How to Improve the Performance in Delay Tolerant Networks under Manhattan Mobility Model

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***Abstract*—Delay Tolerant networks (DTNs) are one type of wireless networks where the number of nodes per unit area is small and hence the connectivity between the nodes is intermittent. In this case, the performance in terms of transport of information from source to destination relies on the mobility of the nodes which would cause their encounters and hence the relay of information from one node to another as well as on the routing protocol that is deployed. There exists several mobility patterns, each yielding a different performance of the network. In this work, we show first that the Manhattan mobility pattern performs worse than other widely-used ones, such as Random WayPoint. In the second part of this work, our aim is to propose and evaluate a new proposal, based on the deployment of fixed relays, so as to enhance the performance of Manhattan.**

***Index Terms*—DTNs, mobility models, Manhattan, routing.**

I. INTRODUCTION

Delay Tolerant Mobile Networks (DTMNs) [2], also termed Intermittently-Connected Mobile Networks (ICMNs) are wireless ad hoc networks, where the nodes themselves form the network, and where the number of nodes is low per unit area which makes connectivity intermittent and the transport of information highly dependent on the mobility of the nodes, along with underlying forwarding, replication and routing mechanisms [3].

Despite of their decisive impact, most of the works that target the evaluation of performance of such networks consider, however, one type of mobility pattern only [4] [5] [6] [7].

The study made in [8] did couple mobility with routing protocols: it investigated DD, Epidemic, SW and PROPHET routing protocols under RWP and MapBased mobility models. But they did only consider random mobility models. And indeed, because of their simplicity, random mobility models are widely used by most of the works. They however fail to represent the real behaviour of the nodes in the network and hence the results are not always realistic.

In [1], we investigated several routing protocols, namely Direct Delivery (DD), Epidemic, Spray and Wait (SW), PROPHET and MaxProp, under different mobility patterns: Random Way Point (RWP), Graph-Based Mobility Model (GBMM), Smooth Random Mobility Model (SRMM) and Manhattan Mobility Model (MMM). These mobility models span to a large extent the broad spectrum of realistic scenarios, ranging from simple, random models, to more complex, deterministic ones. In particular, we have shown that the Manhattan mobility model performs worse than all other mobility models in terms of the message delivery ratio defined as the number of messages that reach the destination divided by the total number of messages that are sent from the source to the destination.

Based on this observation, our goal in this work is to propose an enhancement, based on the use of fixed relays, so as to improve the DTN network performance under the Manhattan mobility pattern.

II. MANHATTAN MOBILITY MODEL

Mobility models can be classified into several classes based notably on their dependency (or not) on space and time. Random mobility models for instance are one class with no dependencies on space and time. Space-dependent models are ones in which nodes mobility may be constrained by some geographic constraints such as streets or highways. Temporal models are ones in which nodes mobility is affected by its history. Others mobility classes include trace-based models or survey-based models [9].

The Manhattan Mobility Model (MMM) [10] considers all dependencies: spatial and temporal. It makes use of a map to confine movement on roads (see Fig. 1).

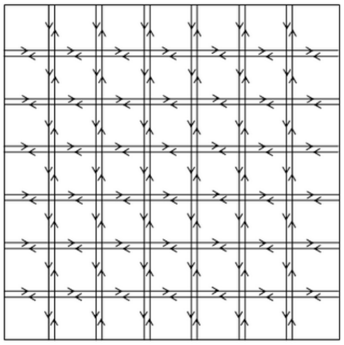


Fig. 1. Map used for Manhattan mobility model

This map simulates an urban environment and is composed of a number of horizontal and vertical streets which have two lanes, one for each direction. The node is free to move on horizontal and vertical streets. Arriving to an intersection, it can turn left or right with probability equal to 0.25 or go straight with probability 0.5. Moreover, nodes move according to a temporal correlation. Also, the node's speed is constrained by the speed of the front node in the same lane [10].

III. SIMULATION SETTING

A. Mobility Models

To illustrate the performance of the DTN under the Manhattan mobility model, we compare the performance of the latter with other, widely-used mobility models, namely:

- Random Way Point (RWP) [11] is the most widely used mobility model. Node movement is free of restrictions, both temporal and spatial. Despite of its conceptual simplicity, it may not be able to mimic realistic mobility
- Graph Based Mobility Model (GBMM) [12] performs as RWP but it constrains the node movement to a connected graph
- Smooth Random Mobility Model (SRMM) [13] enhances RWP by adding a temporal dependency where speed is changed incrementally in a smooth fashion

B. Routing Protocols

To carry out the comparison between the used mobility models, we consider the following routing protocols:

- Direct Delivery (DD) [3] is the simplest protocol: the source waits to meet the destination to forward the message
- Epidemic routing [6] is based on the message flooding: when two nodes meet, they exchange the messages they do not have
- Spray and Wait (SW) protocol [7] is composed of two phases: in the Spray Phase, L message copies are spread to L distinct relay nodes and, in the Wait Phase, each node carrying a copy of the message would only forward it to the destination
- Probabilistic ROuting Protocol using History of Encounters and Transitivity (PROPHET) [4] defines a delivery metric computed at every node for each known destination dependent on the node encounter frequency. The message is sent to the encountered node if the delivery metric of the message destination is high
- MaxProp [5] defines message priority based on the path likelihoods to the destination which is function of node encounter probability. Messages ranked with highest priority are the first to be transmitted

C. Performance metrics

We also define the following performance metrics that will make it possible to quantify the performance of the investigated mobility models.

Let N denote the number of nodes that compose the network. Assuming that an encounter between two nodes occurs when they come within communication range of each other, we define the following mobility-oriented metrics:

- $\bar{E}$: mean number of encounters which counts the average number of encounters performed by one node. $\bar{E} = \frac{1}{N}\sum_{i=1}^{N} e_i$ where e_i is the number of encounters for node i
- $\bar{C}$: mean number of contacts which counts the average number of nodes encountred by one node. $\bar{C} = \frac{1}{N}\sum_{i=1}^{N} c_i$; where c_i is the number of encountered nodes for node i
- $\bar{D}$: mean duration of encounters which counts the average duration of encounters. $\bar{D} = \frac{1}{N}\sum_{i=1}^{N}\frac{\sum_{k=1}^{e_i}\Delta t_{ik}}{e_i}$ where Δt_{ik} is the duration of encounter number k for node i

In addition, we define the following performance-oriented metrics:

- Delivery ratio $DR = \frac{\sum_{i=1}^{N} R_i}{\sum_{i=1}^{N} G_i}$; where R_i and G_i are the number of received and generated messages respectively
- Delivery delay $Dd = \frac{\sum_{j=1}^{R} D_j}{R}$; where $R = \sum_{i=1}^{N} R_i$ and D_j is the delay of the received message j
- Buffer occupancy ratio $BR = \frac{\sum_{i=1}^{N} B_i}{N}$; where B_i is the average ratio of the buffer occupancy for node i

D. Network setting

Let the network size be 50 nodes, the simulation area be $3000m \times 3000m$ and the transmission range be 250m. Speeds of 3, 10 and 60 km/h are used to simulate the mobility of pedestrians, mobile sensors and cars, respectively. A 12h simulation time is used so as to observe mobility on a large time scale. The map used for Manhattan mobility model is shown in Fig. 1. For each simulation, we generate 20 scenarios, based on [14] and [15].

As of the other parameters, we consider that a message is generated by one node each 50 second and is destined to one node among the 49 remaining ones, at random. Each message has 1 KByte size and 3000 second Time To Live (TTL) value. Each node has a 5 MByte buffer capacity. The link layer has a rate of 2 Mbps. For SW, L is fixed to 10.

Eventually, our simulations are carried out on the Opportunistic Network Environment (ONE) simulator [16].

IV. PERFORMANCE OF MANHATTAN

A. Observations with respect to mobility metrics

Figs. 2 and 3 show the mobility metrics: the number of encounters, the number of contacts and the encounters duration, as a function of the three considered speeds for the considered mobility models.

We, first, observe that the number of encounters increases and their duration decreases with the respect to speed (Fig. 2(a) and (c)). This is expected because as the nodes move more and more quickly, they would encounter each other more frequently but for a shorter duration. Indeed, RWP, GBMM and SRMM follow this trend, albeit some differences. RWP and GBMM act similarly and so they lead to the same observed figures: mean number of encounters from 160 at 3km/h to about 2200 at 60km/h, and mean encounter duration from 3,5mn at 3km/h to 0,2mn at 60km/h. SRMM presents, however, temporal correlation and hence the number

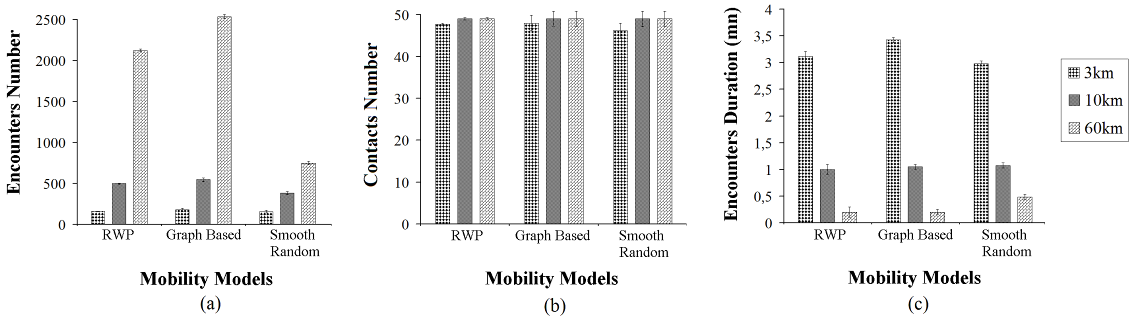


Fig. 2. RWP, GBMM and SRMM: number of encounters (a), number of contacts (b) and encounters duration (c)

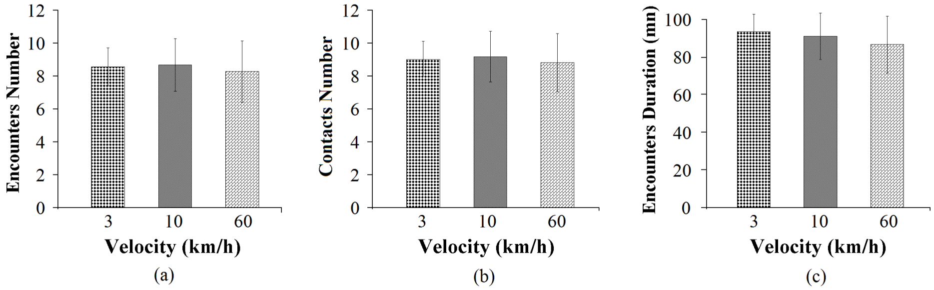


Fig. 3. Manhattan: number of encounters (a), number of contacts (b) and encounters duration (c)

of encounters and their duration have a smoother variation: from about 160 for 3km/h to 750 for 60km/h for the number of encounters, and from about 3mn for 3km/h to about 0,5mn for 60km/h for the duration. Moreover, with respect to the 12h observation time, the mean number of contacts reaches the maximum value of 49, i.e., N-1 for RWP, GBMM and SRMM (Fig. 2(b)).

This is not the case for the Manhattan model.

Fig. 3(a) shows that, for Manhattan, the mean number of encounters is invariant with respect to speed and has actually a small value (about 9) compared to the values obtained for RWP, GBMM and SRMM. Moreover, the contacts number metric has the same behaviour and values as the first metric as shown in Fig. 3(b). As the number of encounters is small, the encounter duration is large. This fact is observed in Fig. 3(c) where each encounter lasts about 90mn on average. So, the nodes moving in Manhattan tend to do so in groups: each node encounters the same number of nodes (given by the same, small values of encounters and contacts) and keeps the link with them for a large period of time (large value of the encounter duration).

This conclusion is closely related to the definition of the Manhattan model. In effect, this model considers a realistic mobility behaviour: First, the nodes movement is constrained by a map, as shown in Fig. 1. Second, the node velocity at time $t + \Delta t$ depends on its speed at time t. Finally, the node's velocity depends on the front nodes' velocities too.

B. Observations with respect to performance metrics

Figs. 4 and 5 show the delivery ratio, delivery delay and buffer occupancy ratio as a function of the 3km/h and 60km/h speeds and DD, Epidemic, SW, PROPHET and MaxProp routing protocols for the considered mobility models.

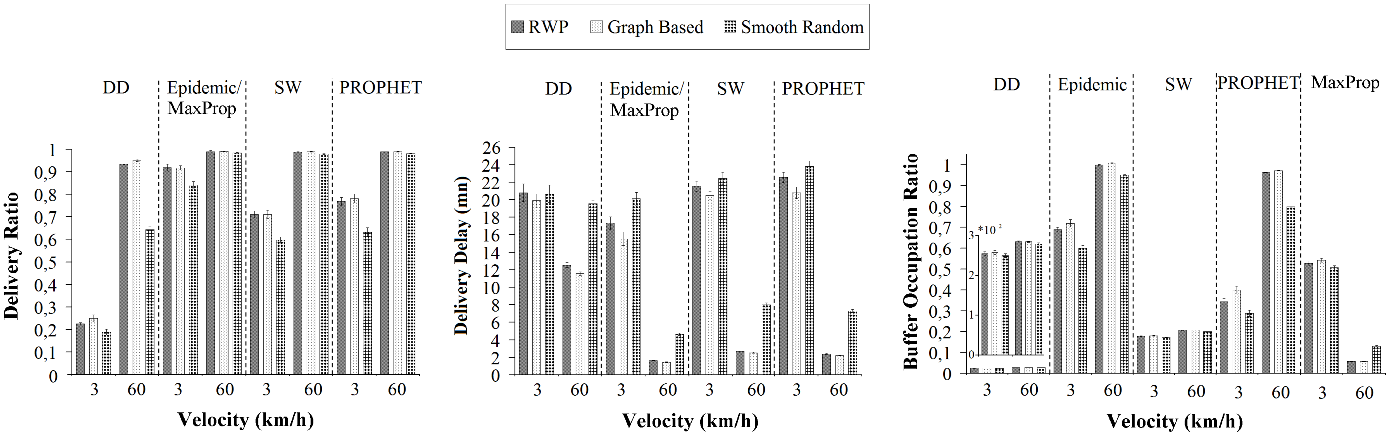
We first note that Epidemic and MaxProp perform similarly in terms of delivery ratio and delay because they make use of flooding and best path selection mechanisms respectively and they do not have buffer constraints.

In addition, we observe that the delivery ratio increases and the delivery delay decreases with respect to speed, and this for RWP, GBMM and SRMM (around 0,25 for 3km/h to 1 for 60km/h for the delivery ratio and around 24mn for 3km/h to 7mn for 60km/h for the delivery delay). Moreover, we observe that the rate of increase or decrease of those performance metrics depend on the routing protocol. (Figs. 4(a) and (b))

Furthermore, the buffer occupancy ratio increases or decreases with respect to speed for protocols that rely on flooding or path selection mechanisms respectively, such as Epidemic or MaxProp respectively (around 0,6 for 3km/h to around 1 for 60km/h for the Epidemic case and around 0,5 for 3km/h to around 0,05 for 60km/h for the MaxProp case). (Fig. 4 (c))

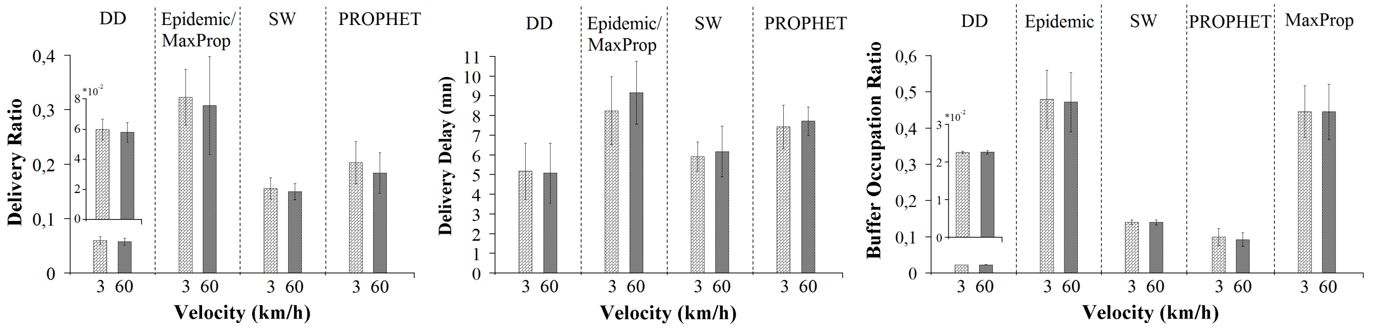
We can see clearly that the results are closely related to the encounter process (number of encounters and their duration which is large enough to allow total message transfer and number of contacts) and routing paradigm. In fact, the more the nodes encounter different nodes, the more the delivery opportunities increase. And so, the delivery ratio increases and the delivery delay decreases; the buffer occupancy increases or decreases depending on whether the flooding or the path selection mechanisms are used, respectively.

Here too, the case of the Manhattan model is quite different from other mobility models. In fact, as shown in Fig. 5(a), in



(a) (b) (c)

Fig. 4. RWP, GBMM and SRMM: delivery ratio (a), delivery delay (b) and buffer occupancy ratio (c)



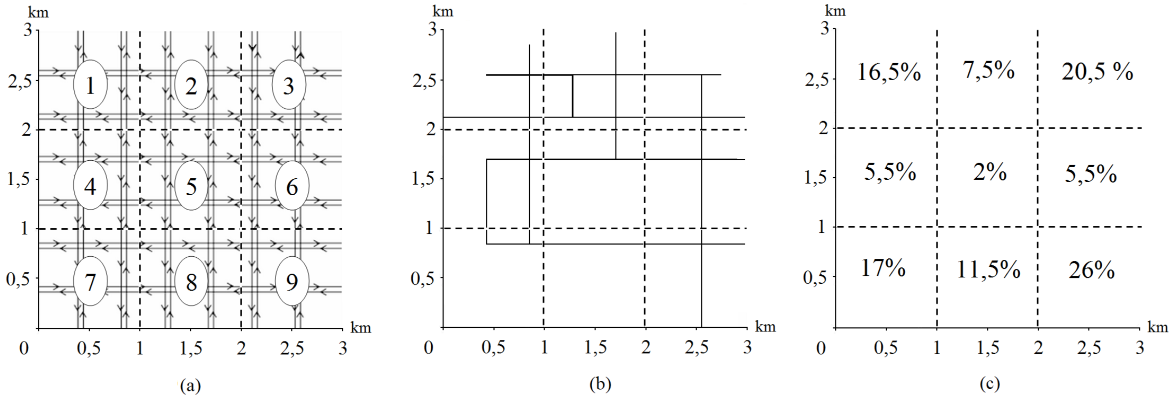
(a) (b) (c)

Fig. 5. Manhattan: delivery ratio (a), delivery delay (b) and buffer occupancy ratio (c)

the case of Manhattan, the delivery ratio does not exceed the value of 0,35 for Epidemic and MaxProp protocols (the best case), and the value of 0,06 for DD (the worst case). The delivery ratio does not decrease much with speed. As of the buffer occupancy, as shown in Fig. 5(c), the values do not exceed 0,5 for Epidemic and MaxProp (the worst case), and the value of 0,03 for DD (the best case). Those values are closely related to the encounter process. The less the frequency of the encounters, the less the number of message exchange and hence delivery. The small variation in the delivery ratio is caused by the small variation in the encounter process too. Since messages must be transmitted from the source to the destination directly in the DD protocol, the delivery and buffer occupancy ratios are the lowest in this case. Epidemic is based on flooding, and so, it obtains the largest values for these metrics. As SW works between the Epidemic and DD cases, the values of the performance metrics are between the values obtained for those two protocols. For PROPHET, as it is based on local mobility information, it presents a better delivery ratio than SW but lower than MaxProp, and a better buffer occupancy than those two protocols.

For MaxProp, buffer occupancy is as in the case of Epidemic routing. The reason is that, in this case, there is more routing information (routing overhead) shared between nodes to decide of the selected path to the destination. PROPHET and MaxProp use both mobility information, they present, however, different buffer occupancy ratios; better values are obtained for the first one. The reason is that PROPHET is based on the encounter history and MaxProp is based on the future encounter process. With Manhattan, the encounter process is invariant with respect to time and speed, the information kept from past is more useful than that of the future. Hence, in this case, MaxProp uses excessively the buffer resources.

As of delays, the Manhattan model seems to be not too bad, as shown in Fig. 5(b). In fact, delays do not exceed the value of 10mn. The reason is that the delivered messages are those delivered within the shortest time. Indeed, with Manhattan, each node moves in a group of the same nodes (9 on average as shown in Figs. 3(a) and (b)). And so, the small number of delivered messages corresponds to the ones shared between the nodes of the group. And hence, the delays of those messages are low. For Epidemic and MaxProp, the number of delivered messages is larger than other routing protocols. And so, the mean delivery delay grows because large delays correspond to those supplementary delivered messages. In addition, for MaxProp, additional delays stem from path calculation and routing overhead. The same case is observed for PROPHET. For DD, delivered messages are those shared between sources



(a) (b) (c)

Fig. 6. Simulation areas (a), Sample of node position trace for 3km/h (b) and Percentage of number of nodes that do not go through each simulation area (c)

and destinations which meet directly. SW shows delays between Epidemic and DD as it operates between those two protocols.

V. PROPOSAL

A. Closer look at Manhattan

To better understand the performance of Manhattan, we now divide the simulation area of $3000m \times 3000m$ into nine, $1000m \times 1000m$ simulation areas, as shown in Fig. 6(a). For each simulation run, we extract, for each node, all its positions during the whole simulation time of 12h and compute the number of nodes that go through each simulation area.

We define a new statistical mobility metric, $P_{nc,l}$, as the percentage of nodes that do not cross simulation area l, $l = 1, ..., 9$. We have, for a total number of N nodes:

$$P_{nc,l} = \left(\frac{N \; - \; number \; of \; nodes \; cross \; l}{N}\right) \times 100$$

Fig. 6(b) shows the trace of the positions of a random node for a mobility scenario with 3km/h speed. For 10km/h and 60km/h, each node goes through all the simulation areas. Fig. 6(c) shows the average values of the P_{nc} metric for 20 simulation runs, for all simulation areas, with 3km/h speed.

As shown in Fig. 6(c), only 2% of the nodes in the network do not go through the central simulation area (zone 5). This area attracts hence all the nodes of the network; all the areas around area 5 have higher P_{nc} values, between 5,5 and 26%.

B. Proposal description

In order to improve the performance of Manhattan, we propose to add some fixed relay nodes whose role is to receive messages from other nodes and forward them using the routing algorithm that pertains to the network. This would, in turn, enhance the delivery ratio of the messages as it increases the delivery opportunities, i.e., when a relay node receives a message from one node and forwards it to yet another one, it is as if those two nodes did encounter each other, whereas in reality, they did not.

In the case of Manhattan, the density of the nodes is, both spatially and temporally, unbalanced with respect to the considered areas. The spatial imbalance is well observed at low speed as shown in Fig. 6(c). At high speeds, all nodes visit all simulation areas; the temporal imbalance is, however, more apparent in this case. This refers to the fact that the nodes pass through the simulation areas at different times. Our aim is, hence, to balance the node density by adding dedicated, relay nodes.

The next question is where to install those relay nodes. By reference to Fig. 6(c), we propose to install them in zone 5, i.e., the area with highest P_{nc} where nodes least pass. Assuming that relays too have the same transmission range as other nodes of the network, this yields the deployment scenario shown in Fig. 7.

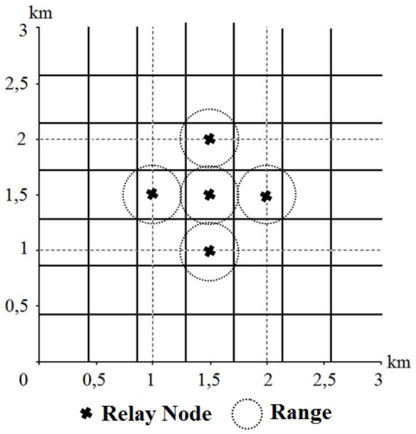


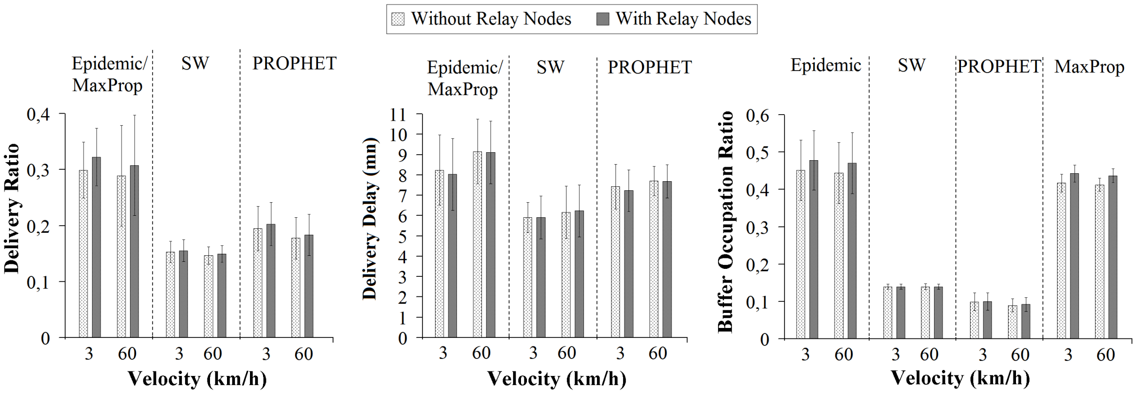
Fig. 7. Position of relay nodes

C. Performance of our proposal

We now turn to the analysis of the simulation results of our relay-based proposal.

Fig. 8 shows the delivery ratio, delivery delay and buffer occupancy, considering the four routing protocols: Epidemic, SW, PROPHET and MaxProp, for the case of Manhattan, without and with the use of relays.

Please note that we have omitted the Direct Delivery routing protocol, because, in this case, the source keeps the message



(a) (b) (c)

Fig. 8. Delivery ratio (a), delivery delay (b) and buffer occupancy ratio (c) in function of routing protocols and velocity for Manhattan without and with relay nodes.

until it encounters the destination and so relays do not play any extra role.

For the remaining routing protocols, we first observe that both the delivery ratio and buffer occupancy increase whereas the delivery delay decreases using relay nodes. Indeed, with relays, the number of delivered messages increases because those relay nodes increase the delivery probability of messages by duplicating them to others nodes following the routing protocol strategy. This is coupled with a decrease in the delivery delay. As of the buffer occupancy, it increases due to fact that the number of copies of the messages increases.

In addition, we observe that the enhancement is best for Epidemic and MaxProp routing protocols. The reason behind this is that the presence of relay nodes improve the flooding and path selection mechanisms, especially that these relay nodes are fixed.

Despite of the enhancement in the network performance brought by the relay nodes, the new metric values, especially the delivery ratio, are still low. This is due to the limited message life time. In fact, the temporal balance role of the relay nodes is affected by the message life time: to be able to play their role, relay nodes must keep the message for a long period of time which allows them to encounter a large number of nodes. As this period is limited by the message TTL, the latter dictates the average number of encounters with the relay nodes. And so, with a suitable, rather large, value of TTL, the impact of the relay nodes on the performance of the network is even larger.

VI. CONCLUSION

The work contained in this paper is motivated by the importance of the encounter process in the performance of DTNs, in terms of information delivery. This encounter process is highly dependent on the mobility pattern, along with routing, forwarding and replication mechanisms. We have, first, shown the quite poor performance of the Manhattan mobility model, as compared to other widely-used ones: Random Way Point, Graph-Based Mobility Model and Smooth Random Mobility. We have, second, proposed the introduction of fixed relays in order to alter the encounter process by increasing the delivery opportunities. This, in turn, yields higher delivery rate, lower delivery delay, at the cost of higher buffer occupancy.

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