Mitigating Congestion in Multi-hop Cellular Network with Distributed Routing

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Abstract - *Multi-hop cellular network is faced with a challenge of data congestion in routing. This paper presents a distributed routing protocol to mitigate the congestion of hybrid network. Unlink the previous routing protocols which route packets in a single direction path, the distributed routing method distributed the routing overhead among a number of nodes, leading to less probability of traffic congestion occurrence. Simulation results show the superiority of the distributed routing protocol in comparison with another routing protocol in terms of network throughput and efficiency.*

Keywords: Hybrid network, Congestion, Distributed routing

1 Introduction

In recent several years, wireless techniques have made tremendous progress in wireless communications network and wireless devices. A new network architecture named multi-hop cellular network (i.e., hybrid network) has been proposed to meet the increasing communication need of our daily life. The multi-hop cellular network is a combination of a traditional cellular network model and a wireless ad hoc network model, aiming to leverage their advantages to improve the performance of wireless communication system. In an ad hoc network, data is routed to its destination in a multi-hop fashion. This makes it easy to construct a temporary local network and make full spatial reuse. In an infrastructure network (i.e. cellular network), nodes communicate with each other through base stations or access points. This provides higher message transmitting reliability and signal robustness with simple routing method.

Although many researches have shown that such multi-hop cellular hybrid networks can improve the performance of the communication systems [1, 2, 3], it still has traffic congestion problem. Most of the hybrid networks incorporate a multi-hop ad hoc network in a cellular network [1, 4, 5] without addressing the limitation of both transmission mode. In these networks, when the source node and destination node in the same cell (i.e., a signal coverage region of a base station), they communicate with each other in a multi-hop mode. Otherwise, they route the data to the base station in a multi-hop fashion, through which they access the internet backbone. Such routing method raise congestion probability from three aspects: (1) The one path direction routing is prone to routing congestion during the data transmission. (2) When being accessed by a large number of mobile gateways nodes simultaneously, a base station is easily to become a hot spot because of its limited transmission channel. Mobile gateways nodes are the nodes connecting infrastructure network and ad hoc network. That is, the offered traffic exceeds the capacity of a base station. (3) Since a lot of the traffic is forwarded to the base station in a multi-hop way, the mobile gateway is easily to be congested.

In this paper, we proposed a distributed routing protocol to reduce the congestion in hybrid networks. In the protocol, the traffic from the source node is distributed to several neighbor nodes which then is forwarded to several base stations in a distributed fashion. Rather than forwarding the data to the base stations in a multi-hop direct fashion, the source node transmits the segments of the source packet streams to a number of selected immediate neighbor node with ad hoc interface. Those neighbor nodes use cellular interface to forward the packets to the base stations directly.

The rest of this paper is organized as follows. Section 2 presents a review of representative hybrid networks and multi-hops routing schemes. Section 3 details the distributed routing protocol. Section 4 shows the performance of distributed routing protocol in comparison with a traditional hybrid network with AODV. Finally, Section 5 concludes the paper and indicates the future work.

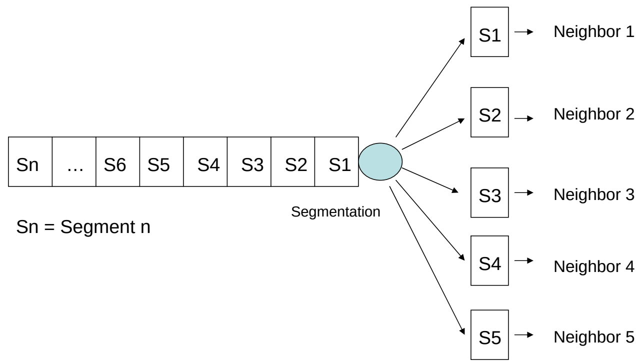

Figure 1. Data transmission in the distributed routing protocol.

2 Related Work

Various hybrid networks with different features have been proposed [6, 2, 5] for wireless networks. In [2], the authors proposed to use pre-deployed, dedicated, and fixed proxy relay agents for message relay. This work is focused on improving call blocking probability in each cell. Although using fixed relay agents can deal with security and billing problem in the transmission, this strategy brings about high cost.

Based on the idea of [2], [5] use mobile nodes as relay nodes to transmit data between neighbor cells. In [5], a node communicates with another node by accessing a base station which will send back routing information from the node to the base station according to network connectivity. Although such centralized management method can improve the routing of the ad hoc network to a certain extend, the mobile nodes close to the base station are still prone to be bottlenecks in the system.

Recently, most of the hybrid networks either simply combine routing schemes in ad hoc networks and in infrastructure networks, or use pre-deployed and dedicated stationary proxy relay agents for packet replaying which increases the system cost. The majority of the works on hybrid network routing protocol nowadays focus on the ad hoc routing that uses mobile nodes as relays to route ad hoc traffic [4]. The routing schemes employed by hybrid networks in their ad hoc network component include AODV [7], DSR [8] routing schemes. DSR and AODV need high overhead for route discovery. They store route information after route discovery. They save routing maintenance overhead, but often fail to observe the up-to-date network topology changes. In addition, in both protocols, all data passes through a single gateway node, which may become a traffic bottleneck. In [1], the authors aim to reduce the number of base stations by requiring every node to engage in the multi-hop transmission. However, this method can only work well in the intra-cell transmission since it still largely depends on traditional multi-hop ad hoc communication mode.

In [9], the base station is used to assist the ad hoc transmission in a single cell. The main transmission mode in the cell is still ad hoc transmission, and the infrastructure transmission mode is served as backup transmission when the performance of ad hoc network is poor. Unlike this work, the proposed distributed routing method mainly considers the inter-cell communication. Hung and *et al.* [10] proposed to adjust base station transmission ranges for the data transmission. However, GPS and single direction antenna equipped mobile stations are assumed in the system, which increases the system complexity. The proposed distributed routing protocol is self-organized, in which on more extra equipments are required except the two-mode interface.

3 Distributed Routing Protocol

3.1 Protocol Description and Analysis

In a hybrid network, when a source node forwards packets from its cell to a destination node in another cell, base stations serve as an infrastructure gateways for packets to access the backbone network. The distributed routing method takes full advantage of the distributed locations of base stations and their high powered cellular interfaces to mitigate congestion in multi-hop cellular networks. Figure 1 shows an example of data transmission in the distributed routing method. In the distributed routing, the source node divides its data stream into several segments S_i $(i \in [1, n])$, each of which is sent to an intermediate neighbor node with ad hoc interface. An intermediate node is a relay node that forwards a message from a source node to a base station in the hybrid network. The intermediate nodes then forward these segments to base stations with cellular interfaces, which further forward the segments to the final base station where the destination node resides. The last hop base station is responsible for resembling the segments to retrieve the original data.

The distributed routing protocol reduces the traffic congestion in the hybrid networks in terms of three aspects. First, the distributed routing protocol mitigates the congestion through reducing traffic overhead. IEEE 802.11 [11] is used in the MAC level of the ad hoc network to reduce collisions caused by hidden terminals [12]. It uses a four-way RTS/CTS/Data/Ack message exchange to guarantee a successful transmission. Specifically, before a node sends out a data packet, it sends out a RTS (Request To Send) message to the node in next hop. If the channel of the node in next hop is free, the node sends back a CTS (Clear To Send) message. After receiving CTS message, the sender then sends a data packet to the next hop node and waits for the receiver replying back a ACK (acknowledgment) message. The neighbor nodes which receive RTS and CTS will wait for a certain time period before generate their packets. The node communication under the MAC protocol leads to high overhead for message transmission. Therefore, in a routing path with multi-hop transmission, the inefficiency of the MAC protocol will lead to high overhead in the channel, making the congestion in the multi-hop transmission even worse. The traditional ad hoc routing schemes such as AODV and SDR take up the channels most of the time to discover, establish and maintain routes or to confirm the state of the neighbor nodes by exchanging the control messages. Much more node communication for these operations exacerbates the traffic congestion situation in the system. In contrast, the distributed routing protocol takes advantage of the high power cellular interface to avoid the multi-hop routing in the ad hoc network, thus reducing the overhead in the system.

Second, the distributed routing method mitigates the congestion through reducing single points. Traditional multi-hop schemes transmit a message in channels along a single route, leading to low channel utilization in other directions and possible network congestion on the route direction. Third, the mobile gateway nodes closed to the base station are also prone to be overloaded considering a large amount of traffic needs to access the base stations for the internet serves and inter-cell communication. On the contrary, the distributed routing protocol avoids congestion by sending the packets to a number of base stations and the mobile gateway nodes are not necessary the nodes close to the base stations.

3.2 Distribution Routing Algorithm

Algorithm 1 presents the pseudo-code of the packet sending algorithm. After randomly dividing the source stream into several parts, the source node checkouts its current neighbors. Among these neighbors, source node chooses a number of neighbor nodes with high data forwarding ability. If a neighbor node is in the overloaded cell, the source node will ignore this node. In this process, congestion in base station is controlled by restricting the traffic in lightly loaded cells. Then, the source node sends each segment to the selected neighbor nodes. After that, if the source node still has segments left, it will update its neighbor links and checkouts new neighbors. This process is repeated until the source node sends out all segments of its source data.

Algorithm 1:
Pseudo-code for sending source data by a node.

```
//operation conducted by a source node
SendPacket(){
1.while (segmentStream.hasNext()){
//check out its current neighbor nodes
2. Checkout(neighbors);
//add all the nodes including source node in a list
3. addIntoList(neighbors+source)
//sort the neighbors according to the
data forwarding ability
4. List.sort()
//transmit the segments to the neighbor node
5. for (each segment){
6.    List.get(i).receive(segment)
7.    i++
//if each neighbor node get a segment
8.    if (i>List.Size())
9.       break
      }
//update this links and neighbors
10. update()
11. return 0
   }
}
```

4 Performance Evaluation

This section demonstrates the performance of the distributed routing in a hybrid network through simulation built on ns-2 [13] in comparison with Hybrid network with AODV. AODV [7] is a widely studied protocol used in multi-hop ad hoc network. In AODV, before sending a data packet, the source node first checks if there is a route to the destination available in its routing table. If yes, the packets are unicasted to the destina-

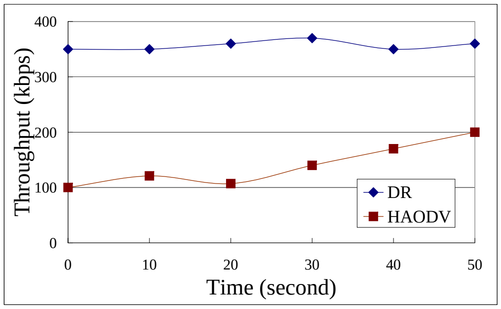

Figure 2. Throughput over time

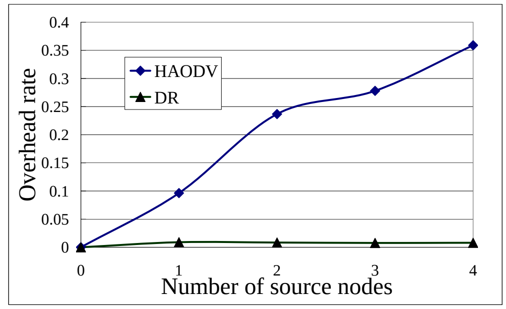

Figure 3. Overhead rate versus the number of source nodes

tion node in using multi-hop transmission. Otherwise, it broadcasts a RREQ message to find the new routing path for the transmission. The RREQ message includes broadcast ID, maximum hops count, source and destination node addresses, and source and destination node sequence number. The broadcast ID is used to distinguish the old query message and the new query message. If an intermediate node notices it has received a higher broadcast ID from the source node before, it will ignore this message. Otherwise, it sets up a reverse route entry for the source node, and checks if it has a rout path to the destination path in its own routing table. If it is true, it unicasts a RREP reply message back to the source node containing the required hop counts. Otherwise, it will rebroadcast message to its immediate neighbors. The same process continues until the message reaches the destination node. The RREQ message is discarded if the TTL (hops counts) reaches the maximum hops count specified. When a RREQ message sends back to the source node, the intermediate node will update its routing table to its destination for the future use. If the link is broken, the node with broken link unicasts a RERR message back along the reverse route back to the source node to report the unreachable path. The intermediate node will also update its information in their routing table.

The simulated network consists of 50 wireless nodes and 4 base stations. Wireless nodes are randomly deployed around the base stations in a field of 1000×1000 square meters. We used the Distributed Coordination Function (DCF) of IEEE 802.11 as the medium access control layer protocol. The radio transmission range for each node is 250 meter, and the raw physical link bandwidth is 2Mbits/s. We use two-ray ground reflection model $(1/r^4)$ as the signal propagation model. The constant bit rate (CBR) is selected as our traffic mode with a rate of 2 packets per second. A source and a node are randomly chosen every 10 second in the experiments.

The random way-point mobility model [14] was used to generate the moving direction, the speed and the pause duration of each node. Each node waits for a pause time randomly chosen in $(1 - 10)$s, then moves to another random position with a speed chosen in (1-20)m/s. The packets of nodes are first transmitted to the base stations and then via base stations to the destination nodes. We assumed that there is no bandwidth and power constrain between the transmission of the base station.

Since when the congestion happened in a system, the throughput of the system will reduce. Meanwhile, the overhead in the ad hoc network is the main reason for the congestion in a hybrid network. Therefore, we use two metrics in the experiments: throughput and overhead to test the performance of the distributed routing protocol in the hybrid network. In the figures, we use HAODV to denote the performance of hybrid network with AODV protocol, and DR to denote the hybrid network with distributed routing protocol.

4.1 Comparison of Throughput

We measured the throughput of distributed routing and HAODV in networks with 50 nodes with the same data transmitting speed versus the simulation time. Figure 2 illustrates the throughput of distributed routing and HAODV in a 50 second time period. The figure shows that the throughput of the distributed routing protocol is much higher than the throughput of HAODV. It is because the transmission hops of the distributed routing protocol is at most 3 hops. The average routing hop in HAODV is about 7 hops. The multi-hop nature of HAODV leads to high control overhead in the system. Furthermore, the distributed feature of distributed routing reduces the packet congestion at the mobile gateway nodes. The figure also shows that the throughput of the distributed routing protocol remains almost the same in the system while HAODV changes all the time. The reason is that the distributed routing does not need to maintain a long multi-hop transmission path. The performance of the HAODV is greatly depends on the nodes' mobility in the system. Since the nodes' mobility is randomly chosen in the system, the throughput of HAODV changes all the time.

4.2 Comparison of Efficiency

In order to verify the conclusions in section 4.1, we measured the overhead in both HAODV and the distributed routing protocol. We set the number of nodes in the network to 50, and tested the overhead rate with different numbers of source nodes in the systems. The new S-Ds will be randomly chosen every $10s$. We define *overhead rate* as the percentage of the control messages in the data messages, and use this metric to evaluate the overhead of routing protocols. Figure 3 demonstrates the overhead rate of distributed routing and HAODV versus different number of source nodes. We can observe that with the same offered traffic in the system, HAODV generates much more overhead than the distributed routing protocol. Furthermore, more source nodes mean a higher traffic during a certain time period. From the figure, we can see that as the number of source nodes increases, the overhead rate of the distributed routing protocol remains almost the same. This means that the increase of overhead is proportional to the number of data messages. It is because for every segment, the source node needs to choose a best transmission mode. Thus, the increase number of segments result in higher overhead. Since distributed routing does not need to maintain the routing path in the system, there is no extra overhead. However, in the HAODV, the overhead rate is increased sharply. As the offered traffic increase, the congestion situation in the HAODV will be worse, hence more control overhead is incurred to maintain the routes in the system.

5 Conclusions and Future Works

The combination of the multi-hop ad hoc network with cellular network can increase system performance. However, it still has traffic congestion problem. To address this problem, we proposed a distributed routing protocol. The distributed routing protocol separates the source stream into several parts, and distributes the segment to several neighbor nodes. The distributed routing protocol can reduce the congestion in the path forwarding. Simulation results shows the high performance of the distributed routing protocol in terms of higher throughput and lower overheads. In the future, we are planing to polish the nodes selection schedules, and build more theoretical models to have a deeper understanding of distributed neighbor node probing methods in the hybrid network.

Acknowledgements

This research was supported in part by the Acxiom Corporation.

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