Improving availability of mobile networks using a cluster routing protocol with redundant cluster head

Rommel Torres
Universidad Técnica Particular de Loja
Email: rovitor@utpl.edu.ec

Liliana Enciso
Universidad Técnica Particular de Loja
Email: lenciso@utpl.edu.ec

Luis Mengual
Universidad Politécnica de Madrid
Email: lmengual@fi.upm.es

***Abstract*—We show a cluster based routing protocol in order to improve the convergence of the clusters and of the network it is proposed to use a backup cluster head. The use of a event discrete simulator is used for the implementation and the simulation of a hierarchical routing protocol called the Backup Cluster Head Protocol (BCHP). Finally it is shown that the BCHP protocol improves the convergence and availability of the network through a comparative analysis with the Ad Hoc On Demand Distance Vector (AODV)[1] routing protocol and Cluster Based Routing Protocol (CBRP)[2].**

I. Introduction

The Ad Hoc, MANET (Mobile Ad Hoc Networks) mobile networks are temporary and self-configurable networks. Its nodes could be its source, destination and a bridge for information. It has finite resources (bandwidth, battery, processing) that must be well used in order to improve the performance of the whole network. In this type of network is important to maximize the availability, speed and state of the network as a whole. For example, if a node has insufficient battery or its processor is saturated, then, in order to not compromise the availability of the whole network, its participation must be limited as a bridge or router in the exchange of information.

A hierarchical router protocol for Ad Hoc mobile networks called the Backup Cluster Head Protocol (BCHP) is proposed. The protocol, based on the Cluster Based Routing Protocol (CBRP), incorporates the use of redundant Cluster Heads (CH) with the aim of improving the availability of the network.

II. Related work

A. Hierarchical Routing

The OSI network layer [3][4], is where the Ad Hoc network processes take place and are identified. In this way the improvement efforts in this layer are directly visible in the upper layers.

The Ad Hoc network routing protocols are generally grouped together as proactive, reactive and as a hierarchical.

The proactive routing protocols keep information about all of the routes in the network, thus these routes are not required. Each node maintains routes on all of the nodes of the network. The Destination-Sequence Distance- Vector routing (DSDV) protocol is an example of this type of protocol.

The reactive routing protocols generate routes on demand when one node wants to communicate with another. There are, in general, two components: discovering the route used when a source does not know how to get to a destination and the route maintenance to deal with failure in the routes brought about by mobility in the nodes. The Ad Hoc Demand Distance Vector (AODV) protocol is an example of a reactive protocol.

The hierarchical routing protocols divide the network into subsets [5] of nodes called clusters, in which a cluster head is used to concentrate and distribute the information generated within the cluster. An example of this type of protocol is the Cluster Based Routing Protocol (CBRP)[[2]. Figure 1 shows the components of our proposed hierarchical routing protocol.

While more nodes become part of a MANET network, the hierarchical router protocols are managed better than the reactive and proactive protocols. In these scenarios the reactive protocols have the disadvantage of the overload that involves maintaining the information on the entire network. The proactive protocols are slower in achieving the convergence of the network as they must exchange information between a greater number of nodes.

This research focuses on improving the sublayer process of an Ad Hoc network using hierarchical routing with so as to achieve the greatest possible availability for the communication processes.

There are several studies [6][7] that identify and group hierarchical routing protocols. These hierarchical routing protocols and strategies center on the choice of Cluster Head and the maintenance of the clusters and do not focus on improving the availability of the whole network, as happens in this research.

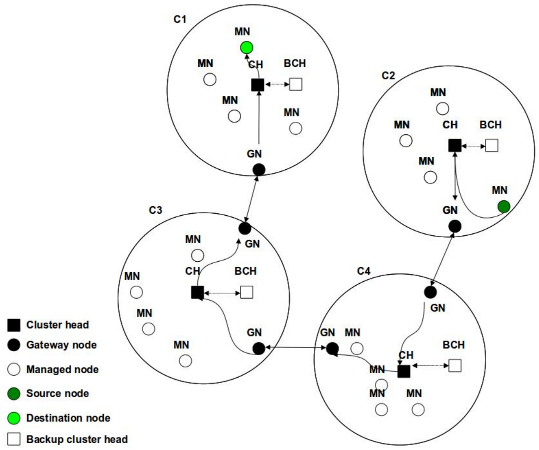
This research is different from previous work as improves the network availability through the use of redundancy for the main nodes.

III. Backup Cluster Head Protocol, hierarchical model

As can be seen in figure 2, we define two levels of interaction access and distribution. The access level has relationship with interaction between the CH, BCH nodes and the managed nodes. The distribution level involves the interaction between the CH node and its respective BCH node.

The division of the Ad Hoc network into clusters allows the overload of the network to be reduced as the communication between the clusters is concentrated and a dominant set of Cluster heads is produced. The nodes belonging to this dominate series communicate between themselves by means

Fig. 1. Model proposed for the MANET Network Management



of a mesh network making up a backbone. The function of the backbone is to transport the information between the nodes.

In each cluster a Cluster Head (CH) will have a node called the Backup Cluster head (BCH) which will take the main functions of the cluster in case of a failure in the main mode. The BCH maintains a periodical communication with its CH in order to obtain updated routing information on the nodes of the cluster and information of the state of the CH. The convergence of the network is improved by means of the BCH as the cluster does not make a new choice of CH.

The processes for the choice of the BCH are implemented in the BCHP protocol as is the communication between the CH and its backup.

A. BCHP components

As can be seen in figure 1, the network is divided into groups called clusters. Each cluster has a cluster head node (CH) and at least one backup cluster head (BCH) and an arbitrary number of Managed Nodes (MN) at a radius of two-hop in the transmission range of its Cluster Head.

The topology discovering process is carried out periodically in order to maintain the network in convergence and synchronize the information in all of the nodes.

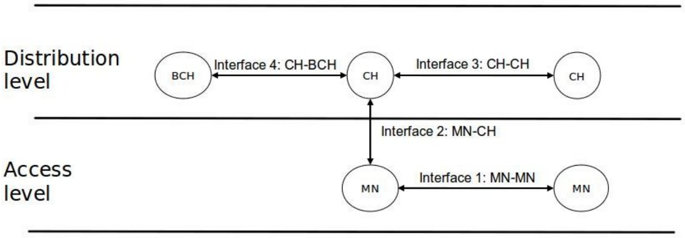
1) Managed Nodes (MN): Three types of managed nodes are defined in the proposed protocol:

a) Managed Node (MN): These are all of the devices that are part of the cluster and send information across the CH node. The MN, at the same time, also manages its membership and the degree of interactivity within the cluster.

b) Selfish Node, SN: The SN is an MN that does not want its resources to be used as an information-forwarding node and explicitly, stops providing information on its state to the CH. The SN can change its state at the MN sending a change state notification to the CH.

c) Gateway Node, GN: A gateway node is any node that is not a CH which allows information to be distributed between CH nodes in different clusters.

Fig. 2. Communication interfaces



2) Cluster Head: The CH node is an MN that has better features than the rest of the nodes belonging to a cluster. The node is selected as a Cluster head when it has the best metrics. The metrics of the node is calculated based on the following criteria [8]:

- Resources available of the node, for example, free capacity for processing, memory, bandwidth.
- The node with the lower mobility (change of topology).
- Range of transmission.
- Level of battery power.

In the network the CHs make up a mesh network to send the information. This mesh network is called a backbone. For the creation and functioning of the backbone it might be necessary to use gateway nodes.

3) Backup Cluster Head: The Backup Cluster Head, BCH, is the second best node, chosen during the same process as the selection of the CH. All of the nodes belonging to the cluster keep the reference of the CH and BCH nodes. This allows the convergence of the all of the network to be accelerated should there be an event that does not permit the work of the CH.

The main purpose of the BCH is to improve the availability. It interacts with the MN and the CH. When the CH fails, this node automatically takes on the CHs functions and immediately invokes the selection process of the new BCH.

The BCH and the CH maintain periodical synchronization sessions in order to validate the integrity of the information. In the best of cases the routing information stored in the CH must be the same as that in the BCH.

B. Communication interfaces of the BCHP

The communication interfaces existing between the different components of the model are detailed in this section. As can be seen in figure 2 the communication interfaces are defined by the relationship between each of the nodes and the components of the model.

1) Interface 1. Communication between NM and NM: The managed nodes communicate between each other to make up a cluster and to carry out the selection of the CH and BCH modes. A variant of the Weighted Clustering Algorithm (WCA)[8] algorithm is proposed for the formation of the cluster. The objective of this variant is for the MN nodes to register the second-best node or the BCH node and that all of the MN nodes saves reference information of the CH, BCH nodes. This information will be used to accelerate the sending and reception of the management information.

Algorithm 1 shows the process for the formation of the cluster and for the choice of the CH and the BCH that is implemented in each node in the network.

Algorithm 1 Cluster formation and choice of CH and the BCH

Require: Routing table of the neighbor nodes $K = \{\sigma_1, \ldots, \sigma_n\}$.
Ensure: Node Status (β_n) updated from $M = \{UNDECIDED, MEMBER, CH, BCH\}$.

if $(\beta_n = UNDECIDED)$ **then**
  $\beta_n \leftarrow CH$
  while $(K \neq \phi)$ **do**
    Obtain the neighbors from σ_i de K
    Obtain neighbor status φ_σ and neighbor metric υ_σ
  end while
  Sort K by υ_σ
  $First \leftarrow FirstK_\sigma$
  $Second \leftarrow SecondK_\sigma$
  if $(First_\varphi \cap \{UNDECIDED, MEMBER, BCH\})$ **then**
    if $(n_\upsilon \geq First_\upsilon)$ **then**
      $\beta_n \leftarrow JC$
    else if $(First_\varphi = CH)$ **then**
      if $(n_\upsilon \geq First_\upsilon)$ **then**
        $\beta_n \leftarrow CH$
      else if $(n_\upsilon \geq Second_\upsilon)$ **then**
        $\beta_n \leftarrow BCH$
      else
        $\beta_n \leftarrow MEMBER$
      end if
    end if
  end if
end if
return β_n

2) Interface 2. Communication between NM and CH: The managed nodes communicate with the Cluster Head for the sending and reception of the routing and data information. The use of the proposed Ad Hoc routing protocol, Backup Cluster Head Protocol (BCHP), is necessary as the MN and the CH can be two-hops from the transmission range.

3) Interfaces 3. Communication between CH/CH: The CH nodes, those with the best features, create a logical communication between each other called backbone or mesh. As it is a logical communication, the presence of a nodes gateway (GN) is necessary. This backbone is used for the sending of information between clusters belonging to the network.

4) Interface 4. Communication between CH/BCH: The communication between the CH and the BCH is part of the contribution of our research. This communication includes two processes: synchronization of the information between the CH and BCH nodes and knowledge on the unavailability both of the CH node and the BCH node. It is propose that the two processes take place using the same strategy: the use of synchronization messages and its respective acknowledgment receipt to determine and provide information on the availability of the CH and BCH nodes.

When the CH is not available, the BCH node will use the information from the previous registered update and will provide information on the new state to the MN nodes. As the NM has the reference information of the BCH, they identify this as a new CH and the information is sent to it. The new CH again invokes the algorithm in order to choose a new BCH.

When the BCH node is not available, the CH node does not obtain the acknowledgment receipt of the synchronization (failed synchronization), then the CH node invokes the algorithm again in order to choose a new BCH.

There is a total synchronization between the CH and the BCH nodes based on the periodical exchange of hello messages. The synchronization interval can be adjusted in accordance with the scenarios in which the proposed management model will be used. This process is initiated by the CH and the information is confirmed by the BCH by means of an acknowledgment of receipt.

The determination of the availability of the CH and the BCH will be by means of periodical messages also used by the synchronization processes and updating of the information. There are three events that identify failures in the main nodes:

- The BCH node does not receive periodic updates of the routing information.
- The CH node does not receive an acknowledgment of receipt in the determined periods.
- The MNs send information to the BCH node as it has been determined that the CH node is not available.

IV. Backup Cluster Head Protocol Specification – Hierarchical Routing Protocol

This section describes the stages of the Backup Cluster Head Protocol, BCHP protocol. The BCHP has been developed based on the CBRP protocol. The main difference between the BCHP and the CBRP is the improvement in the availability of the network through the inclusion of the BCH nodes.

The BCHP protocol has three clearly defined steps: creation, maintenance and routing between clusters.

A. Creation of the cluster

When the nodes begin they do not belong to any cluster and they start their state as UNDECIDED. They calculate a value called a metric in accordance with the speed characteristics, state of the battery and location within the cluster. It later sends its state together with the value of its metric to all of the nodes by means of broadcast messages. With these values each node creates its routing table and determines which neighbors have bidirectional links towards it. This information serves to determine the two nodes with best characteristics and that the CH and BCH can be chosen. Each node stores the address of the CH and the BCH in order to accelerate the routing process. Algorithm 1 shows the creation of the cluster and the choice of the CH and the BCH.

B. Maintenance of the cluster

The movement of the nodes, the consumption of energy and failure of the CH node cause the cluster change in density and location. They are also able to divide or unite which is why in order to maintain the convergence of the network it is important to maintain the hierarchy of the cluster.

When several clusters are united it is possible for the CH to be within the area of coverage of another CH node, in which case a period of contention is initiated. After the period of contention expires the CH node is chosen again as is the BCH of the new cluster.

When a CH is not available the BCH takes on the value of the CH. The BCH node determines that the CH node is not available through the use of periodical messages and the updating of the transmission between them. When the BCH node assumes the hierarchy, it becomes the CH and sends a message by broadcast to all of the nodes of the cluster informing on the new state. Again it is chosen the new BCH node.

C. Routing between clusters

There are three levels of routing:

1) Within the transmission area: in which the nodes can be reached directly since they have a bidirectional scope between them and are directly visible. Here the source node sends the information directly to the destination node.
2) Within the cluster: here the nodes communicate directly among themselves through their table of neighbors. Each node maintains a routing table of neighbors in which the address of the node can be obtained which will serve as a router in order to reach its destination.
3) Outside the cluster: where each CH concentrates the information and sends it towards the destination cluster. One node determines that there is now way towards the destination once the packet is delivered to the Cluster Head. The Cluster Head contains an additional routing table for communication between clusters. The CH sends the information to the destination cluster or by dissemination to all of the CH nodes, depending on whether it has an entry in the routing table to the destination node.

V. Validation of the Proposal

A. Mathematical validation

The availability of an Ad Hoc network is dependent on the probability that there is a BCH in each cluster. In order to calculate the availability, it is necessary to obtain the probability that there is a BCH.

In this manner, an Ad Hoc network that uses a hierarchical routing can be expressed in the following terms [9]:

$$R_i = (ar_0, n) \tag{1}$$

Where R_i is a specific cluster, r_0 is the transmission range of the node, a is a factor that identifies the area of coverage expressed in the transmission range and n is the number of neighbors of the node located within the area of coverage.

A node could be CH and BCH base in its **situation** and the **number of neighbors**. The situation of the node is defined by a series of factors proper to the node which include the state of the node (battery), the speed of the movement of the node and the position or location of the node within the cluster. The values can be expressed in the following way:

The **state** of a node, defined by p_e, can have two values, on or off.

The **speed** of the node, defined by p_v, on a Cartesian plane $A = x \times y$, directly effects the choice of the CH, because if the node is slower than its neighbors it has a greater probability of being chosen as the CH. In such a way that:

$$Mv_i = \frac{1}{T}\sum_{t=1}^{T}\sqrt{(X_t - X_{t-1})^2 + (Y_t - Y_{t-1})^2} \tag{2}$$

Where $Mv_i > 0 \wedge Mv_1 \leq V_{max}$. V_{max} Then

$$p_v = \frac{1}{Mv_i} \tag{3}$$

The **location** of the node, p_u, defined in terms of the transmission range of the del node, r_0, is given by:

$$p_u = \pi(r_0)^2/b, \tag{4}$$

Where $b > 0 \wedge b <= n$, determines the area of incidence of the CH node. Where the smaller the area of incidence, the closer the node is to the cluster. The **number of neighbors** is an independent characteristic of the node and is indirectly proportional to the probability, p_{CH} of it being elected CH. While the more nodes that there are, the less the probability that a node in particular is elected.

Finally the probability that a node is elected CH, is given by:

$$p_{CH} = \frac{1}{n} - \frac{p_u + p_v + p_e}{3} \tag{5}$$

$$n \geq 1$$

The BCH being the node with the following metric less than the CH, a potential CH node, it can be mentioned that the probability that there is a BCH is the same as the probability that there is m cluster heads. Therefore:

$$p_{BCH} = 1 - p_{CH}^{m} \tag{6}$$

$$m \geq 2 \wedge m \leq n - 1$$

The probability that there is a BCH has been determined in equation (6) With this information the availability of the network is calculated:

In the first place the calculation on the availability for just one CH is carried out, and the representation as η_{CH}, is a random binomial variable which assumes the values of $\{1, 2, ..., r\}$, then the $P(\eta_{CH} = i)$ is given by:

$$P(\eta_{CH} = i) = \sum_{i=1}^{r}\left(\frac{r!}{(r-i)!i!}\right) p_{CH}^{i} q_{CH}^{r-i}; \tag{7}$$

$$r \geq 1$$

Now we show that by adding one or more BCH it improves the efficiency or availability of the Ad Hoc network. For this case we define the availability as η_{BCH}. Then:

$$P(\eta_{BCH}=i)=\sum_{i=1}^{r}\left(\frac{r!}{(r-i)!i!}\right)p^{i}_{BCH}q^{m(r-i)}_{CH};; \qquad (8)$$

$$r \geq 1$$

Finally, from (7) and (8) we conclude that:

$$P(\eta_{BCH}=i) > P(\eta_{CH}=i)$$

Therefore the availability of an Ad Hoc network with BCH is better than with just one CH.

B. Validation by simulation

We use the Network Simulator 2[10] for the simulation. In order to define the simulation scenarios, the parameters described in [12]. have been used as a basis. The values for each of these parameters are shown in table I.

For the analysis of the results, some authors [13][14][15][16][17] have revised the series of indicators. In order to evaluate the BCHP protocol, particular indicators have been selected to measure the availability of the network. These indicators are: performance, overload, average delay and the variation in the delay of the packet or jitter. These indicators have been compared with those obtained for the CBRP[2] and the AODV[1] protocol.

Parameters	Values
Simulation area	1000m x 500m
Mobility model	Emergency and rescue
Number of nodes	25, 30, 40, 50, 60, 70, 80, 90, 100
Number of connexions	20
Simulation time	150 seconds
Protocols of the network layer	CBRP, BCHP y AODV
Protocols of the transport layer	Transmission Control Protocol (TCP) and Constant Bitrate (CBR)
Propagation model	TwoRayGround
Type of antenna	Omnidirectional

TABLE I
GENERAL PARAMETERS FOR THE SIMULATION

VI. Results of the simulation

A. Rate of sent packets

The rate obtained between the sent packets for the number of packets received. As the formation and maintenance of the cluster needs the exchange of packets in order to have updated packets, it can be seen in figure 7 that the CBRP and BCHP hierarchical routing protocols have a greater send rate than AODV, while the BCHP protocol in general has a send rate slightly greater than the CBRP protocol as it maintains a more stable formation of the cluster.

Figure 4 shows the send rate of the packets on an application level. The protocol is better because it is closer to one. When TCP are used, in AODV, the reason for sending

Fig. 3. Rate of sent packets

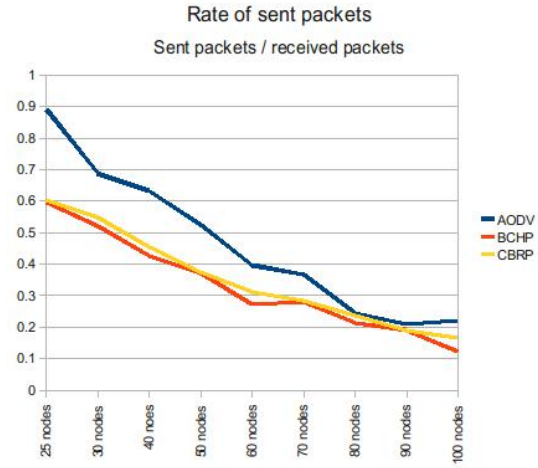
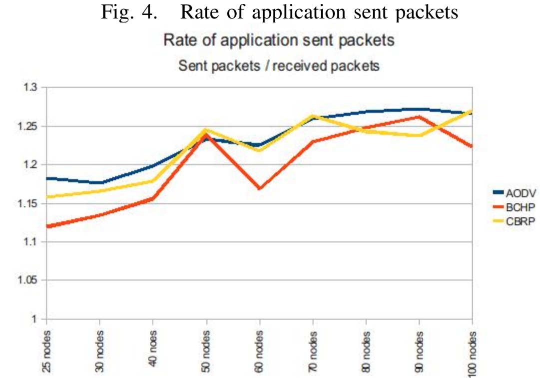


Fig. 4. Rate of application sent packets



is slightly better than the hierarchical routing protocols, while between BCHP and CBRP it is similar, CBRP being slightly better. When CBR connections are used the hierarchical router protocols are equally efficient between them and better than AODV.

B. Average delay

For our purpose, it is a very significant measurement as it is desirable to send and receive network management information as fast as possible.

In figure 5 the BCHP protocol the average extreme delay is slightly better than CBRP when the density of the nodes is less than 70 nodes and it is used as traffic connections with TCP. When CBR connections are used, the hierarchical routing protocols develop well compared to AODV. This means that the use of a hierarchical routing is the best option with traffic not oriented to the connection.

C. Packet delay variation

It is the difference in the delay between extreme to extreme connections between selected packets. In an Ad Hoc network it serves to measure the stability and convergence of the network. As can be seen in figure 6, the average packet delay variation has been obtained for the entire network. The

Fig. 5. End to End delay

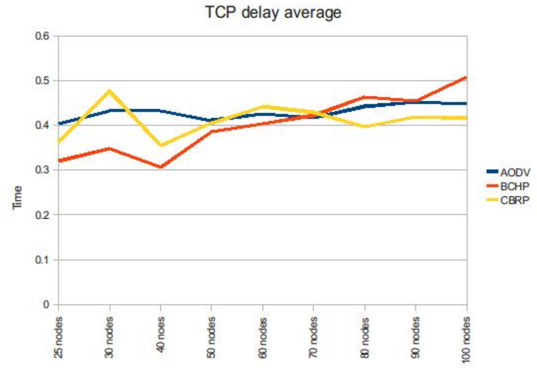
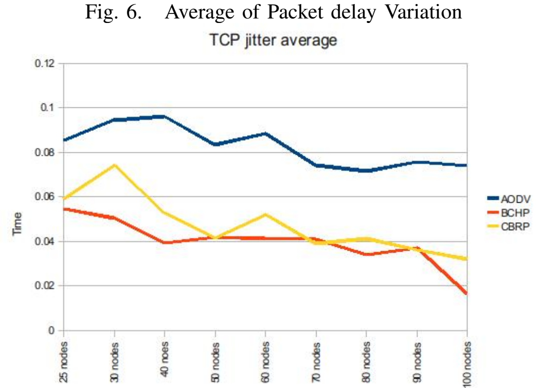


Fig. 6. Average of Packet delay Variation



hierarchical routing protocols function better than AODV. The BCHP protocol has a better variation.

VII. Conclusion and Future Work

A hierarchical routing protocol has been implemented, which has been called the Backup Cluster Head Protocol (BCHP). The BCHP protocol includes the use of the Backup Cluster Head node. It has been demonstrated that the BCHP improves the availability and convergence of the network compared to the AODV and CBRP protocols.

In a future work we will use the BCHP protocol to improve the management of the ad hoc network.

The Backup Cluster Head acts in a reactive manner when there is an event in the network that gives rise to a failure in the cluster head. It is proposed to include a proactive behavior for the head of the backup cluster in future work for when the limits of use of resources of the cluster head are reached.

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