Multi-path Multi-Channel Routing Protocol

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Abstract

In this paper we present a DSR-based multi-path Routing protocol, which has been developed for transmission of Multiple Description Coded (MDC) packets in wireless ad-hoc network environments. The protocol is designed to eliminate co-channel interference between multiple routes from source to destination by assigning a different frequency band to each route. In the route discovery process we use three metrics to select the best multiple routes. These are hop count, power budget, and the number of joint nodes between the different routes. For continuous media communications we show that in order to effectively benefit from the advantages associated with multipath diversity routing, it is important to use a multi-channel protocol such as the one developed here.

1. Introduction

Multi-path routing for IP networks has been explored for many years in order to mitigate the effect of congestion in the network. Only recently it has been finding its way into mobile ad-hoc network applications. This is mainly because wireless multihop links normally operate under harsh channel conditions such as multipath and shadow fading. In addition, due to the multihop routing structure and the mobility of nodes, maintaining an active route over a long period of time, which is essential for delay sensitive continuous media communications, is not always possible. These factors, which are introduced by the mobility of the nodes, can seriously impact the integrity of the link for real-time communications. In such conditions, multiple routes from source to the destination would be especially well suited for continuous media applications given that these routes do not always endure the same losses simultaneously.

Multiple path routing protocols for Ad Hoc networks have been extensively studied in recent years [1-6]. Nasipuri [7] has described an on-demand multipath routing scheme, which is based on the DSR [8] routing protocol. An extension of AODV protocol [9] for multi-path routing (referred to as AODV-BR) has been studied by Lee and Gerla [10]. In both protocols the traffic is not distributed to multi-paths: only one route is primarily used and alternate paths are utilized only when this route is broken. For simultaneously transmitting packets, split multi-path routing (SMR) has been proposed in [11], which focuses on building and maintaining maximally disjointed paths. This protocol is based on DSR and the traffic load is distributed in two routes.

Analytical results in [12] reveal that in comparison with a general single path routing protocol, a split multipath routing mechanism can provide better performance in congestion and capacity. However, in this study the effect of co-channel interference between different paths has not been taken into consideration. Bear in mind that even in the absence of any joined nodes, multiple routes from source to destination are normally within the interference range of each other's. For instance, based on our experiments, such interference can significantly deteriorate the end-to-end communication performance. On the other hand, if each route can operate in different frequency bands, the effect of co-channel interference can be eliminated. Therefore in this paper we are mainly concerned with developing a protocol for multi-channel, multiple routing for continuous media communications. This protocol is specifically suitable for transmission of MDC data packets via two routes where each route uses a different frequency band. Section 2 presents the details of this protocol, which is based on the DSR protocol and consists of route discovery process, packet transmission and route maintenance. Finally, the performance evaluation of the protocol is presented in section 3.

2. Proposed Routing Protocol

In this section, we proposed a Multi-path Multi-channel Routing (MMR) protocol, in which we assume that a node can be assigned to a different frequency channel where the channel assignment is controlled by the media access control (MAC) layer. Based on this assumption, the MMR protocol has been considered for the multi-channel system which consists of three parts; route discovery, packet transmission, and route maintenance.

1) *Route Discovery*

In DSR, when a source node originates a new data packet addressed to the destination node, the source node will insert a source route in the header of the packet, which gives the sequence of hops from the source to the destination. Normally, the sender will obtain a suitable source route by searching its “Route Cache”. If no route is found in its cache, it will initiate the Route Discovery to find a new route to the destination [8].

To initiate the Route Discovery, the source node will broadcast the RREQ packet in order to find the paths to the destination. Each RREQ identifies the source and destination of the Route Discovery, which contains a unique request identification (ID). Each RREQ also contains a record listing the address of each intermediate node through which this particular copy of the RREQ has been forwarded [8].

When another node receives this RREQ, and it is the destination of the Route Discovery, it returns a “Route Reply” (RREP) to the source of the Route Discovery. Otherwise, it will check if this RREQ is duplicated or not by the ID. If it is not the duplicate, it appends its ID and re-broadcasts the packet. Otherwise, it will discard this duplicate RREQ. [8]

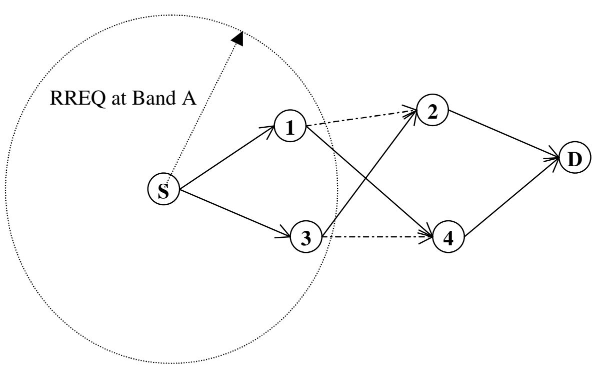

Fig. 1 Route discovery process

It should be noted that it is very likely to lose good routes if we drop all the duplicate RREQs [11]. For example, in Fig. 1, we may only get the routes of S-1-4- D and S-3-2-D. Routes S-1-2-D and S-3-4-D will be discarded because of the duplicate RREQ.

In order to avoid discarding good routes from the source to the destination, in our MMR protocol we modify the transmission schemes of the RREQ compared with DSR. For example, instead of discarding every duplicate RREQ, intermediate nodes will forward the RREQ whose hop count is not bigger than that of the first received RREQ, even if they have the same ID. In this way, the source node may obtain all the possible routes to the destinations.

An example of a two-band routing system is shown in Fig 1. In the proposed MMR protocol, the source node initially sends the RREQ at band A. All the other nodes also use band A to transmit the RREQ and RREP. After the source node receives all the RREPs, it will obtain multiple routes to the destination, which are stored in the route cache. Then the source node will select the two best routes from the route cache for data transmission at two bands. We should point out that it is possible that there would be too many potential routes from the source to the destination, particularly when the node density is high. In order to avoid excessive overhead, we set a threshold in the destination node in such a way that if the number of the RREQ’s received by the destination is smaller than this threshold; the destination will send a RREP. Otherwise, the destination will discard this RREQ (e.g., we set the threshold as 10). To measure the performance of each route for the selection process we use the following metrics,

a) Hop Count.

b) Power Budget: the total power loss when transmitting a packet from the source node to the destination, which is defined as [13]: $PowerBudget = \sum_{i=1}^{N-1} PL_{i,i+1}$

   where $PL_{i,i+1}$ is the power loss between nodes i and $i+1$, N is the hop count of this route, $PowerBudget$ is the total power loss of this route.

c) Number of joint nodes between two routes.

In this protocol, we insert the power budget into the routing entry as shown in the following table.

Destination	Hop Count	Power Budget	Intermediate nodes

Table 1. Routing entry structure

Based on the above metrics, the source node will select the first best route in the route cache according to the following rules: Firstly, a route with the smallest hop count has the highest priority. If two or more routes have the same hop count, then the Power Budget (metric b) is used to select a route with the lowest power loss.

The next step is selecting the second best route amongst the remaining routes. Also in this case, the priority is given to a route with a minimal hop-count. However, if two or more routes have the same minimal hop count, we will consider the number of joint nodes between the current route and the first best route. The route with smallest number of joint nodes will be selected as the second best route. In a case where there are more routes with the same number of joint nodes, the route with the minimal Power Budget will be selected. We should point out that although joined nodes do not have any impact on the MMR's performance as far as co-channel interference is concerned, under mobility conditions it reduces the possibility of losing both routes at the same time.

2) Data Transmission

After the source selects the two best routes to the destination, two data streams will be sent to the destination along these two routes at different bands: A or B as shown in Fig. 2. After the intermediate node receives the data stream, it will relay the data packet according to the sequence of hops stored in the header of the packet. The data packet will be transmitted at the band with which this packet is received.

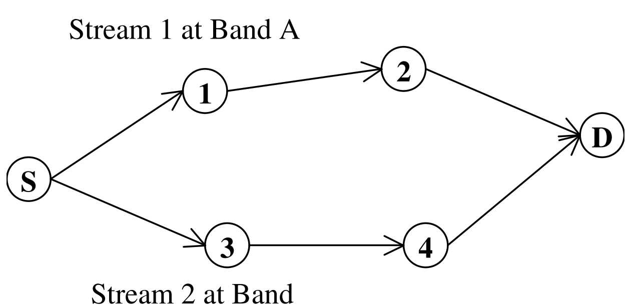

Fig. 2 Data transmission in MMR

3) Route maintenance

Normally, a route can be disconnected because of mobility and packet collision. In our proposed MMR, when one node detects a broken link, it will send the Route Error (RERR) packet in the upstream direction of the route. Once the source node receives the RRER packet, it will remove every route entry in the route cache, which uses the broken link. Under this condition, the source node will assess how many active routes are left in the route cache to the destination using the following steps:

If there is more than one active route left in the route cache, the source node will select the two best routes (i.e., among the left-over routes) according to the rules mentioned above. The data packet will be transmitted with these two routes each using a different frequency band.

If there is only one route left, the source node will continue using it while initiating a new RREQ at a different band. The source node will then append all the newly discovered routes, which may include the existing active route, into the route cache. Finally, the source node will select the two best routes in the route cache for data transmission.

If there is no route left, the source node will initiate a new RREQ at band A or B. Then the source node begins a new route discovery process as discussed before.

In this section, we have proposed the new MMR protocol for multi-path routing. Comparing with other existing methods, it has several advantages. Firstly, we incorporate the Power Budget as a rule for route selection, which can minimize the average energy consumed per packet. Secondly, we select the route, which has the smallest number of joint nodes with the first best route, as the second best route. It can reduce the probability that both routes break simultaneously. Finally, since we transmit data packets with two routes at two channels, the interferences between two routes can be completely eliminated. Therefore we expect that the throughput will be improved greatly.

3. Simulation Results

In order to evaluate the performance of the proposed method, we used our real-time QualNet-based simulation testbed. In this testbed, we considered the IEEE 802.11b standard for evaluating the performance of the MMR protocol. In the simulations, the input data generated at a constant bitrate (CBR), is encapsulated into fixed 500 bytes UDP packets. In the physical layer, the transmission power is 17 dBm, the receiver sensitivity is –93.0 dBm, the IEEE 802.11b data-rate is 2 Mb/s and the noise factor is 10.0. In the MAC layer, the transmit limit is 1. For simplicity, we assume that there's no fading and the path loss model is free space. We then compare the performance of the proposed protocol with the following schemes: scheme 1 uses the DSR protocol, scheme 2 uses Gerla's SMR protocol [11], and scheme 3 uses our proposed MMR protocol. IEEE 802.11b has 11 channels in the 2.4 GHz spectrum, 3 of which (Channel 1, 6 and 11) are orthogonal (non-overlapping). For scheme 1 and 2, nodes are working in Channel 1, and for scheme 3, nodes are working in Channel 1 and Channel 6.

For our MMR protocol, we use the reserved bits of the RREP to carry the power loss information. The process starts from a node located one hop away from the destination node. When this node receives the RREP from the destination, it first calculates the power loss ($PL_{N-1,N}$) from the destination based on the transmitting power and receiving power, and appends it into the route entry. Then it will send this power loss information to the next node in the reverse direction. The receiving node then calculates the new power loss ($PL_{N-2,N-1}$) between these two nodes and adds it to the previous power loss ($PL_{N-1,N}$) from the RREP. After that, it will send the new total power loss ($\sum_{i=N-2}^{N-1} PL_{i,i+1}$) to the next node in the reverse direction with the RREP. This process continues until reaching the source node. In this way, we can obtain the Power Budget for this route.

In the simulations, we use three metrics to evaluate the performance.

- Throughput, which is defined as:

$$Throughput = \frac{numReceived}{numSent} \times 100\%$$

  where $numReceived$ is the number of received packets by the destination and $numSent$ is the number of sent packets by the source.

- $PTwoRoutes$, which is the probability to have two reliable routes simultaneously from the source to the destination. It is defined as:

$$PTwoRoutes = \frac{numWithTwoRoutes}{numSent} \times 100\%$$

  where $numWithTwo\ Routes$ is the number of packets, which are received at the destination via both routes

- $POneRoute$, which is the probability to have at least one reliable route from the source to the destination. It is defined as:

$$POneRoute = \frac{numWithOneRoute}{numSent} \times 100\%$$

  where $numWithOneRoute$ is the number of packets, which are received with either route by the destination.

In our experimental scenario, nodes are randomly placed in a rectangular field (400m × 1500m) and move randomly. The mobility model uses the random waypoint model. The number of nodes was varied to change node density. Fig. 3 shows the throughput comparison between these three schemes. As shown in this Figure, MMR can provide much better throughput than DSR and SMR because of the three advantages mentioned above. Fig 4 and Fig. 5 show the comparison results of the probabilities to have two routes simultaneously and one route between these three schemes. From both of these Figures, we can observe that MMR can provide much more robust routes than DSR and SMR.

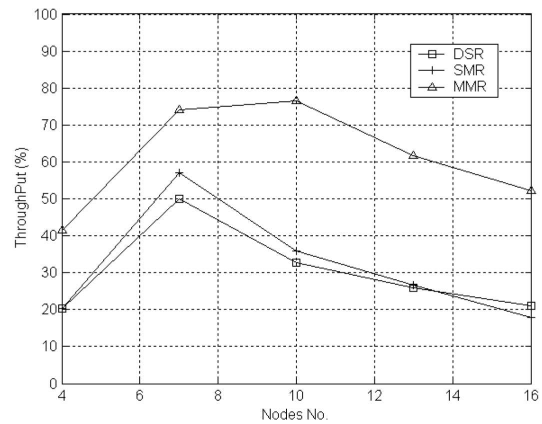

Fig. 3 Throughput comparisons between three schemes.

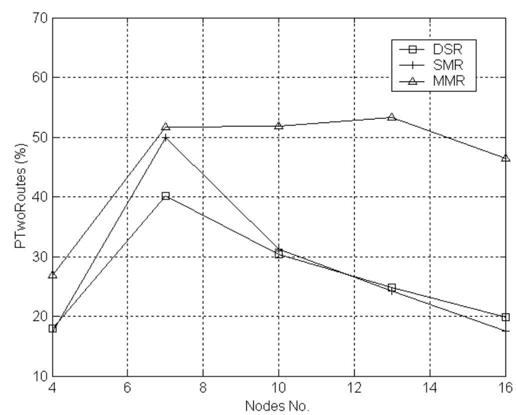

Fig. 4 The comparisons of probability to have two routes simultaneously

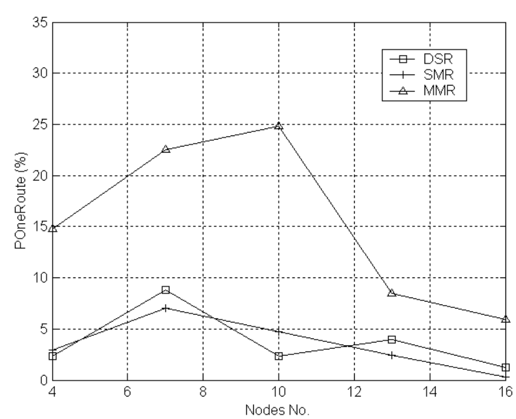

Fig. 5 The comparisons of probability to have one route.

4. Conclusion

In wireline IP networks multi-path diversity routing has shown to be very effective in dealing with network congestions. Unfortunately, in mobile ad-hoc networks environments, this approach normally suffers greatly from co-channel interference due to the simultaneous transmission of packets via multiple routes. To mitigate the effect of this interference we have developed a routing protocol, which guarantees that each route will use a different frequency band. Based on the DSR protocol, for the route discovery process we use three metrics to select multiple routes. These are hop count, power budget, and the number of joint nodes between the different routes. Under various network scenarios we have shown that by eliminating the interface between multiple routes (two in this case) we can indeed improve the suitability of multi-path diversity routing for mobile ad-hoc network applications.

5. References

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