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Augmenting the Floating Car Data Approach by Dynamic Indirect Traffic Detection

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Abstract

An established approach for the mobile determination of traffic parameters is Floating Car Data (FCD) also known as Probe Vehicle Data. Floating cars are equipped with modules for positioning and transmitting the data to a processing unit. There, the data are processed to derive travel times, spatio-temporal traffic information, etc. 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. Furthermore, FCD focuses only on road transport, i.e. pedestrians and cyclists are not detected.

In this paper a new approach for an efficient and low-cost large-scale traffic monitoring 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 by a considerably increase of the underlying database. Since all detections are made indirectly by traffic observers while passing other traffic objects, the new approach closes the gap between FCD and the Floating Car Observer (FCO) principle.

The novel approach is based on a method for anonymous positioning by indirect detection of traffic objects (cars, cyclists, pedestrians) using radio-based Bluetooth/Wi-Fi technologies. This is advantageous, since many traffic participants use devices with activated Bluetooth/Wi-Fi functionality (e.g., mobile phones, headsets). Example: a car, which is equipped with specific Bluetooth/Wifi-receivers, detects all traffic objects, which are in the detection area, by their Bluetooth/WiFi identification number. This identification number is augmented by the time stamps and positions of the detecting objects. The measured data is processed to trajectories, travel times, traffic states, origin-destination matrices and other traffic parameters.

Keywords: Floating Car Data; Floating Car Observer; Bluetooth; Dynamic Traffic Detection; Traffic and Transportation Management

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1. Introduction

The realisation of an adequate traffic management, including the efficient and possibly low cost determination of traffic data (e.g. the determination of travel times, densities and origin-destination (OD) and linkage matrices), requires wide area traffic measurements on the basis of spatial-temporal sensors (Cohn et al. 2009, Leich 2006, Schäfer et al. 2002). In addition to this, the traffic data should possess a high degree of acceptance and credibility concerning the significance of the measured traffic parameters. 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, e.g. inductive loop detectors (Fließ et al. 2001, Leich et al. 2002). An important example for those systems has been the successful implementation of *floating car data* (FCD) systems (see figure 1a), also known as probe vehicle data (Kühne et al. 2005, Schäfer et al. 2002, Zheng et al. 2010). Floating Cars are vehicles driving in a fleet that go with the flow of traffic, which are equipped with a technology (e.g. GPS) to self-detect the cars' positions and which wirelessly transmit their positions and time stamps to a processing system (e.g. a traffic management centre). There, the incoming data is processed to determine traffic states, which can be visualized on a map. FCD works quite well, if the number of equipped vehicles is big enough to ensure statistical significance of the measured traffic data (Gössel 2005). 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. Furthermore, FCD focuses only on road transport, i.e. pedestrians and cyclists are not detected.

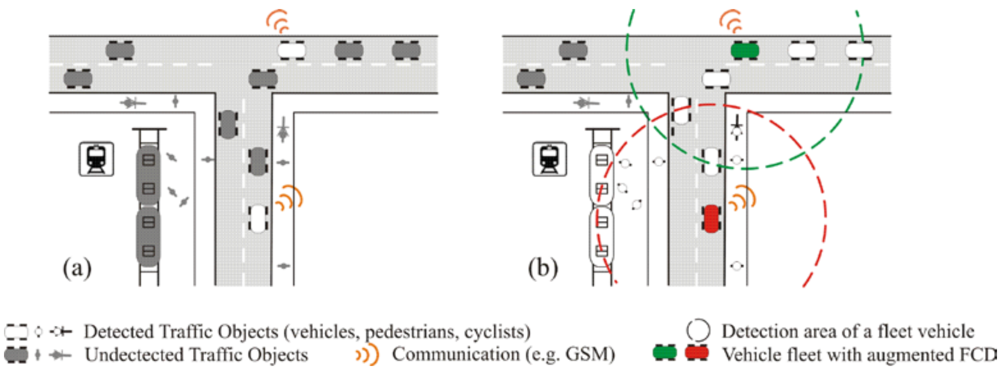

Fig. 1. Different systems for mobile traffic measuring: (a) FCD; (b) with the proposed novel augmented FCD

Another competing method yielding equivalent results is the *floating car observer* (FCO) approach, which was first mentioned by Wardrop and Charlesworth (Wardrop et al. 1954). The idea of FCO is the following: cars that are equipped with adequate sensors, e.g. video, laser radar, etc. follow their route through the network, thereby observing the opposing and surrounding traffic. Thus, in contrast to FCD the FCO approach makes use of the observations of the surrounding environment of the measuring vehicles.

In this paper a new approach for an efficient and low-cost large-scale traffic monitoring 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, by a considerably increase of the underlying database (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 (Schnabel et al. 1997). Since all detections are made indirectly by traffic observers while passing other traffic objects, the new approach closes the gap between FCD and the FCO principles. The novel approach is based on a method for anonymous positioning by indirect detection of traffic objects (cars, cyclists, pedestrians) using wireless radio-based technologies, e.g. Bluetooth/Wi-Fi. This is advantageous, since many traffic participants use devices with activated Bluetooth/Wi-Fi functionality (e.g. mobile phones, headsets). Imagine a car, which is equipped with specific Bluetooth/Wi-Fi-receivers, detects all traffic objects with Bluetooth/Wi-Fi devices, which are in the detection area, by their identification number. This identification number is augmented by the time stamps and positions of the detecting objects. The measured data is processed to trajectories, travel times, traffic states, origin-destination matrices and other important traffic parameters.

This paper examines the approach on the example of Bluetooth and is structured as follows: In the following section 2 some background on Bluetooth and current stationary measures to obtain traffic data, particularly travel times, is given. Subsequently, in section 3 the novel approach to close the gap between the FCD and FCO principles is presented. Furthermore, one application of the method on the basis of the established Bluetooth technology is described, which enables the derivation of dynamic high quality traffic information. In section 4 some first results are presented. Finally, in section 5 conclusions and future prospects are given.

Nomenclature

FCD	Floating Car Data
FCO	Floating Car Observer
MTOU	Mobile Traffic Observer Unit
Wi-Fi	Wireless fidelity. It is also used for products, which use the IEEE 802.11 standard family.

2. Basics on Bluetooth and Measuring Traffic Data

In this section, a short excursion into the Bluetooth standard given. Furthermore, the determination of travel times on the basis of Bluetooth is briefly described.

2.1. Bluetooth Standard & Inquiry Process

Bluetooth devices communicate in the license free ISM band around 2.4 GHz using 79 frequencies of 1 MHz bandwidth each. Since other technologies (e.g. WLAN, microwaves and many others), use the same ISM band, the frequencies are changed up to 1,600 times per second to achieve robustness. This is known as frequency hopping. The available Bluetooth devices are classified in three classes for short range communication up to 10 m (class 3), middle range communication up to 30 m (class 2) and long range communication up to 100 m (class 1). Tests with class 1 and 2 sticks showed an increasing coverage of up to 250 m and more than 70 m respectively, without significant increase of the error bit rate (Holzmann 2002). Using directional antennae increases the coverage further.

The particularity of the implementation of the Bluetooth standard is the worldwide unique identification code of every Bluetooth device – the 12 digit hexadecimal coded MAC address – which is particularly sent out by any Bluetooth device periodically, when the device is looking for a slave (partner) to connect with. This procedure is called inquiry process and can be described as follows: A Bluetooth device A is ready to connect with other Bluetooth devices to form a pico net and thus, switches to the inquiry scan sub state, which is repeated periodically for 1.28 s (default). During this time a second sub time interval of 11.25 ms is chosen at random (inquiry scan window), in which A is able to receive an inquiry by a second Bluetooth device B at one specific inquiry frequency. In the rest of the time A remains idle and is not able to receive inquiry packets from B. When A has received an inquiry packet, an inquiry response packet including MAC and clock information is sent back to B and the connection process can proceed.

To ensure that the inquiry device B hits the specific random inquiry scan frequency of device A in the first scan round, the inquiry package has to be send on all 32 possible inquiry frequencies within the inquiry scan window of 11.25 ms. According to the Bluetooth specification (SIG 2009) this is not possible. A transmitting and receiving cycle lasts 625 µs for each frequency which leads to 20 ms for 32 frequencies. So we need at least two Bluetooth devices working on two disjoint subsets of 16 inquiry frequencies at the same time. But even if two parallel devices are used for the inquiry process 1.919 s are needed for the complete inquiry in the worst case, which is 1.27 s (inquiry scan idle time) + 0.64 s (maximum back off time).

According to this briefly outlined procedure, any Bluetooth device (which is not in a cloaked mode), can be identified by another, which is in range. If the Bluetooth devices move quickly (e.g. in the case of equipped vehicles), the detection of a Bluetooth device can only be ensured in a certain time interval. But up to now, there have several ideas been put into practice to overcome the hindering time consuming inquiry process. See (Anderson & Moser GmbH 2006, Weinzerl 2010) for instance for further details.

Since an identification and re-identification of traffic participants are essential requirements to measure travel times in road networks and thus, to determine traffic parameters like OD matrices, Bluetooth is an adequate technology in traffic management to get detailed and low-cost information about the traffic state on a motorway or in road networks.

Up to now, Bluetooth technology has an increasing equipment level in terms of traffic. There exist many software based packet analyzers which are able to catch MAC addresses and RSSI values from passing Bluetooth devices. This technique was used in our approach to detect discoverable Bluetooth devices. The main disadvantage is the long and stochastic time to detect a device. Combined with the short range of detection radius of about 25 m many fast vehicles passing the detector remain undiscovered. Other problems are multiple detections per station and multiple devices per vehicle.

2.2. Measuring Travel Times

As it was already mentioned in section 1, for traffic and transportation authorities it is desirable to realise a low cost traffic management. Bluetooth is one established technology to do so. One commercially available product to determine spatial traffic data **stationary** is BLIDS (Bluetooth based traffic data collection system) (Anderson & Moser GmbH). A travel time Δt of an object is simply the time interval an identified object at position x at time t, which is re-identified at position $x + \Delta x$ at time $t + \Delta t$. An equivalent parameter is the travel speed v, which can be computed by

$$v = \Delta x / \Delta t \qquad (1)$$

Several papers already evaluated the performance of BLIDS to measure travel times (Hoyer et al. 2008, Weinzerl 2009) and even classify vehicles on motorways in trucks and non-trucks (Spangler et al. 2010) on the basis of travel times. Nearly all of the studies mention, that a complete identification of the Bluetooth equipped vehicles is possible when the cars do not run faster than 150 km/h. The identification and re-identification of Bluetooth devices at different positions enables the estimation of travel times, and it serves as in input for methods that can determine OD and linkage matrices for transportation planning and traffic control. (Note that the matrices generated may have a strong bias, because the vehicles that carry a Bluetooth device might not be distributed as the “typical” average user. In addition, it is usually not known, what is the share of Bluetooth-vehicles compared to the total number of vehicles).

The advantages of the Bluetooth based **stationary determination** of travel times are the simplicity and the accuracy of the obtained data. The disadvantage is mainly the necessity to install such Bluetooth devices at many places to achieve spatially continuous results on motorways or in a road networks.

Consequently, it would very advantageous to enable such a Bluetooth/Wi-Fi based system for **mobile traffic detection**, in which cars by some sort of vehicle fleet themselves identify and re-identify the traffic participants by the ID of their wireless Bluetooth/Wi-Fi devices (e.g. mobile and smart phones, headsets, etc.) within the detection areas. This mentioned principle, which augments the classical FCD approach and thus, closes the gap between the FCD and FCO is introduced in the following section.

3. Augmentation of the FCD Principle to *Dynamic Indirect Traffic Detection*

3.1. Realising Dynamic Indirect Traffic Detection with Bluetooth (Augmented FCD)

The mentioned gap between both data acquisition principles has been filled by the extension of FCD to a *Dynamic Indirect Traffic Detection* approach, which enables the dynamic and mobile detection of traffic participants' ID's and thus, the derivation of anonymous to trajectories on the one hand. On the other hand traffic related parameters, such as routes, route flows, origin destination (OD) and linkage matrices as well as safety related parameters can be derived.

A Trajectory is a space-time relation, which contains the whole information about the motion of a traffic object and is thus capable of representing the motion processes of each vehicle completely. The trajectory consists of information about position, time, anonymous identities and possibly additional facts.

The idea of the realization *Dynamic Indirect Traffic Detection* is shown in figure 2. There is shown a simplified road network, which consists of three intersections and some edges, connecting them. Furthermore there is a white car (which obviously has a Bluetooth device on board, e.g. a smartphone), which moves from A to B. The white car is shown at three different times and positions, yielding the black dashed lines representing the trajectory of the white car. Moreover there is a moving vehicle fleet – the red, blue and green colored vehicles –, which represent the car observers that are equipped with *Mobile Traffic Observer Unit* (MTOU, see 3.2.2), i.e. with a Bluetooth transceiver.

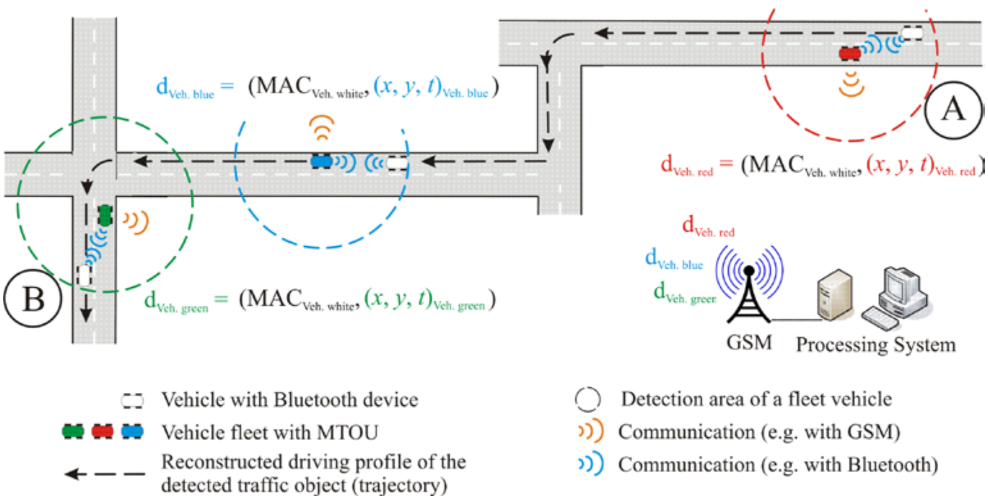

Fig. 2. The *Dynamic Indirect Traffic Detection* principle on the basis of Bluetooth. The vectors (MAC, x, y, t) represent the measured and transmitted data to a processing system

Following the trajectory from A to B now, in case of the red vehicle, the detection of the white car will be only for a short time period at point A, when the red car passes the white one. The same situation happens in the case of the green vehicle at point B. In contrast, the blue vehicle follows the white all the way. Detecting the MAC address of the white car enables the determination of a trajectory of the white car while “floating” in parallel. Clearly, the combination of the punctual measurements of the green and red cars one the one hand as well as the derived trajectory of the blue detector car on the other hand enables the determination of highly accurate and dynamic trajectory data.

The resulting trajectory can be processed further to the travel time of the white car in its way from A to B. Obviously, for any other car, which is equipped with a Bluetooth device, travel times can be determined and thus, route flows and OD matrices can be derived. Thus, each vehicle of an observer fleet, which is equipped with a *MTOU*, is able to detect and observe traffic participants, which use Bluetooth devices. Furthermore, for longer observation times and distances own parameters can be assigned to the detected objects with higher accuracies (e.g. position, speed, etc.). The accuracies depend at least on the following parameter: detection range, distance of detection and detection time.

3.2. Trajectory Reconstruction and Traffic Situation Estimation

A detected object (e.g. the white car) can be assigned to the position of the different observers (e.g. the red, blue and green cars), whereat the inaccuracy of mapping is in relation to the detection range. Anytime the white car is within the detection range of one (or more) moving coloured cars, the vector

$$d_{\text{coloured car}} = \{\text{MAC}_{\text{white car}}, (x, y, t)_{\text{coloured car}}\} \qquad (2)$$

containing the MAC address of the white car, the time stamp and the current positions of the detecting car are sent wirelessly (e.g. via GSM) to the processing system (e.g. a traffic management center). There, the received data is used to reconstruct the trajectories of observed traffic objects. Based on the trajectories, travel times on the edges can be processed. Furthermore, on the basis of statistical investigations highly accurate OD- and linkage matrices for transport planning and operational traffic control can be extrapolated.

3.2.1. Concept of Realization and System Design

The system design is shown in figure 3. The first part of the system is the *Mobile Traffic Observer Unit*, which consists of the Bluetooth transceiver (in this experimental case, other transceiver/readers were possible), a positioning module, a preprocessing unit and a communication module. The second part is a processing unit for dynamic traffic information located, e.g. in a traffic management center. Both system parts consist of other modules, which will be described in the following paragraphs.

3.2.2. Mobile Traffic Observer Unit (MTOU)

Imagine an observer fleet, e.g. taxi, buses, logistic companies, etc.; each single vehicle is equipped with a small module, let us call it MTOU (Mobile Traffic Observer Unit), see figure 4. This module consists in this case of a Bluetooth transceiver device to detect the MAC addresses of the traffic participants, who are equipped with corresponding Bluetooth devices, e.g. mobile phones, head sets, etc. The basic functionality of Bluetooth detection is described in the first section. For the following experiment a smart phone java application to realize an endless inquiry process was implemented to continuously read the MAC addresses of the traffic participants. Furthermore, the MTOU consists of a GPS module for positioning and the determination of the own velocity. The GPS module provides further parameters like Course Over Ground, DOP parameters, e.g. Vertical and Horizontal Dilution of Precision, etc. (SiRF Technology (2008)). To ensure the anonymity of the traffic participants, the detected MAC addresses are encoded by a pre-processing unit, which is placed in this module. Another task of this unit is to augment the data by quality information (Sohr et al. 2010). The communication module is responsible for the transmission of the detected anonymous MAC addresses to a processing unit, e.g. in the traffic management centre.

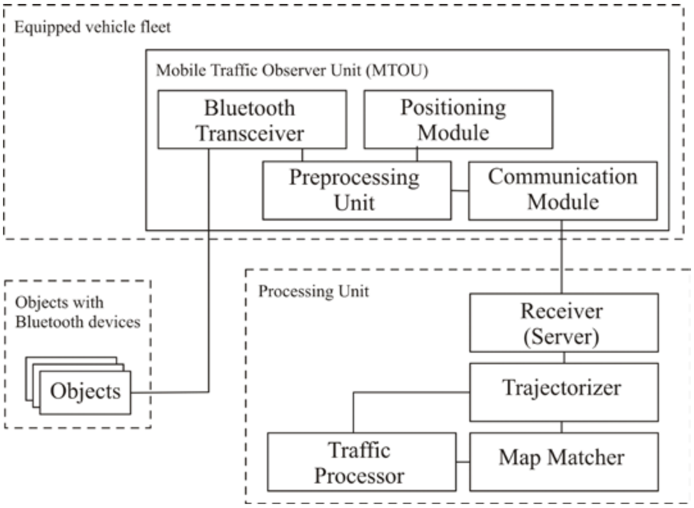

Fig. 3. System design. The vehicle fleet is equipped with MTOU units and the traffic management centre with a processing unit.

3.2.3. Processing Unit for dynamic traffic information

First, the received data are reconstructed to anonymous trajectories in a space-time relation in the Trajectorizer. The Map Matcher matches each point of trajectory to the underlying digital road network. The Traffic Processor creates a routable path of trajectory. In best case a trajectory has enough information to describe a completed path over the road-network. Usually the trajectory will be fragmented in several parts, so that it is possible that between two points the path could have multiple sub-paths. In such cases the Trajectorizer routes the trajectory for obtaining the most plausible path [9]. In the next step travel times and speeds for each link will be computed. These steps are done for each trajectory. The edge based travel times for the road network generated from this approach result from each individual value over a defined period. Finally, traffic parameters, e.g. travel times, travel speed and even OD- and linkage-matrices are visualized on a road map.

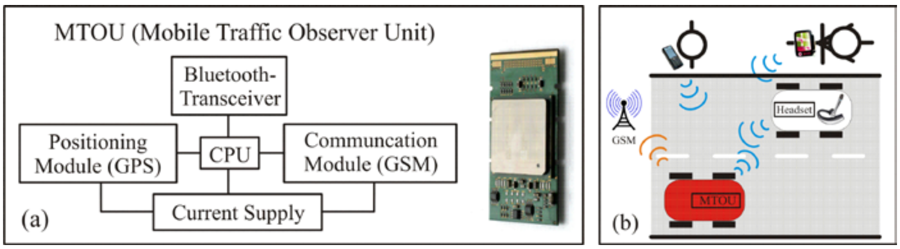

Fig. 4: Mobile Traffic Observer Unit (MTOU): (a) System design for Bluetooth; (b) Detection of traffic objects by the Bluetooth-MTOU in the red car.

3.3. Research Key Questions

To put the method into practice, several fundamental research questions need to be answered first. These questions that prove the novel approach to determine high quality traffic data (trajectories, travel times, traffic state information, OD and linkage matrices, route flows) are for instance (note, that the requirements for the given traffic parameters are likely to differ):

- How big must be the underlying network and how many edges and intersections must be contained?
- How many MTOU must be in use (i.e. how many cars must be part of a particular equipped vehicle fleet to determine high quality)?
- What is the minimum/average mileage of the vehicle fleet per day/weekday/work day/year, etc.?
- Which is the optimal distribution of the vehicle fleet in the network?
- What are the requirements in populated/sparsely populated areas?
- How strong are the dependencies and connections among these parameters?

To find answers on these and even still unknown questions a simulation study on the basis of the traffic simulation SUMO (Simulation of Urban Mobility) is set up. Here, we want to a first impression on how the things should be realised. Answers of these and upcoming questions will be given in subsequent papers.

4. First Results

In this section the basic conditions and the first promising results are presented. The investigations were made on the basis of three test runs on different routes in Berlin (approximately between 12.3 and 14.5 km) on weekdays during 17 May and 21 May 2010. The measurements were realized by two vehicles between 5.00 am and 9.00 pm to ensure to morning and afternoon peek hours. Each test vehicle was equipped with a laptop, a navigation system, a Bluetooth receiver, a GPS tracker and logger and a camera. The MAC addresses of all identified Bluetooth devices were tagged with time stamp and position and were stored on the hard disk on the laptop. Additionally, the co-drivers were asked to note anomalies of the traffic, like traffic state, accidents, etc. and the weather conditions.

To obtain trajectories and travel times by the identified and re-identified Bluetooth MAC addresses, some important results of the route of the federal highway B96 between Tempelhofer Damm and Marienfelder Chaussee were evaluated and are given as a showcase. Clearly, one vehicle needs to identify the MAC addresses and the same or the other vehicle is needed for re-identification. The resulting data were associated with the measured GPS data and the time stamps and processed to trajectories by a processing unit, called the Trajectorizer. The accuracy of the detection of trajectories is about 30-50 m, according to the Bluetooth standard for class 2 receivers. This distance should be maintained to ensure the re-identification of cars.

After investigation of the measured data, two sorts of trajectories could be determined, which we call “floating” and “real observer” trajectories:

- In the case of floating trajectories the test vehicle “floats” downstream with the traffic (and only one measuring car), i.e. the identified car(s) have the same average speed as the measuring car. This usually happens in dense and synchronised traffic [13]. Thereby the identified cars are identified and re-identified more frequently in shorter time intervals (e.g. seconds) until they leave the detection range of the measurement car.
- In the case of real observer trajectories the vehicles usually run upstream in the opposite direction of traffic and are identified by both test vehicles, i.e. one of the test vehicles identifies and the other one re-identifies. Usually, the time interval of the re-identification is longer than in this case instead of the floating, since the positions of the two test vehicles do not share the same positions.

The biggest part of the analysed data yielded floating trajectories of the detected vehicles, which can be explained by the low detection range as well as the slow inquiry process. To receive an impression on the results achieved, figure 5 shows some examples for floating trajectories. The dots characterise the positions and time stamps of the identification and re-identification of the vehicles by the Bluetooth Reader as well as the measured travel times and speeds. The complete database will be evaluated during the next months and the results will be presented in another paper during the year.

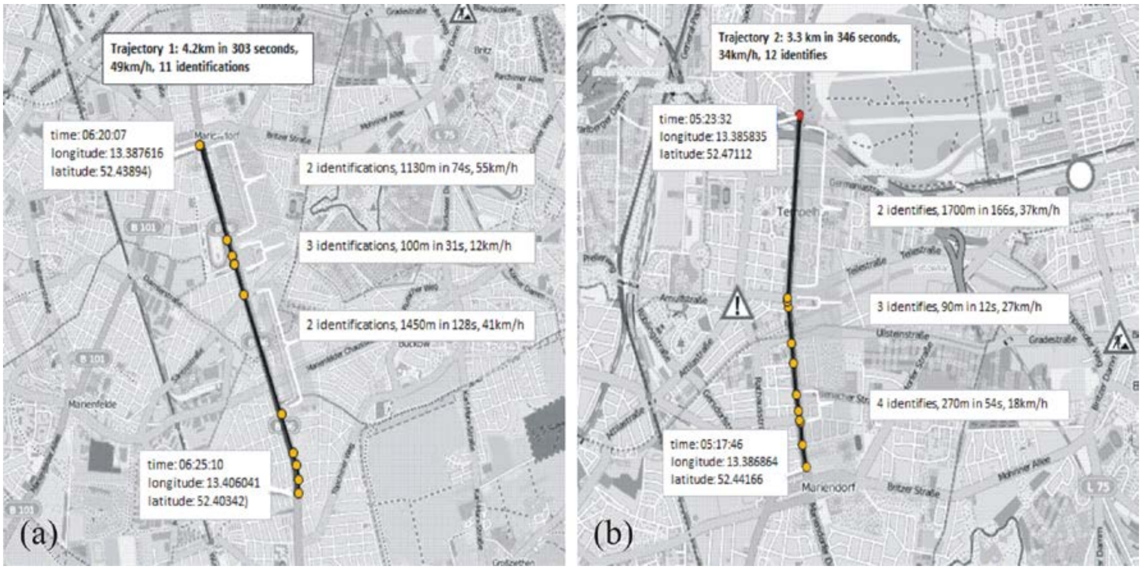

Fig 5. A combination of "floating" and "real observer trajectories" on Tempelhofer Damm. The red and yellow dots show the identifications of the two test vehicles. Additional information (travel times, average speeds, position and time stamps) are given.

5. Conclusions and Future Prospects

In this paper a novel approach for efficient and low-cost large-scale traffic monitoring was presented, which augments the FCD (floating car data) principle to fill the gap between the FCD and FCO (floating car observer) approach. The approach is based on a method for anonymous positioning by dynamic indirect traffic detection of traffic objects (e.g. vehicles, bicycles, pedestrians) using wireless radio-based technologies (here Bluetooth was used). The measured data can be used to compute traffic parameters like travel time, trajectories, flows, etc. Furthermore anonymous traffic densities as well as origin-destination (OD) and linkage matrices can be derived. Moreover, a suggestion for a system design was given, which can be applied in normal vehicles. The architecture contains a *Mobile Traffic Observer Unit* (MTOU) and a processing unit, e.g. a traffic management centre. The first results, achieved on the basis of several test runs on different routes in Berlin, show the inherent potential of the addressed augmented FCD approach in comparison to existing systems. The current problem of the suggested Bluetooth system is the slow inquiry process to detect the MAC addresses from the traffic participants. Thus, only a small percentage can be measured. As mentioned above al least two parallelised Bluetooth device working on disjoint inquiry frequency subsets are needed to minimise the inquiry length and the detection time. Following the Bluetooth Specification (SIG 2009) this could only be realised if the two synchronised devices are running on the two different frequency trains A and B simultaneously. An alternative approach avoiding the specification is currently in work. One opportunity to do so was realised in (Anderson & Moser 2006).

Our future research will deal with methods of anonymisation, the generating process of anonymous densities and OD and linkage matrices, the complete evaluation of the achieved data base and the addressed problem of “measuring” the potential of the novel method by the answering the addressed questions concerning the number of *MTOU* being in use and their mileage, the size of the network, other wireless technologies and several more questions.

References

Anderson & Moser GmbH (2006), Offenlegungsschrift DE 10 2006 048 779 A1 2007.05.16, 12.10.2006

Cohn, N. and Rutten, B. (2009), Navigation with integrated high quality realtime traffic information, *Proceedings of the 16th ITS World Congress*, Stockholm.

Czogalla, O. and Naumann S, Travel Time Estimation using Floating Car Observers. Proceedings of the 14th World Congress on Intelligent Transport Systems, Beijing, October 9–13, 2007.

Fließ, T. and Leich, A. and Jentschel H.-J. (2001). Bildverarbeitung im Straßenverkehr – Überblick über den Stand der Technik, Zwischenbericht, Dresden University of Technology.

Gössel, F. (2005). Informationsentropische, spektrale und statistische Untersuchungen fahrzeuggenerierter Verkehrsdaten unter besonderer Berücksichtigung der Auswertung und Dimensionierung von FCD-Systemen. *Ph.D. Thesis*, Dresden University of Technology.

Holzmann, C.; Oppl, S. (2002). Bluetooth in a Nutshell, *Final report*, Linz University.

Hoyer, R.; Naumann, S. (2008), Floating Car Observer – Ein neuer Ansatz zur Verkehrslageerfassung im Fahrzeugumfeld. *In Fachkonferenz Verkehrsmanagement und Verkehrstechnologien*, May 2008, available at http://www.vm2010.de/web/de/projekte/vaga bund/projektergebnisse.html

Hoyer, R. and Leitzke C., Verfahrenstechnische Bedingungen für die Reisezeitbestimmung mittels Bluetooth-Technologie, Tagungsband HEUREKA '10, Editor Forschungsgesellschaft für Straßen- und Verkehrswesen, 2010.

Kühne, R. D.; Schäfer, R.-P.; Mieth, P.; Lorkowski, S.; Bei, X. (2005). Vehicle Probes as Data Collectors for Asian Metropolitan Areas. *4th Asia Pacific Conference*, 8th - 10th Nov 2005, Xi'an, China 2005.

Leich, A. (2006). Ein Beitrag zur videobasierten weiträumigen Verkehrsbeobachtung, *Ph.D. thesis*, Dresden University of Technology.

Leich, A.; Junghans, M.; Jentschel, H.-J (2002). An Approach to Video based Wide Area Traffic Surveillance, *In Proceedings of the 8th ITS World Congress*, Chicago.

Luber, A.; Bauer, S.; Junghans, M.; Schulz, J.: On measuring traffic with Wi-Fi and Bluetooth. Accepted for publication in ITS World Congress 2011, Orlando, Florida.

Schäfer, R. P. and Thiessenhusen, K. U. and Brockfeld, E. and Wagner, P. (2002). A traffic information system by means of real-time floating-car data, Proceedings of the 9th ITS World Congress, Chicago.

Schnabel, W.; Lohse, D. (1997). Grundlagen der Straßenverkehrstechnik in der Verkehrsplanung. *Bd. 1: Straßenverkehrstechnik. Bd. 2: Verkehrsplanung.* Transpress Berlin 1997.

SIG (2009). Bluetooth Specification Version 4.0 – Master Table of Contents & Compliance Requirements, Vol. 0, 17 December 2009

SiRF Technology (2008). *NMEA Reference Manual*, Part number 1050-0042, Rev. 2.2, November 2008.

Sohr, A.; Brockfeld, E.; Krieg, S. (2010). Quality of Floating Car Data. *In: Conference Proceedings, paper nr 02392. www.digitalpapers.org. 12th World Conference on Transport Research (WCTR)*, 11.-15.07.2010, Lissabon, Portugal.

Spangler, M.; Leonhardt, A.; Busch, F.; Carstensen, C.; Zeh, T. (2010). Deriving travel times in road networks using Bluetooh-based vehicle re-identification: Experiences from Northern Bavaria, *FOVUS - Networks for Mobility*, ISBN: 978-3-00-031958-7, 2010.

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.

Weinzerl, J. (2010). Verkehrsablauf erkennen durch intelligente Sensoren – auf Autobahnen und in urbanen Gebieten, *Tagungsband HEUREKA '10, Editor Forschungsgesellschaft für Straßen- und Verkehrswesen*.

Zheng, F.; van Zuylen, H.; Chen, Y. (2010). An investigation of urban link travel time estimation based on field sparse probe vehicle data, *Proceedings of TRB 2010 89th Annual Meeting*, Washington D.C. 2010.