

A novel, broadcasting-based algorithm for vehicle speed estimation in Intelligent Transportation Systems using ad-hoc networks

Boyan Petrov¹, Dr Evtim Peytchev²

¹Faculty of Computer Systems and Control, Technical University – Sofia, 8 Kliment Ohridski bulv., Sofia 1000, Bulgaria, email: b_petrov@tu-sofia.bg

²School of Science and Technology, Nottingham Trent University, Clifton Lane, Nottingham NG11 8NS, email: evtim.peytchev@ntu.ac.uk

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ABSTRACT

There has been a lot of research effort recently dedicated to identifying appropriate communication paradigm based on car-to-car communication for evaluation of traffic conditions. This paper introduces a novel way of evaluation of one such condition - the average speed of all cars in a street in an urban area using simple broadcasting protocol. The paper presents the protocol, describes the simulation model and reports the results that have been achieved using simulation and real wireless devices communications, but in a static mode, i.e. the devices are not moving. It is anticipated that the real-tests will confirm the conclusions drawn in the paper.

INTRODUCTION

With the advance of the wireless devices a number of application area for such devices emerged. Prime candidate for revolutionising the way it works with implementing the wireless technologies as information gathering and distributing tool are ITS. This situation has been recognised by the EU research bodies and a number of projects have been funded. Examples of such projects are DRIVE [3], GST [4] and SAFESPOT [5]. The main aim of all these projects is to help the drivers in enhancing their road safety, effectiveness and comfort. One opportunity that arises from all this research is to develop novel algorithms capable of identifying and distributing the state of the traffic in real-time without using any infrastructure. This requires that relevant information be exchanged on regular intervals between vehicles, effectively creating a cooperative systems for information delivery. Such information identification and delivery must be efficient and quick and depends on how capable the core communications platform is. The main governing factor and concern, though, of the effectiveness and productivity of the applications is the communication technologies used in ITS. Till now, the idea of connecting car-to-car has not been explored and the chief form of communication has been connecting a car to a cell station (infrastructure node) [6], which only

makes it more important to build a wireless traffic information systems based on car-to-car communication. This can be done by developing new paradigms for the functioning of wireless mobile computers in Mobile Ad Hoc Networks (MANET) [7]. In this paper a novel such algorithm is described, implemented and tested. The results obtained are showed that algorithm could become essential part of any ITS development.

ALGORITHM FOR COMMUNICATION

The theoretical solution of the problem requires a model for behaviour of moving vehicles which are the target objects of the system. The creation of a full probabilistic behavioural model is a very complicated problem whose development is outside of the purposes of this paper. For the needs for testing the algorithm it is used simplified behavioural model of moving vehicles.

Modelling the behaviour of a moving vehicle

The model should be sufficiently generalized to represent different stages of a vehicle moving cycle – stopped stage, starting stage, uniform movement and stopping stage.

A model of behaviour in [1] is used as a standard for testing fuel consumption for a vehicle in city driving cycle. This model is parameterized for each of the stages shown above.

This model is described as duration in seconds for every stage and it is shown on the figure 1.

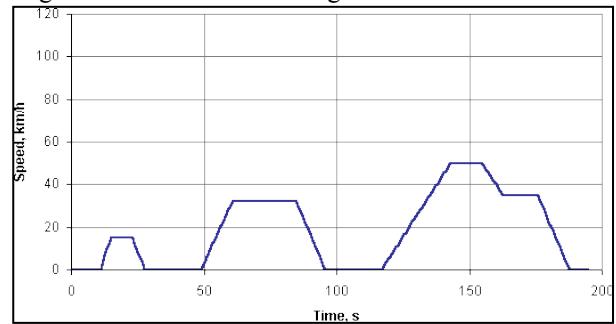


Figure 1: Visual representation of a model of city driving cycle.

This is the model also which is used for calculating the average speed.

Research for the role of driving lanes in data package transmission

Let it be assumed that the lanes of a given road read section have the same number of vehicles and the distances between them are equal and all of the automobiles have the same radio coverage radius. Therefore, from a statistical point of view, the probability of transmitting data package into middle lane is greater than transmitting it to one of the side lanes.

The purposes of the lanes are that the leftmost is used by faster vehicles and the rightmost – by slower ones (the opposite orientation in the UK). Therefore, the speed in the middle lane is between the other two.

It can be concluded that statistical participation of the lanes is not critical for a given road section.

The communication network should provide the ability of dynamical adding and removing participants. In this case it is necessary to create a protocol which will provide a rule for responding when more than one vehicle receives a data package. There are several different methods for prioritizing the access to the wireless media. One of them is prioritizing it by using a number as a function of distance between the sender and the receiver. In that case the priority for responding is defined as a time delay and the problem with adding and removing vehicles from the network is not critical and the changes in the distances between them is forming the priority dynamically. The priority can be formed in two different ways: “the closest vehicle responds first” and “the farthest vehicle responds first”.

A comparison between the algorithms “the closest vehicle responds first” and “the farthest vehicle responds first”

On figure 2 is shown a conditional formation of groups of vehicles on a road section with close speed and small distance between them. Dotted arrows show the movement of data packet which is transmitting using the algorithm “the closest vehicle responds first” (algorithm 1) and in solid lines using “the farthest vehicle responds first” (algorithm 2).

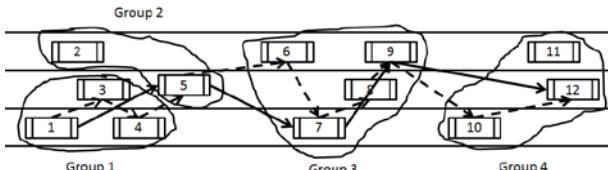


Figure 2: Visual comparison of the two algorithms

In table 1 it is shown the percentage of participation of every group using these two algorithms and the actual percentage of participation.

Group	Actual part.	Algorithm 1	Algorithm 2
Gr. 1	25%	30%	20%
Gr. 2	16.7%	10%	20%
Gr. 3	33.3%	40%	40%
Gr. 4	25%	20%	20%
Number of packages	9	5	

Table 1: Participation of every group

As shown on the table the participation of every group using the algorithms is almost the same, so it can be concluded that the average speed using “the farthest vehicle responds first” provides approximately the same result and the time for distribution the data is less because of the smaller amount of responding vehicles. Therefore this algorithm can be used for determining the timeout.

Main parameters for the algorithm for propagating the data

The purpose of the algorithm is to transmit data about the average speed for a road section, so the propagation of the data is in the opposite direction of vehicle movement direction. In this case it is able to warn vehicles which enter the specific road section.

The packets are broadcasted, so the data can be received from every vehicle which is under the coverage of the sending vehicle. For this purpose the package should have fields for the geographic coordinates and the direction of movement. When the package is received every vehicle can determine if it has to process the data.

According to the constraints about propagation the data the only vehicles which should broadcast the package are behind the sender. In order to include the cases when the road bends it is necessary to define a requirement for a vehicle which is behind the sender and it is moving in the same direction as the sender.

1. *Condition for unidirectional movement of two cars* – the difference between the direction of the sender and the receiver should be less than 45° .
2. *Condition for disposition of the receiver behind the sender* – the angle of rotation of the sender according to its current direction should be between 135° and 225° .

When both conditions are true the receiver becomes a candidate for propagating the data.

The choice is among all of the candidates. Because one device does not have an ability to know how many devices are around it, so it is necessary marks be used. The mark is for independent determination of the next sender. This mark is the time. If every candidate waits a different time, the one with the smallest timeout is able to send its modified data. The distance between the sender and the receiver is used to determine the timeout. This distance is different for every candidate, so the

timeout is different. There are two ways for determination of the timeout:

1. The timeout is decreasing with increasing the distance - “the farthest vehicle responds first”
2. The timeout is increasing with increasing the distance “the closest vehicle responds first”

Data structure of transmitting packages

1. Longitude
2. Latitude
3. Average speed in the current road section
4. Number of measurements
5. Moving direction of the sender
6. Fixed array of real numbers which presents the geographic coordinates of the path of measurements.

Calculating average speed for a vehicle

The speed from a GPS receiver is instantaneous. Therefore, the average speed should be calculated using several different in time records. The algorithm which is used is “moving average” [1]. It is low pass filter. It is calculating V_{avgK} from last N speed records using formula 1 where K is the number of current measurement.

$$V_{avgK} = \sum_{n=K-N}^K \frac{v_n}{N} \quad (1)$$

This algorithm needs at least N measurements to be stored which uses memory and every time when there is a new measurement it takes N steps to calculate the new value.

For optimizing the calculation only the last average speed $V_{avg\ K-1}$ should be stored. The new average speed has to be calculated using formula 2.

$$V_{avgK} = \frac{(N-1)V_{avg\ K-1} + V_K}{N} \quad (2)$$

Calculating average speed for a road section

The calculation of the average speed is performed again with the modified “moving average” algorithm. This time every vehicle which is broadcasting the package is adding its data to the received average speed data. The additional data has a specific weight and it depends on the previous number of vehicles which broadcasted the package. The calculation is via formula 3.

$$V_{avg\ street} = \frac{NV_{avg\ street\ prev} + V_{avgK}}{N+1} \quad (3)$$

When the maximum number of vehicles M is reached the calculation uses formula 4.

$$V_{avg\ street} = \frac{(M-1)V_{avg\ street\ prev} + V_{avgK}}{M} \quad (4)$$

Describing the goals for the algorithm

The realization of the algorithm aims maximum coverage of vehicles on a specific road section, minimum amount of sent packages – for avoiding overloading the network, maximum speed of propagation the data. The propagation of the data is unidirectional and the direction is opposite the direction of vehicles movement. In this case the cars ahead inform the cars to the rear and the new vehicles for this road section.

The direction of propagation is based on the last vehicle which broadcasted the data.

Behaviour of the receiver

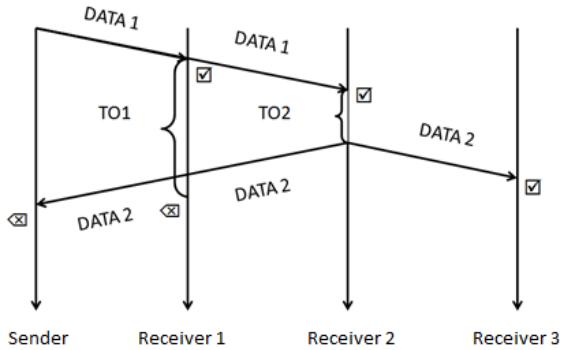


Figure 3: Timing diagram of receiving and broadcasting a package

When a device receives a package, it checks if the direction of movement is the same as its own, it calculates the distance from the sender and the orientation to it. In case the receiver is behind the sender, the receiver stores the data and changes its state to a candidate for broadcasting (☒ on fig. 3). The next sending will be from the farthest candidate. The distance from the sender is converted into timeout (TO1 and TO2 on fig. 3), so the longer distance means shorter timeout, so the farthest is able to broadcast its first data when time is up. If a package is received before the timeout and this package is with the same direction of movement but it is received from a source which is behind the current receiver it means that another candidate has broadcasted the data before the current one. Then the timeout is stopped and the current vehicle is no longer a candidate for broadcasting (☒ on fig. 3).

Behaviour of the sender

A specific vehicle can send a package via the wireless connection in two cases. The first case is when until the timeout event no packages were received which fulfil the conditions from above. Then the device-sender modifies the fields in the package with its own geographic coordinates, direction of movement, calculates new average speed (from the old package and

the average speed at this time), and modifies the number of vehicles.

The second case when a device can broadcast a package is after a specific time when no package was received which fulfils the conditions. This process is called evoking a package.

EXPERIMENTS AND RESULTS

Experiment 1

This experiment is to compare the behaviour of the algorithms in cases where the next sender is fixed N positions away from the current sender and in cases where the next sender is on random positions away in a specific range.

The experimental set is using the described model of movement for a single vehicle.

Let it be assumed that there exists a single lane road, where the distance between vehicles is one second. Every vehicle is using the same model. This will test a behaviour of a motorcade on a road with different obstacles like pedestrians, traffic lights etc.

The comparison between the algorithms is based on the average difference from the absolute average speed and the standard deviation. On figure 4 is shown the simulation set.

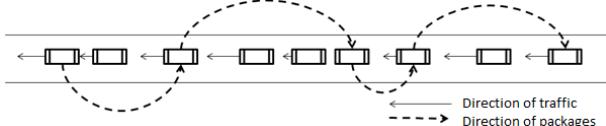


Figure 4: Simulation set for experiment 1

Test configurations of the experiment:

- The distance between the current and the next sender is fixed N positions where $N = \{1, 3, 5\}$
- The distance between the current and the next sender is random positions within the scope. The skipped cars receive the package but they do not broadcast it. The parameter M defines the maximum of a step. This configuration is tested for $M = \{6, 10\}$. The values of M are pursuant with the maximum range of IEEE 802.11b transmitters and the number of covered vehicles.
- The distance between the current and the next sender is defined as “the farthest vehicle responds first”. The maximum range is 10. There are chosen randomly K cars and the next sender is the one with the greatest value. The test is for values of $K = \{2, 3\}$.

Table 2: Set of configurations for experiment 1

Config.	Description	Max leap
1	Each subsequent broadcast	1
2	Every third broadcasts	3
3	Every fifth broadcasts	5

4	A random of next 6 broadcasts	6
5	A random of next 10 broadcasts	10
6	Greater from 2 random broadcasts	10
7	The greatest from 3 random broadcasts	10

The input data for the simulation uses the described model of behaviour of a moving vehicle. The model is defined as speed as function of time in seconds $v(t)$. The position of every vehicle in the motorcade is defined as a delay in seconds from the first car. For example: the car at place k has speed $v(t-k)$. The model is defined for finite number of seconds. In case of $t-k < 0$ the taken value is $(t-k) \bmod M$, where M is the maximum value of seconds where speed is defined.

The output data from the simulation is presented in text files, where every file represents the output data for a certain configuration. The results are real numbers, written on a separate lines and every line is for one tracking of the package from the begin to the end. The count of generated tracings for each configuration is 1 million.

Due to the large number of tracings for the analyses histograms are used. They show the distribution of calculated average speed for each configuration.

The absolute average speed of all cars in the simulation is 17.661 km/h. This speed is used as a reference.

In table 3 are shown the results for each configuration.

Table 3: Results for each configuration

Configurations	Average speed (km/h)	Standard deviation (σ)	Difference with the absolute average speed (km/h)
1	17.5656	7.9549	-0.0951
2	18.1732	3.4089	0.5125
3	18.2307	1.7714	0.5700
4	18.2259	3.3698	0.5652
5	18.2774	1.9673	0.6167
6	18.2473	1.5286	0.5866
7	18.2453	1.4535	0.5846

On figure 4a,b,c,d,e,f,h are shown the histograms of the average speed for each configuration. The horizontal scale for every histogram is the same.

From the results it is clearly shown that the algorithm “the farthest vehicle responds first” causes a “shrinking” in the histograms and the standard deviation decreases. It is shown that the difference between the absolute average speed and the calculated average speed is about 3.3%.

This experiment leads to the following conclusion: applying the algorithm “the farthest vehicle responds first” does not affect the calculated average speed and the distribution of measured average speeds on multiple tests remains the same. Therefore the algorithm is reliable and can be applied.

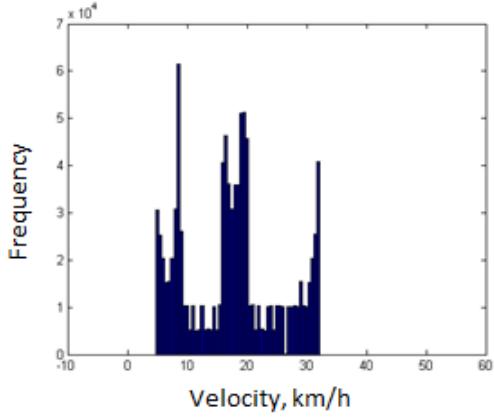


Figure 4a (above): Each subsequent broadcast

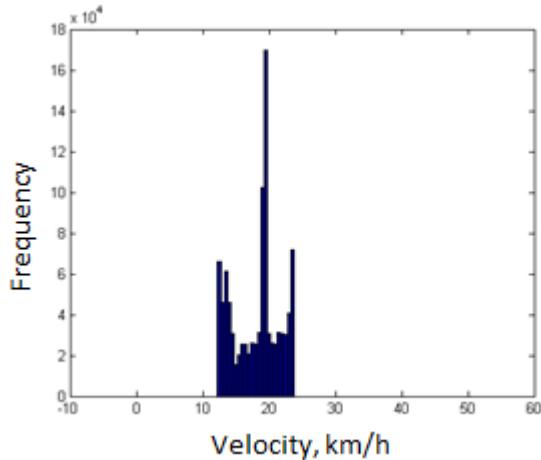


Figure 4b (above): Every third broadcast

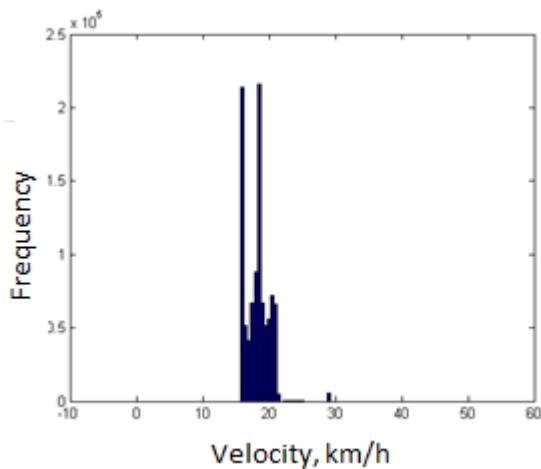


Figure 4c (above): Every fifth broadcast

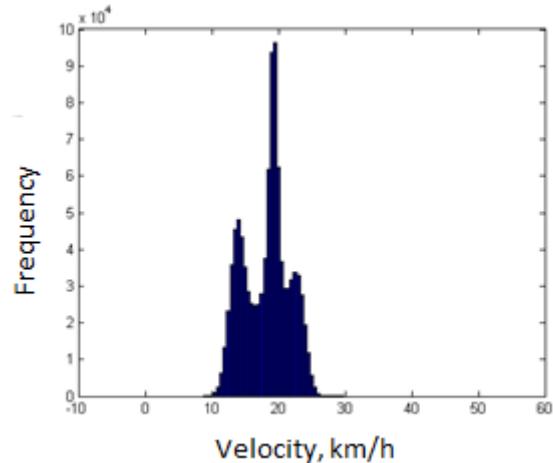


Figure 4d (above): A random sample of next 6 broadcasts

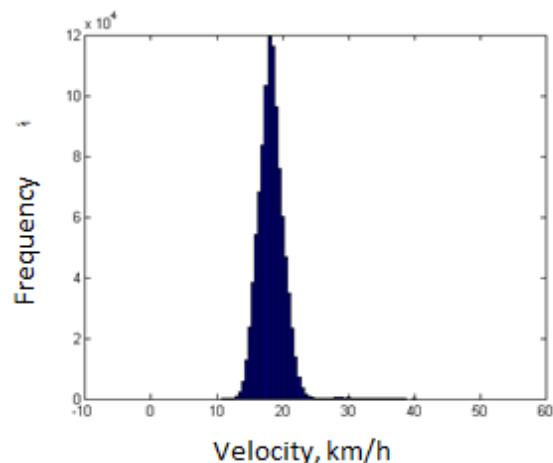


Figure 4e (above): A random sample of next 10 broadcasts

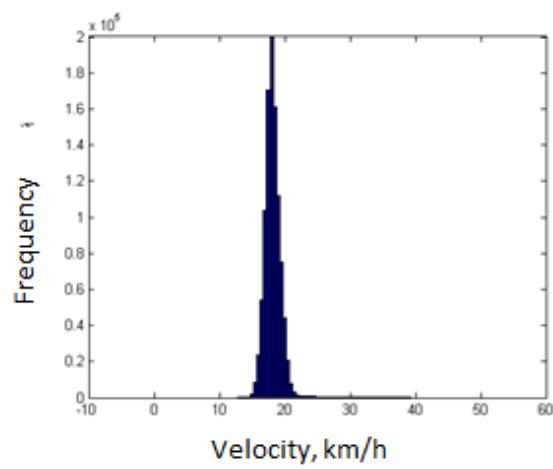


Figure 4f (above): Greater than 2 random broadcasts

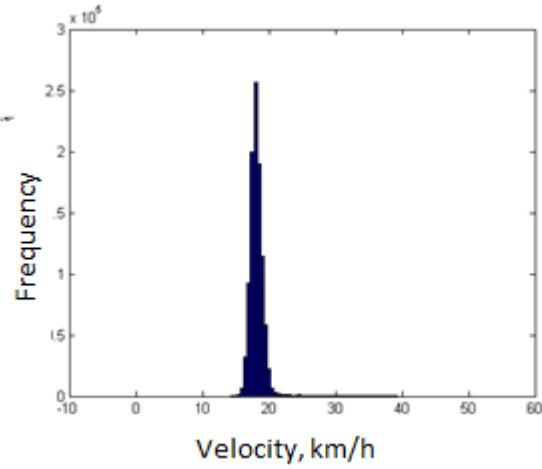


Figure 4g (above): The greatest of 3 random broadcasts

Experiment 2

This experiment is to study the average time for transmitting the package from the beginning of a motorcade to its end and the average time of delay between the intermediate points using the algorithm “the farthest vehicle responds first”. For this experiment is used the experimental set, shown on figure 5, like the previous experiment. With t_N are shown the timeout for a specific vehicle before sending the package and T is for the total time from the beginning to the end.

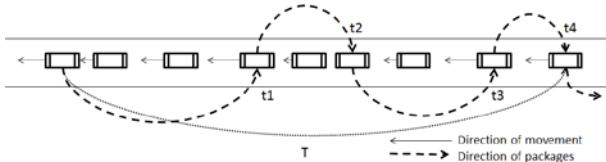


Figure 5: Simulation set for experiment 2

The algorithm “the farthest algorithm responds first” is tested for maximum range 10, where K random numbers are chosen. The greatest of them is the new next sender. Test values for $K = \{1, 2, 3\}$. This will show the behaviour of the algorithm on the average time delay as a function of the density of the traffic. Density of the traffic means mans the number of vehicles covered by the sender which have ability to broadcast. The test configurations are shown in the table 4:

Table 4: Configurations for experiment 2

Config.	Description	Density	Max. leap
1	A random sample of next 10 broadcasts	50%	10
2	Greater from 2 random broadcasts	75%	10
3	The greatest of 3 random broadcasts	87.5%	10

The input data for the simulator is a generator of pseudo random. It generates the size of leaps between two

positions on the path of the data. The leaps are converted in timeout using a function. The total delay is a sum of every single delay. The average timeout is defined as total delay divided by number of vehicles which broadcast the data.

The output data of the simulation are text files. Every file contains data for one of the test configurations. The results are real numbers written in two columns which are average timeout and total delay. There are 1 million tests for each configuration.

In table 5 are shown the results for every configuration.

Config.	1	2	3
Min t, sec	2.6670	1.7080	1.3480
Average t, sec	4.9665	3.4965	2.7633
Max t, sec	6.6210	5.1950	4.3140
Standard deviation (σ)	0.4124	0.3805	0.3273
Total delay, sec	198.648	108.078	76.667

In figure 6 are shown the visual comparison of the configurations.

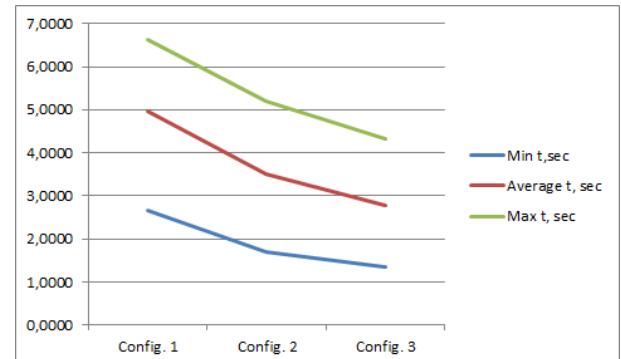


Figure 6: Minimum, Average, Maximum timeouts for every configuration

Figures 7 a, b, c show the histograms of average time delay for different types of density of the traffic – 50%, 75%, 87.5%.

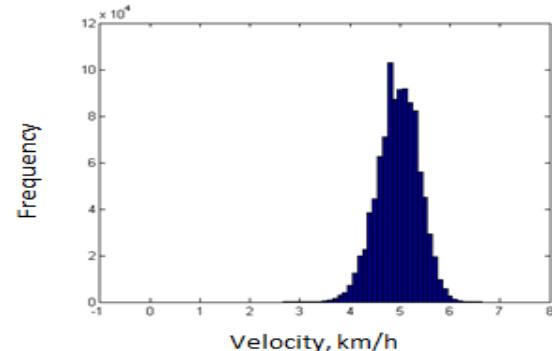


Figure 7a (above): A random sample of next 10 broadcasts

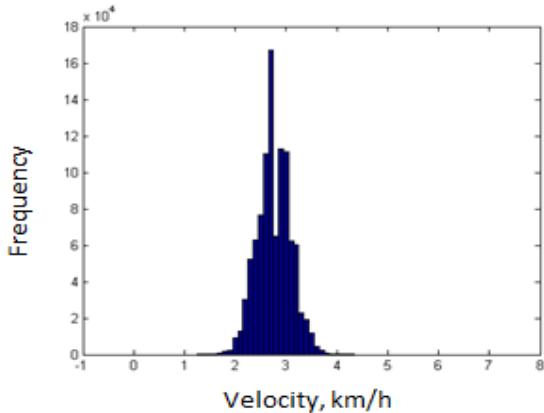


Figure 7b (above): Greater from 2 random broadcasts

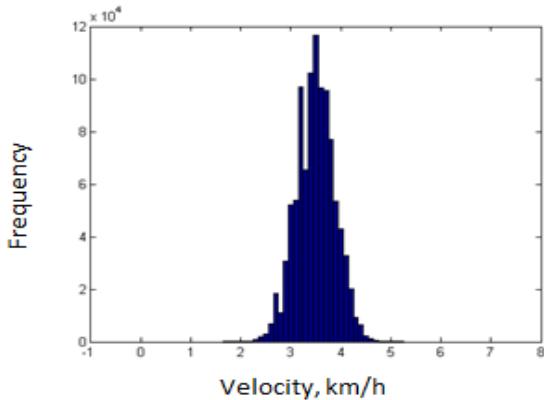


Figure 7c (above): The greatest of 3 random broadcasts

CONCLUSIONS:

Based on the results of the experiment it can be concluded that increasing the density of the average timeout decreases, so in case of situations with higher level of density (e.g. traffic jams) the speed of propagation is faster than without high density.

The algorithm for sending data about the average speed of a road section works successfully and proves the results. The speed of propagation can be increased by using proper hardware realization of device. The amount of data and the packages is low, so the risk of flooding the network is small.

These experiments showed that the distribution of measured average speeds on multiple tests remains the same. Therefore the algorithm is reliable and can be applied for estimating the average speed of the traffic in a given street.

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AUTHOR BIOGRAPHIES

Boyan B. Petrov was born in Plovdiv, Bulgaria and went to Technical University - Sofia, where he studied "Computer systems and technology" and obtained his bachelor degree in 2012. His e-mail address is: b_petrov@tu-sofia.bg and his Web-page can be found at <http://pxpress.net>

Dr Evtim Peytchev is Reader in Wireless, Mobile and Pervasive Computing at School of Science and Technology, Nottingham Trent University, Nottingham, UK. He is research leader of the Intelligent Simulation, Modelling and Networking Group at the school. The group consists of 15 research students, research fellows and lecturers working in the area of Intelligent Transportation Systems (ITS) and it has to its credit numerous journal and conference publications in the area of ad-hoc wireless and mobile networking with traffic information systems as an application domain.