An Efficient Cluster-based Routing Protocol for Mobile Ad Hoc Networks

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Abstract— **Clustering algorithm used in CBRP is a variation of simple lowest-ID clustering 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 this protocol. In this paper the cluster formation algorithm is introduced, that uses the relative mobility metric, the residual energy and connectivity degree. After forming the cluster, whenever the cluster-head's energy is less than the aggregate energy of its member nodes, it remains as the cluster-head. Using NS-2 we evaluate rate of cluster-head changes, normalization routing overhead and packet delivery ratio. Comparisons denote that the proposed CBRP has better performances with respect to the original CBRP and Cross-CBRP.**

Keywords— Mobile Ad Hoc Networks, CBRP, cluster formation algorithm, routing

I. INTRODUCTION

A Mobile Ad hoc Network (MANETs) includes a set of wireless nodes which can communicate dynamically through wireless multi-hop. These networks can be configured without an infrastructure or centralized administration to be controlled.

Each network node can only communicate directly with (those) 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.

The hierarchical routing protocols improve network performances especially when the network size increases. Clustering schemes are typically used by hierarchical routing protocols. Network is divided into clusters and each cluster contains a cluster-head, members and gateways. The cluster based routing protocols decrease the number of engaged nodes in route and also size of neighbor table. Moreover clustering is one of the approaches applied for decreasing the traffic during route discovery process[2].

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. In MANETs, the node mobility causes network's topology to change fast[3].

Clustering algorithm of CBRP due to not considering the mobility and node's energy which are considered as two MANET's limitations, causes the weakness of the routing protocol. Metrics which should be considered are relative mobility and residual energy. To improve cluster-head stability, a new clustering algorithm is introduced that considers relative mobility, residual energy and connectivity degree of nodes.

This paper organized as follow. Section 2 gives a brief summary of related work. In section 3 the CBRP is explained. Section 4 proposes an efficient cluster based routing protocol (AECBRP). Section 5 discusses simulation result and finally conclusions are offered in section 6.

II. REALATED WORK

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[4].

The lowest-ID technique [5] 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.

The next technique is to select nodes with the highest connectivity[6]. 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 technique constructs unstable clusters. Whenever the number of ordinary node in a cluster is increased, efficiency and network performance degrades.

For mobility based cluster formation, Lowest Relative Mobility clustering [7] 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 [2] 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 neighbors, so it will have m values relative mobility that aggregate approach is introduced in this work. Every node set 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 at the aforementioned algorithm are that to form the clusters they only consider a single feature of a node.

The weighted clustering algorithm (WCA)[8], based on a combined weight metric, takes into accounts the ideal degree, transmission power, mobility and battery power of each node. When the node has the minimum weighted sum of four indices, it is selected to be the cluster-head. In this algorithm the node mobility is used as a mobility property whereas the relative mobility between neighboring nodes significantly affects cluster stability.

In [4] to select cluster-head the relative mobility with the connectivity degree is used.

III. OVERVIWE 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 AODV protocol[1]. 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 the modified algorithm of simple clustering algorithm with the lowest ID. In this algorithm, the nodes with the lowest ID are selected as the cluster-head. Cluster-head keeps the cluster membership information.

Each node has a neighbor table and a neighbor adjacency table. The neighbor table is used for receiving the link status for sensing and forming cluster. The neighbor 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 receive from a specific node, that entry will be removed from the table.

A non-cluster-head does not content with a cluster-head node. If two cluster-heads move towards each other, one of them will lose its role as a cluster-head. Cluster-heads are allowed to hear each other in Cluster_Contention_interval periods[3].

In CBRP, besides two member and cluster-head state, to perform cluster better, the undecided state is defined. This state means that a node is still searching its host cluster-head. All nodes start working in undecided state and set the timer with the specific time interval and broadcast a hello message. When a cluster-head receives a hello message it replies with a trigger hello message. Each node uses information of hello message to form a cluster. When the node receives one hello message, it will stop setting time and change its state to "member" state. If the node dose not received a message from a cluster-head and its neighbor table has not bi-directional links to any neighbor, it will enter again to "undecided" state; otherwise it makes the node as a cluster-head. From this moment, it changes the first current part of hello message to cluster-head.

CBRP is based on source routing that using cluster structure to minimize the flooding traffic during 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[4].

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 like other hierarchical routing protocols 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 adopts 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[9].

In CBRP each cluster-head considers all neighbors having bi-directional links, as members. Since each cluster is recognized by its cluster-head, that is fully dependent on the cluster-head behavior, clustering directly influences the overall network performance. Therefore, wise cluster formation as a mainstream part of these algorithms can improve network performance.

Cluster formation is performed with lowest ID algorithm that does not consider any assumption about mobility and node energy. It is possible that a node with the lowest energy and the highest mobility which has the lowest ID is considered as cluster-head and by this selection the node energy ends very soon and the result will be repetition of clustering operation. The repetition of this operation causes the degradation of network efficiency.

IV. THE PROPOSED AECBRP PROTOCOL

The proposed protool is based on mobility, residual energy and connectivity.

Let us consider a network modeled 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 neighbor 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.

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

The aggregate connectivity degree of node x is an average of the connectivity degree of node x, is defined as follows:

$$AC^{degree}(x) = \frac{1}{C^{degree}(x)} \sum_{y \in N_x} C^{degree}(x, y) \quad (2)$$

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 can be estimated from (3). Suppose $M_y^{rel}(x)$ is the relative mobility[2] between n_y and n_x then:

$$M_y^{rel}(x) = 10\log(R_x P_r^{new} x \rightarrow y / R_x P_r^{old} x \rightarrow y) \quad (3)$$

Where $R_x P_r^{new} x \rightarrow y$ is the power current node n_y that has received from n_x. $R_x P_r^{old} x \rightarrow y$ 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[2] is calculated as:

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

Each node in MANETs, depending on its sending and receiving, loses some energy. The consuming energy of node[10] is calculated by as:

$$Energy \quad consumption = M * size(byte) + D \quad (5)$$

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

TABLE I. POWER CONSUMPTION MEASURMENTS[10]

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 as follows:

$$E^{residual}(x) = E^{initial}(x) - Energy \quad consumption \quad 6)$$

After calculating 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 its energy from node y.

$$E^{residual}(x, y) = E^{residual}(y) \quad (7)$$

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

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

Fig. 1. Neighbor Table

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.

V. CLUSTER FORMATION ALGORITHM

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

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.

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 and 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.

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 member, the cluster does not restructured, 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. The algorithm calculates the aggregate energy of member nodes and then compares with the residual energy, and a change of cluster-head state is selected. In this way due to lowering the cluster-head energy, it prevents re-clustering. This approach creates stable clusters.

VI. Simulation Results and Analysis

To evaluate the proposed protocol, the simulator NS-2(version 2.34)[2] in Ubuntu 10.04 environment was performed. The mobility scenarios that use the Random Way Point mobility model with 50 nodes that randomly distributed in a 670m×670m are randomly generated. TABLE II demonstrates the simulation parameters.

TABLE III. SIMULATION SETTING PARAMETER

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×670m

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.

Fig.2 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 Fig. 2, 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.

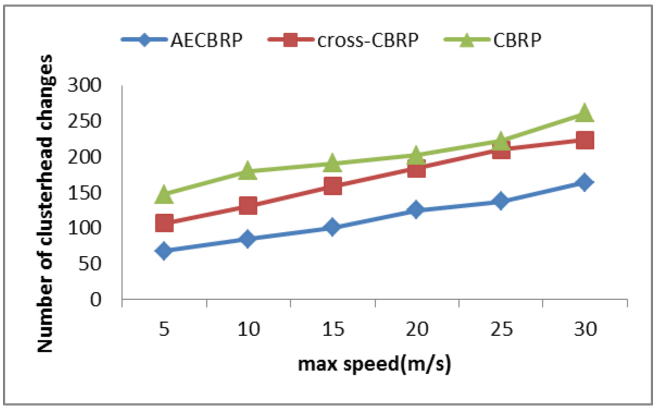

Fig. 2. Number of Cluster-head Changes vs. Node Speed

In the second scenario, the rate of cluster-head changes is estimated versus the transmission range changes. Fig. 3 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.

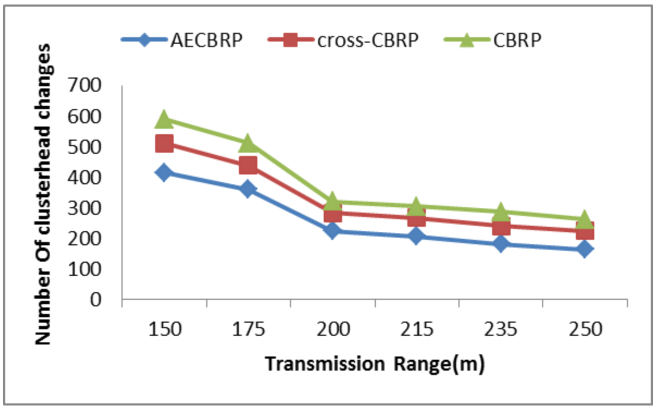

Fig. 3. Number of Cluster-head Changes vs. Transmission Range

In the third scenario, the rate of cluster-head changes versus the number of node's change is calculated. As shown in Fig. 4, 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.

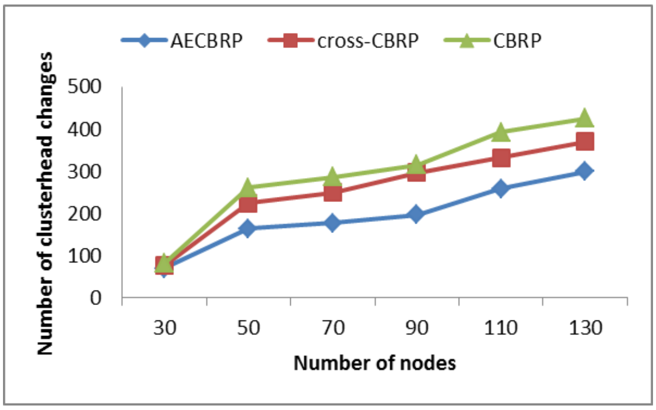

Fig. 4. Number of Cluster-head Changes vs. Number of nodes

In the fourth scenario, 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. Fig. 5 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 Fig. 5 it is clear that AECBRP performs better than both, the original CBRP and the Cross-CBRP.

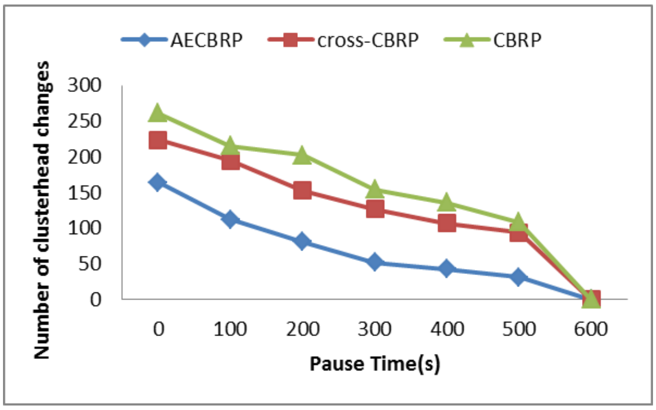

Fig. 5. Number of Cluster-head Changes vs. Pause Time

In the fifth 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. Fig. 6 demonstrates that increasing the speed of nodes will increase the routing overhead. Increasing speed causes fast change of the network topology because with this change, nodes will exchange more routing messages.

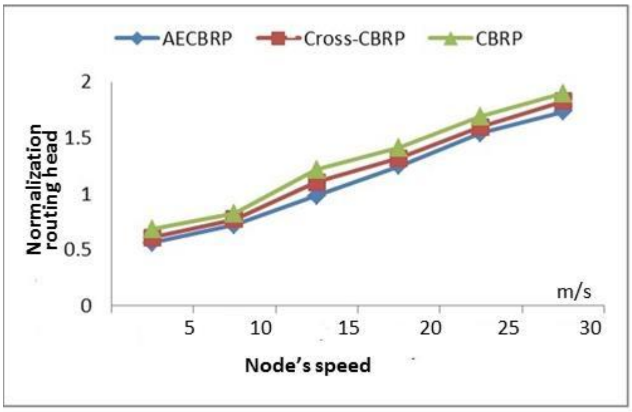

Fig. 6. Normalization Routing Overhead vs. Speed of nodes

In the sixth 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. Fig. 7 indicates that increasing the speed in all tree protocols, the packet delivery ratio decreases.

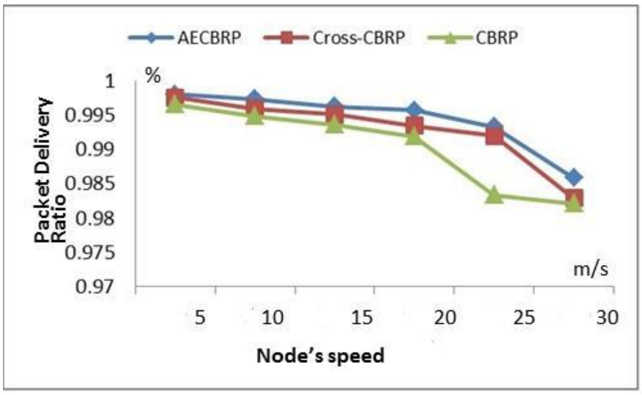

Fig. 7 PDR vs. Speed of Nodes in the Networks

VII. CONCLUSION

The cluster-based routing protocols impact the network scalability. In CBRP the cluster formation algorithm, the lowest 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. 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.

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