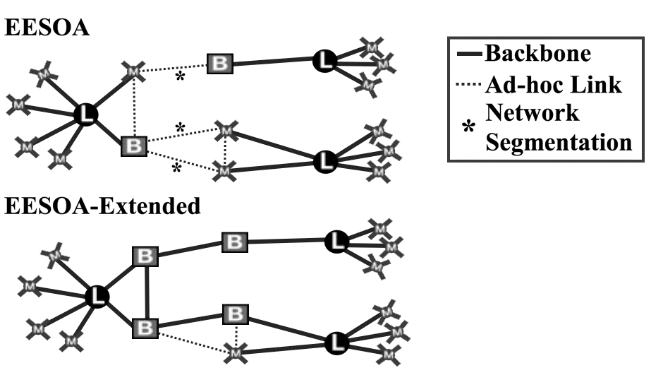


Fig. 1: EESOA vs Extended EESOA.

C. AODV over EESOA-MAC

ESSOA as MAC with its backbone structure will only allow communication between nodes among which its link is defined as backbone. It will be said that a link between two nodes is backbone if the relationship among such nodes meets the criteria defined in Table I. Thus, at EESOA-MAC layer, nodes will gather information of the nodes within one hop and will perform EESOA to self-assign a role. EESOA-MAC will only allow to a node to receive an upper layer packet if it comes from a node with which the link relationship is backbone.

Therefore at AODV routing layer, nodes will be visible among each other as long as the link between them is backbone. Hence, minimizing routes to which the backbone structure allows. The interaction between EESOA-MAC and AODV can be observed on Fig. 2. The aforementioned minimization of possible routes thanks to EESOA-MAC when compared the AODV over Ad-hodc MAC (standard MAC) against AODV over EESOA-MAC can be observed on Fig. 2.

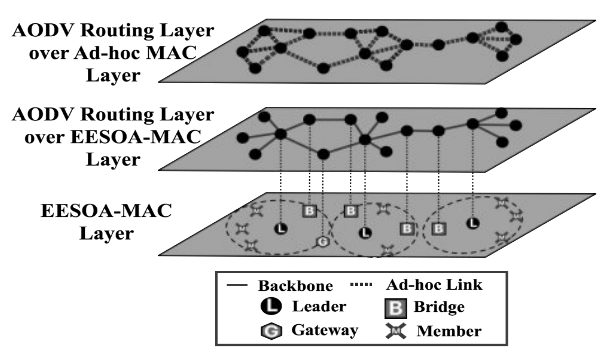


Fig. 2: AODV interface with EESOA-MAC.

V. SIMULATION

Network Simulator 3 [33], is an open sourced discrete-event network simulator. NS3 is the successor of Network Simulator 2 (NS2) [34], as NS2 provides several models as well as a very well documentation and support. The present work chose NS3 for simulation purposes due to high availability of models and protocols. NS3 is described in detail at [24], [34] and [35].

A. EESOA as MAC on NS3

In order to implement EESOA as MAC protocol on NS3 a new MAC protocol module was required [33], [36]. The EESOA MAC module (`EESOA`) is an extension of the NS3 `AdhocWifiMac` module. The `NeighborDiscovery` MAC is an intermediate layer between the EESOA and AdhocWifiMac in order to support modularity and allow support for new clustering algorithms to be added to the module. NeighborDiscovery abstracts the neighbor discovery process from the cluster algorithm implemented as shown on Fig. 3.

The neighbor discovery process consists on a node sending hello broadcast messages with the node's info (`NodeInfo`) such as it's Id on the packet's header (`DiscoveryHeader`). If the node receives a response to such hello message it will add the responder node's Id to it's neighbor table (`NeighborTable`). With the abstraction that the neighbor discovery layer provides, EESOA MAC protocol remains simple, focusing on constructing and maintaining the virtual backbone as well as remaining agnostic to the routing protocol and wireless technology.

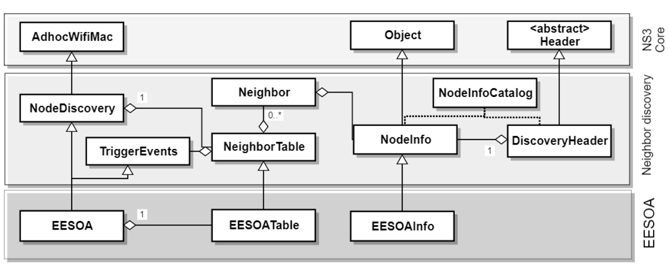


Fig. 3: EESOA Module NS3 Architecture.

EESOA algorithm was implemented as defined in detail at [23] with the addition of the enhancement algorithm `TREAT_BRIDGES` on the EESOA algorithm mentioned on section IV. With the node's neighbor information (`EESOAInfo`) taken from it's neighbor table (`EESOATable`), the node runs the EESOA algorithm as described in [23]. `EESOAInfo` contains EESOA's critical information such as node's Id, role, neighbors and neighbor's role. Once clusters are formed on the wireless network and node's hierarchies roles are assigned, any incoming message which does not come with the neighbor discovery header, which means is a upper routing packet instead of an EESOA packet, in the received packet will be processed. If the packet does not contain a `DiscoveryHeader`, means the traffic is non EESOA, thus must come from the network traffic. EESOA MAC will only allow the flow of packets from one node to another as long as the connection between them is backbone.

The rules of node's communication between nodes are define in the Table I, absent links are defined as non-backbone.

TABLE I: EESOA Backbone Communication.

Bidirectional Hierarchy Role Link
Member $\leftrightarrow$ Leader
Bridge $\leftrightarrow$ Bridge
Bridge $\leftrightarrow$ Leader
Gateway $\leftrightarrow$ Leader

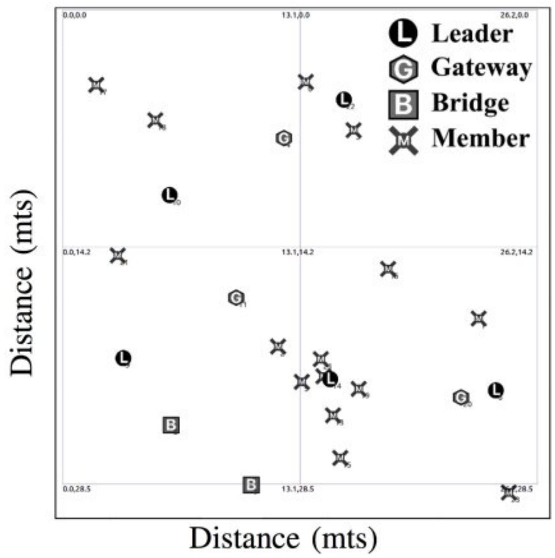
With the aforementioned rules, the network traffic will be limited to let packets flow among nodes of the network as long as they are part of the backbone structure, thus limiting the received broadcast packets, unwanted loops on network traffic and redundant traffic while maintaining a network connectivity due to the virtual backbone structure. As node's energy levels decay and its battery run out of energy, the network will re-clusterize and the backbone structure will be reconstructed. Thus the perceived nodes by the routing algorithm will be much less, leaving a reduced routing table due to the proactive nature of the EESOA MAC protocol.

B. Simulation Environment

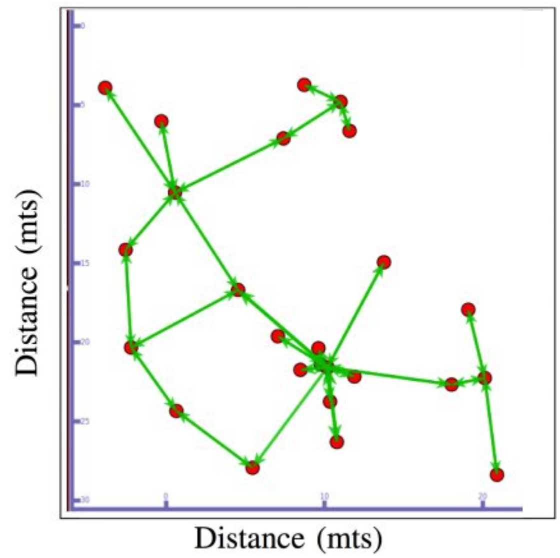
Simulations were conducted on the NS3 network simulator using AODV as the routing protocol and for MAC using the in-built NS3 AdhocWifiMac MAC protocol and the EESOA MAC protocol defined in this section. The setup of parameters used on the NS3 simulation of the presented work is described in detail in Table II. Nodes positions were generated by using NS3 uniform random number generator (RNG) in order to create a connected graph for the network. An example of a 25 nodes, connected graph network deployment on NS3 before simulation start is shown in Fig. 4.

Nodes hierarchy are depicted graphically in NS3 for graphically identification as shown in Fig. 4a. On Fig. 4a is shown the network graph after EESOA-MAC algorithm converges. 5 Leaders, 3 Gateways, 3 Bridges and 12 Members are formed on the simulated network. The backbone structure is formed by creating as many Member nodes as possible. It can be noted that bridge node 16 would form a backbone connection with the potential bridge node 3, which is not bridge due to the `TREAT_BRIDGES` algorithm, which takes into account redundancies since node 3 observes that the gateway node 4 is already connecting its cluster.

Fig. 4b illustrates the network traffic flow through the EESOA-MAC protocol which "filters" non backbone packets, thus causing AODV only to "perceive" backbone nodes on its routing tables. Leaders receive traffic from all of its cluster members, on the other hand, due to the filtering done by EESOA-MAC traffic between Gateway node 11 and Bridge Node 16 is not enabled, while communication between Gateway node 4 with Leaders nodes 10 and 22 is permitted, finally redundant paths anticipating network segmentation are provided by Bridges nodes such as nodes 8 and 7.



(a) NS3 Simulation after EESOA-MAC converges.



(b) NS3 Simulation backbone communication.

Fig. 4: NS3 Simulation Results

TABLE II: NS3 Simulation Structure.

Parameter	Values
NS3 Version	3.25*
Simulation Time	60 seconds*
Simulation Area	50x50 mts*
Number Of Nodes	100*
Channel	Wireless Channel
Propagation Loss Model	Range*, 15 mts
Wifi Standard	802.11b*
MAC Type	AdhocWifiMac*, EESOA*
Routing Protocol	AODV*
Packet Size	256 KB

*NS3 specific parameters.

The aforementioned test scenario provides an example of the packet reduction that EESOA-MAC provides to routing layers by limiting the visibility of nodes in terms of backbone, thus decreasing the network traffic flow as shown on Fig. 4b.

VI. PERFORMANCE EVALUATION

In this section, we conduct simulation to assess the performance of AODV over the proposed EESOA-MAC and the existing NS3 Ad-hoc-MAC.

A. Simulation Testbed

NS3 simulation setup is described on Table II. Simulation consists on a network of 100 nodes distributed in a 50x50 mts area in a uniform randomly manner. Simulation was executed for 60 seconds with random network traffic generation of 10% of the nodes. Network traffic was generated on a time window of 10 to 60 seconds. For the network configuration, AODV routing protocol was selected and EESOA-MAC and default NS3 AdhocWifiMac as MAC protocol.

B. Simulation Results

Fig. 5 depicts the number of Leaders, Gateways, Bridges and Members per simulation. Fig. 6 presents results in terms of packet loss percentage, Fig. 7 presents a comparison of total packets transmitted in the 50 seconds window simulation.

As can be observed on Fig. 5, the aim of the EESOA is to have as many members as possible. As for the number of leaders and gateways, from the 10 simulations, on 9 of the simulation there were less or equal number of leaders than gateways. Finally, on the simulations results it can be noticed that EESOA generated as minimum Bridges as possible while maintaining connectivity and avoiding network segmentation.

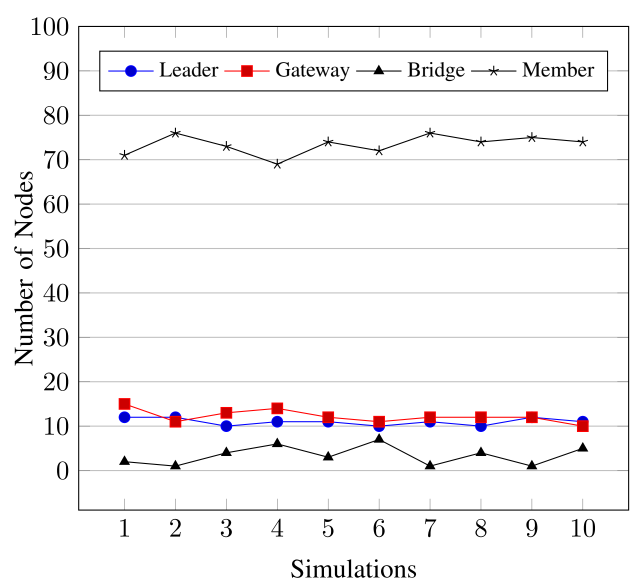


Fig. 5: Number of nodes per cluster hierarchy per Simulation.

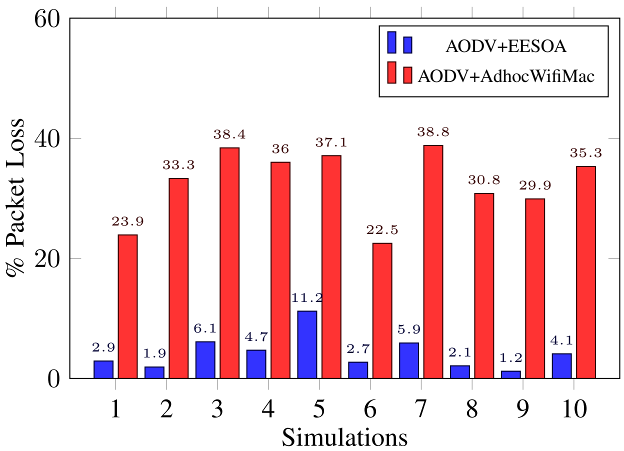


Fig. 6: Packet loss percentage per simulation.

Fig. 6 depicts the packet percentage loss of network traffic generated. From the 10 simulations, it can be observed that the packet loss when the network traffic flows with AODV over EESOA-MAC is remarkably less than when AODV uses the Ad hoc MAC. This is due to the redundancy provided by the virtual backbone constructed and maintained by EESOA, Gateway and Bridge nodes provide alternative routes which AODV takes advantage of.

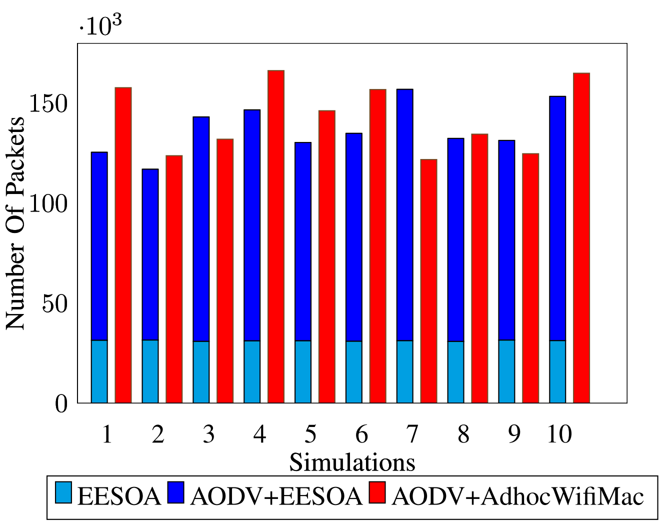


Fig. 7: Total number of packets transmitted per simulation.

Fig. 7 provide the total number of packets transmitted on the 50 second window, starting at second 10. The number of packets transmitted when using AODV over EESOA-MAC is considerably less than when using the normal Adhoc MAC. Although there is an overhead of packet transmission due to the proactive nature of the EESOA neighbor discovery scheme. EESOA-MAC will not permit packets to flow through non backbone paths. Also EESOA-MAC limits the nodes that AODV can perceive as neighbors, thus reducing AODV routing tables as well.

VII. CONCLUSION

In this paper an extension of EESOA was proposed on section IV-B, furthermore the implementation of the EESOA as MAC protocol provided a novel cross-layer solution when combined with a routing algorithm. Nevertheless, the proposed EESOA-MAC scheme remains agnostic to the routing protocol as well as the wireless technology. Additionally, a modular cluster-based agnostic NS3 module is proposed for simulation purposes. Such module is modular for other cluster-based algorithms to be implemented for comparison purposes. Simulation results have shown that the performance of network traffic with AODV over the proposed EESOA-MAC was more efficient than AODV with NS3 AdhocWifiMAC in terms of total packets transmission.

Also the EESOA extension algorithm, `TREAT_BRIDGES` shows promise by addressing the network segmentation problem which translated in less packet loss. Simulation results showed that EESOA improves network performance by reducing redundant traffic, ensures network connectivity and prevent network segmentation by the nature of the virtual backbone constructed by the EESOA algorithm.

VIII. FUTURE WORK

Research on self-organized cluster-based algorithms for wireless ad-hoc networks is still a hot research field [1], [3], [4] , [8]–[11] which presents a wide range of open challenges.

EESOA parameters for optimal performance are required to be found such as hello broadcast transmission and response time intervals as well as the time deltas threshold to remove a node from EESOA's neighbor table. Residual energy consumption of current research is an ongoing investigation and therefore left for future work in conjunction with simulations on a dynamic and mobile topology wireless network.

Finally, to design an EESOA-MAC based routing algorithm that takes full advantage of the EESOA-MAC protocol remains as a open problem.

REFERENCES

[1] M. Ozger, F. Alagoz, and O. B. Akan, "Clustering in multi-channel cognitive radio ad hoc and sensor networks," *IEEE Communications Magazine*, vol. 56, no. 4, pp. 156–162, April 2018.

[2] J. L. J. Loo and H. Ortiz, *Mobile Ad Hoc Networks: Current Status and Future Trends*. 6000 Broken Sound Parkway NW, Suite 300 Boca Raton, FL: CRC Press, 2011.

[3] S. K. Das and S. Tripathi, "Adaptive and intelligent energy efficient routing for transparent heterogeneous ad-hoc network by fusion of game theory and linear programming," *Applied Intelligence*, vol. 48, no. 7, pp. 1825–1845, Jul 2018.

[4] A. M. Desai and R. H. Jhaveri, "Secure routing in mobile ad hoc networks: a predictive approach," *International Journal of Information Technology*, Apr 2018.

[5] A. H. Moshin, K. A. Bakar, A. Adekiigbe, and K. Z. Ghafoor, "A survey of energy-aware routing and mac layer protocols in manets: trends and challenges," *Network Protocols and Algorithms*, vol. 4, no. 2, pp. 82–207, Jun. 2012.

[6] R. Azarderakhsh, A. H. Jahangir, and M. Keshtgary, "A new virtual backbone for wireless ad-hoc sensor networks with connected dominating set," in *Third Annual Conference on Wireless On-demand Network Systems and Services(WONS*, Les Ménuiewa, France, jan 2006, pp. 191–195.

[7] V. Kumar, S. B. Dhok, R. Tripathi, and S. Tiwari, “A review of hierarchical clustering algorithms for wireless sensor networks,” *International Journal of Computer Science Issues (IJCSI)*, vol. 11, no. 3, pp. 92–101, May 2014.

[8] S. Z. Hussain and N. Ahmad, “Minimizing broadcast expenses in clustered ad-hoc networks,” *Journal of King Saud University - Computer and Information Sciences*, vol. 30, no. 1, pp. 67 – 79, 2018. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1319157816300258 (Accessed August 20, 2018).

[9] D. A. Kulkarni, A. Kulthe, P. Moholkar, M. Sawant, and C. Palesha, “An approach to self-organizing adaptive virtual back-bone energy-aware role-based(saver) strategy for manet,” in *2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)*, March 2016, pp. 357–360.

[10] I. Ghosh, “Study on hierarchical cluster-based energy-efficient routing in wireless sensor networks,” *International Research Journal of Engineering and Technology (IRJET)*, vol. 5, pp. 688–691, Mar. 2018.

[11] S. Baskaran, J. A. V. Selvi, and V. R. S. Dhulipala, “Trust based cluster-energy efficient multicast routing in mobile adhoc networks,” *Appl. Math. Inf. Sci.*, vol. 12, no. 2, pp. 421–429, Mar. 2018.

[12] Y. Shi and T. A. Gulliver, “An energy-efficient mac protocol for mobile ad hoc networks,” in *4th Annual Communication Networks and Services Research Conference (CNSR’06)*, May 2006, pp. 10 pp.–88.

[13] A. M. Rani and J. Sivaranjani, “A state of art of various clustering schemes in manets,” *International Journal of Innovative Research in Science and Engineering (IJIRSE)*, vol. 3, pp. 68–75, Feb. 2017.

[14] J. A. Torkestani and M. R. Meybodi, “A mobility-based cluster formation algorithm for wireless mobile ad-hoc networks,” *Cluster Computing*, vol. 14, no. 4, pp. 311–324, Dec 2011.

[15] K. Dalasaniya and N. Dutta, “An efficient cluster management mechanism for manets,” in *2014 IEEE International Conference on Computational Intelligence and Computing Research*, Dec 2014, pp. 1–6.

[16] M. Saxena, N. Phate, K. J. Mathai, and M. A. Rizvi, “Clustering based energy efficient algorithm using max-heap tree for manet,” in *2014 Fourth International Conference on Communication Systems and Network Technologies*, April 2014, pp. 123–127.

[17] M. Chatterjee, S. K. Das, and D. Turgut, “An on-demand weighted clustering algorithm (wca) for ad hoc networks,” in *Global Telecommunications Conference, 2000. GLOBECOM ’00. IEEE*, vol. 3, Nov 2000, pp. 1697–1701 vol.3.

[18] M. R. Monsef, S. Jabbehdari, and F. Safaei, “An efficient weight-based clustering algorithm for mobile ad-hoc networks,” *Journal of Computing*, vol. 3, no. 1, pp. 16–20, Jan 2011.

[19] H. Wang, H. Chen, and L. Song, “Improved aow clustering algorithms for wireless self-organized network and performance analysis,” in *CSQRWC 2012*, July 2012, pp. 142–146.

[20] R. Kalidini, L. Ray, R. Kannan, and S. Iyengar, “Distributed energy aware mac protocol for wireless sensor networks,” in *International Conference on Wireless Networks*, JUN 2003, pp. 282–286.

[21] K. Arisha, M. Youssef, and M. Younis, “Energy-aware tdma-based mac for sensor networks,” in *IEEE Workshop on Integrated Management of Power Aware Communications, Computing and Networking (IMPACCT 2002*, May 2002, pp. 21–40.

[22] T. Sheltami and H. T. Mouftah, “An efficient energy aware clusterhead formation infrastructure protocol for manets,” in *Proceedings of the Eighth IEEE Symposium on Computers and Communications. ISCC 2003*, June 2003, pp. 203–208 vol.1.

[23] J. G. Olascuaga-Cabrera, A. Mendez-Vazquez, and E. López-Mellado, “A novel distributed energy-efficient self-organized algorithm for wireless ad hoc networks,” in *2012 Eighth International Conference on Intelligent Environments*, June 2012, pp. 19–26.

[24] D. Bhatia, “A comparative analysis of proactive, reactive and hybrid routing protocols over open source network simulator in mobile ad hoc network,” *International Journal of Applied Engineering Research*, vol. 11, no. 6, pp. 3885–3896, May 2016.

[25] S. M. Bilal and M. A. Othman, “Performance comparison of network simulators for wireless networks,” in *Proc. IEEE International Conference on Control System, Computing and Engineering (ICCSCE)*, Nov 2012, pp. 34–38.

[26] L. Hogie, P. Bouvry, and F. Guinand, “An overview of manets simulation,” *Electronic notes in theoretical computer science*, vol. 150, no. 1, pp. 81–101, Mar 2006.

[27] S. Siraj, A. Gupta, and R. Badgujar, “Network simulation tools survey,” *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 1, no. 4, pp. 199–206, 2012.

[28] M. H. Kabir, S. Islam, M. J. Hossain, and S. Hossain, “Detail comparison of network simulators,” *International Journal of Scientific and Engineering Research*, vol. 5, no. 10, pp. 203–218, Nov 2014.

[29] Z. Haider, R. Hussain, I. L. Khan, A. Shakeel, B. Ijaz, and S. A. Malik, “Evaluation of capabilities of open source cognitive radio network simulators,” in *2017 13th International Wireless Communications and Mobile Computing Conference (IWCMC)*, June 2017, pp. 1814–1817.

[30] A. S. Toor and A. K. Jain, “A survey on wireless network simulators,” *Bulletin of Electrical Engineering and Informatics*, vol. 6, no. 1, pp. 62–69, Mar 2017.

[31] C. E. Perkins and E. M. Royer, “Ad-hoc on-demand distance vector routing,” in *Proceedings WMCSA’99. Second IEEE Workshop on Mobile Computing Systems and Applications*, Feb 1999, pp. 90–100.

[32] C. Perkins, E. Belding-Royer, and S. Das, “Ad hoc on-demand distance vector (aodv) routing,” RFC 3561, Jul. 2003.

[33] ns3 Network Simulator 3. [Online]. Available: https://www.nsnam.org/ (Accessed August 20, 2018).

[34] ns2 Network Simulator 2. [Online]. Available: https://www.isi.edu/nsnam/ns/ (Accessed August 20, 2018).

[35] N. Sharma, B. M. Singh, and K. Singh, “Performance analysis of multicast routing protocols using ns-3,” in *2016 International Conference on Information Technology (InCITe) - The Next Generation IT Summit on the Theme - Internet of Things: Connect your Worlds*, 2016, pp. 132–137.

[36] Adding a New Module to ns-3. [Online]. Available: https://www.nsnam.org/docs/manual/html/new-modules.html (Accessed August 20, 2018).