Cluster-based Multi-path Routing Algorithm for Multi-hop Wireless Network

Jie Zhang, Choong Kyo Jeong, Goo Yeon Lee, Hwa Jong Kim

Kangwon National University
Kangwondo, Korea

zarg_1982@hotmail.com, {ckjeong, leegyeon, hjkim}@kangwon.ac.kr

Abstract. Multi-path routing has been studied widely in wired networks. Multi-path routing is known to increase end-to-end throughput and provide load balancing in wired networks. However, its advantage is not obvious in wireless multi-hop network because the traffic along the multiple paths may interfere with adjacent paths. In the paper, we introduce a new multi-path routing scheme, Cluster-Based Multi-Path Routing for multi-hop wireless networks. The main idea of the proposed routing scheme is to extend the hop-by-hop multi-path to a cluster-by-cluster multi-path. In cluster network, each cluster can work independently from other clusters and hence reduce interference. The purpose of the proposed scheme is to find a less interfering path for wireless multi-hop networks. We also showed the throughput improvement of the proposed scheme through simulations.

Keywords: cluster-based routing, multi-path, multi-hop, interference, pathID

1 Introduction

Recently, with the proliferation of mobile communication services, a lot of routing schemes have been proposed in wireless networks. Some of them used multiple routing paths to obtain load balancing and make transfer speed faster[1]. It is known that multi-path transporting may decrease the end-to-end delay and increase the whole throughput between source and destination.

However, in the multi-hop wireless networks such as ad-hoc network, transmission over multiple paths is not as efficient as in wired networks because of the RTS/CTS interference between paths, merged path, signal collision, hidden node, and exposed node problem[2][3][4]. These problems may cause data loss, delay or low throughput.

In multi-hop wireless networks, it is important to design a routing algorithm to alleviate these interference problems. In the paper, we investigate the effect of interference between routing paths in a wireless multi-hop network by simulation and then propose a new scheme to set up improved multiple paths between source and destination leveraging the cluster-based routing.

The proposed cluster-based multi-path routing (CBMPR) will achieve maximum throughput and low delay by selecting multiple paths with little interferences among them.

2 Motivation

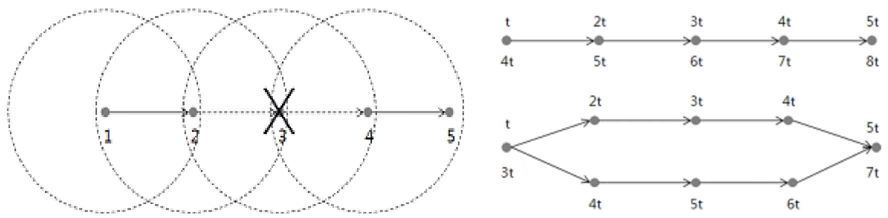
2.1 Review of work on multi-path routing

Multi-path routing can be classified into three types according to the purpose of the multiple paths. The first one is to get a back-up path for emergency. The back-up path is set up simultaneously as the main path. When the main path is down, the source node uses the back-up path. AOMDV (Ad hoc On-demand Multipath Distance Vector) is a typical example of this type[5].

Secondly, multiples paths can be used to handle congestion and keep load balancing. When a path has heavy traffic, other paths will be utilized to reduce the congestion[6-7].

Finally, multiple paths can be used to increase the end-to-end performance (e.g., high throughput and low delay) by transporting data through multiple paths. The proposed routing protocol in this paper can be classified into this category. The efficiency of this type is shown in Fig. 1.

In 802.11, a sender node sends a Request To Send(RTS) message before establish a transmission, if the receiver node is idle to receive data, it sends back a Clear To Send(CTS) message, anyone sides in sender or receiver's transmission range which sense the RTS or CTS, have to set Network Allocation Vector(NAV) and stop all communication. RTS/CTS handshake algorithm is good for avoiding signal collision for a wireless network, but also, it brings unexpected delay from NAV waiting time.



(a) **(b)**

Fig. 1. (a). RTS/CTS interference in single multi-hop path. **(b).** Decrease of transmission interval for load utilization in multi-path.

In Fig. 1(a), packet is relayed through a multi-hop path from node 1 (source) to node 5. The source must wait 3 transmission time to successfully send next packet because of the RTS/CTS interference. While node 2 is receiving packet, node 3 has to keep silent because it senses node 2's CTS, so node 3 cannot transmit packet to node 4.

Therefore node 1 can send next packet only when node 2 does not sense any transmission from node 3.

Fig. 1(b) shows a multiple path case, where source and neighbor nodes suffer less interference than the single path case because of the enough distance between the paths. In the multi-path case, the waiting delay to send the next packet at source will decrease from 3 transmission time (4t-t) to 2 transmission time (3t-t), resulting in 50% throughput gain.

2.2 Inherent Problems in Multiple Transporting

In multi-hop wireless networks, it is shown that channel utilization becomes nearly 1/3 or 1/4 of channel's capacity at best due to the RTS/CTS interference between neighboring nodes[8]. While a node is sending data to the next node, other nodes within the source and neighbor's transmission range must set NAV and keep silent. Certainly, this kind of interference also happens between two or more nearby paths as shown in Fig. 2. In the upper path of Fig 2, the 4th node does not have any interference from 2nd node in the same path, however it have CTS interference from the node in the below path.

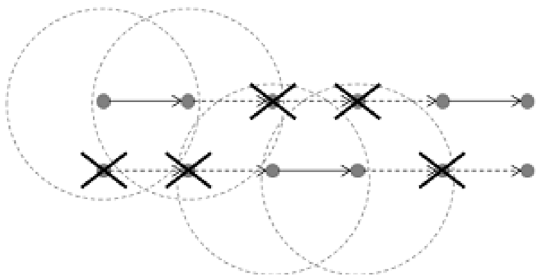


Fig. 2. Interference between two paths. The dotted-circle is the node's transmission range. Nodes within each range sense other node's RTS or CTS and keep silent.

If several paths pass through a node to get a destination, the joining node will experience a heavy congestion and produce large end-to-end delay. If we choose a multiple paths routing algorithm without any means to prevent the path joining problem, there will be very high probability to meet the path joining problem. It is because routing algorithms search the best path using same metrics.

In order to investigate the effect of inter-path interference and path joining, we have simulated multi-path transportation for three cases; 1) paths are mutually interfering, 2) two paths merge at the third node, 3) all paths are apart far enough to interfere each other. We used GlomoSim simulation package[13].

Simulation result is shown in Fig. 3. As we can see from the figure, using several paths is of no use if there is interference between paths or the paths merge. The end-to-end throughput decreases when an interfering path is added to the main path. On the other hand, the end-to-end throughput increases by adding multiple paths if the paths are free from transmission interference. Finding multiple disjoint paths with little or no mutual interference is thus very important. In the next section we present an approach to find efficient multiple disjoint paths.

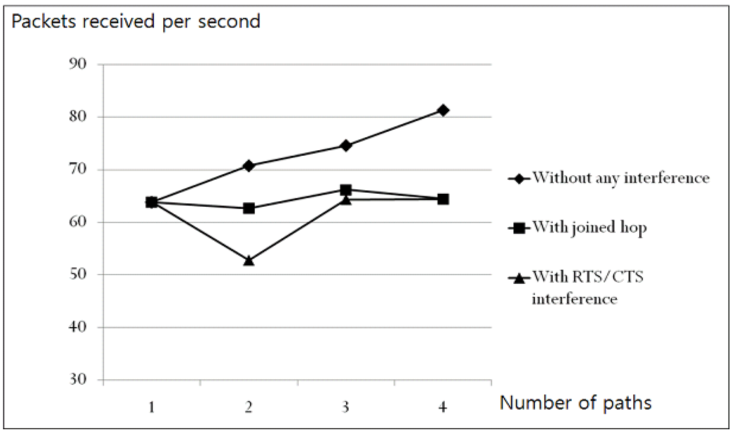


Fig.3. Throughput for various number of hops for three cases: (a) without any interference, (b) with joining paths, (c) RTS/CTS interference between neighboring paths.

3 Cluster-Based Routing

Clustering is usually used to speed up route discovery by structuring the overall network nodes hierarchically[11]. Clusters are setup at start time and maintained periodically or dynamically. Routing is performed at the cluster level, while path setup inside the cluster is done by the cluster maintenance mechanism. The cluster radius is usually set to be two or three hops.

In the previous works on cluster based networking, a cluster network usually contains two types of links: intra-cluster link to connect nodes in a cluster and inter-cluster link to connect clusters. When a cluster is created, a head node is chosen for administration of the cluster. The head node will work as a base station in the cluster to control channel access, perform power measurements, and guarantee bandwidth for real time traffic. Each member node in a cluster is assigned a node ID (NID), and a cluster ID (CID). As a hierarchical routing protocol, a cluster based routing usually uses proactive routing to decrease the delay at the intra-cluster path, and uses reactive routing to reduce control overhead at the inter-cluster path.

3.1 Intra cluster routing

A cluster head has the responsibility of routing from the current cluster to other cluster heads. Packets will be delivered to the destination via low layer intra-cluster routing and then through a high layer inter-cluster routing.

When a Link State Routing (LSR), a typical proactive routing algorithm, is chosen for intra cluster routing, each member node will be recognized by their head node with the NID. The head node collects all link state information from every member node, builds an intra-cluster topology message, and advertises it to all member nodes inside the cluster. On receiving the message, member nodes can create routing tables for intra-cluster communications.

Packets generated inside a cluster and packets passing through the cluster will be forwarded to the gateway node in the cluster to reach other cluster.

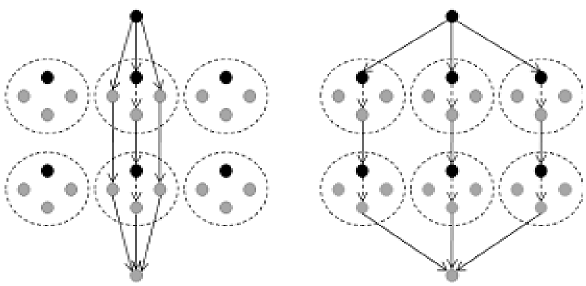
3.2 Inter cluster routing

When a source node wants to communicate with a node in a different cluster, a route request(RREQ) which contains its address will be sent for path discovery. When the RREQ is delivered to a member node of a cluster, it will be forwarded immediately to its cluster head and the head checks if the destination address in the cluster. If destination is in the cluster, the head adds its CID on RREP and sends it back to the source in reverse path, otherwise, the RREQ will be forwarded to the next cluster until it finds the destination.

Unlike traditional node level multi-hop networks, in the cluster based routing, any member node can receive packets from outside and deliver it to the gateway node.

Packet from a source cluster head node uses inter-cluster link to reach the (cluster level) next hop, and arrives at the gateway of the current cluster via the intra-cluster path. The packet then passes through the inter-cluster path to reach its next cluster.

4 Cluster-Based Multi-Path Routing



(a) (b)

Fig. 4. (a) Multiple Paths established with conventional multi-path routing protocol (b) Multiple Paths established with CBMPR

The proposed cluster-based multi-path routing (CBMPR) combines cluster-based routing and multi-path routing efficiently. The CBMPR makes use of cluster network to find multiple paths that provide independent paths. Fig. 4 compares an example of conventional multi-path routing and the CBMPR. Fig 4(b) shows an example of multiple paths which will suffer less interference by choosing routing paths through different clusters.

The main advantage of CBMPR over conventional multi path routing is less interference. Another strong point of CBMPR is its simplicity. Each path in the CBMPR just passes through the heads of clusters, resulting in a simple cluster level hop-by-hop routing. This makes CBMPR convenient and simple reducing the burden of interference calculation needed at every intermediate node.

5 The pathID algorithm

Even though the proposed CBMPR can mitigate the interference problem efficiently, path joining problems may occur because path joining can be easily created while choosing cluster-by-cluster link. With the path joining, the throughput will be worse seriously.

As a solution to avoid the path joining problem, a destination node records and compares the address of intermediate nodes listed in the RREQ. Every node which relays the RREQ to destination is recorded into the node list in the RREP. When the destination receives a duplicate RREQ, it will compare the list of node in the RREQ. Only when the destination verifies there is no path joining among the multiple path it sends back a RREP to the source. Otherwise, the received RREQ is recognized as a route request with path joining and will be discarded[12].

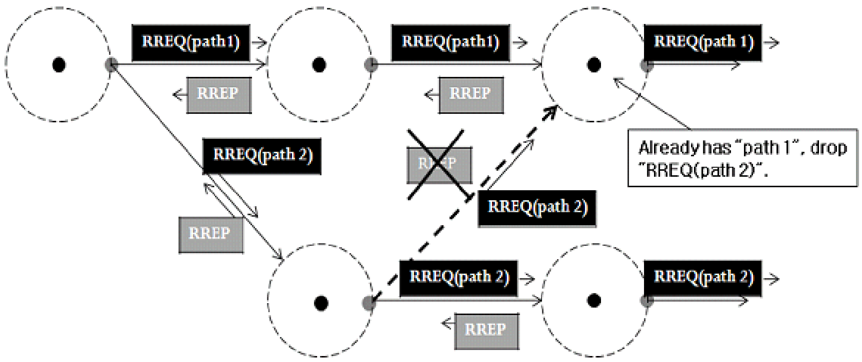


Fig. 5. PathID algorithm: pathID is attached in the RREQ to avoid path joining.

We propose a "pathID algorithm" to efficiently avoid path joining. For inter-cluster routing, source includes a pathID in RREQ and floods it for route discovery. For intra-cluster routing with link state routing protocol, gateway node which received the RREQ advertises the pathID to other members by including it in link state packet, then the pathID will be stored in each member node of current cluster. On receiving a new RREQ, the source address and pathIDs are compared with the stored information in the node's routing table. If the new RREQ finds an entry that has same source address and different pathID in the table, then the request will generate path joining, and should be dropped. This procedure is explained in Fig. 5.

6 Simulation results and discussion

We have simulated the CBMPR to investigate how cluster based multi paths is selected. In simulation, we assume each cluster has four nodes. In each cluster, cluster head and gateway nodes are assigned for cluster-level communication. We used static routing and selected paths manually according to the CBMRP. Each path passes three clusters through cluster heads. Link bandwidth are set to 5, 10, 20 and 50Mbps. Nodes are placed in a 1200m x 1200m area and 1024 bytes CBR packets are generated with an interval of 5ms. Simulation result is shown in Fig. 6 respectively.

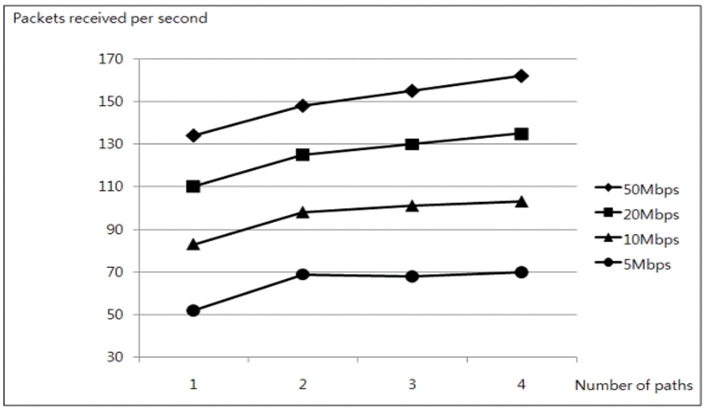


Fig. 6. Throughput of CBMPR.

With bandwidth of 20Mbps and 50Mbps, throughput increases about 5~8% for each additional path, finally reaching at 20~24% increase with four paths. This result is same with the case of the 1st line in Fig.3, the throughput without any interference. From this result, it can be said that the CBMPR selects almost interference-free paths from source to destination. It is also noted that the throughput saturates when there are two paths if the radio bandwidth is 5 Mbps, and addition of more paths does not improve the performance. With bandwidth of 10Mbps, throughput increase slowly when 3rd and 4th path are added. This might be the result of the congestion due to inter-path interference at the source and destination node where paths should be merged. The saturation point increases as the radio bandwidth increases.

7 Conclusion

Most of multi-path transporting researches are focused on wired network. Wired networks have no interference between each path and the efficiency of multi paths is great. For multi-path transmission over wireless multi-hop networks, efficiency is dependent upon the interference among the paths. The traffic is disturbed by RTS/CTS interference and suffers from the congestion at the path joining points. The proposed routing protocol CBMPR is shown to alleviate these problems. We simulated the CBMRP and found out its improvement.

It is also noted that CMNPR can be realized with less complexity compared to conventional multi-path routing schemes which usually requires measuring the interfering signal strength.

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