# Integration of message queue and drop policy in spray and hop distance protocol for DTNs in smart city scenario

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**ABSTRACT**

Implementing delay tolerant networks (DTNs) in smart cities for developing countries is promising. DTNs offer a low-cost network communication solution without expensive infrastructure, such as 3G/4G or LPWA networks provided by commercial operators. This paper considers sensor data collection in the Surabaya smart city scenario, and the use of DTNs is examined instead of the expensive infrastructure. However, a customized and optimized protocol is required since no existing DTN routing protocol perfectly matches the scenario. This paper proposes integrating a hop count-based message queue (HCMQ) and a message time-to-live (TTL)-based drop policy (MTDP) into the spray and hop distance protocol (SNHD), an enhanced version of the spray and wait (SNW) protocol. The Surabaya smart city scenario was simulated on the one simulator with a wide range of message generation rates at each sensor node. The proposed integration significantly improves the total size of delivered messages, especially when the message generation rate is high, i.e., in congested situations, compared to other routing protocols in this scenario. It also exhibits an average latency lower than other routing protocols. Overall, this integration enhances the DTNs protocol's performance in a low-cost alternative data collection in the Surabaya smart city scenario.



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## 1. INTRODUCTION

The advent of smart cities in developing countries has introduced a paradigm shift in urban infrastructure and communication systems [1]. Implementing delay tolerant networks (DTNs) in smart cities for developing countries is promising, as implemented in [2]-[5]. DTNs can be employed as a low-cost communications network in a smart city, utilizing public vehicles as routers/nodes to forward data from IoT devices to monitoring servers in a store-carry-forward manner [6]. Normally, 3G/4G or LPWA infrastructure provided by commercial network operators can handle this data forwarding. However, the high cost of deploying and maintaining 3G/4G or LPWA infrastructure has significantly hindered the widespread implementation of smart cities in developing countries. These technologies require substantial investment, especially for ongoing operational costs, often prohibitively for developing nations. As a result, many urban areas in these regions lack the necessary infrastructure to support advanced communication systems, limiting the scalability and effectiveness of smart city initiatives [7].

The Surabaya smart city scenario, based on the findings in [8], is considered where 40 IoT sensors are installed to monitor environmental conditions at various strategic locations within Surabaya city.

DTNs are employed as an alternative low-cost data collection that forwards data from the IoT sensors to the monitoring server via roadside units (RSUs). However, a customized and optimized protocol is required since no existing DTN routing protocol perfectly matches this scenario. One of the popular DTN routing protocols is the spray and wait (SNW) protocol [9], which is gaining prominence as a practical approach for disseminating messages in DTNs. Some researchers have proposed improvements in SNW to enhance the performance of DTNs, including an adaptive SNW protocol for vehicular DTN [10].

This paper proposes a novel integration of two complementary mechanisms-the hop count-based message queue (HCMQ) and the message time-to-live (TTL) based drop policy (MTDP)-into the enhanced spray and hop distance protocol (SNHD) [11]. The SNHD protocol was explicitly developed to facilitate communication in scenarios with several islands [12]. The protocol has developed from its initial version of the SNW routing protocol, Incorporating additional features to better meet the specific needs of island scenarios. The integration of these mechanisms aims to address the SNHD's deficiencies and enhance its performance in DTNs-enabled smart cities. This includes achieving higher message delivery success rates, reducing congestion, minimizing end-to-end delays, and enabling more efficient and reliable data collection in the Surabaya smart city scenario.

In the following sections, we will delve into the details of the proposed approach, including related work in the field, algorithmic operations, performance evaluation through simulations, and a comprehensive discussion of the obtained results.

## 2. RELATED WORK

Efficient data dissemination in DTNs has been the subject of extensive research due to its vital role in enabling seamless communication among vehicles and infrastructure elements in developing country smart cities. Previous studies have explored various SNW protocol enhancements and investigated HCMQ and TTL-based drop policies in other networking contexts. In this section, we review relevant literature and highlight key findings that have paved the way for our proposed integration of these mechanisms into the Spray protocol.

In DTNs, buffer management typically comprises a message queue and a drop policy. Several researchers have investigated the effects of message queue and drop policy on the performance of DTNs. A novel routing algorithm called DTN-Balance was introduced in [13] which takes into account the forwarding capacity and queue of relay nodes to enhance load distribution within DTNs. Another buffer management policy was developed for the RPRTD routing protocol, and this policy involves determining the selection of messages to be conveyed, identifying the nodes to be treated as senders, and deciding which messages should be dropped in the event of a full buffer [14]. The drop strategy is also proposed in [15] as a buffer management component in DTNs. The other researcher developed a policy based on solution size that involves determining an inception size for selecting messages to be deleted when the buffer in a DTNs gets overloaded [16]. A social community buffer management policy for DTN was developed in [17] that incorporates a community measure that comprises two components: global rank value (GRV) and local rank value (LRV).

The message TTL concept has been explored in various networking domains, including in DTN [18], [19]. A TTL-based drop policy sets a maximum allowable time for a message to remain in the network. If the message fails to reach its destination within the specified TTL, it is discarded to prevent congestion and ensure that stale messages do not impede the network's performance [20]. This approach has been practical in managing message persistence and network resources.

Hop count-based forwarding strategies prioritize messages based on the number of hops traversed through the network. These efforts aim to decrease the number of hops a message needs to traverse to reach its destination, thereby reducing end-to-end delays and enhancing delivery ratios. Integrating hop count-based forwarding into communication protocols has demonstrated the potential to enhance efficiency and reduce communication latencies [21], [22]. The field of intelligent transportation systems has provided valuable insights into enhancing communication within DTNs. Research in this area has explored advanced routing algorithms, traffic modeling, and communication protocols tailored to vehicular networks. These contributions have paved the way for innovative approaches to optimizing data dissemination and enhancing connectivity in developing country smart cities [23].

To address the challenges of low-cost data collection within the Surabaya smart city scenario using DTNs, we introduce an enhancement to the SNHD protocol. This enhancement involves integrating two key mechanisms: the HCMQ and the message TTL based MTDP. These additions aim to improve the performance of the SNHD protocol by optimizing message queuing and drop policies. Furthermore, we have enhanced the Surabaya Smart City scenario by incorporating an integrated RSU.

## 3. PROPOSED METHOD

The SNHD was created in prior research endeavors. Initially, the protocol was devised for an island scenario, supporting a single source and destination. In the aforementioned study, a framework was designed to facilitate handling multiple sources and destinations. The SNW protocol was modified to form SNHD, wherein the hop distance stage includes the number of hop counts necessary for a node to reach the destination node. This routing technique employs a straightforward principle yet exhibits superior performance compared to more intricate routing algorithms.

Prior research indicated that SNHD had limited support for multiple sources and destinations. Therefore, this study aimed to enhance SNHD's capabilities by enabling it to accommodate various sources and destinations and integrate it with the HCMQ and message TTL based MTDP. This enhancement was implemented within the context of the Surabaya smart city scenario. Figure 1 illustrates the integration of the flowchart representing the SNHD routing protocol with the HCMQ and MTDP.

As illustrated in Figure 1, similar to the SNW protocol, the SNHD protocol comprises two phases, distinguished by the number of message copies (L). The first phase is executed when L>1. In this phase, the value of L is redefined using the formula *L*=L/2. Messages are sorted using the HCMQ, with those having the minimum hop count being given higher priority for sending. Each message copy is forwarded to another node with a copy limit set to L=L-L/2. When L=1, the node evaluates the hop distance value. If this value is larger than another node's, HCMQ again sorts the message, and the message with the minimum hop count is prioritized for sending to the other node. If a message is being forwarded to another node and the buffer storage of the receiving node is full, the message in the buffer will be dropped according to the message TTL MTDP. The estimation and maintenance of hop distance information occur in the following manner: each destination node is fixed in position and assigns itself a hop distance value of 0. When two nodes come into contact, they exchange their hop distance values (h) for each destination and update those values. A node that periodically makes direct contact with the destination will have the smallest h of 1. If a node with an h value greater than 1 encounters a nearby node, messages are forwarded to this nearest node, increasing the likelihood of delayed arrival at the destination.

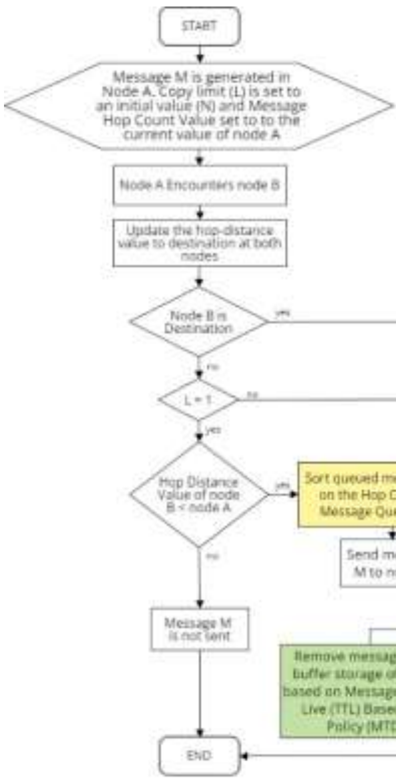



Figure 1. Flowchart of integration SNHD protocol with HCMQ and MTDP

### 3.1. Hop count-based message queue

The HCMQ is designed to intelligently manage the forwarding of messages within the network based on their hop counts. When an intermediate node receives a sprayed message, it evaluates the hop count and prioritizes its forwarding. Messages with lower hop counts are given higher priority for forwarding. This strategy aims to minimize end-to-end delays and increase the likelihood of successful delivery. The HCMQ functions as a dynamic repository for messages, optimizing their dissemination while efficiently utilizing network resources. The pseudocode for sorting by hop count is presented in Algorithm 1.

Algorithm 1. Sort by hop count message queue

```
Begin
   For each message Mi in buffer storage:
       If Mi.getHopCount() == Mnew.getHopCount() then
           Keep the current position of Mi
       Else If Mi.getHopCount() < Mnew.getHopCount() then
           Move Mi to the head of the queue
       Else
           Move Mnew to the head of the queue
       End If
   End For
End
```

### 3.2. Message TTL based MTDP

The MTDP addresses the issue of message persistence within the network. Each message is assigned a predetermined TTL value, representing the maximum allowable time for the message to remain in the network. As messages propagate through DTNs, their TTL values are decremented. If a message's TTL reaches zero before it arrives at its destination, it is discarded to prevent congestion and resource wastage. This policy ensures that stale or outdated messages do not accumulate within the network, thereby maintaining network efficiency and preventing performance degradation.

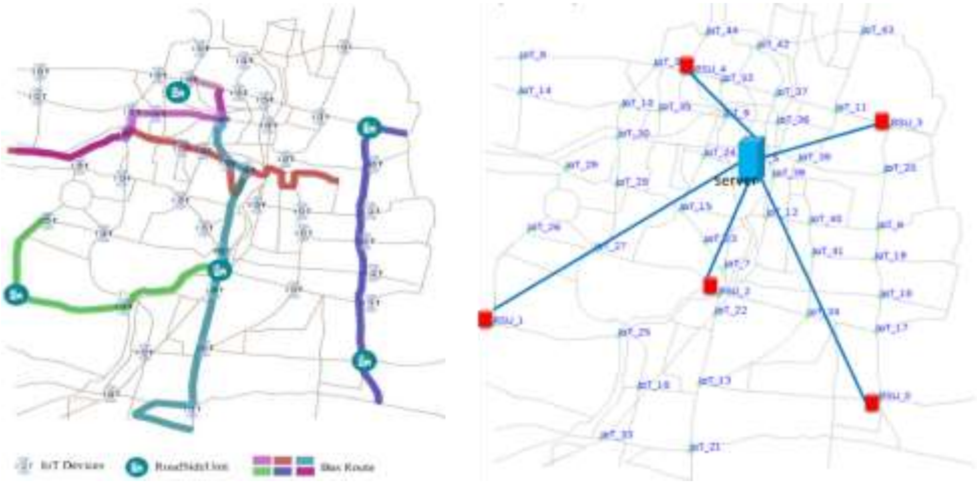
Our previous research integrated the message TTL-based MTDP under the SNHD routing protocol for a multiple-island scenario [24]. This drop policy was based on the remaining TTL and node location. In this paper, we have modified the drop policy to work effectively in a smart city scenario. The revised algorithm prioritizes dropping the message with the lowest remaining TTL value when the buffer size is full and a new message is incoming. The pseudocode for the drop policy based on the remaining TTL is presented in Algorithm 2.

Algorithm 2. Drop policy message by TTL value

```
Incoming Message Mnew
Begin
   If space in buffer storage is available then
       Insert Mnew into buffer storage
   Else
       For each message Mi in the buffer:
           If remainingTTL of Mi < remainingTTL of Mnew then
               Drop Mi
               Insert Mnew into buffer storage
               Exit For
           Else If remainingTTL of Mi > remainingTTL of Mnew then
               Drop Mnew
               Exit For
           End If
        End For
        If no message was dropped:
            Drop a random message Mi in the buffer
            Insert Mnew into buffer storage
   End If
End
```

## 4. RESULTS AND DISCUSSIONS

Surabaya, one of the major cities in Indonesia, is located on the eastern coast of Java Island. As Indonesia is among the developing countries in the world, Surabaya plays a crucial role in its economic and urban development. The Surabaya smart city scenario as shown in Figure 2, is utilized to validate the integrated approach based on previous investigations, as depicted in Figure 2(a). RSUs, positioned at bus stops, traffic lights, and other strategic locations, serve as vehicle data collection intermediaries. These RSUs transmit data to a central server via internet access indicated by blue lines in Figure 2(b). The scenario is executed using the opportunistic network environment simulator [25], Covering an area of about 52.5 square kilometers, as shown in Figure 2(b).




(a) (b)

Figure 2. Surabaya smart city scenario, (a) map with location of IoT sensor and RSU, and SuroBus route and (b) simulation map in the one simulator

The bus route relates to SuroBus, municipal bus service managed by the government of Surabaya city, which serves commuters in the Surabaya area with four distinct routes, each operated by a fleet of ten buses. Forty IoT devices are deployed across various locations in the city. These devices generate data at regular intervals based on sensor readings and send it to the nearest RSU. The number of cars is 150, while the number of buses is 10, with at least two RSUs within a single designated lane for buses. The movement of vehicles follows a random trajectory on the map.

No previous research could suggest what kind of DTN routing protocols are practically useful in the above Surabaya smart city scenario. Therefore, the purpose of this section is to evaluate and investigate the performance of various DTN routing protocols including our proposed integrated one in different congestion conditions through the Surabaya smart city scenario simulation. The simulation is executed multiple times, generating varying total message sizes: 3,416 MB, 4,546 MB, 6,826 MB, and 13,658 MB, with each message being 400 KB over 19 hours within a 24-hour simulation period. Since 40 IoT devices generate those messages, each device’s message generation rates (every hour) range from about 4.5MB/hour to 18MB/hour, from about 11 messages/hour to 45 messages/hour. Each message is assigned a TTL value of 5 hours. Every node, including cars, buses, and RSUs, has a buffer size of 200 MB. Each sensor, car, and RSU employs a Wi-Fi wireless connection protocol with a communication range of 30 meters and a data rate of 4.5 Mbps, as implemented in [26]. The simulation parameters for the Surabaya smart city scenario are detailed in Table 1.

Table 1. Surabaya smart city simulation parameters

| Parameter | Value |
|---|---|
| Duration | 24 h |
| Buffer storage size | 2,000 MB |
| Data rate of Wi-Fi | 4.5 Mbps |
| Communication range of Wi-Fi | 30 m |
| Message TTL | 5h |
| Velocity of Car and Bus | 5 – 20 km/h |
| Total generated messages | 3,416 MB, 4,546 MB, 6,826 MB, and 13,658 MB |
| Message size | 400 Kbyte |
| Duration of message generation | 19 h |
| Warm up time | 1 h |
| Number of message copies (L) | 5 messages |
| Number of IoT device | 40 devices |

We evaluated four routing protocols: epidemic protocol (EP), SNW protocol, the integrated SNHD protocol with SNHD-HCMQ-MTDP, and SNHD with a remaining SNHD-TTLMQ-MTDP for message queue evaluation. The SNHD-TTLMQ-MTDP protocol utilizes the message TTL value to determine its priority. When a node receives a message, it evaluates the remaining TTL and prioritizes the message for forwarding based on this value. Messages with a higher remaining TTL, indicating a greater likelihood of reaching the destination within the available time, are given higher forwarding priority; however, if all messages have the same initial TTL, a random message queue will be implemented for forwarding. In the following subsections, we showed the detailed comparison of the performance of those routing protocols. The results showed that our proposed integrated routing protocol, SNHD-HCMQ-MTDP, could successfully collect a larger number of messages to the destinations compared to the other routing protocols, especially when the message generation rate is high. Based on this, we can conclude SNHD-HCMQ-MTDP can best fit to Surabaya smart city scenario by using the well-tuned control parameters such as L, TTL, and the size of one message. However, in this paper, there is no simple way to find the appropriate control parameters depending on the detailed scenario parameters. We will investigate and develop a way to how to adaptively and dynamically tune the control parameters as future work.

### 4.1. The size of successfully delivered messages

The "size of successfully delivered messages" measures the amount of data successfully transmitted from the source to the destination within a communication network [26]. This refers to the payload received by the destination node, as shown in (1).

$$TSDM = N \times Z \quad (1)$$

Where, Z is the size of a message. N is the number of delivered messages.

As depicted in Figure 3, the size of sent messages from four routing protocols is examined across four distinct message sizes. The SNHD-HCMQ-MTDP protocol has the highest number of successfully delivered messages compared to the other routing methods. SNHD-TTLMQ-MTDP and SNHD-HCMQ-MTDP show equivalent delivery sizes when the cumulatively generated messages range from 3,416 to 4,546 MB. However, when the total size exceeds 6,826 MB, SNHD-TTLMQ-MTDP's performance becomes inferior to SNHD-HCMQ-MTDP's. This demonstrates that the HCMQ performs better than those based on TTL value.

In contrast, the EP exhibits a message delivery size ranging from 2.5 GB to 3 GB, even with an increase in the number of generated messages. As the total volume of generated messages rises from 6 GB to 13 GB, the overall size of delivered messages decreases. This suggests that the network's capacity to handle incoming messages is insufficient, leading to numerous messages being dropped due to buffer storage saturation.

Conversely, with the SNW protocol, an increase in the overall volume of generated messages from 6 GB to 13 GB results in a notable increase in the size of successfully transmitted messages. However, when the cumulative volume of generated messages is less than 13 GB, SNW's performance is the least favorable. The limitation on the number of L copies restricts the number of message duplicates, preventing the network from becoming overwhelmed with excessive messages and depleting essential resources like buffer storage. The message is no longer replicated during the waiting period but delivered directly to the destination node. Leveraging the benefits of SNW, it is evident that the SNHD-HCMQ-MTDP and SNHD-TTLMQ-MTDP can increase the successfully delivered messages even if the total volume of generated messages exceeds 6 GB. Generally, the enhancement of SNHD-HCMQ-MTDP's performance is facilitated. Unlike the SNHD-TTLMQ-MTDP protocol, which prioritizes messages based on their remaining TTL value, SNHD-HCMQ-MTDP assigns higher precedence to newly generated messages.

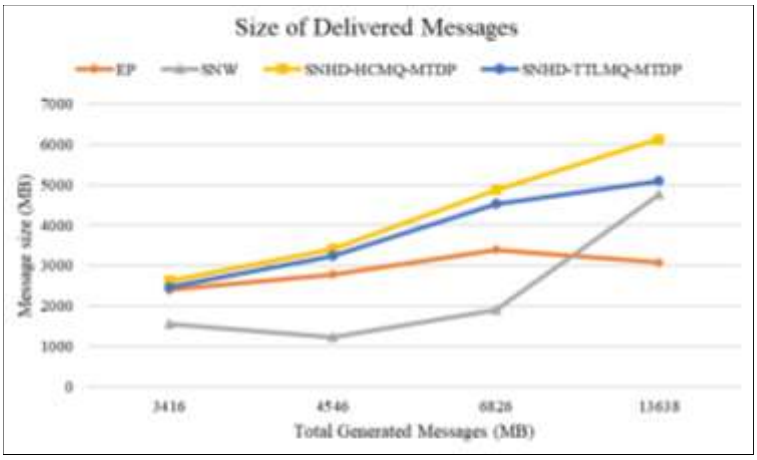



Figure 3. Size of delivered messages

### 4.2. Overhead ratio

In (2) shows the overhead ratio, which compares the total number of message copies in the network to the total number of delivered messages. A lower overhead ratio indicates more efficient and optimal network performance.

$$Overhead\ Ratio = \frac{NDM - N}{N}, if\ N \geq 1$$
$$cannot\ be\ defined, if\ N = 0 \quad (2)$$

Where, NDM is the number of forwarding of a duplicate message in the network. N is the number of delivered messages.

Figure 4 displays the overhead ratio of each routing protocol. The EP protocol does not exhibit the same limitations as other protocols regarding message forwarding; it disseminates each copy of a message to all encountered nodes, leading to a higher overhead ratio than other routing protocols. However, as the total number of generated messages rises, the overhead ratio decreases. This decrease is attributed to the diminishing network resources caused by the increasing number of messages in the network. In contrast, Spray-based protocols SNW, SNHD-HCMQ-MTDP, and SNHD-TTLMQ-MTDP restrict the maximum number of message copies, generally maintaining a consistent overhead ratio. Despite the growth in the number of generated messages, the overhead ratio of each spray-based protocol typically remains constant across all sizes of total generated messages.

The overhead ratio of SNHD-HCMQ-MTDP is higher compared to SNHD-TTLMQ-MTDP and SNW due to the prioritization of messages with the fewest hops in the HCMQ, resulting in a larger number of potential copies being generated during the hop distance phase. In contrast, SNHD-TTLMQ-MTDP uses a message queue based on TTL values, resulting in a lower overhead ratio. SNHD-TTLMQ-MTDP restricts forwarding messages to encountered nodes by only considering those with the highest TTL values. It also has a message drop policy that discards messages with the lowest TTL value when the buffer storage reaches capacity. The SNW protocol, which incorporates binary spray and direct delivery features, exhibits a relatively low overhead ratio compared to alternative routing protocols, making it an efficient routing protocol in terms of overhead. However, when evaluating the size of delivered messages, SNW needs improvement compared to other routing protocols.

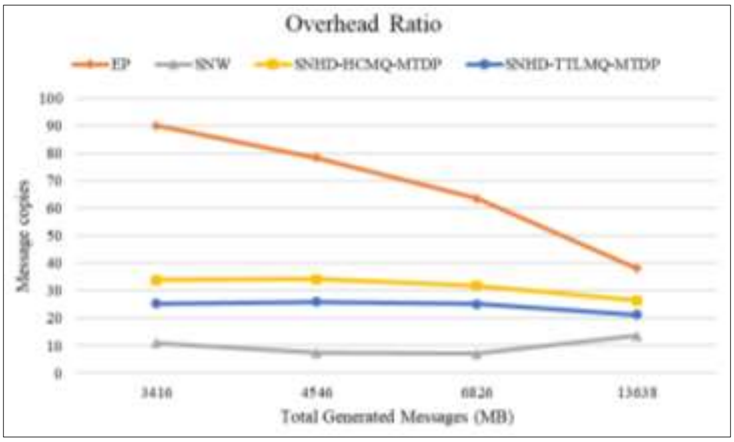



Figure 4. Overhead ratio

### 4.3. Average latency

As defined in (3), the average latency is the average time it takes for a message to be delivered to the destination node from the moment of generation. While a lower average latency is desirable for a network, achieving this is difficult due to the intermittent connectivity inherent in DTNs.

$$Avg\ Lat = \frac{\sum_{n=1}^{N} MDT - MCT}{N}, if\ N \geq 1$$
$$cannot\ be\ defined, if\ N = 0 \quad (3)$$

Where, MDT_n is delivery time of a message. MCT_n is generation time of a message. N is number of delivered messages.

Figure 5 displays the average latency. The absence of a message forwarding policy in the EP protocol contributes to its comparatively higher average latency than other routing protocols. As the number of contacts increases, the number of message copies also increases, leading to higher average latency for EP. The SHND-TTLMQ-MTDP protocol has a slightly higher average latency than the SNHD-HCMQ-MTDP and SNW protocols. This is due to the message queue and drop policy prioritization, where messages with higher TTL values are prioritized for forwarding.

Consequently, these messages exist longer within the network before relaying, resulting in higher latency. Remarkably, both SNW and SNHD-HCMQ-MTDP exhibit the same average delay. In SNW, the binary spray concept limits the number of message duplicates. While HCMQ and SNW have a similar average latency to deliver a message to the destination, HCMQ needs average hops longer than SHW (as shown later in Figure 6). This suggests that HCMQ can select better routes to the destinations to deliver a larger number of messages (as shown in Figure 5) compared to SHW that relies on the direct delivery at the final phase.

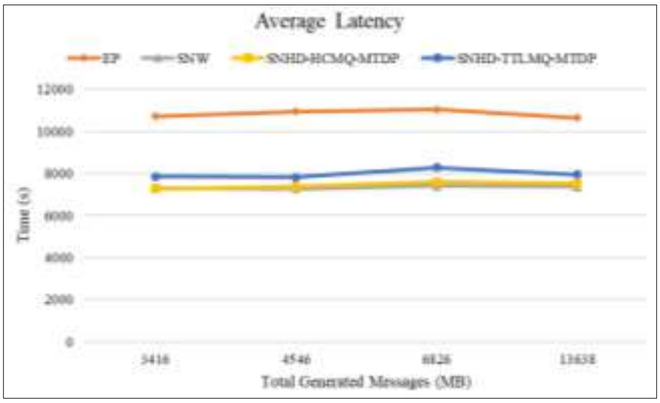



Figure 5. Average latency

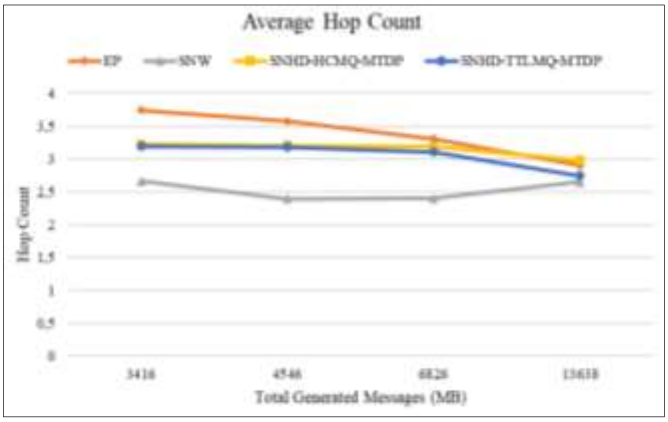



Figure 6. Average hop count

## 4.4. Average hop count

Figure 6 illustrates the average number of hops a message takes to reach its destination. This figure shows that the SNW protocol has the smallest number of hops, whereas the EP has a higher number of hops than the other protocols. The SNHD-HCMQ-MTDP, which employs a HCMQ, has the same number of hops as SNHD-TTLMQ-MTDP, which uses a TTL-based queue, for total generated message sizes of 3,416 MB and 4,546 MB. However, when the total size of generated messages is 6,826 MB, the hop count for SNHD-HCMQ-MTDP is slightly higher than that of SNHD-TTLMQ-MTDP, and it becomes the highest among the routing protocols when the total size of generated messages reaches 13,658 MB. Despite the high hop counts in this condition, SNHD-HCMQ-MTDP achieved a higher delivery rate. Therefore, the HCMQ can work more efficiently in highly congested networks than other message queuing methods.

## 5. CONCLUSION

Implementing smart cities using 3G/4G or LPWA networks in developing countries can be expensive. DTNs provide a low-cost alternative using public vehicles to forward data from IoT devices to monitoring servers. However, no single routing protocol is optimal for all scenarios. This paper proposes integrating the HCMQ and the message TTL based MTDP into the SNHD Protocol. It evaluates this integration in a Surabaya smart city scenario using the one simulator.

Simulation results show that SNHD-HCMQ-MTDP achieves the highest number of successfully delivered messages compared to other routing protocols, especially when the message generation rate is high. It has a higher overhead ratio than SNHD-TTLMQ-MTDP and SNW. It exhibits lower average latency than the EP and SNHD-TTLMQ-MTDP, similar to SNW. Overall, the proposed SNHD-HCMQ-MTDP is the best in terms of both the total number and the average latency of delivered messages.

For future work, exploring the impact of machine learning (i.e., reinforcement learning) to improve the message queue and drop policy performance of the SNHD protocol in smart city scenarios could be considered. Furthermore, developing a hardware prototype for an alternative and low-cost data collection system based on DTNs for smart cities by implementing routing protocols, message scheduling, and message drop policies is needed for real-world implementation.

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