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Adaptive Energy-Aware Cluster Based Routing Protocol for Mobile Ad Hoc Networks

Fatemeh Hakimifar[1], Seyed-Amin Hosseini-Seno*[2], Mohammad Hossein Moattar[3], Thair Al-Dala'in[4], Rahmat Budiarto[4]
[1] Department of Computer Engineering, Payamnoor University of Sari, Iran
[2] Computer Network Research Laboratory, Ferdowsi University of Mashhad, Iran
[3] Department of Software Engineering, Islamic Azad University of Mashhad, Iran
[4] College of Computer Science and Information Technology, Al Baha University, Saudi Arabia
*Corresponding author, email: hosseini@um.ac.ir

Abstract

Due to the downside characteristics of Mobile Ad hoc Networks (MANETs) such as dynamic topology and energy consumption and control overhead, network clustering is one of the promising solutions. Cluster Based Routing Protocol (CBRP) is a robust and scalable routing protocol for MANETs. Clustering formation algorithm used in CBRP is a variation of simple lowest-ID algorithm in which the node with a lowest ID among its neighbors is elected as the Cluster head. Neglecting mobility and energy for selecting cluster head is one of the weakness points of the algorithm. In order to increase stability of the network and to prevent re-clustering an adaptive energy-aware Cluster Based Routing Protocol (AECBRP) is proposed. Two algorithms have been introduced in AECBRP as enhancement to the CBRP: improving the cluster formation algorithm by considering relative mobility, residual energy and connectivity degree metrics, and add in an efficient cluster maintenance algorithm based on the aggregate energy metric of cluster head. Using NS-2 we evaluate the rate of cluster-head changes, the normalization routing overhead and the packet delivery ratio. Comparisons denote that the proposed AECBRP has better performances with respect to the original CBRP and Cross-CBRP.

***Keyword:** Routing in MANETs, CBRP, Cluster Formation Algorithm, Relative Mobility, Residual Energy*

1. Introduction

A Mobile Ad hoc Network (MANETs) includes a set of wireless nodes which can communicate dynamically through wireless multi-hop networks. These networks can be configured without an infrastructure or centralized administration to be controlled. Each network node can only communicate directly with nodes that are in its radio range, therefore, it is required that the nodes perform routing function dedicatedly. In MANET, due to network dynamic structure and lacking centralized management, routing is carried out by all available nodes and via multi-hop way [1].

MANETs routing protocols can be classified into flat routing and hierarchical routing. In the flat routing scheme, each node on a route records the physical next hop towards the destination as its next hop for that route. In fact, in these protocols, all nodes are engaged in routing function. So they increase control packet overhead for route discovery process [2].

The hierarchical routing protocols improve network performances especially when the network size increases. Clustering schemes are typically used by hierarchical routing protocols. The cluster based routing protocols decrease the number of engaged nodes in route and also the size of neighbor table. Moreover clustering is one of the approaches applied in decreasing the traffic during the route discovery process [3],[4]. CBRP is a routing protocol that is designed for routing in MANETs with many nodes. The whole network is divided into overlapping or disjoint clusters. The node which has bi-directional link and the lowest ID among its neighbors are elected as cluster-head. The node mobility causes networks topology to change fast [3]. Since each cluster is recognized by its cluster head, which is fully dependent on the cluster head behaviour, clustering mechanism directly influences the overall network performance. Therefore, a wise cluster formation as a mainstream part of CBRP may improve network performance. Clustering algorithm of CBRP due to not considering the mobility and node's energy which are considered as two MANETs limitations, causes the weakness of the routing protocol. To improve cluster head election, a new clustering algorithm is introduced that

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considers relative mobility, residual energy and connectivity degree of nodes. In addition, the cluster stability is maintained by an algorithm that considers the aggregate energy metric of cluster heads.

The rest of the paper is organized as follows. Section 2 explains the CBRP briefly. Section 3 gives a brief summary of related works. Section 4 proposes an efficient cluster based routing protocol (AECBRP). Section 5 discusses simulation setup, and results. Finally, Section 6 presents the paper’s conclusions.

2. Overview of CBRP

The CBRP is a distributed, efficient and scalable protocol that uses clustering approach to decrease the traffic of route discovery messages in the network. CBRP has less overhead and higher throughput compared to Ad hoc On-Demand Distance Vector (AODV) protocol. In this protocol the whole network is divided into overlapping or disjoint clusters. Each cluster contains a cluster-head, gateways and members. A gateway is a node through which member nodes communicate with the adjacent cluster-head. The clustering algorithm of CBRP is a variation of simple lowest-ID clustering algorithm. The node with the lowest-ID in its neighbours is elected as cluster-head. Each cluster-head considers all neighbours having bi-directional links, as members. Each node maintains a neighbour table (NT) and a cluster adjacency table (CAT). The neighbour table is used for receiving the link status for sensing and forming clusters. The cluster adjacency table keeps the information of adjacent clusters and is used by CBRP's Adjacent Cluster Discovery Procedure. These tables are updated by periodic hello message. The hello message includes the node ID, the node role (cluster-head, member, undecided). If the hello message is not received from a specific node, that entry will be removed from the table [5].

CBRP is based on source routing that using cluster structure to minimize the flooding traffic during the route discovery process. Furthermore, the use of uni-directional links increases the network connectivity. In route discovery procedure cluster-heads searching for a source route are flooded with Route Request (RREQ) Packets. The cluster-head forwards RREQ packet only once and never sends it to a node that has already recorded in the route [6].

The advantage of CBRP is that only cluster-heads exchange routing information. Thus, compared to the traditional flooding methods, the control overhead transmitted is far less. However, CBRP is like other hierarchical routing protocols that has cluster formation and maintenance overhead.

For performance optimization, CBRP recommends a shortening route. Since CBRP uses a source routing scheme, a node gets all information about route when receiving a packet. Nodes exploit route shortening as next hop to minimize the hop number and adapts to network topology changes to choose the most distant neighboring node in a route. Local repair is another optimization method that is employed by CBRP. It checks the routing information contained in the packet whenever a node has a packet to forward and the next hop is not reachable. In a route, if the next hop or the hop after the next hop is reachable through one of its neighbors, the packet is forwarded through the new route [7].

3. Related Works

The clustering algorithms divide MANETs into clusters. Cluster heads manage the cluster and communicate with other clusters. Clustering algorithm construct a logical topology for routing algorithm and allows feedback from routing algorithm in order to adjust that logical topology and make clustering decisions. So the cluster-head stability is important for performance of networks [6].

The lowest ID algorithm [8] is the most common technique to randomly select cluster heads. Each node is identified by a unique ID, and the node with the lowest ID in its neighborhood is considered as cluster head. Since this heuristic is biased to choose nodes with smaller IDs as cluster heads, those nodes with smaller ID's suffer from the battery drainage, resulting short lifetime span of the networks.

In the highest connectivity clustering (HCC) algorithm [9] the degree of a node is computed based on its distance from others. Each node broadcasts its ID to the nodes that are within its transmission range. The node with maximum number of neighbours (i.e., maximum degree) is chosen as a cluster head. Since the node is forced to leave its cluster after finding another cluster head with the higher connectivity, the cluster heads do not play their role well for very long. So this algorithm constructs unstable clusters. Whenever the number of ordinary nodes in a cluster increases, efficiency and network performance degrades.

Adaptive multi-hop clustering [10] sets upper and lower bounds (U and L) on the number of cluster-members within a group that a cluster head can handle. When the number of cluster-members in a cluster is less than the lower bound, the cluster needs to merge with one of the neighbouring clusters. On the contrary, if the number of cluster-members in a group is greater than the upper bound, the cluster is divided into two clusters.

For mobility based cluster formation, Lowest Relative Mobility clustering [11] applies a new metric. A relative mobility with respect to a neighbor is achieved using the ratio of received power between two successive packets. In [4] this relative mobility technique is used and Cross-CBRP routing protocol is introduced. It is a new cross-layer approach to form a cluster in which each node achieves its mobility by the received power levels of two hello message from each neighbor. If each node has M neighbours, so it will have M values relative mobility that aggregate approach is introduced in this work. Every node sets the aggregate mobility in hello message and broadcast to other nodes. To achieve the maximum stability, a node with the lowest aggregate mobility is selected as the cluster-head.

The limitations of the aforementioned algorithm are that to form the clusters they only consider a single feature of a node.

The weighted clustering algorithm (WCA) [12],[13], is based on the use of a combined weight metric that takes into account several system parameters like the node-degree, distances with all its neighbours, node speed and the time spent as a cluster-head. Each node obtains the weight values of all other nodes and information of other cluster heads in the system through rebroadcasting. As a result, the overhead induced by WCA is very high. If a node moves into a region that is not covered by any cluster-head, then the cluster set-up procedure is invoked throughout the whole system. This leads to overheads. In addition, in this algorithm the node speed is used as a mobility property whereas the relative mobility between neighbouring nodes significantly affects cluster stability.

Tao et. al. [6] select a cluster head based on the relative mobility with the connectivity degree is used. The relative mobility metric is obtained using the location information provided by Global Positioning System (GPS) and velocity. However, energy metric is not considered. If a node with lowest mobility and highest connectivity is selected as a cluster-head while has little residual energy, the cluster must be reconstructed. It produces a high overhead.

4. The Proposed AECBRP

As mentioned previously in Section 2, cluster formation algorithm in CBRP is a variation of simple lowest-ID clustering algorithms in which the node with a lowest ID among its neighbors is elected as the Cluster-head. We propose a protocol named as AECBRP which enhances CBRP in terms of: (i) electing the cluster head by taking into account its mobility, connectivity degree and residual energy. (ii) maintaining the formed clusters by considering the aggregate energy metric of cluster heads. The details of the enhancements are described in the following sections.

4.1. Network Model

Let us consider a network represented by a graph $G(V, E)$, where V is the number of nodes and E is the number of bi-directional links. Intermediate nodes help each source node to send data to a destination node. If N_x is the number of neighbour nodes x, $C^{degree}(x)$ is the connectivity degree of node x that is defined by the number of neighbors in the neighbor table. $C^{degree}(x, y)$ indicates that the node x gets the connectivity degree of node y.

$$C^{degree}(x, y) = C^{degree}(y) \tag{1}$$

We assume that each node aggregates the connectivity degree of its neighbors. The aggregate connectivity degree of node x is an average of the connectivity degree of its neighbours, is defined in Equation (2).

$$AC^{\deg ree}(x) = \frac{1}{C^{\deg ree}(x)} \sum_{y \in N_x} C^{\deg ree}(x,y) \tag{2}$$

In mobile ad hoc networks due to random move of node, instead of considering the speed of nodes movement, the relative mobility is used. By comparing the receive signal strength of neighbors with the pervious value in cache. The relative mobility $M_y^{rel}(x)$ between n_y and n_x, is defined in Equation (3):

$$M_y^{rel}(x) = 10\log\left(R_xP_r^{new}x \rightarrow y \,|\, R_xP_r^{old}x \rightarrow y\right) \tag{3}$$

Where $R_xP_r^{new}x \rightarrow y$ is the power current node n_y that has received from n_x, $R_xP_r^{old}x \rightarrow y$ is the power node n_y that has previously received from n_x. If $M_y^{rel}(x) < 0$, it indicates that two nodes are gradually moving away, otherwise the two nodes are moving close to each other. Suppose a node with *M* neighbors, it has *M* number relative values that the aggregate local mobility values [4] is calculated using Equation (4).

$$M_y = Var\left\{M_y^{rel}(x)\right\}_{x=1}^{m} = E\left[M_y^{rel}(x)^2\right] \tag{4}$$

All nodes in MANET are mobile with limited energy sources, while any communication in a network involves energy consumption. The energy consumption of each node depends on its sending and receiving transmission [14] as expressed in Equation (5)

$$Energy_{consumption} = M * size(byte) + D \tag{5}$$

M and *D* are constants, representing the protocol used, sending and receiving information and, are determined by the hardware. Table 1 shows the energy consumption in various states.

Table 1. Power consumption measurements [14]

Parameter	M(µ W. sec)	D(µ W. sec)
Broadcast Send	1.9	266
Point to point Send	1.9	454
Broadcast Receive	0.50	56
Point to point Receive	0.50	356
Idle	843 (m W)	

Each node calculates its residual energy depending on its sending and receiving information. This value in every moment is calculated using Equation (6)

$$Energy^{residual}(x) = Energy^{initial}(x) - Energy_{consumption} \tag{6}$$

Having done the calculation of the residual energy of nodes, this value is set in the hello message and broadcasted among each other. $E^{residual}(x,y)$ indicates that node *x* receives the residual energy of node *y*.

$$Energy^{residual}(x,y) = Energy^{residual}(y) \tag{7}$$

4.2. The neighbor table and hello message format in AECBRP

In this paper we, extend the structure of neighboring table by adding 4 fields, including relative mobility, aggregate mobility, residual energy and connectivity degree as shown in Figure 1.

NeighborID	Neighbor Status	Link status	Relative mobility	Aggregate mobility	Residual Energy	Connectivity degree

Figure 1. Neighbor Table in AECBRP

This information is only used to form a cluster. Each node learns information from received hello message. The hello messages contain not only a neighbor table and cluster adjacency table, but also other information of node x, including aggregate mobility, connectivity degree and residual energy (see Figure 2).

NodeID	Node Status	Aggregate mobility	Residual Energy	Connectivity degree
NeighborID	Neighbor Status	Link status		
…	…	…		
Cluster adjacent ID				
…				

Figure 2. Hello message in AECBRP

4.3. Cluster Formation Algorithm

The basic idea of the cluster formation algorithm is to consider mobility, connectivity degree and the residual energy of nodes to select a cluster. The cluster head formation algorithm is described as follows.

1. All nodes start working in undecided state and set the timer with the specific time interval and broadcast a hello message. Every node broadcasts its own mobility, connectivity degree and residual energy (M and C^{degree} are initialized to 0 and energy is initialized to 400 at the beginning of operations) in a hello message to its 1-hop neighbors.
2. By receiving the hello message, a node compares its aggregate mobility values with its neighbors and the node with the lowest aggregate mobility value $M(x) < M(y)$ is considered.
3. In addition the node compares its connectivity degree with the aggregate connectivity degree of its neighbors and the node with the highest connectivity degree $C^{degree}(x) > AC^{degree}(x)$ is considered.
4. At the end the node with the highest residual energy $E^{residual}(x) > E^{residual}(y)$ is selected.

A node can be a cluster-head if it has less mobility, more residual energy and more connectivity degree to its neighbors. This node will change its state to cluster-head state. By broadcasting hello message, all nodes having bi-directional links with this cluster-head, are recognized as members.

4.4. Cluster Maintenance Algorithm

When clusters are formed, to prevent sudden decrement of cluster-head energy, the cluster-head aggregates the residual energy of its members and continuously compares its residual energy with this aggregate value. When the cluster-head energy is less than the aggregate energy of its cluster members, the cluster-head changes to member state and the cluster formation algorithm is performed again in the same cluster. It is worth to note that after changing the cluster-head node state to a member, the cluster does not restructure, and the node with the highest residual energy in that cluster will be the cluster-head.

Generally, the purpose of the proposed algorithm is to prevent the reformation of clusters. This approach creates stable clusters.

5. Simulation setup and results

To evaluate the proposed protocol, the simulator NS-2(version 2.34) in Ubuntu 10.04 environment was performed. The mobility scenarios that use the Random Way Point mobility model with 30-130 nodes and randomly distributed in a 670m×670m area are randomly generated. Table 2 demonstrates the simulation parameters.

Table 2. Simulation setting up parameters

Parameter	Values
Simulation Duration	600s
Pause time	0s
Maximum Speed of the node	5-30 m/s
Transmission range	150- 250m
Packet Rate	4 pkt /sec
Number of nodes	30-130
Traffic Model	CBR
Max connection	40
Initial Energy	400j
Area	670m×670mm

5.1. Investigation of cluster head changes in network condition

In the first scenario, the number of cluster head changes is illustrated against the speed changes. The number of cluster head change is the total number of cluster head changes during the whole simulation run time. A small value of cluster head change reflects the stability of the cluster structure. Figure 1 demonstrates the rate of cluster-head changes increases by increasing the speed of nodes. Due to mobility increment, the network topology is seriously changed and the cluster formation operations are repeated. From Figure 3, it is found out that the proposed protocol, consider mobility, energy and connectivity degree during the selecting cluster, has better performance compared to the original CBRP and The Cross-CBRP.

In the second scenario, the rate of cluster-head changes is computed versus the transmission range changes. Figure 4 shows that by increasing the transmission range, the rate of cluster-head changes decreases. Having done increasing the transmission range, more nodes are within the range of other node for longer periods of time. Hence, less of large clusters formed and their mobility does not allow them to move frequently in and out of range of each other. Therefore, the number of cluster-head changes decreases. When the transmission range is decreased the rate of cluster-head changes in the AECBRP will get better performance in comparison with the original CBRP and The Cross-CBRP.

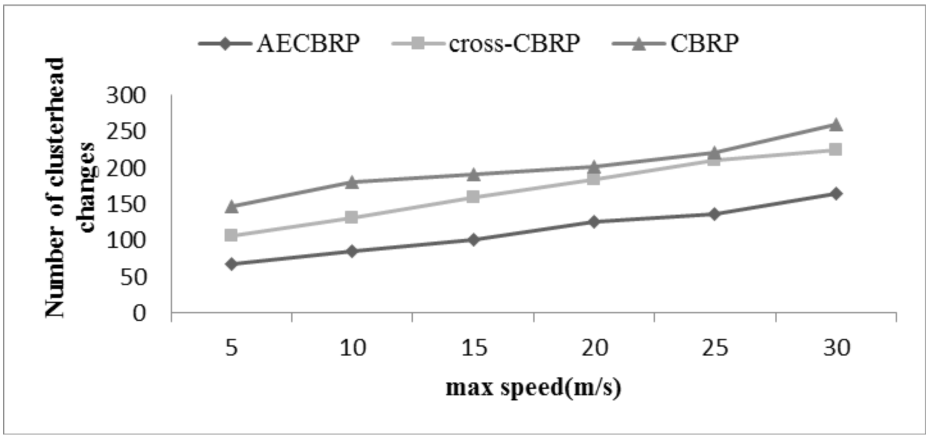

Figure 3. Number of Cluster-head Changes vs. Node Speed

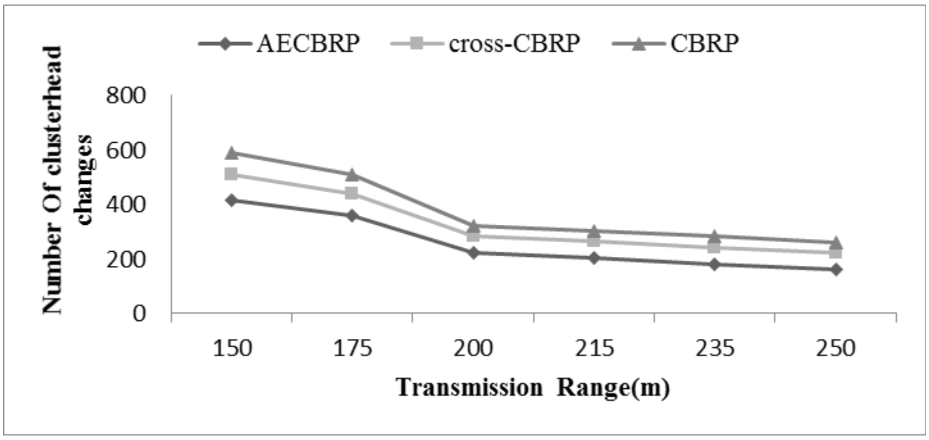

Figure 4. Number of Cluster-head Changes vs. Transmission Range

In the third scenario, the rate of cluster head changes versus the number of node's change is calculated. As shown in Figure 5, by increasing the number of nodes the rate of cluster head changes increases. As the node density increases, AECBRP produces constantly less number of cluster head changes in comparison with the CBRP and Cross-CBRP. As a result AECBRP gives better performance in terms of the number of cluster head changes when the node density in the network is high.

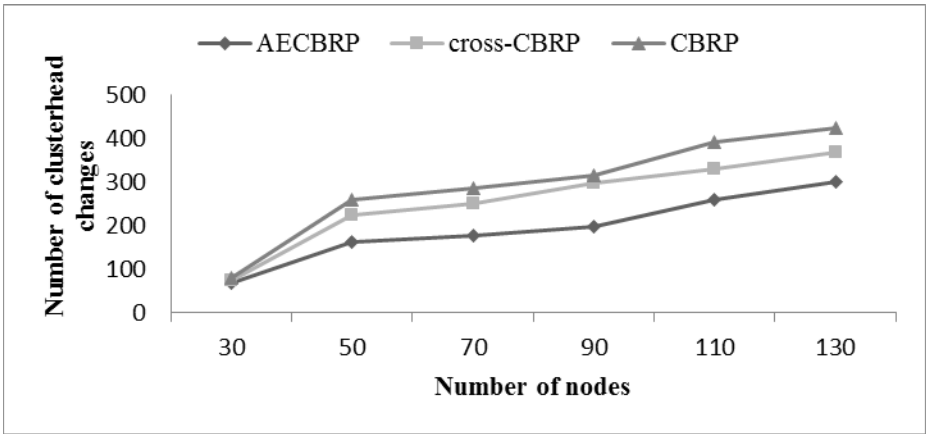

Figure 5. Number of Cluster-head Changes vs. Number of nodes

In the fourth scenario, the number of cluster head changes is calculated against the change of pause time. When pause time increases the required number of cluster head changes are very low. Figure 6 indicates that when the pause time is 0 s, the most mobility is within the network and it is the result of increasing cluster head changes. In the pause time 600s, no mobility is in the network, the rate of cluster head changes is zero. From Figure 7 it is clear that AECBRP performs better than both, the original CBRP and the Cross-CBRP.

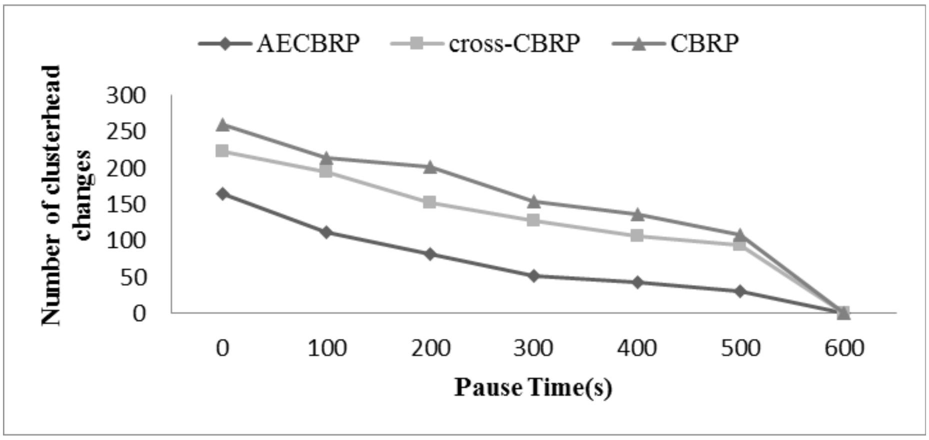

Figure 6. Number of Cluster-head Changes vs. Pause Time

In the fifth scenario, the number of cluster head changes is calculated against the change of packet rate. When traffic injection to the network increases some reasons can cause packets do not received by a downstream node, for example, lack of route or impossibility to access to the media – so packets will hold in the interface queue. If this buffer overflows the last incoming packet will discard. Therefore, if there are some hello packet in this queue these hello packets reach to the neighbours nodes by delay. Therefore Neighbor table updates and information about the status of neighboring nodes can be delayed and increases the rate of cluster head change.

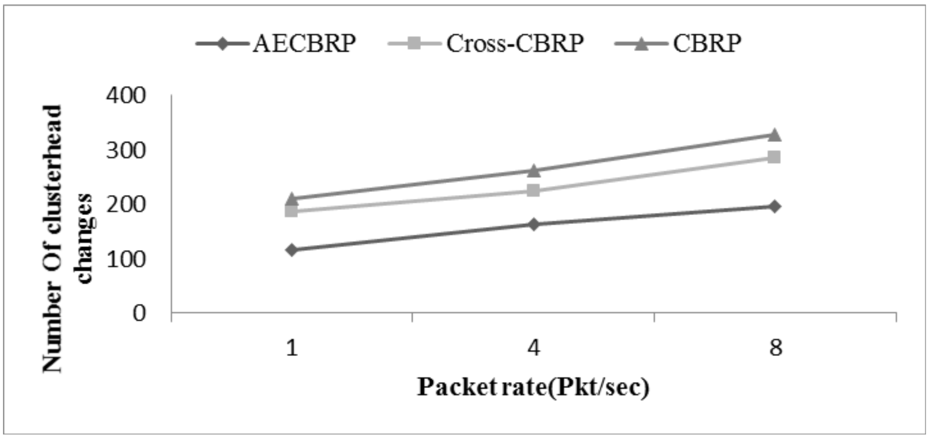

Figure 7. Number of Cluster-head Changes vs. packet rate

5.2. Investigation on normalization routing overhead in network condition

In the sixth scenario, the routing overhead metric is compared to speed changes. This metric determines the overhead caused by transmitting routing packet within the network and the metric equals the fraction of the number of sent routing packet on the number of all received data packet. Figure 8 demonstrates that increasing the speed of nodes will increase the routing overhead. Increasing speed causes a fast change of the network topology because with this change, nodes will exchange more routing messages.

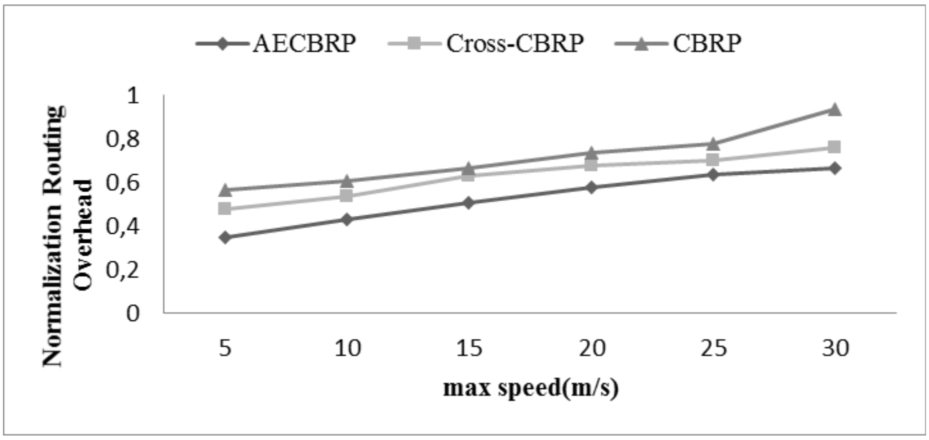

Figure 8. Normalization Routing Overhead vs. Speed of nodes

In the seventh scenario, normalization routing overhead is calculated against the change of number of nodes. From Figure 9 we find out that the more nodes, the more routing overhead. As there are more nodes, both protocols must maintain more routing information in cache and great amount of control message should be forwarded. However, the three lines are very close, showing the AECBRP only increases a little normalization routing overhead.

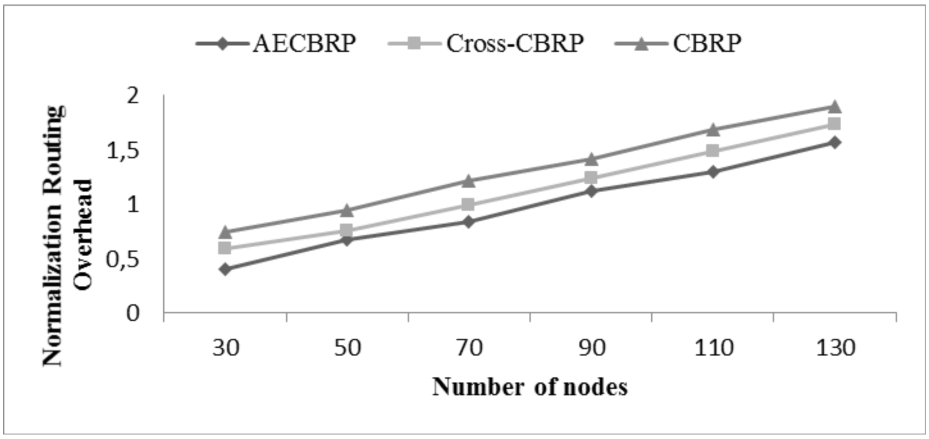

Figure 9. Normalization Routing Overhead vs. Number of nodes

5.3. Investigation of packet delivery ratio in network condition

In the eighth scenario, the packet delivery ratio is compared to the change of speed. Packet delivery ratio is defined as the total number of data packets sent by traffic sources to the total number of data packets received at destinations. Figure 10 indicates that increasing the speed in all three protocols, the packet delivery ratio decreases.

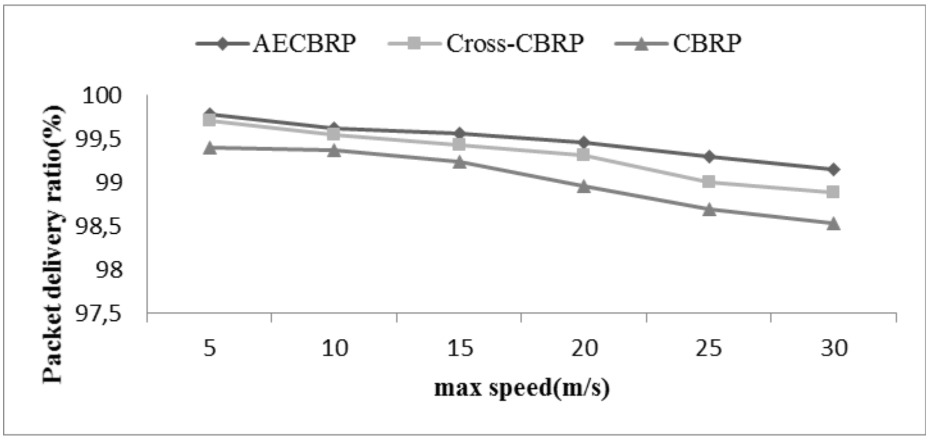

Figure 10. PDR vs. Speed of Nodes in the Networks

In the ninth scenario**,** the packet delivery ratio is estimated versus the number of nodes change. Figure 11 demonstrates that increasing the number of nodes will decrease the packet delivery. The reason is because some paths will become longer if there are more nodes in network, more and more packets are dropped in the process of transmission, then the two data delivery rates decrease.

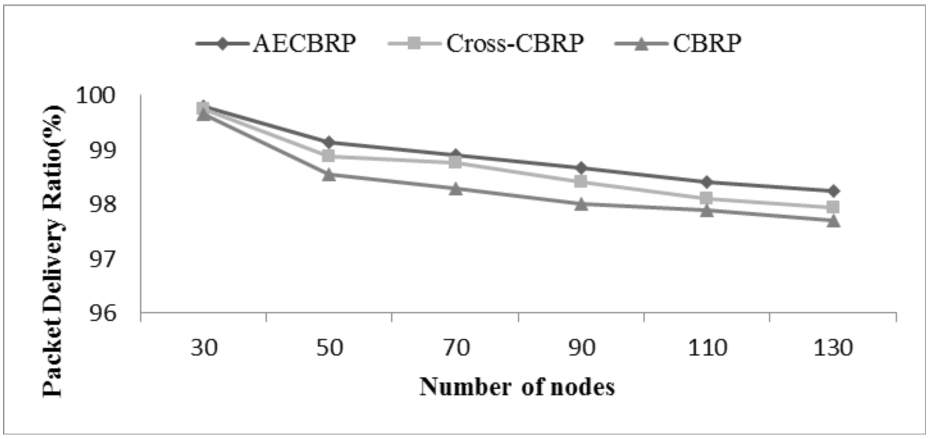

Figure 11. PDR vs. Number of Nodes in the Networks

6. Conclusion

The cluster-based routing protocols impact the network scalability. In CBRP the cluster formation algorithm, the lowest ID algorithm does not consider mobility and nodes energy in MANETs. In this paper, the cluster formation algorithm that uses the relative mobility metric, the residual energy and connectivity degree is introduced. After forming the cluster, to prevent sudden decrement of cluster head energy, an efficient cluster maintenance algorithm based on the aggregate energy metric of cluster head is proposed. This algorithm creates stable clusters. Compared to the original CBRP and Cross-CBRP, the rate of cluster-head changes has significant improvement that causes better throughput and lifetime of the network.

In the future, we plan to implement and evaluate the AECBRP performance using difference mobility models and furthermore to implement the AECBRP in a test-bed MANETs.

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