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Ngurah Indra Er, Kamal Deep Singh, Jean-Marie Bonnin

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Contact Strategy for VDTN

Data Collection in Smart Cities

Ngurah Indra ER
IRISA/ IMT-Atlantique, Rennes-France
&
Udayana University, Bali-Indonesia
indra@unud.ac.id

Kamal Deep SINGH
Laboratoire Hubert Curien
Universite Jean Monnet
Saint-Etienne – France
kamal.singh@univ-st-etienne.fr

Jean-Marie BONNIN
IRISA/ IMT-Atlantique
Rennes – France
jean-marie.bonnin@irisa.fr

Abstract—The number of connected devices will increase exponentially in the coming years, emitting a massive amount of data to the networks. A vehicle-based data collection architecture for smart cities will enable the offloading of some data for delay-tolerant applications. However, our previous work showed the diversity in data pick-up pattern by vehicles based on location in the city. Build on those findings this paper introduces a preliminary study on a contact strategy for wireless sensors data collection utilizing Vehicular Delay Tolerant Networks (VDTN) in smart cities. The strategy formulates relation between mutual communications range, vehicle's speed, and periodic discovery time by the sensor. We then propose sensor's buffer occupancy value as a measure for the adaptation of its communications discovery period, with the purpose of reducing energy consumption.

Keywords— *Contact Strategy, Data Collection, Smart Cities, DC4LED, Hierarchical VDTN Routing*

I. INTRODUCTION

It is forecasted that more than 30 billion connected devices will be installed worldwide by the year 2020, and it will be more than doubled that number in the year 2025 [1]. Most of those devices will provide data for smart cities and its citizen. Consequently, a large amount of data need to be collected and to be delivered to each destination and then processed by corresponding applications. One such application is delay-tolerant applications, where it can be feed by data which does not need to arrive instantly, i.e., communication latency in order of minutes or even hours is adequate. Some examples of such applications are the environmental monitoring, smart metering [2], photos reporting of road degradation, etc.

On the other hand, the era of connected-vehicles is starting to become a reality. Vehicles will have the capability to exchange information between them, as well as with their surrounding environment, with vehicle-to-everything (V2X) communications technology. They can also have the connectivity to the internet by utilizing current and future radio access networks. Decision makers around the world will soon make such capabilities compulsory for vehicles [3], which further elevates the possibility for vehicles to play an integral part in smart cities ecosystems.

Our previous work in [4] put forward an idea of a vehicle-based data collection architecture for smart cities, as illustrated in fig. 1. It is designed to offload data for

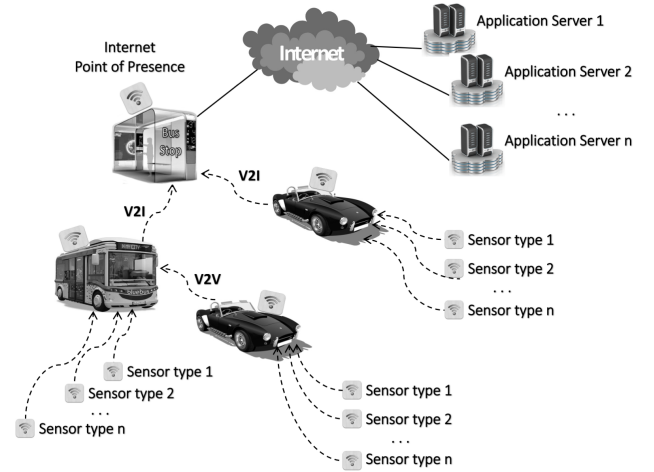


Fig. 1. Vehicle-Based Data Collection Architecture for Smart Cities

delay-tolerant applications, utilizing V2X capabilities. In the architecture, data need to be collected from several wireless sensors in a smart city and delivered to associated application servers. The system utilizes Vehicular Delay-Tolerant Networks (VDTN) with its store-carry-forward mechanism to gather and deliver data to one of the wireless Internet Point-of-Presence (PoP) available in the city. Furthermore, we proposed and evaluated DC4LED (Data Collection for Low Energy Devices): a hierarchical VDTN routing, which sensibly takes into account several common features of mobility in smart cities (e.g., buses, taxis, and cars), and hierarchically defines their role in forwarding the data. A more detailed description of our previous work is presented in the next section.

An interesting result from our previous work is shown in fig. 2. It shows dropped messages percentage and its distribution among nodes, with increases in cars density. It shows that the percentage of dropped messages decrease with the increase in available mobility. It also points out that most of the drops happen in sensors and that drops decrease as more cars are in proximity to gather messages. Note that the number of dropped messages are in decimal as each value was averaged over ten simulation runs with different mobility patterns. The fact that most drops were occurring in sensors motivate us to investigate further into the dynamic of communications contact between sensors and vehicles. Thus, this article aims to put forward

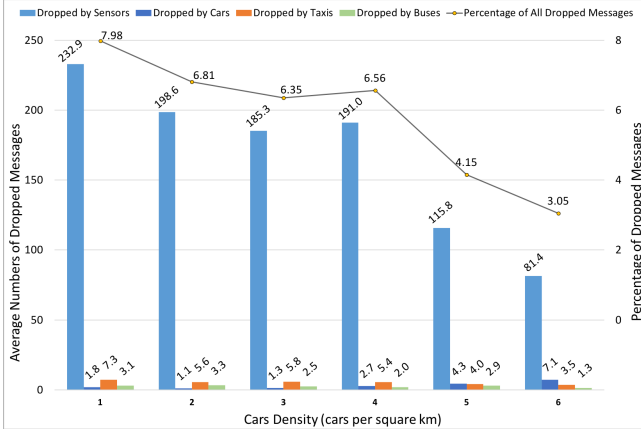


Fig. 2. Dropped messages percentage and distribution

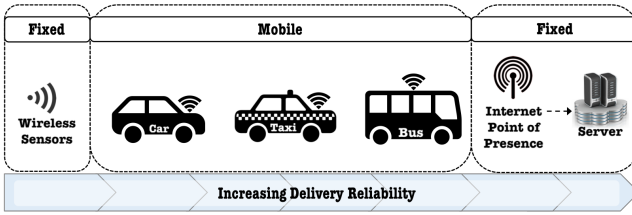


Fig. 3. The Concept of DC4LED: A Hierarchical VDTN Routing

our work in progress towards a contact strategy for VDTN data collection in smart cities.

We organize the rest of this paper as follows. Section II describes our previous work which motivates this study. Section III presents our idea on the contact strategy for wireless sensor. Lastly, conclusions and future works are provided in Section IV.

II. PREVIOUS WORK

As introduced above, our previous work in [4] proposed a vehicle-based data collection architecture for smart cities. We focus on data collection in cities using VDTN routing. The data collection chain in a city starts from sensors and then the data is routed using cars, taxis, and buses, to an Internet PoP and then finally to Server. Our concept of DC4LED: a hierarchical VDTN routing to accommodate the data collection process is illustrated in fig. 3. The hierarchy of its forwarding decisions is based on the reliability and capability of each category of nodes to deliver data to the server. The idea is to statistically assign a level to the nodes in the city, instead of having complex routing decisions and metrics. Note that a node only forward data to another node with a superior hierarchical level. For example, a car will forward data to a taxi, a bus, or directly to an internet PoP, but not to another car. A taxi will forward to a bus, or directly to an internet PoP, but not to another taxi or a car, and so on. We evaluate the performance of DC4LED Routing algorithm by using the Opportunistic Networking Environment (ONE) simulator [5][6]. The simulation scenario envisions an air pollution monitoring in the city of Helsinki, where 37 wireless sensors were placed almost evenly in an area of

TABLE I
SIMULATION PARAMETERS AND VALUES

Parameters	Values
Map size	4.5 km x 3.4 km
Land area	approximately 9 km ²
Simulation time	12 hours
Simulation warm up time	200 s
Message generation window	7 hours
Message Time-to-Live (TTL)	5 hours
Messages created by sensors	3071
Sensors	
Number of sensors	37
Movement model	Stationary
Message size	1 kB
Message generation interval	5 minutes
Buffer size	64 kB
Interface type	802.15.4 link profile
Transmission range	10 m
Transmission rate	250 kbps
Cars	
Number of cars	(9, 18, ... ,54) correspond to cars density of: (1, 2, ... , 6) per km ²
Movement model	Shortest-path map-based
Movement speed	10 - 50 km/h
Stationary time at destination	between 1 - 120 minutes
Buffer size	5 MB
Interface#1 type	802.15.4 link profile
Transmission range	10 m
Transmission rate	250 kbps
Interface#2 type	802.11p link profile
Transmission range	300 m
Transmission rate	6 Mbps
Taxis	
Number of taxis	9, correspond to taxis density of 1 per km ²
Movement model	Shortest-path map-based
Movement speed	10 - 50 km/h
Stationary time at destination	between 1 - 5 minutes
Buffer size	5 MB
Interface#1 type	802.15.4 link profile
Transmission range	10 m
Transmission rate	250 kbps
Interface#2 type	802.11p link profile
Transmission range	300 m
Transmission rate	6 Mbps
Buses	
Number of bus routes	2
Number of buses	4 (2 for each route)
Movement model	Map-route
Movement speed	10 - 30 km/h
Stationary time at destination	between 5 - 30 seconds
Buffer size	25 MB
Interface#1 type	802.15.4 link profile
Transmission range	10 m
Transmission rate	250 kbps
Interface#2 type	802.11p link profile
Transmission range	300 m
Transmission rate	6 Mbps
Internet Point-of-Presence (PoP)	
Number of PoPs	5
Movement model	Stationary
Buffer size	1 GB
Interface#1 type	802.11a link profile
Transmission range	5 km
Transmission rate	100 Mbps
Interface#2 type	802.11p link profile
Transmission range	300 m
Transmission rate	6 Mbps
Server	
Number of server	1
Movement model	Stationary
Buffer size	1 GB
Interface type	802.11a link profile
Transmission range	5 km
Transmission rate	100 Mbps

about 9 km². Table I provides the parameters and values used in the simulation.

Simulation results depicted in fig. 4 and fig. 5 give insight into the dynamics of data collections in the city, where colors and the size of blobs emphasize values of average

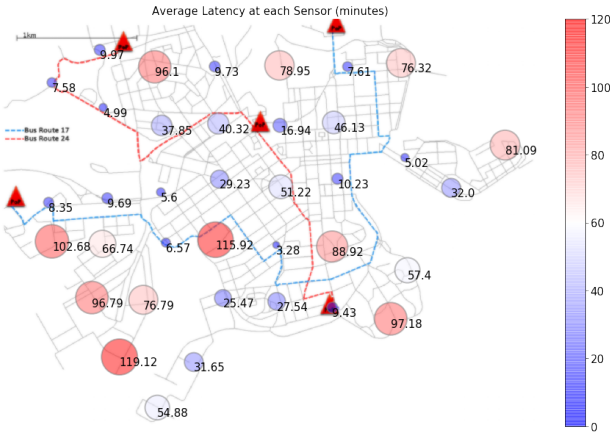


Fig. 4. Mapping of the average latency

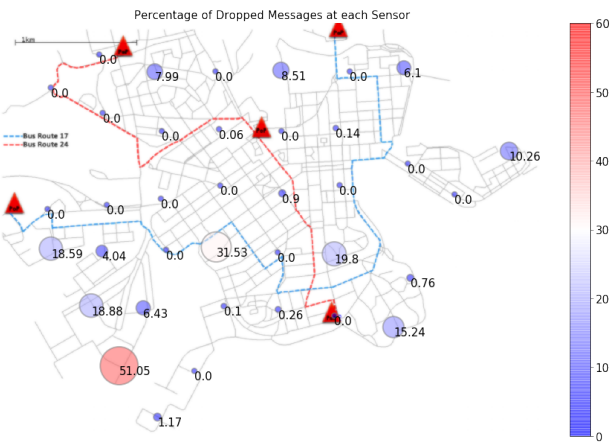


Fig. 5. Mapping of the dropped messages

latency and percentage of dropped messages at each sensor. The statistical snapshots were averaged over all mobility scenarios. Fig. 4 shows average latency values between sensor locations, where generally most sensors located in the outer part of the city had higher latency compared to ones installed in the inner area, with the exception for sensors that had proximity to a bus route. The latency value was as high as 119.12 minutes in one part of the city and as low as 3.28 minutes in another location. There are also some sensors located in the inner city which did not encounter enough mobility while also out-of-range from the nearest bus route, which caused high latency. It points out the disparity in mobility which affects Key Performance Indicators (KPI) in different parts of the city, and that each sensor may have to adapt to different data pick-up patterns.

Fig. 5 illustrates the average percentage of dropped messages for all mobility scenarios, and it gives a contrast of percentages between sensors in different locations. The drops can be as high as 51% in one location and can be none in some other areas. Sensors in this low mobility places will need to have other strategies or even other connectivity such as LPWAN. Further observation showed that drops are primarily caused by messages reaching its Time-to-Live (TTL) of 5 hours. In our scenario, where one message of size 1 KB is generated

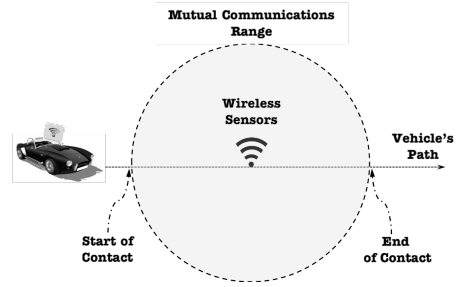


Fig. 6. An Ideal Contact Scenario Between Sensor and Vehicle

every 5 minutes, 64 KB of buffer size in each sensor proved to be sufficient to hold messages for more than 5 hours. This fact shows the relation between the required sensors buffer size and the TTL parameter which reflect the user-defined data usefulness period.

The geographical mapping reveals the disparity of vehicular mobility experienced by sensors related to location, which emphasizes the requirement for each sensor to adapt to different data pick up patterns in the city. This finding is our motivation to investigate further the contact strategy for wireless sensors in VDTN data collection.

III. CONTACT STRATEGY FOR WIRELESS SENSOR

Different phases of data collection in wireless sensor networks with mobile elements have been described in [7], where *contact* can be defined as a condition when two nodes or more are in communications range to one another, thus, are able to exchange data. In our proposed architecture, we consider that the vehicular networks should be agnostic in term of the contact mechanism. Therefore, the contact strategy should be managed by the sensor itself. Fig. 6 shows an ideal contact scenario between a sensor and a vehicle. During contact time, a *discovery* process will take place, which allows sensors to detect the presence of vehicles before starting to exchange data. In an ideal scenario of mobility shown in fig. 6, where we assume that the vehicle's speed V_s (in *m/s*) is constant, we can simply relate it to the mutual communication range R (in *metres*) and find the contact duration C_d (in *seconds*)

$$C_d = \frac{R}{V_s} \quad (1)$$

If we consider periodic discovery time of t (in *seconds*), then we can calculate the highest possible data transfer windows during each contact T_w as

$$T_w = \frac{C_d}{t} \quad (2)$$

Fig. 7 illustrates relations between vehicle's speed, data transfer windows, and different periodic discovery time. In the calculation, we assume a maximum radio communications range of 10 *m* between the sensor and the vehicle, which make up R value of 20 *m*. The vehicle's speed is increased from 30 to 100 *km/h*, which corresponds to values of 8.33 to 27.78 *m/s*. Results for three different t values; 0.1 *s*, 0.2 *s*, and 0.5 *s*, are then presented. The graph shows that for a certain value of R

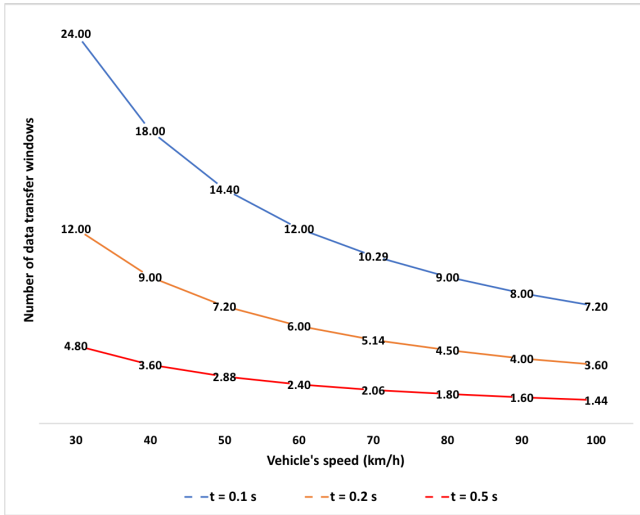


Fig. 7. The Dynamic of Data Transfer Window

and t , the number of data transfer windows decreases exponentially with the increases in vehicle's speed. Furthermore, graph comparison between different t values emphasizes the decreasing number of data transfer windows as the discovery period increases. Hence, the availability of a higher data transfer windows also means more data can be offloaded during contact.

In communications between low energy devices, such as wireless sensors, and moving vehicles; a large portion of energy is consumed during discovery periods [8], while the available contacts cannot be guaranteed. As shown in the previous section, the average availability of vehicles to pick-up data can be in the order of several minutes, or even hours depending on location. Thus, an adaptive contact strategy, particularly in the discovery process, need to be devised to reduce energy consumption. In fig. 8 we put forward a contact strategy which takes into account the buffer occupancy of the sensor. The logic is that when a sensor does not have data in its buffer to send, then the discovery process does not need to be initiated. On the other hand, when the buffer occupancy is high, a sensor needs to initiate the highest possible frequency of discovery (i.e. the lowest possible t). Therefore, sensors with high buffer occupancy will need more data transfer window, while sensors with low buffer occupancy will need less and can reduce their energy consumption, referring back to an example shown in fig. 7.

IV. CONCLUSION AND FUTURE WORKS

This paper has described a preliminary study on a contact strategy for wireless sensors data collection utilizing VDTN in smart cities. The study emanated from our previous work which showed the diversity of data pick-up pattern by vehicles in the city. Therefore, sensors need to adapt its

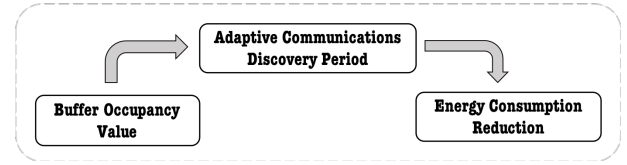


Fig. 8. Sensor's Contact Strategy for Energy Consumption Reduction

discovery period to reduce wasteful energy consumption. We then discussed the relation between mutual communications range, vehicle's speed, and periodic discovery time. Furthermore, we proposed sensor's buffer occupancy value as a measure for the adaptation.

Our work is continuing in the formulation of an adaptive contact strategy through an empirical study based on findings from our simulation of VDTN data collection. There are also possibilities to include other parameters such as the average data latency in each sensor, the average contact duration, etc., to the strategy.

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