# The Cluster-Based Routing Protocol

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### Abstract

Routing in wireless mobile ad-hoc networks should be time efficient and resource saving. One approach to reduce traffic during the routing process is, to devide the network into clusters. Until now, there have been several approaches on cluster-based routing.

The goal of this work is, to give a description of the cluster-based routing protocol, to point out its advantages compared to other routing protocols for mobile ad-hoc networks and to show problems that occur when performing cluster-based routing. Contents

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# 1 Introduction

In recent years there have been some different approaches on cluster-based routing. The essential works that are taken into consideration here—apart from CBRP—are those of Krishna et al. [5], Chiang et al. [1] and Gerla and Tsai [2].

The cluster-based routing protocol (further on referred to as CBRP) was introduced by Jiang et al. [4] in 1999. In CBRP the nodes of a wireless network are divided into several disjoint or overlapping clusters. Each cluster elects one node as the so-called *clusterhead*. These special nodes are responsible for the routing process. Neighbours of clusterheads cannot be clusterheads as well. But clusterheads are able to communicate with each other by using *gateway nodes*. A gateway is a node that has two or more clusterheads as its neighbours or when the clusters are disjoint—at least one clusterhead and another gateway node.

The routing process itself is performed as source routing by flooding the network with a route request message. Due to the clustered structure there will be less traffic, because route requests will only be passed between clusterheads.

The clustering and the routing process will be described in sections 2 and 3. Problems that occur when using CBRP and its limitations are mentioned in section 4 and section 5 will show a comparison of different routing protocols which use a cluster based approach as well.

# 2 Cluster formation

Gerla and Tsai [2] found out, that *identifier-based clustering* is a better choice than *connectivity-based clustering*, according to node movement. When using identifier-based clustering a node elects itself as the clusterhead if it has the lowest/highest ID in its neighbourhood, or a neighbour node if one has a lower ID. Connectivity-based clustering elects the node, which has the most neighbour nodes, as the clusterhead. So, whenever a clusterhead looses a neighbour node its connectivity decreases and it is most likely that another node has to be elected to act as clusterhead. While in the identifier-based approach, a new clusterhead has to be chosen only when nodes with lower/heigher ID appear [2, 6].

The CBRP uses a variation of the *lowest-ID algorithm* specified by Gerla and Tsai [2], which is an identifier-based algorithm.

In order to support the cluster formation process each node uses a *neighbour table*, where it stores information about its neighbour nodes, such as their ID's, their role in the cluster (clusterhead or member node) and the status of the link to that node (uni-/bi-directional). The neighbour table is maintained by periodically broadcasting HELLO messages. A HELLO message contains information about one node's state, its neighbour table and its cluster adjacency table (see section 3).

#### 2 Cluster formation

The following states describe the clustering process depending on the current node state. These states are:

- **Undecided.** This means the node does not belong to any cluster: this usually occurs if a new node appears in the network. Thus, if it receives a HELLO message from a clusterhead and there is a bi-directional link between them it changes its state to be *member* of the cluster indicated by the *clusterhead*. Otherwise it looks up in its neighbour table if it has any bi-directional links. If so, it becomes itself the *clusterhead* of a new cluster, if not, it remains in the *undecided* state and tries again.
- **Clusterhead.** If a *clusterhead* detects that it has a bi-directional link to another *clusterhead* for a time period, it changes its state to *member* if the other *clusterhead* has a lower ID. Otherwise it stays the *clusterhead* and the other node has to change its state. This is a special case which may result in cluster re-organisation (figure 1).
- **Member.** If a *member* looses its *clusterhead*, it looks for bi-directional links to other nodes. If it detects any, it changes its state to *clusterhead* if it has the lowest ID, otherwise it switches to the *undecided* state. Each *member* node belongs at least to one cluster.



**Figure 1.** When clusterhead 5 moves into cluster 2 it gives up its role as clusterhead according to its higher ID. Nodes A and B which lost their clusterhead form new clusters.

Striking for the goal to minimize cluster re-organisation, the structure of the clusters should change as seldom as possible. That means "a non-cluster head never challenges the status of an existing cluster head" [4], even if it has a lower ID.

### 3 Routing

# 3 Routing

CBRP uses two datastructures to support the routing process: the *cluster adjacency table (CAT)* and the *two-hop topology database*.

The CAT stores information about neighbouring clusters. This is, whether they are bi-directonally or uni-directionally linked. That means, a cluster is called

- bi-directionally linked, if there is a bi-directional link between two nodes of the clusters, or if there are at least two opposite uni-directional links between two nodes (figure 2)
- uni-directionally linked, if there is just one uni-directional link between them (figure 2).



Figure 2. Clusters A, B and A, C are bi-directionally linked, clusters C, D are unidirectionally linked.

The two-hop topology database is build from the information received by HELLO messages. It contains all nodes that are at most two hops away.

The routing process works in two steps. First, it discovers a route from a source node S to a destination node D, afterwards it routes the packets.

#### 3.1 Route discovery

Route discovery is done by using source routing. In the CBRP only clusterheads are flooded with *route request package* (RREQ). Gateway nodes receive the RREQs as well, but without broadcasting them. They forward them to the next clusterhead. This strategy reduces the network traffic.

Initially, node S broadcasts a **RREQ** with unique ID containing the destination's address, the neighbouring clusterhead(s)—including the gateway nodes

#### 3 Routing

to reach them—and the cluster address list which consists of the addresses of the clusterheads forming the route.

When a node N receives a **RREQ** it does the following:

```
IF N is member
  IF D is in the neighbour table
    send {\tt RREQ} to D
  ELSE IF N is gateway to clusterhead C
    forward RREQ to C
  ELSE
    discard RREQ
  ENDIF
ELSE IF N is clusterhead
  IF RREQ already seen
    discard RREQ
  ELSE
    record ID in cluster address list of RREQ
    IF D is neighbour OR D is two hops away
      send RREQ to D
    ELSE
      FOR EACH neighbouring clusterhead C DO
         IF NOT C in address list of RREQ
           record C in cluster address list of RREQ
         ENDIF
      ENDFOR
    ENDIF
    broadcast RREQ
  ENDIF
ENDIF
```

If the RREQ reaches the destination node D it contains the loose source route  $[S, C_1, C_2, \ldots, C_k, D]$  (figure 3). D sends a route reply message (RREP) back to S using the reversed loose source route  $[D, C_k, \ldots, C_1, S]$ . Everytime a clusterhead receives this RREP it computes a strict source route, which then consists only of nodes that form the shortest path within each cluster (figure 3).

### 3.2 Routing and route improvement

Due to node movement, (dis-)appearance of nodes or failures, the CBRP includes two mechanisms to improve a route: The first is *Local Repair* and the second is *Route Shortening*.

#### Local Repair

If a connection between two node failes, the CBRP is able to repair the route. Therefore one of the following nodes of the route has to be in the two-hop topology database of the node, that discovered the broken link (figure 4). If the node is unable to repair the route, the route has to be recalculated.

# 3 Routing



Figure 3. The loose source route (non-dashed arrows) and the strict source route (dashed arrows) from S to D.



**Figure 4.** The broken route between N and D (gray arrow) was repaired by using the clusterhead.

#### 4 Problems and limitations

#### **Route Shortening**

Sometimes a node may discover a connection between itself and another succeeding node of the route, that is not its direct successor or a connection between two following nodes, respectively. This can be done by examening the information stored in the two-hop topology database. If so, it shortens the route by excluding the redundant node(s) from the route (figure 5).



Figure 5. Node N discovered a new connection between itself and D (dashed line) and shortened the route.

In both cases, Local Repair and Route Shortening, the destination node is infomed about the changes by receiving a gratuitous route reply packet from the node, that performed the changes.

## 4 Problems and limitations

Like most of the other routing protocols, CBRP has some limitations and problems which are disadvantages compared to other protocols.

If networks and clusters become too big, the overhead per packet increases due to source routing. Every node of the route has to be stored in the routed packet. So the packet size raises proportional to the pathlength of the route. According to this, the transmission time increases as well. Also, if the cluster size grows the size of HELLO messages and stored data structures increases.

According to this rise of overhead and the flat two level hierarchy the CBRP is scaleble to an extend.

Another problem of the CBRP is its support of uni-directional links. When using a network with 802.11 link layer technology these links cannot be supported, because the 802.11 protocol knows only bi-directional links. This could be solved by defining a new protocol that allows uni-directional links. From the view of the 802.11 protocol this would mean to permit that one node may forward Acknowledgement Packets. So a node would be able to send its acknowledgement back to the sender by using multiple hops.

Address resolving by using the Address Resolution Protocol  $(ARP)^1$  is also a problem. The ARP is a protocol to map network IP addresses to Medium

 $<sup>^{1}</sup> http://www.erg.abdn.ac.uk/users/gorry/course/inet-pages/arp.html$ 

#### 5 Comparison of other cluster-based routing protocols

Access Control (MAC) addresses. To resolve such a mapping ARP request messages (who is  $IP_D$  tell  $IP_S$ ) are broadcasted throughout the network. If the destination receives such a request, it replies with an ARP response message ( $IP_D$  is MAC<sub>D</sub>). If two nodes are uni-directionally linked one of them cannot resolve the other's MAC address by using the conventinal ARP. In this case a solution would be a modification of the protocol. So, if the uni-directional link is an intra-cluster linked, the clusterhead could inform the upstream node of the MAC address of the downstream node. In case of an inter-cluster link, the address could be resolved during the process of adjacent cluster discovery (figure 6).



**Figure 6.** For node 3, the MAC address of 5 could be resolved by its clusterhead. For node 2, the address of 1 could be resolved during the discovery of adjacent clusters.

# 5 Comparison of other cluster-based routing protocols

### 5.1 The Cluster-based approach from Krishna et al.

Krishna et al. proposed a cluster-based approach in which clusters are formed by separating the network into overlapping cliques which contain at least two nodes (figure 7). "Each node maintains a list of its neighbors, a list of clusters [...] in the network, and a list of boundary nodes [...] in the network" [5], where boundary nodes are nodes that are members of more than one clique (simlar to the *gateway nodes* of the CBRP).

They created routing tables at each node, using the network topology information provided by the list of clusters and the list of boundary nodes. By applying a shortest path algorithm (e.g. Dijkstra), each node was able to determine a path with fewest hops to each of its neighbouring clusters.

Further more they stated, that using clusters in the way they proposed, one can apply any (fast) routing protocol from flat networks to determine routes.

When comparing their routing protocol to others (table 1) they found out that clustering is a good method for routing, because the complexity (overhead) depends on the number of boundary nodes and not on the number of nodes or links in the network. So, in most cases, the boundary nodes would be less than 50 % of the entire nodes.

5 Comparison of other cluster-based routing protocols



Figure 7. Krishna et al. proposed clusters that are overlapping cliques. The gray nodes are boundary (gateway) nodes.

Protocol	TC	CC
Distributed Bellman-Ford	$\mathcal{O}(N)$	$\mathcal{O}(N^2)$
Ideal Link State	$\mathcal{O}(d)$	$\mathcal{O}(E)$
Diffusing Update Algorithm	$\mathcal{O}(x)$	$\mathcal{O}(\mathcal{D}x)$
NP	$\mathcal{O}(l)$	$\mathcal{O}(x)$
Cluster	$\mathcal{O}(d)$	$\mathcal{O}(\mathcal{B} + \mathcal{D})$
Flooding	0	0

- TCTime complexity (number of steps required for the network to reconverge after a topology change).
- CCCommunication complexity (number of messages required to accomplish the reconvergence).
- NNumber of nodes in the network.
- Number of links in the network. E
- dDiameter of the network (length of the longest shortest path in hops between any two nodes).  $\mathcal{D}$
- Maximum degree of a node.
- $\mathcal{B}$ Upper bound on the number of unique boundary nodes in the network.
- Number of nodes affected by the topological xchange.
- l Diameter of the affected network segment.

Table 1: Complexity (overhead) comparison of various routing protocols [5, p. 59].

### 6 Conclusion

### 5.2 Cluster (hierarchical) Routing Protocol

The cluster (hierarchical) routing protocol (DSCR) [1] relies on the same clusterbased approach as the CBRP. Routing in CGSR is done by using the destinationsequenced distance-vector routing protocol (DSDV). Every node stores a cluster member table and a routing table, so that it is able to find out the next node on the way to the shortest destination clusterhead. In a 100-node network with an average distance of 12.31 hops, Chiang et al. found out, that there is a speed-up of factor 1.025 over DSDV (avarage delay (simulation clock): DSDV 36682, DSCR 35772).

### 5.3 Clusterhead Gateway Switch Routing

As DSCR, clusterhead gateway switch routing protocol (CGSR) [1] relies on the same cluster-based approach as the CBRP. The difference between DSCR and CGSR is, that CGSR routes packets by just using clusterheads and gateway nodes as CBRP does. With an average delay of 32238 this is a speed-up of factor 1.138 over DSDV in the test network mentioned in section 5.2.

# 6 Conclusion

In this work we have seen the structure and the working of the *cluster-based* routing protocol. Its advantages and disadvantages, its problems and limitations were pointed out. So, as we have seen in the sections before, cluster-based approaches on routing in mobile ad-hoc networks are good methods to decrease network traffic and routing overhead. According to its two-level hierarchy CBRP is prefferable against routing protocols on flat networks, but it is far away from the scalebility of hierarchical routing protocols. If network sizes are small (performance evaluation [3] showed that it works fine with networks of 150 nodes), CBRP can be a good routing solution.

### References

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