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Implementation of Enhanced Spray Routing Protocol for VDTN On Surabaya Smart City Scenario

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Abstract

The application of smart-city, which promises better city management in helping to improve people's quality of life, is still inhibited due to the high cost of infrastructure investment. In several Smart cities, it takes at least $ 30 - 40 billion to convert a conventional town into a smart city, Include for Data collection infrastructure, i.e., cellular data subscription and WiFi Infrastructure. Alternatively, low-power wide-area networks (LPWAN) could be considered, but it needs more bandwidth to serve data transmission in a smart city. Vehicle Delay Tolerant Network (VDTN) is one part of DTN that employs vehicles as a communication infrastructure that allows communication in challenging conditions and could make it an alternative network for Data Collection in Smart City. This paper proposes a Surabaya Smart City scenario with VDTN as a data collection. The scenario consists of 40 wireless sensors and 50 to 200 vehicles (car and bus) with 5 Road Side Units that forward data from the sensor to the monitoring server. Furthermore, to increase the VDTN performance, we improve our proposed routing protocol, Spray and Hop Distance (SNHD), with two sprays method (Adaptive and Simple) and multiple sources and destinations data collection support. The evaluation was done by simulation-based comparison with an increase in the number of vehicles to determine the impact of vehicle density on data collection performance in terms of delivery probability, Latency Average, and Overhead Ratio. Based on the simulation results, the simple spray method in SNHD and A-SNHD outperformed the well-known VDTN routing protocol, i.e., Epidemic and Spray and Wait. Moreover, when the number of cars is increased from 50 to 200, the performance of VDTN does not increase significantly as network density increases. It means that VDTN only requires a small number of vehicles for use as a low-cost alternative network for smart city. We also evaluate the impact of data size on the performance of all routing protocols in general.

Keywords: *smart city; vehicle delay tolerant network; surabaya; SNHD; routing protocol*

1. Introduction

The smart city is an innovative technology implemented in the city ecosystem to solve issues and enhance local people's quality of life. Smart City works by connecting several sensors or IoT devices in specific locations. It requires a mechanism to collect all data from various connected IoT devices. The recent data collection in the smart city is a cellular network, Wi-Fi, and low-power wide-area network (LPWAN). Increasing the number of IoT devices and sensors will increase generated data in the network, and it requires a large bandwidth.

However, turning a traditional city into a smart city requires expensive funds. Several smart cities, including London, New Orleans, and San Diego, require at least $40 billion in funds [1]-[3] for Smart City transformation. In some developing countries, especially in Indonesia, financial problems become challenges that limit the implementation of Smart City.

A smart city is conceptualized through the utilization of an Internet of Things (IoT) device, which establishes connectivity to the internet for the purpose of transmitting data generated by the device to a monitoring server. Unfortunately, the usage of cellular networks as a data transmission has become uneconomical due to data subscription fees [4]. On the one hand, LPWAN is not recommended due to the small or limited bandwidth.

The Delay Tolerant Network (DTN) exhibits considerable potential as a viable data collection alternative for Smart City implementations. DTN allows communication even though there are some challenges in connectivity, including high latency, intermittent connectivity, high error rate, and no end-to-end connectivity [5]. The functioning of DTN is predicated upon the utilization of a store-carry-forward mechanism. A storage buffer temporarily stores

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messages before they are forwarded to the destination node. Vehicle Delay Tolerant Network (VDTN) is one part of the development of DTN, where it employs vehicle as DTN router to forward data from source to destination.

Decades ago, there was a widespread proposal to utilise vehicles as Delay-Tolerant Networking (DTN) nodes, serving as an alternate network for data collecting. One example of a data transfer method is the utilisation of Data MULEs (Mobile Ubiquitous LAN Extension), in which mobile nodes are responsible for retrieving data from a specific area and subsequently delivering it to another designated site [6]. Several academics have suggested the adoption of Data MULes, as demonstrated by [7], which presented a solution for addressing the transmission problem through the utilisation of Delay-Tolerant Networking (DTN) to transfer IoT sensor-based mHealth monitoring data. Therefore, the utilisation of buses or other vehicles as data mules enables the transfer of mHealth data from distant rural areas to the nearest urban hospital or medical facility. The performance of the ICN-DTN protocol was enhanced by another researcher by the utilisation of a data mule, which effectively utilises more buffer storage [8]. The investigation carried out by Paper [9] investigated the efficacy of the Delay-Tolerant Networking (DTN) network within the framework of railway scenarios. The study aimed to minimise the delays in message delivery, decrease the delays in telemetry transfer, and improve the total throughput of messages.

Numerous scholars have conducted study on the utilization of Delay-Tolerant Networking (DTN) in the context of smart cities, as evidenced by the scholarly publication referenced as [10]. This study examines the role of public transport infrastructure, such as bus stops and buses, as network nodes and carriers. The implementation of device-to-device transmission in a smart city leads to a reduction in cellular connectivity expenses. The data mules are responsible for collecting non-essential data from Internet of Things (IoT) devices and transferring it to edge computing equipment, with the possibility of further transmission to the cloud. The following study [11] investigates the efficacy of four basic VDTN routing protocols, namely Direct Delivery, First Contact, Epidemic, and Spray & Wait, in order to gain a comprehensive understanding of their strengths and weaknesses. The simulation conducted in this study highlights the inherent trade-off between various strategies utilized by the aforementioned protocols and identifies certain gaps in their implementation. The study conducted by the authors [12] involved utilizing the participation of volunteers who had smartphones in order to establish a Delay-Tolerant Network (DTN) within the given context. The researchers proposed a deployment plan for DropBox based on utility considerations, aiming to improve the interaction of situational data after a disaster. Additionally, the study presented a model for human activity in a smart city, specifically focusing on post-disaster strategies.

The objective of this study is to deploy VDTN as a cost-effective alternative network infrastructure for the purpose of data collecting in Surabaya's smart city initiative. Additionally, we have enhanced our previously proposed routing protocol, known as the Spray and Hop Distance (SNHD) routing protocol [13], to facilitate the collecting of data from numerous sources and destinations. This modification aims to enhance the performance of VDTN (Vehicular Delay-Tolerant Network) in smart city environments. Finally, the performance will be assessed through a comparative analysis between a modified version of the Store-Carry-Forward (SNHD) routing protocol and a widely recognized routing protocol in VDTN. This evaluation will be conducted using different numbers of vehicles as nodes or routers, The objective of this study is to investigate the impact of network density and data size on message delivery probability, overhead ratio, and average latency.

2. Research Methods

We use quantitative research methods that emphasize aspects of the objective measurement of phenomena. An artificial model of the actual system is built to obtain measurement data. The simulated model was developed via the Opportunistic Network simulator (ONE) software [14]. The primary function of the simulator is to model the movement of nodes, the relationship between two nodes, routing, and data handling.

The simulation results are obtained through data analysis through visualization, post-processing tools, and reports. In this study, we used the Surabaya smart-city scenario [15]. The first step was to carry out a literature study, then develop the scenarios that existed in our previous research. Scenarios were designed according to actual conditions in the field by integrating Intelligent Transportation Systems (ITS), as shown in Figure 1. Then conduct an investigation related to the VDTN performance in terms of delivery probability, Latency Average, and Overhead Ratio.

2.1 Simulation Scenario

In this research, we improved the Surabaya smart city scenario used in the previous study [15], where several entities exist, as shown in Figure 1.

Bus route: The bus route refers to the city bus operated by the government of Surabaya City called SuroBus. It serves passengers around Surabaya City, where four routes are used; each route consists of 10 buses.

Sensors: 40 sensors or IoT devices are scattered in several locations around Surabaya city. This device periodically generates data from sensor readings.

Subsequently, the data is transmitted to the VDTN node for the purpose of forwarding it to the application server through the roadside unit.

Roadside Unit: this device is placed in several locations, usually at traffic lights. This device is directly connected to the internet. The data received from the VDTN node is then forwarded to the application server.

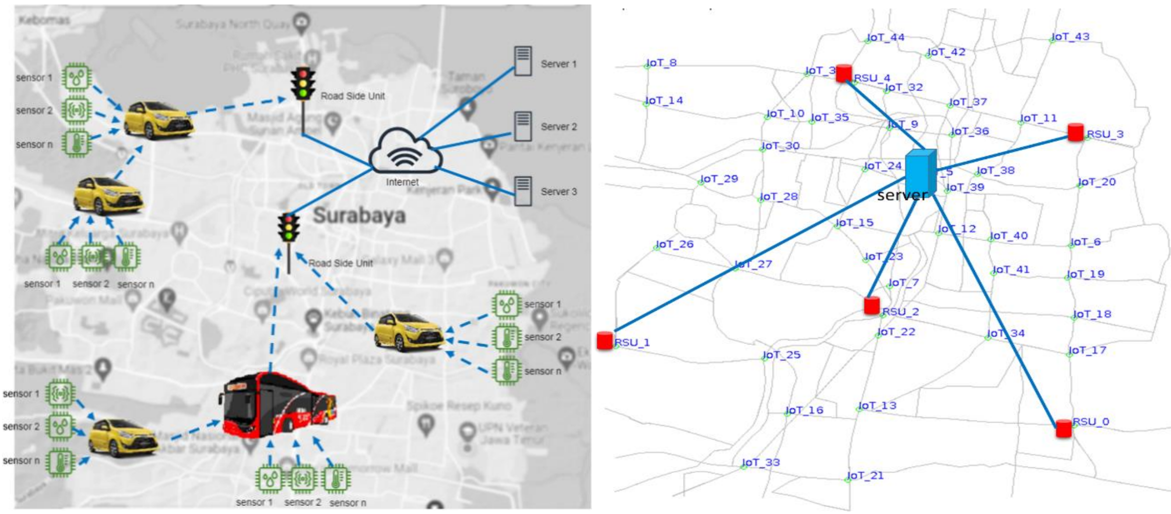

Figure 1. Simulation Map

The implementation of the scenario takes place within the Opportunistic Network Environment (ONE) Simulator, including Surabaya's map with an area size of approximately 52.5 square kilometers. Then, an IoT environmental monitoring system with VDTN as a network was used for data collection. The system collects data from 40 wireless sensors throughout the Surabaya City area. The data generated by the wireless sensor needs to be transmitted to five roadside units (RSUs) located on several bus routes. We assume that wireless sensors have limited capabilities for efficient power consumption, so a simple routing protocol is needed to forward data to mobile nodes. Each wireless sensor is placed in strategic locations such as traffic intersections.

The simulation is run several times with increasing numbers of cars from 50 to 200 cars, with the number of buses remaining the same. It aims to determine the impact of vehicle density on data collection performance. The RSU is placed on the route traversed by the bus, with at least 2 RSUs in one bus lane. The car node will move to all places and all sensors on the map that the bus node cannot reach.

Every sensor employs a Wi-Fi wireless link profile characterized by a communication range of 30 meters and a data rate of 4.5 Mbps. Alternately ten sensors generate 100 Kbyte of data every 1 second with a duration of 19 hours out of 24 hours of simulation duration. Each message has a Time To Live of 5 hours, where the car and Road Side Unit have Wi-Fi connectivity. Each node, car, bus, and RSU has 2000MB of buffer size based on the study [16]. The number of cars in the scenario varies from 50 to 200. The simulation parameters of the Surabaya Smart City Scenario are presented in Table 1. This parameter based on our previous research [15], [17] and field studies in Surabaya City.

Table 1. simulation parameter of Surabaya Smart City

Paramater	Value
Duration	24 h
Buffer Storage Size	2,000 MB
Wi-Fi data rate	4.5 Mbps
Wi-Fi transmission range	30 m
Message TTL	5h
Car and Bus velocity	5 – 20 km/h
Message size	100 Kb
Message Creation Duration	19 h
Warm up time	1 h
Message copy (L)	3 messages

2.2 Enhanced SNHD Routing Protocol

Spray and Hop Distance (SNHD) routing protocol was initially developed for the island scenario that supports one source and one destination [16]. Then in [13], it was improved to support one source, two destinations, and two sources and one destination. Then an adaptive feature is added, in which the number of initial copies (L) will be reset in a particular node called Adaptive Spray and Distance (A-SNHD) routing protocol.

SNHD and A-SNHD is a modified version of the Spray and Wait (SNW) routing protocol [18] with an additional feature, i.e., the hop distance stage, where the number of hop counts is required as a data forwarding method. This router uses a simple concept but performs better than more complex routing protocols. Due to the previous research that SNHD and A-SNHD only supports a limited number of sources and destinations, this research improved the router capabilities to support multiple sources and destinations. Figure 2 depicts a flowchart illustrating the enhanced SNHD and A-SNHD routing protocol.

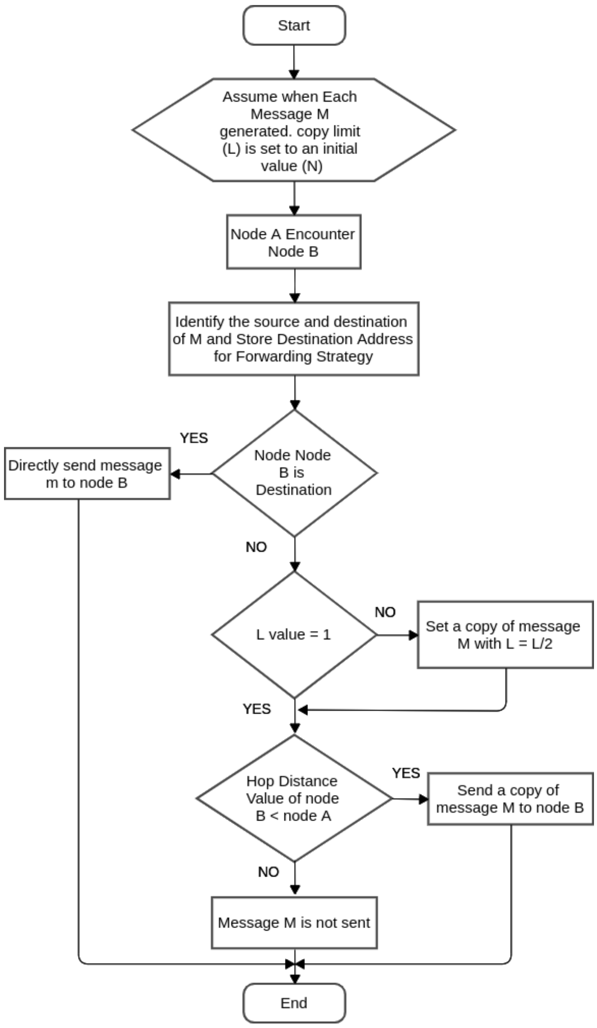

Figure 2. Flowchart Improved SNHD for multiple source and destination

The improved part is the feature to dynamically identify the source and destination of message M to support multiple sources and destinations. SNHD comprises two distinct phases: the initial phase, known as Spray, and the subsequent phase, referred to as hop distance. The switching process between the first and second phase is based on the L value. In the spray phase, the initial L value is added for each message (M) generated. When two nodes are encountered, the node with a message identifies if the other node is a destination, then the message M will forward to the other node. If the other node is not a destination node and the L value is more significant than one, the process goes to the first phase. The L value will be calculated using the formula L – L/2. The message, denoted as m, will be transmitted to a different node in the network, where the hop distance to the intended destination node is smaller than the current hop distance value of the message. The aforementioned procedure will be iterated until the value of L reaches a state of equivalence with 1.

The other condition is if the L value is equal to 1, the process directly to the second phase where the node will send message M when The hop distance value is comparatively lower than its corresponding value. SNHD and A-SNHD routing will determine which node should forward a message based on the hop-to-destination value. When the distance between hops to the destination value is small, the probability of the message successfully reaching the destination node is significantly increased.

3. Results and Discussion

After developing the Surabaya smart city scenario and the SNHD and A-SNHD routing protocol, the next stage is to evaluate VDTN in the Surabaya smart city scenario. The evaluation is done by the simulation according to the parameters in Table 1. To understand the performance of VDTN, we compare SNHD and A-SNDH with the well-known routing protocol in DTN, i.e., Epidemic Routing Protocol and Spray and Wait (SNW) Routing Protocol.

The Epidemic Protocol (EP) is a basic protocol for DTN [19]. It works according to the epidemic concept, where data is forwarded to every encountered node until it arrives at the destination node by flooding all nodes with data. When the network resources are sufficient, the performance of the epidemic is reliable. However, when the network resources are reduced due to the large amount of data sent, the network resources run out, affecting the EP's performance will also decrease.

Spray and Wait (SNW) is an additional routing mechanism, as mentioned in reference [18]. The protocol is comprised of two distinct parts, namely the Spray phase and the Wait phase. In the spray phase, SNW will work by forwarding data to the encountered node until the number of copies of data reaches a predetermined threshold or L value. Once the threshold value or L value has been reached, the system will transition into the subsequent phase known as the Wait phase. During the Wait phase, the data will exclusively be transmitted directly to the target node. In general, the SNW protocol can save the use of network resources. However, the delivery probability of the data sent may be low because, in the Wait phase, the node will only forward data if it meets the destination node directly.

In the given evaluation scenario, the sensor will transmit data to the encountered node via the routing protocol technique. Due to the car will move randomly, there is no guarantee it will encounter the Road Side Unit (RSU). On the other hand, the bus will always encounter RSU because it is located on each bus route. So that the probability of delivery of data on the bus may be higher but produces a higher latency value

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because it requires a long waiting time. Furthermore, cars may encounter RSU units more frequently if the number of cars increases. In this study, we want to assess the influence of node density, which is influenced by the increase in the number of cars, on the performance of VDTN in a smart city context. Specifically, we will examine the effects on delivery probability, average latency, and overhead ratio. The aforementioned research will serve as the basis for our investigation [20], [21].

3.1 Delivery Probability

The calculation of delivery probability involves the division of the aggregate number of messages effectively transmitted to the intended recipient by the overall number of messages generated at the source node, as outlined in equation 1.

$$Delivery\ Probability = \frac{Delivered\ Messages}{Generated\ Messages} \quad (1)$$

The first evaluation compares the delivery probabilities of each routing protocol by adding the number of cars shows in Figure 3. When the number of cars is 50, we assume that the density of networking is low, which means a sparse network. Based on the simulation results, the EP achieved a higher delivery probability, and the SNW protocol achieved the lowest delivery probability. SNHD and A-SNHD achieved slightly the same delivery probability.

However, as the car number increased to 100, A-SNHD achieved a higher delivery probability than the other protocols. Surprisingly, when the number of cars increased to 150 and 200, The SNHD demonstrated superior performance when compared to alternative routing methods. On the other hand, the delivery probability of SNW achieved the lowest in all network density conditions. The limitation of message number copies value (L) caused some messages never to be transferred to the encountered node until the TTL value was exhausted and dropped from the storage buffer.

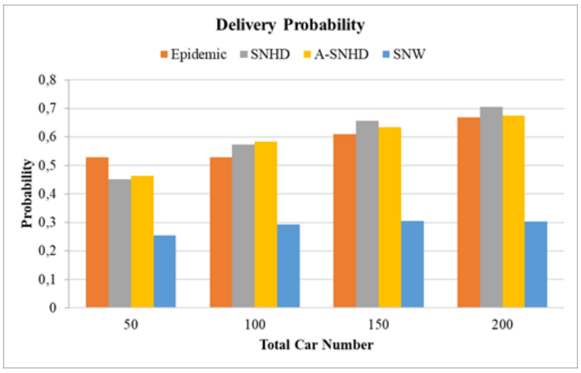

Figure 3. The Delivery Probability Comparison

In SNHD and A-SNHD, although there is a limit on the number of copies of messages, they have a better probability than EP when the car number is increased. The hop distance to destination feature has proven effective in increasing the delivery probability. When a node has a history of encounters with the Road Side Unit node, the L value in the spray phase will be reset to 0, and SNHD will work in the Spray phase until L has reached the given threshold value. Furthermore, there is a performance difference between SNHD and A-SNHD. When the car numbers are 150 and 200, A-SNHD performs better than SNHD. However, when the number of cars reaches 100, The A-SNHD protocol demonstrates superior performance in comparison to other protocols. The adaptive method in A-SNHD does not work efficiently due to increased network density. More cars mean more contact with the Road Side Unit, causing the L value on A-SNHD to be reset more often. This increases the number of hops for each data sent because the data will continue to be forwarded to encountered nodes until the L value is reached.

3.2 Average Latency

The concept of average latency refers to the mean duration required for data to initiate from its origin in the source node and reach the destination node, as specified in Equation 2. It could also be defined as a disruption in the transmission of data within a network. Achieving a lower average latency is a desirable state for a network; nevertheless, it is unattainable due to the intermittent connectivity inherent in the VDTN.

$$Avg\ Lat = \frac{\sum_{n=1}^{N} MDT - MCT}{N\ Delivery\ Messages}, if\ N \geq 1 \quad (2)$$

$$cannot\ be\ defined, if\ N = 0$$

Where MDT is Message Delivery Time and MCT is Message Creation Time.

Figure 4 shows the average latency result for all routing protocols. The average latency value of EP exhibits an upward trend as the number of cars grows, despite the concurrent growth in network capacity. The simple forwarding model in EP sends data to all nodes, causing data to flood into network nodes. So the buffer storage is no longer sufficient to store new incoming data, and the result is that the routing protocol should delete the old data in the buffer storage to receive new incoming data to be forwarded to the destination node. Likewise, for other routing protocols, increasing the number of cars does not affect the average latency value of each protocol. Except for A-SNHD, which has a fluctuating average latency value depending on the number of cars.

The inclusion of an adaptive function in the A-SNHD routing, whereby the L value is reset upon the bus or cars encountering the roadside device, contributes to a reduction in the average latency value. The destination node can be reached by augmenting the quantity of message duplicates throughout the network. Nevertheless, there is a discrepancy in the level of message control between the current situation and the

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last epidemic. On the other hand, the Spray and Wait routing protocol demonstrates the lowest average delay value in comparison to other routing protocols. This may be attributed mostly to the implementation of a restriction on the number of message duplicates distributed over the network. Nevertheless, it is important to acknowledge that the Spray And Wait routing protocol exhibits inferior performance in comparison to other routing protocols, even when considering greater delivery probability values.

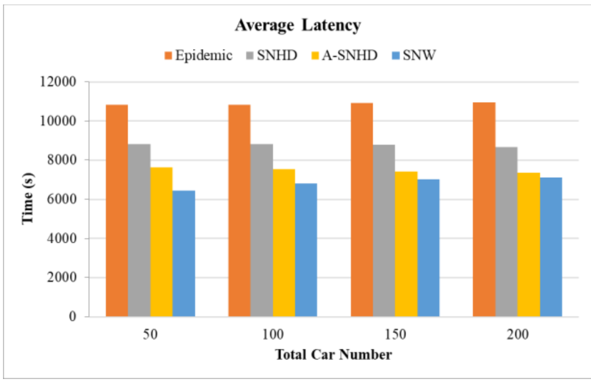

Figure 4. The Average Latency Comparison

3.3 Overhead Ratio

The overhead ratio shows the total number of copies of data in the network for each delivered data. Equation 3 shows how to calculate the overhead ratio. The lower value of the overhead ratio means a network's efficiency performance. Even though the ideal value of the Overhead ratio is 0, but not easy to achieve it unless data is directly delivered to the destination node.

$$Overhead = \frac{TCM-NDelivered\ Msg}{N\ Delivered\ Messages}, if\ N \geq 1 \quad (3)$$

$$cannot\ be\ defined, if\ N = 0$$

Figure 5 illustrates the network cost associated with each routing protocol, specifically in relation to the overhead ratio. The SNW protocol exhibits a comparatively lower overhead ratio in comparison to other protocols, mostly attributed to the restricted number of data copies generated during the spray phase. Despite its little overhead, the quantity of messages received at the destination is comparatively lower than that of the alternative protocol. On the contrary, the overhead value associated with A-SNHD is comparatively lower than that of Epidemic and SNHD. However, it should be noted that the quantity of received messages in A-SNHD significantly surpasses that of SNW. The rise in the number of automobiles is associated with a corresponding increase in the overhead ratio of routing protocols, with the exception of A-SNHD. A-SNHD has a tendency to remain steady despite the increase in car volume. The use of the adaptive spray idea is crucial in enhancing the operational effectiveness of the S-SNHD. The A-SNHD routing protocol demonstrates promising efficiency in the context of the Surabaya Smart City scenario, contributing to improved overall performance.

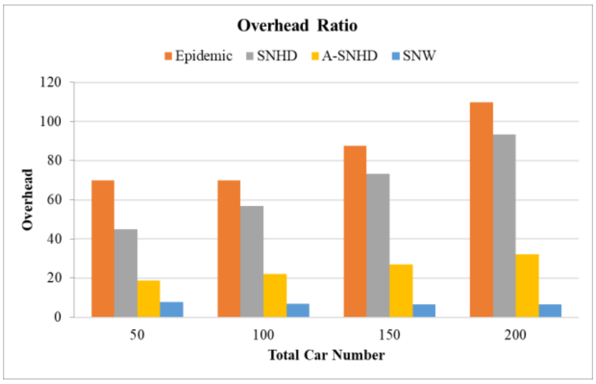

Figure 5. The Overhead Ratio Comparison

3.4 Impact of data size on Delivery Probability, Latency Average and Overhead Ratio

The following evaluation is the impact of data size on delivery probability. In this evaluation, we increased the data size from 204 kb, 496 kb, 614 kb, and 819 kb. They assumed that in actual conditions in the field, each sensor could produce monitoring data of various sizes. We used as many as 150 cars as VDTN routers/nodes for this evaluation. The findings from the simulation indicate that the efficacy of the routing protocol varies in relation to the amount of the transmitted data. As shown in Figure 6, the Delivery probability of each routing protocol decreases as the size of the data sent increases. In general, A-SNHD has the highest delivery among other routing protocols. SNW has the most negligible delivery probability, but when the data sent from the source node to the destination node is 819 kb in size, there is a slight increase in the delivery probability.

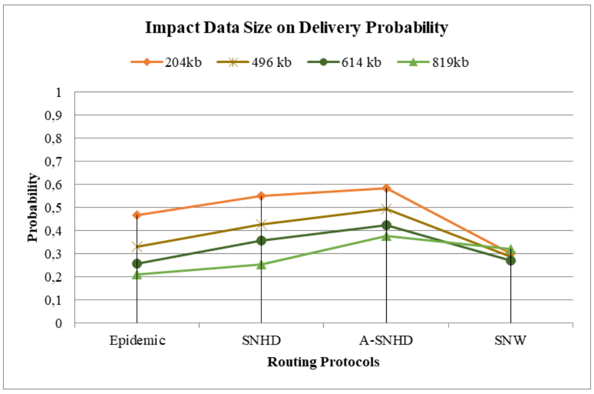

Figure 6. The Impact Data Size on Delivery Probability

Furthermore, The graphical representation in Figure 7 illustrates the relationship between data size and the average latency/delay experienced by each routing mechanism. Generally, the average latency is not affected by the data size sent from source to destination. Each routing protocol has the same average latency, even if the size of the data changes. This means that the routing protocol method/algorithm influences the average data latency. EP has the highest latency among other routing protocols because the flooding method will flood the network with data resulting in high resource usage.

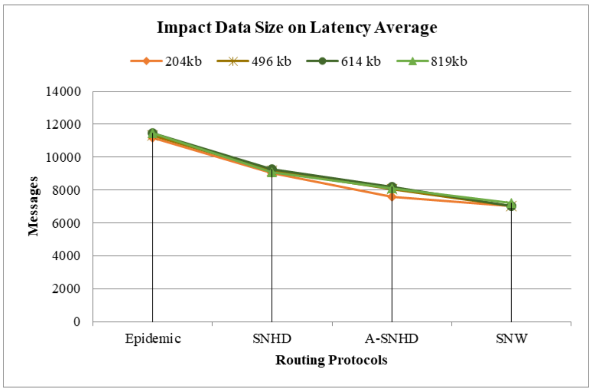

Figure 7. The Impact Data Size on Latency Average

Conversely, SNW, which limits the number of copies of each data, has the lowest latency average but has a lower delivery probability. This is different from A-SNHD, which takes advantage of SNW, namely limiting the number of copies of each data as well as the hop distance and adaptive spray features, which will reset the L value every time a node is encountered with a node that has met an RSU Node in this case the bus. So that A-SNHD has the highest Delivery probability, as well as a low average latency.

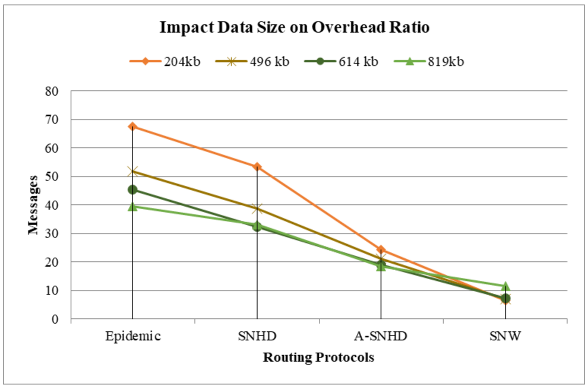

Figure 8. The Impact Data Size on Overhead Ratio

Figure 8 illustrates the correlation between data size and the overhead ratio. The smaller data size affected the overhead ratio of Epidemic and SNHD higher and slightly higher on A-SNHD. The smaller the data size affected more copies of data can be transmitted because the buffer storage of each node can generally accommodate more data. In this simulation, each node's buffer storage size is 2 GB. The efficiency of the A-SNHD protocol is also seen in the impact of data size on the overhead ratio. Even though the data size is small, the overhead ratio on A-SNHD is still small and only slightly higher when data sizes exceed 496 kb. Furthermore, SNW has a small overhead ratio but also a small delivery probability. In general, it can be seen that apart from being influenced by the routing protocol method/algorithm, the overhead ratio is also influenced by the size of the transmission of data from a source to a destination.

4. Conclusion

This research presents a novel approach for cost-effective data collecting utilizing Vehicular Delay-Tolerant Networks (VDTN) in the context of the Surabaya Smart City scenario. Furthermore, there is a need to enhance the efficiency of VDTN, the SNHD and A-SNHD protocols proposed in our previous research have improved their ability to support multiple sources and destinations. From the results of the evaluation using the ONE Simulator, several exciting facts were obtained. When the number of cars is increased from 50 to 200, routing protocol performance does not increase significantly as car density increases. On the other hand, the SNHD and A-SNHD protocol has promising performance in terms of Delivery Probability, Average Latency, and Overhead Ratio compared to the Epidemic and SNW. The delivery probability of the SNHD protocol shown a better level of achievement in comparison to the other protocols. When the total number of cars is 200, it performs a 0.7 delivery probability. In the average latency, SNHD and A-SNHD achieved better performance than Epidemic and slightly higher than Spray and Wait. In the overhead ratio, A-SNHD reached lower than SNHD and Epidemic but marginally higher than SNW. The limitation of the copy of massage in SNW affected it achieved lower overhead ratio and average latency while it has lower delivery probability.

On the contrary, the A-SNHD protocol exhibits a greater overhead value compared to the SNW protocol, while concurrently demonstrating a larger count of successfully delivered messages in comparison to SNW. The adaptive spray concept plays a significant role in increasing the efficiency of the S-SNHD so that the overall performance of A-SNHD promises routing protocol efficiency in the Surabaya Smart City scenario. Additionally, we assess the influence of data size on the overall performance of VDTN. The simulation results revealed a correlation between the size of the data and the delivery probability and overhead ratio of all routing protocols. On the other hand, the latency average for all of the data sizes shows the same results on each routing protocol. Furthermore, message scheduling, buffer management, and routing protocols based on machine learning are considered to improve VDTN performance for smart city scenarios. And also implementation in emulator and hardware prototype are also considered for the future work.

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