Towards Opportunistic Data Dissemination in Mobile Phone Sensor Networks

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***Abstract*—Recently, there has been a growing interest within the research community in developing opportunistic routing protocols. Many schemes have been proposed; however, they differ greatly in assumptions and in type of network for which they are evaluated. As a result, researchers have an ambiguous understanding of how these schemes compare against each other in their specific applications. To investigate the performance of existing opportunistic routing algorithms in realistic scenarios, we propose a heterogeneous architecture including fixed infrastructure, mobile infrastructure, and mobile nodes. The proposed architecture focuses on how to utilize the available, low cost short-range radios of mobile phones for data gathering and dissemination. We also propose a new realistic mobility model and metrics. Existing opportunistic routing protocols are simulated and evaluated with the proposed heterogeneous architecture, mobility models, and transmission interfaces. Results show that some protocols suffer long time-to-live (TTL), while others suffer short TTL. We show that heterogeneous sensor network architectures need heterogeneous routing algorithms, such as a combination of Epidemic and Spray and Wait.**

Keywords-data dissemination; opportunistic network routing; heterogeneous architecture; mobility model; delivery speed.

I. INTRODUCTION

Mobile phones are getting attention as means to collect data. Data gathering can take place in the background, where the mobile phone user once gave permission to do so (e.g., location tracking), or involves continued active user participation (e.g., friend applications, Foursquare, Crowd sourcing, etc.). Collecting data is particularly meaningful when performed by many phones simultaneously. In such a way, the measurements have significantly enhanced reliability and accuracy. Thus, monitoring safety in public spaces becomes a “natural” application for mobile phone sensor networking.

Wireless Sensor Networks (WSNs) have been taken into consideration to replace the existing Wired Sensor Networks, since WSNs provide a wide range of context-awareness for real-time applications at low costs. A variety of sensor types with dense deployment forms a connected wireless mesh network via low power, short-range radios, collaborating to acquire and transmit the target data to sink nodes [1]. But still, the cost of deploying all kinds of such required sensors is considerably high in terms of time and money.

The next step in sensor networks is to enhance, or even replace, wireless sensor networks with mobile phones. Thanks to developments in sensor technology, smart phones, such as the iPhone or Android-based phones, are equipped with a large number of sensors, including GPS, accelerometers, gyroscope, proximity sensors and cameras. But, even regular phones have sensors, although we might not realize they have them: microphones, light sensors, and onboard radios. Not all mobile phones can access 3G mobile internet, especially when a disaster happens, for example, an earthquake or tsunami. But, still mobile phones have the means to participate in the sensor network. Through WiFi or Bluetooth radio, mobile phones can collaborate with nearby ones or the existing infrastructure-based sensor network in the sensing network. As requiring a connected path from source to sink, traditional routing algorithms may perform poorly in scenarios where the communication path is disrupted due to damaged infrastructure or overload in the infrastructure. Opportunistic routing algorithms in Mobile Sensor Networks (MSN) have been proposed in a number of recent studies to evaluate the performance of routing algorithms on sensor data gathering [2][3][4][5]. However, these algorithms use either basic scenarios or simple simulation architectures that are still quite far from real-world applications.

This paper investigates the performance of existing opportunistic routing algorithms in a heterogeneous architecture. We consider heterogeneous means of communication, especially WiFi and Bluetooth. The proposed architecture includes most of real-world components such as Roadside Units (RSUs), buses, cars and pedestrians. To achieve a realistic setting, the architecture is mapped on a real city, the city of Enschede, Netherlands. In addition, a new mobility model will be introduced based on available Shorted Path Map Based model in The ONE simulator [6]. By means of simulations, the proposed architecture and mobility model are used for the comparison of opportunistic routing protocols.

The paper has the following structure: related work is discussed in Section 2. Section 3 presents the architecture, a new mobility model and evaluation metrics. The simulations and an analysis of simulation results are the subject of Section 4. Based on the results, Section 5 gives possible directions for current and future research.

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II. RELATED WORK

In this paper, we focus on performance of message delivery in opportunistic networks that are essentially comprised of the existing wireless sensor networks (intelligent lampposts) and the mobile sensor networks (flocks of mobile phones). The network can be characterized as intermittently connected and sparse mobility. Traditional wireless ad-hoc networks routing protocols require end-to-end connectivity for a data packet delivered. In other words, if the destination is not available on the connected path, the packet delivery will fail and no further effort is taken to secure future transmission of the data. Consequently, routing protocols must be adapted for these new networks. Numerous opportunistic routing algorithms have been proposed in the last few years with different mechanisms, which are generally categorized based on either the type of network (*without infrastructure* and *with infrastructure*) or the pre-known information of the networks (*Stochastic* and *Context-based*) [7]. These categorizations slightly overlap as depicted in Figure 1. If networks are sparse and most nodes possess unpredictable movement, the stochastic protocols are more appropriate. In our opinion, the context-based protocols are more suitable for our considered networks, since the global knowledge of fixed infrastructure and mobile infrastructure can be used to improve the routing performance.

Stochastic routing protocols deliver messages by simply disseminating them all over the network. Being passed from node to node, messages will be gradually delivered at the destination. Epidemic Routing [8] diffuses messages similar to the way virus/bacteria spread in biology. When encountering others, a node will replicate and broadcast the messages to them. These nodes that just received the messages will move to other places and continuously replicate and transmit messages to other nodes whenever they are in range of communication. Though increasing the possibility of message delivery, the method results in flooding the network, and rapidly exhausts available resources. Direct Delivery (DD) [9] only delivers the holding messages directly to the destination; therefore, DD saves huge amounts of resources but decreases significantly the delivery ratio. Spray and Wait (SnW) [10] is a tradeoff between multi-copy scheme (Epidemic) and single-copy scheme (Direct Delivery) by finding an optimal number of copies of messages and dividing the message delivery process into 2 phases (*spray phase* and *wait phase*). First Contact (FC) [11] is a variant of single-copy scheme, which sends messages to the first encountered node or a random node if there are more than one.

Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) [12] is a well-known Context-based routing protocol. PRoPHET estimates the delivery predictability for each known destination at each node before passing a message. The estimation relies on the history of encounters between nodes.

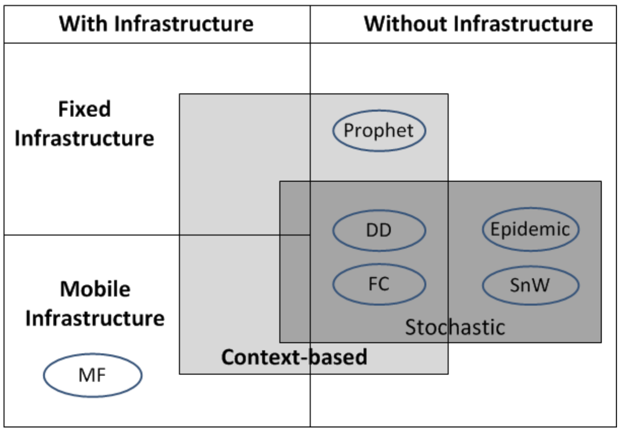

Figure 1. Categorizations of routing protocols in opportunistic networks.

A lot of attention has been given on how to apply above opportunistic routing algorithms in data dissemination for public safety applications. DTF-MSN [2] shows a scheme to gather information in the Delay/Fault-Tolerant Mobile Sensor Network based on an improvement of Direct Delivery and Epidemic. The proposal consists of two key components: queue management and data transmission. Queue management decides the importance of messages, and data transmission decides the node with high delivery probability to send messages to. However, the scenario used to evaluate the proposal has only one mobility model, where both source and sink are mobiles nodes, and is far from realistic for the public safety application domain. Camara et al. [3] present a good mechanism for the distribution of public safety warning messages, but the mechanism is limited to vehicle-to-vehicle and infrastructure-to-vehicle. The work uses only the basic Epidemic routing and there is no comparison with other routing protocols. A variant of Message Ferry (MF) [13] looks ahead at route information of ferries and then schedules messages to be exchanged based on the route information and the priority of messages. However, MF algorithm uses a simple architecture with only few fixed nodes (gateways) and mobile nodes (ferries). This algorithm is entirely constrained by the route and time schedule of ferries. Without the route information, the proposed routing algorithm will perform poorly. Recently, Keranen et al. [14] evaluate opportunistic networks with various mobility models and routing algorithms by using the ONE. Nevertheless, the used architecture does not include fixed infrastructure and the results only show the simulation speed.

This paper uses partially the ONE simulator [6] for simulations. The ONE includes several opportunistic routing algorithms and mobility models. The simulator also allows researchers to import their own maps and to configure the simulator with their own settings by many parameters, such as speed of mobility, message size, buffer size, and etc.

III. PROPOSED OPPORTUNISTIC MOBILE SENSOR NETWORK (OPPMSN)

Most traditional public safety applications are based on fixed and mobile wireless sensor networks and consider nodes to be connected. However, the very recent innovation of mobile phones with different kinds of onboard sensors and available low power consumption radios has brought on a new interest of using mobile phone as the main part of sensor networks. The network becomes an opportunistic network mainly comprised of the existing wireless sensor network and the mobile sensor network. Our proposal focuses on opportunistic mobile sensor networks for public safety applications.

A. Architecture

The considered opportunistic network is separated into several regions based on communities as shown in Figure 2. In order to link these regions, each of them has base stations equipped with long-range interfaces such as satellite, GSM, Internet. Each region consists of the following components: a fixed infrastructure, a mobile infrastructure (e.g., data mules) and mobile nodes.

- *Fixed infrastructure:* Road side units (RSUs) are deployed along main roads of the region. RSUs will be physically integrated in or fixed to the existing infrastructure, like lamppposts, GSM base station, or walls. RSUs form an ad-hoc wireless network, acting as a backbone, connecting mobile nodes with central servers or data sinks. The fixed infrastructure can also be used to disseminate information from central servers to the regions. The distance between RSUs is approximately 50 meters, using WiFi to build the network. There are two types of wireless interfaces for the RSUs, short-range Bluetooth and WiFi 802.11. Messages are transferred among RSUs through WiFi. The Wifi interface is also used to connect to buses, trams, cars, and smart phones. Bluetooth is designed for communication between RSUs and regular phones.
- *Mobile infrastructure:* Equipped with WiFi 802.11, busses and trams with known routes and known stops are considered as the mobile infrastructure in OppMSN applications. Since busses and trams move relatively fast, Bluetooth characterized by short-range (< 10 m) and low speed (< 2 Mbit/s) is not an appropriate option for busses and trams.
- *Mobile nodes:* The last component of the heterogeneous architecture consists of cars and mobile phones (used by pedestrians). There is no information of possible paths towards the sink because mobile phones and cars move unpredictably. Mobile phones are classified into either smart phones or regular phones. Smart phones typically have both WiFi and Bluetooth interfaces, while regular phones have only Bluetooth. For the same reason buses and trams use WiFi only, cars are equipped with WiFi.

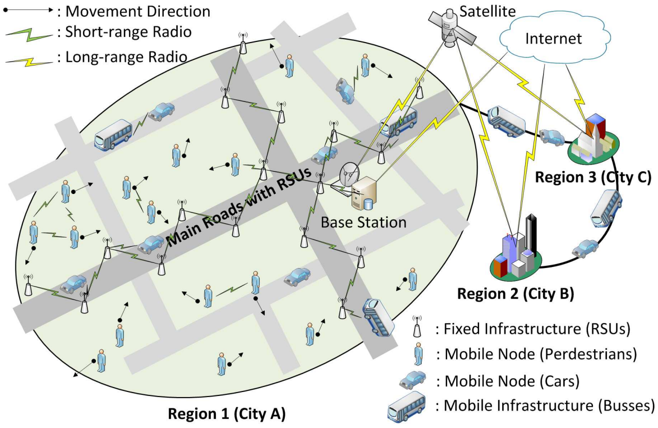

Figure 2. Architecture for Opportunistic Mobile Sensor Networks.

B. Architecture Performance Requirements

Depending on the physical characteristic, each of proposed components has a different degree of performance requirements such as reliability, throughput, latency, and electric power consumption. Fixed infrastructure has unlimited electric power supply, strong and stable signal strength, and large data storages. Therefore, latency and throughput are the most considerable performance requirements, and reliability and power consumption can be ignored. A message should be transferred as fast as possible via the ad-hoc connected network based on fixed infrastructure. Since the RSU network is not a sort of mesh networks, the bottleneck phenomenon probably decreases throughput and increases latency.

Mobile infrastructure, such as busses and trams, has no constraint on power supply, signal strength, and storage capacity. Thus, mobile infrastructure also has no problem with reliability and power consumption. As busses or trams play the role of messengers shuttling between sources and sinks in the network, latency depends significantly on velocity and distance. In addition, mobile infrastructure may become a bottleneck point because many passengers try to connect to a bus or a tram. As a result, the throughput of mobile infrastructure needs to improve as well.

Since mobile phones suffer limited power supply and intermittent connectivity, power consumption and throughput are the most critical performance requirements. Reliability is another considerable performance requirement because mobile nodes are sparse and dynamic. That some people are not willing to turn on the wireless interfaces all the time also makes the network less reliable. Moreover, velocity and unpredictable movement patterns of mobile nodes deter obtaining low latency and high throughput.

C. Network Operations

When a node sends a message to the data sink (base station) by using an opportunistic protocol, the message is transferred towards the base station by the store-carry-forward paradigm. The message is stored in phones or vehicles, and then forwarded to other nodes during opportunistic contacts. The node receiving the message is either the base station, a car, a phone, or a lamppost (RSU). The nodes, except the base station, continuously forward the message when in communication range of other nodes. Eventually, nodes may carry the message to the base station. If reaching a lamppost, the message usually takes the paths based on connected RSUs to go to the base station.

RSUs with a large storage capacity also act as a relay node in the network. Messages are stored at lampposts for a period of time until they expire due to a limited time-to-live (TTL). In some cases, reliability of event detection is enhanced by aggregating data provided by lampposts. A mobile node perhaps receives messages from the fixed infrastructure and then forwards them to other nodes. As a result, a message containing event information will not only be transferred to the base station, but also disseminated to nodes in network.

Busses and trams are not only message ferries as described in [13], but also gateways for passengers. Because the contact durations of mobile phones carried by passengers on a bus are quite long, messages may be fully exchanged among the passengers. Furthermore, these messages are stored at the bus and then disseminated to next passengers or delivered to the base station at the last bus stop.

When moving from one region to another, a mobile node will act as a gateway, transferring messages between regions. The transfer will be slow compared to using the fixed infrastructure. As the anticipated application domain is safety in public spaces, (emergency) messages should reach their destination as fast as possible.

D. Mobility Model

To increase the realism of the mobility model, five basic movement models are applied for different groups of nodes in our architecture. This approach represents the heterogeneous nature of reality, with road side units, cars, busses and pedestrians.

We assume that a portion of mobile nodes represents pedestrians wandering around without any specific purpose. The existing Map Based Movement (MBM) provided by the ONE is likely the most suited. MBM is Random waypoint movement with map-based constraints, in which a mobile node moves from one map node to another by randomly selecting a neighboring map node. This movement is repeated a randomly chosen number of times.

Naturally, people do not just wander around. They want to go somewhere for a purpose, using the shortest or fastest path possible. The choice between walking or taking the car or bus is often decided by the Euclidean distance to the destination. These destinations are very diverse [15], ranging from points of interest in the public domain (e.g., restaurants, parks, offices) to the more private ones (e.g. friends, home, family). The density of mobile nodes will differ accordingly. We propose a new movement model called Random Shortest Path Map Based Movement (RSPMBM) to model the behavior of human-like mobility. A node selects an arbitrary destination within a predefined range and then moves along the shortest path. Euclidean distance ranges are configurable in a setting file, for example, the distance ranges can be set $[50, 500]$ and $[500, 5000]$ meters for pedestrians and cars, respectively.

The new Road Side Unit Placement model defines where RSUs are placed on a map, along side roads with a certain distance between RSUs. The RSUs are stationary and form a wireless ad-hoc network or wireless sensor network.

For people who always take the bus, the Bus Traveler Movement and Bus Movement models are used for bus travelers and busses respectively. These movement models are provided by the ONE simulator.

E. Evaluation Metrics

To evaluate the proposed architecture and the proposed mobility model, we use the inter-contact time, first defined by Chaintreau et al. [16]. Inter-contact time is the time interval between two successive contacts of a pair of nodes, from the end of one contact to the next contact with the same node. Inter-contact time characterizes the frequency of opportunities for nodes to send packets to other nodes. The distribution of inter-contact time has an impact on the performances of different routing algorithms. It also shows that the inter-contact times are power-law distributed with the power-law exponent less than one.

Four metrics are used to evaluate the aforementioned performance requirements of different routing algorithms. Two of them are metrics implemented in the ONE: delivery ratio, and latency. Hop-count metric is no longer an informative metric to assess the delivery cost in time and distance in OppWSNs as it is used in connected ad-hoc WSNs. Instead, we define Delivery Speed and Delivery Cost for a more accurate evaluation.

- *Latency:* The time between the moment that a message is sent at the source and the time it is delivered at the destination.
- *Delivery ratio:* The number of successfully delivered messages divided by the total number of unique sent messages.
- *Delivery speed:* The speed of a message traveling from origin to destination. It is defined by Euclidean distance divided by latency.
- *Delivery cost:* The total number of messages including replicates divided by the number of successfully delivered messages.

IV. SIMULATION AND EVALUATION

In order to evaluate our proposed architecture and mobility model, a realistic simulation environment is set up, using a real city map. The results of running selected routing protocols are analyzed and compared to gain a better understanding on performances of existing routing protocols. From that, we may attain implications for future work.

A. Environment Setup

The simulation uses the center of the city of Enschede as a realistic setting. In the center of the map, there is the central bus station. The map shown in Figure 3 takes up approximately 4000 by 4000 meters and is exported from Openstreetmap.org. To this map several layers, as submaps, are added for lampposts, roads for cars, paths for pedestrians and routes for busses. Lampposts are positioned at the outer and inner ringroads, and four main roads radiating from the center. Cars are restricted to roads, but pedestrians may roam everywhere. Busses follow routes from the real city bus system. Roads in the ONE simulation have zero width. To overcome this limitation, roads are defined by two parallel routes as the lanes of a real road. In this way, communication with vehicles or pedestrians at both sides of the road is more realistic.

The simulation is carried out with 336 intelligent lampposts manually fixed on main roads, 50 cars, and 600 pedestrians moving around inside the city. The initial position of cars and pedestrians is randomly distributed. There are quite many bus lines in the city, but only four are chosen because others have routes overlapping the lamppost lines. Since the lampposts can transfer messages to the base station much faster than busses do, busses that run along lamppost lines have small contributions to the message delivery. Each bus line has two busses shuttling their routes. Since our basic goal is to investigate the contribution of pedestrians in disseminating data, only a small portion of cars, 50 over 650 mobile nodes, are simulated in the simulation. We also assume that the speed of pedestrians remains almost constant, $0.5 - 1.5$ m/s. Therefore, the mobility speed has a minor effect on performance results.

Since our proposed architecture also aims to reduce the use of mobile services, we only consider available short-range interfaces, particularly Bluetooth and WiFi. All mobile phones have Bluetooth Version 2.0 at 2 Mbit/s net data rate with 10 m radio range, while smart phones have only WiFi interface at net data rate of 10 Mbit/s with 60 m radio range. We assume that fifty percent of pedestrians own smart phones and the rest uses normal phone. Lampposts have both interfaces. The remaining nodes, cars and busses, use WiFi only, because they move at speeds that make Bluetooth communication unrealistic.

From the 600 pedestrians, 500 move with a purpose, while 100 are just strolling. Because cars likely possess predetermined routes, RSPMBM would be most suited. Busses follow fixed routes with predefined stops, and are modeled with the Bus Movement mobility model. Finally, pedestrians in busses are modeled with the Bus Traveler Movement model.

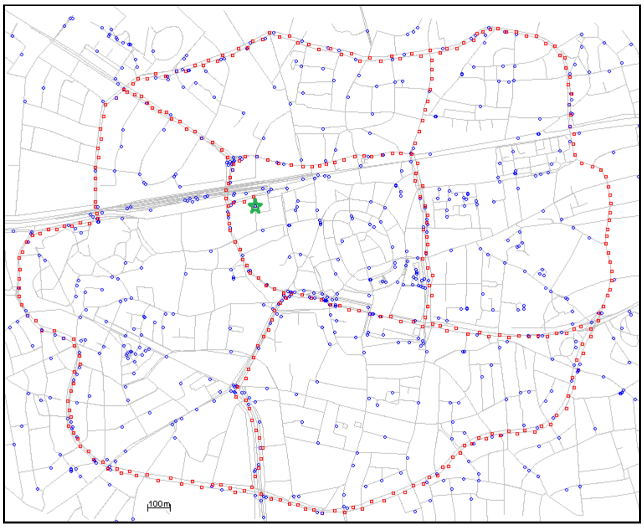

Figure 3. Inner-city of Enschede.

Data dissemination in the above heterogeneous scenario is simulated with a number of opportunistic routing protocols: Epidemic [8], Direct Delivery (DD) [9], FirstContact (FC) [11], and PRoPHET [12], and Spray and Wait (SnW) [10] with the number of copies (n) to be 6. This setting value is default in the ONE simulator. Since Message Ferry (MF) [13] is only useful for busses to transfer messages among base stations of cities, in our simulation with a single city, busses are just considered as a vehicle to transport passengers and do not implement MF.

Messages are generated every $25 - 35$ seconds by random cars and pedestrians. Lampposts do not generate messages, but act as a communication backbone. Messages may contain pictures, video and soundbites and are 500 KB to 1 MB in size. The buffer of normal mobile phones is set to 5 MB, and smart phones, cars, lampposts, and busses have 50 MB buffers.

B. Architecture and Model Evaluation

Figure 4 plots the complementary cumulative distribution (CCDF) of the inter-contact times. The graphs show that the inter-contact time distribution of RSPMBM has a power-law distribution with the exponent approximate 0.3 and similar to the real iMote trace [17]. This power-law distribution does contradict the exponential decay implied by previous mobility models that have been used to design routing algorithms (see [16]). Because the exponent and shape of the distribution may vary between environments, we did not configure parameters to produce the exact same exponent and shape as the iMote trace. Note the match between the iMote

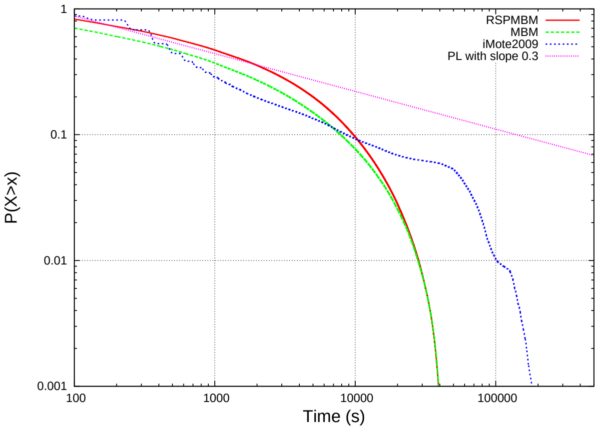

Figure 4. Inter-contact times for RSPMBM compared to the iMote trace.

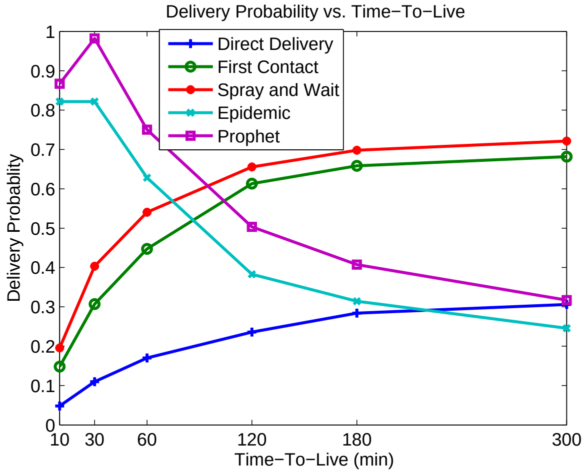

Figure 5. Message delivery probability.

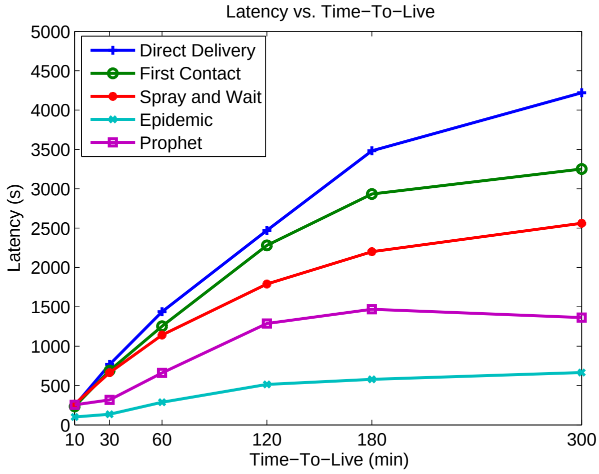

Figure 6. Average latency of message delivery.

trace and RSPMBM in the first two thirds of the graph. The difference in the last part of the graph is due to the longer trace (in time) of the iMote, leading to more contacts with low distribution probabilities. RSPMBM has shorter contact times due to the lamppost communication backbone. In other words, nodes in our simulation environment meet more frequently that those in the iMote experiment.

Figure 4 also shows the inter-contact time distribution for MBM used in the Enschede City Scenario (ECS) for comparison. Surprisingly, both RSPMBM and MBM produce similar tails of distribution (exponent coefficients). However, the inter-contact time distribution of RSPMBM has higher probability than that of MBM. This is expected, inter-contact times usually get shorter with increasing reality [6].

C. DTN Routing Algorithm Evaluation

Time-to-live (TTL) is an important variable for data dissemination, and strongly influences data delivery probability, latency, delivery speed, and delivery cost in opportunistic networks. In safety applications, emergency messages should be delivered with high probability, low latency, and high speed. Setting a high value for TTL is useless, i.e., a message that keeps a high TTL, probably would have a high latency, low speed, and less importance. Though TTL has a huge impact on the performance of routing protocols, it is hardly studied in existing literature. In the remainder of this section, we will investigate the influence of TTL on delivery ratio, latency, speed, and costs of messages.

Figure 5 shows the delivery probability of each routing algorithm as TTL in the scenarios increases from 10 to 300 minutes. In the graph two very different trends in delivery probability can be observed. DD, FC and SnW have increasing delivery probability with increasing TTL, with a highest gain in the lower TTL values. This is as one would expect. The longer the TTL of a message, the more opportunities for message transferring. Counter-intuitive is the decreasing delivery probability with increasing TTL for Epidemic and PRoPHET. This is explained as follows. Epidemic and PRoPHET are multi-copy, thus the number of relayed messages increases exponentially when TTL is long. Eventually, with a limited buffer and limited contact duration, the delivery probabilities of Epidemic and PRoPHET will dramatically suffer. This explanation is reconfirmed in Figure 8, which depicts the delivery cost for each routing protocol.

Figure 6 plots the average latency of message delivery as TTL increases. From the graph, one can see that increasing TTL results in increasing delays in message delivery. This is as expected. Since flooding the network with messages, Epidemic scores best. Although Epidemic has the lowest delivery probability at high TTL values, when a message reaches its destination, the message will have low latency. Direct Delivery scores lowest with high latency. DD delivers messages directly to the destination. So it may take some

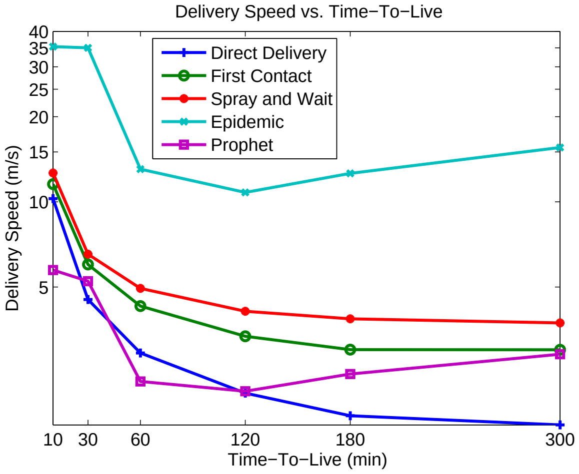

Figure 7. Average speed of message delivery.

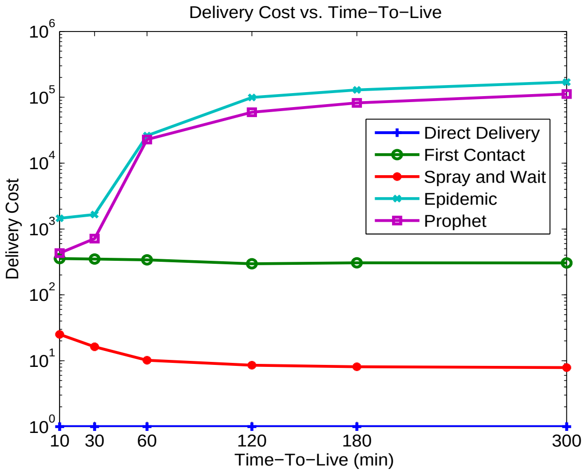

Figure 8. Delivery cost.

time for this opportunity to happen.

The speed of message delivery is depicted in Figure 7. The speed decreases sharply in the first part of the graph for all protocols and then remains almost constant. For 10-min TTL, only messages near the base station or lampposts can reach the destination. Other messages would be dropped before arriving at the base station. Increasing TTL causes more messages farther away from the base station to be delivered. This explains why the average delivery speed declines sharply. However, when TTL is greater than 60 minutes, most messages have sufficient lifetime. Therefore increasing TTL further does not affect the delivery speed.

The delivery speed of Epidemic and PRoPHET goes up slightly when TTL is greater than 120 minutes. Due to overhead, there are fewer messages that could be delivered. Hence, the average delivery speed rises slightly again.

Epidemic has the highest delivery speed since it floods messages over the network. DD has the lowest delivery speed on account of sending messages only when mobile nodes encounter the base station.

As PRoPHET has the second lowest latency in Figure 6, one would expect it to have the second highest delivery speed. On the contrary, the graph in Figure 7 shows that PRoPHET has the lowest delivery speed. The reason lies in the fact that PRoPHET transfers messages based on the frequency of node encountering, called delivery predictability. Owing to the lamppost connected network, most nodes have almost the same delivery predictability. Consequently, messages are wastefully transferred around before reaching the destination. In such way, even the average delay of a message is low, but the Euclidean distance from its source to the base station is short too. That is why the delivery speed of PRoPHET is low even though its latency is not high. This behavior also proves that delay of message delivery is not sufficient enough to evaluate quality of message delivery.

Because the majority of nodes have limited power supply, the delivery costs of opportunistic routing algorithms must be taken into account. The delivery cost represents the ratio between the number of total transmissions needed over that of successfully delivered messages. Figure 8 shows that Epidemic and PRoPHET have the highest delivery cost because they maximize the opportunities of message delivery by replicating copies of messages as much as possible. DD and SnW have the least overhead, as DD has only one single copy of a message and SnW has 6 copies of messages at maximum. Clearly DD has the lowest delivery cost of all routing algorithms. The delivery costs for Epidemic and PRoPHET increase sharply with increasing TTL, but stabilize after a while. The reason is that only a limited number of messages can be transferred during the limited contact duration.

V. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a heterogeneous architecture comprising fixed infrastructure, mobile infrastructure, and mobile nodes. In addition, we proposed the a realistic mobility model and metrics. Several well-known opportunistic routing protocols were tested with this architecture. Our observation shows that none of the evaluated protocols performs well with a heterogenous scenario, such as the one described in this paper. Since a single simple routing algorithm does not suffice to improve the overall message delivery performance, a contribution of several algorithms should be considered:

- Road Side Units (RSU), as used in the lamppost backbone network, should not only carry received information to a central server, but also disseminate information to nearby passing nodes. This communication shortcut leaves the base station out of the loop and contributes a better delivery speed and delivery cost. The Epidemic routing protocol with a flooding control mechanism is best suitable for the RSU network.

- Busses, which act as data mules or message ferries, have a mobility pattern based on fixed routes and time schedules. The Message Ferry routing protocol is most appropriate.
- Pedestrians and cars are best served by stochastic and context-based schemes. However, exchanging messages between nodes that use different routing protocols is a challenge. For examples, nodes running PRoPHET fail to update the delivery predictability of nodes running Epidemic due to the unavailability of delivery predictability in Epidemic router.

We also plan to take message priority into consideration. Because designing an optimal routing protocol with a delivery probability of 100% under all conditions is difficult, prioritizing messages becomes a necessity. Message prioritization perhaps relies on the importance of information, creation time, or source location. Priorities must be defined by a specific application, for instance, public safety applications define the priority based on the source location, creation time, and seriousness of detected events. One last point of concern is the security and privacy of information. A leading principle should be that the creator owns the data and decides how the data can be used by others. However, one may argue that in situations of emergency this principle may be overruled by authorities. This issue will be addressed in future research. Following this research, a testbed is planned to implement and evaluate the proposed heterogeneous DTN architecture.

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