CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the rapidly growing age of IT, the sharing of vital information is necessary for many tasks and an urgent information can be disseminated the sooner or better a task can be completed. With the development of wireless technologies like GSM and Wi-Fi, information is often available anytime and anywhere. But the limitation of these technologies is that they require an infrastructure, i.e., base stations for their functioning. In environments such as disaster management or wartime conflict, this type of infrastructure is generally not available, but information exchange is still desired. An option to communicate in these environments is to use long range radios that enable point-to-point communication. The problems with these systems are that they are often expensive, bulky and provide only low bandwidth communication. Hence multihop wireless Ad hoc network is used. In a multihop wireless Ad hoc network, mobile nodes cooperate to form a network without using any infrastructure such as access points or base stations. Instead, the mobile nodes forward packets to each other, allowing communication among nodes outside the wireless transmission range.

Intermittently connected mobile ad hoc networks are mobile wireless networks where, for most of the time, a complete path does not exist from a source to a destination. Or such a path is highly unstable and may change or break soon after it has been discovered. This is due to constraints
like node mobility, limited radio range, physical obstacles, inclement weather, wide deployment area or other physical factors (Li and Rus 2000). Most ad hoc network routing algorithms are designed for networks that are always connected (Perkins and Belding-Royer 2003, Zhou 2003). While it is certainly desirable to maintain a connected network, various conditions can cause a mobile ad hoc network to become partitioned. This means that there is no single-hop or multiple-hop route between some (or all) source/destination node pairs which might prevent some nodes from communicating with others and result in a partitioned network. The existence of network partitioning requires a new routing approach other than the traditional “store-and-forward" routing paradigm, used in most current ad hoc routing algorithms, in which messages are dropped if no route is found to reach a destination within a short period of time (Abolhasan et al 2004, Mundur et al 2006).

This research work reviews issues in traditional ad hoc routing protocols when frequent disconnections exist in the network. It also discusses current approaches for establishing a route between nodes in intermittently connected ad hoc networks. This thesis then proposes some QoS routing approaches for this type of network in order to improve the delivery rate with optimum delay and overhead ratio for varying buffer spaces, node density, mobility speed etc.

1.2 BACKGROUND

The kind of communication networks addressed in this work are viable only for applications that can tolerate long delays and are able to deal with extended periods on being disconnected. In military war-time scenarios and disaster recovery situations, soldiers or rescue personnel are often placed in hostile environments where no infrastructure can be assumed to be present. Further, the units may be sparsely distributed and mobile so that connectivity between them is intermittent and infrequent (Small and Haas 2005). In any
large scale ad hoc network, intermittent connectivity is likely to be normal. Thus, meaningful research in this area is likely to payoff in practical systems.

1.3 APPLICATION SCENARIOS OF INTERMITTENTLY CONNECTED AD HOC NETWORK

- Ad hoc networks for low cost Internet provision to remote areas/ communities.
  - Africa, Saami, etc.
- Sensor networks for habitat monitoring and wildlife tracking.
  - ZebraNet: sensor nodes attached on zebras, collecting information about movement patterns, speed, herd size, etc.
- Inter-planetary networks (extend the idea of Internet to space).
- Ad-hoc military networks.
- Remote village communication.

1.4 CONVENTIONAL MANET ROUTING PROTOCOLS

MANET routing protocols can be divided into two categories: proactive (table-driven) and reactive (on-demand) routing based on when and how the routes are discovered. Table-driven routing protocols attempt to maintain consistent, up-to-date routing information from each node to every other node in the network. Routing table is updated periodically. On demand routing protocol creates routes only when desired by the source node. If a node wants to send a packet to another node then this protocol searches for the route in an on-demand manner and establishes the connection in order to transmit and receive the packet. The route remains valid till the destination is reachable or until the route is no longer needed. Routing protocols for ad hoc
networks must deal with limitations such as high power consumption, low bandwidth, high error rates and arbitrary movements of nodes.

1.5 CHALLENGES IN SPARSE MOBILE AD HOC NETWORK

Here there are two main challenges - Intermittent Connectivity and Network Partition. In the case of -

Intermittent connectivity:
- When nodes are in motion, links can be obstructed by intervening objects.
- When nodes conserve power, links are shut down periodically.

Network partition:
- When no path exists between source and destination, it is perfectly possible that two nodes may never be part of the same connected portion of the network.

1.6 ISSUES IN CONVENTIONAL MANET ROUTING PROTOCOL

Intermittently Connected Mobile ad hoc network with long disconnection time creates network partition as shown in Figure 1.1. In this context, conventional routing schemes fail, because they try to establish a complete end-to-end path between source to destination before sending any data.
Existing Routing protocols simply discard the packets if the packet is not delivered within a short period of time. These routing protocols fail in Intermittently Connected Mobile Ad hoc networks because of the following characteristics of Network:

- Intermittent network contacts.
- End-to-end path between the source and the destination may never have existed.
- Disconnection and reconnection is common.
- Highly variable link performance.

One of the fundamental problems that arise when designing networks that handle disconnection is routing (Corson and Macker 1999).

1.7 DELAY TOLERANT AD HOC NETWORK

Delay-tolerant networks (DTNs) are designed to address networks that exhibit intermittent connectivity. Unlike conventional networks, DTNs do not necessarily provide end-to-end connectivity between two endpoints, and
nodes may experience longer periods of disconnectivity than periods of connectivity. The latency to send a message may be of the order of hours or more, rather than fractions of a second. It is capable of storing packets in intermediate nodes until an end-to-end route can be established. DTN architecture can be defined by one or more of the following characteristics: sparse connectivity, long or variable delay, asymmetric data rate and high error rate (Cerf et al 2007).

### 1.7.1 Routing

Routing the data from a source to its destination is a fundamental ability all communication networks must have. Delay and disruption-tolerant networks (DTNs), are characterized by their lack of connectivity, resulting in a lack of instantaneous end-to-end paths. In these challenging environments, traditional ad hoc routing protocols fail to establish routes. This is due to these protocols trying first to establish a complete path and then, after the route has been established, forward the actual data. However, when instantaneous end-to-end paths are difficult or impossible to establish, routing protocols must take to a "store and forward" approach, where data are incrementally moved and stored throughout the network in such a way that it will eventually reach its destination.

### 1.7.2 Store and Forward Message Switching

DTNs overcome the problems associated with intermittent, long or variable delay, asymmetric data rates and high error rates by using store and forward message switching. The store and forward message switching is shown in Figure 1.2. In this method, a whole message or fragments of such messages are moved from a storage place on one node to a storage place on another node, along the path that eventually reaches the destination.
DTN routers need persistent storage for their queues for one or more of the following reasons:

- A communication link to the next hop may not be available for a long time.
- One node in a communicating pair may send or receive data much faster than the other node.
- Message may need to be retransmitted if an error occurs at a node or line, or if a node declines the acceptance of a forwarded message.

### 1.7.3 Intermittent Connectivity

When communicating nodes are in motion, links can be obstructed by intervening bodies. These events cause intermittent connectivity. When no path exists between source and destination, a network partition is said to occur. Packets that cannot be immediately forwarded are usually discarded and TCP may retransmit the packets with slower retransmission timing. If packet dropping is too heavy, TCP ends the session, which can cause applications to fail. DTNs, by contrast, support communication between intermittently connected nodes with a store and forward technique.
1.7.4 Opportunistic Contacts

Network nodes may need to communicate during opportunistic contacts, in which a sender and a receiver make contact at an unscheduled time. For instance, moving vehicles, people, aircraft or satellites may make contact and exchange information when they happen to be within their range.

1.7.5 Bundling

DTN suggests combining all application level data and metadata to form a single bundled message, in order to minimize end-to-end transactions. For example, all FTP metadata (login-name, password, file name(s) etc.) and actual data can be sent to FTP server, bundled in one message. This is why DTN layer in a protocol stack is called the Bundle Layer.

1.7.6 The Bundle Layer

The DTN architecture implement store-and-forward message switching by overlaying a new protocol layer called the Bundle Layer on top of heterogeneous, region-specific lower layers so that application programs can communicate across multiple regions. The bundle layer stores and forwards entire bundles or bundle fragments between nodes. A single bundle layer protocol is used across all networks (regions) that make a DTN. By contrast, the layers below the bundle layer (the transport layer and lower layers) are chosen for their appropriateness to the communication environment of each region. The layers which are defined in DTN are shown in Figure 1.3.
DTN payloads are in the form of messages, formally called Bundles. DTN combines all application layer data and associated meta-data into one message called bundle. Bundles can be of variable sizes. They consist of source-applications user data, control information provided by the source application for the destination application. It describes how to process or handle the user data and bundle header inserted by the bundle layer. A bundle layer may break whole bundles into fragments just as an IP layer may break whole datagrams into fragments. If bundles are fragmented, the bundle layer at the final destination reassembles them.

1.7.7 Bundle Encapsulation

The most basic service provided by the bundle layer is its unacknowledged, prioritized unicast message delivery. It also provides two options for enhancing delivery reliability: end-to-end acknowledgments and custody transfer. Applications wishing to implement their own end-to-end message reliability mechanisms are free to utilize the acknowledgment. The
custody transfer feature of the DTN architecture only specifies a coarse-grained retransmission capability. For unicast delivery, this will typically involve moving bundles "closer" (in terms of some routing metric) to their ultimate destination, and retransmitting when necessary. While the nodes receiving these bundles along the way are called "custodians" the movement of a bundle from one node to another is called a "custody transfer".

Since there may not be an end-to-end path in DTN networks, conventional end-to-end reliability mechanisms like retransmissions cannot work. DTN moves the responsibility of reliable delivery from a source node to other DTN nodes lying deeper in the network. This is achieved by moving a copy of message ‘closer’ to the destination. Hence, retransmission related responsibilities move away from source node gradually, breaking the requirement of end-to-end retransmissions, as done in the Internet.

DTNs support node-to-node retransmission of lost or corrupted data at both the transport layer and the bundle layer. However, because no single transport layer protocol operates end-to-end across a DTN, end-to-end reliability can only be implemented at the bundle layer.

The bundle layer supports node-to-node retransmission by means of custody transfers. Such transfers are arranged between the bundle layers of successive nodes, at the initial request of the source application. When the current bundle layer custodian sends a bundle to the next node, it requests a custody transfer and starts a time-to-ack retransmission timer. If the next-hop bundle layer accepts custody, it returns an acknowledgement to the sender. If no acknowledgement is returned before the sender’s time-to-acknowledge timer expires, the sender retransmits the bundle. A bundle custodian must store a bundle until either another node accepts custody or expiration of the bundle’s time-to-live. Time-to-live should be longer than time-to-acknowledge.
The basic bundle protocol defines unacknowledged, prioritized but not guaranteed, message delivery mechanism. For reliability and diagnostic purposes, it defines two kinds of messages. Bundle Status Reports (BSR) provides information about how a bundle is progressing through the network. BSRs are also used for positive acknowledgements as well. Custody Signals are bundle messages, which carry information about the status of custody-acceptance (success or failure) by generating nodes. These are sent to the current custodian of the bundle. If custody is accepted successfully, the generating node becomes the current custodian and upon reception of the custodian’s signal, the previous custodian releases the custody.

1.7.9 Bundle Protocol

The primary DTN protocol running at Bundle layer is called Bundle protocol. Bundle protocol defines semantics, formats and sequences of protocol messages in order to carry out basic bundle layer services, including:

- Asynchronous message transfer.
- Generation of Bundle Status Reports messages.
- Custody transfer related signaling.

It defines a primary bundle message header, along with a payload header and administrative records’ header formats.

Primary bundle header - This header contains the basic information required to route the bundle to its destination. It is included in each and every type of bundle, including administrative records.
**Bundle payload header** - This simple header describes the type of payload, flags indication directions to process the header and a length field describes the length of payload.

**Bundle status report and custody signal formats** - If the primary header’s processing flag indicates that the bundle payload is an administrative record, then the payload is processed according to a specific format. The first byte describes the type of administrative record (status report or custody signal) and some optional flags for additional information, describing directions to interpret remaining fields.

If the administrative record is a status report then the remaining fields describe the type of status report and the time when the event took place, for which the report was generated, in DTN timestamp format. One administrative record message can aggregate multiple reports for the same bundle, thus reducing network traffic.

If the administrative record is a custody-signal message then it just contains the information regarding success or failure of the custody transfer operation, along with an optional reason.

### 1.8 ROUTING SCHEMES FOR INTERMITTENTLY CONNECTED MOBILE AD HOC NETWORK

There are a number of routing protocols available for intermittently connected networks, where there is no guarantee that a fully connected path between source and destination exists at any time. It renders traditional routing protocols incapable of delivering messages between hosts. A number of routing schemes have been proposed to provide communications in highly partitioned networks. Two of them are:
- Mobility assisted approach.
- Transmission power control protocol.

1.8.1 Mobility Assisted Approach

Several models, based on mobility assisted scheme, have been proposed to deal with routing in this type of network. The existing movement-assisted routing methods can be classified into two categories, based on the mobility control:

- Dissemination based approach.
- Message ferrying approach.

1.8.1.1 Dissemination Based Approach

Dissemination based approach uses the random mobility of nodes to transmit messages (Grossglauser and Tse 2002). One of the best existing random movement schemes is epidemic routing (Vahdat and Becker 2000, Khelil et al 2002). Here, an assumption for this algorithm is that the nodes are all mobile and they have infinite buffers. It is a flooding-based algorithm. It means this: whenever a node has a message to send, it propagates the message to all nodes it meets and the nodes which receive the message continue to propagate it. Sooner or later, the data are delivered to the destination with a high probability. This approach can achieve high delivery ratios, and it operates without any knowledge of the network topology or communication pattern. It provides optimal delay only when the traffic is low. Yet, it is well-suited for networks where the contacts between nodes are unpredictable. Animal tracking networks such as SWIM and ZebraNet use random node mobility and flooding-based relaying (Ho et al 1999).
Owing to the considerable number of transmissions involved, these techniques suffer from high contention and may potentially lead to network congestion (Zhang et al 2007). To increase the network capacity, the spreading radius of a message is typically limited by imposing a maximum number of relay hops to each message, or even by limiting the total number of message copies present in the network at the same time. When no relaying is further allowed, a node can only send the message directly to destination when meeting it. One example of such scheme is “Spray and Wait”. This scheme consists of two phases: the first phase distributes a fixed number of copies to the first few relays encountered, and in the second phase each of these relays waits until it encounters the destination itself. Spray and wait scheme yields lower delay and reduce the number of transmissions than the epidemic routing. This protocol gets into trouble when the nodes’ mobility is restricted inside a local area. In Spray-and-Wait, a relay carries its copy until it encounters the destination or until the TTL (time-to-live) for the packet expires. One problem with this scheme is that the relay with a copy will simply wait until it moves within the range of the destination itself. With this problem in mind, another method, Spray and Focus is designed. In this method, the second phase is a ‘focus’ phase, rather than (Wait phase) waiting for the destination to be encountered, each relay can forward its copy to a more appropriate relay. In some situations, network partitions can last for a long period of time. For such network, dissemination based routing approaches are not suitable. Hence it cannot deliver messages between partitions which are mostly permanent or last for a long period of time.

1.8.1.2 Message Ferrying Approach

Message Ferrying is, in fact, a controlled movement model, where nodes may change their original routes to collect and deliver messages (Zhao et al 2004). Message Ferrying is a mobility-assisted proactive routing
algorithm that incorporates message ferries by allowing communication among disconnected nodes. Ferries travel in a specified route, collecting data from sources and delivering data to the appropriate destinations. These message ferries allow nodes to communicate when the network is disconnected and when nodes do not have global knowledge of the network. It is a proactive routing algorithm created to address network partitions in intermittently connected ad hoc networks by establishing non-randomness in node movement. There are two types of nodes in MF scheme: Message ferries and regular nodes. This classification is based on their roles in communication. Ferries are mobile devices which take the responsibility of carrying messages among other nodes, while regular nodes are devices without any such responsibility. Several MF extensions could be carried out by installing multiple ferries (Zhao et al 2005) in a set of sub-regions through partitioning. This idea can be used in remote village communications and remote area connectivity projects for providing Internet access. MF scheme provides regular connectivity in a disconnected network and also improves the performance of data delivery without global knowledge of each node's location.

1.8.2 Transmission Power Control Protocol

Power control should be done in conjunction with routing, since it needs to keep connectivity in mind. Changes in transmission power in mobile computer make changes in transmission range of the signal. Power control affects the three important performance metrics of throughput, energy consumption and end-to-end delay (Gupta and Kumar 2000). Disconnected nodes in the network might be able to build their connection back to the network at increased transmission power. When signal transmission power increases transmission range also increases but reduces the number of hops between mobile nodes. Less number of hops reduces the delay. On the other
hand, by reducing signal transmission power, the probability of contention and collision in signal transmission is also reduced. Hence there is a trade off in controlling the signal transmission power in order to reduce an end-to-end message transmission delay.

Power control affects the performance of the physical layer in two ways. First, power control affects the network capacity. This means, choosing too high transmission power reduces the number of forwarding nodes needed to reach the intended destination. But this creates excessive interference in a medium that is commonly shared. In contrast, choosing a lower transmission power reduces the interference seen by potential transmitters but packets require more forwarding nodes to reach their intended destination. Second, power control affects network connectivity. A high transmission power increases the connectivity of the network by increasing the number of direct links seen by each node. But this is at the expense of reducing network capacity. The effect of transmission power level on network connectivity is shown in Figure 1.4.

Figure 1.4 Effect of power level on network connectivity
The choices of power levels affect the connectivity of the network and consequently it retards the network’s ability to deliver a packet to its destination. The type of power control also affects the connectivity and performance of the network layer. So it becomes necessary to choose a higher transmission power in order to increase the connectivity of the network and reduce signaling overhead. A higher transmission power increases the transmission range of the nodes while at the same time it decreases the number of forwarding nodes between source-destination pairs. Therefore, reducing the signaling load becomes necessary to maintain routes when nodes are mobile. The signaling overhead of routing protocols can consume a significant percentage of the available resources at the network layer, thereby reducing the end user’s bandwidth and power availability.

In these days, existing routing protocols are designed to discover routes using flooding techniques at common-range fixed maximum transmission power. These protocols are optimized to minimize the number of hops between source-destination pairs (Narayanaswamy et al 2003). This will increase connectivity and reduce network capacity. For overcoming this shortage, existing routing protocols may be modified to promote lower transmission power levels in order to increase network capacity and yield a potentially higher throughput. But it is neither a trivial nor a viable solution. For example, lowering the common transmission power forces MANET routing protocols to generate a significant amount of signaling overhead to maintain routes in the presence of node mobility. Similarly, there is a minimum transmission power beyond which nodes may become disconnected from other nodes in the network. Because of these characteristics of MANET routing protocols, transmission power level may be adjusted dynamically to provide connectivity in intermittently connected ad hoc networks.
1.9   PROBLEM DESCRIPTION AND SOLUTION

1.9.1   Problem Definition

Most ad hoc network routing algorithms are designed primarily for networks that are always connected. While it is certainly desirable to maintain a connected network, various conditions may cause a mobile ad hoc network to become partitioned. That is, there is no single-hop or multiple-hop route between some (or all) source/destination node pairs. Node mobility, limited radio range, physical obstacles, severe weather, wide deployment area or other physical factors, might prevent some nodes from communicating with others and result in a partitioned network. The existence of network partitioning requires a new routing approach other than the traditional “store-and-forward” routing paradigm used in most current ad hoc routing algorithms. In these cases, messages are dropped if no route is found to reach a destination within a short period of time. If the partitions last for a long duration of time, then it is not possible to deliver a packet from source to destination. Hence an innovative routing approach is needed to deliver a packet between long lived network partitions.

1.9.2   Problem Solution

Message Ferrying is a mobility-assisted proactive routing algorithm that incorporates message ferries by allowing communication among disconnected nodes. It is known that ferries travel in a specified route, collecting data from sources and delivering data to the appropriate destinations. These message ferries allow nodes to communicate when the network is disconnected and when nodes do not have global knowledge of the network. It is a proactive routing algorithm created to address network partitions in intermittently connected ad hoc networks by establishing non-randomness in node movement. There are two types of nodes in MF scheme:
message ferries and regular nodes. This classification is based on their roles in communication. Ferries are mobile devices which take the responsibility of carrying messages among other nodes, while regular nodes are devices without any such responsibility. Several MF extensions could be carried out by installing multiple ferries in a set of sub-regions through partitioning. This idea can be used in remote village communications and remote area connectivity projects for providing Internet access.

MF scheme provides regular connectivity in a disconnected network and also improves the performance of data delivery without global knowledge of each node's location. The main difficulty in designing ferry routes for arbitrarily moving nodes is that it is not possible to predict correctly the location of the nodes. So it may not be possible to correctly position the ferry to contact the nodes. In the proposed work, the above issue is addressed with certain system requirements, like message delivery latency and buffer space. Here the focus is on the application of Message Ferrying system in disconnected mobile ad hoc networks. Regular nodes are assumed to move within the deployed area and they perform the assigned tasks. Yet they are limited in resources such as battery power, memory and computational power. Regular nodes are geographically distributed such that most of the time they cannot directly communicate with one another.

1.9.3 Application Scenario

This idea can be used in disaster relief missions, remote village communications and remote area connectivity projects for providing Internet access. Remote village communication means communication between disconnected villages. Ferries are special mobile nodes which have more resources than regular nodes. For example, buses (Nekovee and Bogason 2007) shuttle between remote villages which are equipped with memory (i.e. hard disks) and wireless interfaces can act as Ferries to collect and carry data.
among disconnected areas. One or more message ferry periodically visits each cluster/village to collect/deliver messages between disconnected nodes. The assumption here is that each message ferry (MF) follows a fixed and regular route and it makes a certain number of meeting points in its route. In remote village communication, a meeting point is an important place in the village where most of the people meet often regularly at the bus stand, market place etc. At this meeting point, the ferry has the longest contact time with the visited nodes for exchanging messages. In the regular/ Ferry nodes, messages will be dropped when the buffer overflows or the timeout expires. Timeout value depends on the delay requirement of the applications. Message ferrying is suitable for the application which can tolerate much delay, like file transfer, email and other non-real time applications.

1.9.4 Proposed Routing Techniques

In this work, four efficient routing approaches are suggested for delivering data in disconnected ad hoc network using message ferries.

- Controlled Epidemic Routing with Message Ferry.
- Routing with Multiple Message Ferries.
- Routing with Single Message Ferry and Gateways.
- Routing with Multiple Ferries and Gateways (Fixed route and Dynamic route).

In this proposed system, the deployed area is divided into a number of disconnected clusters. Each node must belong to any one of the clusters called Node’s native cluster. Eventually, the goal of these schemes is to maximize message delivery rate and to minimize message latency. In addition, minimizing the total resources such as memory and network bandwidth consumed becomes yet another objective.
All the work has been carried out as per the specification given in Table 1.1 using NS-2 and Opportunistic Network Environment simulator (ONE).

**Table 1.1 Simulation parameter settings**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area size</td>
<td>5400 m x 5500 m</td>
</tr>
<tr>
<td>No.of nodes</td>
<td>10 to 300</td>
</tr>
<tr>
<td>Mobility Speed</td>
<td>0.1 m/s to 40 m/s</td>
</tr>
<tr>
<td>No.of Messages</td>
<td>50 to 2000</td>
</tr>
<tr>
<td>Tr. Range</td>
<td>10 to 500 m</td>
</tr>
<tr>
<td>Tr.Speed</td>
<td>50 to 300 KBps</td>
</tr>
<tr>
<td>Buffer Size</td>
<td>10 to 100 MB</td>
</tr>
<tr>
<td>Movement model</td>
<td>Random waypoint</td>
</tr>
<tr>
<td>Message Size</td>
<td>500 KB – 1 MB</td>
</tr>
</tbody>
</table>

All the performance metrics have been studied using the above specification for varying node densities, transmission range, transmit speed, mobility speed and buffer space.

**1.10 OVERVIEW OF THE THESIS**

Chapter 2 which follows focuses on literature survey. The chapters from 3 to 6, various routing techniques using message ferry for delay tolerant ad hoc network are proposed and enumerated. Chapter 7 demonstrates the results, obtained from implementing routing techniques and compares them with existing systems. Chapter 8 involves a discussion of routing protocol combined with buffer management for differentiated services. It includes a study of two levels of priority services. Chapter 4 to 8 underline the thrust areas of the thesis in so far as the significance of the thesis is concerned. Chapter 9 concludes and highlights future directions in this field of study. Appendix 1 includes information on the simulators NS-2 and Opportunistic Network Environment simulator. Appendix 2 includes snapshots for network of 75 nodes in different routing schemes. Appendix 3 shows node connectivity during the total simulation period of 20,000 seconds for different routing schemes.