19th ITS World Congress
Vienna, Austria
22 to 26 October 2012
smarter on the way

Conceptual Approach for Determining Penetration Rates for Dynamic Indirect Traffic Detection Based on Bluetooth

Gaby Gurczik[1*], Marek Junghans[1], Sten Ruppe[1]
1. German Aerospace Center (DLR), Germany
* Corresponding author: German Aerospace Center (DLR), Institute of Transportation Systems, Traffic Management, Rutherfordstr. 2, 12489 Berlin, Germany
Tel.: +49-(0)30-67055 7928, E-Mail: gaby.gurczik@dlr.de

Abstract

An efficient traffic management requires current and area-wide traffic data. Today different systems exist on highways, main roads and major arteries for a comprehensive traffic collection. It is the goal of traffic authorities world-wide to obtain highly accurate spatial-temporal traffic data without installation of costly and deteriorating physically invasive infrastructure in inner-city and rural areas, too. Therefore, a novel approach for an efficient and low-cost large-scale traffic monitoring was presented in [6], which augments the Floating Car Data (FCD) principles by an anonymous indirect detection of traffic objects (cars, cyclists, pedestrians) using cars which are equipped with specific radio-based Bluetooth/Wi-Fi receivers. By introducing a conceptual method the presented paper deliberates to the question how many equipped cars are required to derive dynamic high quality traffic information on the basis of this new approach.

Keywords:

Floating Car Observer, Bluetooth, Dynamic Traffic Detection, Penetration Rate, Traffic Management

Motivation

The realisation of an adequate traffic management requires area-wide traffic measurements on the basis of spatial-temporal sensors [1, 2]. It is the goal of traffic authorities world-wide to obtain highly accurate spatial-temporal traffic data without installation of costly and deteriorating physically invasive infrastructure [5, 7]. An example for those systems has been the successful implementation of floating car data (FCD) systems (see figure 1a). Floating Cars are vehicles driving in a fleet that go with the flow of traffic. The cars are equipped with a system (e.g. GPS) for self-positioning. The position information of the cars allow conclusion about the traffic condition. The advantage of FCD is that there is no costly stationary infrastructure needed. The drawback is that only a fraction of the real traffic can be used as data base for the generation of reliable traffic information. Another competing method is the floating car observer (FCO) approach, which was first mentioned by [9]. The idea of FCO is that cars equipped with adequate sensors (e.g. video) follow their route through the network, thereby observing the surrounding environment.

In [7] a new approach is presented, which augments the FCD principle and enables the detection of vehicles, pedestrians, cyclists and passengers of public transport to achieve spatio-temporal traffic data (see figure 1b). These data can be very important to answer urgent and to some extend still insufficiently solved questions in operative traffic management and for long-term traffic and transportation planning in urban areas [8]. All detections are made indirectly by traffic observers while passing other traffic objects. With it, this approach closes the gap between FCD and the FCO principles.

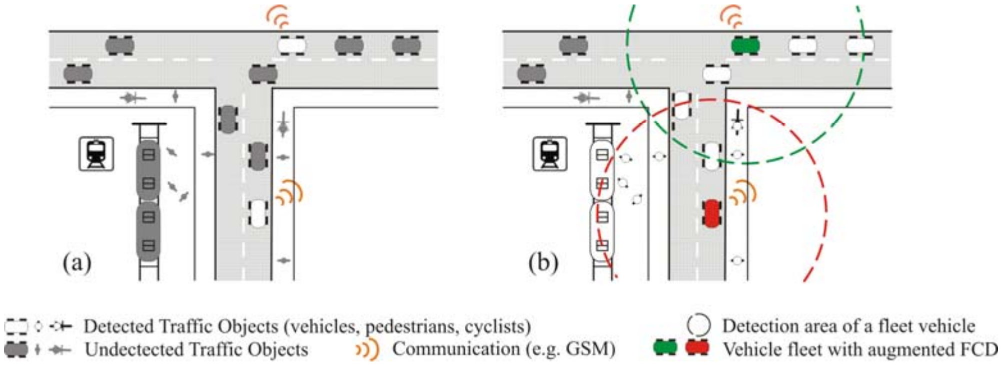


Figure 1 - Different systems for mobile traffic measuring: (a) FCD; (b) new approach [6]

Currently the whole potential of the novel method is not yet measured. Questions concerning the number of Mobile Traffic Observer Units (MTOU) being needed, the size of the covered network and several more questions are not answered at all. The presented paper takes up these points and gives a conceptual approach to answer some of the raised questions. Therefore the paper initially gives basic information on the technical aspects of the introduced approach and makes a declaration of penetration rates. Afterwards the conceptual method is described followed by first results which are separated in three subsequent parts according to the mentioned concept. Finally a conclusion and future prospects complete the paper.

Basics on Dynamic Indirect Traffic Detection and Penetration Rates

Dynamic Indirect Traffic Detection (DITD) allows anonymous positioning by indirect detection of traffic objects (cars, cyclists, pedestrians) using wireless radio-based technologies, e.g. Bluetooth/Wi-Fi. Since many traffic participants use devices with activated Bluetooth/Wi-Fi functionality (e.g. mobile phones), a car equipped with a specific receiver (MTOU) can detect all traffic objects with Bluetooth/Wi-Fi devices being in the detection area by their identification number. Augmented by time stamps and positions of the observer, i.e. MTOU vehicle, the measured data can be processed to trajectories, travel times, etc. A key parameter to be determined is the *Penetration Rate,* which is simply a measure of the amount of MTOU vehicles compared with the total amount of vehicles on a street network.

Concept

In [7] some fundamental research questions were mentioned. For instance, it has to be answered how big the underlying network must be and how many edges and intersections must be contained or how many MTOU have to be in use to prove the approach to determine high quality traffic data. The picked up key question for this paper is to answer, how likely it is to detect a vehicle equipped with a Bluetooth/Wi-Fi device by a MTOU. Answering this question is not easy at all, since there are a lot of parameter interdependencies, which need to be identified and quantified. Thus, the three following steps are intended to investigate a conceptual method, which will be structured and discussed in the next sections:

- Analytical Investigations
- Modeling and Simulation
- Practical Tests

Analytical Analysis

At this point the key parameters will be identified, defined and their interdependencies uncovered described to successfully bring the dynamic traffic detection approach into practice. For instance, the chance to detect a vehicle does not only depend on the detection range, but also on other parameters like the difference of the velocities of the meeting vehicles, the network size, the number of observers, the equipment rate [6] and many more. A general equation can be given—without the requirement of completeness—as follows

$$P_D = f(D, N, V, T, E, \dots).$$

In this equation P_D defines the probability to detect a passing traffic participant, which is a function *f* of

- *D* (detection related parameters, e.g. the distance between observer and vehicle, the detection technology, e.g. Bluetooth, Wi-Fi, which defines the inquiry process),
- *N* (road network related parameters, e.g. network size and type),
- *V* (vehicles related parameters, e.g. vehicles speeds),
- *T* (traffic related parameters, e.g. traffic demand, traffic state, traffic control),
- *E* (environmental parameters, e.g. rain, the construction area, multipath conditions).

Some parts of the parameters *D*, *N* and *V* will be considered by the solution of the geometrical problem given in fig. 2 (see also [4]).

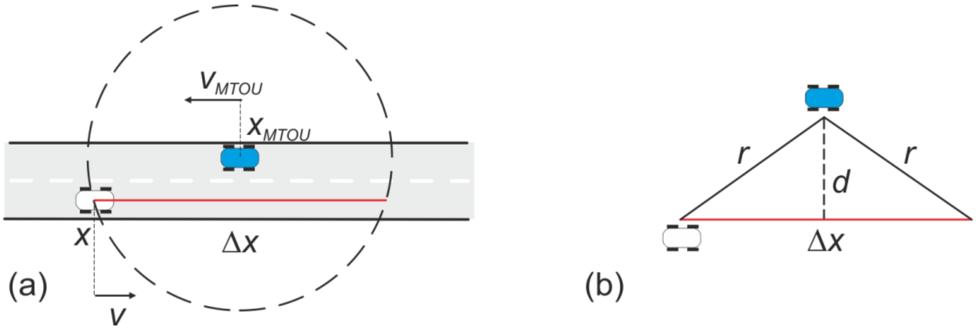


Figure 2 – Microscopic view to compute t_v: (a) the way Δ*x* the white car will be visible for the MTOU (red line); (b) sketch of the geometrical problem

In fig. 2 there is shown a vehicle (white), which enters the detection range of a MTOU vehicle (blue) and will be visible for the MTOU all the way Δ*x*, which is

$$\Delta x = \sqrt{r^2 - d^2}.$$

In fact, it can be seen in fig. 1 that P_D depends on road geometrical features, e.g. the distance *d*, and kinematic characteristics by the moving vehicles, i.e. the speed differences of the vehicle and the MTOU. Thus, the time the vehicle will be theoretically visible for the MTOU will be defined as t_v (visibility time) and can be computed by:

$$t_v(|\Delta v|) = \begin{cases} 2\dfrac{\sqrt{r^2 - d^2}}{|v - v_{\mathrm{MTOU}}|} & |x - x_{\mathrm{MTOU}}| \leq r \\ 0 & |x - x_{\mathrm{MTOU}}| > r, \end{cases}$$

which contains the detection range *r* of the MTOU, the vertical distance *d* between the two vehicles (road geometry), the detection range of the MTOU (technical features and parameters) and the absolute values of the velocity differences $|\Delta v| = |v - v_{\mathrm{MTOU}}|$ (kinematic characteristics).

One can recognize that t_v approximates zero, if $|\Delta v|$ is very high. On the other hand, t_v will be infinity if both vehicles follow each other at the same speed. Further, t_v is strongly influenced by r, which can vary between 10 to 100m for Bluetooth and up to 500m in the case of Wi-Fi. The parameter d can sometimes be disregarded, if the vehicles run on the same road. If r grows, clearly d becomes more interesting in the case of intersections, motorways, etc., which is not taken into consideration here. Further, it is clear that P_D reaches the theoretical maximum if $d = 0$ and P_D is minimal if $d = r$.

To compute the detection probability, we rely on some experimental results given in [3], which show that it is 95% likely to detect a Bluetooth vehicle within the so called limiting enquiry time of $t_{\mathrm{lim}} = 7.68\mathrm{s}$. Thus, we assume the detection probability $P_D\ (t_v \leq t_{\mathrm{lim}})$ to increase linearly to 0.95 within 7.68s, Since we obtained very rare enquiry detections even after 80s we assume to have a 100% detection probability at 100s:

$$P_D(t_v) = \begin{cases} \dfrac{0.95}{7.68s} t_v & t_v \leq t_{\mathrm{lim}} \\ \dfrac{0.05}{92.32s} t_v + \dfrac{87.32s}{92.32s} & t_{\mathrm{lim}} < t_v \leq 100s \end{cases}$$

Inserting $t_v(|\Delta v|)$ into $P_D(t_v)$ we are capable of computing the empirical detection probability $P_D(|\Delta v|)$ in dependence on the absolute value of the velocity differences $|\Delta v|$:

$$P_D(|\Delta v|) = \begin{cases} \dfrac{0.95}{3.84s} \dfrac{\sqrt{r^2 - d^2}}{|\Delta v|} & (t_v \leq t_{lim}) \cap (|x - x_{MTOU}| \leq r) \\ \dfrac{0.05}{46.16s} \dfrac{\sqrt{r^2 - d^2}}{|\Delta v|} + \dfrac{87.32s}{92.32s} & (t_{lim} < t_v \leq 100s) \cap (|x - x_{MTOU}| \leq r) \\ 0 & |x - x_{MTOU}| > r \end{cases}$$

Consequently, we have found an analytical model to compute the detection probability of a single vehicle in dependence of the dynamics of the vehicles (speed differences), the geometrical road characteristics (distance d) and technical parameters (detection range r). The model is still incomplete and needs to be developed further to make it more realistic. Results for the detection probability P_D for some different parameters will be given in *Practical Tests.* Besides a still necessary comprehensive analysis of the mentioned parameters D, N and V, the other missing ones are of are of our current research interest and will follow later in other publications.

Modeling and Simulation

In dependence on the analytical results the described method will be modeled and simulated within the next step. Therefore a simulation study on the basis of the traffic simulation software SUMO (<u>S</u>imulation of <u>U</u>rban <u>Mo</u>bility) is set up. With this study, quantitative and qualitative statements towards required penetration rates on different simulated case scenarios shall be given. We simulated a simple generic network, where parameters like fleet mobility, fleet disposition or the sum of driven kilometers are initially fixed. By varying the number of equipped MTOU vehicles statements on optimal fleet amounts and with it penetration rates should result.

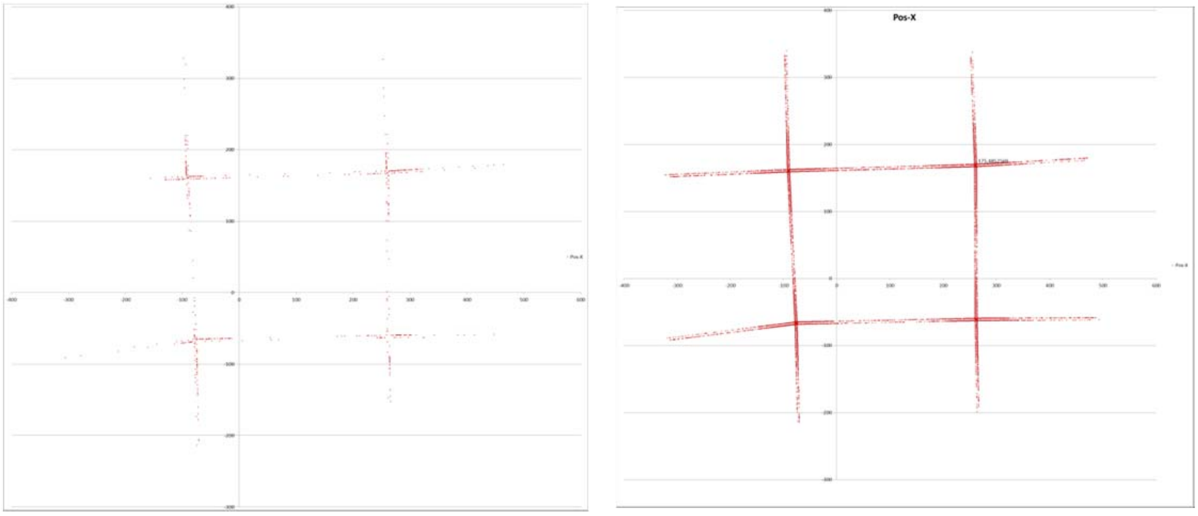
The objective of the simulation study was to find out the overall detection probability of a number of Bluetooth/Wi-Fi vehicles by a number of MTOUs in a generic network of four intersections. It must be stated that we only considered a re-detection probability, i.e. the vehicles had to be detected by one MTOU and re-detected by a different MTOU. The following setup was chosen. The simulation results are given in the next chapter:

- Size of the network: approximately 550m x 800m
- 4 traffic light's controlled intersections of a phase time of 90s
- The single-lane roads of the network are used in both directions.
- A vehicle is set into the simulation at the beginning of the road every 1s at a speed of 50km/h. When approaching the intersections the speeds decreased, since the vehicle density increased, and after the intersection the speeds increased again.
- The average vehicle density in the network was 29.5 vehicles/km
- The traffic demand is constant at the beginning, but changes during the simulation, since the routes are equally distributed and we applied traffic assignments to avoid traffic jams.
- The detection range of the MTOU vehicles was chosen r = 64m
- Simulation time: 10,000s; the simulation was repeated 26 times
- The simulation was done for a varying MTOU vehicle ration from 1% to 30%.
- The detection probabilities $P_D(t_v)$ or equivalently $P_D(|\Delta v|)$ increased from 26%, since the vehicles slowed down when approaching the intersections and a detection is more likely and decreased, when the vehicles accelerated again.

Practical Tests

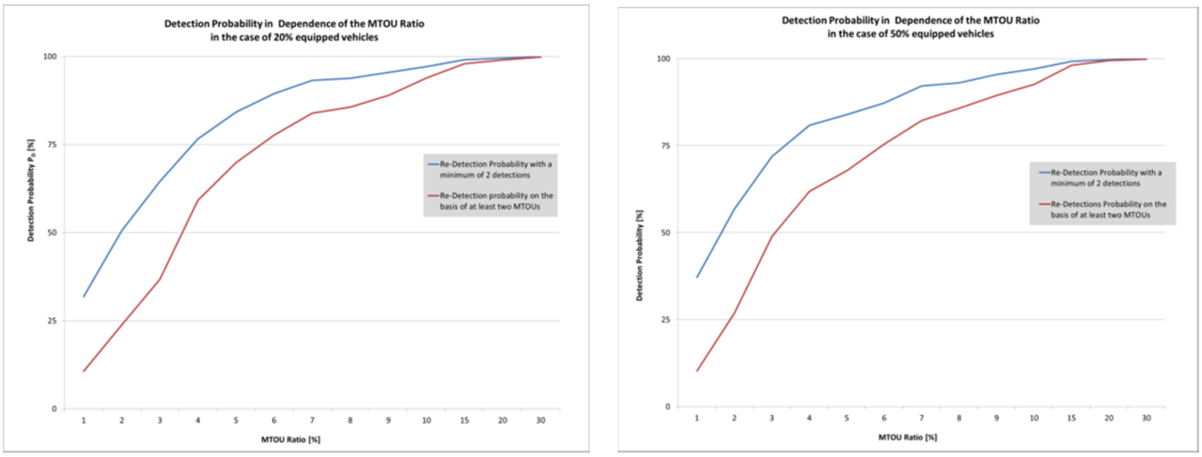
In the generic scenario the results obtained are much more interesting and need to take further investigations. In fig. 3 all positions of the detections of the equipped vehicles by 1% or 10% MTOU vehicle ratios are shown. One can realize that even if the MTOU vehicle ratio is low—near the typical FCD ratio—the number of detections is high enough to derive trajectories for traffic management. In the case the MTOU vehicle ratio is 10% the number of detections increases by far.

In fig. 4 the results of re-detection of equipped vehicles generally (a) or by at least by two different MTOU vehicles (b) are visualized. It can be seen, that the detection probability increases to almost 100% of the equipped vehicles at a MTOU ratio of less than 30%. Even if the number of MTOU vehicles is only about 8%, the re-detection probability reaches approximately 80%. If the ratio of Bluetooth/Wi-Fi-equipped vehicles is 50%, then even for only 1% MTOU vehicles we could obtain almost a re-detection quality of 40%. Obviously, the potential of the DITD approach to derive spatio-temporal traffic data in the case of a small number of MTOU vehicles can be seen.



(a) 1% MTOU, 10% equipped vehicles (b) 10% MTOU, 50% equipped vehicles

Figure 3 – The positions of all detections of the vehicles for two different MTOU ratios.



(a) 20% equipped vehicles (b) 50% equipped vehicles

Figure 4 – Re-Detection Probabilities in dependence of different MTOU ratios.

Conclusion and Future Prospects

In this paper some analytical and simulation results of the Dynamic Indirect Traffic Detection approach [1] were pictured. Although the proposed model is for answering the given research questions in [1] is still at the beginning we could show some remarkable results, which show the potential of the approach. It can be stated, that in a small generic network of four intersections and vehicle speeds of about 50km/h already more than 80% of all the vehicles equipped with Bluetooth/Wi-Fi can be detected and even re-detected by less than 10% of Mobile Traffic Observer Units. This fact is very important for deriving spatio-temporal traffic data. However, a lot of research work is still in the pipeline to answer all the mentioned research questions and furthermore, to answer the questions given in another paper [4].

References

1. Cohn, N.; Rutten, B. (2009). Navigation with integrated high quality realtime traffic information, In Proceedings 16th ITS World Congress, Stockholm, Sweden.
2. Fließ, T.; Leich, A.; Jentschel H.-J. (2001). Bildverarbeitung im Straßenverkehr – Überblick über den Stand der Technik. Zwischenbericht, Dresden University of Technology, Dresden, Germany.
3. Franssens, A. (2010). Impact of multiple inquirers on the Bluetooth discovery process – And its application to localization. Thesis, p. 24-27, University of Twente, Netherlands.
4. Gurczik, G.; Junghans, M.; Ruppe, S. (2012). Determining Optimal Fleet Distribution for Dynamic Indirect Traffic Detection Based on Bluetooth, In Proceedings European Transport Conference 2012, Berlin, Germany.
5. Leich, A.; Junghans, M.; Jentschel, H.-J (2002). An Approach to Video based Wide Area Traffic Surveillance, In Proceedings 8th ITS World Congress, Chicago, USA.
6. Ruppe, S. et al. (2011). Augmenting the Floating Car Data Approach by Dynamic Indirect Traffic Detection, In Proceedings Transport Research Arena – Europe 2012, Berlin, Germany.
7. Schäfer, R. P.; Thiessenhusen, K. U.; Brockfeld, E.; Wagner, P. (2002). A traffic information system by means of real-time floating-car data. In Proceedings 9th ITS World Congress, Chicago, USA.
8. Schnabel, W.; Lohse, D. (1997). Grundlagen der Straßenverkehrstechnik in der Verkehrsplanung. Bd. 1: Straßenverkehrstechnik. Bd. 2: Verkehrsplanung. Transpress Berlin, Germany.
9. Wardrop, J. G.; Charlesworth, G. (1954). A method of estimating speed and flow of traffic from a moving vehicle. In Proceedings of the Institution of Civil Engineers, Part II, 3: 158-171.