Performance Evaluations of Various Message Ferry Scheduling Schemes with Two Traffic Classes

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ABSTRACT

Designing a routing scheme for partitioned ad-hoc networks is challenging since end-to-end connectivity may not exist. A Message ferrying (MF) scheme has been proposed recently for delivering non-real-time traffic. In this ferrying scheme, message ferries are used to collect and deliver packets. In the past, we have designed an elliptical zone forwarding (EZF) scheme for a ferry to deliver messages among partitioned nodes that are moving around. In this paper, we first discuss a weakness of the EZF scheme. Then, we describe three ferry route design with lookahead schemes that are capable of achieving higher delivery ratio, namely (a) the Minimum Weighted Sum First (MWSF) scheme, (b) the fixed K-lookahead scheme (FKLAS) and (c) the dynamic lookahead scheme (DLAS). We also present extensive simulation results that compare the different schemes in various scenarios e.g. with different node mobility models, message deadlines etc. Our results indicate DLAS provides the best delivery performance, followed by FKLAS and the MWSF scheme.

I. INTRODUCTION

The advent of mobile communication technology opened up exciting new wireless applications together with a number of design challenges. One of the challenges is to maintain the communication links between participating entities as they move around. Such entities usually have wireless interfaces and hence can form ad-hoc networks. Wireless ad-hoc networks allow nodes to communicate with each other without any existing infrastructure. These rapidly deployable networks are very useful in many areas such as the battlefields, disaster relief centers etc. Many routing algorithms have been proposed for ad-hoc networks [1],[2]. However, most of these algorithms assume that an end-to-end connectivity between any pair of nodes exists. However, in real life scenarios, node mobility, the existence of physical obstacles, limited radio range etc may prevent nodes from communicating with others and result in network partitions. The deployed network may also be sparse because devices need to be deployed over a wide geographical range with a limited budget.

It is difficult to support real time applications in sparse ad-hoc networks, since it is hard to predict how long the networks may be disconnected. However, there are several useful applications that do not require bandwidth or delay guarantees e.g. messaging, emails and file transfer. As long as messages from these applications are delivered within their respective deadlines, they are still considered useful especially in the battlefield and disaster relief scenarios.

The above discussions reveal that more intelligent routing schemes need to be designed to allow information to be disseminated in intermittently connected networks e.g. military networks. A number of routing schemes e.g. [3],[4],[5],[6] have been recently proposed to provide communications in highly partitioned networks. In [4], the authors propose a Message Ferrying (MF) scheme, where a set of nodes called "message ferries" take the responsibility of carrying messages between disconnected nodes. The concept of Message Ferrying is attractive not only in the common battlefield and disaster recovery scenarios where network partitions often occur, but it is also important in sensor networks [5], and remote village communication [6].

In [7], we consider the case where there are two message classes, namely urgent and regular messages. A methodology for designing the ferry route given the constraint that urgent messages will be delivered immediately after being picked up, and the performance evaluation of the proposed method was presented. In [10], we investigate a message ferrying scenario where the available buffers at the ferry and the nodes are limited and that the nodes move. An elliptical zone forwarding (EZF) scheme for the ferry route was designed. We evaluated in [10] how the buffer allocation scheme impacts the satisfactory ratio of urgent messages (i.e. urgent messages that are delivered on time), and the message dropping rates of both the urgent and regular messages as a result of buffer contentions at the ferry and the regular nodes.

However, there is a weakness in the EZF scheme that prevents it from achieving high delivery ratio. In this paper, we discuss this weakness and design two

new lookahead ferry route scheduling schemes that provide better delivery performance than the EZF scheme. We also compare our two new schemes with a scheme designed by UCLA researchers called Minimum Weighted Sum First (MWSF) scheme. Our contributions in this work are:

- Description of three k-lookahead ferry route design schemes, namely (a) the fixed k-lookahead scheme (FKLAS), (b) the dynamic lookahead scheme (DLAS), and (c) the minimum weighted sum first (MWSF) scheme described in [17]. We design both the FKLAS and DLAS.
- Evaluation of the impacts of message deadlines, service priority, traffic models and different k-lookahead values on the delivery performance of these ferry route design schemes. Our results indicate that (a) the delivery ratio improves when service priority is turned on, (b) higher delivery ratio is achieved with sensor-like traffic model compared to the random traffic model, (c) higher delivery ratio is achieved with less stringent message deadlines.
- Comparison of the various ferry route designs via extensive simulation studies. Our results indicate that the DLAS achieves the highest delivery ratio with reasonable message delivery latency.

The rest of this paper is organized as follows: In Section II, we describe a ferry scheduling scheme called the EZF scheme that was presented in [10] and its weakness. Then, we describe the three k-lookahead schemes, namely (a) the fixed K-lookahead scheme (FKLAS), (b) the dynamic lookahead scheme (DLAS), and (c) the minimum weighted sum first (MWSF) scheme. In Section III, we describe the simulation model, the traffic pattern and the mobility model that we used to evaluate the various ferry route design schemes. In Section IV, we present and discuss our simulation results. In Section V, we discuss some future work we intend to do.

II. FERRY ROUTE DESIGN SCHEMES

In our work, we consider a network with one message ferry and fifty regular nodes. The regular nodes are far away from one another and can only communicate via a message ferry. The regular nodes use long range radios to request for the ferry's service upon new message arrivals. The reservation message

provides information about the expiry time of the new message, the current location and velocity of the node. We are interested in designing a ferry route scheme that allows us to provide differentiated services to two classes of traffic. Below, we give the descriptions of a few ferry route design schemes.

1) Overview of the Elliptical Zone Forwarding (EZF) Scheme

In [10], we design the Elliptical Zone Forwarding (EZF) scheme. In this scheme, the ferry maintains a list of destinations that need to be visited and another list of reservations that it has received (i.e. nodes with messages that need to be pick up). Currently, in the EZF scheme, we give service priority to those messages that have been picked up over those that are waiting to be picked up. Figure 1 illustrates this EZF scheme. Assume that the ferry is at location X and that the destination of the most urgent message is at Y_i . The ferry uses X and Y_i as the foci, calculates the delay requirement R_i of the message destined to Y_i , and use R_i as the length of the major axis to construct an ellipse. If the ferry visits any node Z within the ellipse, then the traveling time is such that $XZ + ZY_i < R_i$. If such a node exists and the ferry has enough buffers to accommodate its request, the ferry will visit that node. If more than one node exists, then the node with the minimum $XZ + ZY_i$ will be chosen to be visited next. Otherwise, the ferry will just visit Y_i . Such an approach reduces the overall message delay while maintaining a high delivery ratio for urgent messages. Note that only packets that can meet the deadline requirements are delivered. Ferry always checks for expired messages in its buffer or in the to-be-picked list.

Figure 1: Elliptical Zone Forwarding

2) Overview of the Fixed K-lookahead Scheme (FKLAS)

However, there is a weakness associated with the EZF scheme. In the EZF scheme, we give priority to urgent messages that are already in the message ferry buffer. However, there may be urgent messages waiting to be picked up at *other nodes* that have smaller deadlines than the most urgent message in the picked up queue. To overcome this problem, we allow the ferry to check the deadlines of both the urgent messages in its ferry buffer and also those that have yet to be picked up. First, the ferry maintains a list of

urgent messages which are ordered based on their deadlines. Each message in this list contains the information about whether the message has yet to be picked up, message deadline, the source and destination nodes of the message. Then, the ferry looks through the ordered message list, and inserts either source/destination nodes (or both for messages yet to be picked up) into a visiting set, S . Each node is inserted only once into the visiting set, S . Once there are k nodes in the set S , the ferry will design a tour using the combined Lin-Kernighan heuristic and delay-based 2-opt technique as described in [11] to visit these nodes. The process is repeated after all the nodes in set S has been visited. A new set S will be formed. We refer to this enhancement as the fixed K-lookahead scheme (FKLAS). The k-lookahead can also be message-based and not node-based which means that the ferry only includes the nodes associated with the first k messages in the ordered message list. If there are different classes of messages, then one can use service priority to schedule the delivery of higher priority messages first. For example, with two classes of traffic, the ferry can maintain two ordered message lists (ordered based on message expiry times), one for the urgent messages, and another for the regular messages. Then, with the message-based K-lookahead, the ferry can schedule the first K urgent messages. If there are fewer than K urgent messages, then the ferry can include messages from the ordered list of regular messages. Similarly, with the node-based K-lookahead, the ferry will use the ordered list of urgent messages first. If after including all nodes associated with the messages in this urgent list, there are still fewer than K nodes, then, the ferry will look into the ordered list of regular messages.

3) Overview of the Dynamic K-Lookahead Scheme (DLAS)

Another lookahead scheme is the dynamic lookahead scheme (DLAS). In DLAS, the ferry visits a set of nodes in each cycle. To decide on the set of nodes that the ferry will visit, the ferry maintains an ordered message list per message class similar to the FKLAS. The ferry also keeps track of the ferry tour time in each cycle so that it can derive an average ferry tour time, denoted as ET . At the beginning of each cycle, the ferry checks the two lists to select a set of nodes, S_v , to visit. The nodes to be included are those which have messages with deadlines smaller than $1.5 \cdot ET$. This message deadline value is picked because we want to ensure that queued messages wait at most for $1.5 \cdot ET$ seconds before being picked up. The destination and possibly the source (for those messages

that have yet to be picked up) nodes of all qualified messages in the ordered message list will be included in S_v . An example of how S_v is constructed is shown in Figure 2. Of course, one can further add in the K lookahead constraint to ensure that each tour will not serve either more than K -messages or more than K nodes.

Urgent Message List	t+1 n_3	t+2 n_3	t+3 n_5	t+5 n_6	t+7 n_6	
Regular Message List	t+1 n_4	t+3 n_5	t+4 n_8	t+7 n_9		
Expiry Time	t+1	Deadline: t+1.5 ET = t+5				
Dst Node	n_3					
No Service Priority						
With Service Priority						
$S_v = \{1,3,4,5,6,8\}$	$S_{v1} = \{1,3,5,6\}$					
	$S_{v2} = \{4,5,8\}$					

Figure 2: Construction of S_v for DLAS

4) Overview of the Minimum Weighted Sum First (MWSF) Scheme.

The last scheme we consider is the minimum weighted sum first (MWSF) scheme described in [14]. In this scheme, the deadline used is the buffer overflowing time, not the message expiry time. This scheme takes both deadline and traveling cost into account when making a decision which node to visit next. The weighted sum metric is defined as follows:

$$W_i = \alpha(\text{deadline}_i - \text{current_time}) + (1 - \alpha)\text{cost}_i$$

where deadline is chosen as (a) the buffer overflow time if the node is a source node, (b) the expiry time of the most urgent message to a node if the node is a destination node, or (c) the minimum between the two values if the node is both a source and destination node. The time taken for the ferry to move from the current location to node i is the traveling cost. The ferry evaluates the weighted sum metrics of all nodes and visits the node which has the minimum weighted sum. This process is repeated after servicing that selected node.

III. SIMULATION MODEL

In this section, we describe the simulation model that we used to compare the different ferry route design schemes. We implemented the five ferry route design schemes discussed in Section III using NS-2 simulator [9].

A. Network Model

In our experiments, we consider a network where 50 nodes are randomly distributed over an area of $5000 \times 5000 \text{ m}^2$. The locations of the nodes are chosen such that they are far away from one another and hence can only communicate via a message ferry. There is only one message ferry in the simulated network. The

nodes use IEEE 802.11 radios [9] to communicate with the message ferry. The regular radio transmission range is 250 meters and the channel capacity is 2Mbit/sec.

Each simulation lasts for 10,000 seconds of simulation time. Unless otherwise stated, the ferry speed is fixed at 15 m/s. The buffer size is either varied from 100 to 600 messages or set at 600 messages. In our simulator, we use a dynamically-partitioned scheme for buffer management. In this dynamically-partitioned scheme, the regular messages are allowed to occupy the buffers but they can be pre-empted by urgent messages up to the point where the regular messages can occupy at most $(1-x)\%$ of the buffer space.

B. Traffic Pattern and Mobility Model

We assume that there are 25 randomly chosen communication pairs. Each source generates traffic according to Constant Bit Rate (CBR) model at a rate of 0.05 pkts/sec and with a packet size of 512 bytes. In some scenarios, we assume all 25 pairs are regular messages while in other scenarios we assume there are 10 pairs of urgent flows and 15 pairs of regular flows. Unless otherwise stated, the message deadlines for urgent and regular messages are set at 2000 and 3000 seconds respectively.

In all scenarios, we assume that regular nodes move according to the random waypoint (RWP) model described in [2] with a maximum speed of 5m/s. In RWP, the nodes move towards a randomly picked location at a constant speed. Once the location is reached, another new location will be randomly chosen and the node will start moving towards the new destination after a certain pause time. This behavior is repeated for the whole duration of the simulation.

C. Performance Evaluation

To evaluate the performance of the various ferry route design schemes, we use the following metrics:

- *Message delivery ratio* – the ratio of the number of delivered messages that meet the deadlines to the number of messages sent by the sources. We compute the overall message delivery ratio (consider both urgent and regular messages together) and the individual urgent or regular message delivery ratio.
- *Average End-to-End Delay* – the time taken from when the source generates the message to when the destination receives it.

These metrics reflect the efficiency of the ferry route design and the buffer allocation scheme. A good ferry route design and buffer allocation scheme should achieve a high message delivery ratio for urgent messages, a high overall message delivery ratio and low average end-to-end delay. However, a scheme that provides a high delivery ratio for urgent messages may have to settle for a slightly lower overall message delivery ratio since the regular messages may be dropped to make room for the urgent messages.

The values for the simulation parameters are tabulated in Table 1.

Parameter	Value
Simulation area	5000x5000 m^2
Number of nodes	50
MAC	802.11 DCF
Bandwidth	2Mb/s
Traffic pattern	UDP/CBR
Traffic load	Vary in each experiment
Message Rate	One every 20sec
Delay requirement	2000 sec (high-priority message) 3000 sec (low-priority message)
Buffer Size	100,200,300,400,500,600 messages
Simulation time	10000 sec
Node speed	0~5m/sec
Mobility model	Random way-point
Ferry speed	15m/sec
Transmission range	250m

Table 1: Simulation Parameters

IV. SIMULATION RESULTS AND DISCUSSIONS

In this section, we present simulation results of three ferry scheduling schemes in various scenarios e.g. different message deadlines, different ferry speeds, different traffic models etc.

1) Comparison between FKLAS, DLAS, and the MWSF scheme

In this subsection, we compare the performance of FKLAS, DLAS, and the MWSF scheme. In our first set of experiments, we use 25 regular message flows. Each message flow has a message generation rate of 0.05 msg/sec. Recall that the ferry speed is set at 15 m/s. We study two subcases, namely (a) sensor-like traffic model where all flows have the same destination node, (b) random traffic model where each flow independently chooses a node in the network as the destination. We vary the message deadlines. Node-based lookahead is used in FKLAS and we set K to be 8. No K-lookahead message or node constraint is set for DLAS which means that the messages will be served in each ferry cycle as long as their deadlines are smaller than

1.5*ET. Figures 4 & 5 show the delivery ratio and the average message delivery latencies achieved using EZF, FKLAS, DLAS, and the MWSF scheme.

a) Performance with different message deadlines

The results in Figure 4 show that the delivery ratios achieved by all three schemes increase with increasing message deadlines. Both DLAS and FKLAS achieve higher delivery ratios than the MWSF and the EZF schemes for both types of traffic models. DLAS gives the best performance while the EZF scheme is the worst among the four schemes. This may be attributed to the fact that in DLAS, as long as there are enough messages with deadlines within 1.5*ET, the ferry will start a tour. In addition, DLAS considers the deadlines of messages yet to be picked up while the EZF scheme does not. Higher delivery ratio is achieved by all three schemes with the sensor-like traffic model since there is only one destination node.

Figure 4: Delivery Ratio versus Message Deadlines

From Figure 5, we observe that the average message delivery latency with the sensor-like traffic model is smaller than that achieved with the random traffic model. With the sensor-like traffic model, the average message delivery latencies achieved by all four schemes are comparable until the message expiry time exceeds 2700 seconds. Then, the FKLAS achieves smaller delay than the other three schemes. The EZF scheme achieves slightly lower message delivery latency than the MWLS and the DLAS with the sensor-like traffic model. This may be attributed to the fact that both MWLS and DLAS incur longer delay to deliver some messages that are dropped by the EZF scheme. With the random traffic model, the FKLAS experiences the highest average message delay while the DLAS and the MWSF schemes achieve comparable message delays. The delay for the EZF

scheme is higher than that achieved using DLAS and MWSF schemes but lower than that achieved using the FKLAS scheme. With the random traffic model, the MWSF scheme achieves slightly higher message delivery latency than DLAS until the message expiry time exceeds 2600 seconds when the MWSF scheme achieves slightly lower message delivery latencies.

b) Performance with different ferry speeds

In this section, we investigate the impact of ferry speed on the delivery performance of the three different ferry route design schemes. We use 25 regular message flows with each flow generating 0.05 msg/sec. CBR traffic model is used. The sources and destinations of these message flows are randomly selected. We vary the ferry speed from 15 m/s to 30m/s.

Figure 5: Average Message Latencies versus Message Deadlines

Figures 6 & 7 plot the delivery ratio and average message delivery latency for the EZF, FKLAS, DLAS, and the MWSF schemes. The results indicate that the delivery ratio improves with faster ferry speed for all four schemes. The DLAS scheme remains the best scheme in terms of both the delivery ratio as well as the average message delivery latency.

Figure 6: Delivery Ratio vs Ferry Speed

c) Performance with two traffic classes with/without service priority

In the third set of experiments, we use 10 pairs of urgent and 15 pairs of regular messages. In this set of experiments, we only consider FKLAS, DLAS and MWSF schemes. We investigate two subcases, (a) when urgent messages are not given any special treatments, (b) when urgent messages are given higher service priority. We fix the difference in the message deadlines of the urgent and regular messages to be 1000 seconds but vary the absolute value of the message deadline for urgent messages.

Figure 7: Average Delay vs Ferry Speed

Figures 8, 9, and 10 show the delivery ratio and the average message delay of the urgent and regular messages for the case where urgent messages are not given any special treatments. Figures 11, 12 and 13 show similar plots for the case where urgent messages are given higher service priority. Without service priority, the plots in Figures 8 & 9 show that the DLAS scheme achieves the highest delivery ratio followed by the FKLAS for both types of messages. The MWSF scheme achieves the lowest delivery ratio. Figure 10 shows that the MWSF scheme achieves the lowest message delivery latency. The DLAS has a higher message delivery latency than the FKLAS until the message deadline exceeds 1600 seconds. After this, the DLAS has lower message delivery latency. The higher message delivery latency experienced in DLAS and the FKLAS is expected since the messages that are potentially dropped using the MWSF scheme are now being delivered by the DLAS and FKLAS, and such messages increase the ferry touring time and hence the message delivery delays. The two sets of plots in Figures 11&12 also show that with service priority, urgent messages can achieve higher delivery ratio but at the expense of the delivery ratio of the regular messages. If we compare Figures 10 & 13, we see that the overall message delay improves with

service priority for all the three ferry scheduling schemes.

Figure 8: Delivery ratio of urgent messages vs. deadlines of (urgent, regular) messages

Figure 9: Delivery ratio of regular messages vs. deadlines of (urgent, regular) messages

Figure 10: Average delay vs. deadlines of (urgent, regular) messages

V. CONCLUSIONS AND FUTURE WORK

In this paper, we investigated how the ferry visit schedule should be designed for a message ferrying system where there are two message types, namely urgent and regular messages with different delivery

deadlines. We described various ferry route design schemes, namely (a) the elliptical zone forwarding (EZF) scheme that we designed in [10] for delivering urgent and regular messages in such a message ferrying system, (b) the fixed K-lookahead scheme (FKLAS), (c) the dynamic lookahead scheme (DLAS), and (e) the minimum weighted sum first (MWSF) scheme. We then evaluated and compared the various schemes using different scenarios e.g. different traffic models.

Figure 11: Delivery ratio of urgent messages with service priority on vs. deadlines of (urgent, regular) messages

Figure 12: Delivery ratio of regular messages with service priority on vs. deadlines of (urgent, regular) messages

Our results indicate that the DLAS scheme achieves the highest delivery ratio for urgent and regular messages at the expense of increased message delivery delay sometimes. We also evaluated the sensitivity of the K-lookahead values on the delivery performance of the DLAS scheme and show that the K-lookahead based on nodes is slightly more effective than the K-lookahead based on the messages. We intend to investigate how the DLAS scheme performs with different mobility models and in the presence of multicast traffic. In addition, we assume in this work that regular nodes use long-range radios to make

reservations with the ferry when new messages arrive. We are working on a ferry route scheduling algorithm that removes this assumption. The results of this new scheme will be presented in another paper.

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