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**Abstract:** Communication is essential to the coordination of public transport systems. Nowadays, cities are facing an increasing number of bikes used by citizens therefore the need of monitoring and managing their traffic becomes crucial. Public bike sharing system has been introduced as an urban transportation system that can collect data from mobile devices. In this context, we introduce "IoB-DTN", a protocol based on the Delay/Disruption Tolerant Network (DTN) paradigm adapted for an IoT-like applications running on bike sharing system based sensor network. This document presents the simulation results obtained by evaluating the Binary Spray and Wait inspired variant of IoB-DTN with four buffer management policies and by comparing three variants of IoB-DTN by varying the number of packet copies sprayed in the network.

**Key-words:** Delay Tolerant Network, Internet of Things, Public bike sharing system

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# Evaluation du protocole IoB-DTN pour l'application IoT mobile

**Résumé :** La communication est essentielle à la coordination des systèmes de transport public. De nos jours, les villes font face à un nombre élevé de vélos utilisés par les citoyens, d'où la nécessité de surveiller et de gérer leur trafic. Le système de partage de vélo public a été introduit en tant que un système de transport urbain capable de collecter des donnés à partir des appareils mobiles. Dans ce contexte, nous introduisons « IoB-DTN » un protocole basé sur le paradigme DTN (Delay / Disruption Tolerant Network), adapté aux applications de type IoT et fonctionnant sur un réseau de capteurs basé sur un système de partage de vélos. Ce document présente les résultats de simulation obtenus en évaluant la variante Binary Spray and Wait inspirée de IoB-DTN avec quatre politiques de gestion de tampons et en comparant trois variantes de IoB-DTN en faisant varier le nombre de copies de paquets diffusés dans le réseau.

**Mots-clés :** Réseaux tolérants aux délais, Internet des objets, Système de partage de vélo public

# 1 Introduction

The United Nations Population Division shows that from 1950 to 2050, the part of world's population living in urban areas will grow from 30% to 66% [1]. This generates multiple undesirable effects such as air pollution, dirty streets, noise, dangers to our health, a lot of traffic jamming and crowded neighborhoods. Therefore, there is a need to a mechanism to monitor the air pollution, highlighting the environment and transportation issues. In our work, we are interested to the last problem. One of the major solutions of urban transportation issues is public transportation system. They have been designed to connect smart devices to the Internet and they have been used to collect data from mobile devices. Public bike sharing systems have been introduced as part of the public transportation system and could be used as a mobile sensor network. In the present document, we give a description of IoB-DTN protocol applied to mobile network IoT (Internet of Things) devices running a data collection application and a performance evaluation of the protocol on real networks and in particular on connected bicycles.

# 2 Related Work

Many works focused on communication based public transport network have been proposed. Latora and Marichiori present the first network-based studies of urban transportation systems [19]. The DakNet [22] provides low-cost digital communication to remote villages in India and Cambodia. Buses are used in DakNet to transfer data between Internet access points and Internet kiosks in villages. The KioskNet [24] uses buses and cars as "mechanical backhaul" devices to transfer data between remote villages and Internet gateway. Authors rest on the pioneering lead of Daknet and extend the Delay Tolerant Networking Research Group architecture [23] to present a detailed architecture that addresses the problem of low-cost and reliable connectivity for rural kiosks. Zhao et al. [29] present a vehicle assisted data delivery (VADD) for vehicular ad hoc networks. The VADD is based on the carry and forward paradigm [26] where vehicles are used as data carriers and the path to the destination is determined based on the ad hoc connectivity of the vehicles. The DieselNet [12] is equipped up to 40 buses with access points in Amherst. Each bus has two 802.11 radios, a GPS and 40GB hard drive. Data is transmitted via bus-to-bus communications enabling their intermittent connectivity. DieselNet has led to the design of the MaxProp routing protocol. The authors in [13] propose a public transport based sensor network, called BusNet, to monitor road surface condition. BusNet is a sensor network designed to monitor environmental pollution using sensors embedded on public transport buses. This network generates and delivers data by using the stable transport infrastructure and it does not rely on the ad hoc connectivity between vehicles. The BikeNet project [14] defined a mobile networked sensing system embedded into a cyclist's bike. Nakamura et al. propose a web framework in Tokyo involving bicycles with sensors communication in a Wide Area Ubiquitous Network (WAUN) [21]. There are many public bicycle schemes that collect real-time data. Most of hire schemes collect data when bikes leave their bicycle stations include those in Germany [11] and Netherlands [7]. Several studies focused on analyzing the movement of bikes in public hire systems such as the public cycle hire scheme in London [28], Lyon [10] and Barcelona [16]. In [27], Wirtz et al. propose Direct Interaction with Smart Challenged Objects (DISCO) enabling objects to define and provide their interaction patterns and interface immediately to users. The authors, in [8], introduce DIRSN, an optimized delay-tolerant approach for integrated RFID-sensor networks (RSNs) in the IoT. Their framework provides an optimized architecture for integrated RSNs in addition to a delay-tolerant routing scheme. Elmangoush et al. [15] propose an architecture enabling the interconnection of standard-based machine-to-machine (M2M) platforms to DTNs in order to collect data from sensor devices.

# 3 Simulated scenario

In our work, we are interested to the use of IoT on connected bikes. We propose a simplified mechanism enabling bicycles to collect and send data to different sinks. Each bike embeds a sensor and a 802.11p communication device. Bicycles generate data every second, store it in their buffers and then transfer it to its neighbors depending on the duty cycle used. They exchange data until they reach a sink. Each neighbor is in communication range with a base station, it forwards all data stored in its buffer. In the next section, we details more the description of the protocol.

# 4 IoB-DTN: Internet Of Bikes-DTN protocol

The IoB-DTN proposed protocol is inspired by DTN flooding protocols [18]. Flooding strategies are based on the principal of replicating messages to enough nodes so that destination nodes must receive it. These protocols can not be applicable for the context of IoT because of their need for high memory storage and energy consumption. In this context, we introduce "IoB-DTN" protocol inspired, more precisely, by Binary Spray and Wait protocol [20] which can be applied to a mobile network IoT devices for data collection application.

The number of packet copies ($N^0$) sprayed in the network is an interesting technique to control the level of flooding. For our study, we evaluate three variants of IoB-DTN:
$N^0 = 2$: Two-Hop Relay protocol [17]
$N^0 = 8$: Binary Spray and Wait protocol [25]
$N^0 = \infty$: Epidemic Routing protocol [26]

The buffer management policies is an important parameter of IoB-DTN which leads to find a slot in the buffer node when generating or receiving a packet. When the buffer is not full, it gives the next free slot else it decides which packet will be rejected and which should be kept.

We propose four buffer management policies:

1. **KONP: Keep Oldest No Priority:** The packet generated or received is discarded if the buffer is full.

2. **NP: No Priority:** The new packet is replaced by the oldest one which has a high probability to be sent to neighbors and reached a sink.

3. **GPP: Generated Packet Priority:** If the new packet is generated, it replaces the oldest received packet. If it is a received packet, it is discarded. If the full buffer contains only generated packets, the oldest one is then rejected.

4. **LC: Lesser Copy:** The new packet replaces the packet having the smallest number of copies.

As indicated in the previous section, each bicycle generates periodically a packet and stores $N^0$ copies in its buffer. When the duty cycle is over and the base station is in the communication range of a bike, this latter sends all data stored to the sink. If not, the bicycle verifies if it has at least two copies of each packet, then it transfers one copy and keeps the other one. If it has one copy of the packet, it keeps it until it reaches the destination.

When receiving a packet, the bike determines its position number in the neighbors list sent with the corresponding packet and calculates the number of copies that it should take as shown by this equation:

$$N' \leftarrow \frac{N}{2^{pos+1}}$$

The variable *"pos"* indicates the position of the bicycle in the neighbors list, *"N"* corresponds to the initial number of copies and *"N′"* is the new number of copies calculated. If the buffer management policy provides a slot in the buffer and the receiver bike has at least one copy , it stores the packet with the corresponding number of copies and sends an ACK to the transmitter. If not, the packet is rejected.

At the reception of an ACK, the bike verifies the sender node. If it is a base station, it deletes the packet. If it is another bicycle, it updates the number of copies of the packet.

# 5 Simulation dataset

The urban environment we used to evaluate the IoB-DTN proposed protocol is the city of Lyon, France. Lyon is situated in east-central France, in the Auvergne-Rhône-Alpes region and it is the third-largest city after Paris and Marseille. Lyon is one of the first cities in the world that tested the self-service bicycles called Vélo'v [2]. The system, launched in May 2005, provides more than 4000 bikes available 24/7 from over 350 stations situated around the cities of Lyon and Villeurbanne. Each citizen takes his bike as close to his starting point and returns it as close to his point of arrival. Figure 1 depicts one of the bicycle station in the city center.

Figure 1: Vélo'v station

The Vélo'v stations data are described in the platform "Data Grand Lyon" [3]. It is characterized by reference information (name, address, number of nodes, etc.) and real-time information indicating the availability of bicycles or places. These data are integrated with the map of Lyon from OpenStreetMap [4]. Our results was simulated in the central area of the city as indicated in Figure 2.


Figure 2: City area of Lyon

These data are imported to SUMO which is an open source road traffic simulation package [9]. The urban mobility simulator allows to import and generate road networks, bike routes and obstacles. The Veins module framework [5] connects SUMO to the discrete event simulator OMNeT++ [6] via a TCP socket. The vehicular network simulation includes a real model of 802.11p and radio propagation.

Table 1 summarizes the simulation configuration used for our scenario. We simulate four cases as shown in Table 2 by varying the buffer size and the duty cycle.

| | |
|---|---|
| Number of bike stations | 49 |
| Number of bikes | 47 |
| Travel time | Min = 550s / Max = 1418s |
| Packet generation time | Every second |
| Communication model | 802.11p |

Table 1: Simulation parameters

| | Buffer size | Duty cycle |
|---|---|---|
| Case 1 | 250 | 50 |
| Case 2 | 250 | 150 |
| Case 3 | 500 | 50 |
| Case 4 | 500 | 150 |

Table 2: simulated cases

# 6 Simulation results

In this part, we present our simulation results. We compare the performances by evaluating two metrics: the loss rate and the delivery delay which is the time between the generation of a packet by a node and its reception by a base station.

## 6.1 First scenario

We compare the performances of the IoB-DTN protocol by fixing the number of copies to 8.

From Figure 3 we notice that GPP and LC behave better than NP and KONP policies by evaluating the loss rate in all cases. When the duty cycle is lower, GPP has better performances since it prioritizes the generated packets and therefore the redundancy provides robustness. LC has almost same performances than GPP policy since it rejects packets having the smallest number of copies and a high probability to be arrived to a base station. NP outperforms slightly KONP. It provides bad performances comparing to GPP and LC since it discards the oldest of generated and received packets. KONP is the worst, more precisely when the buffer is small. In this case, the buffer is saturated by the first generated packets quickly and then all others are discarded.

Figure 4 presents the delivery delay of received packets. NP offers the best performances since it drops both the oldest of generated and received packets. GPP and LC behave in the same way and have almost similar performances than NP. KONP gives a bad transmission delay since it forwards only the oldest packets.

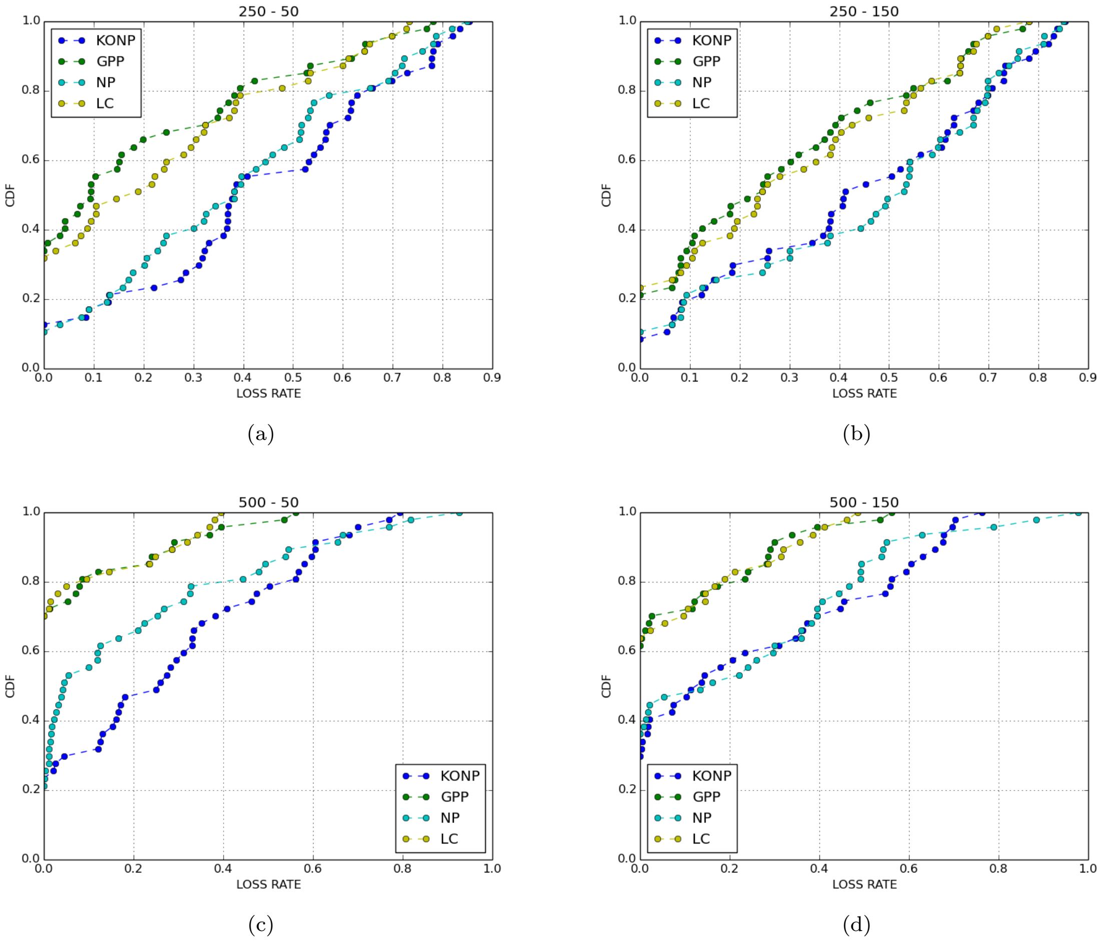
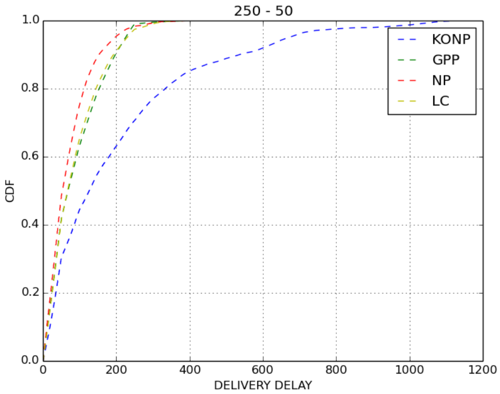



Figure 3: Loss rate

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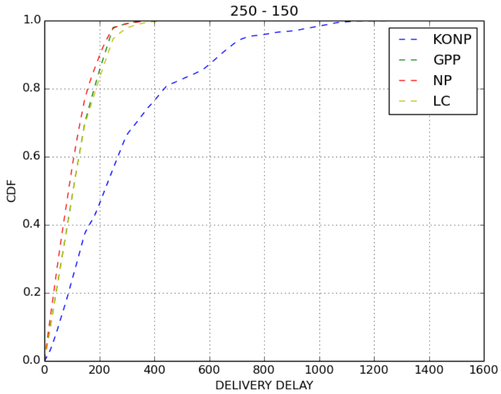


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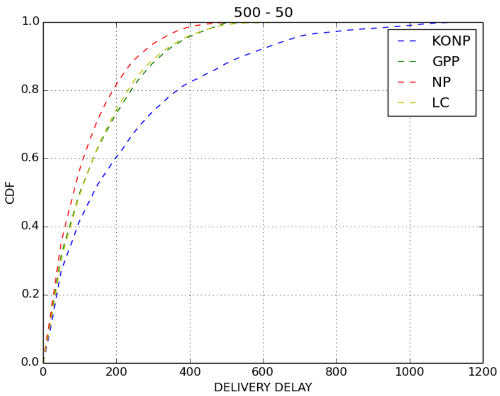


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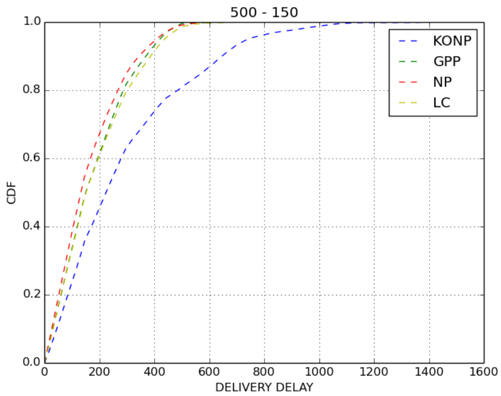


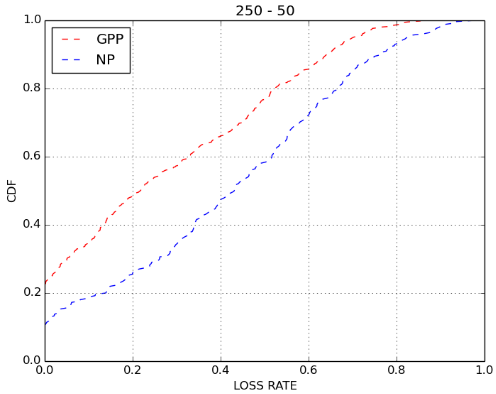

(d)

Figure 4: Delivery delay

By evaluating the both metrics in the simulated scenario, we can classify two categories of policies: KONP and NP; GPP and LC. From the first one, KONP has bad performances on the loss rate and the delivery delay. GPP provides softly best performances than LC according to the second category.

In order to confirm our results obtained for the previous scenario, we simulated ten scenarios with different paths of bicycles. We considered only the best policy for each category: GPP and NP policies.

Figure 5 depicts the average loss rate obtained for the ten scenarios by varying the paths of bikes.

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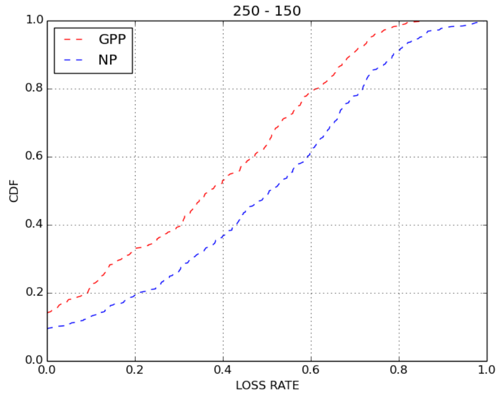


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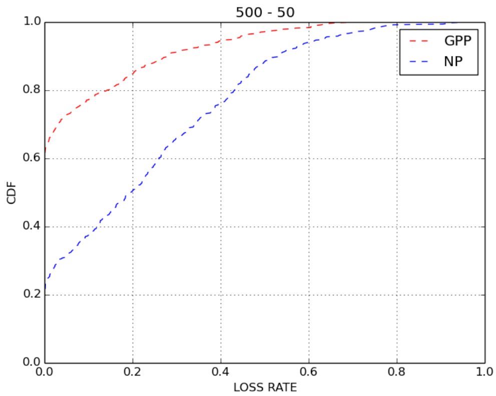


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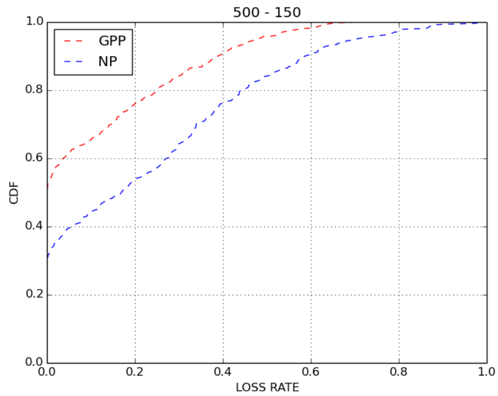


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Figure 5: Average loss rate for ten scenarios by varying the paths of bicycles

Figure 6 presents the average delivery delay of received packets for the ten scenarios simulated.

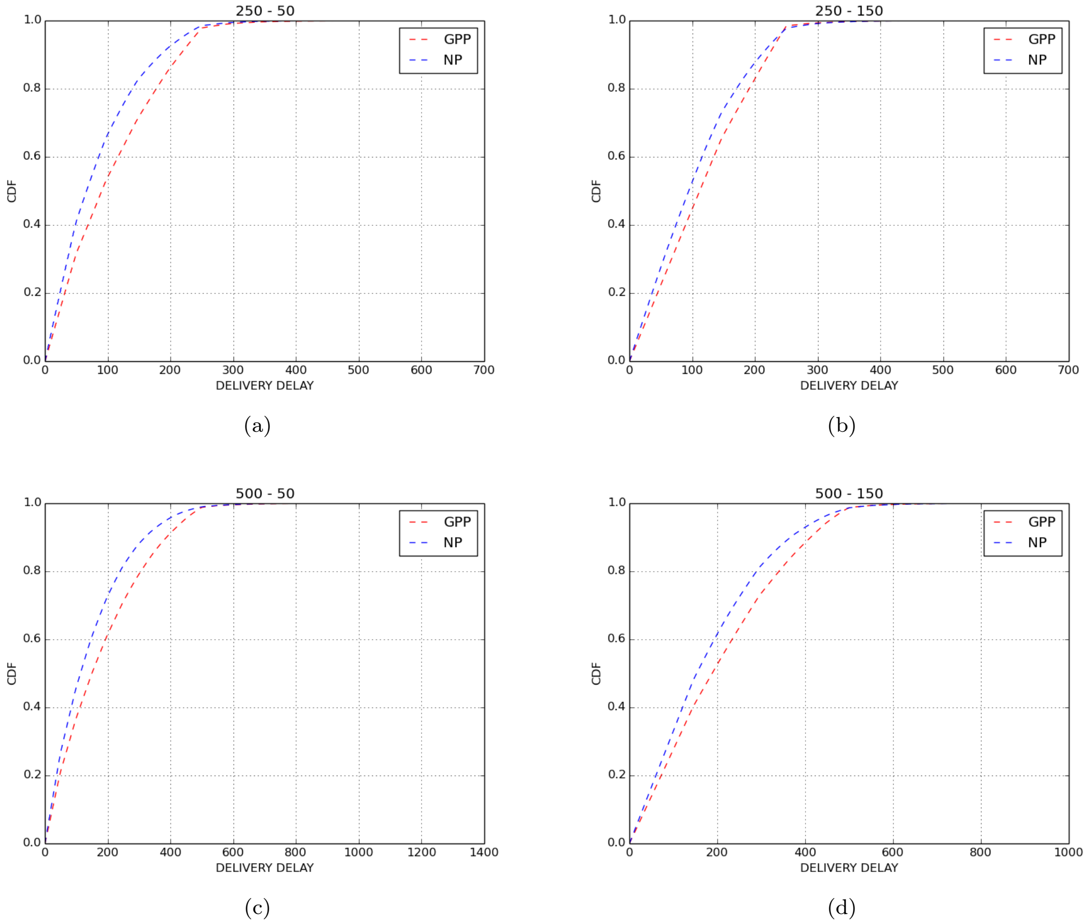



Figure 6: Average delivery delay for ten scenarios by varying the paths of bicycles

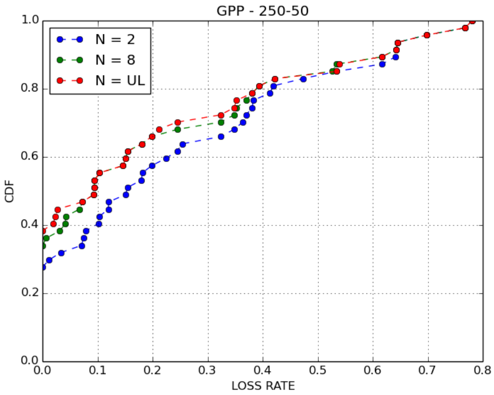
From figures 5 and 6 we notice that the results obtained for the ten scenarios are similar to those presented for the previous scenario.

In our second scenario, we evaluate three variants of IoB-DTN by varying the number of copies sprayed in the network and comparing the two buffer management policies NP and GPP.

## 6.2 Second scenario

As previously mentioned, in this section, we evaluate three cases by varying the number of copies.

From Figures 7 and 8, Epidemic Routing protocol has better performances on loss rate for GPP and NP policies since it diffuses many copies in the network. GPP outperforms NP in all cases thanks to its priority to generated packets. Binary Spray and Wait has almost similar results as Epidemic Routing protocol while Two Hop relay is the worst. This phenomenon is due to the bed choice of the neighbor node chosen as relay or to the need of more than two hops to transmit the redundant packet.

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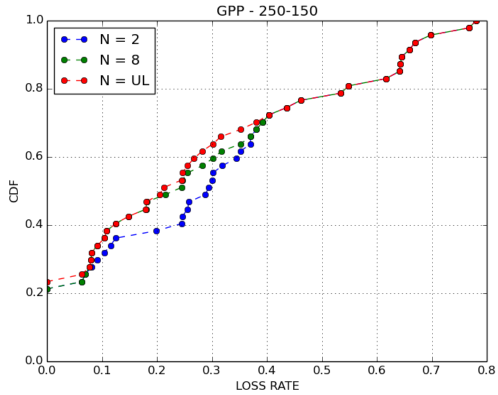


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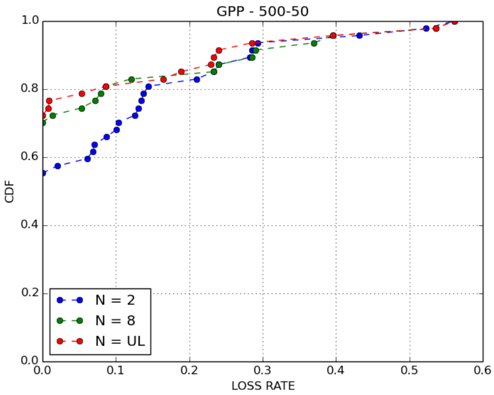


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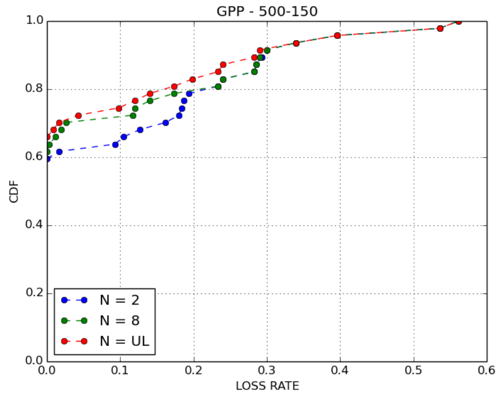


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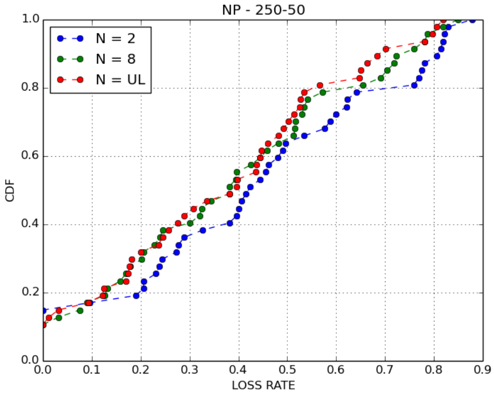
Figure 7: Loss rate for GPP by varying the number of copies

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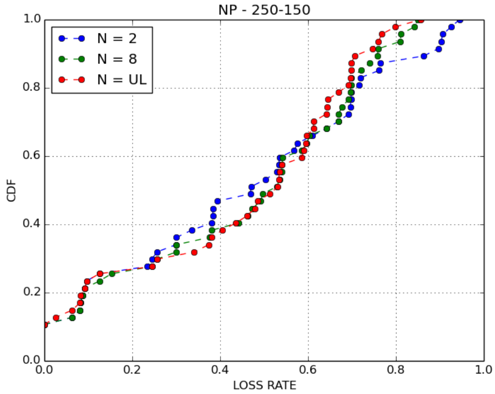


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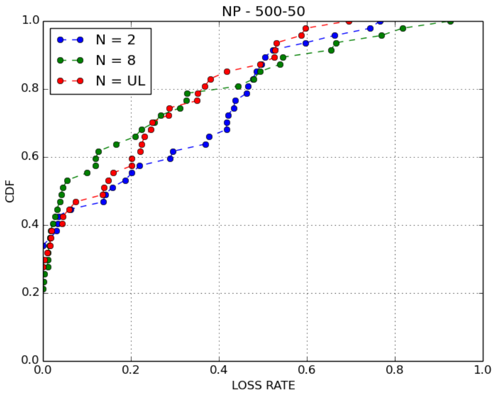


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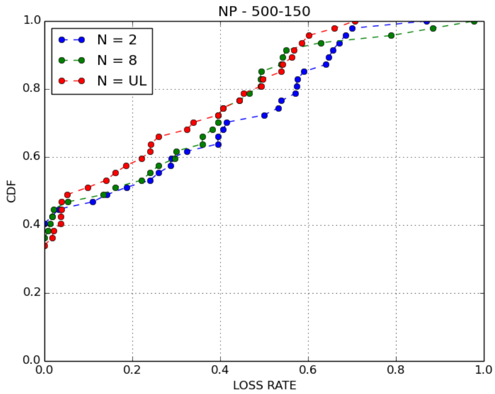



(d)

Figure 8: Loss rate for NP by varying the number of copies

We observe from Figures 9 and 10 that the three variants of IoB-DTN have similar delivery delay. More precisely, Two Hop Relay is the better and Epidemic Routing is the bad. Binary Spray and Wait and Epidemic Routing disseminate a large number of copies in the network therefore they send old packets which degrades the delivery delay.

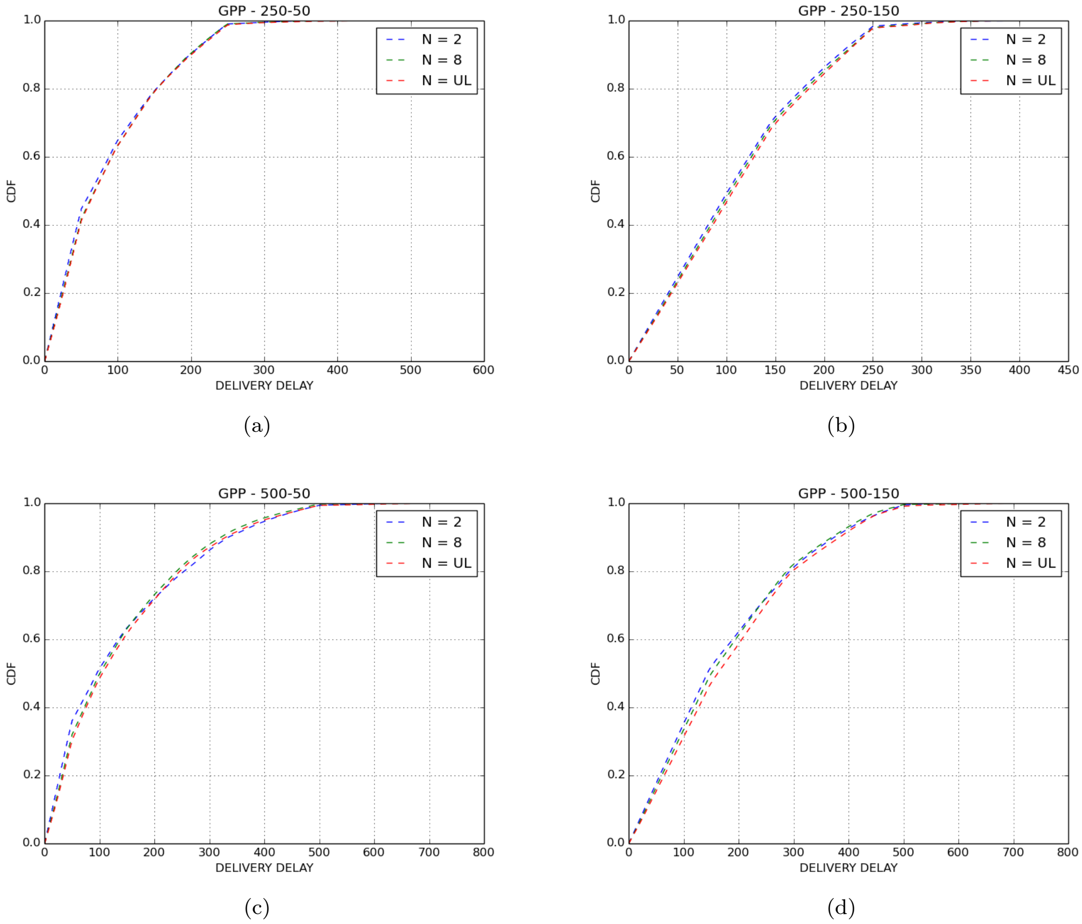
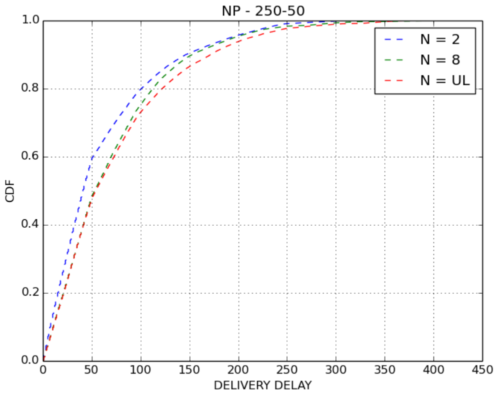



Figure 9: Delivery delay for GPP by varying the number of copies

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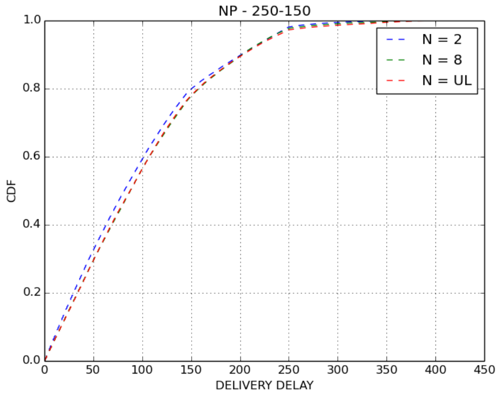


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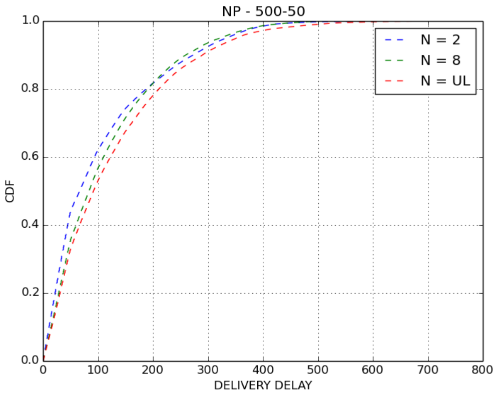


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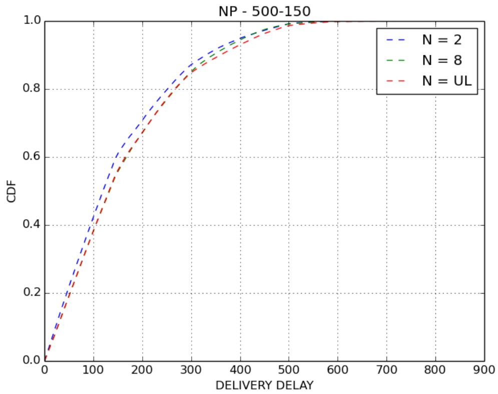


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Figure 10: Delivery delay for NP by varying the number of copies

# 7 Conclusion

In this report, we have presented IoB-DTN protocol inspired by Binary Spray and Wait applied to an IoT-like applications running on bicycle sharing system based sensor network. Our simulation results shows that by giving priority to self generated packets as buffer management and by limiting the number of copies sprayed in the network gives the best performances on loss rate and delivery delay.

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