Performance Evaluation of Binary Spray and Wait OppNet Protocol in the Context of Emergency Scenario

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***Abstract*— Opportunistic Networks (OppNets) can be used as an alternative way to communicate or to interact with each other when a fixed communication infrastructure is down during an incident like an earthquake or tsunami. In this paper, we investigate the factors effecting the performance of an OppNets routing protocol which is Binary Spray and Wait protocol in a condition of emergency situation. We have conducted four experiments; 1) 20 pedestrians, 2) 20 cars, 3) 100 pedestrians, and 4) 100 cars. We evaluated this protocol using Opportunistic Networking Environment (ONE) simulator and analyze the performance in term of delivery probability, number of message dropped, latency average, and hop count average by varying size of buffer and message size.**

***Index Terms*— opportunistic network, emergency situation, Binary Spray and Wait routing protocol.**

I. Introduction

In the past few years, we have seen great disasters, such as 9/11 terrorist attack, Hurricane Katrina, tsunami in the Southeast Asia, and earthquake in Haiti. These disasters have shown the effect that they can have on people, property, and the economy. Repercussions include, but are not limited to shortage of electric power, water, food, and protection from the elements of nuclear or chemical hazards. In such situations, emergency response becomes increasingly difficult and constrained.

The casualties and damages are too often compounded by problems faced by the first responders and relief agency workers. There is a common threat to all these problems: lack of adequate communication facilities in the disaster areas and beyond. Therefore, providing means of dependable communication in emergencies must be viewed as a fundamental challenge to communication and information technologies.

An OppNets is an emerging communication paradigm in wireless communication. The key idea behind these networks is to enable communication between source and destination without the support of a fixed infrastructure. OppNets have the advantage of being able to employ "store and forward" data transfer where data is not sent from one end of the network to the other immediately, but is instead passed hop-by-hop and stored on intermediate nodes until that node has a suitable connection opportunity to pass it on in turn. This allows opportunistic network to cope with large variations in network topology and with poor link qualities, in addition to traditional networking situations (e.g. where Internet access is available). Usual elements to become parts of OppNets are smartphone, notebook, and etc. that have any kind of communication technology such as Wi-Fi, Bluetooth, and so on.

In this world of technology, smartphone becomes a part of human daily life. They cannot miss it anytime and anywhere. Statistically, 3.3 billion people worldwide use cell phones [1]. Because of it is completely integrated with sensors; Global Positioning System (GPS) tell where we are, cameras tell what we looked at, Wi-Fi and others, it will create a huge number of contact opportunities. Therefore, it will be the best element for opportunistic communications in disaster area.

The research [2], released at Mobile World Congress, shows that across the global smartphone user base sampled, 91% of smartphone subscribers use WiFi for data usage purposes. Also, for an overwhelming majority of smartphone users, WiFi is employed as the primary data connection of choice. We propose a WiFi-capable OppNets smart phone to assist in emergency response.

The paper is organized as follows. Section II presents a background. Section III discusses the OppNets based application in an emergency response scenario. Then we describe the evaluation setup in Section IV. Section V shows simulation results for the model using different parameter settings. Finally, Section VI concludes the paper.

II. Background

It is impossible to have wireless coverage everywhere and with constant or stable link. Therefore, in order to send messages from one location to another location, the current Internet protocol, which is TCP/IP, can fail to work. The TCP/IP protocol [3] can operate smoothly depends on the following physical link assumptions: 1) There is at least one end-to-end path between data source and the destination; 2) The maximal round-trip time (RTT) between any two nodes cannot be too long; 3) End-to-end packet loss probability is small enough.

Therefore, more intelligent protocol which is Delay Tolerant Networks (DTN) whom Kevin Fall first proposed this concept in 2003 [4] try to solve this issue. The main characteristics of DTN are large delays, intermittent

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connectivity and most importantly, the absence of end-to-end path nodes.

Previous examples of DTN applications are DAKNET [5], ZebraNet [6], SWIM [7], CarTel [8] and Bytewalla [9]. Delay Tolerant Networking Research Group (DTNRG) [10] has explored this aspect. The DTNRG has developed the Bundle protocol [11], capable of reliable data transfer in a store-and-forward fashion scenario described. Bytewalla project has successfully implemented a simple message forwarding application using DTN bundle protocol on an Android smart phone.

We considered a device like smart phone as the best element for DTN because it has the capability to sense, collect and communicate information. In DTN, messages are delivered to destination hop by hop in a store-carry-and-forward technique as shown in Fig.1. A smart phone source, S, is able to send a message to destination, D, by using other mobile nodes such as C1 which store, carry, and then forwarded the message to C3. This technique increases the probability of successful delivery of the messages to the destination.

In 2006, Lilien et. al. have developed a similar paradigm as DTN with the name of Opportunistic Networks (OppNets) [12].

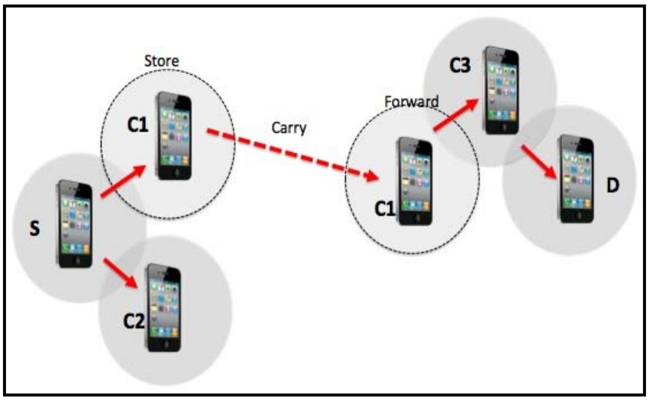

Fig. 1. Store-carry-and-forward technique

III. OPPNETS BASED EMERGENCY SERVICES

Recent history gives a few motivating examples, e.g., the earthquake and tsunami in Japan, and the earthquake in Haiti. In these incidents, the communication infrastructure and power are disrupted (i.e. cellular networks are completely or partially damaged, and satellite networks are overloaded) for weeks if not months. Surveying the disaster area for survivors under the rubble might takes from days to weeks (with some inspiring examples of survivors emerging after tens of days), thus, communications became very critical in such situations.

It is clear that the absence of end-to-end connectivity in IP-based networks will hinder the user to request for emergency services. Consider the scenario where a victim is located in a collapsed building and trapped without communication means. In such isolated places, the only means of interaction with the emergency service center are through ad-hoc communication. We proposed using OppNets as a transit network for communication of emergency calls. In such a scenario, OppNets should route the emergency calls in an ad-hoc manner through OppNets routers to the network provider using opportunistic forwarding (i.e. forwarding data to a potential node over a WiFi link as shown in Fig. 2).

This use case might be helpful to relay SOS information or photos of victims. It can also be use as a means for the victims to inform their friends or families that they are still alive.

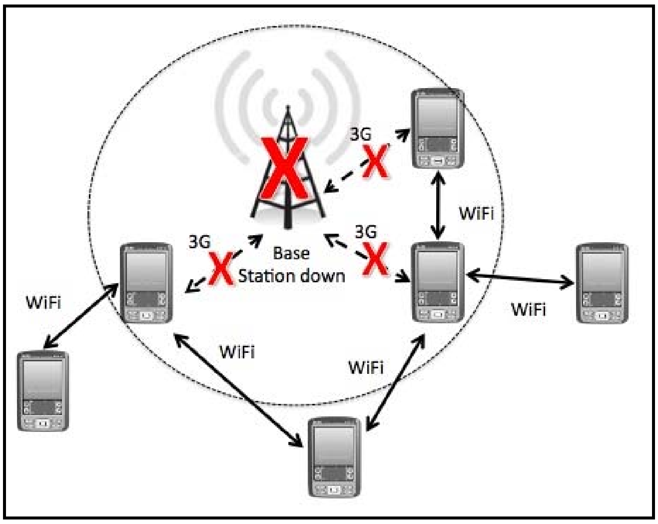

Fig. 2. Smart phones with WiFi extending last mile without network support.

In this paper, we assumed mobile devices such as smart phones as a way to communicate because there is a huge amount of untapped resource such as big storage capacity, WiFi built-in, and CPU power. The only scarce resource is power, but advances in battery technologies have meant that, with a single charge mobile phones can now last for a week, while still remaining in constant contact with the network.

One of the most important things in emergencies is the number of messages created during the emergency. The need for buffering is very important to store the messages and to reduce the frequency of message drops during transmission of SOS information or photos of victims in emergency scenarios.

Many researchers have published papers on OppNets in the context of disaster and emergency network support [13, 14, 15]. For example, the Multimedia and Mobile Communications Laboratory (MMLAB) [13] at Seoul National University have been investigating its Architecture for Intelligent Emergency DTN or OppNets using extensive temporary wireless communications. However, none of the published papers cover the impact of buffer size and message size on performance in such critical situation.

IV. EVALUATION SETUP

There are three main classes of research methodologies in research area which are mathematical, simulation, and experimental. In this work, we have chosen to use simulation methodology in our evaluations. Simulation plays an important method in analyzing the performance of routing protocol in OppNets. We have used Opportunistic Networking

Environment (ONE) simulator [16] to simulate an existing protocol in OppNets, which is Binary Spray and Wait routing protocol for the performance evaluation in the context of emergency services.

1) Scenario

Our emergency scenario consists of two different situations. At first, only a group of pedestrians which move at a random speeds of 0.5-1.5 m/s with pause times of 0-120s is available in an emergency place. Second, only a group of cars which move at car speeds, 2.7-13.9 m/s along the streets as shown in Fig. 3. The number of pedestrians and cars involved in an emergency, change with the lowest density, 20 and highest density, 100. For both situations we use a Shortest Path Map Based Movement where pedestrians are able to walk to everywhere on the map while cars are able to move only on roads. We choose a map-based model Helsinki downtown (default map in ONE simulator) with a simulation area of 4500x3400m.

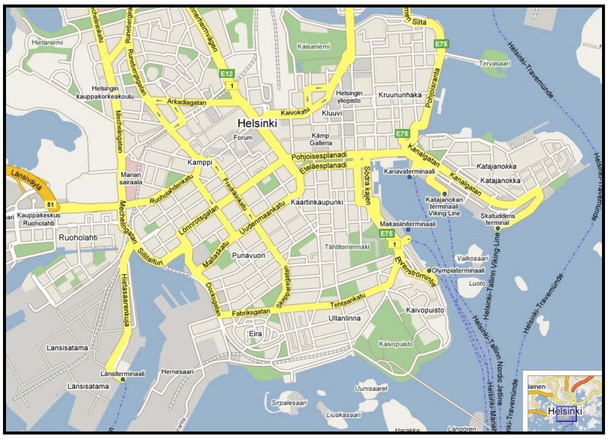

Fig. 3. Helsinki Downtown Map

2) Routing Protocol for Evaluations

In literature, numerous OppNets routing protocol have been proposed by many researchers in order to increase the probability of messages to reach the destination [17] [18] [19] [20]. In this work, we have used an existing OppNets routing which is Binary Spray and Wait protocol proposed by Spyropoulos et. al. [17] for our emergency scenarios simulations.

The Spray and Wait is one of the initial protocols that control the number of copies of messages in the network. In Spray and Wait, message is delivered in two phases; the spray phase and the wait phase. In the spray phase, multi-copy idea is used but source node spread a small number of copies to only a few relays. A node that has more than one copy of the message left can give either a copy to another node (the normal mode) or half of the copies (the binary mode) and keeps the rest to itself. If the node has only a single copy of the message left, it is directly transmitted only to the destination (wait phase). By using a different amount of initial copies, Spray and Wait can balance between high diffusion of messages and excess use of resources. We use Spray-and-Wait in binary mode: a node carrying k copies of a message forwards k/2 of them to the next nodes it meets until the k =1. Then, a node waits till it meets the destination.

3) Performance Evaluation

The default settings in our simulations are as follows. We have setup the duration of the simulation as 43200s or equal to 12 hours. The source and the destination nodes are both randomly chosen from the user nodes. Each node generates a message at every 30 seconds on an average (the time between two message generation is chosen randomly between 25 to 35 seconds) with message lifetime of 300 minutes. All nodes are equipped with WiFi that can transmit at speeds of 10 Mbit/sec with 10-meter range. We have considered initial number of message copies to be 6. The summary of main simulation parameters are listed in Table I.

TABLE I. MAIN SIMULATION PARAMETERS

Parameter	Value
Simulation Time (s)	43200
Simulation Area (m^2)	4500x3400
Routing Protocol	Binary Spray and Wait
Number of Copies	6
Mobility Model	Shortest Map Based Movement
Transmission Range (m)	10
Transmit Speed (MB/s)	10
TTL (minutes)	300

In this work, we have conducted four experiments, shown in Table II. We evaluate the Binary Spray and Wait routing protocol on performance metrics in the context of emergency services when buffer size and message size varies.

TABLE II. EXPERIMENTS

Experiment	Group	Number of nodes	Speed (m/s)
1	Pedestrians	20	0.5 - 1.5
2	Cars	20	2.7 - 13.9
3	Pedestrians	100	0.5 - 1.5
4	Cars	100	2.7 - 13.9

4) Performance Metrics

A set of metrics that we have used in evaluating Binary Spray and Wait routing protocol in OppNets are:

1) Delivery probability: It is a ratio between the number of messages arrives at destination and the number of messages sent. The delivery probability defined as in equation 1

$$\text{Delivery Probability} = \left(\frac{1.0*D}{C}\right) \quad (1)$$

where D is a number of messages delivered at destination and C is a number of messages created at a source node. High delivery probability means that more messages are delivered to the destination.

2) Message dropped: It is the number of messages dropped from nodes' buffers during transmission. Messages are dropped once the buffer is full.
3) Latency average: The latency average is defined in 2 is an average time taken for a message to reach destination.

$$\text{Latency Average} = \sum_{i=1}^{n} \left(\frac{Ri-Ci}{n}\right) \quad (2)$$

where n is a number of messages arrive at destination, Ri is the time when a message i reaches at destination, and Ci is the time when a message i is created. OppNets latency is high due to its network nature.
4) Hop count average: It is an average number of hops between source and destination nodes.

High performance often means high delivery probability, less number of message dropped, low latency average, and less hop count average.

V. SIMULATION RESULTS

In this section, we show results obtained from the simulation described in the previous sections. The results presented here are averages from 10 simulation runs. We observed that simulation parameters like buffer size and message size greatly impact the performance of Binary Spray and Wait routing protocol. We compare pedestrians group and cars group on varies performance metrics.

1) Varying the Buffer Size

TABLE III. SPECIFIC PARAMETERS

Parameter	**Value**
Buffer size (MB)	5 -100
Message size (B)	500k -1M

The goal of our evaluations is to find the effective size of buffer in emergency scenarios. We varying the buffer size from 5MB to 100MB with an increment of 5MB and each message uniformly distributed in the range of 500kB - 1MB an average size for a message with text and a small image as shown in Table III. Performance metrics will be constant at a certain buffer size.

A. Impact on Delivery Probability

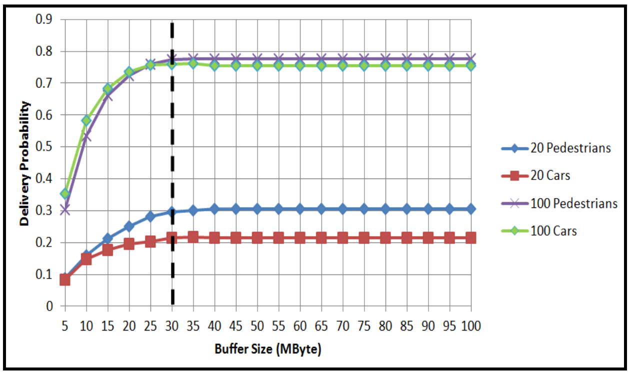

Fig. 4. Delivery probability vs. buffer size.

B. Impact on Number of Message Dropped

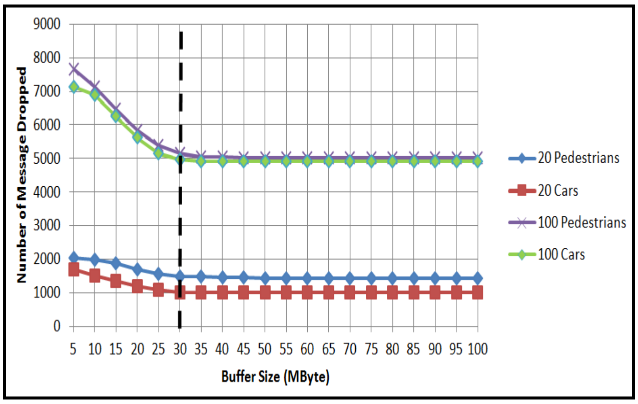

Fig. 5. Number of message dropped vs. buffer size.

C. Impact on Latency Average

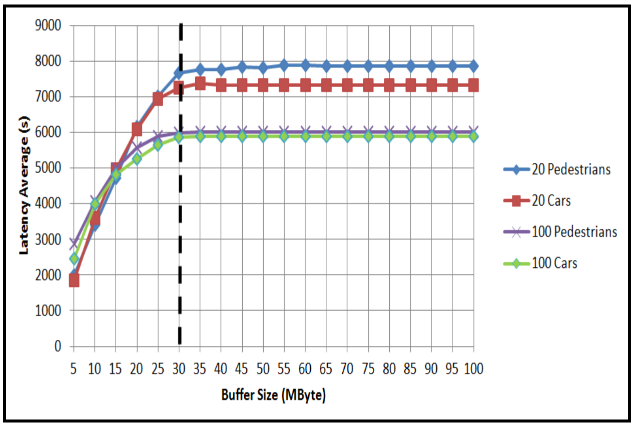

Fig. 6. Latency average vs. buffer size.

D. Impact on Hop Count Average

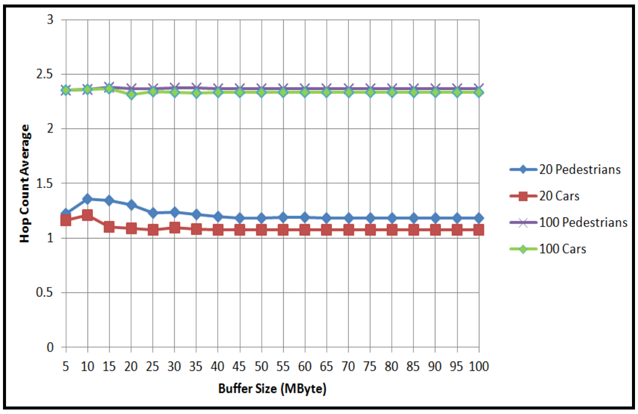

Fig. 7. Hop count average vs. buffer size.

Fig. 4 shows the performance of pedestrians and cars group with respect to delivery probability. When buffer size (the number of messages can be buffered) increase, delivery probability also increases because the number of message dropped are less. We observed that the delivery probability of the both groups start stable when the size of buffer reach at 30MB. It means that, 30MB buffer size is enough to satisfy the requirement to store emergency data. Pedestrians perform better delivery probability than cars.

In Fig. 5, we see that when the buffer size increase, the number of message dropped decrease. Messages are dropped due to the limited buffer size. The number of message dropped for pedestrians group is high, nodes cannot relay messages to another because buffer are full due to the pedestrians speed (pedestrians move slower than cars). The number of message dropped became stable when the size of buffer are more or equal to 30MB.

Fig. 6 represents the effects of buffer size with respect to latency average. It can be clearly seen that pedestrians have high latency average campared to cars group. The speed of nodes effect the time taken for the messages reach at the destination. Therefore, the lower the speed, the longer the time. Like delivery probability and message dropped, the value of latency average also stable start from 30MB.

Fig. 7 shows the impact on hop count average when buffer size varies. In an average, the number of hops between source and destination for 20 nodes for both groups are between 1 to 1.5 and pedestrians have more number of hops than cars. It is because due to the speed of nodes. When a node move slowly, the probability to meet the destination is low. Therefore, many hops are required in order to send messages to the destination node. The performance of 100 pedestrians and 100 cars are very similar.

From the results obtained, we observed that, the effective size of buffer in emergency scenario is 30MB.

2) Varying the Message Size

TABLE IV. SPECIFIC PARAMETERS

Parameter	**Value**
Message size	500kB - 5MB
Buffer Size	30MB

The main goal that we want to achieve here is to find optimum value of message size for 30MB size of buffer. Therefore, in this simulations, we initially investigate how message size impacts the delivery probability, latency average, and hop count average for Binary Spray and Wait routing protocol. We have selected five different sets of message size (500kB-1MB, 1.5MB-2MB, 2.5MB-3MB, 3.5MB-4MB, 4.5MB-5MB) with fixed buffer size, 30MB as shown in Table 4.

A. Impact on Delivery Probability

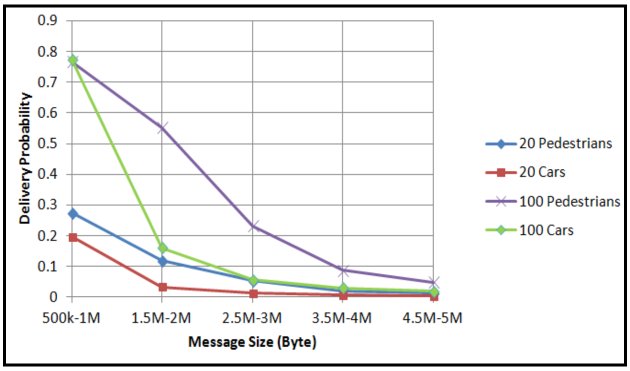

Fig. 8. Delivery probability vs. message size

B. Impact on Average Latency

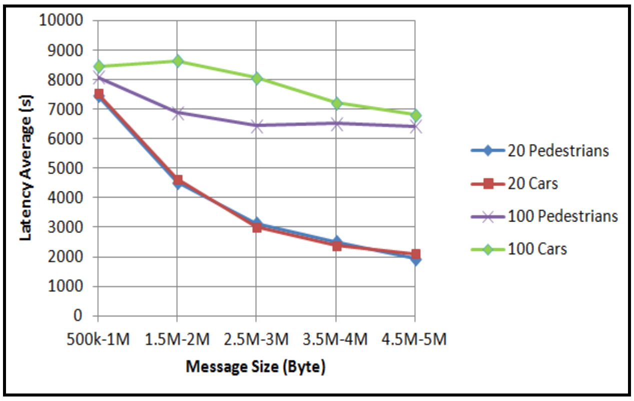

Fig. 9. Average latency vs. message size

C. Impact on Hop Count Average

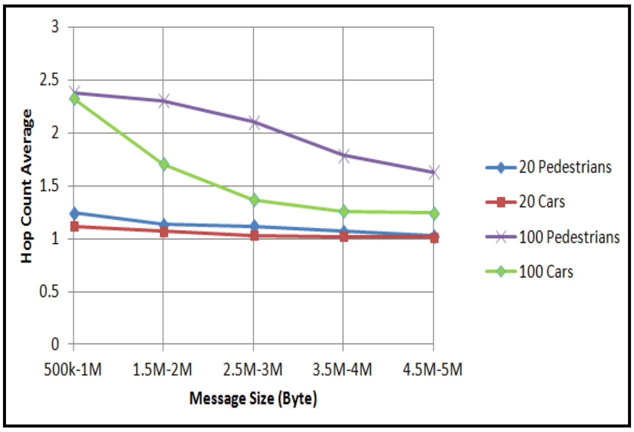

Fig. 10. Hop count average vs. message size.

Looking at the graph of the delivery probability over message size in Fig. 8, we see that the message size impact on the Binary Spray and Wait protocol. As the message size becomes larger, the delivery probability decreases. It is due to a situation where nodes unsuccessful to relay messages to another because buffers are full due to the size of those messages. When the size of messages is in the range of 4.5 - 5M, the value of delivery probability for all cases is became low, approximately 0. If we considered only 100 pedestrians involved in an emergency, the optimum value of message size is 500kB to 2MB because the delivery probability is above 50%. While for 100 cars, the optimum message size is 500kB to 1MB. It is due to the speed of movement. Pedestrians have lower speed than cars. When the speed is low, the chance to forward and buffer more messages is high compared to the high speed.

In terms of latency average and hop count average, Fig. 9 and Fig. 10 shows, as the value of latency average decrease, the number of hop count average decrease. The decrease in hop count average reflects the fact that message has consumed fewer resources to reach its destination. The minimum value of hop count average confirms less latency average. The latency average of 20 pedestrians and 20 cars perform very similar.

From the results obtained, we observed that, the gap between 20 pedestrians and 20 cars for all performance metrics are low. It means that, the speed of low density of nodes has less impact to the routing performance. In order to delivery emergency information's, the most important thing is to ensure the messages sent totally reach at the destination compared to how long the time taken for messages reach at destination. Therefore, for high density of nodes, due to the delivery probability, we found that the optimum value of message size for 100 pedestrians is from 500kB to 2MB while only 500kB - 1MB for 100 cars.

VI. Conclusion

Opportunistic Networks (OppNets) is very useful in the context of emergency scenarios where main communication infrastructure is unuseable.

In an OppNets routing protocol, which is Binary Spray and Wait protocol, the copies of messages are sprayed with no consideration about any information like buffer size, message size, etc. Therefore, in this paper, we investigate two factors; buffer size and message size that affecting the performance of the Binary Spray and Wait protocol in a condition of emergency situation. The suitable value of buffer size and message size is very important to avoid the frequency of packet loss especially during transmission of SOS information or photos or video of victims in emergency scenarios. From the simulation results, we observed that, the effective size of buffer is 30MB and the optimum value of message size is depending on situation. If we considered 100 pedestrians involved in an emergency, the message size is 500kB to 2MB while 500kB to 1MB for 100 cars.

Further studies are required to understand the impact of battery consumption and which decision to store which messages in order to ensure critical messages are conveyed in the emergency context.

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