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Mitigating the impact of node mobility using mobile backbone for heterogeneous MANETs

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ABSTRACT

Routing in Mobile Ad hoc Network (MANET) has been an active research area in the past few years. It is observed that as the mobility of nodes increases, the performance of existing cluster based routing protocols tends to deteriorate rapidly. Although many mobility based clustering schemes have been proposed to address this problem, majority of these proposals assume the movement of nodes follows group mobility. In this paper, we propose a new cluster based routing protocol FASTR which utilizes mobile backbone to mitigate the impact of node mobility for networks with high node mobility and low group mobility. Our scheme eliminates the delay caused by cluster head election and enables nodes to start communication immediately after joining a cluster. Through simulation and analysis, our protocol is shown to possess good scalability, incur lower control overhead and achieve higher packet delivery ratio than existing OLSR and HOLSR routing protocols for various node mobility. Furthermore, unlike other proactive routing protocols, the control overhead of FASTR is shown to be independent of node mobility and consume less network resources than HOLSR and OLSR.

1. Introduction

Mobile Ad hoc Networks (MANETs) are dynamic and self-organizing networks which allow nodes to establish communication without network infrastructure support. To study the scalability of MANET, Gupta and Kumar [1] show that the capacity of the pure ad hoc network scales as $\Theta(1/\sqrt{n \log n})$, i.e. the network does not scale well. In recent years, with the advance of wireless technology, modern network nodes with multiple heterogeneous wireless interfaces have triggered the advent of heterogeneous MANETs in which some more powerful nodes have additional wireless interfaces than others. It has been shown by Zemlianov and Veciana [2] that the network capacity can be improved by deploying backbone nodes which are interconnected by additional high capacity links. On the other hand, network capacity is not the only factor impacting the scalability. Another important factor is the routing protocol. Routing in MANET has been a research area of great interests in the last decade and many routing protocols have been proposed. Early routing protocols, such as Optimized Link State Routing (OLSR) [3], Destination-Sequenced Distance Vector (DSDV) [4], are usually "flat", but flat routing protocols often have scalability issues [5]. To address this issue, cluster based routing protocols are proposed to improve the scalability. In cluster based routing, nodes are divided into virtual groups called clusters and there is usually a node called Cluster Head (CH) in each cluster acting as the local controller. All cluster heads together form a network backbone. Topology changes in local cluster can be concealed within the cluster and the local control packets can be contained within each cluster. The control overhead is then reduced and network scalability is improved. The routing process within each cluster is commonly referred to as intra-cluster routing and routing between clusters is called inter-cluster routing.

Although several cluster based routing protocols [6–13] have been proposed, the main research focus of cluster based routing has been on the clustering method itself, mainly to achieve different goals such as controlling the cluster size, improving the cluster stability or reducing the latency incurred by the cluster formation process. The problem of clustering has been well studied and many clustering methods have been proposed. Two basic clustering schemes are Lowest ID Clustering [14] and Highest Connectivity Clustering (HCC) [15]. Lowest ID Clustering assumes each node has a node ID and elects nodes with the lowest ID in their neighborhood as cluster heads. On the other hand, in HCC, clustering nodes with the largest number of neighbors becomes the cluster head. Least Cluster head Change (LCC) [16] improves the cluster stability by restricting the re-clustering condition such that unnecessary re-clustering is avoided. ABP [17] forms clusters based on factors such as node degree and battery level. It attempts to reduce cluster head re-election by introducing a penalty factor such that cluster head is only re-elected when the network structure experiences major modification. In [18], the clustering problem is

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formulated into an Integer Linear Programming (ILP) problem and a heuristic is proposed to generate stable clusters. *K*-clustering [19–24] is another class of clustering method in which each node is either cluster head or is at most *k* hops away from its cluster head. Thus, the size of clusters can be controlled. Clustering can also be modeled as finding a Dominating Set (DS) in a graph. Given a graph $G = (V, E)$ over a set of nodes V, a subset $S, S \subset V$, is a dominating set if $\forall v \in V, v \in S$ or $\exists u \in S, (u, v) \in E$, i.e. any node is either in the dominating set or it is a direct neighbor of some node in the dominating set. A Connected Dominating Set (CDS) $C(G)$ is a DS such that the graph induced by $C(G)$ is connected. By finding a minimum CDS, a network backbone of minimized size can be constructed. There has been a large amount of research work done on this topic [25–32] and the focus of these work has been mainly on improving the approximation algorithm for CDS construction.

Since conventional clustering algorithms usually require a convergence time before the clustering process completes, most of the aforementioned clustering methods assume network to be static or semi-static; at least the network topology does not change during the cluster formation. However, this assumption might not hold in highly mobile networks such as vehicular networks or aerial networks. High node mobility can cause frequent link breaks and network topology changes which can in turn severely impact the stability of clusters. To address this issue, several mobility aware clustering schemes are proposed [33–43]. These mobility aware schemes are based on the assumption of group mobility, i.e. movement of nodes are assumed to follow certain pattern. By grouping nodes with similar mobility pattern together, these nodes exhibit low relative mobility and hence the stability of the clusters can be greatly improved. This approach is especially useful for vehicles on expressways. However, it might not be suitable for other scenarios. Considering in urban area where there are many crossings on the street, cars on the roads may follow diverse routes even if they have some common destinations. Thus, these cars might arbitrarily turn into a different street at any crossing. In this scenario, vehicles will probably only exhibit group mobility when traveling along the road segment between crossings. At each crossing, clusters might experience major change due to cars leaving or joining the cluster. This could trigger frequent re-clustering and in turn routing updates. This is quite different from the case on expressways. Another example is networks formed by aerial platforms such as Unmanned Aerial Vehicles (UAVs). In disaster rescue scenario, each UAV may be used to search certain area and there may not exist any group mobility among these UAVs. In a military scenario, ground vehicles could form networks together with UAVs in the sky. The vehicles and the UAVs may not share similar movement trajectory, thus group mobility might not be observed and approaches assuming the existence of group mobility might not work well.

Therefore, it will be useful to investigate how to mitigate impact of node mobility where nodes do not exhibit similar mobility pattern while retaining the benefits of cluster based routing. To this end, we start by reviewing the basic steps of cluster based routing. As illustrated in Fig. 1, upon startup, network nodes will first attempt to elect cluster heads and form clusters. Then routing protocols are executed within each cluster to populate routing tables. Nodes can forward data packets once the routing table is populated. If a node leaves or joins the cluster, the routing protocol will detect the topology change and re-populate the routing table for each node. However, if there is a major change in the cluster structure, for example, the cluster head has left the local cluster, a new cluster head must be elected. This will trigger a re-clustering process. Therefore, the impact of node mobility mainly comes from two aspects: firstly, minor topology change invalidates existing entries in routing table. It will take some time for the routing protocols to find a new route. Secondly, when there is major cluster structure change, re-clustering is required. In this case, the routing protocols might need to wait until the clustering process completes before routing tables can be properly updated. The latency incurred by these two aspects prevents nodes from quickly adapting to the topology change and could severely impact the routing performance. Thus, if we can minimize the time taken by clustering and route discovery, the routing performance can be greatly improved.

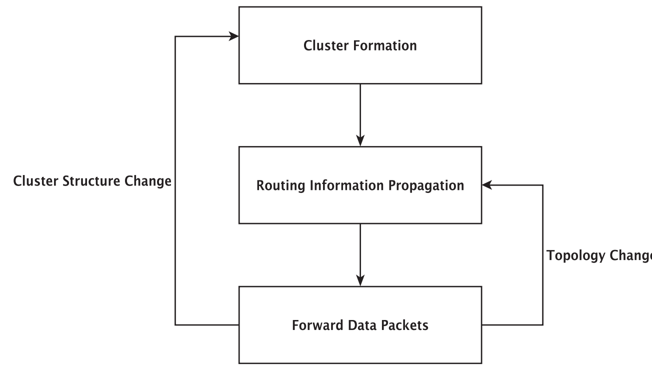

Fig. 1. An illustration of basic steps of cluster based routing.

Considering the design space illustrated in Fig. 2, conventional clustering methods fit nicely in the region with low node mobility. In the region with high node mobility, mobility aware clustering methods can work well when group mobility can be observed. However, it largely remains to be explored for the scenario with high node mobility and low group mobility. Furthermore, most existing cluster based routing protocols reuse flat routing protocols such as OLSR or DSDV for intra-cluster or inter-cluster routing. These flat routing protocols are not designed to minimize the route discovery delay. It is desirable to design a routing protocol to enable nodes to quickly adapt to topology changes. In addition, Wu et al. [44] have shown that the routing overhead of proactive routing protocols is a function of node mobility. Therefore, in a highly mobile network, the routing overhead can be very high. Thus, it is also desirable that the control overhead of the routing protocol be independent of node mobility.

To address these issues, in this paper, we propose a new cluster based routing protocol FASTRoute (FASTR) for highly mobile heterogeneous MANETs without group mobility. In order to minimize the clustering delay, we take advantage of heterogeneous MANET by pre-selecting all powerful nodes with multiple interfaces as cluster heads. In this way, the cluster head selection procedure is eliminated. Each cluster head will periodically gather the network topology of local cluster and send out HEARTBEAT messages with

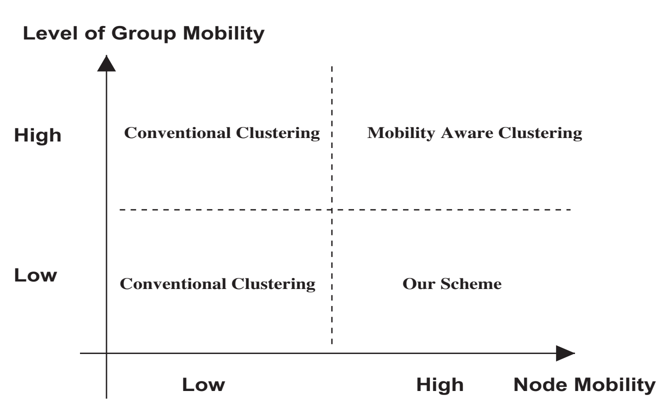

Fig. 2. An illustration of the design space of cluster based routing.