For An Efficient Internet of Bikes : A DTN Routing Protocol Based On Data Aggregation Approach[*]

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Abstract

Nowadays, cities are facing an increasing number of bikes used by citizens therefore the need of monitoring and managing their traffic becomes crucial. With the development of Intelligent Transport Systems (ITS) in smart city, public bike sharing system has been considered as an urban transportation system that can collect data from mobile devices. In such network, the biggest challenge for sensor nodes is to forward data to sinks in an energy efficient way because of the following limitations: limited energy resources, limited storage capacity and limited bandwidth. Data aggregation is a key mechanism to save energy consumption and network capacity. It can be defined as an approach to combine data of various sensors into a single packet, thus reducing sensor communication costs and achieving a longer network lifetime. The main contribution of this paper is to introduce an efficient, "Internet of Bikes", IoB-DTN routing protocol based on data aggregation being applied to mobile network IoT devices running a data collection application on urban bike sharing system based sensor network. We propose three variants of IoB-DTN: IoB based on spatial aggregation (IoB-SA), IoB based on temporal aggregation (IoB-TA) and IoB based on spatio-temporal aggregation (IoB-STA). We compare the three variants with the multi-hop IoB-DTN protocol without aggregation and the low-power long-range technology, LoRa type. Comparison results verify that the three variants of IoB-DTN based on data aggregation improve the delivery rate, energy consumption and throughput.

1 Introduction

Transport has become fundamental in the cities to the well functioning of the economy and the welfare of the city population. For several years, transporta-

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tion faces many issues such as traffic jamming, high accidents rate, unhealthy life due to smoke and dust, air pollution as a result of carbon emission, etc. To deal with these matters, researches integrate digital technologies to ground transportation which is known as Intelligent Transport System (ITS). ITS can sense, analyze, collect, control and communicate different data. Public bike sharing systems have been introduced as part of the urban transportation system and could be used as the support of a mobile sensor network. They have been designed to allow people to borrow and return bikes from any bicycle stations with a reduced price. In June 2014, more than 700 cities, in 50 countries on 5 continents, around the world have their own bike-share systems [11], like Hangzhou, Shanghai, Paris, Lyon, London, Washington, etc.

In this article, we consider a smart bike sharing system to collect and forward data from sensors were mounted on bicycles to a set of sinks. We are interested on the application of Internet of Things (IoT) on real networks and in particular on connected bikes. The communication mechanism is opportunistic and it is based on converge cast algorithm. In previous work [20], we proposed the "Internet of Bikes-Delay Tolerant Networking" (IoB-DTN) routing protocol which applies DTN paradigm to the IoT applications running on urban bike sharing system based sensor network. It is designed for being applied to mobile network IoT devices running a data collection application. To cope with the intermittent connection between bikes, the DTN paradigm is applied. It operates in challenged networking environments characterized by intermittently connected network due to the lack of instantaneous end-to-end paths between mobile devices, long variable latency, limited resources, high error rate, etc [5]. Examples of such networks are those operating in underwater sensor network, vehicular adhoc networks (VANET), military communication networks, satellite networks, etc. In such network, the routing process is performed over time to forward data. Data are progressively displaced and stored in buffers of intermediate nodes until they eventually reach their destinations. Therefore, data is relayed hop by hop until the destination node receives a message from any relay nodes. The performance evaluation of IoB-DTN is presented in details in [20] and [19]. In our preceding work [19], we were interested to compare the multi-hop IoB-DTN protocol to a low-power wide-area network (LPWAN) technology, more precisely LoRa/LoRaWAN type. Our results show that by using a DTN-based multi-hop topology, it gives better throughput while by applying a long range technology, where there is only bike to bike station communication, it provides better energy consumption.

In order to upgrade the performance of the multi-hop IoB-DTN protocol, data aggregation is performed before forwarding data to destined targets. Data aggregation is a vast research area of wireless sensor networks [6]. It can reduce the energy consumption and network capacity thus achieving a longer network lifetime. In previous studies [16, 15], spatial and temporal aggregations are often based on raw data. With regards to spatial aggregation, data is collected from neighboring sensor nodes, while regarding temporal aggregation data is collected at different time instants.

In this paper, we investigate an efficient IoB-DTN routing protocol based on data aggregation being applied to mobile network IoT devices running a data collection application. We propose three variants of IoB-DTN: IoB based on spatial aggregation (IoB-SA), IoB based on temporal aggregation (IoB-TA) and IoB based on spatio-temporal aggregation (IoB-STA). We give a comparison evaluation of each variant with IoB-DTN without aggregation and the low-power long-range technology, LoRa type. Performance is measured in terms of delivery rate, delivery delay, throughput and energy consumption.

The rest of this paper is organized as follows. The following section discusses the related work. Section 3 presents the description of our scenario. Section 4 illustrates simulation settings. The simulation results are presented and analyzed in Section 5. The results are discussed in Section 6. Finally, we conclude this paper in Section 7.

2 Related Work

In the recent years, several researchers have focused on applying DTN paradigm to the IoT. In [17], the authors propose Direct Interaction with Smart Challenged Objects (DISCO), enabling smart objects to define and supply their interaction interfaces immediately to users. Elmangoush et al. [4] propose an improvement architecture to interconnect an M2M platforms to opportunistic networks to collect data from sensor devices with strong energy constraints. Many authors focused on applying DTN with IoT in the domain of delay-tolerant Wireless Sensor Network (WSN). Most of these researches are dedicated to targeted sensors or applications. We proposed in [20], the IoB-DTN (Internet of Bikes) routing protocol which applies the DTN paradigm to the IoT applications running on urban bike sharing system based sensor network. It is designed to collect data from mobile network IoT devices.

During the last years, many works on data aggregation in WSNs have been investigated. According to the works of literature, there are two categories of data aggregation: aggregation structures and aggregation functions.

Several works proposed aggregation structures such as tree-based, cluster-based and backbone-based structures. Shan et al. [12] introduce a centralized algorithm and design a distributed protocol for building a tree routing structure with maximum lifetime. The authors of [7] construct a data aggregation tree (MECAT) that minimizes the total energy cost of data transmission and provide a 2-approximation algorithm. They investigate two types of the problem: one without relay nodes and one with relay nodes having imperfect link quality. They prove for the first type that every shortest path tree has an approximation ratio of 2. For the second type, the problem is proved to be NP-complete and a seven-approximation algorithm is proposed. In [10], the authors present a spatial clustering algorithm for sensor networks. The algorithm constructs a dominating set based on the information description performance of the dominators to realize the data aggregation. Sinha et al. [13] are based on performance evaluation of data aggregation at data fusion center for a WSN which contains plenty sensor clusters. They propose an energy efficient method for clustering the nodes in the network. The clustering process is distributed and based on the category of sensed data, independently of geographic positioning and distance measures. The authors in [18] introduce Data Quality Maximization (DQM) protocol based on a backbone composed of a set of gateways. They consider a mobile sink moving along a fixed trajectory without stop to collect data. DQM is based on predictability of the sink movement and selects the gateways adjacent to the predicted path of the sink. In [3], the authors propose Similar-evolution Based Aggregation (Simba), a raw data-independent aggregation to consider the evolution of data rather than the raw data. Simba creates a group of isolated nodes which execute data aggregation, thus reducing the energy consumption.

Many researches focused on aggregation functions which is the way to do aggregation. Liu et al. [8] present an experimental study of using the ARIMA model for energy efficient data collection in WSNs. Their method leads to keep sensor nodes from forwarding redundant data, which can be predicted by the sink node. In [9], the authors propose an A-ARMA technique based on the forecasting by means of an ARMA model over moving average windows. The A-ARMA method reduces the computation in every sensor node and it does not have a pre-computation phases. The authors in [2] propose Agnostic Aggregation (A2), a dynamic forecasting function which can predict values with self-tuned model based on temporal aggregation. The theory of compressive sampling methods are presented in [1].

In this paper, we aim to apply the data aggregation mechanism to IoB-DTN routing protocol based on mobile network IoT devices running a data collection application.

3 Scenario description

Our scenario is based on the use of IoT in connected bikes. More explicitly, we consider a smart bicycle sharing system in which each bike has embedded sensors, a 802.11p communication device, periodically generates a data packet and stores it in its buffer. All bicycle sharing stations are equipped with base stations that are connected to the Internet. Each bike station has a 802.11p interface and acts as a fixed sink. In IoB-DTN protocol, each packet is relayed until it reaches one of the sinks. Due to the fitful connection of bikes, data are stored in the buffers of intermediate nodes and forwarded at an ensuing time to another neighboring nodes or to the final destination. IoB-DTN protocol is inspired by Binary Spray and Wait DTN routing protocol [14] which diffuses a limited number of copies of a packet sprayed in the network in order to maximize its probability to reach the destination. The detailed description of IoB-DTN protocol is given in [20]. The buffer management policy is a paramount parameter of IoB. When the buffer is full, it decides which packet should be rejected or kept. In [20], we evaluated the performances of four buffer management policies in terms of loss rate and delivery delay. From our results, Generated Packet Priority (GPP) gives the best achievements since it always gives the priority to the self generated packets.

The goal of this paper is to apply the data aggregation mechanism to IoB-DTN in order to enhance its performances regarding several metrics. It is performed during the generation and the reception phases of a new packet as shown in Algorithms 1 and 2 respectively. We evaluated three variants of IoB with:

- *Spatial aggregation (IoB-SA)*: packets are aggregated if they were generated in the same area in which its communication range is defined in meters.
- *Temporal aggregation (IoB-TA)*: packets are aggregated if they were generated less than a variable defined in seconds later or earlier than the reference packet.
- *Spatio-temporal aggregation (IoB-STA)*: packets are aggregated if they satisfy the two previous aggregations.

Algorithm 1: *Generation phase*: IoB with data aggregation

```
At each sensor reading period;
Generate a packet $p$ with the readings;
if ($\Delta$ ($p$, $p'$) ¡ ($\Delta$ area —— $\Delta$ period —— ($\Delta$ area + $\Delta$ period) ) ) then
    Aggregate $p$ with the packet $p'$
else if Buffer management provides a slot then
    Store $p \cup N^0$ in the buffer [$N^0$ copies of $p$ are stored]
```

Algorithm 2: *Reception phase*: IoB with data aggregation

```
On reception of packet $p \cup N \cup L$ (list of neighbors);
$pos \leftarrow$ self position in $L$;
$N' \leftarrow \frac{N}{2^{pos+1}}$;
if ($\Delta$ ($p$, $p'$) ¡ ($\Delta$ area —— $\Delta$ period —— ($\Delta$ area + $\Delta$ period) ) ) then
    Aggregate $p$ with the packet $p'$;
else if Buffer management provides a slot and $N' \geq 1$ then
    Store $p \cup N'$;
    Send ACK for receiving $N'$ copies of $p$;
else
    Packet is rejected, no ACK is sent;
```

In our scenario, we assume that every generated packet has size of 20 byte that could be sent by long range technology such as LoRa. Since the 802.11p packet size, considered in our previous work [19], was set to 160 byte, we can distinguish two approaches:

- *Without size reduction aggregation*: each node can combine until 7 data packets coming from different intermediate nodes into the same packet without data processing.
- *With size reduction aggregation*: each node receiving more than 7 data packets to be combined into the same packet, it combines and compresses the readings coming from this different sources. In order to limit the number of data packets aggregated in the same packet, each node applies the basic aggregation functions to process data. The simple operations used are Average, SUM, COUNT, MAX, MIN, etc. The operation used depends on the type of collected data in such application. Our protocols are independent of the aggregation function, we thus do not consider it.

4 Simulation settings

Our scenario simulates 51 bicycles moving between 49 bike stations in the Lyon city center, France as shown in Figure 1. The open data including the description of the bike sharing system in Lyon, called Vélo'v[1], are imported from the platform "Data Grand Lyon" [2], integrated with the street network from OpenStreetMap [3] and simulated with SUMO [4]- Veins [5]-OMNeT++ [6] framework. We simulate 5 scenarios by varying the paths of bicycles in each scenario. Each node generates a packet every second. The simulation time is 30 minutes. We consider the GPP policy as buffer management policy and the number of packets copies sprayed in the network is set to 8 in all our scenarios. The transmission power of nodes considered is 10 MW which gives a communication range $\backsim$ 350 meters. It gives the compromise between the evaluated metrics in [19]. We simulate four sets of parameters as depicted in Table 1 by varying the buffer size and the duty cycle. It is interesting to note that the copies of a data packet stored in a buffer are virtual. We increment a counter and each packet occupies only one slot of the buffer. The duty cycle represents the period defined in seconds to transmit all data packets stored in the buffer.

5 Simulation results and performance evaluation

In this section, we evaluate the performances of IoB-DTN protocol by applying the data aggregation mechanism. More specifically, we compare the three variants of IoB cited above. The performance metrics used for the analysis are the delivery rate, delivery delay, throughput and energy consumption.

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[1] Vélo'v: https://velov.grandlyon.com

[2] Data Grand Lyon: https://data.grandlyon.com

[3] Openstreetmap: https://www.openstreetmap.org

[4] Sumo: http://sumo.dlr.de/index.html

[5] Veins: http://veins.car2x.org/

[6] OMNeT++: https://omnetpp.org

Figure 1: Simulated area of Lyon

	Buffer size	Duty cycle (s)
Case 1	250	50
Case 2	250	150
Case 3	500	50
Case 4	500	150

Table 1: Simulation parameters

5.1 Spatial aggregation

The aggregation area is defined where the sensed values by the different sensor nodes are assumed to be generated in the same range. We simulated three values of the aggregation distances: 20m, 50m and 100m.

Figure 2 shows the average delivery rate for spatial aggregation. We notice that the impact of the aggregation area is negligible. The transmission rate increases slightly by rising the aggregation distance. In the same context, the throughput as illustrated in Figure 4 is approximately the same. Thus, it shows that the nodes mobility is more impacted than the aggregation area.

The average delivery delays of the received packets are depicted in Figure 3. By using a small duty cycle, the delays are better, since they are delivered faster, and almost the same for the three parameters.

The average protocol cost is evaluated in terms of the number of data packets transmitted in the network and it is presented in Figure 5. Each column contains two fields: NPSNG which is the number of packets sent to nodes and gateways and NASN that represents the number of acknowledgments sent to nodes. The first observation we make is the reduction of the forwarding of data packets

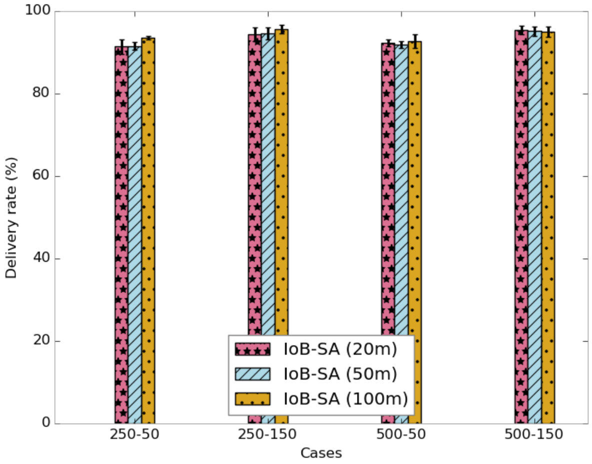

Figure 2: Average delivery rate for spatial aggregation

in the network by increasing the aggregation area. This indicates that there is more packets aggregated in the same data packet thereby saving communication cost. It is also interesting to notice that using a large value of duty cycle, it reduces the communication in the network since the data packets are stored more time in the buffers.

5.2 Temporal aggregation

The aggregation period is defined where the sensed values by the different sensor nodes are assumed to be generated less than a variable defined in seconds later or earlier than the reference packet. We evaluated three values of the aggregation period: 2s , 5s and 10s.

The average delivery rate for temporal aggregation is depicted in Figure 6. It clearly illustrates that by rising the buffer size, the delivery rate reaches 100 % for all cases. We also notice that by increasing the aggregation period, the delivery rate rises respectively. It is fair to note that the transmission rate obtained by using temporal aggregation is better than applying spatial aggregation. Indeed, this impacts the throughput as shown in Figure 8. Figure 7 shows the delivery delays. We note that by increasing the aggregation period, the delays rise gradually. As for spatial temporal, using smaller duty cycle gives better performance of delivery delays.

Figure 9 shows the average protocol cost for temporal aggregation. We notice that by rising the aggregation period, the number of data packets sent in the network decreases. As using spatial aggregation, by increasing the aggregation parameter the aggregated packets in a data packet rises. It is interesting to note that the number of packets forwarded in the network using temporal aggregation

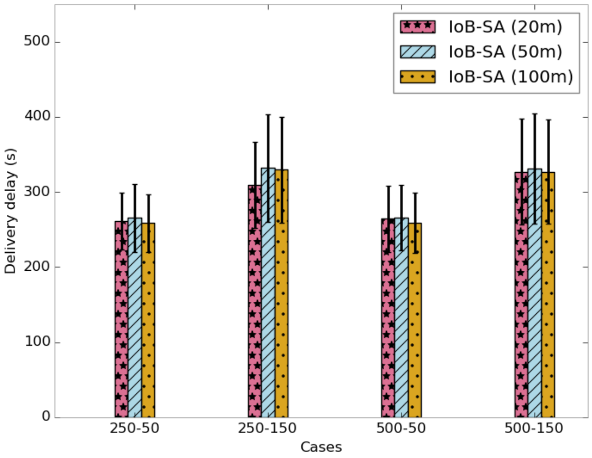

Figure 3: Average delivery delay for spatial aggregation

is twice that the one applying spatial aggregation.

The number of data packets aggregated per packet is an important parameter to evaluate the energy consumption. As mentioned before, more than it receives further than 7 data packets to be aggregated, more than it applies the aggregation functions which influences the energy consumption of each node,thereby the overall lifetime of the network. Due to lack of space, we present in Figures 10, 11, 12 and 13 the number of data packets aggregated per packet for each parameter simulated for temporal and spatial aggregations and we only show the results of cases 1 and 4. It is clear to note that temporal aggregation allows to aggregate less than the spatial aggregation. It is also important to point out that using smaller parameters for both aggregations can achieve better performances in terms of energy consumption.

5.3 Performances comparison

In this section, we gives a performance comparison of six protocols: multi-hop IoB-DTN without aggregation , IoB-DTN with one hop, IoB-LR protocol and the three variants cited above by applying data aggregation. The ”IoB one hop” has the same behaviour than the multi-hop IoB-DTN without aggregation except there is only bike to bike station communication. IoB-LR operates as a long range technology. It uses a radio propagation that gives around 1 kilometer as communication range and it is characterized by bicycle to gateways communication. The comparative evaluation between IoB-DTN without aggregation and IoB-LR is given in details in [19].

From the results obtained above, spatial aggregation with 20 m as aggregation area and temporal aggregation with 2s as aggregation period offer the best

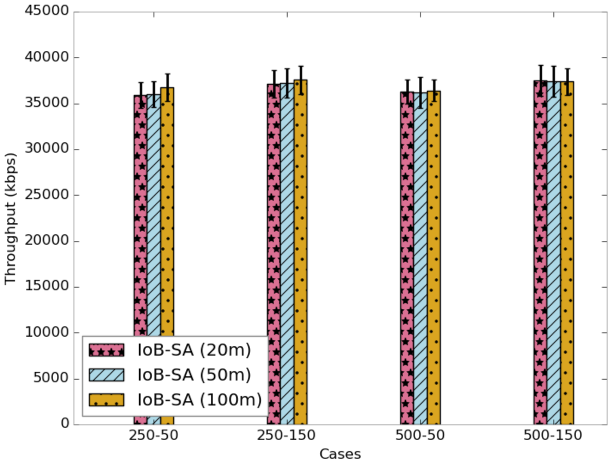

Figure 4: Average throughput for spatial aggregation

performances in terms of all the metrics simulated. Thus, in this section, we compare each variant of them and we combine the two aggregations which is appointed spatio-temporal aggregation.

Figure 14 shows the delivery rate of the six protocols. We note that the three variants of IoB based on data aggregation offer the best delivery rate in all cases. By aggregating data packets, the probability to reach their destination increases. More precisely, IoB-based on temporal aggregation gives the best transmission rate. It is crucial to point out that by using smaller buffer size, spatial aggregation provides better delivery rate than spatio-temporal aggregation; whereas by increasing the buffer size, this result is inverted.

The delivery rate influences the throughput which is depicted in Figure 16. The three variants based on data aggregation give better result in term of throughput.

Figure 15 shows the average transmission delays of the received packets. We notice that the three variants based on data gathering have higher delays. As expected, by combining data packets of several nodes into a single packet causes a significant delay. More specifically, spatial aggregation has the higher delays.

The average transmission communication is presented in Figure 17. We notice that by using data aggregation mechanism reduces the number of data packets sent in the network. In particular, spatial aggregation has the lower protocol cost.

Figures 18 and 19 show the number of packets aggregated into the same packet for spatial aggregation, temporal aggregation and spatio-temporal aggregation. It clearly illustrates that spatio-temporal aggregation gives the best performances for saving energy by combining both spatial and temporal aggregations.

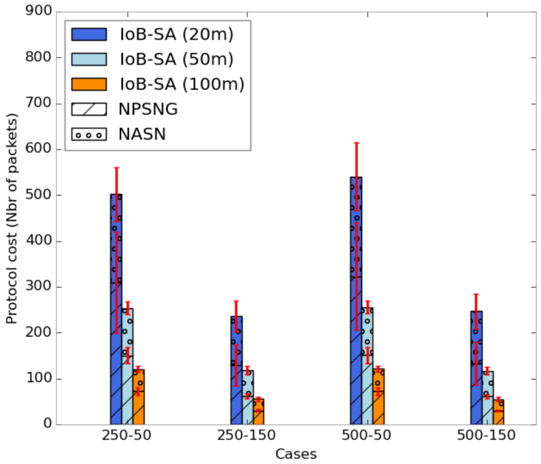

Figure 5: Protocol cost for spatial aggregation

6 Discussion results

Considering the results obtained, we can argue that IoB-DTN routing protocol based on data aggregation mechanism can accomplish best performances by saving communication cost and network capacity, achieving better delivery rate and better throughput.

The choice of the type of aggregation to be used in such urban application depends on the data sensed. We present in Figures 20 and 21 a radar schema summarizing the performance of each simulated protocol with respect to simulated metrics. Here, we use a score between 1 and 5 which indicates that the higher score provides the better performance.

As discussed above, each application requires some metrics to be higher than others. In Figure 22, we present the demands of five applications regarding spatial or temporal aggregation, throughput and delivery delay.

7 Conclusions

In this paper, we present an efficient multi-hop IoB-DTN routing protocol based on data aggregation mechanism. This approach leads to combine data packets of various sensor nodes into a single packet. We propose three variants: IoB based spatial aggregation (IoB-SA), IoB based temporal aggregation (IoB-TA) and IoB based spatio-temporal aggregation (IoB-STA). Each node generates or receives a new packet verifies the possibility if it can be aggregated according to the aggregation area and/or aggregation period used. Our results show that the three proposed variants give better performances than the multi-hop IoB-DTN

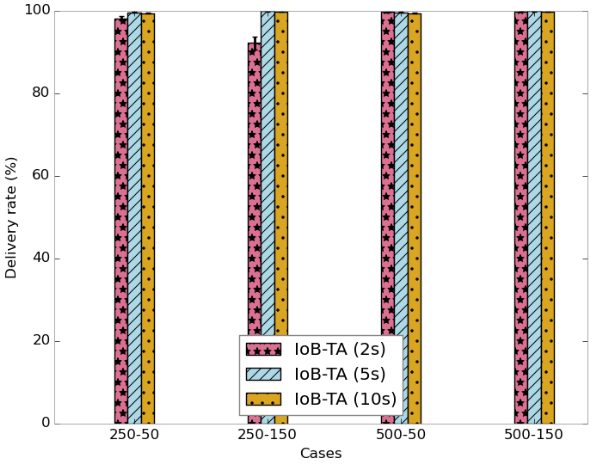

Figure 6: Average delivery rate for temporal aggregation

protocol without aggregation and the low-power long-range technology, LoRa type. They can save energy, network capacity and upgrade the delivery rate.

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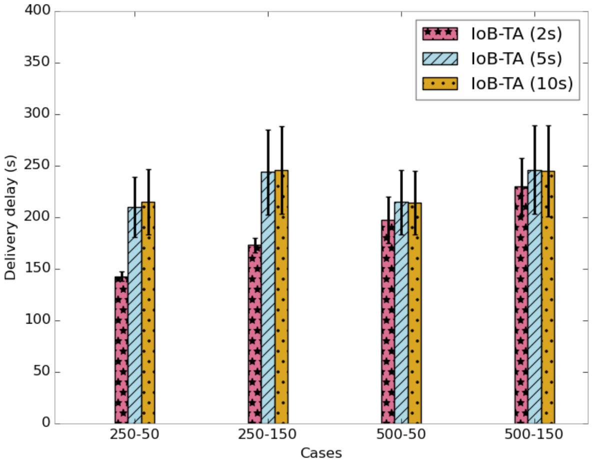

Figure 7: Average delivery delay for temporal aggregation

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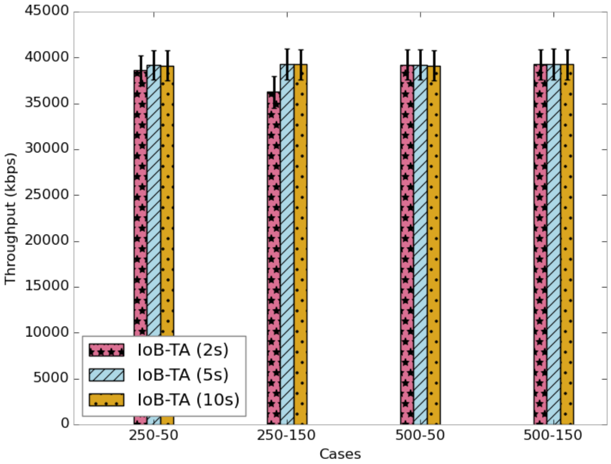

Figure 8: Average throughput for temporal aggregation

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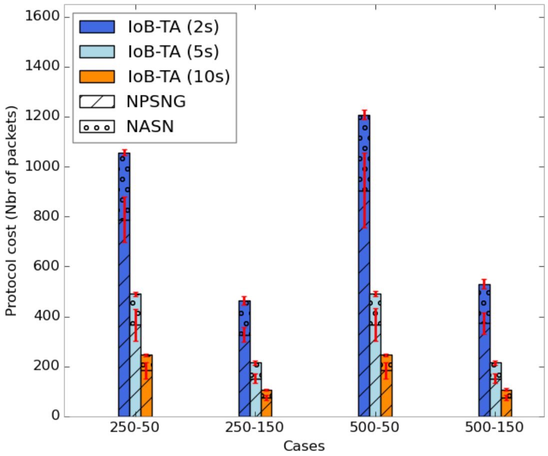

Figure 9: Protocol cost for temporal aggregation

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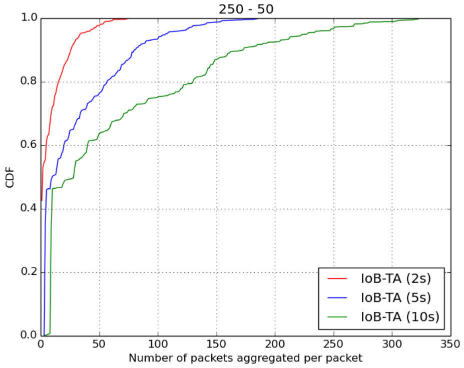

Figure 10: Temporal aggregation

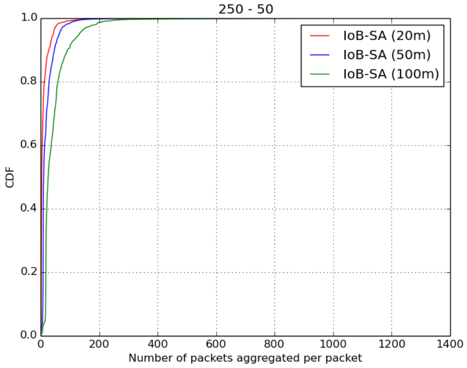

Figure 11: Spatial aggregation

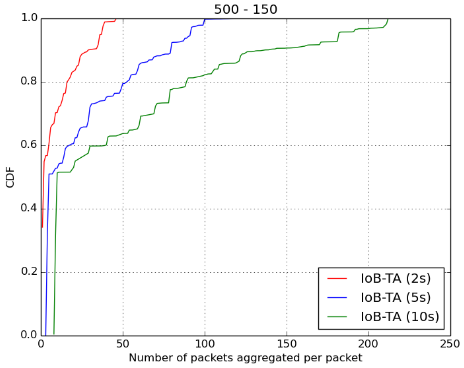

Figure 12: Temporal aggregation

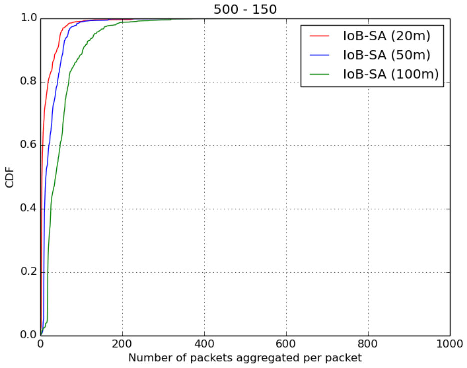

Figure 13: Spatial aggregation

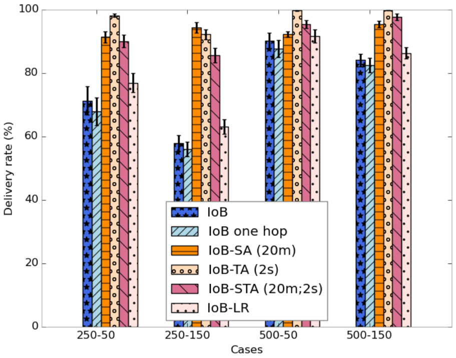

Figure 14: Average delivery rate comparison

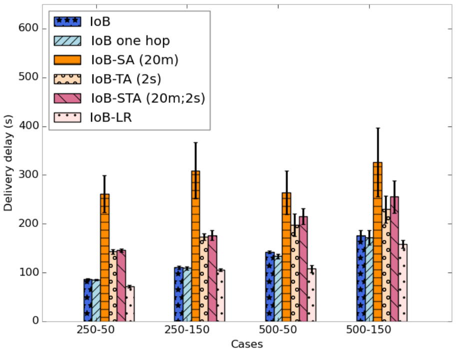

Figure 15: Average delivery delay comparison

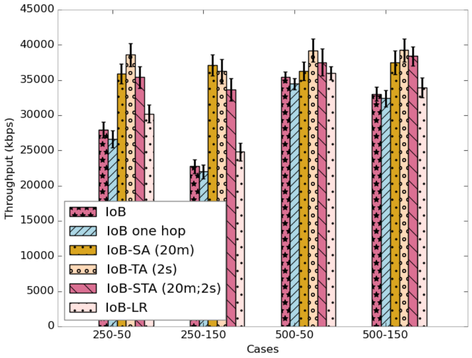

Figure 16: Average throughput comparison

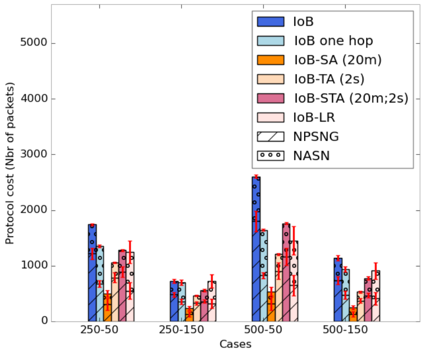

Figure 17: Protocol cost comparison

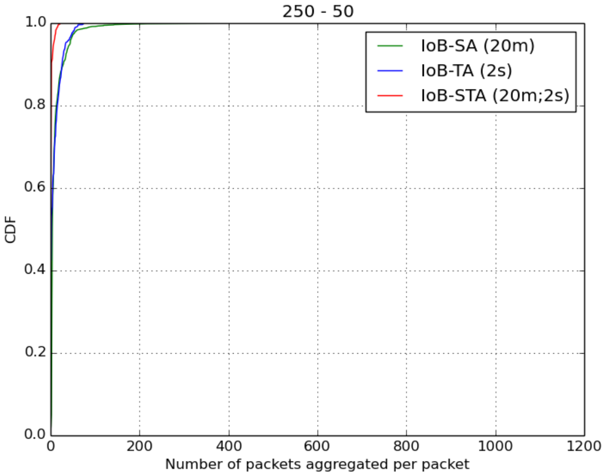

Figure 18: Comparison of number of packets aggregated

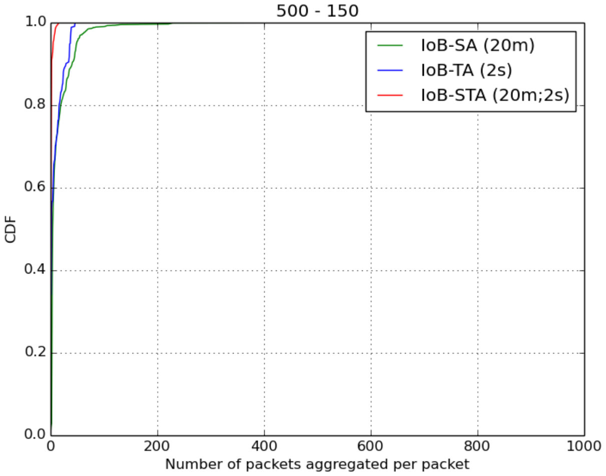

Figure 19: Comparison of number of packets aggregated

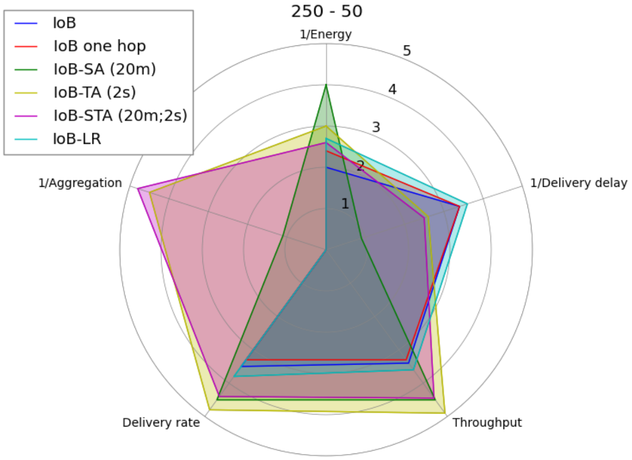

Figure 20: Comparison between six protocols for case 1

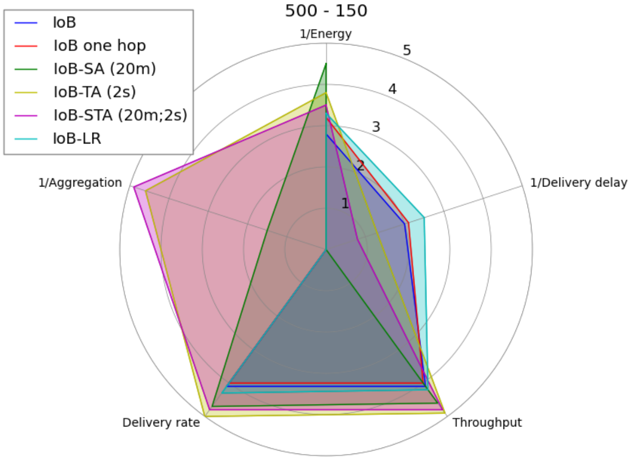

Figure 21: Comparison between six protocols for case 4

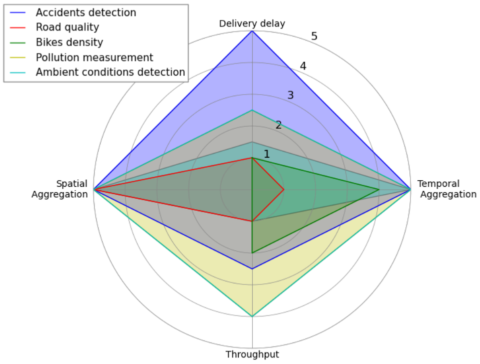

Figure 22: Comparison between five applications