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Integration of mobile wireless RF sensors into a traffic information system

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Abstract

A traffic data collection system using wireless radio frequency (RF) technologies, e.g. Bluetooth or Wi-Fi, allows for area wide measurement of traffic. This includes travel times on the whole road network. This paper aims to present the technical overview of a newly developed ITS system called DYNAMIC. This system supports indirect data acquisition by moving detectors, processing and provision of floating observer information on the basis of mobile wireless RF data. DYNAMIC consists of sensor hardware and software components like data collection, data import, transport mode detection, data processing, data fusion and visualization.

Keywords: indirect mobile wireless RF detection, traffic information system, floating observer data ; mobile bluetooth data; data collection; data processing, data visualization

1. Introduction

The DYNAMIC approach can be seen as an enhancement of well-known Floating Car Data (FCD) approach [1]. Here, the observer vehicles do not only provide their own positional information, but also collect identification information obtained from nearby objects, e.g. vehicles, pedestrians and cyclists. Furthermore, the observer is not necessarily a car, but might be a pedestrian or bike as well. Hence, the DYNAMIC approach [2, 3] differs from existing FCO (floating car observer) approaches [4, 5, 6] using camera systems for deriving information about the

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surrounding traffic. The proposed approach is based on the detection of anonymized MACs of RF devices. Due to the MAC's unique character re-identification of traffic participants can easily be done. Anonymization ensures proper privacy handling of the traffic participants. Figure 1 shows an observer vehicle with an activated RF device on-board (white), traveling from point A to point B. Three vehicles of an observer fleet equipped with the MTOU are shown in red, blue and green. These vehicles are able to detect the MACs of RF devices, carried by the observed objects (here the white vehicle) while they are passing the detection areas (dotted circles) of the observers. The observers determine the current time and their own positions in addition to the identification data obtained from the observed vehicle. This data is sent to a processing system using GSM or C2I. There the received data will be processed to extract the trajectories of observed vehicles (dotted line connecting A with B). Trajectory data is subsequently processed to traffic data (e.g. origin destination (OD) matrices, route paths and flows, travel times and speed).

This paper is structured according to the structure of the proposed ITS system that integrates moving RF sensors. An overview of this system is given in chapter 2. Here, the basic data flow from acquisition to visualization is presented. The subsequent chapter 3 explains in detail the data acquisition and the different entities involved, e.g. observer devices, and their data structures. Hereby the differentiation between observer and observed objects with their respective transport mode is of great importance. Furthermore, involved hard- and software components will be presented. Next chapter 4 introduces means of data import, management and provision. Here the different modules and their interaction are described. Additionally a brief overview of data structure is given. Subsequent chapter 5 describes the processing and augmenting of data in detail. The most important point is how to estimate the mode of transport of an observed traffic object. Also the processing of raw data to augmented data and the fusing of data with other sources of relevant data will be presented in detail in this chapter. Chapter 6 introduces data visualization and how augmented information is presented to users. The actual installation of the system and conducted trials are presented in chapter 7. The final chapter 8 gives a conclusion and an outlook of the topic.
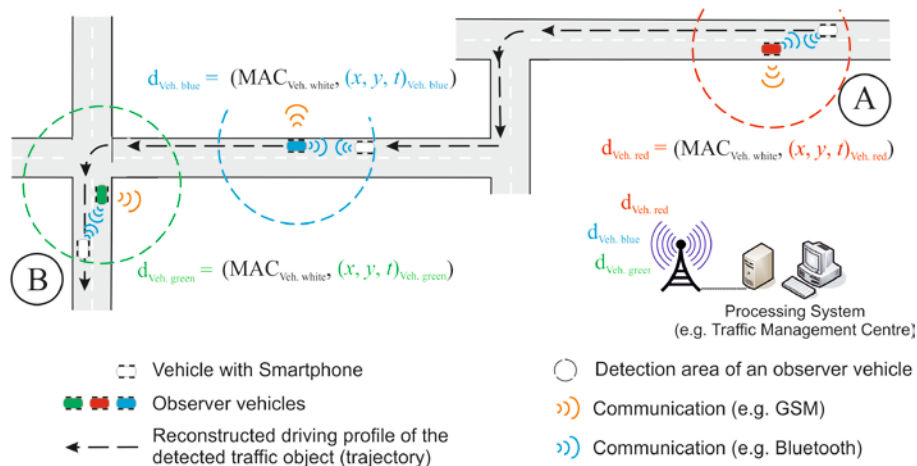

Figure 1: DYNAMIC indirect traffic data collection principle [3]

Nomenclature

ARM	Acorn RISC Machine
C2I	Car to Infrastructure
DLR	German Aerospace Center
DYNAMIC	Method of indirect traffic data collection using moving wireless RF sensors
FCD	Floating Car Data
FOD	Floating Observer / Object Data
FPD	Floating Phone Data

GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ID	Identifier
ITS	Intelligence Transportation System
LOS	Level of Service
MTOU	Mobile Traffic Observer Unit
RF	Radio Frequency
TDP	Traffic Data Platform
TPMS	Tire Pressure Monitoring System
Wi-Fi	Wireless Fidelity. It is also used for products, which use the IEEE 802.11 standard family.

2. DYNAMIC System Architecture for Traffic Information System

The proposed ITS system is depicted in Figure 2 as an overview. The first part deals with the collection of data in the field. Here, OBUs installed at floating observers and equipped with appropriate firmware are used for the indirect traffic data acquisition on the basis of Bluetooth or Wi-Fi signal detection. The collected raw data consists of device IDs, local time, signal strength captured from the observed client devices nearby, the sensor position and local speed. This data is parsed, validated, aggregated, anonymized and transmitted to the server component. In this second stage - Data Import - data are basically preprocessed and provisioned for further processing. The subsequent stage 3 is data processing through a series of processing modules on the server side. One of these modules determines the actual transport mode. Subsequent modules are responsible for data filtering, generation of trajectories, map matching and link speed calculation as well as travel time estimation. The generated traffic information for single transport modes like "car" or "bus" are saved into databases. The last stage 4 deals with the visualization of the data. For that purpose DLR developed Keep Moving framework.
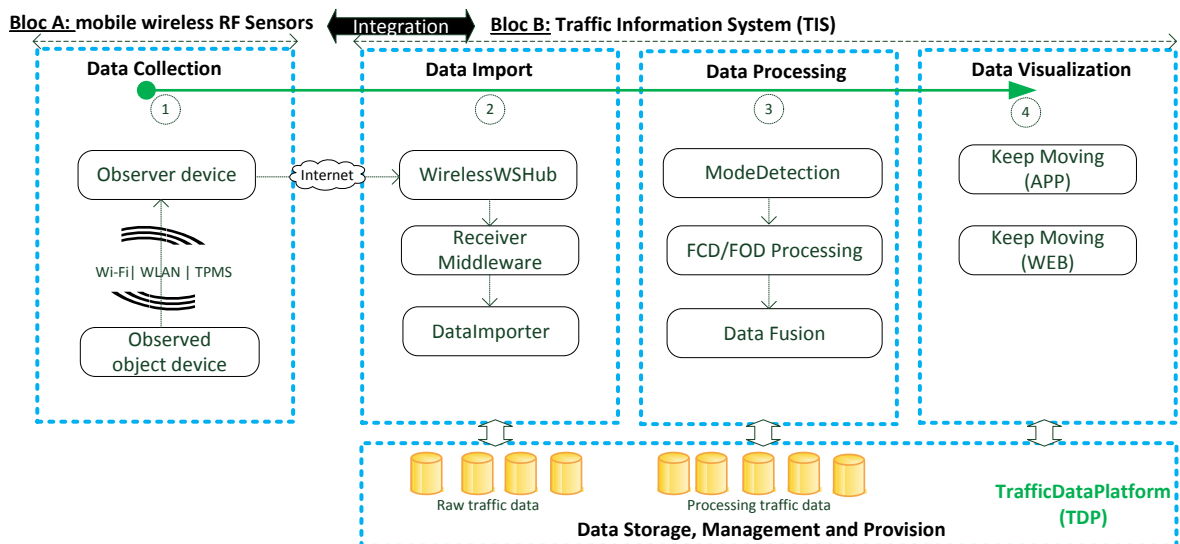

Figure 2: DYNAMIC ITS architecture

The FOD-system has been successfully tested by the German Aerospace Center (DLR) in different test campaigns in Berlin, Germany.

3. DYNAMIC Data Collection

In the following the data obtained by the proposed system are explained in detail. In addition the understanding of the difference between observer and observed data is of essential importance. As shown in Figure 3 each of these two entities form a particular layer. According to this point of view the traffic can be divided into two groups and each traffic object belongs either to the observed group or the observer group. Naturally observers continuously determine their own position and will detect traffic objects, i.e. observed objects, if present in observer's proximity. To sum it up Table 1 provides a brief overview of the difference of observer and observed traffic object and their respective data
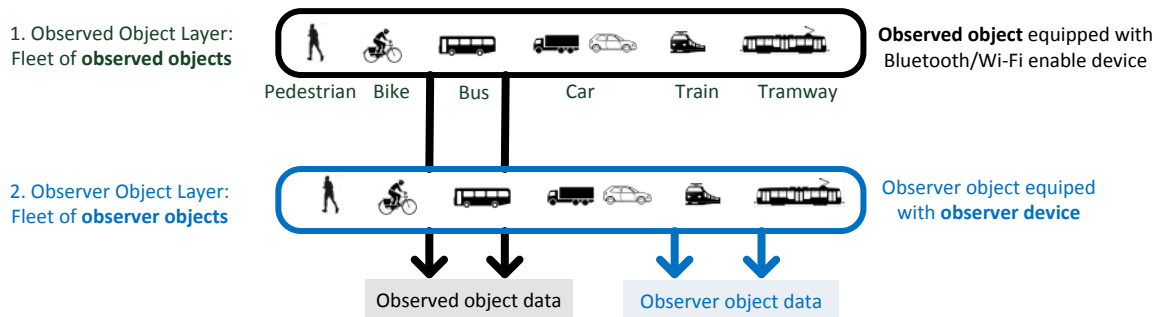

Figure 3: Differentiation of observer and observed object layer

Table 1: Differentiation of observer and observed object data

	Observer versus. Observed Object	
No.	Observer	Observed
1	Object: An object equipped with an observer RF device.	Object: Any traffic object equipped with RF technology and therefore is detectable.
2	Device: A RF device according to Bluetooth, Wi-Fi, ZigBee or other standards that is scanning for other RF devices nearby.	Object Device: A RF device according to Bluetooth, Wi-Fi, ZigBee or other standards that responses to another scanning RF devices nearby.
3	Object Traffic Mode: It determines whether the object is moving or stationary. A moving object can represent different modes of traffic, e.g. bicycle, vehicle, pedestrian.	Object Traffic Mode: It determines whether the object is moving or stationary. A moving object can represent different modes of traffic, e.g. bicycle, vehicle, pedestrian.
4	Object Data: Basically the FOD from the object comprising at least spatiotemporal data.	Object Data: Comprises at least a unique ID and a timestamp of detection. This data has to be correlated with corresponding observer object data.

3.1. DYNAMIC Observed Object Device

In terms of DYNAMIC indirect traffic detection there is a multitude of observed object devices (e.g. navigation devices, smartphones) that can be detected by an observer device. The minimum requirements for observed object devices are:

- The support of common RF wireless communication interface like Bluetooth or Wi-Fi.
- The device must be activated and must respond to scanning procedures.

3.2. DYNAMIC Observer Device

DYNAMIC observer device is a wireless RF sensor that operates as a signal detector of wireless communication interfaces. The observer device or detector may be implemented as an application for smartphones or as a dedicated sensor system for embedded or PC platform installed in an observer object.

3.2.1. DYNAMIC Observer Device – Hardware

The modular approach of DYNAMIC observer device and its required components is illustrated in Figure 4. The observer device consists of several parts. A main sensor module shown in dark blue consists of radio interfaces supporting Wi-Fi, Bluetooth, GPS and GSM/UMTS and computer unit. The sensor module (see Figure 4a) can operate in a mobile environment like vehicle, bus, tramway, train, bicycle or attached to a pedestrian.

In addition the sensor may be operated in a stationary manner as shown in Figure 4b. Here a housing (dark gray) is added to encapsulate the main sensor module. The system can be completed with an optional solar module for runtime extension.
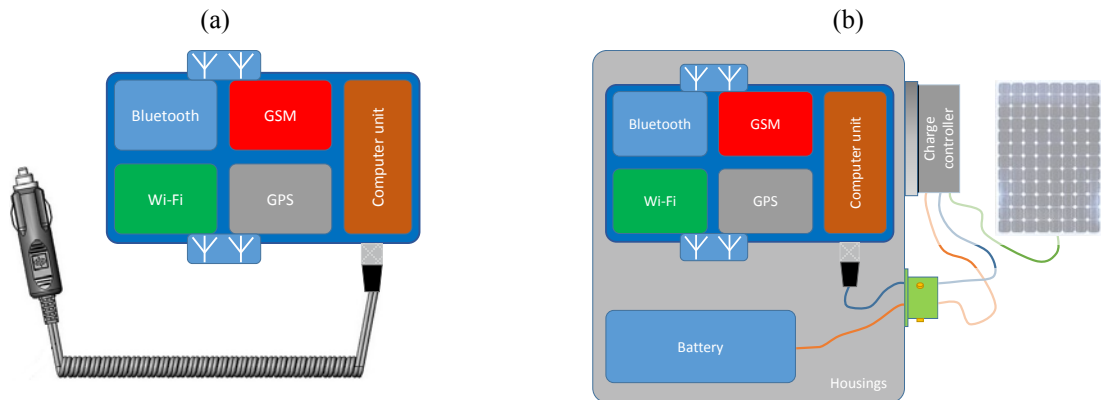

Figure 4: Schematic representation of the observer device sensor units – (a) without – (b) with housing und solar module

Figure 5 gives a brief overview of actual hardware that is used in different versions of sensor modules. Figure 5a and 5b show off-the-shelf Bluetooth respectively Wi-Fi dongles that can be used as a scanner. Figure 5c and 5d show self-made packet sniffers for Bluetooth and TPMS (tire pressure monitoring system) signals. A TPMS sensor typically installed in a tire is depicted in Figure 5e. Figure 5f and 5g show highly integrated sensor platforms that support GPS, GSM, Bluetooth and Wi-Fi modules as well as a general processing module. Finally Figure 5h shows a stationary sensor platform that can be operated autonomously mounted on a lamp pole.
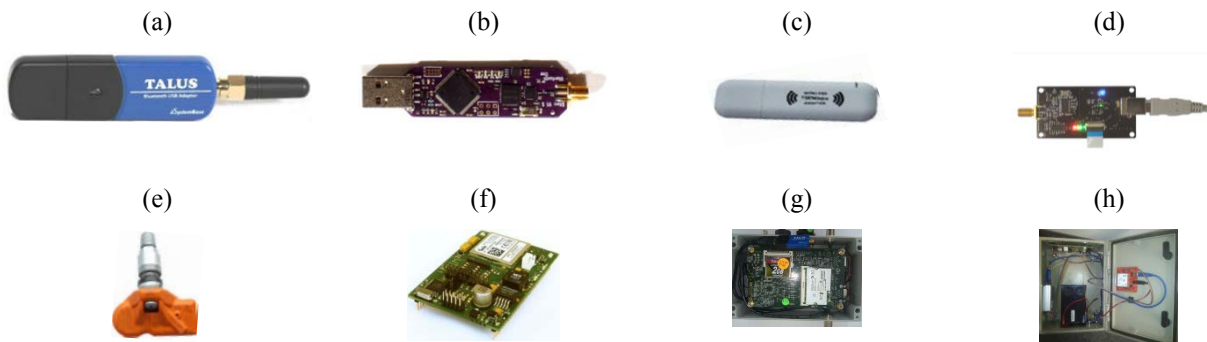

Figure 5: (a) off-the-shelf Bluetooth dongle; (b) Bluetooth sniffer dongle; (c) off-the-shelf Wi-Fi dongle;(d) TPMS sniffer dongle-;(e) TPMS sensor;(f) embedded sensor system;(g)mobile sensor system;(h)stationary sensor system

3.2.2. DYNAMIC Observer Device - Firmware

The operation of observer device requires a firmware or other software components (see Figure 6) for different device platforms (e.g. embedded systems, pc and smartphones). The requirements of the firmware, i.e. main features, are as follows:

- Detection of available packets from each observed object device in the range using common RF standards.
- Geo-localization data via GNSS device.
- Anonymization of ID data.
- Data filtering, aggregation and compression.
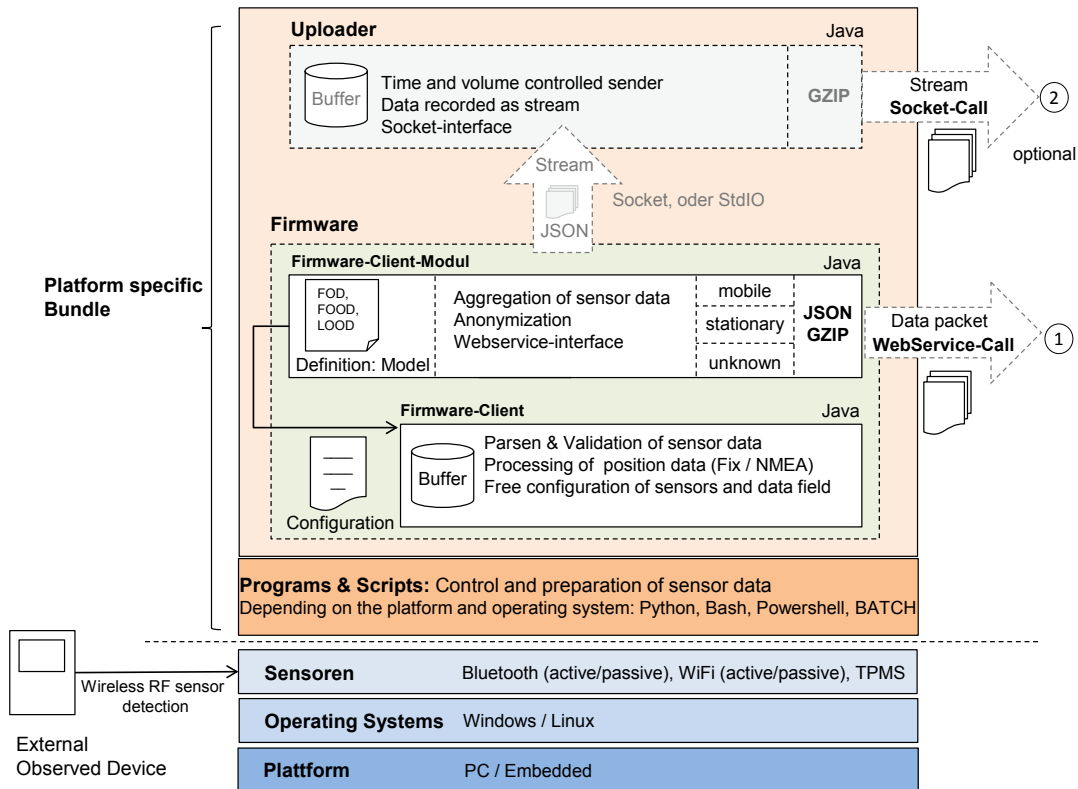- Data transfer to the server side using GSM or C2I

Figure 6: Firmware - software components of an observer device as designed by DLR

Additionally to the web service communication interface to send all collected data packet from the observer device to the backend system, the current implementation of DYNAMIC firmware provides also an optional communication channel based on the socket technology to send the collected data as a stream to the server side

Depending on the scenario used, the observer device may be stationary, moving or operated as an unknown mode. Further it may be an active or passive detection process. Depending on the detection mode and type there are different forms of data that an observer device can generate. Figure 7 shows the three different modes and the corresponding packet type thereby generated

- In floating or mobile mode FOD-Packet (Floating Observer Data Packet) and FOOD-Packet (First Observed Object Data Packet) are generated by the floating observer device (FODev). The FOOD-packets are generated with each detection of an observed device.
- In stationary mode FOOD-Packet and LOOD-Packet (Last Observed Object Data Packet) are generated by the stationary observer device, these two packets are dependent. The FOOD-packet is created by each first detection of an observed object devices while the LOOD-packet by the last detection of the same observed object device. By the stationary mode it is possible to detect the observed object device more time in the range of stationary observer device.
- In unknown mode data are generated like in floating mode. If necessary the data from stationary mode can be derived from these data.
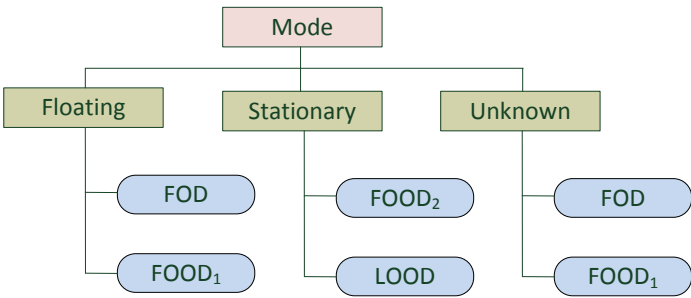
Figure 7: Detection mode and corresponding generated data packet types

The information about the three data packet type FOD, FOOD and LOOD is described in detail in the section appendix A.

3.2.3. DYNAMIC Observer Device Platform

The observer device firmware is customized to support different device platforms:
- Embedded platform (ARMv6, ARMv7),
- Personal computer (PC x86) platform equipped with a Linux operating system,
- Mobile device platform supporting Android operating system.

Some observer client devices developed by DLR and supporting the three categories of platform mentioned above are depicted in Figure 8. JBluB means Java Bluetooth box because the firmware for client devices is implemented in Java programing language.
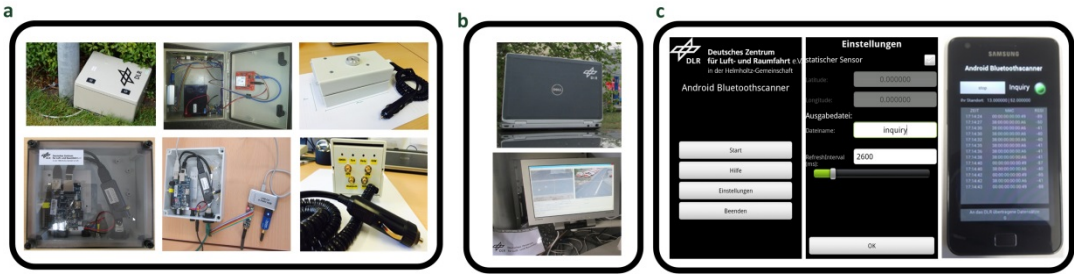

Figure 8: DLR observer devices types (a) JBluB embedded version; (b) JBluB PC version; (c) AndroidBluB Android version.

3.3. DYNAMIC Traffic Detection Type (Bluetooth, Wi-Fi, TPMS)

Currently there are three different types of RF technologies that can be detected. Additionally the detection can be done in an active or passive manner. Active detection is the sending of an inquiry packet and waiting for an answer of a device, whereas passive detection is the sniffing of radio packets at a particular channel. In the latter case no decryption in the sense of eavesdropping is conducted since the relevant ID information is not encrypted at all. Table 2 gives an overview of detection capabilities currently implemented.

Table 2: Current supported detection types for observer device

Detection type	Detection abbreviation	Description

Bluetooth active	BT-A	Bluetooth inquiry process; Necessity of a visible Bluetooth interface
Bluetooth passive	BT-P	Sniffing of Bluetooth packets; Necessity of a currently transmitting Bluetooth device that may be invisible
Wi-Fi active	WF-A	Act as an AP and collect probe requests
Wi-Fi passive	WF-P	Sniffing of Wi-Fi packets; Necessity of a currently transmitting Wi-Fi device
TPMS-Sensor passive	TPMS-P	Sniffing of TPMS packets sent frequently by tire-side sensors

3.4. DYNAMIC Mobile versus Stationary versus Combination

Compared to the existing data collection sensors, the DYNAMIC approach for traffic data acquisition has the advantage to support two modes of traffic detection (dual detection mode). Depending on the traffic data scenario to be used, observer devices can be deployed to support the following two detection modes:

- Floating traffic detection: The observer object client device is moving. The position of observer device changes with the time and can be compared to floating car data (FCD) technology. [1]
- Stationary traffic detection: The position of observer device is fixed and can be compared to the loop detector technology.

Table 3: Overview of uses cases

Use Case No.	Observer			
	Floating	*Stationary*	*Single*	*Multiple*
1	x			x
2		x	x	
3		x		x
4	x	x		x

Having those two modes five use cases can be defined as presented in Table 3. In addition to the detection modes the amount of observer devices to be considered may differ. Use case 1 represents a fleet of floating observers, e.g. taxi, which observes traffic objects. In this case area wide measurement of traffic parameters, like travel times and speeds or O/D matrices can be determined. Use case 2 represents a single stationary detector that delivers point based traffic parameters, like local speeds and counts. Use case 3 consists of multiple stationary detectors. Here, section based traffic parameters, e.g. travel times, can be derived. Use case 4 represents a combination of the above use cases and delivers the complete range of traffic parameters.

4. Data Import, Management and Provision

The raw traffic data collected from the observer as well as observed object devices are continuously sent to the DYNAMIC backend system using system standard client interfaces. The following three server components are responsible for the data import and data distribution process:

- WirelessWSHub: This module is a web application that provides standard web service interface to exchange the data packet between the observer devices and the backend system. All data are compressed by the client side and sent to the WirelessWSHub via a predefined web address in a configured time interval. The received data packet is forwarded to the ReceiverMiddleware component using activeMQ interface customized for this purpose.
- ReceiverMiddleware: The tasks of the ReceiverMiddleware module are:
  - To extract the traffic data from the received compressed data packet obtained from the WirelessWSHub,
  - To assign the data to the three corresponding packets (FOD, FOOD and LOOD) and
  - To store the data as raw data into the database corresponding to observer or observed object data.
- Data-Importer: The Data-Importer module imports as input the output data from ReceiverMiddleware from the database and separates these data to obtain the data corresponding to the observer respectively to the observed object raw data. The two differentiate raw traffic data are stored separately in the database. The raw

traffic data model of an observer and observed object data are depicted in Table 4. The identified traffic parameters relevant for each data source are also represented.

Table 4: Observer and observed object raw traffic data model

Traffic parameter	Data type	Value sample	Data Unit	Data description	Relevant Data for observer	Relevant Data for observed object
Observer ID	String	MST200001		The unique identifier of observer	Yes	No
Observed Object ID	String	6E9BA26018FBA3		The unique identifier of observed object	No	Yes
Local time	Timestamp	2015-09-12 10:12:06		The measurement time of	Yes	Yes
Position	Geography(Point)			WGS84 Geography Point as longitude and latitude	Yes	No
Object UAP	String	TomTom		Device manufacturer	No	Yes
Detection mode	Integer	1| 2| 3		Current observer's detection mode (1= MOBILE, 0=STATIONARY, 2=UNKNOWN)	Yes	No
Detection type	integer	1|2|3|4|5|6		Current detection type of observer object (1=BTA - BT active, 2=BTP –BT passive, 3=WFA – WI-FI active, 4=WFP - WIFI passive, 5=RKDS, 6=UNKNOWN))	No	Yes
Local speed	Integer	60	km/h	Current travel speed of observer Observers to the time of measurement (in km/h)	Yes	No
Tracking Radius	Integer	30	meter	Radius of the signal strength of observer (in meter)	No	Yes
Direction	Integer		Degree	Travel direction of observer	Yes	No
Accuracy longitude	Integer		Meter	Accuracy of position measurement for latitude (in meter)	Yes	No
Accuracy latitude	Integer		Meter	Accuracy of position measurement for longitude (in meter)	Yes	No

4.1. Data Management and Provision

ITS traffic information systems require robust and reliable tools for data management and provision. For this purpose DLR has developed a Traffic Data Platform (TDP) [11, 12] as ITS infrastructure for storage, management and provision of all collected raw as well as processed traffic data. The TDP constitutes an integral part of the new DYNAMIC ITS traffic information system presented here. Using common TDP data interfaces, TDP users and partners can have access to all data [13] (e.g. traffic data, infrastructure data and simulation data) available within the TDP in a secure way.

5. DYNAMIC Data Processing

5.1. Transport Mode Detection

The position data that is saved in the database has to be evaluated. To use it for further current traffic information it is important to know which means of transportation is used. The aim is to be able to recognize walk, bicycle, car, bus and train movements. Therefore, it is distinguished between the reported positions of the observer itself and the positions of other traffic participants detected by the observer by scanning for Bluetooth signals. To be able to use the algorithm as independent as possible from local maps or other third party information no further information sources like street maps or public transport routes and timetables are used. The transport mode detection modules are executed every *n* minutes with *n* = one to three minutes. Each run examines the whole track as known at that timestamp, not only the new incoming positions.

5.1.1. Mode Detection for Observer

The observer sends its position regularly (for example with a frequency of every second) so that it can be tracked constantly. Its position and moving direction can be determined relatively exact, depending on its GPS module and the environment. If the observing device is a smartphone, further helpful data can be recorded and sent together with the position data. An example is the accelerator sensor data that nearly every smartphone provides. The most difficulties exist by deciding between means of transportation with similar speeds and by detecting a slow driving car because of congestions. From the point of view of ITS business the latter is of special interest for example to be able to detect queueing traffic and jams or to calculate current travel times for distinct means of transportations for streets.

A two-step algorithm is used. In the first step the position data of an observer is divided into smaller segments, in that a change of the mean of transportation is implausible, for example between two stops. The modes walk, bicycle, bus, car and train are tried to be identified by using a Fuzzy rule system. An object moving with 40 km/h can be a tram, a bus or a car. Together with further characteristics like turning angles, start accelerations, length of stop and moving periods, strength of vertical and horizontal accelerations a specific transportation mode is more probable than another. The named characteristics are described by unsharp boundaries and the membership of a real measured value is a matter of degree. So an object with 40 km/h as maximum speed is 0.8 a tram, 0.7 a bus and 0.65 a car. Together with a measured turning angle of the tracked object of 60 degrees which hits the area of "clearly" of variable "changeOfHeadingAfterStop" with 1, the evaluation of the fuzzy rules decides for "CAR". This system of Fuzzy rules is permanently enhanced and modified.

After the evaluation of the Fuzzy rules that worked on segments of the tracked route, the whole route (that means as far as it is known at a specific timestamp) is regarded. This is the second step of the algorithm. Now some logical evaluations are made and single modes of the segments are corrected. An example for this is a walk segment for less than 30 seconds between two car segments. In this case it is assumed that the walk segment is also a car movement. There are similar corrections for bicycle and walk segments after a fast mode like car or train if there is no change of direction. Further description and results can be found in [14] and [15].

5.1.2. Mode Detection for Observed Objects

To get the transportation mode of observed objects is much more difficult. Only the less exact location of the object is known (somewhere near the observer, with specific signal strength) and the time. If the observed objects are detected by a Bluetooth or Wi-Fi scan, the specific MAC address is known. There are some MAC address ranges that belong to a specific producer (see Figure 9). And if this is a typical car navigation device producer the probability that the observed object is a car is very high. Of course this not a satisfying approach because it affects just a part of devices. The observed object cannot be tracked like in the transport mode detection for observer, because just small time slices with reported positions are at hand. One observer detects it for a few seconds and later a second observer detects the same object again. About the time between these two reporting points we know nothing. In this case it is helpful to match the reported positions on a street map and calculate the moved distance if

there was a moving and a minimum speed to travel this distance. Without a street map the real travelled distance can only be roughly estimated

The authors are working on creating a system of conditional probabilities in Bayesian networks that leads to most likely transportation mode. Therefore, variables of the system are position, timestamp, MAC address (to get information about the producer if possible), other observed objects in that area/street, travelled distance from previous observations and further traffic information of that area are considered. The transportation mode can be obtained if some of the listed information are available. If for example for the observed object a speed of 100 km/h is estimated then the probability that it is a pedestrian or cycler is rather low. Time and location can also be very useful: Not all means of transportation are available at every time or at every place, for example no bicycles on a motorway whereas an observed object in a pedestrian zone gets a high probability for being a pedestrian.

The conditional probability distributions have to be determined by expert knowledge or by practical studies. The work on this is still in progress [16].
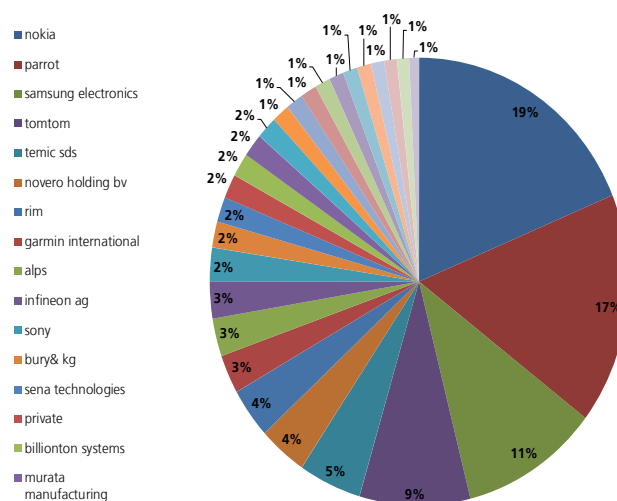

Figure 9: Classification of used observed object devices (Data from 2013, Berlin, Germany)

5.2. FCD/FOD Data Processing

5.2.1. Data Processing Chain

The module described herein (see Figure 10) processes the raw data FCD (GPS positions) to travel times, which are referenced to a specific road network. In addition to the standard Floating Car Data Processing, the Module was enhanced, so that it can now process the observed GPS data as well. The necessary modules for the processing of all GPS location data are shown in:

- Filter: The filter cleans up the raw data based on specified filter criteria. These criteria include duplicate positions (obviously) erroneous data (time stamp and positions).
- Trajectorizer: The task of Trajectorizer is to append incoming raw data to existing trajectories or to create new trajectories. A trajectory is a collection of geographical locations (waypoints) of a vehicle in time-ordered sequence.
- Matcher: The Matcher expands each trajectory by road network specific information. This means that the individual waypoints of the trajectory are projected onto a road network ("matched"). This process is therefore also called Matching. The second task of the matcher is to extend the trajectories into cohesive routes. By short routings between the projected positions on the digital road network, missing route segments (road network edges) are complemented by the Matcher. As a result, the waypoints of each trajectory are

projected to the road network and there is a complete travel history of the trip as a series of road network edges.

- LinkSpeedGenerator: The task of the LinkspeedGenerator is to calculate and provide travel times and travel speeds per travelled edge in the road network. To do this, for each projected trajectory segment on the road network the time points and driven speeds are determined. Then the velocity is calculated from the travelling time between two waypoints. To this end, the ever traversed by traffic road section speeds driven and the time points are determined on the image projected on the road network waypoints of the trajectories. The velocity is calculated directly from the traveling time between two waypoints. Measurements during taxi-status changes, which may cause non-traffic-related changes in driving behaviour, are rejected. Status changes are, for example, passenger take off and passenger drop off.
- GraphLoader: The GraphLoader provides functionality for loading the digital road network from the database
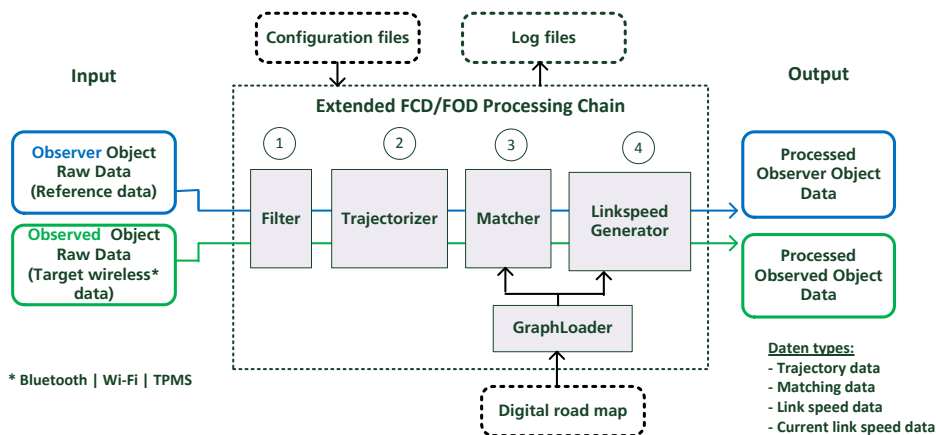

Figure 10:   Extended DLR traffic data processing module for dynamic indirect wireless RF detection sensors data

5.2.2. FCD/FOD Processing Data

After processing DYNAMIC raw data from observer respectively observed object device, the following types of traffic data are generated from the processing module and saved separately into the database tables customized for this purpose:

- Trajectory data: A trajectory is a short anonym moving profile and contains the GPS-traces of an observer at a defined time interval.
- Matching data: As a "Match" we understand the projection of a GPS Point on the digital road network.
- Link speed data: The combination of the Matches with the driven route of a vehicle ends up in a driven velocity for each traveled link in the road-network (fod/fcd-on-edges).
- Current link speed data: If more than one vehicle travels in one time slice the same link, the speeds are fused to the so called current-speed, representing the current traffic situation on that link.

Table 5 gives some examples of schematic representation of the processing data listed above

Table 5: Traffic data and schematic representation

No.	Data type	DYNAMIC wireless data	Schematic representation	Description
1	Raw data	raw data		GPS trace of 2 observer vehicles (1=black and 2=blue)
1	Processed data	Trajectory data		Trajectory obtained from the GPS trace of the 1. Observer
2		Matching data		Map matching of GPS coordinates of the 1.Observer on the road network links: The matching data contains also the distance to original GPS point.
3		Link speeds data		The Link speed data contains additionally the information of links without match and driven speeds for each vehicle.
4		Current link speed data		e.g. Link based local travel speed calculated from observer 1 and 2 → level of service (LOS) is derived from the current speeds

5.3. Data Fusion

5.3.1. Data Fusion Module

The fusion of traffic data obtained from different sources like taxi FCD, Floating Phone Data (FPD), loop detector or wireless RF data from floating objects can improve significantly the quality of generated overall traffic information. To use the benefit of all these data, a data fusion module realized by DLR using Level of Service (LOS) based weight quality median has been adjusted and integrated into the DYNAMIC ITS traffic information system. The algorithmic concept of the data fusion used here is described in detail in [7] and the technical realization is depicted in [8].

5.3.2. Fusion Traffic Data Model

The data fusion module generates fused persistent traffic data that are saved into the database. Additionally the shape files corresponding to the overall traffic information as well as from the single data sources are also provided and can be separately visualized using the DLR KeepMoving [9,10] app, web portal or other existing map viewer tools. An overview about the traffic data generated from the data fusion module is shown in Table 6.

Table 6: Fusion traffic data model

Traffic data	Data type	Value sample	Data Unit	Data description
Link id	Integer	-2050921136446		Road link unique identifier
Local time	Timestamp	2015-09-09 09:27:22		Data time stamp
Level of service	Integer	0		Current level of service 0=A,1=B,2=C,3=D
Los type	Integer	4		e.g. 3 or 4 LOS categories

Data sources	String[]	{Taxi-FCD, FOD_CAR_Observer, FOD_CAR_observed}		List of available data sources
Travel speed	decimal	130.0	km/h	Travel speed on the road link
Limit ration	decimal	0.80		Limit ration obtained from link speed and local speed
Quality	integer	100	Percent	Quality of data

6. Traffic Data Visualization

6.1. KeepMoving – Traffic Information Visualization Tool

The DLR KeepMoving [9, 10] mobile app (see Figure 11) and web portal (see Figure 12) provide tools for map visualization of the traffic information from DYNAMIC wireless RF sensors as well as from other data sources like FCD or loop detector. The benefit of such tools is to support the development of the integrated DYNAMIC system and to facilitate the evaluation of the quality of the obtained data results.
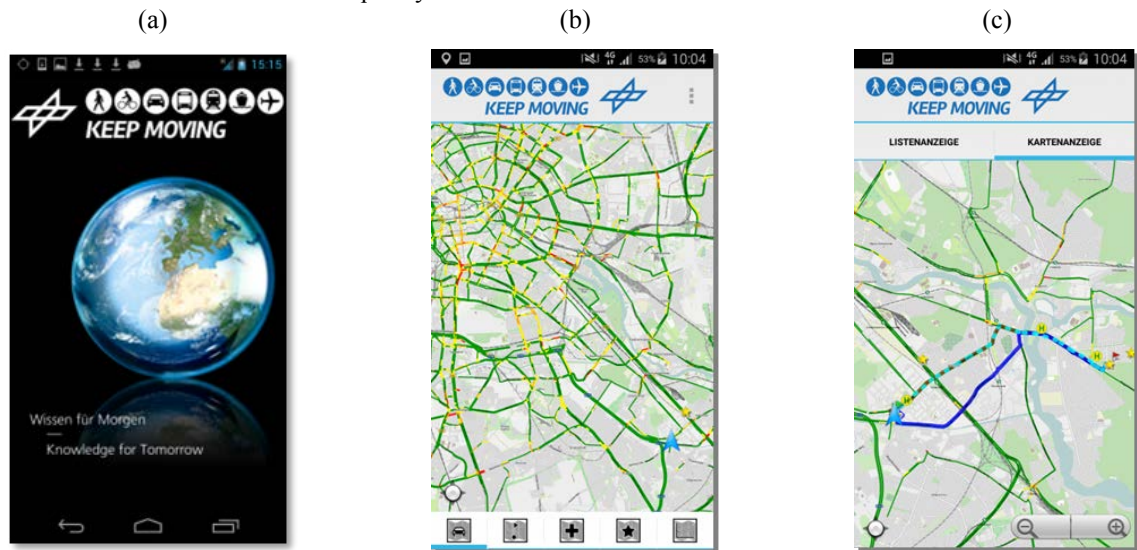
(a)　　　　　　　　　　　　　　　(b)　　　　　　　　　　　　　　　(c)

Figure 11: DLR KeepMoving App (a) Splash screen; (b) Fusion traffic information; (c) Route information and alternatives.

In addition to the visualization of overall traffic information obtained from different traffic data sources and different means of transport (motorized private and public transport), the App as well as Web version of KeepMoving provides also a wide range of functions such as route calculation, route monitoring, on trip information about alternative routes, quality assessment of the route, origin destination search, tracking and tracing.

The current implementation of KeepMoving App supports Android platform and it is planned to couple the KeepMoving App and the available Android version of observer device (AndroidJBluB). After the realization the KeepMoving App can be able to operate simultaneous in three operation modes: as a mobile multimodal travel assistant, as floating observer or as detector of mobile wireless RF sensors.
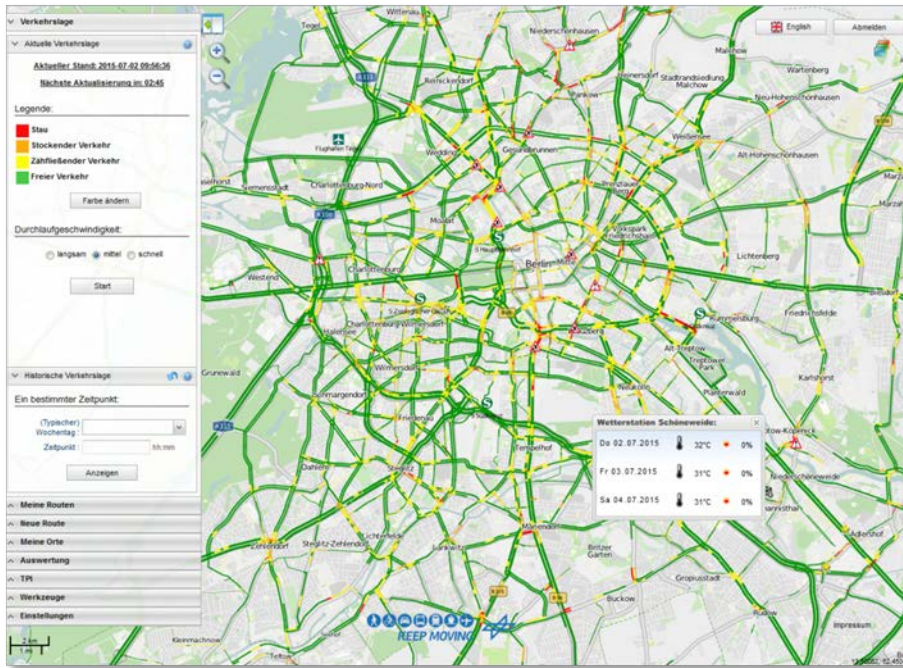
Figure 12: DLR KeepMoving web portal

7. DYNAMIC Traffic Information System Installation and Test

7.1. DYNAMIC System Installation

For the installation and deployment of the dynamic traffic system in the online productive system the following requirements are needed:

- The backend server: the system components, database and application server for example are installed on this server. The server capacity (CPU, memory) depends on the fleet size.
- Observer device (hardware) with preinstalled appropriate firmware (software) customized for different application platforms (embedded, pc and mobile smartphone).
- A fleet of multimodal mobility participants equipped with observer device and supporting wireless RF communication.

7.2. DYNAMIC Test Campaign

To test the whole integrated traffic system based on the dynamic indirect RF wireless method, the data from a test campaign conducted in 2013 have been used [3] and post processed. For the two hours field test sixteen multimodal mobility participants (8 pedestrians, 4 cars, 4 bicycles) equipped with appropriate observer device sensors moved on predefined routes in the WISTA area in Berlin Adlershof. Figure 13 shows a comparison of traffic information obtained from taxi FCD, the dynamic indirect Bluetooth traffic detection method (floating observer and observed object data) and the resulting overall traffic information obtained from the fusion module of all data sources. The analysis of the data shows the complementarity between the data obtained from the different sources and therefore the benefits of the data fusion improving the quality of the generated traffic information.

(a)   (b)

(c)   (d)

Figure 13: Traffic information obtained from (a) Taxi-FCD; (b) Floating Observer Object Data; (c) From Bluetooth observed object data; (d) The resulting data fusion; in WISTA test field Berlin Adlershof. (Visualization in KeepMoving Web portal)

8. Conclusion and further works

In this paper, the traffic monitoring system DYNAMIC is depicted with its basic hard- and software components like data collection, data import, data processing, data fusion and visualization. The main focus was on the presentation of the different algorithms and technologies used for the implementation of the system as well as the requirements for ITS installation and deployment.

The DYNAMIC ITS architecture includes different data processing modules which are responsible for data filtering, trajectories generation, map matching and link speed as well as travel time estimation. Further modules determine transport modes or provide data fusion and a map-viewer for visualization. An intelligent backend system using standard client interfaces assure the data import and data distribution process. A Traffic Data Platform ensures robust and reliable tools for storage, management and provision of all collected raw as well as processed traffic data.

To sum up, the following results from the processing of DYNAMIC data can be stated:

- Mode detection for observer vehicles can be realized using a Fuzzy rule system; mode detection for observed objects is rather complex and might be realized by creating a system of conditional probabilities in a Bayesian network (work in progress).
- Data fusion using LOS based weight quality median improves the overall traffic information quality.

- Real world test campaign shows significant improvements in the amount of traffic information in comparison to traditional FCD data.

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 further modified to process DYNAMIC data in an optimal way. 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. As stated earlier, the transport mode detection algorithms for observed objects are also subject to further research. In addition, on the basis of the available results another field test ought to be planned to answer questions in relation to the mentioned uncertainties and to prove exact quality statements.

Since not all research questions can be answered by a new or even several field tests we aim to get the impression what DYNAMIC is really capable of by adopting microscopic traffic simulation to our tasks. For instance, in [3], [17], [18] and [19] the dependencies between observers, traffic objects, Bluetooth equipment ratio, detection range, network structure and size were systematically analyzed.

Acknowledgements

Appendix A. Data structure of data packets FOD, FOOD and LOOD
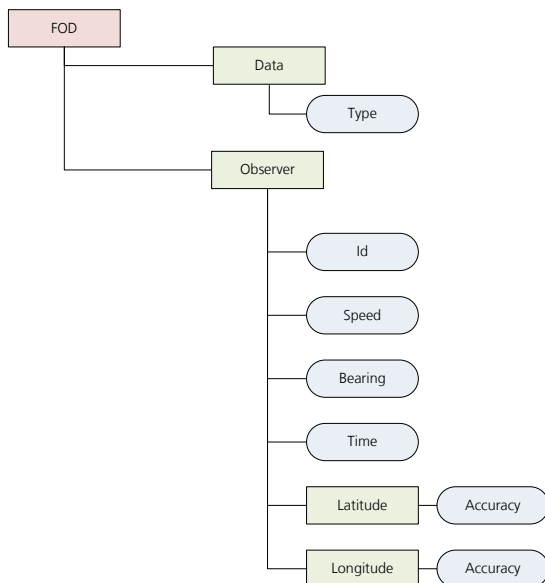

FOD-Packet (Floating Observer Data Packet)

1. Observer_ Time: Millisecond Linux Timestamp
2. Observer_Id: unique identifier of observer/ Observers/Sensor
3. Observer_speed: local speed of Observer
4. Observer_bearing: geographic direction of observer (0° = geographic north)
5. Observer_latitude: Latitude of observers in WGS84
6. Observer_longitude: Longitude of observer in WGS84
7. Observer_Latitude_accuracy: accuracy [m]
8. Observer_Longitude_accuracy: accuracy [m]
9. Data_Type: Packet type = 0: Packet type (0=FOD, 1=FOOD and 2=LOOD)
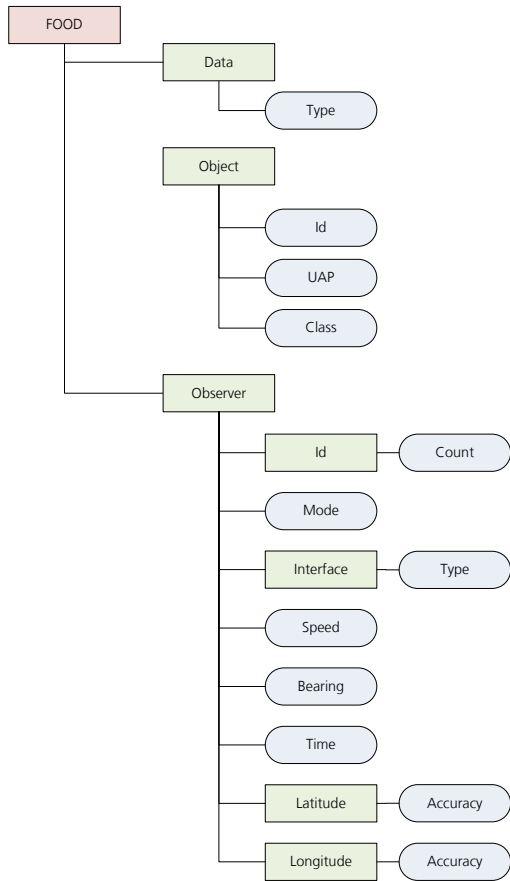
FOOD-Paket (First Observed Object Data Packet)

1. Object_UAP: manufacturer information
2. Object_ID: hashed Identifier of observed Object
3. Object_class: additional classification of the interface
4. Observer_ Time: Millisecond Linux Timestamp
5. Observer_mode: Mode of observer (stationary, mobile/floating, unknown)
6. Observer_id: Unique Identifier of Observers / Sensors
7. Observer_id_count: Counter to bind FOOD und LOOD packets
8. Observer_interface_type: Type of Observer / Sensors (BT-A, BT-P, WF-A, WF-P, RDKS)
9. Observer_speed: local speed of observer in [km/h]
10. Observer_bearing: Geographic direction of observer (0° = geographic north)
11. Observer_latitude: Latitude of observer in WGS84
12. Observer_longitude: Longitude of observer in WGS84
13. Observer_latitude_accuracy: Accuracy in [m]
14. Observer_longitude_accuracy: Accuracy in [m]
15. Data_type: Packet type = 1: Packet type (0=FOD, 1=FOOD and 2=LOOD)
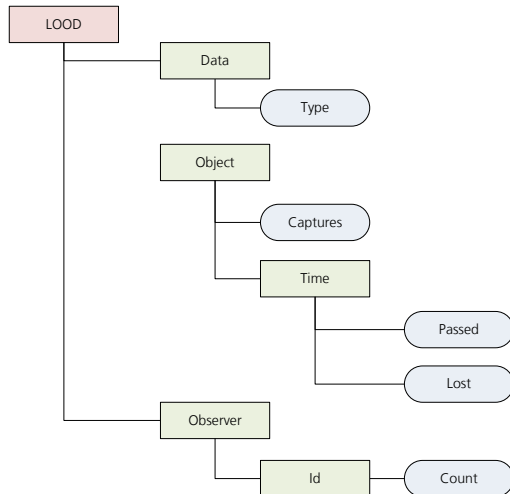
LOOD-Paket (Last Observed Object Data Packet)

1. Observer_id_count: Counter of the corresponding FOOD Packet
2. Object_captures: Number of detection
3. Object _time_passed: delta time
4. Object _time_lost: delta time
5. Data_type: Packet type = 2: Packet type (0=FOD, 1=FOOD and 2=LOOD)

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