Incentive Based Data Sharing in Delay Tolerant Mobile Networks

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***Abstract*—Mobile wireless devices play important roles in our daily life, e.g., users often use such devices to take pictures and share with friends via opportunistic peer-to-peer links, which however are intermittent in nature, and hence require the store-and-forward feature proposed in Delay Tolerant Networks to provide useful data sharing opportunities. Moreover, mobile devices may not be willing to forward data items to other devices due to the limited resources. Hence, effective data dissemination schemes need to be designed to encourage nodes to collaboratively share data. We propose a Multi-Receiver Incentive-Based Dissemination (MuRIS) scheme that allows nodes to cooperatively deliver information of interest to one another via chosen paths utilizing few transmissions. Our scheme exploits local historical paths and users' interests information maintained by each node. In addition, the charge and rewarding functions incorporated within our scheme stimulate cooperation among nodes such that the nodes have no incentive to launch edge insertion attacks. Furthermore, our charge and rewarding functions are designed such that the chosen delivery paths mimic efficient multicast tree that results in fewer delivery hops. Extensive simulation studies using real human contact-based mobility traces show that our scheme outperforms existing methods in terms of delivery ratio and transmission efficiency.**

***Index Terms*—Incentive mechanism, publisher/subscriber, delay tolerant networks, data sharing, mobile networks.**

I. INTRODUCTION

WITH the rapid advancement of wireless technologies, mobile wireless devices, e.g., smartphones, PDAs, and laptops have emerged and are gradually woven into our social life. Such devices allow people to access information anywhere at anytime since these devices have increasingly larger storage and support multiple network interfaces including cellular, WLAN, and Bluetooth. Thus, besides using such devices to make phone calls and send text messages, users can utilize these devices to access and store interesting data items such as news clips, sports events, finance forecast, and trending tweets.

While cellular data services are available almost everywhere, constantly using such services to access information is costly because the energy consumed with such constant access is high. On the other hand, it is attractive to exploit peer to peer ad hoc networks [1], [2], [3], [4] formed by these wireless devices utilizing lower-power radios (e.g., Bluetooth or Wi-Fi) to share useful information among users. As such, stored data items can be organized into various categories, e.g., entertainment, finance, politics, technology. Users can acquire data items from their peers by expressing their interests based on either data categories which are used to describe these data items [5], [6], [7].

Although content dissemination schemes have been proposed for ad hoc networks in the past, e.g., [5], [8], [9], [10], such approaches usually assume that the networks are well-connected. However, interfaces such as Wi-Fi and Bluetooth have shorter radio range and hence connectivity between mobile devices using such interfaces is dynamic and intermittent. Delay tolerant networking technology [11], [12], [13], [14] has been proposed to allow nodes in such environments to still communicate by storing data packets when connectivity disappear and exchanging stored packets once connectivity reappears. In addition, traditional content dissemination schemes do not consider users' changing interests from time to time. Thus, new content dissemination schemes [15] need to be user-centric and address the intermittent connectivity issue.

In order to enable smooth information sharing in delay tolerant mobile networks, the participants need to be cooperative. However, since such networks are typically human-contact based networks, users are selfish and wish to preserve their devices' resources such as communication bandwidth and battery power. Thus, in practice, any useful content dissemination scheme needs to incorporate an incentive or reputation mechanism to encourage users to cooperate for effective information sharing.

Most existing incentive mechanisms [16], [17], [18] have been designed for unicast scenarios. While these schemes can effectively encourage selfish nodes to help relay others' packets, their achieved transmission efficiency may be low in multicasting scenarios, which are representative in publish/subscribe systems for delay tolerant mobile networks as the same data items may be interested by multiple users. A recently proposed incentive-aware data dissemination [19] seemed promising for multi-receiver scenarios. However, the incentive mechanism in this work focused on rewarding the last-hop relay node which communicates with the destinations, which is not fair for all other relay nodes. Moreover, the performance of the incentive mechanism [19] degrades when data items are sparsely distributed among nodes due to its restrictive replication mechanism[1].

In this work, we aim to design a Multi-Receiver Incentive-Based Dissemination (MuRIS) scheme that not only encour-

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[1] We found this problem during our experiments and confirmed this inefficiency with the authors of [19].

ages nodes to cooperate via our proposed incentive mechanism, but also wisely selects paths that can reach multiple subscribers efficiently. Specifically, we propose multi-receiver based charge and rewarding functions that would favor the paths which can reach more subscribers at intermediate hops. We further show that our charge and rewarding functions can prevent edge insertion attacks. This type of attacks is the easiest approach for relay nodes to obtain extra incentives without obvious misbehaviors. Such attacks can significantly impact the fairness of the network since subscribers need to pay more total rewards. In addition, other honest relay nodes on the same delivery path receive fewer rewards than the relay node launching the edge insertion attack. Our charge and rewarding functions provide no rewarding gain for adversarial nodes, which insert fake intermediate nodes during their edge insertion attacks. Moreover, we show that our information sharing scheme allows nodes to utilize locally maintained information about past node encounters and partial delivery paths to determine if they should forward received data items to other nodes they encounter such that the chosen delivery paths are those that efficiently reach many subscribers.

To evaluate the effectiveness of MuRIS, we use the traces from the MIT reality mining experiment [20] and the Haggle project [21] together with the ONE simulator, which is a trace driven simulator specially designed for DTN environments. The performance of MuRIS is compared with existing data dissemination approaches with or without incentive mechanism. The simulation results demonstrate that our approach can achieve high delivery ratios similar to the Epidemic scheme (where nodes simply re-broadcast whatever they receive) while maintaining a low overhead ratio in different scenarios. Moreover, it performs especially well when the publisher and subscribers come from different communities.

The rest of the paper is organized as follows. Section II discusses related work for incentive-based stimulation and data dissemination in DTNs. The models of our scheme is described in Section III. Section IV presents our Multi-Receiver Incentive-Based Dissemination (MuRIS) scheme. Section V evaluates the effectiveness of MuRIS and compares its performance with existing approaches. Finally, Section VI concludes the paper.

II. RELATED WORK

Recently, there are active researches in exploring effective schemes for providing content distribution services in delay tolerant networks. For example, *ContentPlace* [22] exploited the dynamically learned information about users' social relationships to determine where to place data objects in order to optimize content availability. *MOPS* [23] designed a publish/subscribe system for delay tolerant environments such that nodes within the same community could communicate directly when published data items match the interests of nodes, while brokers are used to bridge different communities. Similarly, *SANE* [24] described a social-aware forwarding scheme which utilizes user interests and their similarity to assist making forwarding decisions. In these three studies, each published data item belongs to a particular data category. An efficient data dissemination scheme CUCID [25] was developed for human-contact based networks. Such scheme allows each node to operate distributively based on locally gathered information. Furthermore, Gao and *et. al.* [15] proposed a social centrality metric by considering social contact patterns and interests of users simultaneously to achieve efficient content disseminations.

All the above works assumed that users are cooperative and do not refuse to forward data item to others. However, this assumption is not always true in real-world scenarios, especially in human contact-based networks, since wireless devices have limited resources e.g., battery power, storage space and available bandwidths provided by opportunistic links. Thus, the provision of an incentive mechanism to induce cooperations among nodes is necessary. Toward this end, *MobiCent* [16] is a credit-based incentive system in Delay Tolerant Networks (DTNs) for delivering unicast messages. The charge and rewarding functions designed in MobiCent encourage intermediate nodes to cooperate and prevent them from launching edge insertion and edge hiding attacks. *RELICS* [17] is another cooperative-based mechanism to combat selfishness in DTNs, in which a rank metric is defined to measure the transit behavior of a node. Nodes with higher rank indicate higher cooperation. These two incentive-based schemes focus more on delivering unicast messages, while we are more interested in one-to-many communication pattern, which is typical for information sharing in a publish/subscribe system.

The most relevant study to our work is proposed by Ning and *et. al.* [19] where an incentive based forwarding scheme is developed to reward the last hop relay node. In this scheme, every node computes its effective interest contact probability (ECIP) for each data category, which represents the probability that this node contacted a node interested in the corresponding data category either directly or indirectly. Upon encountering each other, two nodes would exchange data messages based on the calculation of ECIP to maximize their own expected credit rewards. Under this scheme, a node without any messages is unable to receive any data item from other nodes it encountered, unless the data item is of its interests. Thus, such design is restrictive and not suitable for networks where data items are sparsely distributed among nodes, since nodes without data items might be the only node that could reach the nodes interested in the data items. Another recent work [26] uses a similar incentive based forwarding scheme, which assumes senders will pay rewards to relay nodes for successful deliveries. In [26], relay nodes can trade virtual checks in order to get rewards from senders. Similar to [19], the performance in [26] may degrade when data items are sparsely distributed among the nodes. Different from the previous studies, our MuRIS scheme can achieve better delivery ratio in networks where data items are sparsely distributed among nodes. In addition, our scheme can thwart insertion attacks launched by selfish intermediate nodes.

III. MODELS

A. Network Model

Each node in the network represents a user who carries a mobile device with multiple wireless interfaces including cellular, WLAN, and Bluetooth. We consider nodes with same transmission and reception ranges. The bandwidth of each node is large enough to process the data exchanges when two nodes encounter. The movement of nodes can be described by a non-homogeneous mobility model, i.e., the contact rate and the contact duration between different pairs of nodes are different. Furthermore, we consider that the message delivery paths from a source node to destinations may repeat frequently. This is reasonable since most scenarios have similar conditions: for example, users/students in the MIT reality mining experiment may encounter each other frequently between classrooms and dormitories on the same campus. Similarly, in the Haggle project, users are participants of Infocom conference who meet each other frequently in the same hotel. The repeatability of delivery paths suggests that historical paths in DTNs are still useful although the frequency of such repeatability varies much.

The nodes in our network are assumed to be authenticated first when they join the network. Every node is interested in receiving data items belonging to some categories. To encourage cooperative dissemination, a node is willing to be charged a certain amount of virtual "money" that can be a function of the number of hops it takes to deliver a data item to that node. Every node in a delivery path shares the same reward. The rewards are based on the final RSS and RNS values when a message is delivered to a subscriber. Any subscriber along the delivery path will also have to pay relay nodes in its delivery path. The reward is inversely proportional to the total hop count in the delivery path such that nodes are encouraged to choose paths with fewer transmissions. The formal definition of reward is described in Section IV. In addition, every node is considered to be selfish, which means it will not help to relay data unless it can gain some benefits, i.e., for example, some "money" that can be used in the future to stimulate other selfish nodes' cooperation. We assume that there is a central transaction server offering secured service, which guarantees each node can collect their rewards weekly or monthly.

B. Data Model

Data items in our network may be organized into different categories. For example, news from CNN may be classified into the following categories: politics, weather, entertainments, and etc. All news related to politics can be further described using various sub-categories such as healthcare and debt crisis. A more comprehensive data model based on categories and keywords can be found in [25]. In this work, we use a simplified channel-based model [1], [22], where the information is organized in different channels to which users can subscribe.

C. Publisher/Subscriber (User)

In our work, each node can be a publisher, a subscriber or both. Each publisher can publish data items that belong to different channels. Further, each subscriber has an interest list indicating the channels that the subscriber is interested in. We assume users tend to use fixed/same subscription (e.g., users are used to get news information from ABC news).

D. Messages

There are three types of messages in our system:

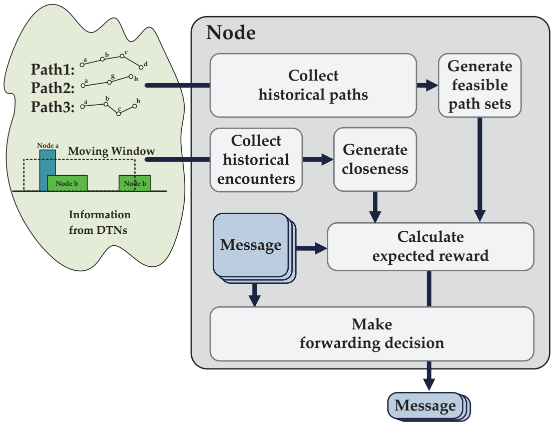


Fig. 1. Overview of MuRIS scheme.

- **Probe Messages:** Probe messages are used to record possible paths from publishers to subscribers. They are only forwarded during warmup period or when nodes have been idle for a while.
- **Receipt Messages:** Receipt messages are only generated by subscribers to confirm the path information carried within a newly received probe message.
- **Data Item Messages:** Data item messages are generated by publishers to distribute data contents in the network. In the rest of our work, *messages* will be used without specification to describe the data item messages.

IV. INCENTIVE DRIVEN INFORMATION SHARING

In this section, we present the Multi-Receiver Incentive-Based Dissemination (MuRIS) scheme, which aims to provide efficient information sharing in DTNs when non-cooperative users are present. We first provide an overview of MuRIS. Then we introduce the multi-receiver based incentive mechanism used in MuRIS. Next, we define two important concepts, namely the *closeness vector*, and the *feasible path set*, before we present our incentive driven information sharing scheme.

A. Overview of Our Incentive Based Forwarding Scheme

We focus our design on one-to-many dissemination scenarios such as the publish/subscribe systems for DTNs that can benefit from the multicast capability. One simple way to provide one-to-many dissemination is to have all the nodes rebroadcast whatever new messages they receive. However, even though such broadcasting mechanism can reach all interested nodes, it results in many useless message replications and hence waste the limited network and power resources. To efficiently use the resources, a new information sharing scheme needs to be designed such that data replications can be kept to the bare minimum. In addition, an incentive mechanism needs to be integrated with the dissemination scheme to encourage selfish nodes to cooperate. In this work we propose Multi-Receiver Incentive Based Dissemination (MuRIS) scheme for efficient information sharing, especially for one-to-many dissemination scenarios. Our MuRIS scheme dynamically constructs efficient multicast delivery tree for multiple receivers interested in the same message. The incentive mechanism incorporated in MuRIS encourages intermediate nodes to cooperate rather than being selfish so as to gain some rewards associated with their forwarding efforts.

A high level overview of MuRIS scheme is shown in Figure 1. Each node that supports our MuRIS scheme collects historical path information and encounters in the network. Such information is used to construct two pieces of information used in our scheme, namely, feasible path set and closeness, which will be further described in Section IV-D. Upon encounter with any node, a forwarding decision will be made for every message carried by the node based on the expected reward may be obtainable from the message. The forwarding decision process will be discussed in Section IV-E.

The detailed approach of our incentive based forwarding scheme is outlined as follows:

Information Collection: During the warm up period or after any node has been idle for a while, a node uses probe/receipt messages to learn potential paths from publishers to various subscribers in the network. Additionally, when two nodes encounter, both nodes exchange the path information they are aware of, and update their knowledge of paths if the other node has a new and better path. Based on the path information it learns, every node constructs its *feasible path set*, which will be further described in Section IV-D2. Each node in the network records the encounter events, and a closeness vector (to be defined later) is constructed based on such encounter histories. We note that since nodes refusing to forward probe/receipt messages are not recorded as available relay nodes in the feasible path sets of other nodes, a regular node interested in receiving rewards is willing to forward the probe/receipt messages.

Data Forwarding: When two nodes encounter, they first exchange new messages of interests from each other. Then, for the remaining stored messages at a node, the node estimates the potential reward for forwarding any message based on the closeness vector and feasible path set, and decide to only forward the message if the path via the other node can provide the highest expected reward.

In subsequent paragraphs, we provide more details of our new incentive-based dissemination scheme.

B. Background

In this section, we introduce some background on designing an incentive mechanism that prevents edge insertion attacks [16]. In a fair incentive mechanism, rewards are distributed to all cooperative intermediate nodes along the delivery path of a message, and the reward should be proportional to the consumed resources for the delivery. Moreover, if we assume the identical resource consumption for every intermediate node, the charge and reward regarding a n hop delivery path must satisfy the Equation (1) to ensure that the charge can cover all the rewards.

$$\mathbb{C}(n) \geqslant n \times \mathbb{R}(n), \tag{1}$$

where the $\mathbb{C}(n)$ and $\mathbb{R}(n)$ indicate the charge to a subscriber receiving a message, and the reward per intermediate node on an n hop delivery path, respectively. To note that publishers are considered as intermediate nodes when the total reward is computed in Equation (1).

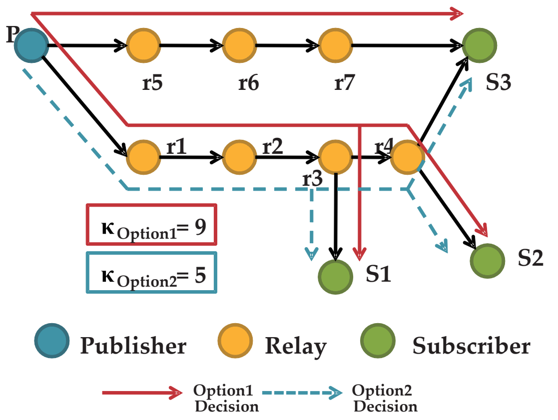


Fig. 2. Comparison of efficiency for different forwarding scheme.

However, an incentive mechanism simply following the Equation (1) is vulnerable to the cheating performed by some greedy intermediate nodes e.g., edge insertion attacks, to gain additional rewards. Such attacks can be prevented by designing an incentive mechanism [16] which adheres to the following rules:

***Rule* 1.** *To prevent an intermediate node from gaining in an edge insertion attack, the reward $\mathbb{R}(n)$ for relaying the message via an n hop path must be no less than the total rewards gained through an insertion attack, i.e.,* $2 \times \mathbb{R}(n+1) \leq \mathbb{R}(n)$.

***Rule* 2.** *To prevent a subscriber from benefiting in an edge insertion attack, the charge $\mathbb{C}(n)$ for receiving a message via an n hop path must be no larger than the new resulting charge after the insertion attack,i.e.,* $\mathbb{C}(n+1) - \mathbb{R}(n+1) \geq \mathbb{C}(n)$.

Although the above two rules are presented with single hop insertion, MobiCent [16] has proved that inserting multiple hops cannot benefit any node. The authors in [16] have presented the Multiplicative Decreasing Reward (MDR) mechanism which strictly follows the above two rules. Although the MDR incentive mechanism is incentive compatible under edge insertion attacks, their work only focuses on unicast cases. In this work, our incentive mechanism is designed not only to thwart edge insertion attacks, but also to cooperate our multi-receiver dissemination scheme for DTNs.

C. Multi-Receiver based Incentive Mechanism

We first use a simple example to illustrate the importance of considering collectively the reachability to multiple receivers in the forwarding decision in one-to-many communication scenarios. All nodes in Figure 2 are mobile nodes which use the same dissemination scheme. Assume that a publisher P wants to send a message to three subscribers $S1$,$S2$, and $S3$. There are two possible forwarding paths as shown by the directed lines. Note that even though we have shown paths consisting of directed lines from P1 to all the subscribers, such end-to-end paths do not exist simultaneously. A path consisting of directed lines merely means that the different node pairs in each hop encounter each other at different times with encounters at earlier hops happening first. Figure 2 shows that there are two forwarding path options: *Option1*, represented by the solid line, selects the shortest paths for each individual pub-sub pair, while *Option2* selects a delivery path that minimizes the total number of transmissions. It is obvious that the total energy consumed by the nodes in *Option1* is higher than that consumed in *Option2* because *Option2* uses fewer transmissions. This example illustrates the usefulness of considering multiple receivers in any forwarding decision.

Based on the above observation, we aim to design an incentive mechanism that encourages nodes to cooperate such that the selected forwarding paths use few transmissions and hence achieves high network efficiency. Furthermore, we realized that to encourage nodes to make such forwarding decisions in one-to-many dissemination scenarios, the delivery status of messages must be considered. Therefore, we assume that every message has a header which contains a pair of values (RSS, RNS) defined as follows:

Definition 1. *The* ***Reachable Subscriber Size (RSS)*** *of a message m is the number of subscribers that have already received m on the path that this message has gone through before being received by the current node.*

Definition 2. *The* ***Relay Node Size (RNS)*** *of a message m is the number of intermediate nodes that have successfully delivered at least one copy of m to a subscriber on the path that this message has gone through before being received by the current node.*

We utilize Figure 2 to explain how RSS and RNS work in a packet dissemination. Assume the publisher P has chosen the Option2 to send a packet to three subscribers $S1$, $S2$ and $S3$, and $r3$ will meet $r4$ after it first meets with $S1$. When the packet goes through $r1$, the RNS value is only increased by 1 since $r1$ cannot deliver the packet to any subscriber. Same thing happens when the packet goes through $r2$. However $r3$ can successfully deliver the packet to $S1$ before it meets $r4$, so both RSS and RNS are increased by 1 when the packet is passed to $r4$. When the packet reaches $r4$, the RSS value is 1 and RNS is 3, which indicate that the packet has already been delivered to one subscriber on its way to $r4$ and there are three relay nodes before the packet reaches $r4$.

With RSS and RNS, we propose the following charge and rewarding functions:

$$\mathbb{C}(n,\nu) = 2^N - 2^{N-n}(1+\theta(n,\nu)) \tag{2}$$

$$\mathbb{R}(n,\nu,\psi) = 2^{N-n}(1-\phi(\nu,\psi)), \tag{3}$$

where N is a predefined maximum allowed hop counts in the network for scalability control, ν, ψ are values of RSS and RNS respectively, and $\theta(\centerdot)$, $\phi(\centerdot)$ are two synthetic functions that are introduced to utilize the information from RSS and RNS. The RSS and RNS do not require the prior knowledge of the topology, instead, they are locally derived from the relaying experience of each relay node, which is particularly suitable for ad-hoc networks

Two key goals guiding the design of our charging and rewarding functions in Equation (2) and (3) are: 1) to design an incentive mechanism that can favor efficient delivery paths which traverse more subscribers, and 2) to thwart edge insertion attacks launched by selfish nodes. However, to simultaneously satisfy above two goals, the design of our incentive mechanism experience several challenges:

1) **Incentive compatibility:** Both the charging and rewarding functions must be positive to ensure meaningful operations of scheme.
2) **Breakeven forwarding operations:** Equation (1) must be satisfied to ensure that the charge collected from a subscriber can cover all rewards paid to intermediate nodes on the corresponding delivery path, so that every intermediate node on the delivery path is guaranteed its share of incentives.
3) **Resilience to selfish intermediate nodes:** Selfish intermediate nodes are eager to launch edge insertion attacks since it is the easiest way to obtain extra rewards. To thwart the edge insertion attacks launched by intermediate nodes, *Rule 1* must be satisfied to ensure that no intermediate node can get any benefit by launching an edge insertion attack.
4) **Robustness against dishonest selfish subscribers:** Since we assume that all nodes are selfish, the subscribers although are willing to pay for data they are served with, they always desire to launch edge insertion attacks to obtain incentives. Therefore, *Rule 2* must be satisfied to ensure that no subscriber can launch an edge insertion attack.

We particularly choose the function described in Equation (4) to be our $\theta(n,\nu)$ to ensure the conditions (1), (2), and (4):

$$\theta(n,\nu) = \begin{cases} 0 & \text{if } \tau = 0 \\ \frac{\nu}{\tau} & \text{if } 1 < \nu \leq \tau, \end{cases} \tag{4}$$

where $\tau = \max(\nu)$ is a constant in the system and ν is maintained locally by every node itself.

Similarly, to guarantee the conditions (1), (2), and (3), we define $\Lambda = \nu + \psi$ and $\tau' = \max(\Lambda)$, and choose the function described in Equation (5) to be our $\phi(\nu,\psi)$:

$$\phi(\nu,\psi) = \begin{cases} 0 & \text{if } \Lambda = 0 \\ \log_{\tau'}(\Lambda) & \text{if } 1 \leq \Lambda \leq \tau'. \end{cases} \tag{5}$$

Eventually, with the chosen functions $\theta(\centerdot)$ and $\phi(\centerdot)$, our charge function favors the paths with fewer hops and larger RSS values, and our rewarding function favors delivery paths with fewer hops and smaller RSS values. This design is reasonable, since selfish intermediate nodes would favor the path that can reach more potential subscribers to maximize its rewards in total.

With the above definitions of $\theta(\centerdot)$ and $\phi(\centerdot)$ we show that our charge and reward functions satisfy the breakeven condition in following lemma and its proof.

Lemma 1. *The incentive mechanism with charge and rewarding functions in Equation (2) and Equation (3) satisfies the breakeven condition in Equation (1).*

Proof: We show that with the characteristics of functions $\theta(\centerdot)$ and $\phi(\centerdot)$ in Equation (4) and Equation (5), the total charge and rewards satisfy the inequality in Equation (1). In particular, we first prove that when publishers directly deliver messages to subscribers Equation (1) is satisfied. Then we prove that Equation (1) is also satisfied when messages are delivered to subscribers through intermediate nodes.

Proof for satisfying Equation (1) when publishers deliver messages to subscribers directly:
In direct deliveries, $n = 1$ and $\psi = 0$ because there is no relay nodes, Equation (1) becomes

$$\mathbb{C}(1, \nu) \geq \mathbb{R}(1, \nu, 0). \tag{6}$$

Therefore, the left hand side of the inequality in Equation (6) is derived as:

$$\begin{aligned} \mathbb{C}(1, \nu) &= 2^{N} - 2^{N-1}(1 + \theta(1, \nu)) \\ &= 2^{N-1}(1 - \theta(1, \nu)). \end{aligned} \tag{7}$$

And the right hand side of the inequality in Equation (6) is derived as:

$$\mathbb{R}(1, \nu, 0) = 2^{N-1}(1 - \phi(\nu, 0)). \tag{8}$$

Since $\theta(1, \nu) = \frac{\nu}{\tau}$ and $\phi(\nu, 0) = \log_{\tau}(\nu)$, we can derive that $\theta(1, \nu) \leq \phi(\nu, 0)$ when $\nu \leq \tau$. Hence, $\mathbb{C}(1, \nu) \geq \mathbb{R}(1, \nu, 0)$, and Equation (1) is satisfied when the publishers directly send messages to subscribers.

Proof for satisfying Equation (1) when publishers deliver messages to subscribers through intermediate nodes:
When messages are delivered to subscribers through intermediate nodes, $1 < n \leq N$. We let $p = 1 + \theta(n, \nu)$ and the left hand side of inequality in Equation (1) is derived as:

$$\mathbb{C}(n, \nu) = 2^{N} - 2^{N-n} \times p. \tag{9}$$

From Equation (4) we know that $0 \leq \theta(n, \nu) \leq 1$, hence $1 \leq p \leq 2$ and Equation (9) is within the range $2^{N} - 2^{N-n+1} \leq \mathbb{C}(n, \nu) \leq 2^{N} - 2^{N-n}$.

Similarly, we let $q = 1 - \phi(\nu, \psi)$, and the right hand side of the inequality in Equation (1) is derived as:

$$n \times \mathbb{R}(n, \nu, \psi) = n \times 2^{N-n} \times q. \tag{10}$$

We further find that $0 \leq n \times \mathbb{R}(n, \nu, \psi) \leq n \times 2^{N-n}$ because $0 \leq \phi \leq 1$ in Equation (5) and $0 \leq q \leq 1$. Furthermore, we prove that the charge and rewarding function in Equation (9) and Equation (10) satisfy $\mathbb{C}(n, \nu) \geq n \times \mathbb{R}(n, \nu, \psi)$, since $2^{N} - 2^{N-n+1} = 2^{N-n}(2^{n} - 2) \geq n \times 2^{N-n}$ for $n > 1$. This completes our proof for Lemma 1. ■

Moreover, our proposed charge and rewarding functions are incentive compatible under edge insertion attacks, which can be shown with following lemmas and their associated proofs.

Lemma 2. *The incentive mechanism with charge and rewarding functions in Equation (2) and Equation (3) is incentive compatible under edge insertion attacks.*

Proof: We prove that Equation (2) and Equation (3) satisfy both *Rule* 1 and *Rule* 2. Let N_r and N_s represent a dishonest intermediate node and a dishonest subscriber which will launch an insertion attack if it is profitable. According to Equation (2) and Equation (3), we assume in all following cases, N_r receives an initial reward of $\mathbb{R}(n) = 2^{N-n}(1 - \phi(\nu, \psi))$ from an n hop path, and N_s needs to pay an initial charge of $\mathbb{C}(n) = 2^{N} - 2^{N-n}(1 + \theta(n, \nu))$. We argue that each subscriber must pay for its received message, which is enforced by the authenticator. In addition, we assume that values of RSS and RNS are protected by an onion-style encryption [27], and hence RSS cannot be modified by a subscriber without modifying RNS. Besides, changing such a value incurs extra charges for a dishonest node for it needs to acquire extra authenticated node identifiers. The full discussion of the privacy issue is out of the scope of this paper and will be explored in our future work.

Proof for satisfying Rule 1:
To prove that our incentive mechanism satisfy $Rule\ 1$, we need to show that there is no benefit for N_r to insert an intermediate node or modify the RNS value. First, we prove that *inserting an intermediate node is not profitable for* N_r. The new reward after N_r has launched an insertion attack is $2 \times \mathbb{R}(n+1) = 2^{N-n-1}(1 - \phi(\nu, \psi))$. Therefore, the difference between these two rewards is:

$$\begin{aligned} \mathbb{D}_1 &= 2 \times \mathbb{R}(n+1) - \mathbb{R}(n) \\ &= 2^{N-n}(\phi(\nu, \psi)) - \phi(\nu, \psi)) \\ &= 0 \end{aligned} \tag{11}$$

satisfied. Since $D = 0$, N_r cannot gain benefits by inserting intermediate nodes.

Second, we prove that *inserting an intermediate node and modifying the RSS value simultaneously is not profitable for* N_r. Assume that the reward after inserting an intermediate node and increasing RSS value by 1 is $2 \times \mathbb{R}(n+1) = 2^{N-n}(1 - \phi((\nu+1), \psi+1))$. The difference between this reward and the initial $\mathbb{R}(n)$ is:

$$\begin{aligned} \mathbb{D}_2 &= 2 \times \mathbb{R}(n+1) - \mathbb{R}(n) \\ &= 2^{N-n}(\phi(\nu, \psi) - \phi(\nu+1, \psi+1)) \\ &\leq 0 \end{aligned} \tag{12}$$

since $\phi(\nu, \psi)$ is monotonically increasing with $\Lambda = \nu + \psi$, which means there is no benefit for N_r to insert an intermediate node and modify RSS by 1. This completes the proof that our incentive mechanism satisfies $Rule 1$.

Proof for satisfying Rule 2:
To prove that our incentive mechanism also satisfies $Rule$ 2, we need to show that there is no benefit for a subscriber to insert an intermediate node. First we prove that *inserting an intermediate node is not profitable for* N_s. By inserting an intermediate node, N_s will be charged $\mathbb{C}(n+1) = 2^{N} - 2^{N-n-1}(1 + \theta((n+1), \nu))$ but receive a reward of $\mathbb{R}(n+1) = 2^{N-n-1}(1 - \phi(\nu, \psi))$. The final charge after inserting an intermediate node is $C' = C(n+1) - R(n+1)$. The difference between $\mathbb{C}'$ and initial charge $\mathbb{C}(n)$ is:

$$\begin{aligned} \mathbb{D}_3 &= \mathbb{C}' - \mathbb{C}(n) \\ &= 2^{N-n-1}[2 \times \theta(n, \nu) - \theta(n+1, \nu) \\ &\quad + \phi(\nu, \psi)] \end{aligned} \tag{13}$$

Since $\theta(n, 0) = 0$ and $\phi(0, 0) = 0$, and $\theta(n, \psi)$ is independent of n, $2\theta(n, \psi) > \theta(n+1, \psi)$, thus $\mathbb{D}_3 > 0$. Hence, there is no benefit for N_s to insert an intermediate node.

Second, since the charge function is independent of ψ, N_s cannot gain any benefit from modifying RNS value alone. Third, we also need to prove that *inserting an intermediate node and modifying RSS value cannot benefit* N_s. Assume that the charge for N_s after inserting an intermediate node and increasing RSS by 1 is $\mathbb{C}(n+1) = 2^{N} - 2^{N-n-1}(1 + \theta(n+1, (\nu+1)))$, and the extra reward from the insertion attack is $\mathbb{R}(n+1) = 2^{N-n-1}(1 - \phi((\nu+1), \psi+1))$. Thus, the difference between the new total charge $C' = C(n+1) - R(n+1)$ and the initial charge C is:

$$\begin{aligned}\mathbb{D}_4 &= \mathbb{C}' - \mathbb{C}(n)\\ &= 2^{N-n-1}[2 \times \theta(n,\nu) - \theta(n+1,(\nu+1))\\ &\quad + \phi((\nu+1),\psi+1)]\end{aligned} \tag{14}$$

Since $2\theta(n,\nu) > \theta(n,(\nu+1)), \mathbb{D}_4 > 0$. Hence, there is no incentive for N_s to insert an intermediate node and modify RSS value by 1. This completes our proof for $Rule2$. ■

D. Closeness Vector and Feasible Path

MuRIS exploits historical encounters and path traversal information available at each individual node to assist incentive-based forwarding. We introduce two building blocks, *closeness vector* and *feasible path set* that can be used to aid in making forwarding decision. Particularly, *closeness vector* is a metric used to predict future encounters, and *feasible path set* provides possible paths information for data forwarding.

1) Closeness Vector: The encounter time and the associated contact duration recorded by a node when it meets another node can be used to predict future encounters. We define the concept of closeness using the cumulative window (C-window) approach [28], which calculates the average node encounter duration during previous time windows. The node N_i maintains its list of encountered nodes in the most recent observation window $W = \rho \times \Delta t$, where Δt is the unit time, and ρ is the number of units within the observation window. We define the *Closeness* between two nodes N_i and N_j as:

$$c_{ij} = \frac{\sum_{k=1}^{\rho} \delta_{ij}^{k} \times \Delta t}{W} = \sum_{k=1}^{\rho} \delta_{ij}^{k} \times \rho, \tag{15}$$

where k is the index of time slot and δ_{ij}^{k} is an indicator function which has a value of 1 when N_i and N_j encounters during k^{th} unit time slot Δt, and 0 otherwise. Thus, each node N_i maintains a *closeness vector* C_i defined as:

$$C_i = [c_{i1}, ..., c_{iJ}]^T, \tag{16}$$

where J is number of nodes that N_i has encountered during the previous observation window. Each node computes its Closeness Vector based on its own local information.

2) Feasible Path Set: Because nodes move around in DTN, the available paths between a pair of nodes change dynamically. A common way to describe the available paths between two nodes in DTNs is to use a sequence of nodes and their corresponding probabilities of reaching a certain destination [15], [23]. However, such probabilities may not capture the dynamics of the actual node movements since they are often computed based on the assumptions that the node inter-encounter times are exponentially distributed. In this work, we let each node maintain a set of paths that have been used in the past to reach certain subscribers. We refer to this set of paths as the *Feasible Path Set*.

Definition 3. ***Feasible Path Set (FPS)*** *of node N_i is defined as $\mathbb{F}_i = (\mathbb{V}_i, \mathbb{Q}_i)$, where the subscriber set $\mathbb{V}_i = \{V_i^1, ..., V_i^M\}$ contains S subscribers $V_i^m = \{v_{m,1}, ..., v_{m,S}\}$ interested in the m^{th} channel that N_i is aware of; and the path set $\mathbb{Q}_i = \{Q_i^1, ..., Q_i^M\}$ consists of K paths $Q_i^m = \{p_{m,1}, ..p_{m,K}\}$ that have been used to reach the subscribers within corresponding subscribers set V_i^m.*

Construction Process: To collect historical path information initially, every publisher regularly sends a probe message labeled as a particular data category that this publisher will publish. Nodes only forward the probe message during the warmup period, or when nodes are idle for a while. Whenever the probe message reaches a subscriber interested in it, the subscriber sends a receipt message containing the path information carried by the corresponding probe message to all relay nodes on the recorded path. Eventually every involved node can receive the historical path information, and construct or update its FPS for corresponding data category.

To cope with the highly dynamic environment of DTNs, in addition to construct or update the FPS by means of probe/receipt messages, every node exchanges its FPS with other nodes it encounters to keep the path information updated. By comparing the feasible path set from the other node (remote FPS), this node can tell whether there is any subscriber unknown to the current node. If that is the case, such subscriber and corresponding feasible paths will be added to the local feasible path set (local FPS). Moreover, if the subscribers from the remote FPS are already known by the local FPS, a path is added to the local FPS only when the path can reach the subscriber with fewer hopcounts than any of existing paths in the local FPS.

Control of feasible path sets: We use two parameters to control the size of the feasible path set: N *(maximum hopcount)* and t_p *(maximum cache time of paths)*. These two parameters can help to limit the number of message copies in the network, thus reducing the number of involved relay nodes. This increases the scalability of our delivery system. Any feasible path is eliminated if its hopcount reaches N or its storage time exceeds the maximum cache time. Considering that the behaviors of nodes in DTNs may mimic mobile social networks, in our study, we set $N = 6$ in the simulations based on the average separation for humans discussed in [29], [30], [31]. Furthermore, we particularly use $t_p = 10$ hours and $t_p = 48$ hours in the simulation using the trace from the Haggle project. Since the maximum cache time of paths also affects the correctness of the feasible paths, we consider the study of the impact of paths' cache time as our future works. We will discuss the impact of maximum cache time of paths later in Section V-C4.

E. Incentive Driven Information Sharing

A node may be aware of multiple paths that can reach different number of subscribers. Thus, when a node encounters another node, it needs to decide if it should forward a message to that node based on the expected rewards it can gain. We calculate the expected rewards utilizing the closeness vector, feasible path set, and the rewarding function described in Section IV-C.

1) Expected Rewards: We first discuss how to compute the expected rewards, which are estimated rewards that a node N_i can gain if a message is relayed by N_i and eventually successfully delivered to subscribers before the message expires.

Assume that a message has gone through n hops when N_i receives it and it will be sent to its next hop node N_j. Further, we assume that K_l more subscribers can receive the message, and M_l additional intermediate nodes can deliver the message to subscribers at l^{th} hop after N_i. For example, K_1 is the number of subscribers that N_j can reach. If $K_1 \neq 0$, $M_1 = 1$ otherwise $M_1 = 0$. Thus, the expected reward of node N_i sending a message to a next hop node N_j can be computed as:

$$\mathbb{E}_{ij} = \sum_{l=1}^{P} K_l \times 2^{c_{ij}} \times \mathbb{R}(n+l, \nu+K_l, \psi+M_l), \tag{17}$$

where $P = (N-n)$ is the number of additional hops allowable before the maximum hop count is reached, and $2^{c_{ij}}$ measures how likely node i and node j will encounter each other in the future.

Equation (17) is the total expected reward N_i can receive after forwarding the message to N_j. However, K_l in Equation (17) requires complete path information which is not available at node N_i. Therefore, we simplify the problem as follows: assume that currently node N_i knows of H paths to a subscriber S_j via a next-hop node N_j with each path having to traverse an additional w_h, $h = 1, ..., H$ hops after node N_i. We use $h_l = \sum_k w_k/d$ to estimate the future hopcounts to S_j, and assume there is no change in ν and ψ. It is interesting to study how the errors from hop count estimation impacts our delivery performance in our future work. The expected reward of any message message can then be computed as:

$$\mathbb{E}_{ij} = \sum_{l=1}^{D} 2^{c_{ij}} \times \mathbb{R}(n+h_l, \nu, \psi), \tag{18}$$

where D is the number of possible subscribers, both of them can be derived from $\mathbb{V}_i$ and $\mathbb{Q}_i$ in N_i's Feasible Path Set.

Algorithm 1 Incentive Driven Forwarding

```
Require: Message $m$, $forwardNode \leftarrow null$
  for $neighbornode$ interested in $m$ do
    $sendMessage(m, node)$
  end for
  if $nexthopList(m).size \neq 0$ then
    $expReward \leftarrow calExpReward(m, thisNode)$
    for all $nexthop$ in the list $nexthopList$ do
      if $expReward < calExpReward(m, nexthop)$ then
        $expReward \leftarrow calExpReward(m, nexthop)$
        $forwardNode \leftarrow nexthop$
      end if
    end for
    if $forwardNode \neq null$ then
      if $forwardNode$ is in communication range then
        $sendMessage(m, forwardNode)$
        return
      end if
    end if
  else if $thisNode = sourceof(m)$ then
    for all $node$ in the communication range do
      $sendDataMessage(m, node)$;
    end for
  end if
  return
```

2) Dissemination Scheme: Our multicast-efficient incentive compatible forwarding scheme is described in Algorithm 1. In our scheme, a node always firstly tries to transmit any message carrying a message to any node who has interest in the message. Furthermore, we denote Feasible Next Hop Set of a message as $nexthopList(m)$ in Algorithm 1, which are the next-hop nodes of all feasible paths to any subscriber of the message currently present in node N_i's Feasible Path Set. For each node in the Feasible Next Hop Set, node N_i will compute its expected reward by using the Equation (18), and see which next-hop node (say Node N_j) yields the maximum reward. If this maximum reward for forwarding to N_j is larger than that without forwarding, and N_j is within the communication range of N_i, then that message will be decided to be forwarded.

To guarantee deliveries and limit overhead, only publishers are allowed to forward their own messages to any node that they encounter when there is no next-hop node in its feasible next hop set of the message. We argue that such design is reasonable since publishers are also considered to be selfish, which means they would like to disseminate the copies of their own information as much as possible.

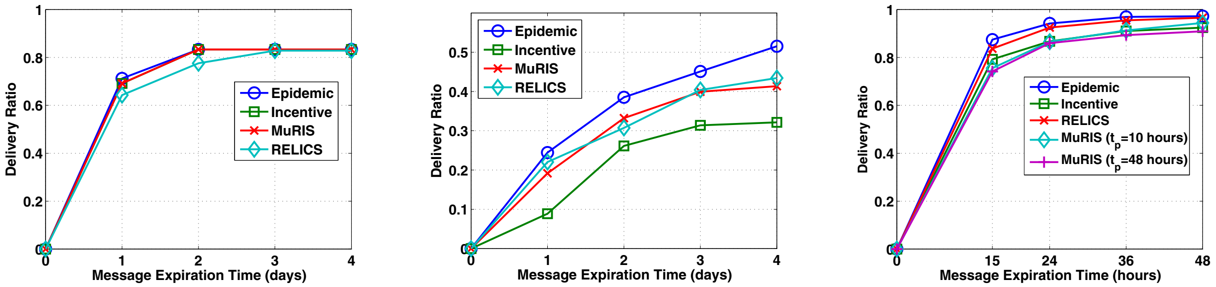
V. EVALUATION

We evaluate our proposed multicast efficient incentive driven forwarding scheme using the Opportunistic Network Environment (ONE) simulator [32], which is a trace driven simulator specially designed for DTN environment. In this section, we first describe our simulation methodology, followed by the comparison and discussions.

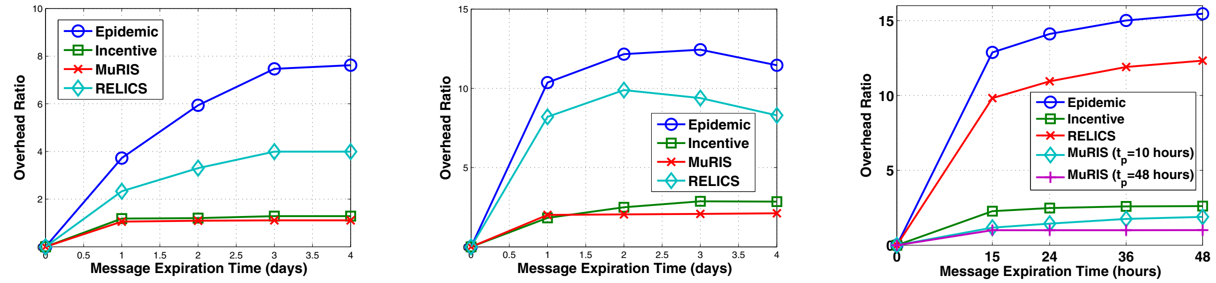
A. Simulation Methodology

To show the effectiveness of MuRIS, we utilize two real human contact-based traces, *MIT-trace* from MIT reality mining experiment [20] and *Infocom-trace* from the Haggle project [21]. The MIT-trace is collected with smart phones carried by 97 participants on MIT campus over a 6-month period, while the Infocom-trace is collected from 41 iMotes distributed to Infocom05' attendees. Each trace contains information about the IDs of the devices within the communication range of each other, and the starting and ending times of their encounters. For the MIT-trace, we use the first 8 days of the trace for our simulation. In particular, we use the first day trace as the data for our warmup period, where nodes build the knowledge of subscribers and construct feasible path sets for our dissemination scheme. The rest of the 7-day trace is used for the evaluations of different dissemination schemes. Similarly, we use the first 8 hours of the Infocom-trace as the warm up period and the rest, i.e. around 2.5 days for the evaluations of MuRIS and comparison of performance between different schemes.

In addition, we note that nodes in the MIT-trace form different communities [23], [33] based on their contact frequencies. We design two scenarios to study the impact of having publishers/subscribers coming from the same/different communities: (1) Scenario 1: we randomly select both publisher(s) and subscriber(s) of a particular data channel from the same community; (2) Scenario 2: we randomly select both publisher(s) and subscriber(s) of a particular data channel from different communities. Therefore, the contact rates between



(a) MIT-trace Scenario 1 (b) MIT-trace Scenario 2 (c) Infocom-trace



(d) MIT-trace Scenario 1 (e) MIT-trace Scenario 2 (f) Infocom-trace

Fig. 3. Performance comparison with 6 subscribers per channel using MIT-trace Scenario 1 (high contact rate), MIT-trace Scenario 2 (low contact rate), and Infocom-trace.

publishers and corresponding subscribers are high in Scenario 1 and low in Scenario 2. We also observe that nodes within the Infocom-trace frequently meet with each other due to the small geographical area, and therefore the contact rate between publisher and subscribers is high with the Infocom-trace.

We compare MuRIS with three existing schemes: *Epidemic*, *RELICS*, and *Incentive*. The implementation of these schemes in our work is provided as below:

Epidemic. In this scheme, messages are simply flooded when a node encounters another node. Because every node blindly replicates messages in the network, the epidemic scheme maximizes the possibility of success delivery of messages in networks with uncertain connectivity (i.e., DTNs).

RELICS [17]. This is an incentive-based forwarding scheme built upon PROPHET [34]. Our RELICS implementation does not include the energy adaptation feature since this is not the focus of our work. However, we did extend RELICS to multicast scenarios for comparison.

Incentive Forwarding [19]. This is a recently proposed incentive-based dissemination scheme for DTNs. Every node in this scheme maintains an interest-based contact probability to predict future encounters with other nodes of a certain interest preference. When two nodes encounter, descriptions of messages carried by each node are exchanged first. Based on the descriptions, both nodes make decisions whether or not to forward messages to each other.

B. Experiment Setup

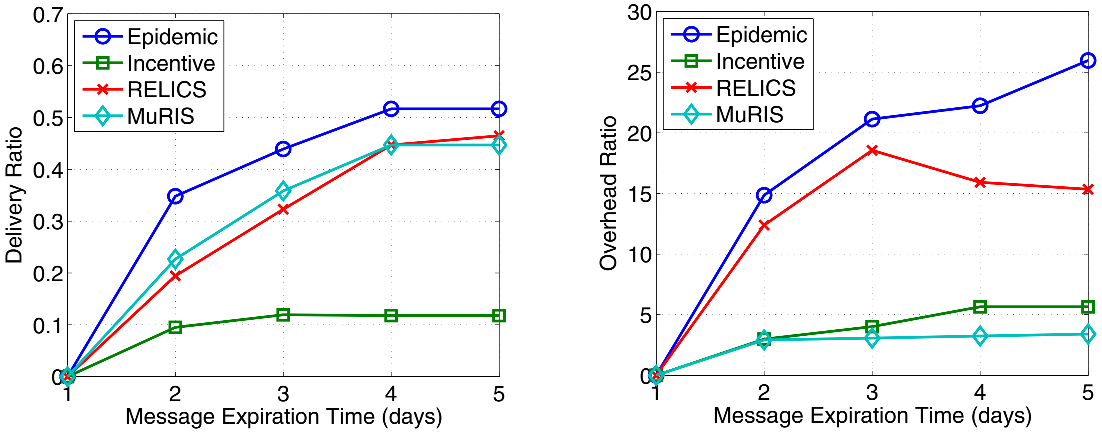
We use the following default settings for our simulation studies: there are three publishers in the network, each publishing messages belonging to a particular data channel. The interarrival time of a new message is uniformly distributed in the range $[140s, 180s)$. Each publisher starts generating messages after the warmup period, and stops generating after 1000 items have been published. We set the storage size of each node to be $100M$bytes (which can store $70K$ messages, each with an average size of $2.5K$bytes) so that there will be no message losses due to limited storage size. The bandwidth available at each node is $250kbps$ which is about 30 messages per second. We focus our study on the efficiency of the different dissemination schemes. We vary the number of subscribers for each data channel to study its impacts on the delivery performance. The publishers and the subscribers are randomly selected, and each presented result is the average of 10 simulation runs.

The following metrics are used to compare different dissemination schemes:

- **Delivery Ratio**: the proportion of messages that have been delivered out of the total unique messages created.
- **Average Delay**: the average time that is used to deliver messages to corresponding subscribers. We consider the delay time of undelivered messages as the time that they have been staying in the network by the time our simulation stops.
- **Overhead Ratio**: the ratio of the total number of messages relayed over the total number of unique messages delivered.

C. Performance Comparison

1) Effectiveness of MuRIS: Figure 3 presents the simulation results of the MIT-trace and the Infocom-trace as we vary the message expiration time from 1 day to 4 days for the MIT-trace and 15 hours to 48 hours for the Infocom-trace. From Figure 3 (a), (c), (d), and (f), we observe that MuRIS has the lowest overhead ratio of all schemes. The overhead ratio of MuRIS is 50% less than that of Epidemic and RELICS schemes. In addition, the MuRIS achieves similarly high delivery ratio as the other three schemes for both traces. Our results



(a) Delivery ratio

(b) Overhead ratio

Fig. 4. Performance comparison with 3 subscribers per channel using MIT-trace Scenario 2.

clearly show that MuRIS can effectively achieve good delivery ratio without incurring large overhead for different traces. This is because by using the feasible path set, MuRIS scheme is aware of multicast-efficient paths to reach subscribers, thus the number of copies of a message in the network is minimized. Although the Epidemic scheme has the highest delivery ratio, it also has the highest overhead ratio due to its blind replication strategy. The overhead ratio of the RELICS scheme is less than that of the Epidemic scheme but is still much higher than the Incentive and MuRIS schemes.

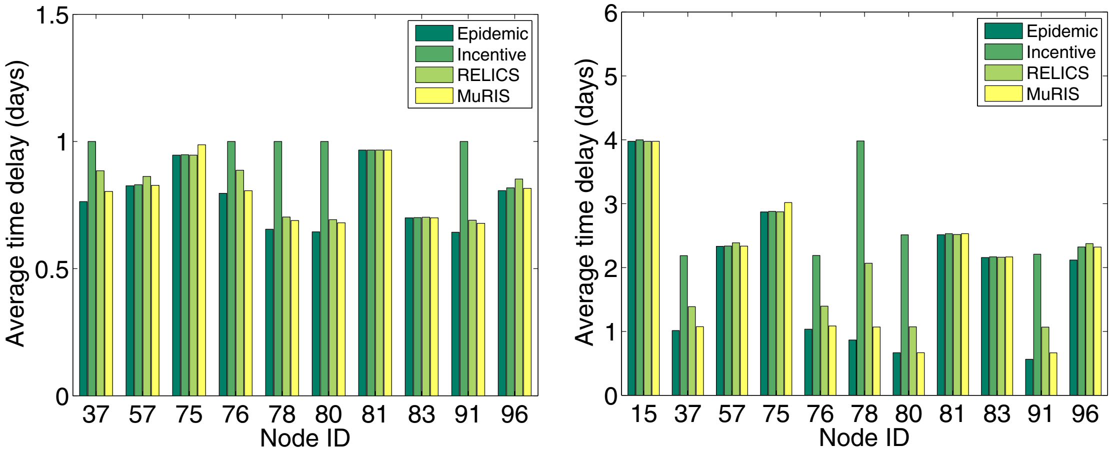
Additionally, Figure 3(b) and (e) show that even in the situation that a publisher does not contact subscribers frequently, MuRIS can still maintain a much lower overhead ratio (more than 50% less) than the RELICS and Epidemic schemes while achieving a similar delivery ratio. Although the Incentive scheme has a very similar overhead ratio to the MuRIS scheme when the message expiration time is 1 day, the MuRIS scheme has 50% more successful deliveries than the Incentive scheme. This is because the Incentive scheme has a restrictive relay strategy and its performance degrades when nodes are sparse in the network.

2) Impact of Number of Subscribers per Channel: We also studied the impact of having different subscribers per data channel. Figure 4 plots the delivery ratio and overhead ratio of four forwarding schemes using the MIT-trace with 3 subscribers and 1 publisher from different communities (Scenario 2) in each data channel. Compare to the results in Figure 3(b) and (e), we observe that for both 3 and 6 subscribers scenarios, the MuRIS scheme has a high delivery ratio that is the closest to the Epidemic scheme, and its overhead ratio is always the lowest.

Another interesting observation is that the Incentive scheme performs poorly in the scenario with smaller number of subscribers in the network. Figure 4(a) shows that the Incentive scheme has a low delivery ratio. This is because in the Incentive scheme, nodes either receive the messages they are interested in from other nodes, or exchange messages that they are not interested in based on EICP of packets. Therefore, if a node does not carry any message and is not interested in any message, it is not able to help to relay messages, hence the delivery ratio is limited. Such limitation only exists when subscribers are sparse in the network. The Incentive scheme can achieve similar delivery ratio as other schemes with more subscribers in the network as shown in Figure 3. However, from Figure 4(b) we observe that the MuRIS scheme still achieves compatible delivery ratio with the lowest overhead ratio for the 3 subscribers scenario. Although the Incentive scheme has similar overhead ratio as the MuRIS scheme in Figure 3(e), the MuRIS scheme achieves lower overhead ratio if we merely consider those messages that are successfully delivered in both schemes.

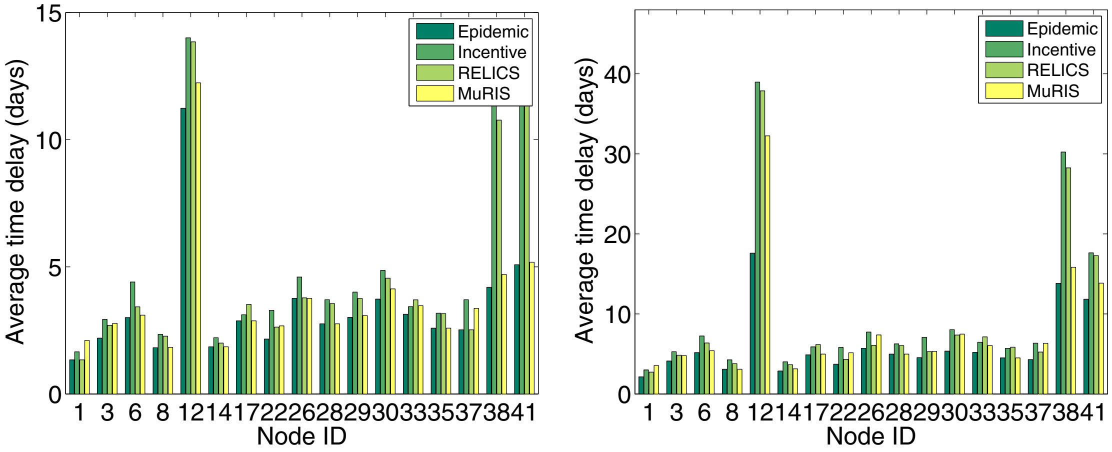
3) Latency Comparison: We further studied the average delivery latency of the four dissemination schemes with different scenarios. Figure 5 presents the distribution of the average delay in the MIT-trace Scenario 1 when the message expiration time is 1 day and 4 days, and the Infocom-trace when the message expiration time is 5 hours and 48 hours. In MIT-trace, the MuRIS scheme has a much lower average delay for most subscribers than the Incentive scheme does. Comparing to the RELICS scheme, the MuRIS scheme has a similar average delay while its overhead ratio is much lower than the RELICS scheme in Figure 3(e). Moreover, in the Infocom-trace, the MuRIS scheme has the lowest average delay for most subscribers than both the Incentive scheme and the RELICS scheme do. This indicates that the MuRIS scheme chooses appropriate delivery paths that can reach subscribers faster and yet with fewest total transmissions in terms of the lowest overhead ratio illustrated in Figure 3(e). The Incentive scheme has a much longer average delay as a result of its restrictive replication strategy. we also observe that the Epidemic scheme always achieves the shortest delay due to its blind forwarding nature. However, the overhead of the Epidemic scheme is the highest compared to the other dissemination schemes.

4) Maximum Cache Time of Paths: In addition, we study the impact of t_p, the maximum cache time of paths. In particular, we compare the performance of MuRIS by applying two different t_p, 10 hours and 48 hours, in the simulation using the Infocom-trace. As shown in Figure 3(c), we find that MuRIS achieves similar delivery ratios for the cases with $t_p = 10$ hours and $t_p = 48$ hours. This indicates that a scenario with high contact rate between nodes (e.g., the



(a) Expiration time = 1 days, MIT-trace Scenario 2

(b) Expiration time = 4 days, MIT-trace Scenario 2



(c) Expiration time = 5 hours, Infocom-trace

(d) Expiration time = 48 hours, Infocom-trace

Fig. 5. Distribution of average delay with 6 subscribers using MIT-trace and Infocom Trace.

Infocom-trace) is not sensitive to the cache time of paths. Moreover, Figure 3(f) shows that MuRIS also achieves the lowest overhead ratio when $t_p = 48$ hours. This is reasonable since many delivery paths repeat themselves in the Infocom-trace. We suspect that the communication overhead of MuRIS can be further reduced by using a longer maximum cache time of paths.

VI. CONCLUSIONS

In this work, we have proposed an incentive driven dissemination scheme called MuRIS that not only encourages nodes to cooperate but chooses delivery paths that can reach as many subscribers as possible with fewest transmissions. The wise choice of delivery paths is achieved via our proposed multi-receiver based incentive mechanism. Furthermore, our charge and rewarding functions not only thwart edge insert attacks but also allow us to achieve high network efficiency. MuRIS exploits locally maintained node encounter history and historical path information to construct Closeness Vector and Feasible Path Set. Simulation studies using human-contact based traces show that MuRIS outperforms other existing schemes in achieving high delivery ratio with low overhead ratio. MuRIS performs especially well when the publisher and subscribers come from different communities. Additionally, it will be interesting to explore the impact of feasible path set or the closeness vector on the delivery performance of individual nodes.

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