Evaluation of an Opportunistic Collaborative Traffic Monitoring System

José Geraldo Ribeiro Júnior*†, Igor M. Quintanilha*, Miguel Elias M. Campista*, and Luís Henrique M. K. Costa*

* Grupo de Teleinformática e Automação, UFRJ - COPPE/PEE - DEL/Poli, Rio de Janeiro – RJ – Brazil
Email: {jgrjunior, quintanilha, miguel, luish}@gta.ufrj.br

† CEFET-MG - Campus III - Leopoldina - MG - Brazil
Email: jgrjunior@leopoldina.cefetmg.br

***Abstract*—Automated traffic monitoring is getting more and more important as the number of vehicles in circulation grows. Nevertheless, traffic control is still predominantly done manually using video cameras. In this work, we extensively analyze our previous collaborative and opportunistic traffic monitoring system to evaluate the proposal on scenarios with more than one vehicle. Based on the information received by IEEE 802.11 beacon frames, vehicles provide its location by a central entity to handle and disseminate information about traffic conditions on urban roads, exploiting readily available network resources. Experiments performed in the ns-3 conducted via simulations demonstrate the possibility to infer traffic conditions using a simple architecture and generating a small quantity of traffic on network.**

I. Introduction

Daily traffic jams in big cities are a direct consequence of the constant increase in the number of vehicles in circulation. Preventive actions have to be taken as a priority and many proposals to reduce traffic problems depend on efficient and automated monitoring. However, to date the most used form of monitoring large avenues is still the old-fashioned operated video cameras, where all traffic control is visually. These systems are not efficient enough since they neither react nor foresee potential circulation problems.

Automated systems have been proposed in the literature to allow timely countermeasures [1]–[5]. In a companion paper, we have proposed an opportunistic and collaborative traffic monitoring using existing IEEE 802.11 networks [1]. The location, direction, and speed of vehicles are inferred using only information from beacons of existing IEEE 802.11 networks, without modifications on neither network elements nor existing protocol. Client nodes receive beacons, treat the received data, and send the information to a central unit. The central unit processes the received data and share consolidated information to users. We have presented results obtained in real scenario for one vehicle using the proposed method, and compared with results collected by GPS, presenting good similarity. The results have also shown that even with a received signal with power as low as -60 dBm, it is possible to infer the vehicle location with an error of less than 10 meters [1]. In the proposal, it is not necessary to use GPS (Global Positioning System) to define the vehicle location.

To automatically infer the movement of vehicles in a highway, other proposals use image recognition resources [2] or sensors in cars and along the road [6]–[8]. In our proposed method, the network traffic to define the vehicle location is smaller than with GPS or image recognition because each vehicle sends only one packet by highway stretch[1]. Also, the proposal does not present cost to the final user, unlike 3G [9].

In this paper we present an implementation of the proposed 802.11-based traffic monitoring system, including the client and server applications. We present also the simulation results to evaluate the system under more general conditions. In order to keep reality conditions, we conduct simulations using modified implementations of mobility and lane change models designed to ns-3 [10] and we also increase the number of running vehicles. Even in such larger scenarios, we are still able to attest the efficiency of the proposed monitoring system. In addition, compared with GPS-based proposals, we show that the proposed system adds 200x less control traffic.

The remainder of this paper is organized as follows. Section II provides details on the system implementation. Section III presents the validation of the mobility and lane change model. Section IV presents some case studies and the results obtained from simulations. Finally, Section V concludes the paper and presents topics of future investigations.

II. Architecture and Implementation of the 802.11-based Traffic Monitoring System

To improve the traffic conditions, at least five steps are needed: (1) road information gathering, (2) treat this information, (3) traffic conditions dissemination, (4) detect problematic traffic elements, and (5) additional traffic flow improvement. This work analyzes the first three steps, including the dissemination of traffic conditions to devices inside or outside the road.

The system requirements are: (1) IEEE 802.11 coverage, at least partial, on the road; (2) periodical dissemination of

[1] A highway stretch is defined as a piece of road between two access points (Figure 4).

978-1-4673-4404-3/12/$31.00 ©2012 IEEE

beacons by the access points; (3) participation of client nodes (vehicles); and (4) access points with known geographical location [1]. In addition, as illustrated in Figure 1, the main elements of the previously proposed architecture are: the client nodes (devices with IEEE 802.11 interface inside the vehicles), access points, and the central unit. Client nodes are responsible of detecting the moment when the vehicle is close to an access point so to as send the information about the vehicle location to the central unit. The central unit, on the other hand, is responsible of organizing the obtained information and, after comparing them with its locally-stored information, generate the road stretch condition for dissemination.

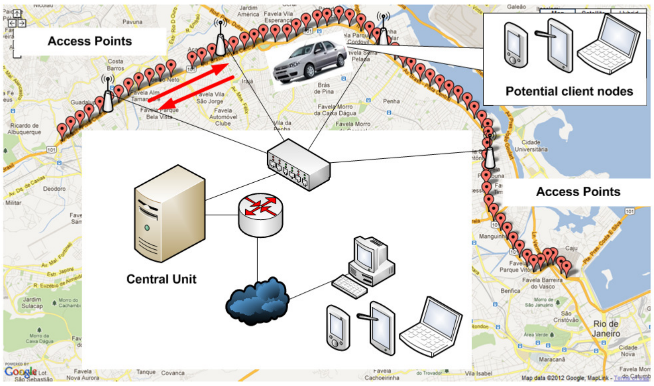

Fig. 1. Proposed system architecture.

In this work, we implement a client application so as to keep users aware of current traffic conditions. Figure 2 presents the implementation details. To detect a desired network, the client application automatically sets the network interface in monitor mode. Thus, the network interface can collect IEEE 802.11 beacon frames even if it is not associated to the network. When the client receives an IEEE 802.11 beacon from known ESSID (Extended Service Set Identification), it attempts to associate to the access point. Once the client is associated to the network, the client application changes the interface to infrastructure mode and continues to collect beacon frames, but now only beacons from the associated network. This change happens in execution time and it does not affect client location because it t happens when vehicles are within weak signal zones. In opposition, our method considers only the moments where the signal is strongest to infer vehicle position. Upon receiving data, clients parse only the following information of received data: the access point MAC address, the received signal power, and the packet generation time. These data are stored ordered by the signal power, once the goal is to know the moment when the signal received has the highest power. If the client node is connected, it sends only one packet per highway stretch to the central unit, containing the information: the access point and client MAC addresses, received signal power, and time of beacon generation. The following algorithm shows how the vehicle detects when one highway stretch ends.

```
...
  actualPower = 0;
  maxPower = 0;
  Create a structured vector; //store power values
  WHILE true DO
    $actualPower = Obtained power value;
    IF ($maxPower - $actualPower >= 10) THEN
      send information to the central unit
    ELSE
      Store $actualPower on vector
      Sorted signal power values in descending order
    FI
...
```

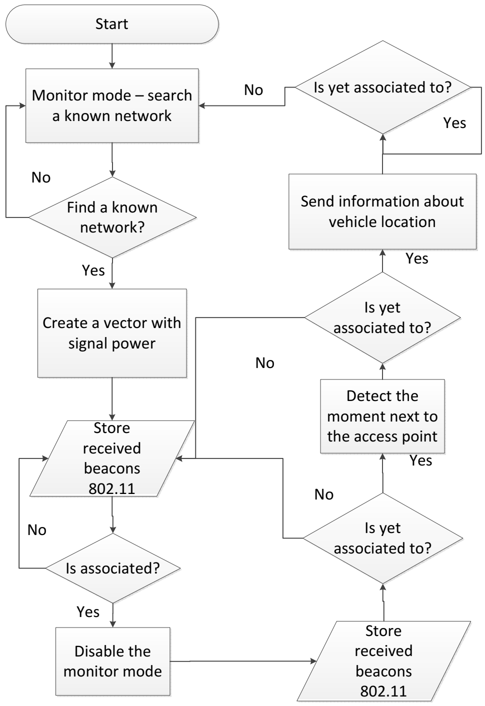

Fig. 2. Client Application.

Figure 3 illustrates the details of the central unit application. The central unit stores the data received from client nodes and, based on local information, computes the location and direction of the vehicle in real time, in predefined time intervals (e.g. 30 seconds). To locate the vehicle on the road, we get the last information sent by the client, indicating which access point it was associated to. To determine the vehicle's direction it is necessary to know the MAC address of the last two access points from which the client node sent information to the central unit. The last step is to disseminate the highway condition using any Internet connection or a local peer to peer network.

The number of highway stretches depends on the number of access points and on the road characteristics. Each direction is considered a different stretch. The number of highway stretches is given by:

$$N_{HS} = ((N_{AP} - 1) * N_D), \quad (1)$$

where N_{HS}, N_{AP}, and N_D are, respectively, the number of highway stretches, the number of access points, the number of directions.

When the central unit receives information from at least two vehicles in a highway stretch (e.g. highway stretch 1 of Figure 4), the system calculates the simple harmonic mean of received speeds, to infer the highway stretch condition. The simple harmonic mean is the number of nodes (n) divided by the sum of the inverse of their speeds (Equation 2). Using the harmonic mean it is possible to eliminate outliers, for example, when we have police cars or ambulances.

$$WHS = \frac{n}{\sum_{i=1}^{n} \frac{1}{s_i}}, \quad (2)$$

where s_i is the speed of node i, and $s_i > 0$.

III. Mobility and Lane Change Model

We used in our simulations an Intelligent Driver Model (IDM), that provides real vehicle movements, and a MOBIL lane change model, both proposed by M. Treiber and D. Helbing [11] and implemented in ns-3 by Hadi [10]. The authors have implemented a Highway class to represent a straight multiple-lane bi-directional roadway. The Highway object manages the mobility of vehicles on the road. Each vehicle is a wireless node in ns-3. Thus, vehicles can move with realistic mobility models ou using realistic trajectories and communicate with each other to form a VANET. We have created customized road-side and on-board units with user-defined actions and event handlers to implement the proposed monitoring system in realistic simulation scenarios.

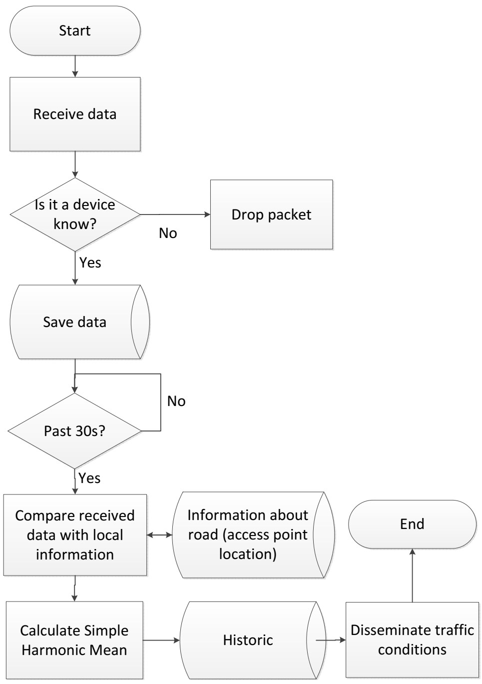

Fig. 3. Server application.

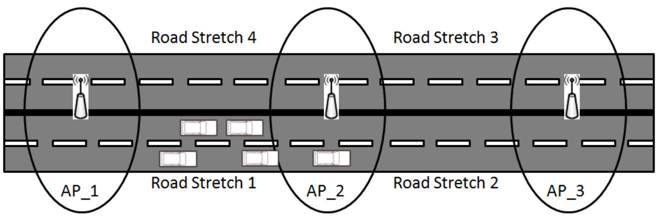

Fig. 4. Example of road stretches and vehicles used for traffic condition calculation.

In IDM model, each a vehicle's acceleration or deceleration depends on: (1) its current speed; (2) its target speed; and (3) the position and speed of the vehicle immediately ahead in the same lane. Each vehicle has a desired speed, safe time headway (time needed to cover the gap between two vehicles), acceleration in free-flow traffic, comfortable braking deceleration, and desired minimum distance to the front vehicle. These parameters and the current state of the vehicle and front vehicle are used to compute the new acceleration. The acceleration is used to update the speed and position of the vehicle. For auto-injection of vehicles in the highway, there is a `injection gap` parameter that specifies the minimum distance between two vehicles entering the highway. The parameter `injection mix` value is the percentage of cars and trucks, where 100 corresponds to 100% of cars (sedan) and 0% of truck.

A. *Model Evaluation*

To evaluate the used models, we have defined a road with the parameters presented in Table I. Part of scenario is illustrated on Figure 5.

TABLE I
Parameters used on simulation

Parameters	Values
Highway length	5200
Lane width	5
Number of lanes	3
Number of access points	9
Two directions	True
Lane change	True
Auto inject	true
Injection gap	600
Injection mix value	100

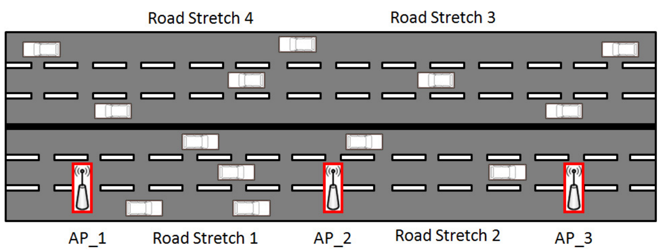

Fig. 5. Example of part of the validation scenario.

The first goal of the simulations was to experiment with vehicles moving in both directions. Figure 6 shows the moments when the vehicles cross each access point, in eastbound or westbound directions. Each line represents one vehicles trace. On X axis, we have the time, and on Y axis, we have the identifier of the access point. We positioned the access points over the right lane of the road to function as obstacles (Figure 5) and to force cars changing lanes, resulting in speed variations.

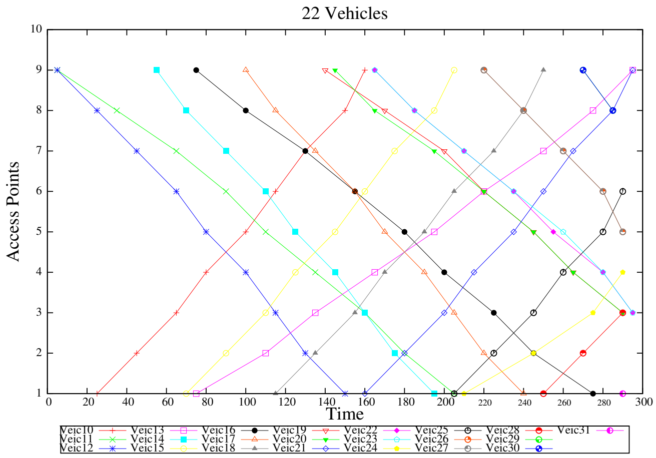

Fig. 6. Vehicle traces on two directions.

To check if one obstacle was enough to close one lane, we have created a scenario with only one lane, with access points inside. All vehicles were stopped in front of the first access point.

IV. Simulations Results

This section presents three experiments based on the same parameters shown in Table II.

TABLE II
Parameters used on simulation

Parameters	Simulation 1	Simulation 2	Simulation 3
Highway (m)	18,200	18,200	18,200
Lane width	5	5	5
Number of lanes	2	3	4
Number of access points	36	36	36
Highway stretches	35	35	35
Two directions	False	False	False
Lane change	True	True	True
Auto Inject	True	True	True
Injection gap	20	20	20
Injection mix value	70	70	70
Simulation time (seconds)	600	600	600

We have conducted simulations using one highway 18.2 km long. In each experiment, the highway had 2, 3, and 4 lanes in one direction. The width of each lane is 5 m. We have distributed 36 access points (always placed in lane one to force vehicles to change lanes and produce speed variations) every 500 m, performing a total of 35 highway stretches. The vehicle type distribution was composed of 70% of sedans (lentgh=4 m) and 30% of trucks (lentgh=8 m), and the safe distance between the vehicles was set to 20 m (below international standards). The highest speed was 110 km/h and the simulation duration was 10 minutes.

To evaluate the results of the proposed system, we have simulated a GPS sending information about the vehicle position at each 0.25 second. Thus, we had high precision on vehicle position to compare with the obtained results. However, more information about the vehicle location generates more traffic in the network. In the proposed method, the vehicle only sends one packet per highway stretch.

To compare the precision of system, we have defined three speed intervals to qualify traffic conditions: from 0 to 40 km/h, the system indicates that the traffic is SLOW; from 41 to 80 km/h, the traffic is considered GOOD, and above 80 km/h, it is considered FAST. We consider good precision when both results are at same interval.

Figures 7, 8, and 9 present the results for a two-lane highway. In this scenario, until the highway stretch number is 15, we had a high speed variation, due to the vehicles changing lanes. After the highway stretch 15, with a smaller number of vehicles, the mean speed became more constant. Figure 7 shows the traffic conditions on the last minute of simulation per stretch, moment when we have vehicles in all highway stretches. Table III shows the number of packets generated on communication between vehicles and central unit. Figure 8 shows the number of vehicles per highway stretch on the last minute of simulation. These vehicles are used to calculate the simple harmonic mean, to define the traffic condition per stretch. Finally, Figure 9 shows the rate of sedans and trucks used in the simulation. The compared methods were at same interval in 22 of the 35 road stretches, almost 60%. This is the worst scenario among the tested, since we have only two lanes (one with obstacle), and a large number of trucks (30% of total of vehicles).

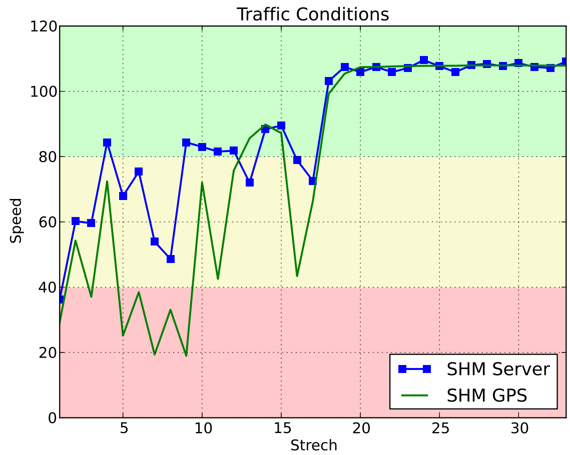

Fig. 7. Highway traffic condition - 2 lanes.

Figures 10, 11, and 12 present results where the highway had three lanes. In this scenario, the speed variation was lower than when we had 2 lanes, and the results of stretches traffic conditions were very similar (Figure 10). Both methods were

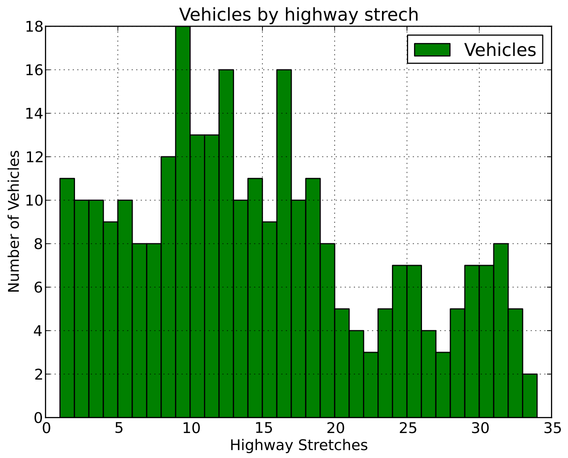

Fig. 8. Number of vehicle by stretch - 2 lanes.

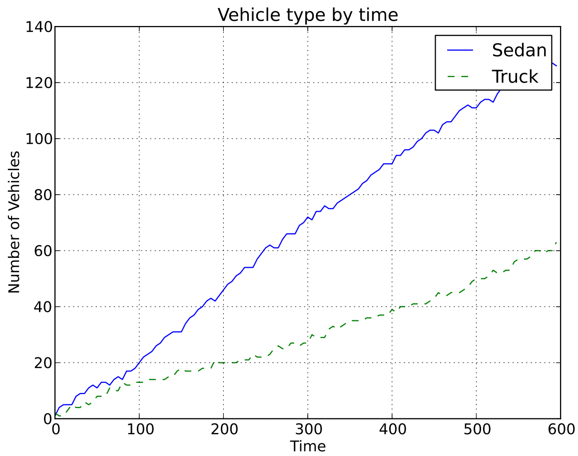

Fig. 9. Number of vehicle by type - 2 lanes.

at same interval in 32 of the 35 road stretches, almost 90%.

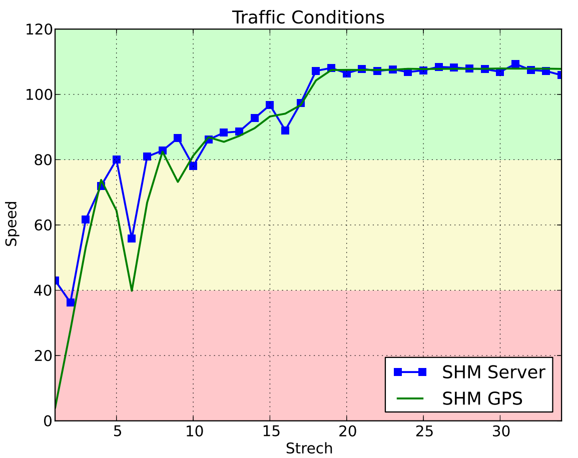

Fig. 10. Highway traffic condition - 3 lanes.

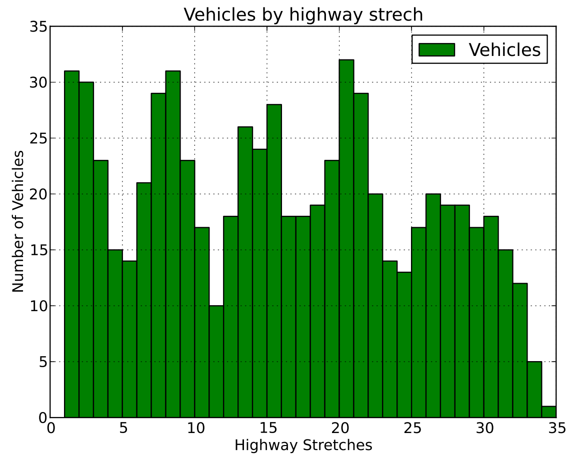

Fig. 11. Number of vehicle by stretch - 3 lanes.

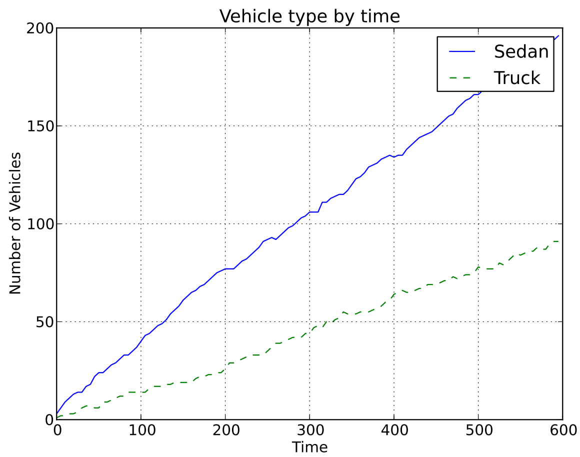

Fig. 12. Number of vehicle by type - 3 lanes.

Figures 13, 14, and 15 present results where the highway had four lanes. In this scenario, because we had a higher number of free lanes, the speed variation was smaller, and stretches traffic conditions presented high similarities (Figure 13). Both methods were at same interval in 33 of the 35 road stretches, almost 94%.

The results show that our monitoring system proposed in [1] works even on large scenarios, with high number of vehicles and lanes. The traffic condition presented was very similar when compared with a GPS sending information every 0,25 second. To infer the traffic conditions, the proposed method generated a traffic more than 200 times smaller than the GPS-based monitoring. This traffic is generated on communication between vehicles and central unit (Table III).

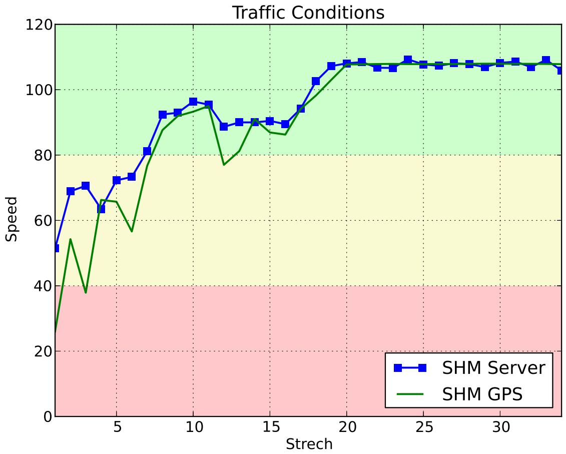

Fig. 13. Highway traffic condition - 4 lanes.

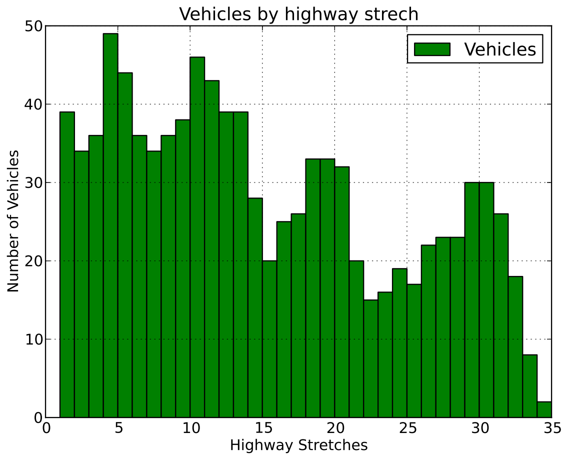

Fig. 14. Number of vehicle by stretch - 4 lanes.

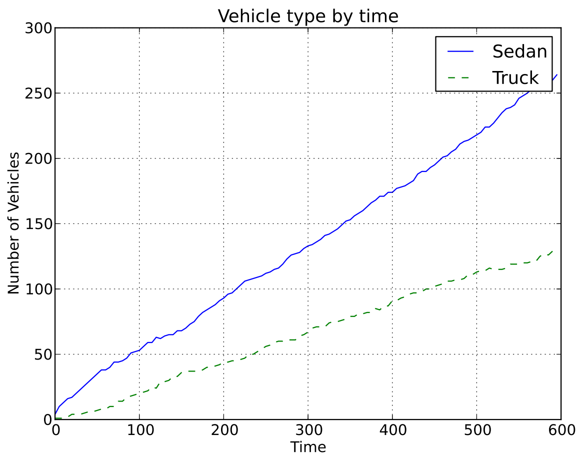

Fig. 15. Number of vehicle by type - 4 lanes.

TABLE III
NUMBER OF PACKETS SENT TO CENTRAL UNIT.

Number of lanes	Access Point	GPS
Two	9,399	3,518,307
Three	21,652	5,377,277
Four	30,160	7,261,779

V. CONCLUSION

We have presented an evaluation of an opportunistic collaborative traffic monitoring that relies on already available IEEE 802.11 networks. We evaluated the previous proposed method on more general scenarios with a higher number of vehicles. The results have shown that it is possible to perform traffic monitoring using simple algorithm and architectures, while generating small traffic overhead. The obtained results show high similarity with more complex methods which achieve high level of precision, at the cost of higher control traffic.

As future work, we will simulate others scenarios where there are transmission errors, with packet loss. We will also vary the number of access points and the distance between them to improve the accuracy to infer the traffic condition on road stretches.

ACKNOWLEDGMENTS

This work was partially funded by CAPES, COFECUB, FAPERJ, CNPq, and FINEP/FUNTTEL.

REFERENCES

[1] J. G. R. Júnior, M. E. M. Campista, and L. H. M. K. Costa, "Opportunistic system for collaborative traffic monitoring using existing ieee 802.11 networks," *Intelligent Vehicular Networking: V2V/V2I Communications and Applications - IEEE International Conference on Communications - ICC 2012*, pp. 7294 –7298, June 2012.

[2] R. Cucchiara, M. Piccardi, and P. Mello, "Image analysis and rule-based reasoning for a traffic monitoring system," *Intelligent Transportation Systems, IEEE Transactions on*, vol. 1, no. 2, pp. 119 –130, jun 2000.

[3] Google, "Google Maps," *Available in http://maps.google.com/support*, 2011, accessed in January 2012.

[4] Yahoo, "Yahoo Maps," *Available in http://maps.yahoo.com/*, 2011, accessed in January 2012.

[5] Microsoft, "Microsoft Maps," *Available in http://br.bing.com/maps/*, 2011, accessed in January 2012.

[6] C. D. T. CDT, "CalTrans," *Available at http://www.dot.ca.gov/*, 2011, accessed in January 2012.

[7] A. Edelmayer, M. Miranda, and V. Nebehaj, "Cooperative Federated Filtering Approach for Enhanced Position Estimation and Sensor Fault Tolerance in Ad-hoc Vehicle Networks," *Intelligent Transport Systems, IET*, vol. 4, no. 1, pp. 82 –92, march 2010.

[8] V. Bychkovsky, K. Chen, M. Goraczko, H. Hu, B. Hull, A. Miu, E. Shih, Y. Zhang, H. Balakrishnan, and S. Madden, "The CarTel Mobile Sensor Computing System," in *Proceedings of the 4th international conference on Embedded networked sensor systems*, ser. SenSys '06. New York, NY, USA: ACM, 2006, pp. 383–384. [Online]. Available: http://doi.acm.org/10.1145/1182807.1182866

[9] A. Balasubramanian, R. Mahajan, and A. Venkataramani, "Augmenting mobile 3G using WiFi," in *Proceedings of the 8th international conference on Mobile systems, applications, and services*, ser. MobiSys '10. New York, NY, USA: ACM, 2010, pp. 209–222. [Online]. Available: http://doi.acm.org/10.1145/1814433.1814456

[10] H. Arbabi and M. C. Weigle, "Highway mobility and vehicular ad-hoc networks in ns-3," in *Proceedings of the Winter Simulation Conference*, Baltimore, MD, dec 2010.

[11] M. Treiber and D. Helbing, "Realistische mikrosimulation von strabenverkehr mit einem einfachen mod," *16. Symposium "Simulationstechnik ASIM 2002" Rostock. Edited by Djamshid Tavangarian and Rolf Grutzner*, pp. 514–520, September 2002.