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Using Ferry Access Points to Improve the Performance of Message Ferrying in Delay-Tolerant Networks

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Abstract—Delay-Tolerant Networks (DTNs) are sparse, wireless networks where disconnections are common due to host mobility and low node density. The Message Ferrying (MF) scheme is a mobility-assisted paradigm to improve connectivity in DTN-like networks. A *ferry* or *message ferry* is a special node in the network which has a per-determined route in the deployed area and relays messages between mobile hosts (MHs) which are intermittently connected. Increased contact opportunities among mobile hosts and the ferry improve the performance of the network, both in terms of message delivery ratio and average end-end delay. However, due to the inherent mobility of mobile hosts and pre-determined periodicity of the message ferry, mobile hosts may often 'miss' contact opportunities with a ferry. In this paper, we propose the combination of stationary *ferry access points* (FAPs) with MF routing to increase contact opportunities between mobile hosts and the MF and consequently improve the performance of the DTN. We also propose several placement models for deploying FAPs on MF routes. We evaluate the performance of the FAP placement models through comprehensive simulation. Our findings show that FAPs do improve the performance of MF-assisted DTNs and symmetric placement of FAPs outperforms other placement strategies.

Keywords—Service infrastructure, delay-tolerant network, message ferry routing, placement models.

I. Introduction

POPULARITY of mobile devices equipped with wireless network interfaces and affordable wireless communication options are introducing new demands in wireless network access trends. An increasing number of mobile device consumers today demand access to wireless services anytime, anywhere. This increasing demand for ubiquity is provoking research towards network connectivity architectures in extreme, challenging environments. Delay-tolerant networks (DTNs) [1, 2] have emerged as a research domain for addressing such challenged networks. DTNs have similarities with mobile ad hoc networks (MANETs) [6]. MANETs can be deployed on-the-fly with no pre-existing communication infrastructure, facilitate wireless, mobile hosts and data forwarding is possibly multi-hop. However, DTNs address more versatile environments where there is no contemporaneous set of wireless links that define an end-to-end path between a source and destination host and connectivity among hosts is intermittent. Such situations may arise in a number of practical scenarios due to mobility, geographically large deployment areas, infrastructure issues and energy limitations at the hosts. In absence of pre-established routes, DTNs with mobile hosts rely heavily on a combination of hop-by-hop forwarding via opportunistic contacts and a store-carry-and-forward [7] scheme to store data at intermediate hosts before the next contact opportunity is available. In most cases, successful delivery of data largely depends on the number of available contact opportunities or *encounters* with other mobile hosts over time. The end-to-end delay of delivering data to destinations relies on the inter-contact time which is the time between host A meeting host B and host A subsequently meeting host C or any other host in the network. Reducing inter-contact time between encounters would result in reduction of overall delay of the network. Therefore, increasing contact opportunities while maintaining low inter-contact intervals would improve the delivery and delay performance of a DTN. To improve connectivity in sparse, intermittent networks like DTNs, the Message Ferry (MF) [8] scheme was introduced to overcome the problem of data delivery with high probability of partitions and low host density. It is a proactive mobility-assisted approach which utilizes special mobile nodes called *ferries* to provide communication services for nodes in the network. The ferries move in deployed areas along pre-defined routes and collect messages from source hosts, and carry them until delivery to corresponding destination hosts. Data delivery is therefore inherently asynchronous. Units of data delivered by ferries are referred to as messages and will be used henceforth in the remainder of this paper. The main idea behind the MF approach is to introduce *non-randomness* in the movement of hosts and exploit such non-randomness to help deliver data. Message ferrying can be used effectively in a variety of applications including battlefields, disaster relief, wide area sensing, non-interactive Internet access and anonymous communication [3]. There are issues in MF design with mobile hosts. Ferries are restricted to defined routes. In order to avoid missing contact opportunities with ferries, hosts should know ferry schedules and arrive at the ferry route accordingly to 'catch' the ferry and transfer data. If hosts do obtain such ferry availability information, 'catching' a ferry would disrupt a mobile host's inherent mobility and may not be desirable in practice. In this paper, we use *ferry access points* (FAPs) to overcome the above problems of existing MF approaches. We introduce FAPs as static synchronization points on MF routes, with wireless interfaces and substantial storage capabilities. FAPs are stationary points on MF routes and therefore may act as rendezvous points between ferries

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with periodic routes and mobile hosts with arbitrary mobility, hence creating contact opportunities where one would otherwise be missed. For example, a ferry *m* may be periodically travelling on a route Ω which includes a set of locations *U* and *U* = Ω . Suppose a mobile host *n* at time t_i passes a location (x_i, y_i) and $(x_i, y_i) \in U$. However the ferry reaches (x_i, y_i) at time $t_i + k$. Therefore, *n* misses a possible contact opportunity with the ferry *m*, even though they do encounter each-other on a time-varying scale by *k*. But if a FAP were placed at (x_i, y_i) then mobile host *n* could leave the message with the FAP at time t_i. The ferry *m* could subsequently pick up the message from the FAP on arrival at (x_i, y_i) at time $t_i + k$ and carry it for delivery to the intended destination. Figure 1 shows the advantage of having FAPs in a MF network. Here, MH is trying to communicate with the ferry for transferring a message 'M'.

In presence of FAPs, if a mobile host does not know the ferry schedule it can still leave a message at a FAP rendezvous, even if the ferry is not present. FAPs increase contact opportunities in sparse networks by being omnipresent and available, which improves network capacity. FAPs also reduce overall delay by reducing host-to-ferry contact time. In addition to introduction of FAPs, we also discuss FAP placement strategies on MF-routes, as they affect data flow through the network. We propose three deterministic placement models based on FAP positions between waypoints of a ferry route and evaluate the performance of the models thorough simulations. Our results indicate that symmetrically placed FAPs improve message delivery ratio and decrease average end-to-end delay of the network.

The remainder of this paper is structured as follows. We discuss related work in the following section. In Section III, we describe FAP characteristics and the network model assumptions. In Section IV, we address the issues of FAP deployment and study various FAP placement models. Simulation results and analysis are presented and summarized in Section V. Finally, we summarize our findings and conclude the paper in Section VI.

II. Related Work

Previous MF research explores how ferry routes can be optimized in terms of delay and bandwidth for stationary nodes [8]. On the other hand, if deployed hosts are mobile, they can proactively adapt their trajectories to meet and exchange messages with a ferry [9]. These schemes rely on hosts and ferries having special long range radio capabilities and also assume that a ferry may detour from a pre-defined route to meet hosts, which may not be feasible in real implementations. A probabilistic approach to MF route design is presented in [10] where the ferry contacts hosts at selective waypoints with some probability *p* by waiting a finite amount time, once every tour. However, once the ferry route is determined the properties of end-to-end delay in the network become fixed. Further work on MFs involves algorithms deploying multiple ferries into a network [11] and election algorithms to find ferry replacements in multiple ferry networks [12]. These papers address a critical problem of MF design, where a ferry poses a single-point of failure in the network. If hosts without any prior connectivity are connected only through MF, then a failure of that ferry will gradually render the network disconnected.

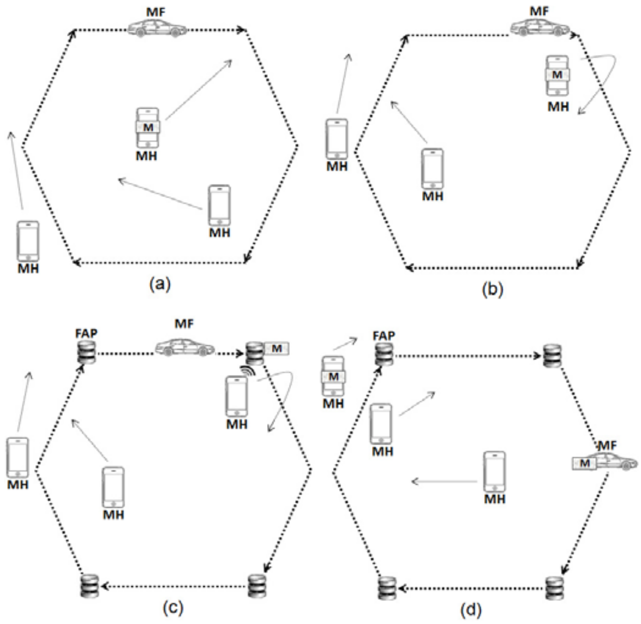

Fig. 1. FAPs as rendezvous points for MF and MHs: (a) MH moving towards location (x_i, y_i) at time t_i ; (b) MF at location (x_i, y_i) at time t_{i+k} ; $t_{i+k} > t_i$. MH missed contact opportunity with MF; (c) MH moving towards location (x_i, y_i) at time t_i - meeting FAP and transferring data 'M' to FAP; (d) MF received data 'M' from FAP at time t_{i+k} ; $t_{i+k} > t_i$.

In this work, we integrate FAPs with MF to improve the performance of MF to MH transfer opportunities. We assume FAPs to be stationary, wireless derives with storage. Infostations [4] and throwboxes [5] have similar strategies for improving performance of intermittent networks with infrastructure. In the Infostation model, users can connect to the network in the vicinity of ports (or Infostations), which are geographically distributed throughout the area of network coverage. The Infostation architecture which was originally proposed by researchers at WINLAB2, includes low-power base stations. Infostations provide strong radio signal quality to small disjoint geographical areas and, as a result, offer very high rates to users in these areas. Throwboxes [5] are relay nodes deployed anywhere in the network area and route information between mobile nodes in a disruption-tolerant fashion. FAPs share the relay concept of throwboxes, except we use FAPs as rendezvous points for MF and MHs and FAPs are always co-located on MF routes. In the next section we discuss our network and communication model.

III. Message Ferry-Assisted Network Model Using Ferry Access Points

In this section we present our network model with assumptions of FAP, MF and MH characteristics. Then we present the communication model for data exchange in the network. Finally, we define our performance objectives and evaluation methodology.

A. Network Model

We assume a sparse network composed of *n* mobile hosts, *m* MFs (here, *m=1*) and *k* FAPs. We consider the network to be a finite, two dimensional space *S* where *S* is defined by a set of four co-ordinates of the form (X_s, Y_s), where X_s represents x-coordinates and Y_s represents y-coordinates. All devices - MF, MH and FAPs communicate with each other through wireless interfaces (e.g., 802.11) and are equipped with storage that carries network data. Assumptions for network devices are as follows:

Mobile Hosts - Mobile hosts (MHs) generate data for other MHs in the network in the form of application layer data units called messages (i.e., bundles [11]). At the same time, these MHs are interested in receiving the messages that other MHs have generated for them. MHs can exchange messages with one another when they are within communication range. We assume that all the messages are unicast, i.e., they have a single unique destination. Messages can be of varied sizes and have infinite time-to-live (TTL) values. Messages are dropped in a first-in-first-out (FIFO) manner only if there is no accommodation space left in device buffers. We assume MHs move according to some mobility model and the movement of the MHs cannot be disrupted.

Message Ferry - A single special node called message ferry (MF) is responsible for delivering messages between MHs. The ferry achieves this by traversing a predetermined route repeatedly. We refer to each traversal through this route as a tour *T*, and a tour is equivalent to one round-trip time (RTT) of the ferry. If L is length of the ferry route and f is the ferry speed then the RTT for a ferry is $\frac{L}{f}$. Therefore, $T = \frac{L}{f}$. Consider *r* to be the communication range of MF. A ferry route can be defined by the tuple: Ω = *(R; W; f; r)*. Here, *R* is an ordered set of MF waypoints drawn from the network area and $W = w_s : s \in R$ is the set of corresponding waiting times on the chosen waypoints. We assume that the MF moves from one way-point to another with speed f in a straight line. We further assume MFs are neither sources nor destinations and can interact with mobile hosts or FAPs.

Ferry Access Points - FAPs have the potential to improve delivery and minimize delay. The objective of FAP usage is to increase transmission opportunities in a highly mobile environment. We assume ferry access points (FAPs) are stationary are modeled to be placed on or between consecutive ferry waypoints P = (x_i, y_i) and Q = (x_j, y_j) on the straight line of the ferry tour between P and Q where P, Q$\in$*R*. Placement models for FAPs are discussed in detail in section IV. Like MF, FAPs are neither sources nor destinations and FAPs never interact with each other, but can interact with both MHs and MF. In addition, we assume that FAPs have sufficient and reliable storage capabilities to buffer large number of messages at a time and provide highly available (always *on*) contact points for message exchanges.

B. Communication Model

We now describe the communication model of the network. We assume that all devices (MF, FAPs and MHs) are equipped with a similar radio of given communication range with radius, *r*. Devices can communicate with each other only when they are within a distance, d_l of each other that is less than the communication range, i.e. $d_l < r$. Devices are said to be in contact when they are within the communication range of each other. We assume limited communication range because devices may be energy constrained and may not be able to use long range communication channels that may require more power. Furthermore, while FAPs and MF may be modeled to be able to use a long range radio, the range of two-way communication between the MH and MF and FAPs would still be limited by the communication range of the MHs. But we do assume that FAPs and MF can have larger buffer capacity than MHs due to the declining cost of storage.

TABLE I
COMMUNICATION MODEL FOR MESSAGE EXCHANGE

Message exchange	to FAP	to MF	to MH	retain copy of message after forwarding
Mobile Host (MH)	√	√	√(if it's the destination)	×(node buffer limited)
Ferry access points (FAP)	×(FAPs are disjoint and stationary)	√	√(if it's the destination)	√
Message Ferry(MF)	√	×(only one MF)	√(if it's the destination)	√

As a communication model for message exchange, we assume that MHs generate messages to be sent to other MHs in the network, which are destinations. FAPs are intermediate stationary buffers while MFs are intermediate mobile carries of messages, and neither are sources nor destinations. Upon each successful contact between a ferry and a MH, first the ferry gives any messages it is carrying to the MH if the MH is the intended recipient of the message. Next, within the contact duration, the MH forwards messages onto the ferry. Once forwarded, MH deletes copies of those messages from MH buffers. Similarly, upon each successful contact between a FAP and a MH, the FAP gives any messages it is buffering to the MH if the MH is the intended recipient. Next, within contact duration, the MH forwards messages onto the FAP and deletes copies of those messages from MH buffers. When there is contact between two MHs, messages are exchanged only if the other MH is the final destination. Upon successful contact between a FAP and MF, the MF first transfers message to the FAP and keeps a copy of the message in it buffer. Then the FAP transfers messages to the MF while retaining a copy of the message in its buffer. This exchange is irrespective of the destination address. This is admissible in order to increase the delivery probability of the network by allowing intermediate devices to have a copy of all yet undelivered messages and be able to deliver them upon contact with the destination. We summarize message exchange policy and copy retaining policy of the communication model in Table 1.

We note that message exchange is limited by contact duration of devices, which means it is not ensured that any device will be able to transfer all messages from outgoing buffers within contact duration. Also, message exchange may be aborted due to mobility of communicating devices. During a message exchange between two devices (e.g. MF and MH), before the entire data included in the message can be transferred devices move away such that $d_l < r$, then contact is discontinued and a message *abort* occurs. Devices try to retransmit aborted messages during later contact opportunities. In contrast, message drops occur if there is no space to accommodate newly transferred messages onto incoming buffers of the device. Our model assumes a FIFO policy for messages drops. Dropped messages are lost from the network and therefore, cannot be retransmitted.

We characterize transmission opportunities using average capacity, which is the maximum data rate that can be sent between two devices. Let u_{ij} be the average contact duration and be v_{ij} the average inter-contact time between device i and j. We compute the average capacity as $C_{ij} = \frac{u_{ij}.w}{(u_{ij}+v_{ij})}$ where w is the transmission data rate when device i and j are in contact and devices can communicate with each other for a fraction of $\frac{u_{ij}}{(u_{ij}+v_{ij})}$ time. Note that the average capacity is shared by traffic in both directions. For brevity, we do not address wireless interference issues in this paper.

C. Performance Objectives

In this paper, we evaluate the performance of FAPs in terms of successful message delivery and average end-end delay in a DTN. Due to uncertainty of mobile host movement patterns, inter-contact times between MHs and MF can be large, especially in sparse networks. FAPs can provide asynchronous rendezvous opportunities for MHs at points that a ferry will visit with high probability, p where $0 \leq p \leq 1$ and p can be modeled to be 1 with knowledge of ferry waypoints. This reduces average inter-contact time, v_{ij} and consequently increases the average capacity C_{ij} where i and j represent a MH and the ferry, respectively. Increasing average transmission capacity improves delivery performance. Since a ferry is solely responsible for message delivery in a MF-assisted DTN, reducing inter-contact time between hosts and ferries would also reduce the average delay for delivery of messages in the network. Observably, further optimization of network performance is possible by methodically placing FAPs in locations which would maximize network performance, instead of deploying them randomly in the network. We propose our ideas for FAP placement in the section III.

D. Evaluation Methodology

We evaluate results of $'k'$ FAPs with MF through simulations in section V. We wish to show that FAPs do improve delivery performance of the network and that average message delivery delay can be significantly reduced with increasing number of FAPs. Naturally, in intermittent networks with MHs, it is desirable to place the FAPs in locations which would maximize network performance, especially if number of deployable FAPs is limited. We propose placement models in section IV and later on study the performance of the models through simulations. Evaluating message delivery and end-end delay performance, we conclude with the best placement approach among proposed ones for the described network model.

IV. Ferry Access Point Placement Models

An objective of having a MF in a sparse DTN is the ferry is highly accountable for message deliveries in the network. As node density is low, source MHs may never come in direct contact with destination MHs due to network partitions. MFs can effectively carry messages to different parts of the network for delivery. For successful delivery of messages, it is desirable that MHs have high contact probability with MF, so that messages that need to be delivered to other parts of the network can be carried by the ferry. We have established that placing FAPs on MF routes can improve the contact probability between a MF and MHs (section III). In this section we develop strategies for FAP placement based on knowledge of set of MF waypoints, R of MF route $\Omega =$ *(R; W; f; r)*. We assume that there is a pre-defined MF route in the network and that route is optimal. An optimal ferry route is one that can *service* MHs in the network with desired probability and has been discussed in detail in [9].

Let *k* be number of deployable FAPs and *h* is the location where a FAP can be placed. We assume:

a) FAP's are placed on MF routes, Ω and not elsewhere in the network area, *S*. Therefore, the number of deployable locations is limited by locations toured by the ferry.

b) $k_h \in 0, 1$ is co-located at or between consecutive waypoints in *R*, where 0 is the absence of an FAP at location *h* and and 1 is its presence at location *h*. Note that the number of deployable FAPs is bounded by cardinality of the set *R* of ferry waypoints and $k \leq R$. With above assumptions we propose the following placement models:

1. *Symmetric model:* In the symmetric model FAPs are placed at mid-Euclidian distance between two consecutive ferry waypoints in *R*. Let, $P = (x_i, y_i)$ and $Q = (x_j, y_j)$ be two consecutive ferry waypoints on the straight line of the ferry tour between P and Q where P, Q $\in$ *R*. In this model, FAP would be placed at $h = (\frac{|x_i - x_j|}{2}, \frac{|y_i - y_j|}{2})$ and $k_h \in 0, 1$ where k_h is the number of deployed FAPs at location *h*.

2. *Asymmetric model:* In this model, FAPs are placed asymmetrically between consecutive ferry waypoints $P = (x_i, y_i)$ and $Q = (x_j, y_j)$ on the straight line of the ferry tour between P and Q where P,Q $\in$ *R*. Possible placements would be at $h = (x_k, y_k)$ where, $x_i \leq x_k \leq x_j$ and $y_i \leq y_k \leq y_j$ and $k_h \in 0, 1$.

3. *Waypoint model:* In this model, FAPs are placed on MF waypoints and $h \in R; R \in \Omega$. We restate here that MF waypoints are explicit points in the ferry route where MFs stop with corresponding waiting times, $W = w_s : s \in R$ and continue transit to the next waypoint in *R*. Here, $|W| = |R|$.

Among the above models, symmetric placement is the most uniform while asymmetric is a random strategy. We evaluate the performance of the models with simulations in the following section.

V. Performance Evaluation

In this section we evaluate the impact of FAPs in MF-assisted DTNs, and wish to verify through simulations that: (i)

FAPs enhance delivery, (ii) FAPs reduce delays and (iii) FAP placement behavior on MF routes vary network performance. We use the *opportunistic network* (ONE) simulator [13] to simulate the various models proposed in this paper.

A. Simulation Settings

For our simulations we consider the following settings. We simulate 20 mobile nodes (or, MH) under the random waypoint mobility (RWM) model in a $5000m \times 5000m$ area. Each node repeatedly moves to random locations in the area with random speeds between $1.5m/s$ and $5m/s$ and pause times randomly selected between 1sec. to 50secs. We consider a uniform traffic model where all 20 nodes are chosen as sources with random destinations. Messages are generated every 15 seconds and each source generates messages at the same data rate. Messages are 500 bytes unless specified otherwise. We assume messages have infinite timeout values, which can be expected in DTNs. The node buffer size is 1000 megabytes which is equivalent to 2 million messages. We find this practicable due to the declining cost of storage.

We simulate a single ferry (or, MF) with speed of $15m/s$. The default ferry route follows a rectangle with (1250, 1250) and (3750, 3750) as diagonal points and four waypoints at (3750, 1250); (3750, 3750); (1250, 3750); and (1250, 1250) with the ferry starting its tour at (3750, 1250) in each simulation. The ferry wait time at each of the waypoints is 5secs. We model ferry access points as stationary nodes in the simulation area with stationary movement model. The number of FAPs varies for different evaluation settings and is mentioned accordingly. Both FAPs and the ferry have 2000 megabytes of buffer and can accommodate twice as many messages as a MH. Transmission range of MHs, MF and FAPs are 100 meters with a transmission speed of 2Mbps. We ran the simulations for 80,000 seconds and messages timeout is 40,000 seconds with a warm-up time of 1000 seconds. In all cases we take the average of 5 simulation runs. MHs, MF and FAPs perform routing using customized routers running on each node in the simulation. These routers implement the communication model in section II-B and are mentioned in Table 2 along with summarized default settings.

B. Performance Metrics

For evaluation, we consider two performance metrics, namely message delivery ratio and delay. The *message delivery ratio* is defined as the ratio of the number of successfully delivered messages to the total number of unique messages generated. Messages might be dropped because of buffer overflows. The delivery ratio is computed over the simulation duration, which measures how successful each scheme is in delivering messages. The *message delay* is represented in time units of seconds as the average end-to-end delay and is the average time from the generation of a message to the earliest reception of the message at the destination. The message delay considers delivered messages only.

TABLE II
DEFAULT PARAMETER SETTINGS

	speed	router	movement model	buffer size	transmission range; speed
Mobile nodes	1.5m/s - 5m/s	Host Router	RWP	1000MB	100 meters; 2Mbps
Message ferry	15m/s	Ferry Router	External Movement [13]	2000MB	
FAP	0 m/s	FAP Router	Stationary Movement		

C. Results and Analysis

Under the above parameters and metrics, we consider the impact of deployment of $'k'$ FAPs on the performance of the network. We then evaluate the performance of FAP placement models and how different parameters affect these models.

1) Performance improvement with FAPs: To observe the effect of FAPs performance in a MF-assisted DTN, we gradually deploy an increasing number of FAPs into the network on the MF route. We remove the restrictions on buffer sizes and let all MHs, MF and FAPs have unlimited buffer space. Since messages also have infinite timeout values; they are not dropped due to buffer overflow nor do they expire due to timeouts. This represents an ideal situation for message delivery. And as shown in figure 3, high delivery ratios are achieved. Compared to the case of no FAP, four FAPs present improved delivery, even under ideal situations. In this case, the more interesting improvement is in the delay metric. In DTNs, under ideal delivery conditions it is desirable to have as less delay as possible, since delays can be very high under intermittency. Figure 4 shows the gradual decrease in average end-to-end delay for increasing number of FAPs. A reduction of up to 10% in delay is achievable by increasing from 0 FAPs to 4 FAPs. A higher number of FAPs would further improve the message delay.

2) FAP Placement Models: In the above graphs, we implemented FAPs without knowledge of MF waypoints. In this section we observe how deploying FAPs with knowledge of ferry route waypoints can change the outcome of network performance. We implement the three placement models proposed in section IV, and evaluate each model by varying number of FAPs, changing ferry speed and increasing message size. For the *symmetric model* we assume FAPs are place exactly on mid-points of two consecutive FAPs. For our simulations, they were placed at (3750, 2500); (2500, 3750); (1250, 2500) and (2500, 1250) respectively. For the *waypoint model*, we placed FAPs on ferry waypoints (3750, 1250); (3750, 3750); (1250, 3750); and (1250, 1250). Under the *asymmetric model*, FAPs can be placed randomly between consecutive ferry waypoints. For each simulation run, we randomly generate co-ordinates for FAP placement between waypoint pairs ((3750, 1250); (3750, 3750)), ((3750, 3750); (1250, 3750)), ((1250, 3750); (1250, 1250)) and ((1250, 1250); (3750, 1250)) respectively.

i. Effect of Increasing FAPs

We observe the performance of the placement models

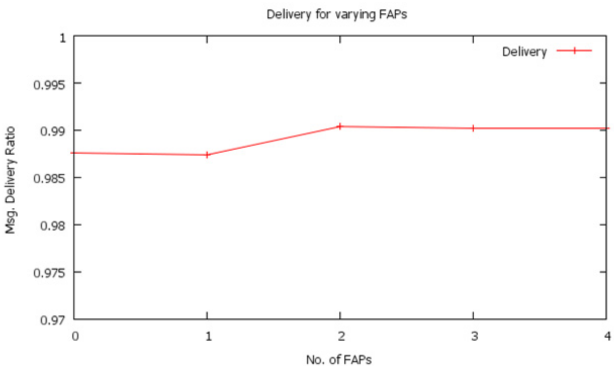

Fig. 2. Performance with increasing FAPs - Delivery Ratio

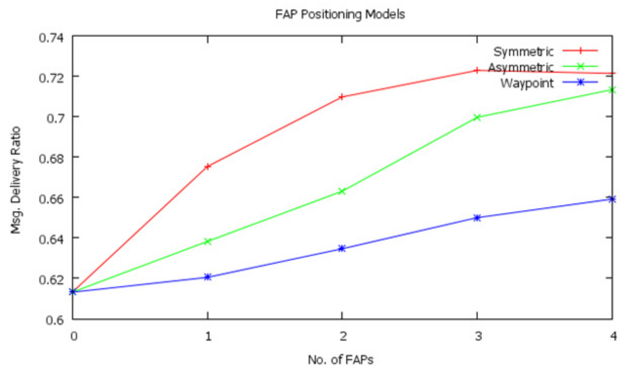

Fig. 4. Placement models with varying number of FAPs - Deivery Ratio

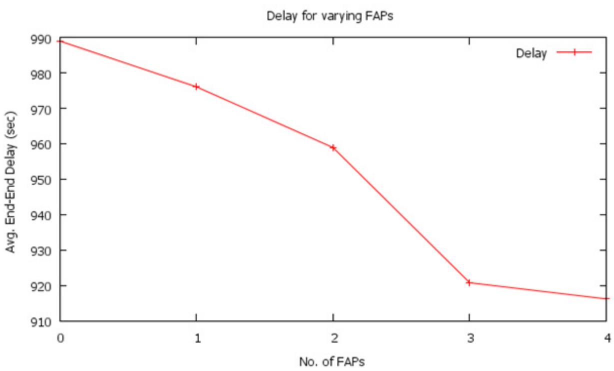

Fig. 3. Performance with increasing FAPs - Delay

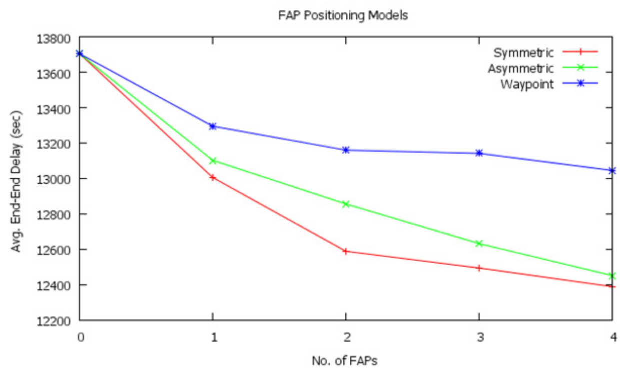

Fig. 5. Placement models with varying number of FAPs - Delay

gradually increasing the number of FAPs along the MF route. In figure 4 and 5, we find that symmetric placement is best followed by asymmetric and waypoint. For waypoint placement, the FAPs are places at waypoints of the ferry where the ferry waits with a certain pause time. For the amount of the pause duration, the ferry becomes a stationary node and holds the properties of an FAP. Therefore, in symmetric and asymmetric model, in addition to the number of deployed FAPs, we have a FAP-like MF at waypoints while the ferry waits. This gives symmetric and asymmetric an advantage over waypoint placement. In waypoint model, when the FAP is on the waypoint and the ferry also pauses at the waypoint, they do exchange data, but at but with less impact. The message delay is also reduced as more FAPs become available.

ii. Effect of Ferry Speed (m/s)

We gradually increase the speed of the MF from 15 m/s to 2000 m/s in figure 6 and 7. Until 500 m/s, delivery ratio improvements are apparent. However as MF speed increases, the delivery ratio is affected by message aborts. At higher ferry speeds, contact duration of the ferry with other nodes becomes limited. Reduced contact duration affects the maximum data rate that can be sent between two devices and thus reduces the average capacity C_{ij}. Message delays also increase due to more transmissions required to deliver a message. Symmetric model outperforms asymmetric and waypoint at all ferry speeds.

iii. Effect of Message Size (bytes)

In figure 8 and 9, observe the impact of increasing the message size in the network under various FAP placement models with a MF speed of 15m/s. Larger messages require longer contact durations for successful transfer. Let, message size = X bytes and transmission speed = T_x bytes/sec. Then, $\frac{X}{T_x}$ sec's are require to transfer the message between two communicating devices. We can see that the symmetric model provides higher contact opportunities, due to the uniformity of FAP deployment. MHs receive uniform opportunities to interact with FAPs. With larger message sizes, buffers can no longer accommodate messages and message drops occur, thus significantly affecting the message delivery ratio. Delay is however not affected on the same scale, because messages drops do not affect the average end-to-end delay, and only message that are successfully delivered are accounted for.

VI. Conclusion

We propose the integration of FAPs with message ferries to enhance the network capacity of mobile DTNs. By acting as rendezvous points between ferry and mobile hosts, FAPs increase communication opportunities and improve the performance of the network. We verify this improvement through simulations using message delivery and delay as metrics. In this paper, we also present three placement models to deploy

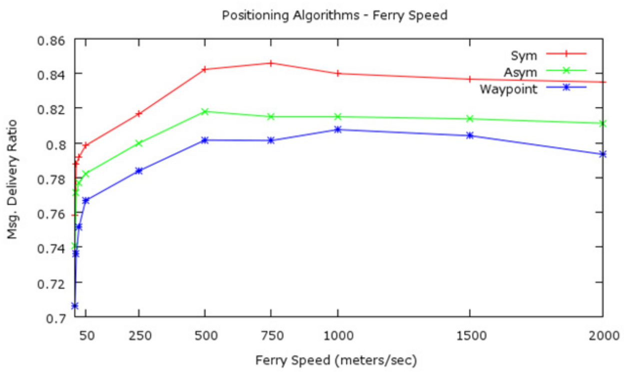

Fig. 6. Placement models with changing MF speed (m/s) - Delivery Ratio

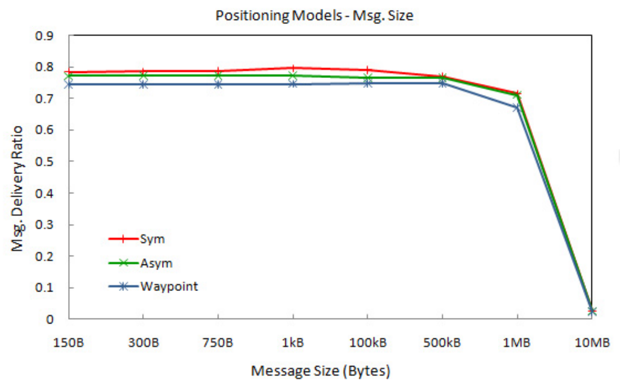

Fig. 8. Placement models with increasing message size (bytes) - Delivery Ratio

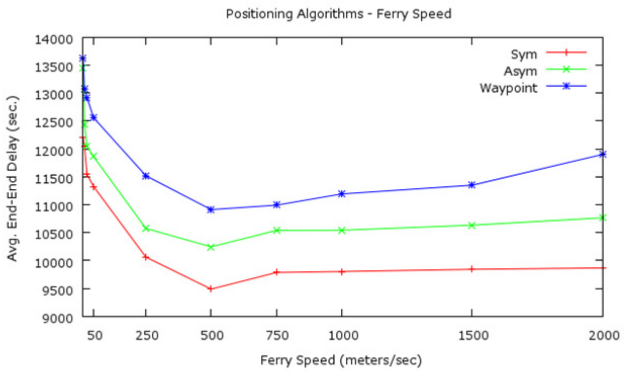

Fig. 7. Placement models with changing MF speed (m/s) - Delay

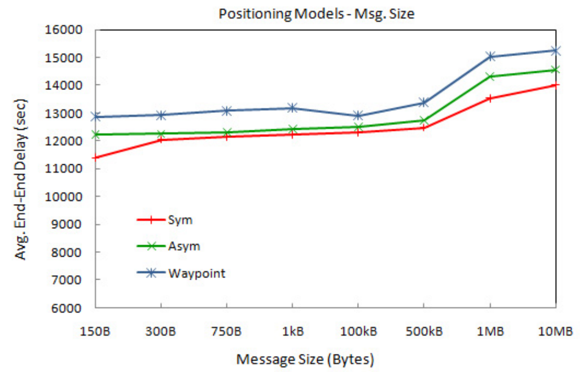

Fig. 9. Placement models with increasing message size (bytes) - Delay

FAPs on MF route. We evaluated the models with simulations in ONE. Results indicate that FAPs are very effective in improving throughput and delay, when FAPs are deployed symmetrically on MF routes. In sparse environments with randomly moving MHs, the symmetric model provides higher contact opportunities due to the uniformity of deployment on MF routes. Asymmetric model is non-uniform, but has an advantage over the waypoint model that when a ferry pauses at waypoints, both in the symmetric and asymmetric model, the number of FAPs increase by 1 within the MF paused duraduration. This furthermore establishes the positive impact of ferry access points in MF-assisted DTN network. In future, we hope to study the performance of FAP placement models under varied mobility models of mobile hosts and extensive attributes of message ferries.

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