Performance of Delay Tolerant Network Protocol in Smart City Scenario

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Abstract. The smart city is being developed in many big cities to support local governments for resources and infrastructure optimization in terms of enhancing services for the citizen. Large investment costs are required to implement a communication network for the smart city infrastructure (i.e. Internet of Things (IoT) devices) using 4G or Wi-Fi networks. This study aims to implement Delay Tolerant Network (DTN) as a low-cost alternative network for the smart city. We use Surabaya smart city plan scenario in which smart mobility services are provided in city transportation and infrastructure. The IoT devices are installed in numerous locations and continuously transmit messages to the monitoring server located in the city hall, bus and car employed as a DTN node. In this paper, as a preliminary research, we investigate the performance of well-known DTN routing protocols (Epidemic, Maxprop, and ProphetV2) with our proposed protocol called Spray and Hop Distance (SNHD). The evaluation is performed using the ONE simulator in terms of the number of delivered messages, the average latency, and the overhead ratio. The results show the performance of SNHD is better than the well-known DTN protocols in various conditions when the total size of delivered messages is large. Unfortunately, none of those routing protocols has a good performance in all of the scenario conditions. In the future, we desire to implement this system in real smart city system in Surabaya and do simulation with more realistic scenario such as real traffic-trace.

Keyword. DTN, Routing Protocol, SNHD, Smart City, Surabaya

1. Introduction

The Smart City concept has been widely conceived and even has been implemented for many major cities in the world. The smart city could improve the quality of life of the citizen. Some of the latest technology models are used to provide better services in health, transportation, education, etc [1]. The smart city employs numbers of Internet-of-Things (IoT) devices to monitor and manage infrastructure and environment in the smart city. The IoT device needs to be connected via 4G and/or Wi-Fi to transmit sensor data periodically to the monitoring server. Costs incurred for the implementation of a smart city are still fairly expensive [2]. This is one of the fundamental problem why implementation of the smart city are delayed. DTN was originally developed for interplanetary networks, it could operate in conditions where traditional networks neither, such as conditions where end-to-end connections are sparse, high delay rates, and high error rates [9]. Some research has been done to implementation DTN in various conditions, especially in the terrestrial condition because of its advantages compared with conventional networks [18]. One of the implementations is to provide
network communication in the small and remote island [3] in which we found the major disadvantage of DTN, that is no single routing protocol works well in all scenarios. Therefore, in this paper, as a preliminary research to implement alternative/low-cost networks for smart cities using DTN, we evaluate the performance of well-known routing protocols and the routing protocol we developed in the previous paper (Spray and Hop Distance (SNHD) routing protocol [4]). We use a smart mobility scenario (i.e. efficient transport, multi-modal access) in the city of Surabaya that consists of Internet of Things device located on the highway/traffic light. The IoT device continuously transmits message to the monitor server located in the City hall Surabaya.

The rest of the paper is arranged as follow: Section 2 presents the related work; in Section 3 we discuss the protocols in Delay Tolerant Network (DTN); Section 4 focuses on the concept of the smart city scenario in Surabaya, parameter setting and simulation; in Section 5 we discuss the evaluation results. We conclude the paper and suggest future works in Section 6.

2. Related Work

DTN has been widely investigated as an alternative network. researcher in [14] developed DTN as alternative network for disaster situation, in [15] implemented as digital and social inclusion using DTN, Researcher in [16] focused on development of an alternative solution for satellite networking. In [3] utilizing DTN as an alternative network for the small and remote islands, this study employs buses and ferry boat as DTN nodes, then in [4] implemented DTN as an alternative network in the multiple island scenario. The implementation of DTN on smart city has been widely developed, in [5] conducted a performance assessment on VDTN regarding its ability in data collection in smart cities, this paper studies the impact of different parameters in the routing protocols performance using a large set of simulation and two scenarios, the results show that there is no perfect routing protocol that is the best for all scenarios. Research in [6] uses DTN by utilizing drones to deliver data from source to destination in smart cities, as a solution to replace large investments in developing communication infrastructure for smart cities. Simulation results show optimum results when the tradeoff between the number of remote nodes in the area and the rarely of their distribution in the city is established. Study in [7] is almost the same with [6], this study exploiting bus mobility by developing a routing protocol namely Sink and Delay Aware Bus. The routing protocol takes advantage of the predictable and quasi-periodic mobility. The results show that the protocol was possible to increase the delivery probability while reducing the average delay at the cost of a small increase in overhead. Research in [2] also uses buses and acts as a network backbone for low-cost smart cities. This study develops a low-cost smart city model whereas initial results are based on a data set of public transit network from Chapel hill, North Carolina. The model developed is the placement of sensors consisting of on-route and off-route, where off-route sensor performance has a bad network latency and poor delivery probability compare on-route sensors. Our research uses the smart city of Surabaya plan with buses and car employs as DTN node to transmit data from smart city devices (i.e. internet of things/sensor) that located in highway/traffic light to the monitoring server located in City Hall of Surabaya. As preliminary research, we investigate the performance of well-known routing protocols and our proposed protocols we developed in previous studies [4] to find the advantage and disadvantage of DTN routing protocol in a smart city scenario.

3. Routing protocol in Delay Tolerant Network (DTN)

Delay Tolerant Network (DTN) has been developed and studied for more than a decade, especially in terms of improving performance in various scenarios. The main difference with traditional networks is the store-carry-forward paradigm, where each DTN node has a storage buffer to store messages while waiting for an opportunity to forward messages, this process repeatedly with the result that the message is sent to the destination node. Therefore, DTN can operate on challenge networks with high
error rates, no end-to-end connections, and high delays where traditional networks neither [19]. The routing protocol determines the message transmission path from source to destination, whether the message could be transmitted to the encountered node or not, based on the requirements of the routing protocol method [20]. In this study, the well-known routing protocols and our proposed routing protocol are evaluated to understand the advantage and disadvantage of DTN as an alternative network in the Smart City Scenario. The routing protocol we evaluated is as follow:

2.1 Epidemic Protocol (EP)
This protocol transmits the message to all of the encountered nodes except the other node already has the copy of the message. The flooding mechanism that employed in this protocol, affected all nodes in the network may be stored the copy of a message. [9].

2.2 Maxprop Protocol
Maxprop protocol is a complex protocol that developed based on the priority for forwarding message to the other encountered nodes and for drop message from the buffer storage. This protocol is implemented for Vehicle-Based Disruption-Tolerant Networks. [10].

2.3 ProphetV2 Protocol
This protocol is a development version of the Probabilistic Routing Protocol using History of Past Encounter and Transitivity (Prophet), that employs contact history to predict the probability that messages will be delivered to the destination node [11].

2.4 Spray and Hop Distance (SNHD) Protocol
SNHD protocol is the development version of the Spray and Wait routing protocol [12], it consists of two phases i.e. spray and wait. In this protocol, the wait phase replaced with a hop distance estimation from the source to the destination node. Then the hop distance value is used to determine whether the message should be transferred to the other encountered node or not [4].

4. Smart City Scenario

![Figure 1. Surabaya map with traffic condition source: maps.google.com](image)
The smart city scenario is implemented concerning the Surabaya's smart city development plan [13]. One of the plans is to provide smart mobility services in city transportation and infrastructure. There are two services in the smart mobility will be adopted in Surabaya i.e. adaptive traffic control system (ATCS) and Variable Message System (VMS) to develop Surabaya Integrated Mass Rapid Transportation and Electronic Road Pricing. As the preliminary research, Smart City/IoT device is placed at numerous locations according to the level of traffic jam in the Surabaya area, Google Maps used to indicate the level of traffic jam in Surabaya as shown in Figure 1a. The IoT devices send sensor data periodically to the monitoring servers located in the Surabaya city hall through the DTN nodes. Figure 1b shows the converted maps with the location of IoT Devices and the monitoring server. There are 16 bus and 50 cars move around in the maps of Surabaya. The bus movement based on the bus route in Surabaya taken from www.movitapp.com. The car node moves randomly on the map. The message generated periodically with the size is 200 KB and the total size of the delivered message are 191.2 MB, 381.6 MB, 766.8 MB, 1549 MB, and 3074.4 MB. The message size and message generation rate are appropriate (fit) to the smart mobility service application. In which the IoT devices send the sensor data periodically to the monitoring server.

Table 1. The Simulation parameter of smart city scenario

| Simulation Parameter                          | Value                                           |
|----------------------------------------------|-------------------------------------------------|
| Simulation Duration                          | 24 hours                                        |
| The capacity of Node buffer storage          | Bus and Car = 200 MB, IoT device = 2000 MB       |
| Network transmission bandwidth               | 4.5 mbps                                        |
| Network transmission range                   | 30 meters                                       |
| Message Time To Live (TTL)                   | 14 hours                                        |
| Car and bus velocity                         | Car = 10-30 km/h, Bus = 5-20 km/h               |
| The total size of message creation           | 191.2 MB, 381.6 MB, 766.8 MB, 1549 MB, and 3074.4 MB |
| The duration time of message creation        | 8 hours                                         |
| The size of Message                          | 200 KB                                          |
| Simulation warm-up time                      | 60 minutes                                      |
| The number of message copy (L) of SNHD Protocol | 10 messages                                    |
| Drop policy of message                       | Drop Oldest                                     |

5. Performance Evaluation
The routing protocols evaluated using the total size of delivered messages, the average latency, and the overhead ratio.

5.1 The total size of delivered messages
This metric evaluates the total size messages delivered in the destination node. As shown in Figure 2a, all routing protocols achieved diverse performance depend on the total size of generated messages. The epidemic is a base protocol for performance evaluation, achieved lower performance compare with SNHD and Maxprop. A simple flooding mechanism in Epidemic will forward the message without priority or limitation to all encountered nodes that do not have a copy of message. When the network resource is enough, this protocol will work optimally. On the other hand, when the network resource is sparse i.e. the buffer storage is full, the performance of Epidemic became worst. This condition also happens in the Prophet V2 (PV2) router, it achieved the lower performance compared to the other routing protocols, the history-based contact implemented in this protocol does not work well in this scenario. The multiple source nodes that generates messages to one destination may cause some node have the same transitivity value, affected the priority based on transitivity does not work optimally, and
this protocol works like an Epidemic protocol. On the other hand, Maxprop achieved better performance than epidemic and prophet V2, although it also employed history-based contact, the priority-based mechanism helped Maxprop to achieve better performance in the total size of messages delivered in the destination node. SNHD Router achieved almost the same performance with Maxprop except in 3074.4 MB case. In this case, the SNHD router outperforms the other routing protocols. Spray phase that employed direct transmission mechanism and hop distance to the source node priority helps to increase the performance of this router.

5.2 The average latency
The average latency indicates the duration time of a message takes in the network before reaches the destination node. As shown in Figure 2b, Epidemic as the base protocol for performance evaluation, achieved higher average latency in 3074.4 MB case. In this condition, flooding mechanism affected newly generated message will always forward to all node instead of the old message due to implementation of drop oldest as the buffer management in this protocol. ProPhetV2 achieved almost the same average latency with Epidemic since in 381.6 MB case. SNHD and Maxprop achieved roughly the same latency average since in 381.6 MB case. The direct transmission and the priority based on hop distance to destination that implemented in SNHD can be considered in the scenario with multiple source node that generates message to one destination. That methods are simple than history-based contact method in Maxprop. Although it has the same performance in the average latency, the performance of SNHD is better than Maxprop in term of overhead ratio and the total size of delivered messages.

5.3 The overhead ratio

![Graphs showing the relationship between size of generated messages and total size of delivered messages, latency average, and overhead ratio for different protocols.]

- a. Total size of delivered messages
- b. Latency Average
- c. Overhead ratio
Figure 2. The performance of all routing protocol

The overhead ratio indicates the number of copies of a message in the network before it reaches the destination node. It also indicates the efficiency of the routing protocol in terms of network resource usage. As shown in Figure 2c, the overhead ratio of all routing protocols fluctuates depending on the total size of generated messages. The epidemic protocol achieves the lower performance. The overhead ratio of the Maxprop is higher than ProPhetV2 and SNHD although it has good performance in the total size of delivered messages, the sending mechanism on the Maxprop affected to increase the number of copies of a message in the network. ProPhetV2 has lower overhead ratio compared with Epidemic and Maxprop. SNHD protocol outperforms the other protocol in terms of the overhead ratio, indicated SNHD more efficient than the other protocols. The Spray mechanism adopted from Spray and Wait Router has restriction of the number of copies of a message (L value), in which control the limitation of message copy in the network.

6. Conclusion and Future Work

This paper discussed the performance of the Delay Tolerant Network (DTN) as an alternative network for the smart city. The scenario is based on the smart city plan in Surabaya, in which to deliver smart mobility for citizens. The evaluation is done by simulation through the ONE Simulator with evaluation of the total size of delivered messages, the average latency and the overhead ratio. Simulation results show there is no single routing protocol that performed best in all scenarios. As a preliminary research, the implementation of DTN for the smart city is promising, especially to provide a low-cost network by utilizing the existing infrastructure such as mass transportation. For further investigation, we will include people mobility with a smartphone as DTN router, increase the number of IoT devices, and do more realistic simulation that include real traffic-trace to implement this system in real Surabaya smart city. Furthermore, the buffer management impact of DTN for smart city scenarios is also considered, due to large data transmission occurring in the smart city.

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