An Efficient Cluster Management Protocol using GPS Based Geographic Clustering with Surrogate Cluster-heads for a Large Ad hoc Network

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Abstract: *We believe that it is not a trivial job to maintain and manage clusters in a highly mobile ad hoc scenario where host mobility and changes in node activity status causes frequent and unpredictable topological changes. It requires continuous and efficient management protocol for frequent up-dation and re-clustering which are costly in a resource-poor environment. This maintenance process may even degrade the performance of the network as a whole. In this context, we describe a convenient cluster management protocol that incurs very little communication overhead for maintaining a stable cluster structure. Our protocol defines a geographical boundary for each cluster using GPS information that enables the mobile nodes to get alarmed while crossing the cluster boundary and generate timely cluster bind requests. Here a cluster-head is also free to leave its cluster after delegating the leadership to any member-node.. This member-node now will act as a surrogate cluster-head of the cluster. The simulation results indicate that this mechanism reduces as much as 30% of the overhead traffics involved in cluster maintenance Thus the network performance metrics such as throughput and delay that are tightly coupled with the overhead of cluster management will get improved.*

1. Introduction

The clustering is always of significant importance for network management, routing methods, QoS, resource allocation, topology update effect and in this context, they should be maintained and managed efficiently. Once a network gets clustered it needs to be maintained and managed efficiently to support seamless communication. This task becomes complicated in a highly mobile scenario and results in much overhead with increase in cluster size [2, 3, 4].Existing periodic trigger based clustering management protocol incorporates large intra and inter-cluster traffic which degrades the performance of the network as a whole.

Here we describe a convenient and a low cost cluster management protocol for large mobile networks. We assume that the locations of the nodes are available directly using GPS (Global Positioning System). Clusters are formed initially using a modified Max-Min-D-cluster formation algorithm [1] and we propose to construct a static geographical boundary for each cluster using GPS of the boundary nodes. In this protocol the nodes are free to move from one cluster to another keeping the cluster structure entirely stable within the proposed region boundary. This boundary information is available with all the members of a cluster. Our technique enables all the mobile nodes of a cluster to get alarmed while crossing the cluster boundary and is able to generate a timely request for unbind and bind with old and new cluster-head respectively.

This paper also proposes a novel optimistic cluster head-surrogating scheme for achieving efficiency in cluster management process. In this scheme a cluster-head is also free to leave its cluster after delegating the leadership to any member-node of its current cluster. This member-node now will act as a surrogate cluster-head of the cluster. The surrogating system can be executed upon any of the neighbouring nodes of the current cluster-head. The process actually duplicates a copy of headship program and related member information list to the selected surrogate-head.

This particular technique of defining the clusters with fixed boundaries has following advantages.

(i) The cluster structure becomes robust in the face of topological changes caused by node motion, node failure and node insertion /removal.
(ii) The ability of surrogating cluster headship from a mobile cluster head to any of its neighbor.
(iii) Independent and autonomous cluster control and maintenance by the mobile members only.
(iv) No performance degradation of the network due to cluster management protocol.
(v) The impact of node mobility has been localized within the cluster and its immediate neighbors only.

2. GPS bounded cluster Structure Algorithm

To obtain the initial set of clusters, we referred a leader election algorithm - Max-Min D –Cluster Formation algorithm proposed by Alan D. Almis, Ravi Prakash, Vuong Duong and T. Huynh [1]. There are several advantages for using Max-Min D–Cluster Formation algorithm over other existing clustering algorithms like the nodes can asynchronously run the heuristics so no need for synchronized clocks, we can customize the number of clusters as a function of d.

In our proposed GPS based clustering algorithm we have used the initial leader election part of the Max-Min D–Cluster algorithm in the first phase. In the second phase the elected leader or the cluster head will be able to recognize its boundary by getting the GPS information from all of its member nodes and will announce this boundary location values within d hop. Thus all the member nodes get alarmed about the current cluster boundary and will utilize this value while going out of this cluster. The cluster boundary algorithm can be explained in two phases.

Phase I Max-Min D–Cluster Formation algorithm :

Step I: At some common epoch each node initiates **2d** rounds of flooding of information exchange (**node id**) where d is the given heuristic. Each node maintains a logged entry of two arrays, **WINNER** and **SENDER** to store the results of each flooding round.

Step II: Initially each node sets its winner to be equal to its own node id.

Step III: This is the phase for **FLOODMAX** where a node chooses the largest value among its own **WINNER** array and this process continues for d rounds.

Step IV: This **FLOODMIN** phase follows **FLOODMAX** where a node chooses the smallest rather than the largest value as its new **WINNER** to reclaim some of their territory.

Step V : After these two d rounds of information exchange a node is able to determine its cluster-head.

Now the existing Max-Min D–Cluster Formation algorithm can be stopped here. In our protocol there is no need for gateway selection phase for these clusters. The first phase of the algorithm will form the following clusters with a given set of nodes.

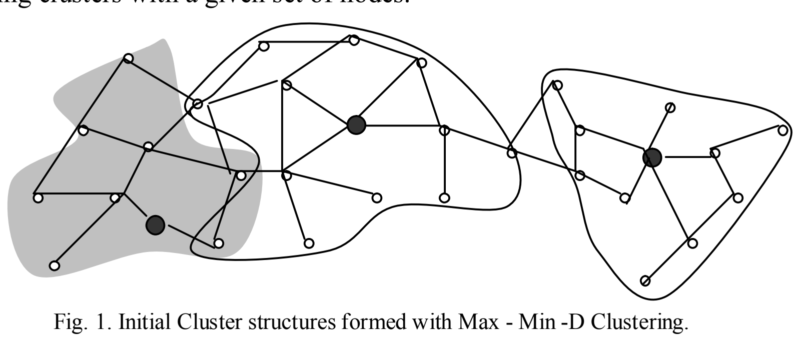

Fig. 1. Initial Cluster structures formed with Max - Min -D Clustering.

After the cluster head selection procedure is over we proceed to define a static geographic boundary for the clusters. This geographic boundary can be easily defined with the absolute coordinate position (GPS) of the nodes lying at the boundaries. Thus the standard Max-min-D-cluster formation algorithm will be stopped earlier and our modifications using GPS technology will start.

Phase II : Cluster Boundary Formation algorithm:

Step I : The cluster head broadcasts **get_Position_ forAll ( )** request message along with its own GPS to get percolated within d hop.

Step II : All member nodes in turn unicasts back the message **node_GPS ( )** to the cluster-head using geographical routing.

Step III : Cluster-head receives all the GPS values of its members and calculates the maximum limiting coordinates for Left, Right, Up and Down values to define its boundary.

Step IV : The cluster head then broadcasts the message **get_Boundary_values( )** within the d hop transmission range to notify all the member nodes about the cluster boundary.

Step IV: All the member nodes become alarmed about the rectangular cluster boundary information which can be verified while changing their positions.

Thus following our GPS based clustering algorithm the network will get partitioned into a number of geographically overlapping clusters. The cluster boundary getting fixed in this way is not at all required to be redefined again with the mobility of the boundary nodes. This boundary value will be once notified to all the members of a cluster and will remain fixed until all the nodes move away from this region. In that case only the cluster–head will recall the initial clustering algorithm again to remain connected and the cluster boundary does not exists any more

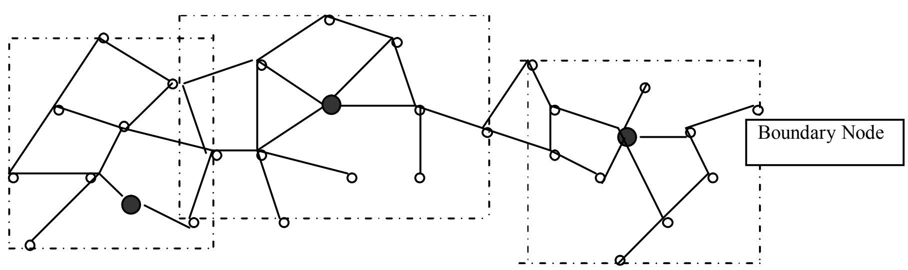

Fig. 2. Cluster boundaries formed with GPS of the boundary nodes

3. Cluster management Protocol

Whenever a node movement becomes greater, the communication overhead increases drastically for managing the mobile nodes and results in performance degradations [2].Usually cluster maintenance is applied to support this node mobility, which has twofold communication overheads.

- The huge communication overhead involved due to change of cluster architecture caused by topology changes and which needs to be reflected within the network. The frequency of re-clustering has an impact on the performance of the network i.e. if the periodic triggers are too closely spaced then the system may run even when there has no noticeable topology change, and if the periodic triggers are too far apart then the topology may change leaving the nodes to be stranded without a CH.

- Generally for periodic beacon based cluster maintenance protocols if a cluster member is moving out of the transmission range of the CH, the member node searches for the new head by detecting the new CH beacon signal. There is no other intelligent way to track the mobility of a member node.

Here we have proposed a cluster maintenance protocol using GPS technology, which is able to maintain a stable cluster structure even in presence of high mobility incurring little overhead. The protocol works in the following way

```
When my GPS  = = Boundary GPS  then
 Start listening to beacon signal of the neighboring nodes.
 If  member of other cluster available then
        Get GPS of the New CH;
        Unicast  a membership bind request message to the New CH;
        Unicast  a  membership unbind request message to the Old CH;
 Else  if I have not received a beacon and the signal duration time is over then
       Start broadcasting myID ;
       Declare myID = CHID ( I am  the CH);
       Declare my memberlist to be NULL.
```

4. Cluster Head mobility management with surrogate cluster-heads

The problem of node mobility is much more alarming when the cluster head itself becomes mobile and thereby generating the necessity of frequent re-clustering. The scheme of surrogating the CH actually provides a feasible solution for improving seamless data communication without performance degradation of the network in highly dynamic ad hoc environments. It also reduces the repeated overhead traffic involved in re-clustering.

We have proposed a pessimistic surrogating algorithm, which will be sufficient to keep the stable cluster structure with minimum overhead. The departing cluster head arranges any of its neighbouring nodes for delegating the cluster headship and thus can surrogate the original CH to facilitate the propagation of data communication process.

We have selected various nodes as surrogating head depending on different metrics like position with respect to cluster boundary or mobility etc. This entire process of surrogating actually involves the transfer of CH information and re-announcement of new CH id.

. We have found that if the surrogating head can be selected from the middle of the cluster then though the initial multihop transfer overhead is much higher, the cluster head duration increases remarkably. The selection can be also made from the mobility metrics of the nodes or using the hybrid metrics of (mobility + location) and the stability of CH duration can be analysed explicitly.

5. Performance analysis and Simulation Results

We conducted experiments on a simulated ad hoc network consists of 100 to 1000 nodes to evaluate the performance of the proposed cluster management algorithm and compared the communication overhead involved in cluster management and maintenance with that of standard max-min D-hop clustering [1] algorithm. Communication overhead involved in our GPS based cluster maintenance protocol comes under the following headings (i) Hello protocol, (ii) Cluster formation and cluster maintenance information message flow, (ii) Cluster boundary information flooding within d hop cluster members, (iv) Location registration events due to node mobility between clusters,(v) Handoff or transfer of headship due to cluster-head mobility. In this paper we have separately calculated the overhead associated with initial cluster formation, cluster maintenance.

We first analyse the communication overhead involved for cluster maintenance with varying the important clustering parameters i) cluster size, ii) Degree of node mobility. It has been observed in all the graphs shown in the following fig [3a and 3b] that a significant amount of overhead traffic can be reduced for cluster maintenance using the GPS based cluster management protocol.

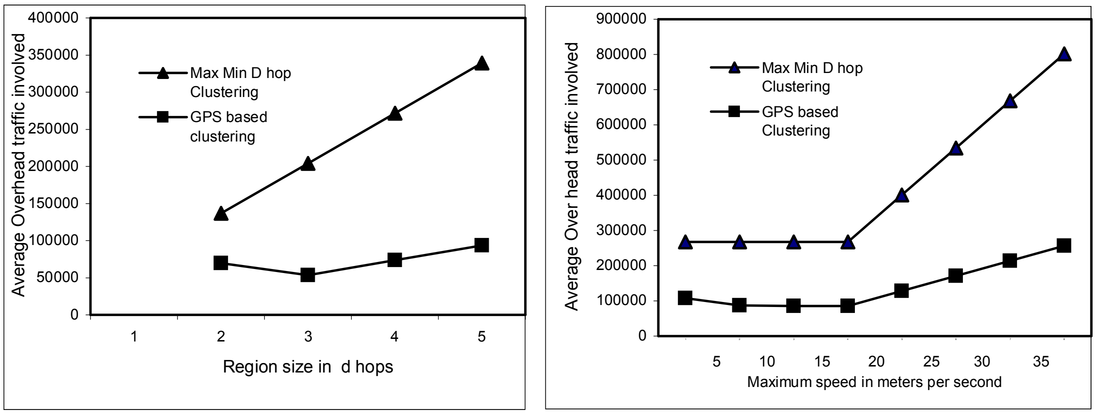

Fig. 3 Average overhead involved in cluster maintenance with a) varying cluster size b) varying node mobility.

So it can be concluded that while the average number of cluster maintenance overhead rapidly increases with the increase in cluster size and mobility for any periodic beacon based clustering algorithm [1] there is a very gradual rise in the curves showing communication overhead using GPS based clustering and the difference between the curves also increases prominently with increase in network size.

6. Conclusion

Here we have tried to minimize the frequency of re-clustering by proposing a GPS based stable cluster maintenance protocol. We have shown that using a one time absolute geographical boundary for a cluster, it can be kept stable over a region for a long period (until all the nodes move away). In our GPS based clustering management protocol there is no need for frequent periodic re-clustering announcements. Here the mobility can be managed locally by the mobile members using auto-generation of registration and de-registration messages whish implicitly keeps the cluster structure stable and as such the communication overhead gets heavily reduced. The cluster belonging ness can be determined once by using the deterministic GPS based approach and any further modifications in the member belongingness can be taken care locally without having a little impact on the rest of the network. This GPS based robust approach together with the support of Surrogate cluster-head makes this approach highly deployable in an extremely mobile environment.

7. References

[1] Alan D. Amis Ravi Prakash Thai H.P. Vuong Dung T. Huynh. Max-Min D-Cluster Formation in Wireless Ad Hoc Networks. IEEE INFOCOM , March , 2000.

[2] John Sucec and Ivan Marsic Rutgers University. Clustering Overhead for Hierarchical Routing in Mobile Ad hoc Networks. IEEE INFOCOM 2002.

[3] I-Shyan Hwang, Chih-Kang Chien and Chiung-Ying Wang. A Novel GPS-Based Quorum Hybrid Routing Algorithm (GPS-QHRA) for Cellular-Based Ad Hoc Wireless Networks. Journal of Information Science and Engineering, Volume 21, Number 1, January 2005.

[4] P. Basu, N. Khan, and T.D.C.Little. A Mobility Based Metric for Clustering in Mobile Ad Hoc Networks. Proc IEE E ICDCS 2001 Workshop on Wireless Networks.