IoB-DTN: a lightweight DTN protocol for mobile IoT Applications to smart bike sharing systems

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***Abstract*—Information and communication are key to the intelligent city of tomorrow. Many technologies have been designed to connect smart devices to the Internet. In particular, public transport systems have been used to collect data from mobile devices. 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. In this paper, we introduce the "Internet of Bikes" IoB-DTN protocol which applies Delay/Disruption Tolerant Network (DTN) paradigm to the Internet of Things (IoT) applications running on urban bike sharing system based sensor network. We evaluate the performance of three variants of IoB-DTN with four buffer management policies. Our results show that limiting the number of packet copies sprayed in the network and prioritizing generated packets against relayed ones, improves on low loss rate and delivery delay in urban bicycle scenario.**

I. INTRODUCTION

In 2016, 54.8 per cent of the world's population lives in urban areas. By 2050, it is expected to increase to 70 per cent. Urbanization yields critical sustainable development challenges, in particular air pollution and transportation issues. Biking is emerging as one of the major sustainable transportation modes. Contributing to improve on congestion, accidents, noise, energy consumption and air pollution, cycling has a positive effect on the overall health and the public life [1]. Following the development of connected vehicle innovations, the idea to embed sensors and communication capabilities directly in bikes has emerged. Such "smart bikes" could then sense and collect data of useful for municipalities and citizens, e.g. needs for road maintenance, air pollution where people are breathing deeply, ambient noise, etc. The bikes are human powered and a comparatively cheaper than vehicles, therefore they are a practical solution to be low cost and low power. The forthcoming challenges are thus closer to the field of IoT devices than traditional gas or electric cars [2], [3].

In this paper, we consider a "smart" bike sharing system in which bikes have sensing and communication capabilities, a small amount of memory and computing power, and a weak source of energy. We focus on the networking protocols that could support efficiently the collection of the data sensed by the bikes. At first sight, existing wireless sensor networks protocols could be suitable. However, most of the multi-hop wireless routing protocols assume that the network is fully connected, tolerating short duty cycles for energy saving issues. This assumption is very strong and the signaling cost of most of these protocols rise with the dynamic of the network [4].

Delay Tolerant Networking (DTN) is an alternative paradigm. However, usual DTN protocols are not suitable to be applied out-of-the-box for the context of IoT because of their need for higher computing power or memory storage. Several DTN protocols for IoT have been studied, in particular by specializing each protocol to a given application [5].

The main contribution of this paper is the proposal of "IoB-DTN", a DTN-like protocol dedicated to the following characteristics of a connected bike scenario:

- *converge cast* traffic: the data sensed by the bikes have to be collected on "the Internet" through a given set of sinks. There is no point-to-point traffic.
- *time bounded disconnection*: at worst, each bike is getting back to a sharing station. All stations are sinks.
- *urban mobility*: our mobility patterns are human-generated, hence unpredictable and without known random properties to exploit.
- *energy and computing power constrained*.

In particular, IoB-DTN can be seen as a "lightweight" version of several n-copy DTN protocols, since many features of these protocols are useless and removed, thus decreasing the memory required. No complex computations are performed either (e.g. statistics on the history of neighborhood). We evaluate the performance of several variants of IoB-DTN in a realistic scenario and provide the following engineering insights:

- there is a tradeoff between the loss rate and the energy consumption of the protocols
- a clever buffer management policy mitigates the need for

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sending redundant packets but do not improve on the delivery delay
- redundancy can help to improve the delivery delay and the loss rate if the buffer management policy rely on it.

The remainder of this paper is organized as follows. Section II discusses related work. Section III describes our scenarios. Section IV introduces IoB-DTN and Section V depicts our simulation environment. Section VI is dedicated to the analysis of our results. Section VI concludes the paper.

II. Related work

Many works focused on communication based public transport network have been proposed [6], [7], [8], [9]. As for an example, DieselNet [10] was 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. Bicycles are also used as an urban transport system to collect and transfer data. The BikeNet project [2] was a pioneering work defining a mobile networked sensing system embedded into a cyclist's bike. It leverages the cellular data plan of the cyclist's mobile phone to transfer the sensed data. In [11], Nakamura et al. propose a web framework in Tokyo involving bikes with sensors communication in a Wide Area Ubiquitous Network (WAUN). During the last few years, applying Delay Tolerant Networking to the Internet of Things (IoT) has been a challenge [12]. Wirtz et al. [13] discuss the need to handle intermittent Internet connectivity between smart objects and mobile users in the Internet of Things. They propose Direct Interaction with Smart Challenged Objects (DISCO) enabling objects to define and provide their interaction patterns and interface immediately to users. In [14], the authors introduce DIRSN, an optimized delay-tolerant approach for integrated RFID-sensor networks (RSNs) in the IoT.An architecture is proposed in [15] to interconnect standard-based machine-to-machine (M2M) platforms to DTNs in order to collect data from sensor devices with strong energy restrictions. There has been a large amount of research effort on DTN with IoT and more specifically in the domain of delay-tolerant WSN that focus on routing algorithms [16]. Most of these proposals are dedicated to targeted sensors or applications, e.g. underwater sensor networks [17], and do not use standard protocols.

The present paper introduces the "Internet of Bikes" IoB-DTN protocol which applies Delay Tolerant Networking to the specific Internet of Things (IoT) scenario of an urban bike sharing system. We adapt flooding DTN based routing protocols. We are interested in opportunistic communications based on converge cast algorithm for urban scenarios. We hence simplify routing mechanisms targeting bicycles that collect and transfer data to a set of sinks.

III. Our scenario

Public bicycle systems, also known as bicycle-sharing systems have been introduced as part of the urban transportation systems in several cities. They have been introduced in European cities in the mid-2000's and have spread worldwide. Such systems are today operating in more than 1,000 cities around the globe, with more than one million bicycles [18], [19]. The present paper focuses on the use of IoT in connected bicycles. More specifically, we consider a "smart" bike sharing system as follows.

- The bikes have embedded sensors and a 802.11p communication device [20].
- Each bike periodically reads its sensors, generates a packet and stores it in its buffer.
- Each bike sharing station is equipped with a base station that is connected to the Internet. It has a 802.11p interface and acts as a fixed sink.
- All sinks are equivalent. The IoB-DTN protocol relays the packets until they reach one of the sinks.

Figure 1 depicts a scenario with three bikes and two base stations. Bicycle 1 leaves Station 1 and starts generating data. When Bikes 1 and 2 are within communication range, they exchange data. The data are stored in the bicycle buffers until a base station comes in range. Bike 3 lies in the area of Station 2, therefore it sends all data stored in its buffer.

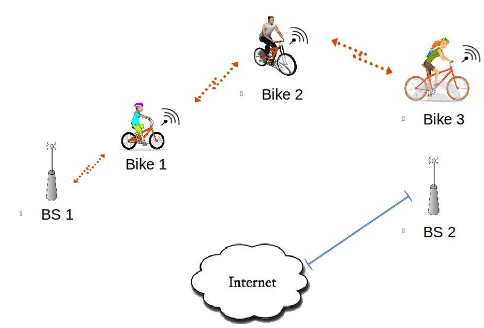

Figure 1: Illustration of our bike system

IV. IoB-DTN : Internet of Bikes-DTN protocol

In this Section we introduce the IoB-DTN protocol. The mobility of our network of bikes is human generated, it is neither predictable nor periodic in a time frame that would make learning strategies efficient, such as in public transportation. It is also difficult to rely on stochastic properties of the mobility pattern since urban biking mobility is not well understood yet. In order to cope with that, IoB is inspired by flooding DTN protocols that do not require any knowledge on the network topology [21]. Flooding strategies are based on the replication of the messages that are relayed in the network. In some sense, the lack of knowledge is mitigated by an amount of redundancy and extra resource consumption. The description of the protocol is detailed in Algorithm 1.

It is worth noting that the copies of a packet stored in a buffer are virtual. We are just incrementing a counter and each packet uses only one slot of the buffer. There are actually several hard copies of a message if and only if they have been sent to another node.

Algorithm 1 IoB-DTN

At each sensor reading period
Generate a packet p with the readings
if Buffer management provides a slot **then**
  Store $p \cup N^0$ in the buffer {N^0 copies of p are stored}
end if

When duty cycle is over
$\mathcal{L} \leftarrow$ the list of neighbors
if a base station is in $\mathcal{L}$ **then**
  Send all packets in buffer
else
  for all packet $p \cup N$ in buffer **do**
    if N (number of copies) > 1 **then**
      Send $p \cup N \cup \mathcal{L}$
    end if
  end for
end if
Wait for next duty cycle

On reception of packet $p \cup N \cup \mathcal{L}$
$pos \leftarrow$ self position in $\mathcal{L}$
$N' \leftarrow \frac{N}{2^{pos+1}}$
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
end if

On reception of an ACK of p and N'
if sender node is a base station **then**
  Delete p from buffer
else
  Update the number of copies of p : $N'' \leftarrow N - N'$
end if

A. Initial number of copies

The number of copies N created when a message is generated is an important parameter of the protocol. As stated in the protocol description, a node replicates and forwards to its neighbors only the packets that have at least two copies in its buffer. Its first neighbor takes half of these copies, the second one takes one fourth, and so on and so forth. This behavior is at the heart of the well known *Binary Spray and Wait* DTN protocol [22]. At worst, each packet is duplicated N^0 times in the network. The larger N^0, the more redundant the protocol is.

In Binary Spray and Wait, N^0 is set to 8. By setting N^0 to 2, IoB-DTN mimics the behavior of *Two-Hop Relay* DTN protocol [23]. In this variant, each packet is duplicated to the first encountered node then the two nodes carrying the packet wait for their connection to a base station. Alternatively, one can set $N^0 = \infty$ (or a large enough value) and get the behavior of the *Epidemic Routing* protocol which floods the network [24]. In our simulations, we compare these three variants.

B. Buffer management policy

Another major parameter of IoB-DTN is the buffer management policies used to find a slot in the buffer when a packet is generated or received. If the buffer is not full, the buffer management provides the next free slot. If the buffer is full, it is then necessary to decide which packet has to be discarded, with the risk that no copy of it reaches a base station, and which should be kept.

1) KONP: Keep Oldest No Priority: This policy is an usual "*First In First Served*" buffer, such as in basic network router buffers : if the buffer if full, the new packet is discarded.

2) NP: No Priority: Alternatively, this policy keeps the new packet. It considers that a packet that has spent a long time in the buffer has a higher probability to have been forwarded to another node and to arrive to its destination. Hence, the oldest packet in the buffer is discarded and replaced by the new one.

3) GPP: Generated Packet Priority: In the buffer there are two kinds of packets: those that have been generated by the node itself and those that have been received from another node. The goal of GPP is to avoid situations in which the received packets take all the place in the buffer and block all the packets generated by the node itself. Therefore, when a packet is generated, it replaces the oldest received packet. But if there are only generated packets, then it replaces the oldest one. If a packet is received while the buffer is full, it is discarded.

4) LC: Lesser Copy: This policy does not consider the time at which packets have been generated but the number of copies stored in the buffer. A packet with a small number of copies is more likely to be delivered to a base station by another node than one with all its copies. When a packet is received or generated, it thus replaces the packet having the smallest number of copies in the buffer.

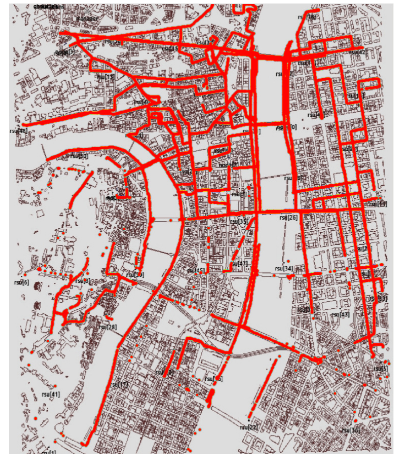

Figure 2: Mobility traces of bikes

V. Simulation settings

In this section, we describe the simulation settings used for our experiments. Our scenario simulates 47 bikes moving across the Lyon city center, France as depicted in Figure 2. The data is imported from the open data of the bike sharing system of Lyon, integrated with the street network from OpenStreetMap and then simulated with the SUMO-Veins-OMNeT++ framework. The histogram of the biking travel times is depicted in Figure 3.

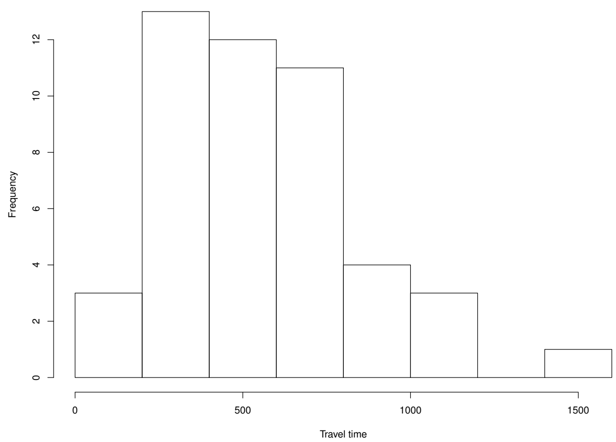

Figure 3: Bikes travel time in seconds

Each bike reads its sensors and generates a packet each second when it is moving. The mean travel time is around $550s$, the longest being $1418s$, with as many packets generated. The transmission power used is 10 mW which leads to have communication range approximately to 350 m.

We simulate four sets of parameters as shown in Table I. In this paper, apart from Figure 4, we only show the results of cases 1 and 4. The remaining scenarios are presented, in detail, in our research report [25].

We remark that it is very likely that packet loss occurs since the buffers' sizes are not large enough to store all the packets generated by one bike. This concerns the devices that are constrained in memory.

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

Table I: Simulation parameters

In each simulation we evaluate the distributions of delivery delays (the time between the generation of a packet and when it is received by a base station) and the loss rate.

VI. Simulation results

First, we compare the performance of the four buffer management policies introduced before with the Binary Spray and Wait inspired variant of IoB-DTN. We then compare the impact of the number of copies.

1) Evaluation of buffer management policies: We evaluate the performance of the four buffer management policies when the number of copies per packet allowed in the network is limited to 8. Figure 4 shows the loss rates. We notice that in all cases GPP and LC perform better than NP and KONP policies.

As expected, KONP performs poorly, in particular when the buffer is small. In this case the generated packets saturate the buffer very fast and all other packets are dropped. More surprisingly, NP have similar performance in most cases.

Since GPP prioritizes the generated packets in the buffers, the duplicated packets have less impact on the loss rate. However, the fact that the performance is better when the duty cycle is lower, implies that the redundancy induced by the mechanisms provides robustness.

LC has similar performance to GPP. Indeed by discarding packets that have less copies in the buffer, it secures packets that have not been shared yet. This increases the redundancy of the packets in the network, hence the robustness.

GPP outperforms slightly LC when the buffer size is small. In this case the relative impact of the redundancy is higher.

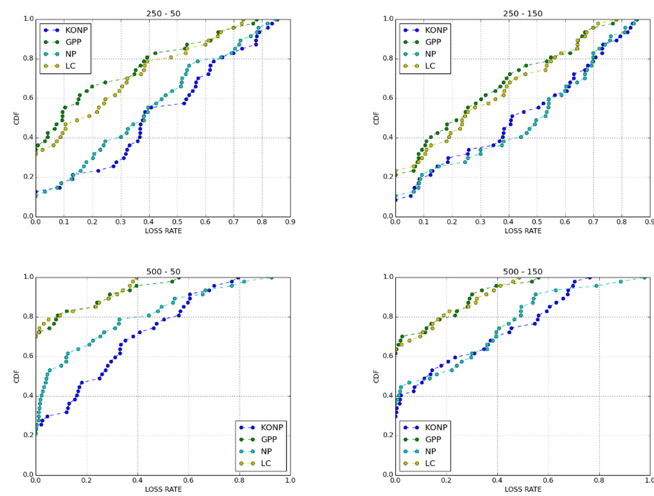

Figure 4: Loss rate

Figure 5 shows the delivery delays of the packets that are received. These results should be analyzed with the loss rate in mind.

KONP is the worst policy in terms of delivery delay. This is an obvious consequence of the "keep old" policy: only the oldest packets are delivered. On the other hand, NP offers the best delivery delay in all cases. Here again, this behaviour was expected as the protocol drops old packets.

GPP and LC policies have similar performance to NP while granting a better loss rate. There are thus older packets that are delivered. The similar delay distribution shows that they are also delivered faster. The redundancy of packets in the network indeed increases the routing diversity.

From our results, one can see two classes of policies: KONP and NP on one side, GPP and LC on the other. KONP is clearly a bad buffer management policy as it has poor performance both on loss rate and delivery delay. GPP and LC behave quite similarly despite their apparently opposite philosophies: one protects self production against redundancy while the other rely on redundancy to make place to new packets. In some sense, we could expect that NP and LC behave similarly since older packets are more likely to have less copies.

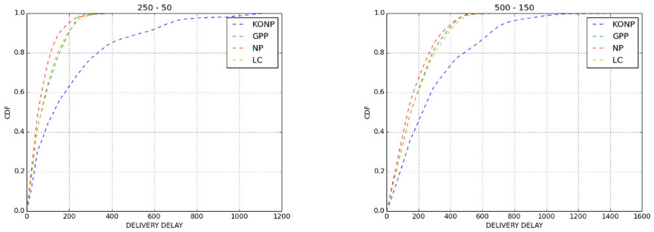

Figure 5: Delivery delay

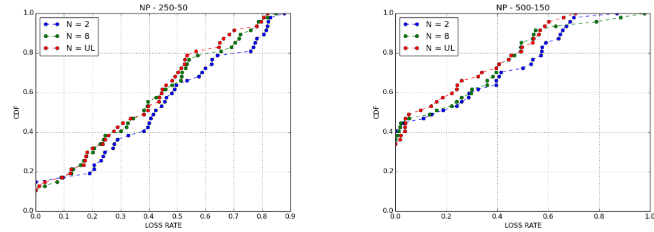

Figure 7: Loss rate for NP

In order to confirm the results presented in this section, we simulated ten scenarios for GPP and NP policies with different paths of bicycles in each scenario. In all scenarios, we got similar results on loss rate and delivery ratio with results presented here. Due to lack of space, the detailed results for the ten scenarios are presented in our research report [25].

Next, we evaluate three variants of IoB-DTN, depending on the number of copies sprayed in the network. We only compare the performance of GPP, which gives the best tradeoff between delivery delay and loss rate, and NP, which gives the best delivery delay.

2) Studying number of copies: We simulate three cases summarized in Table II. The first case behaves like the Two-Hop Relay protocol [23], the second like Binary Spray and Wait [22] and the last case like Epidemic Routing [24].

	Number of copies
Case 1	2
Case 2	8
Case 3	UL

Table II: Number of sprayed copies

Figures 6 and 7 show the loss rate for GPP and NP policies. We observe that Epidemic routing protocol offers the lower loss rate for GPP and NP policies. By disseminating a large number of copies in the network it maximizes the redundancy and the robustness. GPP has a better loss rate comparing to NP in all cases thanks to its protection of self production.

Binary Spray and Wait provides similar performance while Two-Hop Relay is significantly worse. This may have two explanations. One is that there is not enough diversity and, sometimes, the neighbor chosen as relay is not the best choice to deliver the packet to its destination. Another reason can be that more than two hops are necessary to deliver the redundant packets.

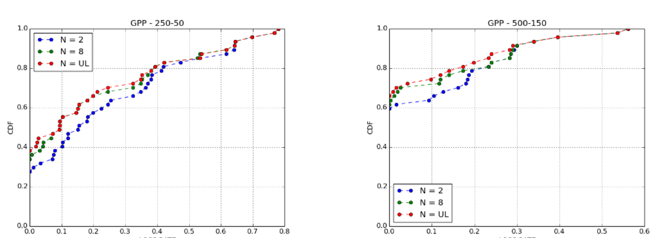

Figure 6: Loss rate for GPP

Figures 8 and 9 show that the three protocols provide similar results in terms of delivery delay. More precisely, Two-Hop Relay protocol offers the best delivery delay while Epidemic routing is the worst. This should however be balanced by the loss rate. Since Epidemic and Binary Spray and Wait deliver more packets, they guaranteed to deliver the older ones, hence degrading the overall delivery delay. The small gap between all performances results leads to conclude that Two-Hop relay is not a good trade-off.

Table III gives the average number of packets actually sent by a node to another in each scenario. This metric is directly linked with the energy consumption of the protocol: at the cost of a small extra storage or extra signaling, which is neglected in our simulation, a node can send to its neighbors only the packets they don't have a copy of. As expected, the more copies sprayed, the more transmissions are needed. It is however not linear with the number of copies and Epidemic consumes only twice as much as Two-Hop relay.

It is interesting to note that NP generates more transmissions than GPP. Indeed, the mobility of the bike is not uniformly random but constrained by the urban topography. Therefore, the networking neighborhoods have phases of stability, e.g. when a group of bikes follow the same street. Since GPP keeps the generated packets in priority, it is more likely that after a while all neighbors of a node have a copy of its packets and no more duplication occurs.

		250-50	250-150	500-50	500-150
GPP	N = 2	471	280	738	463
	N = 8	638	317	1113	604
	N = UL	833	329	1437	682
NP	N = 2	600	376	917	562
	N = 8	888	469	1410	762
	N = UL	1265	596	1827	829

Table III: Average number of transmission per node

VII. Conclusion

In this paper, we have introduced the IoB-DTN protocol. It is a n-copy protocol closely inspired by Binary Spray and Wait. It is tailored for being applied to mobile network IoT devices running a data collection application. Depending on the parameter settings and the buffer management policies that are implemented, several variants of the protocol can be defined. We have evaluated these variants on a realistic scenario of a smart bike-sharing system where each bike embeds sensors and a 802.11p communication device. Our results highlight the impact of redundancy of packets induced by our protocol and the efficiency to give priority to self generated packets or to already sprayed packets. This redundancy however costs energy as part of packet transmission. This cost can be partially mitigated by exploiting the stability of the radio neighborhood induced by the urban mobility pattern.

As future work, we are investigating the performance evaluation of our urban system at a larger spatio-temporal scale and we are conducting experiments on real testbed.

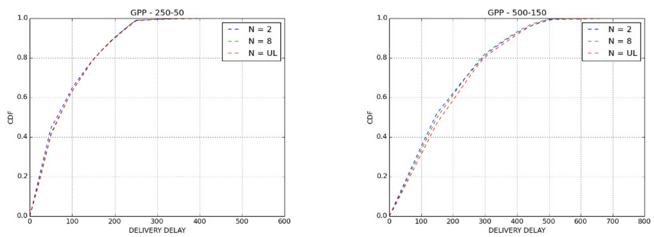

Figure 8: Delivery delay for GPP

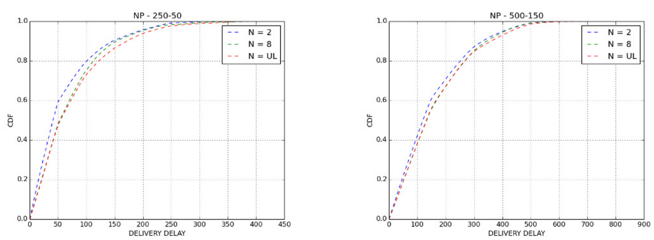

Figure 9: Delivery delay for NP

VIII. ACKNOWLEDGMENT

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