Multipath Routing in Ad Hoc Wireless Networks with Directional Antenna

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Abstract: Multipath routing protocols are distinguished from single-path routing by the fact that they look for and use several routes from a source to destination. Several routing schemes have been proposed in the context of mobile ad hoc networks that uses multiple paths simultaneously by splitting the information among the multitude of paths. However, the effect of *route coupling* in this environment can severely limit the gain offered by multipath routing strategies. Route coupling is a phenomenon of wireless medium and occurs when multiple routes are located physically close enough to interfere with each other during data communication. In this paper, we investigate the effect of directional antenna on multipath routing. We have shown that the effect of route coupling across multiple paths with directional antenna is much less compared to that with omni-directional antenna. As a result, the routing performance using multiple paths improves substantially with directional antenna compared to that with omni-directional antenna.

Key words: Ad hoc networks, multipath routing, route coupling, directional antenna.

1. INTRODUCTION

Ad hoc wireless networks [1,2] are envisioned as infrastructure-less networks where each node is a mobile router, equipped with a wireless transceiver. Recently, there is a growing interest in ad hoc networks and its applications. Usually, the user terminals in ad hoc wireless networks use omni-directional antenna. However, it has been shown that the use of directional antenna can largely reduce radio interference, thereby improving

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the utilization of wireless medium and consequently the network throughput [3, 4]. To achieve this, a Wireless Ad Hoc Community Network (WACNet) testbed has been developed at ATR where the user terminals are equipped with small, low-cost directional antenna, known as ESPAR (Electronically Steerable Passive Array Radiator) antenna [3]. ESPAR antennas have a much higher gain than their omni-directional counterparts; so their use significantly reduce the RF power necessary to transmit packets. They can suppress co-channel interference and can therefore enlarge the capacity in terms of node-density (more terminals per unit area) in the network. In our earlier work, we have developed the MAC and routing protocol using ESPAR antenna [5]. The objective of this paper is to illustrate the advantages of multipath routing with directional antenna in the context of WACNet.

The routing schemes for ad hoc networks usually employ single-path routing which might not ensure desired end-to-end delay. However, once a set of paths between source s and destination d is discovered, in some cases, it is possible to improve end-to-end delay by splitting the total volume of data into separate blocks and sending them via selected multiple paths from s to d, which would eventually reduce congestion and end-to-end delay [6]. Utilization of multiple paths to provide improved performance, as compared to a single path communication, has been explored in the past in the context of wired networks [7,8].

The application of multipath techniques in mobile ad hoc networks seems natural, as multipath routing allows to diminish the effect of unreliable wireless links and the constantly changing topology [9]. The On-Demand Multipath routing scheme is presented in [10] as a multipath extension of Dynamic Source Routing (DSR), in which alternate routes are maintained, so that they can be utilized when the primary one fails. It has been shown that the frequency of searching for new routes is much lower if a node keeps multiple paths to the destination. However, the performance improvement of multipath routing on the network load balancing has not been studied extensively. M. R. Perlman et al.[11] demonstrates that the multipath routing can balance network loads in their recent paper. However, their work is based on multiple channel networks, which are contention free but may not be available in most cases. The Split Multipath Routing (SMR), proposed in [12], focuses on building and maintaining maximally disjoint multiple paths.

However, it has also been shown that deployment of multiple paths does not necessarily result in a lower end-to-end delay. In [11], the effect of Alternate Path Routing (APR) in mobile ad hoc networks has been explored. It was argued that the network topology and channel characteristics (e.g., *route coupling*) can severely limit the gain offered by APR strategies.

Suppose, only two sources s_1 and s_2 are trying to communicate data to d_1 and d_2 respectively. Let us assume that we select two node-disjoint paths for communication : $s_1\ x_1\ y_1\ d_1$ and $s_2\ x_2\ y_2\ d_2$. Since the paths are node-disjoint, the end-to-end delay in each case should be independent of each other. However, if x_1 and x_2 and/or y_1 and y_2 are neighbours of each other, then two communications can not happen simultaneously (because RTS / CTS exchange during data communication will allow either x_1 or x_2 to transmit data packet at a time, and so on.) .So, the end-to-end delay between any source and destination does not depend only on the congestion characteristics of the nodes in that path. Pattern of communication in the neighbourhood region will also contribute to this delay.

This is a phenomenon known as *route coupling*. Route coupling occurs when two routes are located physically close enough to interfere with each other during data communication. As a result, the nodes in those two routes are constantly contending for access to the medium they share and can end up performing worse than a single path protocol. Thus, node-disjoint routes are not at all a sufficient condition for improved performance in this context.

In this paper, we propose a notion of zone-disjoint routes in wireless medium where paths are said to be zone-disjoint when data communication over one path will not interfere with data communication in other path. However, getting zone-disjoint or even partially zone-disjoint routes in ad hoc network with omni-directional antenna is difficult, since the coverage area of each node is high and the MAC has to take care of hidden terminal problems as well. One way to reduce the coverage area of a node is to use directional antenna. In this paper, we investigate the effect of directional antenna on multipath routing. We have experimented with zone-disjoint paths and compared their effectiveness with respect to node disjoint paths. We also show that the probability of getting zone disjoint paths are much higher with directional antenna as compared to that with omni- directional antenna. As a result, the routing performance using multiple paths improves substantially with directional antenna compared to that with omni-directional antenna.

2. ZONE-DISJOINT ROUTES

The effect of route coupling has been measured in [13] using a correlation factor η. The correlation factor η of two node-disjoint paths is defined as the number of the links connecting the two paths. The total correlation factor of a set of multiple paths is defined as the sum of the correlation factor of each pair of paths [13].

In this paper, we propose a notion of zone-disjoint routes in wireless medium where paths are said to be zone-disjoint when data communication over one path will not interfere with data communication in other path. In other words, if there is no link (η =0) between two node-disjoint paths, we say the two node-disjoint paths are *zone-disjoint*. Otherwise, the two node-disjoint paths are η - related. This is shown in figure 1 (from [13]).

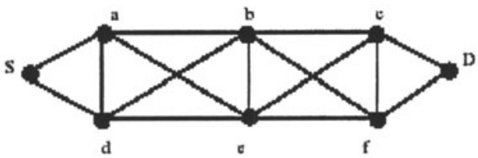

Figure 1. Two node-disjoint path with $\eta = 7$ (taken from [13]).

It has been shown that larger the correlation factor, the larger will be the average end-to-end delay for both paths. This is because two paths with larger correlation factor have more chances to interfere with each other's transmission due to the broadcast feature of radio propagation. In addition, larger the correlation factor, the larger will be the difference of end-to-end delay along multiple paths [13]. Based on this study, it can be concluded that the success of multipath routing in ad hoc networks heavily dependent on the correlation factor among multiple routes.

However, it is difficult to get multiple zone-disjoint routes using omni-directional antenna. With directional antenna, it is possible to de-couple multiple routes, thereby reducing the correlation factor among multiple routes. For example, if each of the nodes in figure 1 uses directional antenna towards its target node only, then the communication between S-a-b-c-D will not affect the communication between S-d-e-f-D.

Even if we get multiple zone-disjoint routes using omni-directional antenna, the best-case packet arrival rate at the destination node will be 1 packet at every $2*t_p$, where t_p is the average delay per hop per packet of a traffic stream on the path p. The best-case assumption is, single traffic stream in the network from S to D with error-free transmission of packets. In contrast, if we use directional antenna, best-case packet arrival rate at destination will be one packet at every $t_{p.}$ Table 1 and 2 illustrate this point. Let us refer to figure 1 and assume that each node is equipped with omni-directional antenna. Let us further assume that the two paths shown are zone-disjoint i.e. η = 0. Let us denote t_p as a time-tick, i.e. at each time-tick, a packet is getting transmitted from one node to other. Consider table 1. S is sending a data-packet P_1 to node a at time-tick T_0 and node a is sending data-packet P_1 to node b in the next time tick i.e. T_1. With omni-directional antenna, S has to sit idle during T_1, because S has received RTS from node a. So, S can only transmit its second packet P_2 to node d (first node of the second path) at time-tick T_2. Similarly, when c is sending data to D, b will also be affected and node a cannot send data to b during that time to avoid collision at b. The packet transition is shown in Table 1 and destination D will receive packets in alternate time-tick. Even if we increase the number of zone-disjoint paths, the situation will not improve with omni-directional antenna.

Table 1. Packet Arrival Rate at D with Omni-directional Antenna

	S	a	b	c	d	e	f	D
T_0	P_1 >a							
T_1		P_1>b						
T_2	P_2>d		P_1>c					
T_3				P_1>D	P_2>e			P_1
T_4	P_3>a					P_2>f		
T_5		P_3>b					P_2>D	P_2
T_6	P_4>d		P_3>c					
T_7	...	...	...	...	...	...	...	...

However, with directional antenna, when node a is transmitting a packet to node b, S can transmit a packet to node d simultaneously. Thus, as shown in Table 2, destination D will receive a packet at every time-tick with two zone-disjoint paths using directional antenna. It is to be noted here that two zone-disjoint paths with directional antenna is sufficient to achieve this best-case scenario.

Table 2. Packet Arrival Rate at D with Directional Antenna

	S	a	b	c	d	e	f	D
T_0	P_1 >a							
T_1	P_2>d	P_1>b						
T_2	P_3>a		P_1>c		P_2>e			
T_3	P_4>d	P_3>b		P_1>D		P_2>f		P_1
T_4	P_5>a		P_3>c		P_4>e		P_2>D	P_2
T_5	P_6>d	P_5>b		P_3>D		P_4>f		P_3
T_6	P_7>a		P_5>c		P_6>a		P_4>D	P_4
T_7	...	...	...	...	...	...	...	...

We have done a simulation study in order to establish that it is much easier to get a set of two zone-disjoint paths with directional antenna than that with omni-directional antenna. In this study, nodes were randomly placed into an area 1000 x1500 at a certain density. A source and destination were randomly selected such that they are multi-hop away from each other. First, we have assumed that all the nodes are equipped with directional antenna with fixed transmission range. Between the selected source and destination, two 4-hop, zone-disjoint routes were found out. If two 4-hop, zone-disjoint routes were not available for that source-destination pair, another source-destination pair was selected. Then we have assumed that each node is having omni-directional antenna and computed the correlation factor η_{omni} among those two routes that are zone-disjoint with directional antenna. This experiment was repeated for 25 source destination pair. As discussed, in each case, η_{dir} is zero and we compute η_{omni}. Then, the average η_{omni} were found out. Then, we change the node density and repeat this experiment. The results are shown in figure 2. As the number of nodes in the system increases, average η_{omni} increases. However, η_{dir} is zero in all the cases. This indicates that it is possible to get zone-disjoint paths with directional antenna at different node densities but those zone-disjoint paths with directional antenna will have high correlation factors, if we use omni-directional antenna.

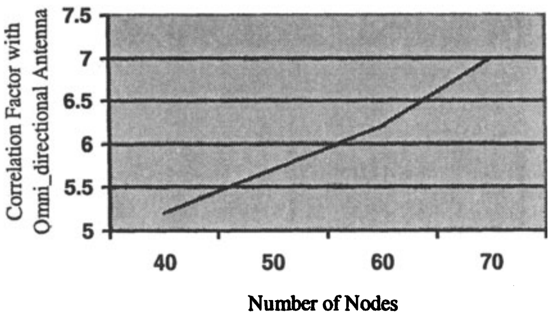

Figure 2. Average Correlation factor η_{omni} at different number of nodes when η_{dir} =0.

3. A MECHANISM FOR MULTIPATH ROUTING USING DIRECTIONAL ANTENNA

In order to make the directional routing effective, a node should know how to set its transmission direction effectively to transmit a packet to its neighbors. So, each node periodically collects its neighborhood information and forms an Angle-SINR Table (AST) [3]. $G^{u}_{n,m}(t)$ is the strength of radio connection from node n to node m at an angle u with respect to n and as perceived by m at any point of time t. AST of node n specifies the strength of radio connection of its neighbors with respect to n at a particular direction. Affinity of node m with respect to node n, $a^{w}_{n,m}(t)$, is a number associated with a link $l^{w}_{n,m}$ at time t , such that $a^{w}_{n,m}(t) = \text{Max } [G^{u}_{n,m}(t), 0< u <360]$. In other words, the transmission angle w with respect to n maximizes the strength of radio connection from n to m, as perceived by m at any point of time. Based on this, a Neighborhood-Link-State Table (NLST) at each node is formed

We have designed a modified link-state protocol to make the nodes in the network *topology aware* [5]. Our primary aim is to collect all topology-related information from each node in the network and distribute them periodically (as updates) to only one of its neighbor, without flooding the network with topology-update packets. A node maintains a complete (but approximate) topology map of the entire network, called Global Link State Table(GLST). It not only depicts the connectivity between any two nodes but also the strength of connection or *affinity* value of the connection. In order to use the directional antenna, a node propagates its perception of the topology-information to only one of its neighbors at a periodic interval. Selection of target neighbor to propagate topology-map based on a criterion termed as least-visited-neighbor-first. Each node monitor a metric called recency of its neighbors to decide which of them has received least number of update messages. The neighboring node that has received least number of update messages so far will be the target node for updating.

Whenever, a source S wants to communicate with a destination D, it computes multiple node-disjoint routes from S to D. From these multiple routes, it computes zone-disjoint routes. However, if zone-disjoint multiple routes do not exist between S and D, it selects single route. The assumption here is that, unless correlation factor is zero, performance improvement through multipath routing cannot be guaranteed. However, due to mobility and slow link-information percolation, it may not be possible to maintain zero correlation factor among multiple routes. To improve performance under mobility, the source node periodically computes multiple zone-disjoint paths and adaptively modifies its routing decision.

4. CONCLUSION

In order to make effective use of multipath routing protocols in the mobile ad hoc network environment, it is imperative that we consider the effects of route coupling, especially in single channel networks. However, high degree of route coupling among multiple routes between any source and destination pair is inevitable, if we use omni-directional antenna. This paper has analysed the problem and proposed a mechanism to alleviate the problem of route coupling using directional antenna. As a result, the routing performance using multiple paths improves substantially with directional antenna compared to that with omni-directional antenna.

REFERENCES

1. E. M. Royer and C-K Toh, "A Review of Current Routing Protocols for Ad hoc Wireless Networks", IEEE Personal Communication, April 1999, pp. 46-55.
2. J. Broch, D. A. Maltz, D. B. Johnson, Y. C. Hu, and J. Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols,' *Proc. ACM/IEEE Mobile Comput. and Network.*, Dallas, TX, Oct. 1998.
3. S. Bandyopadhyay, K. Hasuike, S. Horisawa, S. Tawara, "An Adaptive MAC Protocol for Wireless Ad Hoc Community Network (WACNet) Using Electronically Steerable Passive Array Radiator Antenna", Proc of the GLOBECOM 2001, November 25-29, 2001, San Antonio, Texas, USA
4. Y.-B. Ko, V. Shankarkumar and N. H. Vaidya, ``Medium access control protocols using directional antennas in ad hoc networks," Proc. Of the IEEE INFOCOM 2000, March 2000.
5. S. Bandyopadhyay, K. Hasuike, S. Horisawa, S. Tawara, "An Adaptive MAC and Directional Routing Protocol for Ad Hoc Wireless Network Using Directional ESPAR Antenna" Proc of the ACM Symposium on Mobile Ad Hoc Networking & Computing 2001 (MOBIHOC 2001), Long Beach, California, USA, 4-5 October 2001
6. N.S.V.Rao and S.G. Batsell, QoS Routing via Multiple Paths Using Bandwidth Reservation, in Proc. of the IEEE INFOCOM98, 1998.
7. S. Bahk and W. El-Zarki, Dynamic Multi-path Routing and how it Compares with other Dynamic Routing Algorithms for High Speed Wide-area Networks, in Proc. of the ACM SIGCOM, 1992
8. S. Murthy and J.J. Garcia-Luna-Aceves. Congestion-oriented Shortest Multi-path Routing, in Proc. of the IEEE INFOCOM96, 1996.
9. Aristotelis Tsirigos Zygmunt J. Haas, Siamak S. Tabrizi , Multi-path Routing in mobile ad hoc networks or how to route in the presence of frequent topology changes , MILCOM 2001.
10. A. Nasipuri and S.R. Das, "On-Demand Multi-path Routing for Mobile Ad Hoc Networks," Proceedings of IEEE ICCCN'99, Boston, MA, Oct. 1999,
11. M. R. Pearlman, Z. J. Haas, P. Sholander, and S. S. Tabrizi, On the Impact of Alternate Path Routing for Load Balancing in Mobile Ad Hoc Networks, MobiHOC 2000, p. 150, 3-10.
12. S.J. Lee and M. Gerla, Split Multi-path Routing with Maximally Disjoint Paths in Ad Hoc Networks, ICC 2001.
13. Kui Wu and Janelle Harms, On-Demand Multipath Routing for Mobile Ad Hoc Networks EPMCC 2001, Vienna, 20th – 22nd February 2001