Early Warnings Dissemination for Urban Micro-scale Monitoring Using Vehicular Sensor Network

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***Abstract*—This paper presents the beaconless multi-hop Decentralised Dissemination of Warnings (DDW) mechanism for micro-scale monitoring applications in urban environments. It is designed for a Vehicular Sensor Network (VSN) based on mobile nodes with limited resources. Mobile nodes sense and generate high pollution levels early warnings in near real-time. The warning messages are disseminated toward Static Monitoring Units used by the local authorities to monitor onsets of harmful pollution level episodes. The DDW is a distance-based mechanism where a receiving node calculates the waiting time before rebroadcsting the message based on the distance from the sending node and the distance to the Static Monitoring Units. The DDW mechanism performance is evaluated in an urban environment with different number of mobile nodes in the network. Results show that the proposed mechanism collects more non-duplicated warnings at the Static Monitoring Units than other evaluated dissemination protocols. It is also shown the DDW mechanism reduces the amount of duplicated warning messages sent in the network, which is especially important when mobile nodes are resource constrained.**

Keywords: Vehicular sensor network, data dissemination, warning messages

I. Introduction

One of the main concerns of local authorities in urban areas is the presence of high air pollution levels caused by the urbanisation and an increased vehicular activity. If the onsets of harmful pollution levels are timely detected and this information made available to local authorities, the exposure of public to harmful pollution levels could be minimised.

In an urban area, the fast fluctuation of a pollution level is caused by external factors such as current atmospheric conditions and a street configuration. Usually, air pollution monitoring in urban areas is performed using a limited number of monitoring stations or by deploying a Wireless Sensor Network consisting of a large number of fixed sensors. Monitoring stations are often placed at crowded locations such as main streets or intersections, where potential high pollution levels are expected to occur. Distances between stations can reach up to couple of kilometres, thus they can not depict fast fluctuations of a pollution level on a per street (micro-scale) basis [1], [2]. Monitoring can also be done with WSN sensors, but in order to obtain fine-grained pollution data on a per street basis, a large number of sensors is necessary to cover an entire urban area. Therefore, to detect fast fluctuations of a pollution level on a per street basis with the aforementioned monitoring approaches considerable investment is required. Alternatively, a finer spatio-temporal resolution of the pollution data can be obtained using Vehicular Sensor Network (VSN). Here, vehicles (car, buses, bicycles) are equipped with on-board units with sensing, processing and communication capabilities. Vehicles (mobile nodes) collect pollution data on their routes and exchange it with other vehicles in the network or central server that perform data analysis. Thus, a VSN approach deployed on the existing urban transportation network enables the collection of pollution data from locations that can not be monitored with fixed sensors units. In case the cars and buses are used as a part of VSN-based monitoring approach, it is assumed their on-board units are powered by the vehicles' batteries [3]. Thus, these vehicles do not have major limitations in terms of processing capabilities, battery and storage. However, these types of vehicles produce additional exhaustion of pollution gases in the air.

One of the growing trends in the big cities is using public bicycles in everyday transportation, which represents a promising platform for a VSN monitoring infrastructure. For example, work in [4] presents a smart e-bike monitoring system (SEMS) that uses electrically-assisted bikes (e-bikes) equipped with sensors to collect the local environmental data. Unlike cars and buses, bicycles are an environment-friendly vehicles as they do not have pollutant exhaustions. On the other hand, if bicycles are used for monitoring applications they would have constrained on-board resources. Considering the limitations of a bicycle-based monitoring scheme, we present a Decentralised Dissemination of Warnings (DDW) mechanism for a micro-scale pollution monitoring applications. In the proposed urban scenario, mobile nodes are able to generate early warnings about hazardous pollution levels in near real-time which are then packed inside the warning messages and forwarded towards the Static Monitoring Units (SMU). The warnings collected at the SMUs are then made available at any time to local authorities which could be used to identify unexpected changes in the pollution levels. The proposed DDW mechanism disseminates warning messages without the need for periodic exchange of nodes' state information (beacons), such as e.g. position or velocity. Instead, the receiving node leverages the SMUs' position and the distance

from the sender to calculate the waiting time the node needs to wait before rebroadcasting the message.

The remainder of this paper is organised as follows: Section II describes related work, Section III presents the proposed DDW mechanism. Section IV gives description of the simulation setup and results. Section V outlines the final remarks.

II. Related Work

Message dissemination has received considerable attention from the research community, especially for event-driven (e.g. safety) applications in the area of Vehicular Ad Hoc Networks (VANETs) [5]. In these type of applications when an event of interest occurs, for example, an accident on the road, usually a single source node (vehicle) starts disseminating emergency messages about it. In this scenario it is assumed the vehicles have no resource limitations, and the aim is to inform as many vehicles as possible in the defined area of interest. However, these dissemination solutions designed for VANET are not suitable for the considered pollution monitoring scenario which is based on the vehicles with limited resources (e.g. public bicycles). Also, in urban monitoring more than one vehicle can detect events, such as pollution level exceeding threshold, after which the emergency (warning) messages are disseminated. Additionally, the aim is to directionally forward the warning messages towards the Static Monitoring Units. In this section we present dissemination protocols for multi-hop dissemination of emergency messages and data gathering protocols for sensing applications, designed for urban environments.

Work in [6] presents a data dissemination protocol for vehicular networks DRIVE, which does not require an exchange of beacons between the vehicles. Here, vehicles calculate a waiting time before they rebroadcast the message and a vehicle's communication area is composed of four quadrants. Each quadrant has a defined sub-area that represents a *sweet spot*, an area in which vehicles are best positioned to perform data dissemination. Work in [7] presents an adaptive and decentralised (AID) approach for the information dissemination in an urban environment which also does not require a beacon exchange between vehicles in the network. It assigns a random time slots to the vehicles that receive a warning message for the first time. AID counts how many times a message is received until the time slot expires, and stores time intervals between messages' receptions. A vehicle compares the ratio of a time slot and the number of message duplicates with the time intervals between messages' receptions.

Work in [8] proposes a beaconless Back off-based Per-hop Forwarding (BPF) data gathering protocol designed for sensing applications in an urban environment. Here, vehicles gather environmental data that needs to be delivered to the static final destination node whose position is known to the vehicles. The back-off timer is calculated based on distance of the sender and receiver from the final destination node. The same authors extended their work and proposed an Urban Data Collector (UDC) protocol [9] which includes different suppression techniques to reduce message rebroadcasting in the network. Work in [10] introduces a safety message broadcasting protocol based on beacon exchange among vehicles. Here, a waiting time for message rebroadcast is calculated according to the number of vehicle's neighbours and a distance from the sender vehicle. Authors in [11] introduce the enhanced Street Broadcast Reduction (eSBR) warning dissemination beacon-based scheme. In order to forward a warning message, a vehicle in eSBR needs to be positioned in different street segment than a sender vehicle, or if they are in the same street segment a vehicle needs to be closer to the intersection. The same authors presented an extension of the eSBR [12] where only the vehicle closest to the center of an intersection performs warning message rebroadcasting.

Unlike in the proposed DDW mechanism, works [10], [11] and [12] require a periodic beacon exchange between the nodes (vehicles) to perform message dissemination. Despite the use of beacons contributes towards creating of vehicle's awareness of its surrounding, the beacon traffic could cause congestion of communication channel and possible loss of broadcasted messages. Also, beacon exchange requires additional transmission activity of the nodes, which is not desirable for scenarios where nodes have limited resources.

Dissemination protocols [8] and [9] use only the distance between the node and the static final destination node to calculate a back-off timer before message rebroadcasting. However, in case of message dissemination it is also important to consider the distance between the sender and receiver. Choosing the receiver furthest away from the sender for message forwarding contributes to a larger communication coverage [5], which enables faster message spreading inside an urban area. Therefore, the proposed DDW mechanism considers the part of dissemination approach proposed in [8] and extends it with additional consideration of a distance between the nodes. Despite the nodes in [7] dynamically make broadcasting decisions based on the number of received messages, AID uses randomly generated value for a time slot, which is not the case with the DDW mechanism. Contrary to [8] and [9], the work in [6] does consider a distance between the sender and receiver when calculating a waiting time depending on the node's position (inside or outside of a *sweet spot*). Unlike the DDW mechanism, DRIVE assigns larger waiting times to receivers that are further away from the sender regardless of the nodes' position inside a communication range.

III. Decentralised Dissemination of Early Warnings (DDW) Mechanism

This section introduces the mechanism for Decentralised Dissemination of Early Warnings (DDW) designed for the air pollution micro-monitoring applications using VSN. This type of monitoring is the focus of our on-going research [13] and [14]. In [13] we introduced a data dissemination and harvesting mechanism for collection of the pollution data, and in [14] we presented a data fusion framework for processing the pollution data.

A. System Model

In the proposed mechanism, we assume the mobile nodes have a digital map of a city in which streets are divided into street segments. Here, one street segment is defined between two consecutive intersections and has a unique identification (ID) j , where $j = \{1, ..., S\}$ and S is the total number of street segments in the city. As in [13], the nodes periodically sense the level of Nitrogen Oxide (NO) pollution and process it with the Delayed State Information Filter (DSIF) that creates pollution estimates. The set of estimates and their timestamps, together with the street segment ID for which they refer to are stored in the node's database, as described in [13], and processed as in [14]. A mobile node in the network performs the following:

a) For every street segment stored in the database, a node periodically analyses pollution data with a period of ΔT_g to detect high pollution levels. In case a high pollution level is detected, a node generates an early warning for that street segment which is then encapsulated within a warning message. The warning message is consisted of: coordinates of the node that broadcasts a warning message (x, y), a timestamp when a warning message is generated (T_c), and a sequence of L street segment IDs for which the warnings refer to.

b) Apart from sending the warning messages, nodes act as forwarders of the warning messages received from other nodes in the network by calculating a waiting time (t_w). This time shows how long mobile nodes need to wait before they rebroadcast the warning message.

B. The Proposed DDW Mechanism

Suppose the mobile node k receives a warning message from the mobile node h after which it triggers the DDW mechanism shown in Algorithm 1. In case the message is received for the first time (Alg. 1 line 1), the node k takes its own coordinates to calculate the Eucledian distance from every SMU, d_{mk}, where $m = \{1, .., N_{SMU}\}$ and N_{SMU} is the number of SMUs in the network. The node k also uses the sender's position from the received warning message to calculate the sender's distance from SMUs d_{mh} (Alg. 1 line 2). The node determines the closest SMU m by finding the minimum distance d_{min} to one of them from previously calculated distances d_{mh} and d_{mk} (Alg. 1 lines 3-4).

In the DDW mechanism, rebroadcast of a warning message is determined by calculating the waiting time t_w which takes into account the following parameters: the distance of the sender and the receiver from the SMU m (d_{mh} and d_{mk} respectively), distance between the sender h and the receiving node k (D_{hk}), a communication range R and a time coefficient t_c. A distance between the nodes and the SMUs contributes that nodes which are closer to the SMUs are more likely to rebroadcast the warning message. However, in urban scenarios where number of mobile nodes on the street segments is high, values of these distances can be negligibly different. If only this distance is considered for t_w, the waiting times of the nodes would also be negligibly different. This could potentially lead to an increased broadcasting activity of the mobile nodes and spreading of the duplicated warning messages.

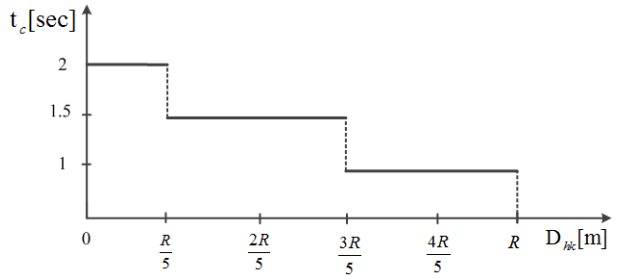


Fig. 1: The time coefficient (t_c) values

Thus, to avoid the aforementioned problem, additional D_{hk} parameter is introduced to make the differences of nodes' waiting times more significant (Alg. 1 line 5). A receiving node is classified based on its position within the sender's communication range as either: *nearby* $(D_{hk} < R/5)$, *medium distant* $(R/5 \leq D_{hk} < 3R/5)$ and *far away* $(D_{hk} \geq 3R/5)$, as shown in Alg. 1 lines 6-9. Based on this, the time coefficient t_c is the highest for a *nearby* node, while it is the lowest for a *far away* node (Fig. 1). The time coefficient makes the messages propagate longer distances and contributes to better spreading of the messages in an urban area. The mobile node calculates t_w according to Alg 1. line 10, and when the this time expires, the node rebroadcasts the warning message (Alg. 1 line 11).

In case the mobile node k had already received the warning message (Alg. 1 line 12), it checks whether there is an active waiting time for that message. In such case, the node k cancels t_w and discards the received warning message (Alg. 1 line 13), which means this message has already been sent by some

Algorithm 1 *The DDW* mechanism

1: **if** $(warning\ message\ received\ first\ time == TRUE)$ **then**
2: calculate d_{mh} and d_{mk} where $m = \{1, .., N_{SMU}\}$
3: find $d_{min} = min(D_h \cup D_k)$ where $D_h = \{d_{mh}\}, D_k = \{d_{mk}\}$
4: find m for which $d_{min} \in D_h$ or $d_{min} \in D_k$
5: calculate $D_{hk} = \sqrt{(x_h - x_k)^2 + (y_h - y_k)^2)}$
6: **if** $(D_{hk} < \frac{R}{5})$ **then** $t_c = 2$
7: **else if** $((D_{hk} \geq \frac{R}{5})\ and\ (D_{hk} < \frac{3R}{5}))$ **then** $t_c = 1.5$
8: **else if** $(D_{hk} \geq \frac{3R}{5})$ **then** $t_c = 1$
9: **end if**
10: calculate $t_w = \frac{d_{mk} - d_{mh} + R}{2R} + (1 - \frac{D_{hk}}{R}) \cdot t_c$
11: when t_w expires, rebroadcast a warning message
12: **else if** $(t_w\ active == TRUE)$ **then**
13: cancel scheduled t_w and discard a warning message
14: **else** discard a warning message
15: **end if**

other node. Finally, the node k discards the received warning message if it had already rebroadcasted that message in the past (Alg. 1 line 14).

IV. Simulation Evaluation

A. Simulation Setup

We evaluate the proposed DDW mechanism by a set of simulations in an urban environment scenario using the Veins simulator [15], which couples the network simulator OMNET++ [16] and the road traffic simulator SUMO [17]. The Manhattan grid road network of 4 km^2 size and 2x2 km dimensions is chosen as an urban environment in simulations. This network is consisted of 64 building blocks and has 144 street segments, where the length of each street segment is 250 meters. The existence of building blocks makes radio propagation environment more realistic, and traffic light system is included to replicate a traffic mobility in an urban environment. The Manhattan grid network with the building blocks (grey rectangles) is shown in Fig. 2, while Fig. 3 presents a street segment. In the considered scenario there are three Static Monitoring Units, shown in Fig. 2, acting as collectors of warnings which are extracted from warning messages received from the mobile nodes.

The evaluation of the proposed dissemination mechanism is based on two simulation scenarios with different number of mobile nodes in the network, 100 and 200. The nodes have random routes and enter the simulation based on the exponential distribution with the mean inter-arrival time of 1 second. The parameters such as dimensions, acceleration, deceleration and minimum gap between the moving nodes (bicycles) is set according to [17]. The maximum speed of the nodes is set to 2 m/s, transmitting power to 10mW and the communication is based on the IEEE 802.11p standard. The parameters R and ΔT_g in the DDW mechanism are set to 250 meters and 30 seconds, respectively. The DSIF embedded in the nodes is configured as in [13] and [14], while the NO

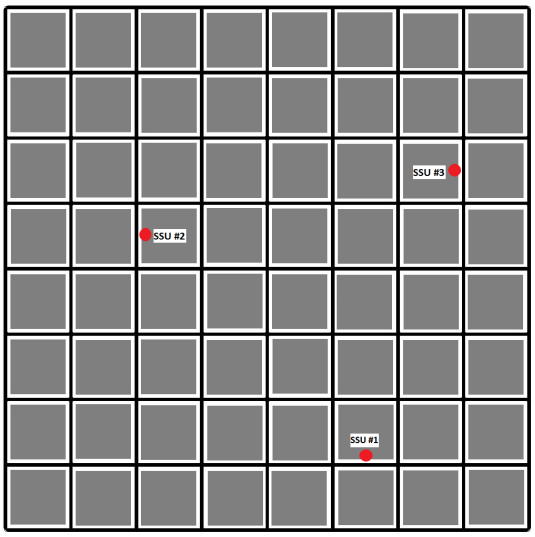


Fig. 2: The Manhattan network.

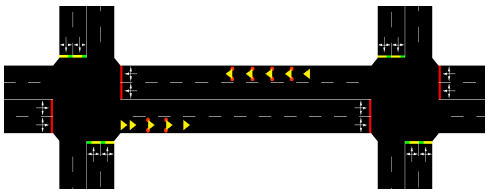


Fig. 3: An example of a street segment scenario from the SUMO simulator.

pollution data used is provided by the authors of [18]. The simulation time is set to 30 minutes and results represent an average of 20 simulation runs.

The proposed DDW mechanism is compared with the existing dissemination protocols: DRIVE [6], AID [7], BPF [8] and UDC [9] with the weak suppression technique (further called UDC-weak). These protocols are selected for the comparison as they are designed for urban settings and do not require additional exchange of beacons between the nodes. They are adapted for the considered micro-scale pollution monitoring scenario so that each node can send multiple warning messages inside the network. The nodes in the simulation communicate and process pollution data based on the DDH mechanism [13] and DDF framework [14], respectively. Also, we assume the nodes in all evaluated dissemination protocols process the same pollution data to generate the warnings which are disseminated according to the protocol.

B. Performance Metrics

In order to evaluate the performance of the DDW mechanism the following metrics are defined:

1) ***Monitoring capability*** ***(M_C)*** represents the ratio of the number of warnings received by SMUs excluding warnings' duplicates (non-duplicated warnings) N_{war} and the number of all warnings generated by the mobile nodes in the network N_{gen_war}. This metric is expressed as a percentage and is calculated according to:

$$M_C = \frac{N_{war}}{N_{gen_war}} \cdot 100 \qquad (1)$$

Here, $N_{gen_war} = |N_g|$, $N_g = \bigcup_i G_i$, where G_i is a set of generated warnings by the mobile node i, and $i = \{1, ..., N\}$ is a number of mobile nodes in the network, and N has values 100 and 200. $N_{war} = |N_w|$ where $N_w = \bigcup_m W_m$ and W_m is a set of warnings excluding the warnings' duplicates received at the SMU m, $m = \{1, ..., N_{SMU})$ represents a number of Static Monitoring Units, and N_{SMU}=3.

2) ***Warning collection*** ***(W_C)*** is defined as the ratio of the number of warnings received by SMUs excluding warnings' duplicates N_{war} and the number of all received warnings gathered by the SMUs including duplicates $N_{all_rec_war}$. This metric is expressed as a percentage

and is calculated according to:

$$W_C = \frac{N_{war}}{N_{all_rec_war}} \cdot 100 \quad (2)$$

Here, $N_{all_rec_war} = |N_r|$ where $N_r = \sum_m W_m$, and W_m is a set of received warnings at the SMU m.

3) ***Transmitting activity*** ***(T_A)*** represents the average number of warning messages transmitted per mobile node in the network:

$$T_A = \frac{\sum_i T_{A_i}}{N} \quad (3)$$

where T_{A_i} is a number of warning messages transmitted by the mobile node i and N is a number of mobile nodes in the network.

4) ***Duplicated warning messages*** ***(D_W)*** is a metric which shows the average number of duplicated (already received) warning messages received by the mobile node in the network:

$$D_W = \frac{\sum_i D_{W_i}}{N} \quad (4)$$

where D_{W_i} is a number of duplicated warning messages received by the mobile node i.

C. Simulation Results

Evaluation of the M_C metric in Fig. 4 shows the DDW mechanism provides higher percentage of generated warnings that reached SMUs than other dissemination protocols. Having more collected warnings enables better insight about the spatio-temporal distribution of the monitored pollution in an urban area. Despite BPF and UDC-weak leverage the knowledge of the SMUs' positions to disseminate warning messages, this does not guarantee higher monitoring capability, which can be seen from Fig. 4 when compared to AID. Additionally, the DDW mechanism provides 12% higher M_C when the number of nodes rises to 200, whereas the increase of M_C for BPF, UDC-weak and AID is 6 %. By observing the W_C metric in Fig. 5 it can be seen the proposed DDW mechanism outperforms other dissemination protocols for the different

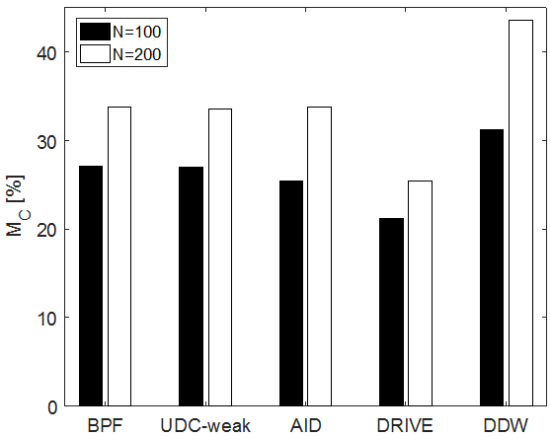


Fig. 4: Evaluation of the *Monitoring capability*.

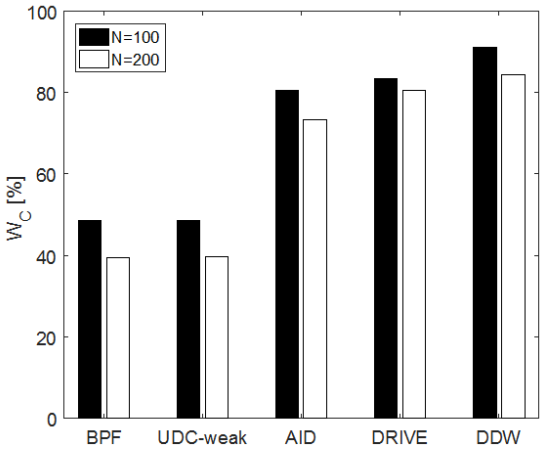


Fig. 5: Evaluation of the *Warning collection*.

number of mobile nodes in the network. BPF and UDC-weak have the lowest W_C due to node's high transmission activity of warning messages which causes an increase of redundant information in the network that eventually reaches the SMUs. Thus, higher values of W_C metric are preferable as they indicate the node's resources are efficiently utilised for warnings dissemination.

T_A metric reflects the mobile node's transmission activity of the warning messages in the network. The D_W metric shows received duplicated warning messages by the mobile nodes and indicates the amount of redundant information disseminated in the network. Since mobile nodes have limited resources, it is desirable to have T_A and D_W as low as possible. From Fig. 6 it can be seen BPF has the highest transmitting activity T_A, followed by UDC-weak with the suppression technique which reduces transmitting activity of the nodes, and AID. Since AID enables the nodes to broadcast the warning message that has already been broadcasted a number of times by other nodes, its T_A is higher than in DRIVE. When compared to the DDW mechanism, AID's T_A performance is approximately the same, however its performance is weaker in terms of M_C metric. This means the nodes in AID transmit and receive more duplicated warning messages, as can be seen in Fig. 6 and Fig. 7. As presented in Fig. 6, the nodes in DDW mechanism transmit more warning messages than in DRIVE, while the difference in D_W performance is not significant according to Fig. 7. The reason for higher transmission in DDW mechanism is that nodes transmit more warning messages which are not duplicates than the nodes in DRIVE. Consequently, this enables the SMUs to collect greater number of warnings excluding duplicates and have better monitoring capability performance, as shown in Fig. 4.

The simulation results show the protocols with node's high transmitting activity, such as AID, BPF and UDC-weak do not guarantee achieving the better monitoring capability. The proposed DDW mechanism provides efficient dissemination of non-duplicated warnings in the network and better performance of W_C and M_C metrics than other dissemination protocols, while keeping D_W metric on a low level.

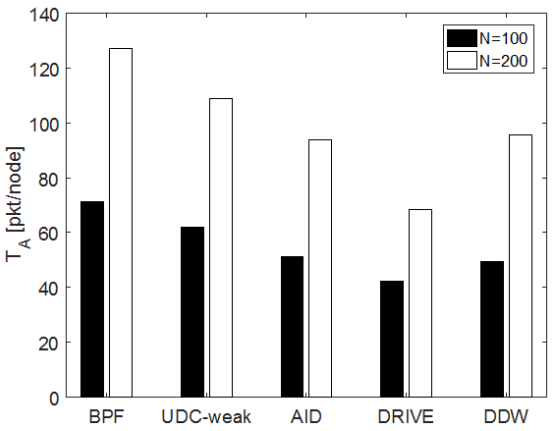


Fig. 6: *Transmission activity* evaluation.

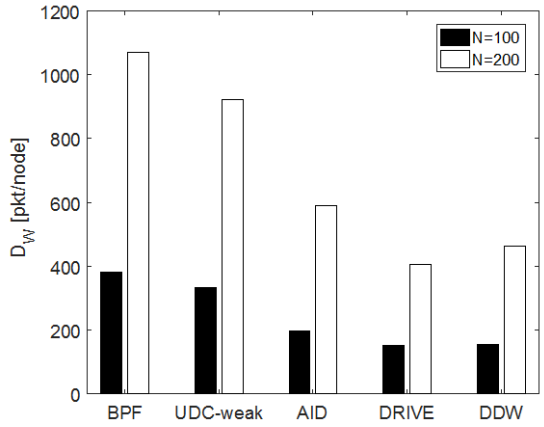


Fig. 7: Evaluation of the *Duplicated warning messages*.

V. Final Remarks

In this paper we present a beaconless multi-hop Decentralised Dissemination of Warnings (DDW) mechanism to support real-time urban micro-scale pollution monitoring, based on mobile nodes with limited on-board resources. The mobile nodes generate early warnings when a hazardous pollution level is detected, and send the information in a warning message towards the Static Monitoring Units. In the DDW mechanism, a receiving node calculates the waiting time before rebroadcasting the message based on the distance from the sender and their distances to the Static Monitoring Units. The proposed mechanism is assessed via a set of simulations with different number of mobile nodes in the network. It is shown the DDW mechanism outperforms other dissemination protocols in terms of the non-duplicated warnings collected at the Static Monitoring Units. It also provides an efficient utilisation of the nodes' resources, which is especially important when mobile nodes have limited resources.

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