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FLOATING OBSERVER INFORMATION PROCESSING ON THE BASIS OF MOBILE BLUETOOTH DATA

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Abstract. *The German Aerospace Center (DLR) developed a new traffic monitoring approach (called DYNAMIC) which combines the advantages of Floating Car Data (FCD) and Floating Observer Data (FOD) principles by avoiding their drawbacks. Using DYNAMIC, spatio-temporal traffic data are obtained whereas the number of costly traffic detection infrastructure (e.g. mounted traffic sensors, detection gantries, etc.) is minimised or avoided at all. DYNAMIC is based on detections which are made by Floating Traffic Observers (FTO) using wireless radio-based technologies (e.g. Bluetooth/Wi-Fi) while passing other traffic objects (vehicles, cyclists, pedestrians). The DLR has a long experience with the processing and handling of traffic data like FCD to gain link based and network-wide travel times. The current DLR processing tools that support FCD have been extended to support the processing of Bluetooth data obtained from the floating (DYNAMIC approach) or static detection system. This work describes in detail the newly developed method to process the Bluetooth data and gives the results from conducted field-tests which had been performed to display applicability in a real environment.*

1 INTRODUCTION

An effective and low cost traffic and mobility management is a key requirement to tackle current and future traffic problems. Up-to-date and comprehensive traffic information are the basis of an efficient, environmentally friendly and safe mobility management. The realisation of such an adequate mobility management requires wide area traffic measurements on the basis of spatiotemporal sensors. Long time, stationary traffic monitoring infrastructure (e.g. induction loops, optical systems) was used for that purpose [1, 2]. Today, mobile traffic monitoring systems, which use GPS information to derive data from specific equipped traffic participants (e.g. Floating Cars) are employed [4, 5]. Floating Cars are vehicles driving in a fleet that go with the flow of traffic. The cars' positions are self-detected via GPS and including time stamps transmitted wirelessly to a processing system (e.g. a traffic management centre, TMC). The processing system then determines traffic states [6, 7]. FCD works quite well, if the number of equipped vehicles is big enough to ensure statistical significance of the measured traffic data [3]. 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 [9].

Up to now, high resolution and accurate spatiotemporal traffic data for transport planning and efficient traffic management and control is not available. Although good progress was made in the development of new traffic sensors and in the field of Intelligent Transportation Systems (ITS), the relevant data objects for traffic planning, i.e. OD[1] matrices, routes and flows, are still determined by manual traffic census and augmented by macroscopic and microscopic traffic models and prognoses [10, 11]. This is due to unsatisfactory solutions for re-identification of traffic participants by e.g. Automatic Number Plate Recognition (ANPR). ANPR moreover causes also a privacy problem since the number plate recognition allows the building of profiles of the car driver [8]. More promising solutions for the re-identification problem is the use of unique ICT[2], e.g. MAC addresses [12, 13, 14]. To overcome the mentioned problems and to realise an accurate and infrastructure free measurement of OD matrices and route paths the DLR developed the DYNAMIC traffic detection approach [20], which is briefly described in the following section 2. Then, in section 3, the field test is introduced to obtain the first results concerning the potential of DYNAMIC. In section 4, the FCD/FOD processing chain is introduced and in chapter 5, the results are discussed. Finally, in section 6, conclusions and future prospects are given.

2 BASICS

In contrast to the well-known FCD approach, in the DYNAMIC approach the observer vehicles do not only transmit their own positions, but they also collect the identification information obtained from the surrounding vehicles, pedestrians and cyclists. In that fact, DYNAMIC is very similiar to the so called FCO (floating car observer) approach [15, 16, 17] where optical systems are used to derive data from the surrounding traffic. New in the DYNAMIC approach is that the identification information, which are used, are the detected MAC addresses of Bluetooth devices. Due to the MAC addresses' unique character re-identification of traffic participants as it is realised using ANPR can easily be done as well, but pseudonominised to fulfill the privacy aspects of the traffic participants.

[1]OD - Origin-Destination.
[2]ICT - Information and Communication Technology.

Figure 1 shows an observer vehicle with an activated Bluetooth device on-board, traveling from point A to point B. Three cars of a vehicle fleet (red, blue, green), the so called observer cars, which are particularly equipped with the MTOU[3], are able to detect the MAC address of the Bluetooth device, of the observed object (e.g. car, pedestrian, cyclist) while it passes the detection areas (dotted circles). The observer cars could consequently add the current time stamp and their own positions to the identification data of the observed car and send these augmented data using, let's say, GSM or C2I to a processing system (e.g. a TMC). There the received data will be processed to extract the trajectories of observed vehicle (dotted line connecting A with B), which will be further processed to get the usable traffic data (OD matrices, route paths and flows, travel times and speed).

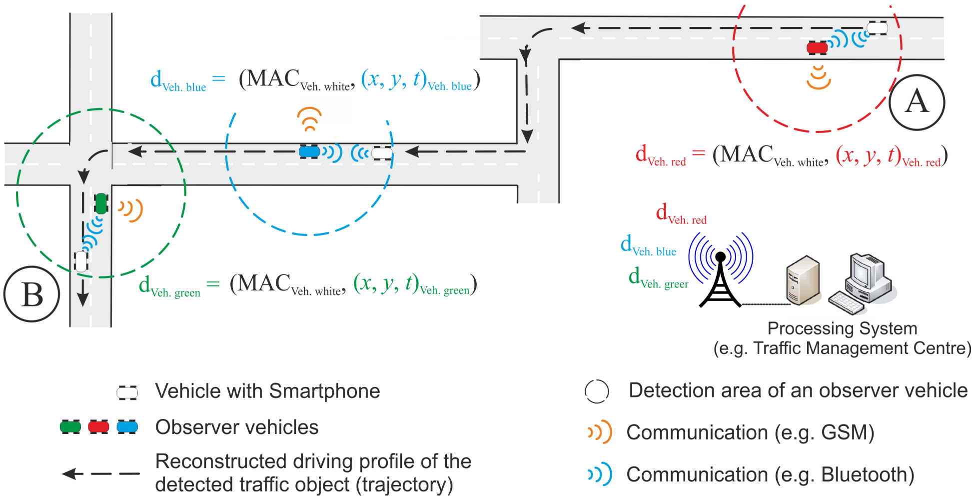


Figure 1: DYNAMIC detection principle

3 FIELD TEST

In the field test multimodal observer objects (i.e. cars, cyclists and pedestrians) carrying MTOUs and moving on well-defined routes on the so called WISTA area in Berlin-Adlershof were used (see Figure 2). Contemporaneously, these objects were considered as the traffic participants, which should be detected by all the other observers.

The two-hour field test took place on November 25th 2014 between 3 p.m. and 5 p.m. As preparation, requirements were collected and several pretests in laboratory as well as in the field were conducted. In the observer cars and on the bicycles our prototyped MTOU Bluetooth monitoring systems (called Bluetooth-Box, shortened "BluB") was installed. Due to the weight of these BluBs, the pedestrians instead carried just a smartphones with an installed Android application (called "And-BluB"), which adopts the same functionality as the bigger BluB version. The routes were chosen from requirements and the ability of the observer objects, e.g. longer routes and more covered area for motorised observer objects, whereas mainly shorter routes were selected for pedestrians. Altogether 16 different routes were considered. The course of the routes was created in that way that maximum overlap respectively meeting points between two or more observers should guarantee mutual detection, which is indeed the main idea of DYNAMIC (see also Figure 2 for illustration). Per route one test person was employed, this is

[3] MTOU - The Mobile Traffic Observer Unit is a mobile on-board hardware device.

16 persons for the whole measurements.

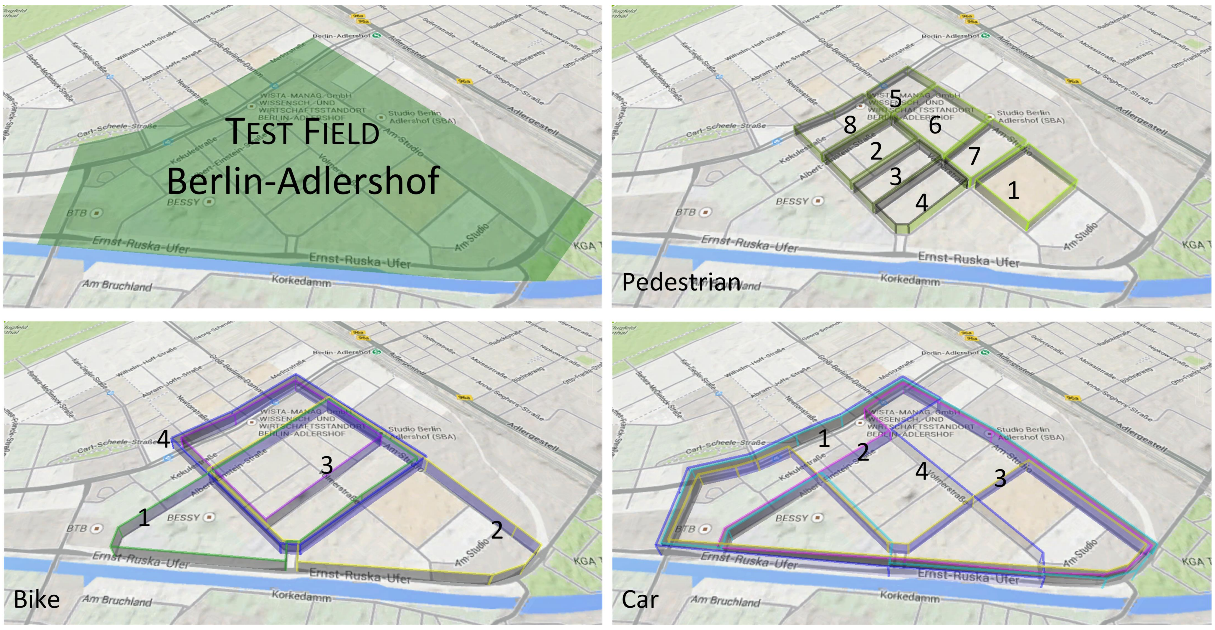


Figure 2: Defined field test observer routes (map source: Google©): pedestrians (upper right), cyclists (lower left) and cars (lower right)

At the beginning of the field test, a 15-minute functionality test was done. Following a successful trial, all test persons went to their starting points of their specific routes and continued along their routes for the time of the measurements. When arriving at the starting point again, a test person should run its route for a second time. There were no specifications or limitations made concerning the number of tackled rounds of routes. The test persons moved freely according to their desired speed respectively to local feasibility as well as under consideration of the German Road Traffic Act (StVO). In spite of the functionality test at the beginning of the field test one observer (car 2) failed during the field test so that data from a total of 15 observer objects were available for evaluation.

4 PROCESSING METHOD

The processing was carried out on the basis of existing processing chain for floating car/object data (FCD/FOD) developed by DLR [18, 19], which was extended for the use of DYNAMIC. There are two factors, which need to be considered here. (1) The first factor concerns the type of data to be processed by the FCD/FOD processing chain. Basically the processing chain uses following data sets: object id, time stamp, longitude and latitude. In contrast, the data set generated by the DYNAMIC approach also contains object id, time stamp, longitude and latitude, but the difference is that location and time of the floating traffic object are related to the observer object at the time of detection. (2) The second factor concerns with the time resolution of the data. The used GPS receiver provides a location-based data within seconds. The frequence of DYNAMIC data depends on how often and how long a floating traffic object is detected by an observer. Currently, we expect a detection frequency at low resolution in time domain. One advantage of the FCD/FOD processing chain is that despite large time gaps in the detection possible routes are calculated. In addition to travel times and speeds trajectories gained from the way-points of the indirect measurements are computed. Depending on the completeness of the data OD-relationships can be derived. Because of the reason mentioned above we decided to use the existing FCD/FOD processing chain as basis for further customisation to support the DYNAMIC approach.

The question that will be answered is: How suitable is the existing FCD/FOD processing chain for the processing of data generated by the DYNAMIC approach?

In chapter 3 is mentioned that the following situation is simulated with the realised field test: The observer objects, i.e. cars (CAR), bicycles (BIKE) and pedestrians (PEDESTRIAN), all equipped with the MTOU, move on the predetermined routes. At the same time all observer objects operate as a reference floating traffic object (reference data) as well as a target floating traffic object (target data) that can be detected by other observers, which means, observers play a dual role. Due to the two roles of observers the following two data-sets are available for processing:

(a) Reference data (Floating Object Data)

(b) Target data (DYNAMIC Bluetooth Data)

The processing of data in the extended FCD/FOD processing chain contains five steps (see. Figure 3).

1. Raw Data Extraction
   The existing processing chain was extended by an additional pre-processing step (raw data extraction). Due to the dual role of observer objects, this step separates the data in the reference and the target data-sets. For the reference data-set no further processing is required in this step. The target data-set was prepared according to the DYNAMIC approach as follows: The MAC addresses are pseudonomised and the geo-coordinates are assigned for each device.

   - The **Reference data** consist of GPS position (longitude, latitude) and time stamp (t), object-id, sorted by object-id and time.
   - The **Target data** consist of GPS position (longitude, latitude) and time stamp (t) of the observers at the time of detection, the observer-id, the object-id sorted by object-id and time.

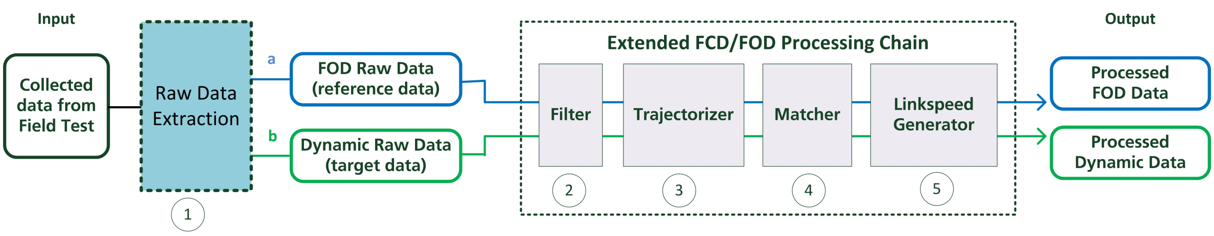


Figure 3: Extended FOD/FCD processing chain to support DYNAMIC approach

To support the DYNAMIC approach some additional modifications were necessarily needed in the processing chain with regard to the data model, database model and the interface. The processing chain contains the following steps:

2. Data Filtering in Filter
   The Filter component filters the raw input data based on the predefined configurable filter criteria. For instance, these criteria include duplicate positions, obviously incorrect/wrong data (false time stamps and positions).

3. Trajectories Generation in Trajectorizer
   The task of the Trajectorizer component is to build trajectories from the incoming filtered raw data and to merge them continuously over a time horizon t. A trajectory is defined here as a collection of geographic locations (way-points) of a vehicle (FCD) or a traffic object (FOD and DYNAMIC) ordered by the time sequence. The maximum velocity on a straight line was limited for the following objects as: CAR (70km/h), BIKE (30km/h), PEDESTRIAN (13km/h).

4. Map Matching and Route Completion in Matcher
   The Matcher component expands the information of each generated trajectory by road network specific information like link-id, travel speed and distance, offset distance related to the link. The first task of the Matcher is map matching, which consists of projecting, i.e. matching, the way-points of the trajectories on the road network. The second task is routing, i.e. the traveled routes in the road network related to the trajectories are generated. Missing route segments (road network links) are supplied by short path routing between projected consecutive positions on the road network. The result is the projection of way-points of each trajectory and the complete traveled route as a sequence of links in the road network.

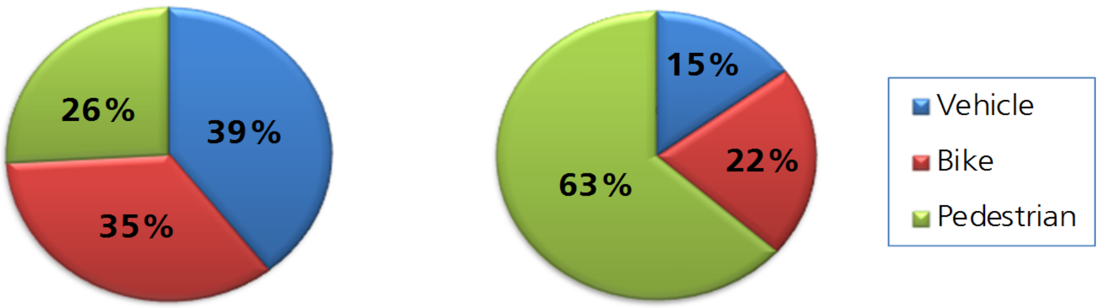
5. Speed Calculation in LinkspeedGenerator
   The Task of the LinkSpeedGenerator component is the calculation of the travel time and speed for each traveled link in the road network. For this, the travel speed on each frequented road section is determined by the time stamps and geo-coordinates of the projected way-points of the trajectories on the road network. The velocities are then derived directly from the travel time between the way-points.

The processed traffic data are stored in an appropriate database designed for DYNAMIC. In addition, KML and Shape files of individual trajectories are generated for traffic monitoring and visualisation purpose.

5 RESULTS ANALYSIS AND EVALUATION

In this section results of the field test and its evaluation are presented. The evaluation of the acquired data lead to first statements about the quality and amount of detection and re-detection of traffic objects (pedestrians, vehicles and bicycles). One interesting question is comparing the gain when using the proposed principle of mobile detection of traffic, i.e. the DYNAMIC approach, compared to detection using FCD. Another question is about the usage of a well-established FCD tool chain for the DYNAMIC data: Is it possible to use this tool chain to derive routes from DYNAMIC data and further, can it be used for determination of the recent state of traffic in terms of a level of service.

During the two-hour field test with 15 observers in a suburban area about 8000 objects were detected in total. From these 8000 objects about 2000 objects were DYNAMIC detections with an unknown traffic mode. 831 of these could be assigned to moving objects, since they were detected by at least another observer at a different place. It is planned to analyse these detections in detail further in order to make assumptions about the types of the detected objects. In this paper we focus on the validation of the proposed method. Thus, we will have a closer look at the remaining 6000 DYNAMIC detections of the observers themselves and their performance. Figure 4a shows the distribution of detections per observer type and figure 4b shows the distribution of detections for the three classes car, pedestrian and bicycle. This means that 26% of all detections were made by pedestrian observers but 63% of all detection were pedestrians (green parts of the plots). The latter corresponds to their nominal observer amount of approximately 53%. This figure emphasises the different performance of the equipped sensor systems. 47% of the observers, i.e. three vehicles and four bikes, detected 74% of all reference traffic objects, whereas the other 53%, i.e. pedestrians equipped with a phone based detector system, detected only 26% of the traffic objects.



(a) per observer

(b) as type

Figure 4: Distribution of detections

Using reference loop detectors the rate of vehicle detections could be determined. Furthermore, the performance compared to a stationary Bluetooth detector system was evaluated. Four mobile observer vehicles detected about 23% of all motorised traffic objects whereas stationary Bluetooth sensors detected 30% of overall traffic. So there is a loss of about 7% by using the mobile detection approach although 2 more sensors were used for mobile detection.
In the following the routing capabilities of the DYNAMIC approach will be evaluated. Therefore, the reference tracks of the observers are compared to the routes derived from external detection data. Figure 5 displays the reference and derived DYNAMIC route of a pedestrian observer as an example. Black dots represent the order of links belonging to the reference route. Red and blue dots represent false and correct choices of links calculated by the FCD routing algorithm. According to that plot many parts of the true route could be restored correctly. However, there are a lot of false link choices.

By comparing all of the reference-data-tuples an overall value for route correctness and completeness can be given. In Table 1 completeness and correctness values are given. The overall completeness in this field test is about 44%. Almost every second reference link could be detected by DYNAMIC. The overall mean for correctness of DYNAMIC links is about 60%. These values prove a general applicability of FCD tool chain but clearly show potential of improvement. Looking into detail reveals that the system performed best using pedestrians as observers and observed traffic objects. This is due to their comparatively low speed, which generally enables a better detection possibility and localisation.

Finally, the DYNAMIC data can be used for determination of traffic parameters. These include speeds of different traffic modes and a traffic state as a level of service for the respective

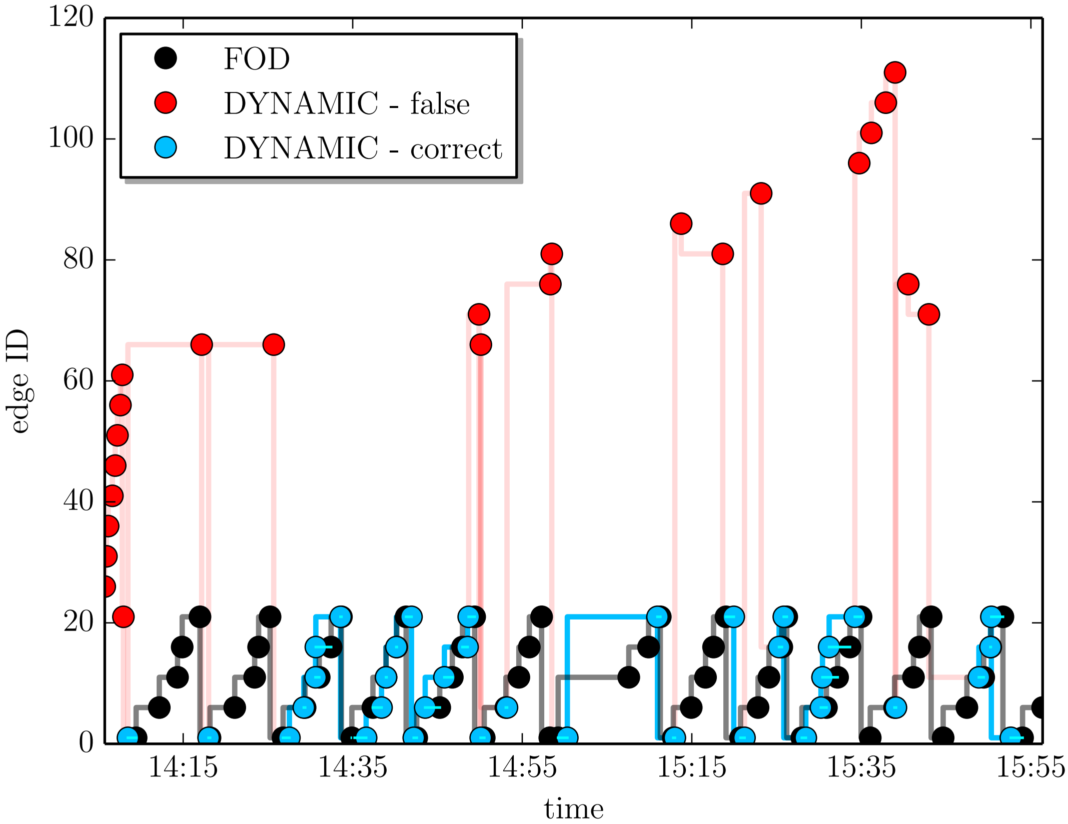


Figure 5: Correctness of derived DYNAMIC route from a pedestrian compared to the reference track

links. Figure 6 shows a 10-minute aggregated link speed time slot for bikes derived from all bike routes detected by the DYNAMIC approach at this particular time. Links are color coded according to their speeds for better differentiation. Additionally, these links show the current coverage of the field with bike data. The actual speed values differ about 2 km/h from reference link speeds. Speeds for other transport modes can be derived accordingly.

In the following a brief summary of field test results is given. The detection performed by DYNAMIC yields more traffic objects that interior detection methods like the FCD approach. The mean object detection rates per observer were 50 object-detections and 25 object-re-detections per hour. This led to a significant gain of object detection compared to the classic FCD approach. This approach potentially yields a more dense and complete state of traffic. The most important parameter is the range of the detector system. This parameter has to be chosen carefully to result in a good trade-off between localisation accuracy and route completeness.

object	completeness	correctness
vehicle	37% +/- 8%	57% +/-13%
bike	45% +/- 6%	59% +/-15%
pedestrian	47% +/- 6%	62% +/-11%
total	44% +/- 7%	60% +/-12%

Table 1: Completeness and correctness of DYNAMIC routes compared to reference

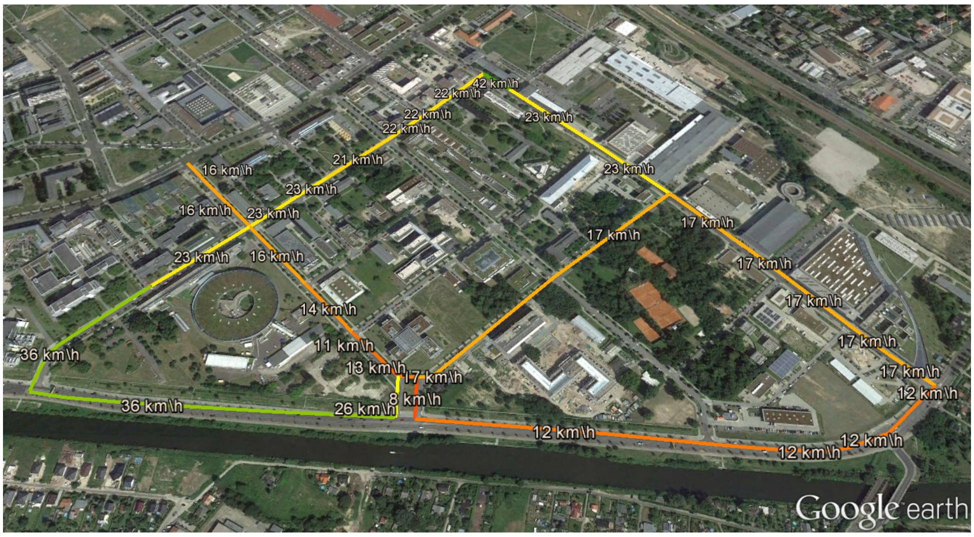


Figure 6: Aggregated link speeds for a 10-minute time slot of DYNAMIC data for bikes (map source: Google©)

The overall position accuracy is worse compared to FCD. This is a matter of the DYNAMIC detection principle. Additionally, there is a need to choose the detector range dynamically according to the difference in speeds of observer and detected object. Having low (differences in) speeds in times of traffic jam or red light stopping one might choose a smaller range in order to have a better localisation of the DYNAMIC detection. This speed depended accuracy also leads to speed depended link completeness and correctness.
Speaking generally, despite a lot of improvements have to be done concerning the technical part and methodology a new quality in determination of the state of traffic becomes possible by combining exterior detection and the FCD approach.

6 CONCLUSION AND FUTURE PROSPECTS

In this paper it could be shown that a determination of the traffic state (level of service) within the area of the field test was possible. Although it was not possible to generate high resolution trajectories of the traffic participants, we could detect not only cars, but, which is very important, cyclists and pedestrians. We can state that the potential of DYNAMIC can be estimated as very high and needs to be further analysed. In particular we were able to answer some research questions of the previous publications [20, 21, 22], but on the other hand, there have risen new research questions which need to be answered more comprehensively and in more detail. Then, quantitative and resilient answers to determine the potential of DYNAMIC can be given.

Due to the identified tasks with regard to the uncertainty of positioning, the speed dependence of the detection approach in general as well as due to the problems in routing and matching of the positions to the streets in the road network, the FCD/FOD processing chain needs to be modified to process DYNAMIC data. Thus, the current uncertainties in positioning and the speed dependence of the detection must be considered in a scaleable manner within a modified detection module. In addition, current routing and matching algorithms, particularly with regard to multi-modal aspects of drivers, pedestrians and cyclists need to be modified and maybe rethought completely. On the basis of the available results another field test ought to be planned to answer questions in relation to the mentioned uncertainties. Further, not all of the mentioned research questions can be answered by a new or even several field tests completely. To get the impression what DYNAMIC is really capable of, we aim to find answers by adopting microscopic traffic simulation, e.g. SUMO (simulation of urban mobility) [23] to our tasks. For instance, several scenarios are to be developed, which systematically analyse the tuple [observers, traffic objects, equipment ratio Bluetooth, detection range, driving speed and difference in speed, network structure and size, etc.]. A comprehensive answer of DYNAMIC's potential will then be possible. The results obtained are of course not restricted to Bluetooth, thus, other wireless communication technologies, e.g. WiFi, can be used as well.

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