Evaluation of a Routing Architecture for Wireless Messaging Ad-Hoc Networks

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Abstract. *The Short Messaging Service(SMS) which has become very popular in cellular networks is very highly priced. We show in this paper how self-organizing ad-hoc networks can be used to provide the short messaging service, at a much lower price. We propose a routing protocol for wireless messaging networks, which explores the characteristics of ad-hoc network routing in which mobile nodes are allowed to relay in place of static nodes. We demonstrate, using simulations, how this increases connectivity in the network and decreases the required node density for full connectivity. As our scheme relies on the delay tolerant properties of short messages, we explore the delay characteristics of our routing scheme as well.*

1 Introduction

Although voice communication still forms the dominant segment of revenues in mobile communication, short messaging services (SMS) are becoming increasingly popular. Conventional networks such as cellular networks offer these services at a high price. Although many services on the Internet([1],[2]) provide free messaging service, accessibility is a problem, especially in developing countries.

Self-organizing *ad hoc networks* may emerge as an alternative to provide easy access to a communication infrastructure. They can provide a cheaper and more flexible messaging service. They comprise of independent nodes which collaborate in order to transport data. They lack a central controlling authority to coordinate the entire network. Hence all network services are provided by the nodes themselves.

Ad-hoc networks may be further subdivided into static ad-hoc networks and mobile ad-hoc networks(MANETs)[3]. In static networks, the position of a node may not change once it becomes part of the network while in the mobile ad-hoc networks, nodes may move and change positions arbitrarily. In *multihop* ad-hoc networks, each message is routed along several hops to reach the destination, which allows for increased coverage. However, the performance of communication decreases with the number of hops due to link errors and losses at each link.

The remainder of the paper is organized as follows: Section 2 describes the related work in this area; Section 3 describes the motivation for our problem; Section 4 describes the system and the protocol design; Section 5 describes the abstraction made from the protocol for the simulator; Section 6 describes the simulation results; Finally, Section 7 concludes the paper and presents future research directions.

2 Related Work

Several routing protocols have been proposed so far for self organizing ad-hoc networks. Perkins and Royer[3] propose the Ad hoc On Demand Distance Vector (AODV) routing algorithm suitable for a dynamic self-starting network and scalable to large populations of mobile nodes. In [4], Perkins and Bhagwat propose the highly dynamic Destination Sequenced Distance Vector Routing (DSDV) in which each Mobile Host acts as a specialized router, periodically advertising its view of the interconnection topology to other Mobile Hosts within the network. Johnson and Maltz[5] propose the Dynamic Source Routing protocol (DSR), designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes, allowing the network to be completely self-organizing and self-configuring. In [6], Ferriére, Grossglauser and Vetterli propose Last Encounter Routing (LER), a new approach for location services and routing in mobile adhoc networks. It relies upon nodes maintaining a database of their last encounters with other nodes. Exponential Age Search (EASE) and GREASE[7] are two simple versions of the LER algorithm. Some real-world applications of mobile ad-hoc networks have also been proposed. Morris *et al.*[8] propose CarNet, a highly scalable application for a large ad hoc mobile network system which places radio nodes in cars, which communicate using Grid, a novel scalable routing system. In [9], Jorjeta *et al.* propose The Ad Hoc City, which is a multi-tier wireless ad hoc network routing architecture for general-purpose wide-area communication.

3 Problem Statement

In this paper, we present a new routing protocol for messaging ad-hoc networks. Messaging networks are designed to deliver short data packets called *messages* as opposed to traditional networks carrying streaming traffic. Messages are a specific type of traffic, consisting of small data packets, and possess the desirable property of being *delay tolerant*, unlike streaming traffic. This means that if a given link in their path does not exist, they may be stored at a router temporarily and forwarded subsequently once the link is restored. The delay constraints of messages are likely to be in the order of some minutes as opposed to streaming traffic, where these constraints are at most in the order of a second.

We propose a routing protocol that adapts well to the specific properties of messages and enables messaging without heavy route discovery. We build upon the protocol for messaging in ad-hoc networks proposed by SOWER[10]. SOWER involves only static nodes for routing and requires that these nodes be within each others radio range in order to connect. We propose a combination of static and mobile networks embedded with *virtual links* (refer to section 4.3), which allow unconnected static nodes to be connected via mobile nodes. We propose a protocol using multihop communication which adds scalability to the network, reduces delays and maximizes connectivity in the messaging network.

4 System Description

4.1 The protocol design

While designing the protocol, we kept the following issues in mind:

1. **Reliability :** Probability of message reaching the destination must be high.
2. **Efficiency :** Optimized to minimize delays and overheads.
3. **Load Balancing :** Must distribute the load evenly over the network.
4. **Robustness :** Must function even in unexpected situations.
5. **Security :** Must be secure from malicious users and loopholes.
6. **Energy Optimization :** Must minimize energy consumption for the battery operated mobile devices.

4.2 Network Architecture

We assume two kinds of nodes which connect to the network: static nodes (called *home devices*) and mobile nodes (called *mobile devices*). A user must acquire both devices to be able to participate in the network. The message routing between mobile devices is similar to the MobileIP scheme [11]. The *home agent* of the mobile device is installed at a particular location (such as home, office etc.) while the mobile device is carried by the user.

The mobile device is attached to the network via the nearest home device in its vicinity (which may be different from it's home agent), called its *attachment point*. It sends updates to its home agent about its current location via its attachment point.

We assume that the radio capabilities of the home devices and mobile devices is the same (for example based on 802.11b radio standard). We work with fixed radio ranges and bidirectional links.

Home devices form the *wireless backbone* of the network since they are static (longer than mobile devices) and maintain all the routing information. One or more mobile devices may relay the messages between unconnected home devices, forming a *virtual link*.

We allow for a single user message to be sent via *multiple paths* to reduce dependency on a single link. In multipath routing, the probability of link failure along *every* chosen path is very small, thus increasing reliability and decreasing average delay. However, this is at the cost of increased traffic overhead arising from multiple message copies.

We define *link failure* as the non-existence of a link for a long (pre-defined) time while instantaneous non-existence of a link is the immediate absence of a link involving a mobile device. A non-existent link is "not failed" if restored before the timeout.

Basic Entities in the Network

1. **Message:** Messages are data packets that are identified by their message IDs and have a fixed source node and a fixed destination node. Messages may be of two types, namely *user messages*, generated by a user and *control packets*, generated by the network itself. We assume that typically the control packets are smaller than user messages and hence contribute very little to the traffic overhead in the network.
2. **Home Device:** Home devices are static devices, not constrained in resources such as memory and energy. They do not require periodic updates about each other's positions. Updates are only broadcasted if a new home device is added, a home device is deleted or moved, to immediate neighbours.
3. **Mobile Devices:** These are the battery operated, mobile units of the network. They can relay messages between unconnected home devices and thus form virtual links between them. They may be present or absent at a particular location with a certain probability (according to the mobility model deployed).
4. **Attachment points:** The home device nearest to a mobile device, called its attachment point, is its point of connectivity to the network. All messages for a mobile device are re-directed by the home agent of the mobile device to its attachment point. Success acknowledgements and failure reports are sent by the attachment points to the mobile device's home agent.
5. **Home Agent:** We assume that each home device is a home agent to one mobile device. Its mobile device is free to move in the network and attach to other home devices. However, the home agent knows the location of its mobile device in the network via periodic *location updates* sent by the mobile device.

4.3 Virtual Path and Virtual Links

Virtual Link: It is a connection between any two home devices in the network, not via any other home device. We refer to it as a *direct virtual link* if the two home devices are within each others radio range and can connect directly and to an *indirect virtual link* if they require mobile devices as relays between them.

Virtual Path: A path between two home devices which may be a single virtual link or a sequence of virtual links involving several mobile and home devices is known as a virtual path. Thus every virtual link is a virtual path but not vice versa. Figure 1 clearly shows the distinction between them.

Virtual Path Costs: Cost of a virtual path is the sum of the costs of the individual virtual links. A low cost virtual link requires:

1. A high *probability of existence*. The probability of existence is the product of the probabilities of existence of links between successive mobile devices involved in relaying between two home devices.
2. A small *hop count* (the number of nodes traversed on the link to reach the destination) since link errors and packet drop rates scale as the hop count.

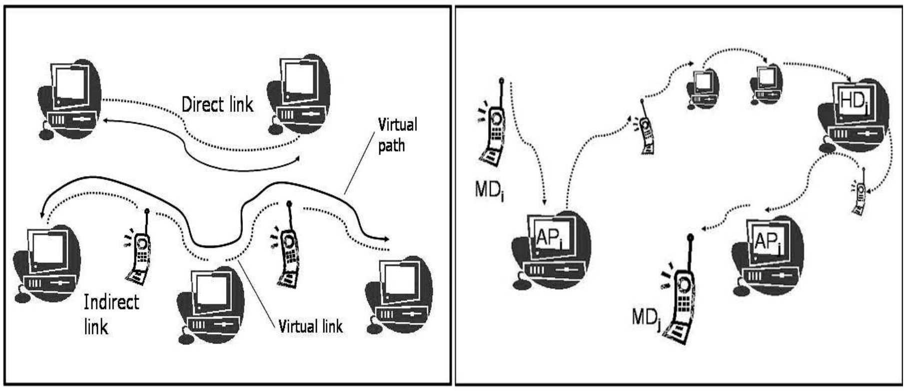

Fig. 1. Virtual path and a Virtual link(left);Routing of a packet in the network from mobile device i to mobile device j(right)

3. Low energy consumption during path traversal. Energy loss is proportional to d^{α}, where α is the path loss exponent[12]. There are several factors that affect the transmission energy, such as antennae gain etc.

Thus the cost of a link is quantified as :

$$Cost = \frac{1}{p} * L * d^{\alpha}$$

where p is the probability of existence, L is the hop count, d is the transmission distance and α is the path loss exponent

4.4 Routing Entities Stored by Home Devices

1. *Routing Tables:* They contain the next hops to every other home device in the network to which it is possible to connect. They may store distinct next-hops for the multipaths to the same destination.
2. *Attachment Tables:* This is a list of all the mobile devices for which the home device serves as an attachment point and the address of their home agents.
3. *Location Entry:* It stores the attachment point of its own mobile device (one for which it is the home agent).
4. *Neighbors Table:* Each home device also maintains a list of its neighbors in the virtual network, which are home devices which are within its radio range. Route discovery broadcasts are sent only via neighbors.

During route discovery, responses from other home devices not within the home devices radio range may be received and the paths with shortest response times and higher probabilities of existence are preferred. Mobile devices store their own attachment point and home agent details. They participate in packet forwarding, but do not perform routing activities such as search for a destination, maintaining routing tables etc.

4.5 Protocol Execution

Attachment Point Discovery A mobile device chooses its nearest home device and sends an attachment request. The home device replies with an acknowledgement message and adds an entry in its attachment table. If no reply is received within a time period, the mobile devices tries to attach itself to the next closest home device. The mobile device must confirm its attachment periodically within a timeout preset by the attachment point, to avoid deletion from the latter's attachment table. Since this update is performed locally, it does not introduce significant overhead into the network.

Location Update To keep the home agent updated about its mobile device location in the network at all times, the attachment point sends updates of a newly attached mobile device to its home agent till it receives an acknowledgement from the home agent.

Packet Sending As shown in Figure 1, if a mobile device (say MD_i) wants to send a packet to MD_j, it first routes the message to its attachment point AP_i. AP_i does not know the location of MD_j in the network. Thus it routes the message to the home agent of MD_j(say HA_j). HA_j re-directs the packet to this attachment point AP_j, which performs the required checks for connectivity with the mobile device MD_j and forwards the packet. It sends acknowledgement or error messages back to the home agent HA_j as the case may be. Upon error, HA_j waits for a location update from the MD_j for a defined time before trying to re-send the packet. This wait time increases exponentially upon repeated failures. If a relaying mobile device leaves, a home device searches for other mobile devices within its radio range or waits for the link to be restored, whichever is quicker.

5 Abstraction for Simulator

1. **Mobile Devices:** Mobile devices are simulated by assigning an instantaneous *probability of existence* to the link(s) involving the mobile device, at any given location. Direct virtual links have a higher probability of existence than indirect links. Since there are no physical mobile devices present, there are no attachment tables, location entries and location updates.
2. **Routing Decisions:** The protocol is assumed to be *pro-active*, meaning all routing tables are built at the beginning of the network. When a route discovery is initially made, *entire routes* (and not just next hops) for the fastest few responses are saved, depending on the number of multipaths specified. Messages store the entire path from the source to the destination, with no routing decisions being made at intermediate nodes.
3. **Virtual Links:** For simplicity of the simulator, we assume that two home devices can be connected by a maximum of one mobile device, to avoid the extra overhead and deployment of a special protocol for communication between the mobile devices. Thus the overhead incurred is local and does not significantly affect network overhead. We leave the development of such an extended scheme as future work.

Table 1. Simulation parameters

Parameter	**Value**
Area	$1000m$*$1000m$
Radio Range of nodes	75 m
Time to Live(of user messages)	Between 5 and 30 cycles
No. of home devices	Between 10 and 110
No. of multipaths	Between 1 and 7
Probability of existence : direct link	0.95
Probability of existence : indirect link	0.75 or 0.55
Probability that a home device generates a message(per cycle)	0.2
User message size	256 Bytes
Control Packet size	40 Bytes
Time of simulations	1000 cycles
No. of simulations	50

6 Simulation of the Routing Protocol

6.1 Description of the Simulator

We developed a simulator in C++ to investigate the performance of our protocol. In the simulator, we work in time units called *cycles*. A cycle is the time unit in which we update the existence or absence of links according to the given probability model, using probabilities of existence.

The *time to live* (TTL) of a message is defined as the maximum number of cycles that a user message can remain in the network without being delivered. It denotes the maximum delivery time requirement of a message. Table 1 provides a summary of the simulation parameters. We evaluated the following metrics of our routing protocol:

Delivery Ratio: Ratio of the total number of user messages delivered to the total number of user messages in the network.

Average delay per message: Ratio the total number of cycles used by all delivered messages in delivery to the total number of user messages delivered.

Average Overhead per user message: Ratio of the total overhead due to all user messages to the total number of user messages in the network.

Largest connected component: Ratio of the total number of nodes in the largest connected component to the total number of nodes in the network

For evaluating delay per message, we calculated delay only for the first message delivered and not for subsequently reaching duplicate messages via the multipaths. However, the overhead is calculated per user message generated since duplicate and undelivered messages contribute to the overhead. All acknowledgement messages also contribute to delay and overhead. We require all multipaths to be different in atleast one link involved.

6.2 Simulation Results

We obtained the following results from the simulator:

The largest connected component ratio is expected to increase as the node density increases. Figure 2 shows the results. As expected, it increases from about 0.2 for 10 static nodes in a 1 km^2 area to about 0.9 for 90 nodes and almost 1 for 100 - 110 nodes. This is a significant improvement over the previous protocol presented in [10], which relied on the directly connected home devices. In this latter case, the required node density for achieving full network connectivity is 220 nodes per km^2.

We also evaluate the effect of the Time To Live (TTL) parameter on the delivery ratio. Figure 2 shows the delivery ratios as a function of the number of home devices in the network, evaluated for various values of TTL and for 3 multipaths. We observe that upto 80-90 nodes, since the network connectivity values are low, all curves are similar. However, the curves branch out after 80 nodes since the network is now connected and the TTL now determines the shape of the curve. For low values of TTL, more messages which could have been potentially delivered, are dropped due to lower allowed TTL and hence the delivery ratio falls. For higher values of TTL, the message is allowed to stay in the network for a longer period and attempt to reach its destination. Hence the delivery ratio increases since all messages which can be delivered, are delivered. For 100 and 110 nodes, when there is almost full network connectivity, delivery ratios also approach 1.

Next we evaluate the effect of increasing multipaths on the delay per message delivered and overhead per user message. For this evaluation we fix the number of nodes at 80 and the TTL value at 20. Figure 3 shows the results obtained. As expected, the average delay per message delivered decreases with increase in number of multipaths. However, since the same message is sent along several paths, the overhead per message increases.

We evaluate the delay and overhead results, with the probability of existence of a virtual link involving mobile devices reduced from 0.75 to 0.55. We observe a more marked improvement in delay due to multipath routing for lower probabilities, as demonstrated by the greater slope for the delay curve for probability 0.55 in Figure 4. This can be attributed to the fact that links with higher probabilities are more reliable and will have a lower dependence on multipath routing. The overhead per message values remain almost unaffected by the change in probability.

7 Conclusion

In our paper, we have proposed and a routing protocol for messaging ad hoc networks.

We have shown that the node density requirement in our protocol falls drastically as compared to the SOWER [10] due to the presence of virtual links in the network using mobile nodes as relays between static nodes. We have studied the effect of multipath routing on average delay per message delivered and on overhead per message. We observe that delays decrease with an increase in the number of multipaths while the overhead increases almost linearly, as antici-

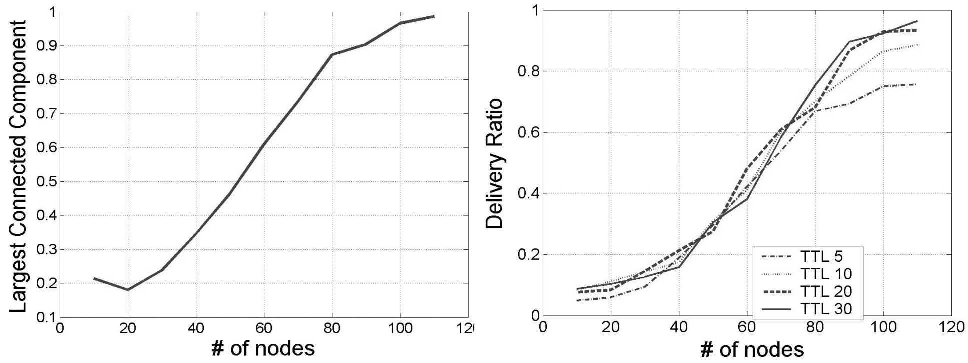

Fig. 2. The largest connected component and delivery ratios for various TTL vs number of home devices

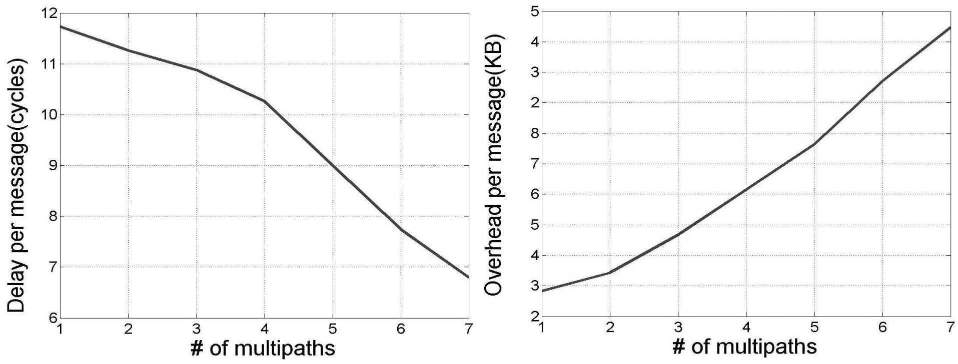

Fig. 3. Delay per message delivered and overhead per message as a function of number of multipaths

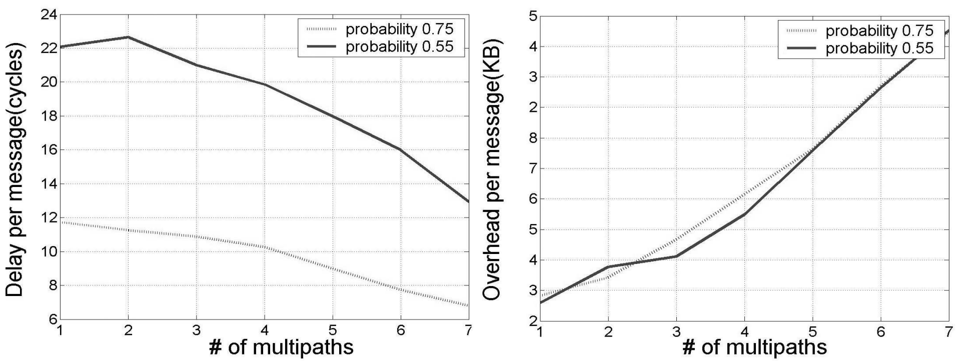

Fig. 4. A comparison of the delay per message delivered and the overhead per message as a function of number of multipaths for different probabilities of indirect link existence

pated. We also show that the benefit of multipath routing is more evident when we assign lower existence probabilities to links involving mobile devices.

In the current model, only the probability of existence of links is taken into account in the calculation of the cost of virtual links. As a next step, we will carry out simulations taking other parameters such as security, network congestion and energy optimization into consideration. Furthermore, we will implement a mobility model for mobile nodes similar to real networks. Currently we explore only the outdoor layout model for the home devices. We will further explore the urban city model and study the effect of indoor-outdoor links. We will also test it for on-demand routing and compare the results with the pro-active protocol.

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