GLOBAL AGGREGATION NETWORK NODES FOR CREATION OF TRANSIENT NETWORKS

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Abstract : The stationary nature of nodes in a mesh network has shifted the main design goal of routing protocols from maintaining connectivity between source and destination nodes to finding high-throughput paths between them. In recent years, numerous link-quality-based routing metrics have been proposed for choosing high-throughput paths for unicast protocols. In this paper we study routing metrics for high-throughput tree or mesh construction in multicast protocols.

We show that there is a fundamental difference between unicast and multicast routing in how data packets are transmitted at the link layer, and accordingly there is a difference in how the routing metrics for each of these primitives are designed. We adapt certain routing metrics for unicast for high-throughput multicast routing and propose news ones not previously used for high-throughput.

We present simulations that show that using MTM yields an average total network throughput increase of 20% to 60%, depending on network density. In addition, by combining the MTM with a medium time fair MAC protocol, average total network throughput increases of 100% to 200% are obtained over traditional route selection and packet fairness techniques.

***IndexTerms* – Wireless Networks, HiperLAN, Network Nodes**

1. INTRODUCTION

Ad hoc wireless networks are self-organizing multi-hop wireless networks where all nodes take part in the process of forwarding packets. One of the current trends in wireless communication is to enable devices to operate using many different transmission rates. Many current and proposed wireless networking standards have this multi-rate capability. These include the 802.11b [1], 802.11a [2], 802.11g draft, and HiperLAN2 [3] standards. The reason for this multi-rate capability stems directly from some of the fundamental properties of wireless communication. Due to the physical properties of communication channels, there is a direct relationship between the rate of communication and the quality of the channel required to support that communication reliably. Since distance is one of the primary factors that determines wireless channel quality, there is an inherent trade-o® between high transmission rate and effective transmission range.

This range speed trade-off is what has driven the addition of multi-rate capability to wireless devices. Consumer demands for wireless devices always include both higher speed and longer range. Unfortunately, a single rate represents a single trade-o® point between these two confecting goals. Since multi-rate devices support several rates, they provide a wide variety of trade-offs available for use.

This gives them a great deal of Flexibility to meet the demands of consumers. This added flexibility is the primary driving force behind the adoption of multirate capability. It is also reasonable to assume that this type of capability will also be present in future wireless networking standards. While multi-rate devices provide increased flexibility, they cannot change the inherent trade-o® between speed and range. Both high speed and long range cannot be achieved simultaneously. Long range communication still must occur at low rates, and high-rate communication must occur at short range. This multirate capability merely provides a number of different trade-off points. Multi-rate devices must have protocols that select the appropriate rate for a given situation.

In infrastructure-based networks, all communication takes place between nodes and access points. In this case, an additional protocol required to sup-port multi-rate is necessary only at the medium access control (MAC) layer. In these networks, the routing protocol must select from the set of available links to form a path between the source and the destination. Short links can operate at high rates, but more hops are required to reach the destination. In addition, the path selected by the routing protocol will not only affect the packets moving along that path, but will affect the level of congestion at every node within the interference range of the path as well. Our Contribution. We provide a general theoretical model of the attainable throughput in multi-rate ad hoc wireless networks. This model is derived from the properties of the physical and medium access control layers. The traditional technique used by most existing ad hoc routing protocols is to select minimum hop paths. These paths tend to contain long range links that have low effective throughput and reduced reliability. We present the *Medium Time Metric* (MTM) that selects higher throughput paths and tends to avoid long unreliable links.

The MTM minimizes the total medium time consumed sending packets from a source to a destination. This results in an increase in total network throughput.

2. RELATED WORK

Ad Hoc Routing Protocols: A large number of routing protocols have been proposed by the ad hoc wireless networking community. Typically, these have adopted one of two major strategies: on-demand such as in AODV [4] and DSR and proactive such as in DSDV [6] and OLSR [7]. The vast majority of these protocols where originally designed for single-rate networks, and thus have used a shortest path algorithm with a hop count metric (min hop) to select paths.

While min hop is an excellent criterion in single-rate networks where all links are equivalent, it does not accurately capture the trade-off present in the more complicated multi-rate networks. As ad hoc networks are likely to be deployed in multi-rate networks, it should be possible to enhance the network performance of almost any existing shortest path-based protocol by adapting it to use our medium time metric. Signal Stability Based Ad Hoc Routing Protocols. In [8] the authors show that the minimum hop path generally contains links which exhibit low reliability. In [9] and [10] the authors present routing protocols which are based on signal stability rather than just shortest path in order to provide increased path reliability. In our work, signal stability information is used not only to increase path reliability, but also to increase network throughput.

MAC Layer: Since our proposed solution is derived from properties of the MAC and physical layers, it is important to understand existing MAC layer techniques. The IEEE 802.11 standard [11] defines the most commonly used MAC protocol in ad hoc wireless networks. 802.11 based devices are used be- cause of their widespread availability, low cost, and 802.11's ability to provide distributed medium access control when operated in \ad hoc" mode. This mode causes the stations to use the Distributed Coordination Function (DCF) protocol that operates using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).

The method of rate selection in multi-rate capable networks has been leftun specified by the 802.11 standards. As a result, several auto rate protocols have been proposed. The most commonly used protocol is Auto Rate Fallback (ARF). ARF was originally developed for Lucent's Wave LAN II devices [12], and was later enhanced for 802.11b devices [13]. ARF operates using the link level ACK frames specified by the 802.11 standard. Each node increases the rate it is using to communicate with its neighbor after a number of consecutively received acks, and decreases the rate after a number of consecutively missed acks. The advantage of this technique is that it is easy to implement because it is purely sender based, requires no modifications to the 802.11 standard.

3. NETWORK MODEL

Network Assumptions; This work relies on a few specific network assumptions. We assume that the ISO/OSI physical layer is capable of operating using multiple rates. We also assume that the ISO/OSI MAC layer is capable of selecting the rate used by the physical layer. In addition, we assume that the MAC layer is capable of providing information to the ISO/OSI network layer that indicates the selected rate. The network layer can then use this information to improve its routing decisions. This work stresses the importance of inter-layer communication in wireless networks.

Multi-Rate Model:

The multi-rate model presented in this paper is based on the 802.11b standard [1]. The topics discussed here apply to other multi-rate standards, but all examples, ranges, and rates shown in this work are based on 802.11b.

Throughout the remainder of the paper we present the results of a number of NS2 [16] simulations. In order to simulate multi-rate 802.11b, we started with the ns-2.1b7a code base and the multi-rate extensions available from the Rice Networks Group [17] that contain implementations of the RBAR and OAR protocols. The 802.11 MAC and physical wireless parameters were further modified to match the published specifications of a Lucent ORiNOCO PC Card [18], a commonly used 802.11b wireless adapter (see Table 1). Since the carrier sense (CS) threshold specification is not published, we provide an estimate. This estimate was produced by setting the difference between the carrier sense threshold estimate and the 1.0 Mbps receive threshold equal to the difference between the NS2 default carrier sense threshold (-78 dBm) and default receive threshold (-64 dBm).

Table 1. NS2 Simulation Parameters

Parameter	Value
Frequency	2.4 GHz
Transmit Power	15 dBm
11.0 Mbps Receive Threshold	-82 dBm
5.5 Mbps Receive Threshold	-87 dBm
2.0 Mbps Receive Threshold	-91 dBm
1.0 Mbps Receive Threshold	-94 dBm
Carrier Sense Threshold	-108 dBm
Capture Threshold	10
Propagation Model	Two Ray Ground
System Loss	0 dBm

Table 2. 802.11b Ranges

Rate (Mbps)	Maximum Range
11.0	399 m
5.5	531 m
2.0	669 m
1.0	796 m
CS	1783 m

Table 2 shows the ranges resulting from these simulation parameters. Real world ranges are considerably smaller due to non-zero system loss, additional noise sources, obstructions, and propagation effects beyond the simple two ray ground model. The results presented here should be valid for any set of ranges with similar proportions regardless of magnitude.

4. MINIMUM HOP ROUTE SELECTION

Most existing ad hoc routing protocols have utilized hop count as their route selection criteria. This approach minimizes the total number of transmissions required to send a packet on the selected path. This metric is appropriate in single- rate wireless networks because every transmission consumes the same amount of resources. However, in multi-rate networks this technique has a tendency to pick paths with both low reliability and low effective throughput.

Throughput Loss: In multi-rate wireless networks, the selection of minimum hop paths typically results in paths where the links operate at low rates. This is because the shortest path contains the fewest number of nodes between the source and destination. Fewer intermediate nodes correspond to longer links in order to cover the same distance. Since distance is one of the primary factors that determines channel quality, the long links have low quality, and thus operate at low rates. So given the opportunity, in an effort to minimize the number of hops, shortest path selection protocols will pick paths composed of links close to their maximum range that must operate at the minimum rate.

Not only do the low link rates produce a low effective path throughput, but as a result of the shared wireless medium, this path selection degrades the performance of other flows in the network. This occurs due to the large amount of medium time required to transmit a packet at a slow link speed. All nodes within interference range of the transmission must defer while it takes place.

As a result, routes are often established between nodes that are on the fringe of connectivity. This occurs when nodes are able to receive broadcast transmissions, but data/ack packets are unable to be successfully delivered. While routing broadcasts are typically extremely small in size, data packets typically occupy the full frame size, making them more susceptible to corruption at high bit error rates (BER). This tendency is even further exaggerated by the way 802.11 handles broadcast transmissions as opposed to unicast transmissions. While broadcasts are sent as a single frame, unicasts require a full RTS-CTS-DATA-ACK exchange for successful delivery, which is more likely to be disrupted by a low-quality channel. The end result is that small broadcasts can often be delivered even when data communication is not possible.

5. SIMULATION RESULTS

Throughput

Figure 2, column "Throughput-simulations" shows the relative throughput results for the different ODMRP versions. In particular, ODMRP has the lowest throughput,

ODMRP SPP and ODMRP PP have the highest throughput, and on average, ODMRP SPP, ODMRP PP, ODMRP METX, ODMRP ETX and ODMRP ETT achieve about 18%, 18%, 16%, 14.5%, and 13.5% higher throughputs than ODMRP, respectively. Note that we also did simulations under lower load and found similar qualitative results, but are not shown due to space limitation. defined as a random change in the attenuation of a communication channel. Fading can directly affect the link quality.

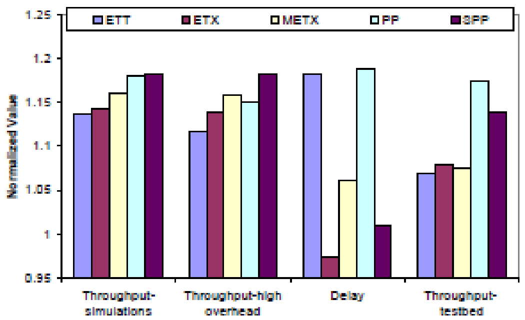

Figure 2. The relative performance of the different routing metrics in terms of throughput and delay normalized with respect to ODMRP.

ODMRP performs poorly because of fading. Fading is every receiver has a *receive threshold*, which defines the signal strength below which the receiver cannot receive a signal properly. With fading, the signal strength may fluctuate up and down. This can cause a packet that would have been dropped to be received and vice versa. In particular, the quality of long links is adversely affected.

The path from a source to a receiver, chosen by ODMRP, depends on the path taken by the JOIN QUERY that reaches the receiver first, which is, in most cases (except when the JOIN QUERY along the shortest paths is lost), the shortest hop path from a source to a destination which typically consists of long links. As fading causes long links to be lossy,ODMRP tends to choose low-throughput paths. In contrast, all other ODMRP versions take into account the link quality in terms of loss rate, delay, or available bandwidth while picking paths, and therefore, they tend to pick paths with shorter links which achieve higher throughput.

6. CONCLUSION

In this work we have shown that minimum hop protocols tend to select paths with long slow links. As a result, these paths have low effective throughput and increase total network congestion. In addition, these paths are likely to contain long links that result in low reliability.

We have presented an improved technique for route selection in multi-rate ad hoc wireless networks. The medium time metric is proportional to the time it takes to transmit a packet on a given link. This metric selects paths that have the highest effective capacity. We have also shown the optimality of this technique under the full interference condition by presenting a formal theoretical model of the attainable throughput of multi-rate ad hoc wireless networks.

Our simulation results show an average throughput gain of 20% to 60%, depending on network density, over traditional minimum hop route selection in 802.11b networks. By combining the MTM with the Opportunistic Auto Rate (OAR) protocol, an increase of 100% to 200% is obtained over the traditional route and rate selection techniques. Our results demonstrate the importance of inter-layer communication in ad hoc routing protocol design.

7. REFERENCES

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