Incentive Driven Data Sharing in Delay Tolerant Mobile Networks

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Abstract— This work focusses on data dissemination in delay tolerant mobile networks. The important roles in our daily life are played by Mobile wireless devices, e.g., Such devices are often used by users for being in touch with the friends like to take pictures andshare with friends and for bank transactions via opportunistic peer-to-peer links. Store and forward feature is adopted in Delay Tolerant Network since the links are intermittent in nature. Selfish nodes with rational behaviour is considered due to limited resources i.e, Communication bandwidth and battery consumption and are not willing to forward data items to other devices. This can be overcome by adopting effective data dissemination schemes to encourage nodes that can collaboratively share data.In this paper, Multi-Receiver Incentive-Based Dissemination (MuRIS) is proposed in which the nodes are allowed to deliver information cooperatively to another via chosen delivery paths in which few transmissions are utilized.A scheme known as credit-based incentive is proposed to promote nodal collaboration considering the selfish nodes with rational behaviour.

Key words: Incentive mechanism, publisher/subscriber, delay tolerant networks, data sharing, mobile networks.

I. INTRODUCTION

This paper focuses on data dissemination in a mobile wireless networks. The figure of the data dissemination networks is depicted in Fig.1. With this rapid advancement, mobile wireless devices such as smartphones, PDA's and laptops have emerged.Since these devices support multiple network interfaces including cellular, WLAN and Bluetooth,these devices allow people to access information anywhere at any time. This system exploits free, low-power, short range radio (e.g., Wifi or Bluetooth) that is commonly available on phones, PDAs, and laptops that establishes an intermittently connected mobile network for data transmission. The connectivity of the network is dynamic and very low due to unrestrained nodal mobility and short radio communication range where only occasionally a node connects to other nodes forming a delay-tolerant network.

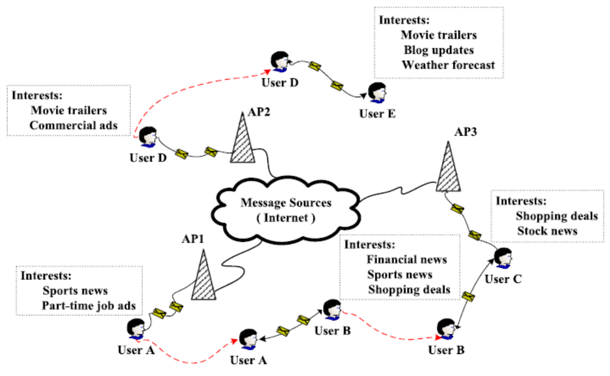


Fig. 1. An example of data dissemination.

Thus, besides using these devices only for the purpose of making calls or sending text message, users can utilize these devices for storing interesting data items like sports events, finance forecast, and trending tweets. Even though these cellular data services are available almost everywhere, continuously using these services to access information is quite expensive because of the energy consumption which is too high.As such the data items which are stored can be categorized into various fields such as entertainment, finance, politics and technology. Users are able to acquire the data items from their respective peers by their interests based on the either data categories [5], [6], [7]. Although schemes like content dissemination have been proposed for Mobile Adhoc networks e.g, [5], [8], [9], [10], these approaches usually have assumed that the networks are well connected. However due to the shorter radio range of interfaces such as WIFI and Bluetooth, the connectivity between such interfaces is both dynamic and intermittent. Technologies like Delay tolerant networking technology [11], [12], [13], [14] has been proposed to allow nodes to still communicate in such environments by storing data packets when connectivity disappears and exchanging stored packets once connectivity reappears. In addition to this, traditional schemes like content dissemination do not consider users changing interests from time to time.Thus new dissemination schemes[15] is expected to address the intermittent connectivity issue and to be user-centric. Cooperation should be there among the participants in order to enable smooth information sharing in delay tolerant mobile networks. The users will be selfish and wish to preserve their devices resources such as communication bandwidth and battery power since such networks are typically human contact based networks. Thus, in practice, an incentive or reputation mechanism is to be incorporated to encourage users to cooperate for effective information sharing. The existing systems [16], [17], [18] have been designed for unicast scenarios Selfish nodes are effectively encouraged by these nodes to help relay other's packets, but however their achieved transmission efficiency may be degraded in multicasting scenarios in which they are represented as publish/subscribe systems for delay tolerant mobile networks as multiple users will be using the same data.A recently proposed incentive-aware data dissemination [19] is a promising approach for multi-receiver scenarios. However the incentive mechanism focusses on rewarding the last-hop relay node which communicates with the destinations that is not fair for all other relay nodes. And moreover among nodes, if the data items are sparsely distributed due to its respective replication mechanism, the performance of the incentive mechanism [19] is degraded.

The aim of this work is to design a Multi-Receiver Incentive - based Dissemination (MuRIS) scheme that wisely select paths that can efficiently reach multiple subscribers along with encouraging nodes to cooperate via our proposed incentive mechanism. Addition to that, MURIS scheme also incorporates charge and reward function that stimulate the cooperation among nodes such that the edge insertion attacks will not be launched. Extensive simulation studies using real human contact-based mobility traces show that our MuRIS scheme outperforms existing methods in terms of delivery ratio and transmission efficiency. These simulation studies show that our scheme outperforms existing methods in terms of delivery ratio and transmission efficiency.

Specifically a multi-receiver based charge and rewarding functions that would favour the paths which can reach more subscribers at intermediate hops is proposed. It is further shown that the charge and rewarding function s can prevent edge insertion attacks. With these attacks the approach is made easier for relay nods to obtain extra incentives without obvious misbehaviours. These attacks significantly impact the fairness of the network since the subscribers need to pay more total rewards. Addition to this, other honest relay nodes on the same delivery path receive fewer rewards than the relay node launching the edge insertion attack. The charge and rewarding function which we have adopted provide no rewarding gain for adversarial nodesin which the fake insertion nodes are inserted during insertion attacks. Moreover, it can be shown that our information sharing scheme allows nodes to utilize locally maintained information about past node encounters and partialyy delivery paths that determines if they should forward received data items they encounter such that the chosen delivery paths are those that efficiently reach many subscribers to other nodes. The effectiveness of MURIS can be evaluated by using 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 the MURIS is compared with the existing data dissemination approaches. From the simulation results it can be shown that our approach can achieve high delivery ratios similar to the Epidemic scheme (where nodes simply re-broadcast whatever they receive) while a low overhead ratio in different scenarios is maintained.

The performance is extremely well if the publisher and subscriber come from different communities.

II. RELATED WORK

The effective schemes for providing the content distribution services in delay tolerant networks is explored by the active researches. For example, ContentPlace [22] designed the dynamically learned information about users' social relationships to determine where to place data objects in order to optimize content availability. 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 is published by MOPS [23]. Similarly, a social-aware forwarding scheme which utilizes user interests and their similarity to assist making is described by SANE [24]. . In all the above mentioned 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. These schemes allow each node to operate distributively on the basis of the locally gathered information. Furthermore, a social centrality metric by considering social contact patterns and interests of users simultaneously to achieve efficient content disseminations is proposed by Gao and et.al. [15].In all the above works mentioned, it is assumed that the users are cooperative and do not refuse to forward data item to others. However in real world scenarios, this assumption is not always true, especially in human contact based networks, since wireless devices have limited resources provided by opportunistic links. Thus cooperation among nodes can be induced by providing an incentive mechanism. Mobicent[16] is a credit-based incentive system that is developed in delay tolerant networks developed for delivering unicast messages. The Mobicent system offers a charge and rewarding functions that encourage intermediate nodes to cooperate and prevent them from launching the edge insertion and edge hiding attacks. The another scheme called cooperative-based mechanism to combat selfishness in DTN's is RELICS[17] in which a rank metric defined to measure the transit behaviour of node. Higher cooperation is offered by the nodes with higher rank. The above mentioned two incentive based schemes focus more on the delivery of unicast messages, while, here themore importance is given to one-to-many communication pattern, which is typical in publish/subscribe system. The most relevant study to our work is proposed in which an incentive based forwarding scheme is developed to relay the last hop relay node. This scheme is proposed by Ning and et.al. [19], in which every node computes its effective interest contact probability (ECIP) for each data category, in which the probability is calculated that this node contacted a node interested in the corresponding data category either directly or indirectly. Upon encountering each other, the data messages can be exchanged between the two nodes based on the calculation of ECIP to maximise their own expected credit rewards. Under this, a node is unable to receive to any data items from other nodes it encountered, unless the data item is of interest if it doesn't have any messages from nodes. Thus such design is 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] assumes that the senders will be paying rewards to relay nodes for successful deliveries. This work uses similar incentive based forwarding scheme. In [26], in order to get rewards from senders, relay nodes can trade virtual checks. Similar to [19], if the data items are sparsely distributed among the nodes, then the performance in [26] is also degraded. Being different from other previous studies, our MURIS scheme can achieve better delivery ratio in networks where data items are sparsely distributed among nodes. Addition to this, our scheme can thwart insertion attacks too launched by selfish intermediate nodes.

III. MODELS

A. Network model:

Each network consists of various nodes which represents a user in the network who carries a mobile device with multiple wireless devices including WLAN, cellular and Bluetooth. Nodes are considered with the same transmission and reception ranges. When the two nodes encounter, the bandwidth of each node is large enough to process the data exchanges when two nodes encounter. A non-homogeneous mobility model is adopted to describe the non-homogeneous mobility model, i.e, each different pair of nodes has a different contact rate and contact duration. Furthermore, it can be considered that the message delivery paths from the source node to destinations may repeat frequently. Similarly in the project called Haggle project, users are the participants of Infocom conference who meet each other frequently in the same hotel. According to the repeatability of delivery paths, the historical paths in DTNs are still useful although the frequency varies much. The nodes in the network are assumed to be authenticated when they join the network. To support 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 each node will take to deliver a data item to that node.The same reward is been shared by every node in a delivery path. The rewards are based on the final RSS and RNS values whenever a message is been delivered to subscriber. Any subscriber in the delivery path will also have to pay relay nodes in its delivery path. Addition to this, each node is considered to be selfish, which means that it will not help to relay the data, unless it is benefitted with some gain.i.e, for example, some "money" that can be used to stimulate other selfish nodes' cooperation in future.It is assumed that there is a central transaction server offering secured service, which guarantees that each node can collect their rewards weekly or monthly.

B. Data model:

Data items can be organized into various categories. And each category can also be divided into sub categories. A more comprehensive data model can be found in [25]. In this work, a simplified channel-based model [1], [22], is used where the information is organized in different channels to which users can subscribe.

C. Publisher/subscriber(user):

In this work, each node can be made a subscriber or a publisher or both. Each publisher is able to publish data items that belong to different channels. Further, each subscriber will be having an interest list indicating the channels in which the subscriber is interested in.

D. Messages:

Three types of messages can be defined in our system:

1) Probe messages

These messages are used to record possible paths from publishers to subscribers. They are only forwarded when the nodes have been idle for a while or during warmup.

2) Receipt messages

Receipt messages are only generated by the subscribers. It is just passed to confirm the path information carried within a newly received probe message.

3) Data item Messages

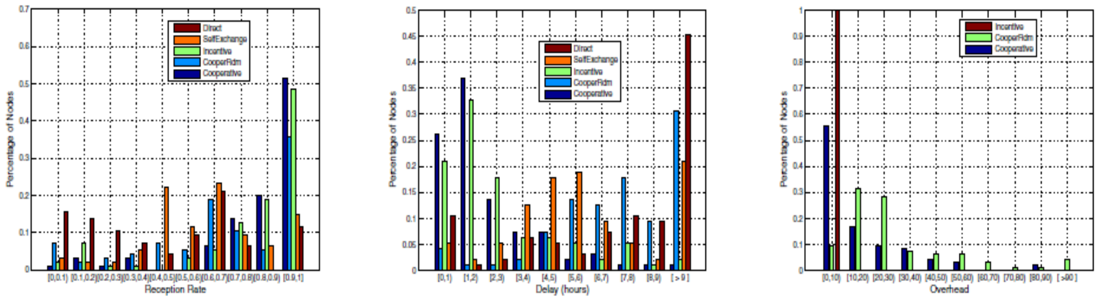
These messages are generated by publishers to distribute data contents in the network.

IV. SIMULATION RESULTS

To evaluate our proposed incentive mechanism, we have carried out simulations. In this section, first simulation setup is introduced followed by performance comparison and discussions.

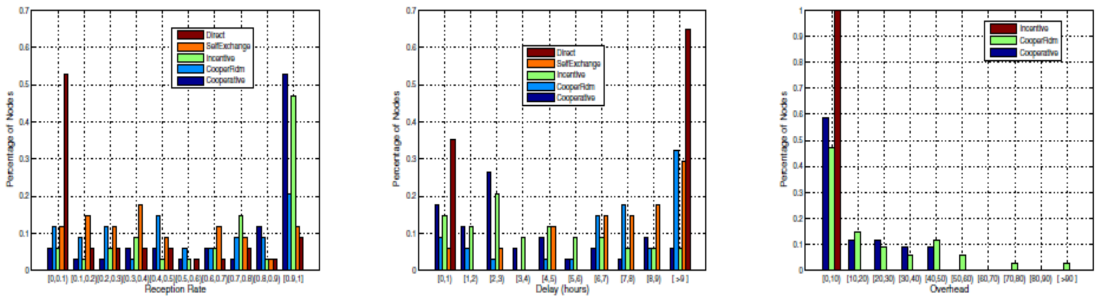
A. Simulation setup:

Due to the uniqueness of the network setting, thye mechanisms that described in II are not comparable



(a) Reception Rate Distribution. (b) Delay Distribution. (c) Overhead Distribution.

Fig. 2. Distribution of reception rate, delay and overhead under the Haggle Trace.



(a) Reception Rate Distribution. (b) Delay Distribution. (c) Overhead Distribution.

Fig. 3. Distribution of reception rate, delay and overhead under the DieselNet Trace.

with our scheme. Different schemes are compared by varying the degree of cooperation of nodes: the "Direct" scheme where there exists no cooperation among nodes and thus a node can only download its interested messages from corresponding APs; where a node is able to obtain its interested messages from an AP or a mobile node but does not carry any message that is out of that is not of its interest; the "Cooperative" scheme, where nodes are fully cooperative and always choose the most valuable messages to carry after satisfying its own interests; and our proposed incentive scheme (denoted by "Incentive"). Trace data of the Cambridge Haggle project [24] and UMass DieselNet project [25] are employed in our simulations, which represent human social networks and vehicular networks, respectively. In the Haggle project, mobile nodes called iMotes were distributed to 50 people attending IEEE INFOCOM workshop. Its datasets include contacts between iMotes and Bluetooth devices. We adopt the dataset which involves 98 iMotes and Bluetooth devices and run the simulation for a total period of 342, 915 seconds (or 3 days). In the UMass DieselNet project, a DTN testbed is constructed by 30 –40 transit buses, serving an area of approximately 150 square miles. The trace data provides contact events between buses. Our simulation is based on the trace data obtained in 2006 with 37 buses [26] for a period of 1, 250, 847 seconds (or about two weeks). As the default setting of our simulations, we assume there are three APs and 15 interest types in the network. The message generation rate of the source is one message per 100 seconds. The queue size of each node is 100 messages. The values of α and β in Eqs. (1) and (2) are both 0.1, which are the best to reflect the impact of the historic status. We randomly choose some nodes as the APs and average the results over 10 simulation runs. Our goal is to disseminate data messages to corresponding sinks with both delay and traffic overhead as low as possible. In our simulation studies, we are interested in the following metrics for performance evaluation: the network-wide data delivery rate, the distribution of nodal reception rates, the average delivery delay, and the message forwarding overhead. The network data delivery rate is defined as the ratio of the total number of delivered messages to the total number of messages that should be disseminated to the network. The reception rate of a node is the ratio of the total number of its interested messages received to the total number of such messages generated by the sources. The average delivery delay is a measure of how long a node waits to get an interested message. Message forwarding overhead is a cost factor, defined as the communication cost of a delivered message. Lower overhead means fewer transmission traffic inthe network.

B. Performance comparison:

The comparison of the overall performance of different schemes based on Haggle trace and the DieselNet trace is shown in Tables I and II respectively. They both show that the Cooperative scheme achieves the highest network data delivery rate, followed by Incentive, CooperRdm, SelfExchange and Direct schemes.

TABLE I
OVERALL PERFORMANCE COMPARISON BASED ON HAGGLE TRACE.

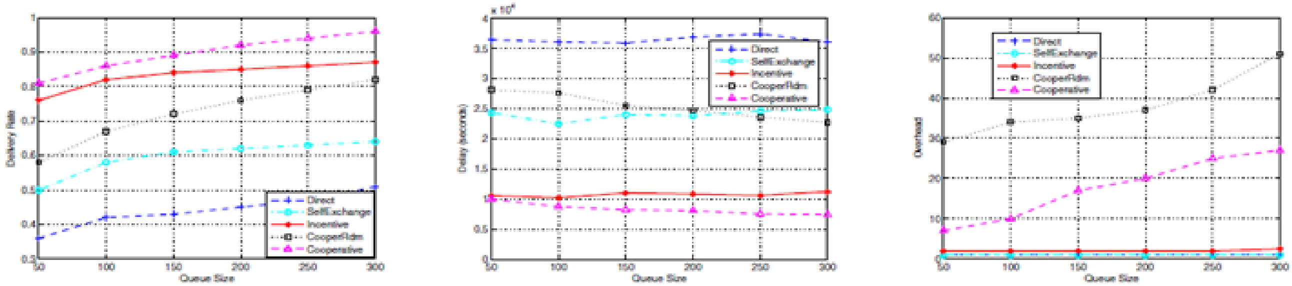
	Data Delivery Rate	Delay	Overhead
Direct	0.42	36109s (10.1h)	1
SelfExchange	0.58	22510s (6.25h)	1
CooperRdm	0.67	27653s (7.68h)	34
Incentive	0.82	10238s (2.84h)	2
Cooperative	0.86	8764s (2.43h)	10

TABLE II
OVERALL PERFORMANCE COMPARISON BASED ON DIESELNET TRACE.

	Data Delivery Rate	Delay	Overhead
Direct	0.27	56850s (15.7h)	1
SelfExchange	0.48	34696s (9.6h)	1
CooperRdm	0.59	38615s (10.1h)	22
Incentive	0.70	13684s (3.8h)	3
Cooperative	0.76	11810s (3.3h)	9

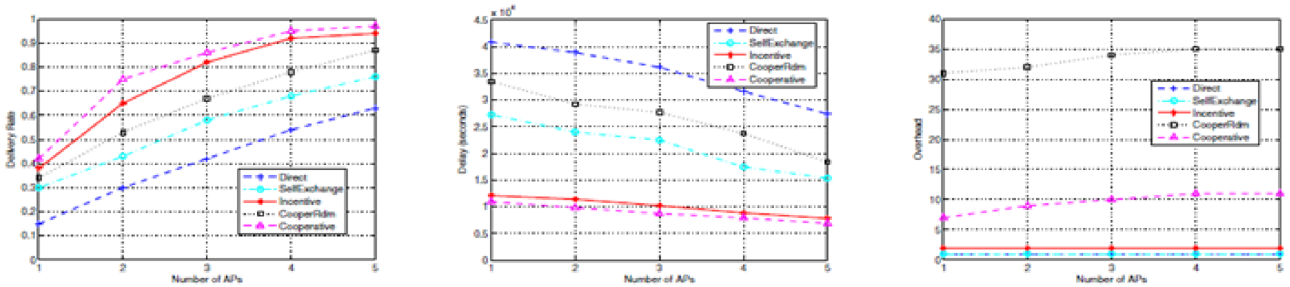
The highest delivery rate of the Cooperative scheme is attributed to the fact that the nodes are altruistic to help each other by always choosing the most valuable messages to carry after satisfying its own interests, thus the chance of a message being delivered to the interested nodes therein is the highest among all schemes. At the same time, we notice that although the CooperRdm scheme is also fully cooperative and nodes are willing to carry others' messages for free, its delivery rate is much lower than the proposed Incentive scheme, serving as an evidence of the importance to exploit the estimated value of a message to make an appropriate decision on whether or not to carry it, especially under limited storage resources. In our proposed Incentive scheme, the estimated value of messages effectively fosters cooperation among nodes and makes efficient use of communication resource (that is determined by the capacity of nodes and their meeting opportunities), thus leading to higher delivery rate. Finally, if messages are simply forwarded at random, the chance for its delivery is low.Since the nodes in the SelfExchange scheme only exchangetheir interested messages and refuse to carry messages of other nodes' interests, the message dissemination is greatly hindered, resulting in a low delivery rate. Similarly, nodes under the Direct scheme do not cooperate at all, resulting in the lowest delivery rate. The average delays of Cooperative and Incentive schemes are much shorter than other schemes, because both of them leverage the message value to estimate the probability to deliver the message and choose the best routes to forward it, thus delivering the message in a shorter time. Although the delivery rate and average delay of Cooperative scheme are better than the Incentive scheme, we can see that the former has a much higher overhead than the latter, because its altruism leads to more messages to be duplicated and distributed in the network. In a contrast, the proposed Incentive scheme achieves very low overhead, since a node receives a message copy only if it is confirmed that this copy can benefit it. Clearly, the overhead of Direct and SelfExchange is always one, because a node only receives its interested messages. Figs. 2 and 3 illustrate the distribution of reception rate, average delay and overhead among nodes, under the Haggle trace and the DieselNet trace, respectively. The overhead of Direct and SelfExchange are omitted because they are always one as discussed above. Fig. 2 shows that about 48% of nodes under the proposed Incentive scheme can receive more than 90% of their interested messages, compared with 11% in

Direct, 13% in SelfExchange, and 35% in CooperRdm. Although 52% of nodes in Cooperative achieve higher than 90% of reception rate, it is at the cost of 30% of the nodes with overhead greater than 20. This indicates that those nodes always play the role of relays and contribute much more than others to the network. In a sharp contrast, the proposed Incentive scheme stimulates the cooperation among nodes and allows a node to strike the balance between its individual interests and contribution to the network. As a result, none of the nodes have their overheads greater than 10. As shown in Fig. 2(b), about 56% of nodes in the Incentive scheme receive the interested message in less than 2 hours, while the average delay of more than 20% of nodes in Direct, SelfExchange and CooperRdm schemes is greater than 9 hours. Similar trend is observed in Fig. 3, i.e., the results under the DieselNet trace. The impact of queue size is illustrated in Fig. 4. With the increase of the queue size, the data delivery rate of all schemes improves. Particularly, the delivery rate of Cooperative and CooperRdm increases significantly. This is because longer queue size allows them to buffer more data messages that can be exchanged and delivered later, thus increasing the delivery rate. At the same, their average delay decreases. The accompanying side effect is the rapidly increasing overhead. On the other hand, the increase of queue size has less impact on the performance of the proposed Incentive scheme, becauseit exchanges messages based on interests of individual nodes, aiming to promote rewards. Thus the nodes do not aggressively utilize the additional queuing space. Fig. 5 shows the performance of different schemes by varying the number of APs. All APs are connected to thesources (e.g., via the Internet) that generate messages at a certain rate. Increasing the number of APs means that nodes can have more opportunities to access data sources and update their message buffers. This explains why the delivery rate of all schemes increases and the average delay decreases in Figs. 5(a) and 5(b). We also note that the average delivery rate of Cooperative is only about 3% better than the proposed Incentive scheme, while the overhead is about 5 times higheras shown in Fig. 5(c). It means that the exchange process in Incentive greatly reduces the transmission cost and at the same time maintains a preferable delivery rate and average delay. Fig. 6 compares the performance by varying message generate rate. As shown in Fig. 6(a), with the increase of message generate rate, the delivery rate of Direct, SelfExchange and CooperRdm decreases, while the delivery rate of



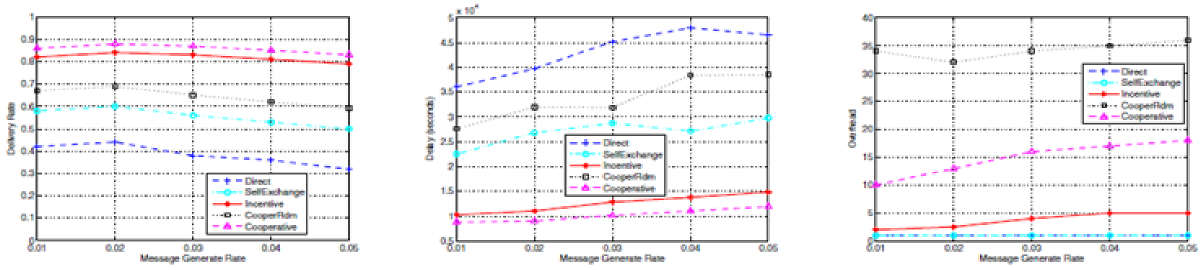
(a) Delivery Rate. (b) Delay. (c) Overhead.

Fig. 4. Variation of queue size.



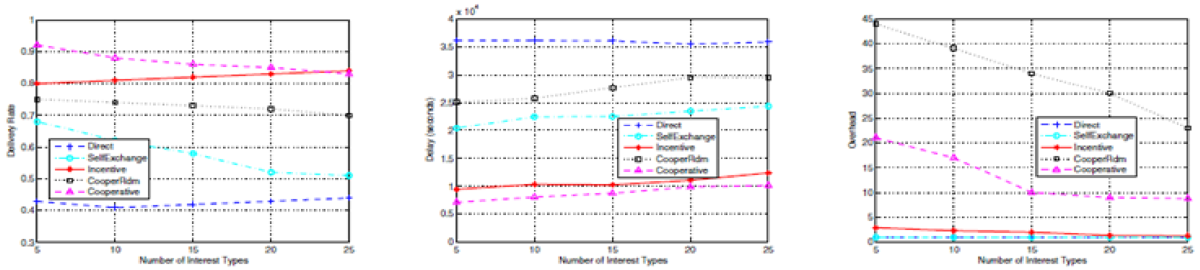
(a) Delivery Rate. (b) Delay. (c) Overhead.

Fig. 5. Variation of the number of APs.



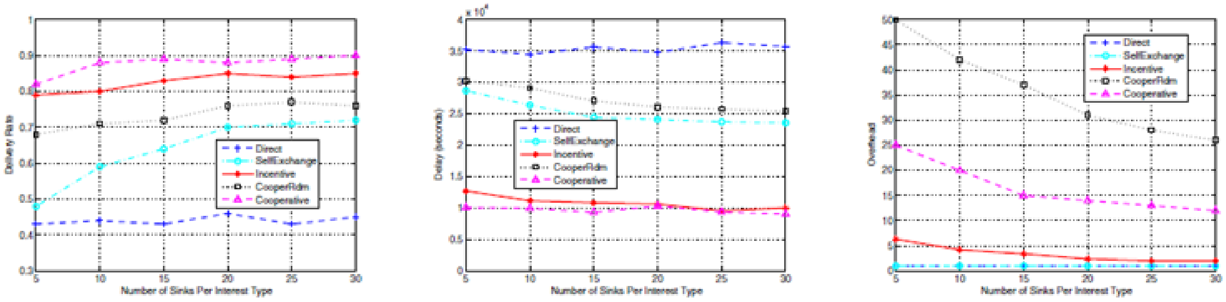
(a) Delivery Rate. (b) Delay. (c) Overhead.

Fig. 6. Variation of data message generate rate.



(a) Delivery Rate. (b) Delay. (c) Overhead.

Fig. 7. Variation of the number of interest types.



(a) Delivery Rate. (b) Delay. (c) Overhead.

Fig. 8. Variation of the number of sinks per interest type.

Incentive and Cooperative is stable. A higher generate rate means that more messages are generated by the sources. The more messages the sources generate, the higher workload the network must carry. If nodes don't contribute much to the network, such as in the Direct and SelfExchange, more messages would reside at sources and can't be disseminated to corresponding sinks in an acceptable delay time, thus resulting in decreasing delivery rate. In the Cooperative scheme, nodes are trying to distribute messages as many as possible and contribute their buffers and energy altruistically. That's the reason it can maintain the delivery rate stable. One might wonder why the delivery rate of the proposed Incentive scheme does not decrease. The reason lies in that fresh messages always have greater values and selfish nodes are willing to get those valuable ones in order to maximize their rewards. The cost of maintaining the delivery rate is the increasing overhead as shown in Fig. 6(c), since more messages are duplicated during their transmissions. With the increase of message generation rate, delay increases as demonstrated in Fig. 6(b). Given the limited resources at individual nodes, the higher the generate rate, the longer the messages need to reside at the sources and intermediate nodes, leading to longer average delay. Fig. 7 depicts the impact of the number of interest types in the network. We assume each node can have at least one and up to N interests, where N is the max number of interest types. Fig. 7(a) shows that, with the increase of the number of interest types, the delivery rate decreases under SelfExchange, CooperRdm and Cooperative scheme, but increases slightly in the Incentive scheme. This is because cooperation between nodes in Incentive improves the possibility of delivering messages to each other when nodes have more interests. We observe in Fig. 7(b) that the average delay of all schemes slightly increases except the Direct scheme. From Fig. 7(c), we notice that the overhead of the proposed Incentive scheme is stable. This is because a node only chooses the most beneficial messages to trade and never wastes its resources to free-riders. Fig. 8 illustrates the impact of the number of sinks per interest type in the network. Each interest type can be associated with multiple nodes. The more nodes in one interest type, the more overlapped interests two nodes may have. As the number of sinks per interest type increases, delivery rate increasesslightly, while the delay and overhead decrease, as illustrated in Figs. 8(a), 8(b) and 8(c), respectively. The reason is that with more common interests between nodes, there is a higher chance that a node can get its interested messages from others and thus the messages are disseminated in a shorter time.

V. CONCLUSION

In this work we have studied the problem of data dissemination in delay-tolerant mobile networks. We have considered selfish nodes with rational behavior, and proposed a creditbasedincentive scheme to promote nodal collaboration. The key challenge is to effectively track the value of a message under such a unique network setting with intermittent connectivity and multiple interest types. These characteristics make the development of incentive mechanism a unique, interesting and challenging problem. In this paper, we have presented effective schemes to estimate the expected credit reward, and formulated nodal communication as a two-person cooperative game, whose solution has been given by the Nash Theorem. Extensive simulations have been carried out based on realworldtraces to evaluate the proposed scheme in terms of data delivery rate, delay and overhead. To our best knowledge, this is the first work that incorporates incentive stimulation into data dissemination in delay-tolerant mobile networks with selfish nodes and multiple interest types.

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