2

Telematics

2.1 Introduction

The term *telematics* describes the combination of the transmission of information over a telecommunication network and the computerised processing of this information. It is the anglicised version of the French word *télématique* which is a merger of the words *télécommunication* and *informatique* and has been coined 1978 by Simon Nora and Alain Minc in their report titled *L'Informatisation de la société*[1]. This report was mandated by the French president Valéry Giscard d'Estaing in 1976 who was solicitous that *"the applications of the computer have developed to such an extent that the economic and social organisation of our society and our way of life may well be transformed as a result"*.

Recent developments of computer and telecommunication technology have an equally important impact on society and economy today as the increasing availability of small and affordable personal computers in the seventies. As computers are becoming much smaller and less energy-hungry, computing devices are becoming mobile and pocket computers can accompany us wherever we are. Telecommunication technology can be embedded in those mobile devices enabling wireless telecommunication with stationary devices and other mobile devices. The emergence of new fields of application has resulted in new branches of computer science sometimes described with the terms *mobile computing*, *ubiquitous computing*, or *pervasive computing*. With the recent developments in wireless communication and portable computing devices, there is a shift in the interpretation of the term telematics towards applications based on wireless communication. In addition, it is often presumed that at least one computing device is involved which is not a conventional computer or laptop. Throughout this work the focus will be on telematics applications according to this interpretation of the term telematics.

This chapter gives an introduction into the enabling technologies for telematics applications, in particular those concerned with transportation. A definition of the

[1] See Nora and Minc (1978)

term *transport telematics* is given and those transport telematics applications which are of particular concern to motor carriers are surveyed.

2.2 Enabling technologies

In this section the most important enabling technologies for telematics applications concerning commercial vehicle operations are surveyed, i.e. wireless communication, positioning systems, and Geographical Information Systems.

2.2.1 Wireless communication

Wireless communication is a prerequisite for information exchange between vehicles or drivers, and stationary systems. Wireless communication is primarily realised using electromagnetic waves, however, short distances can also be bridged using infrared communication. The coverage of very large areas encounters several problems which originate from the characteristics of electromagnetic waves. In an idealised scenario electromagnetic waves spread equally in all directions and their intensity reduces quadratically with the distance to the transmitter. In real-life, reflections, absorptions, scattering, refractions, and electromagnetic perturbations reduce the intensity of electromagnetic waves significantly. Thus, the reduction of intensity reduces in the fourth power with the distance[1]. That is, in order to double the geographic coverage, a 16 times stronger transmitter is needed. As electromagnetic waves with equal frequencies sent by different transmitters interfere with another, radio communication requires the reservation of the used radio frequencies. However, frequency ranges are limited and wireless communication techniques have to appropriately deal with this problem. In this section the most important wireless communication techniques are described.

2.2.1.1 Trunked radio

Conventional radio communication requires the reservation of radio frequencies for each user group. The licensed radio frequencies are only used by one user group and each user group must license their own frequency. To deal with the increasing demand and the finite amount of available radio spectrum, trunked radio system use several frequencies which are allocated to individual users on demand. This allows for more efficient utilisation of limited frequencies because each user group does not require a dedicated channel.

TETRA (**TE**rrestrial **T**runked **Ra**dio)[2], is a European standard for modern digital trunked radio defined by the European Telecommunications Standards Institute (ETSI). For civil systems in Europe the frequency bands 385-390 MHz, 395-399.9 MHz, 410-430 MHz, 450-470 MHz, 870-876 MHz, and 915-921 MHz, have been allocated for TETRA by ERC Decision (96)04[3]. Data transfer with TETRA is

[1] See Freeman (1987)

[2] TETRA was formerly known as abbreviation of **T**rans **E**uropean **T**runked **Ra**dio

[3] See European Radiocommunications Committee (1996)

at 7.2 kbps. Due to the low frequency used, high levels of geographic coverage can be achieved with a smaller number of transmitters. TETRA was developed to meet the needs of organisations and companies who need fast one-to-one and one-to-many voice and data communication in their daily work. Users of trunked radio communication are typically public safety and security organisations such as police, fire and rescue forces, but also other professional user groups such as commercial vehicle fleets.

2.2.1.2 Cellular communication

In cellular communication networks the covered area is partitioned into multiple cells and each cell is serviced by its own low range transmitter. Each mobile telephone communicates with a transmitter within range and the information is forwarded within the cellular network towards the recipient. Cellular communication networks have the advantage that only a small distance to the stationary transmitters has to be bridged. Furthermore, transmitters which are far apart can use the same frequencies as illustrated in figure 2.1. When a mobile user travels from one cell to another the communication link has to be reconfigured. As neighbouring cells use

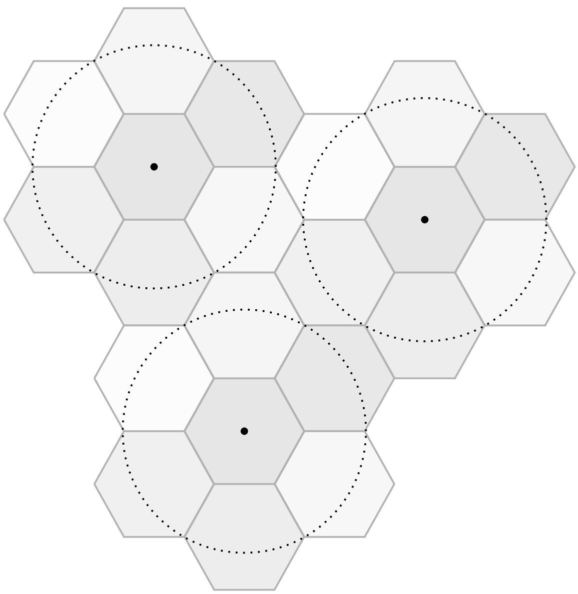


Fig. 2.1: Base stations of cells with the same colour can use the same frequencies due to the limited range of the signals

different frequencies, the mobile device switches its frequency to the new cell. This reconfiguration is called *handover*.

First generation mobile communication system were introduced in the eighties and were analog systems primarily developed for voice communication.

The *Global System for Mobile Communication* (GSM) differs significantly from its predecessors. Both signalling and speech channels are digital, which means that it is seen as a second generation mobile communication system. For GSM the frequency bands 890-915 MHz and 935-960 MHz have been allocated by ERC Decision (94)01[1]. GSM allows bitrates of 9.6 kbps for data transfer.

Second generation cellular communication networks were built mainly for telephone calls and only had slow data transmission capabilities. Due to the rapid changes in technology, these factors do not meet the requirements of today's wireless revolution. The *Universal Mobile Telecommunications System* (UMTS) is a third generation mobile communication system allowing much higher bitrates. UMTS is designed with both terrestrial and global satellite components. For terrestrial UMTS the frequency bands 1900-1980 MHz, 2010-2025 MHz and 2110-2170 MHz, and for satellite UMTS the frequency bands 1980-2010 MHz and 2170-2200 MHz have been allocated by ERC Decision (97)07[2]. The bitrate is 144 kbps for full outdoor mobility applications in all environments, 384 kbps for limited-mobility outdoor applications in the micro and macro cellular environments (in urban and suburban areas), and 2048 Mbps for low-mobility outdoor applications, particularly in the pico and micro cellular environments (in indoor and urban areas).

2.2.1.3 Satellite communication

Voice and data communication can be realised by the use of communication satellites. Satellite communication can be classified according to whether the satellites are positioned in a geostationary orbit (GEO) or low-Earth orbit (LEO).

GEO satellites orbit in an altitude of 35785 kilometres above the Earth. In this height they move at a speed which is synchronous with the circulation of the Earth. Thus, they are stationary relative to a point on the Earth's surface. Due to the large distance to the Earth each geostationary satellite can cover a huge area, see figure 2.2. Assuming a minimum ground antenna elevation angle of 10 degrees, a single satellite in geostationary orbit can cover about 34 percent of the Earth's surface. The large altitude of a geostationary satellite results in a one-way time delay of at least 0.25 seconds[3].

Geostationary satellite communication systems are provided by Inmarsat and Qualcomm[4]. Inmarsat operates nine geostationary satellites which provide global coverage. Only four of the satellites are active, and five are for emergency back-up. Communications via the Inmarsat-C system are data or message-based. Messages are

[1] See European Radiocommunications Committee (1994)
[2] See European Radiocommunications Committee (1997)
[3] See Comparetto and Ramirez (1997)
[4] See Inmarsat (2005) and Qualcomm (2005)

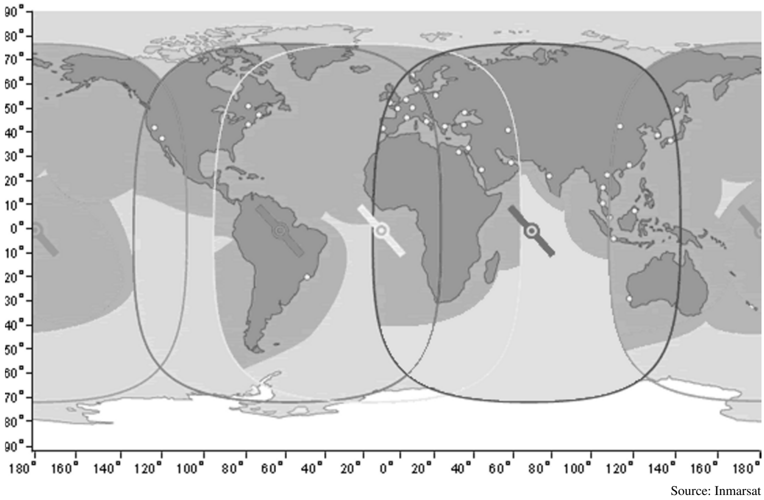


Fig. 2.2: Global coverage with four geostationary satellites

transferred to and from an Inmarsat-C terminal at an bitrate of 600 bps. Frequencies are 1530.0-1545.0 MHz (downlink) and 1626.5-1645.5 MHz (uplink). The EutelTRACS service provided by Qualcomm is realised by two satellites covering Europe, the Mediterranean, an the Middle East. The satellites operate on the frequency bands 10.70-11.70 GHz and 12.50-12.75 GHz (downlink) and 14.00-14.25 GHz (uplink) providing low bitrate data communications. The downlink bitrate is between 5 kbps and 15 kbps while the uplink is between 55 bps and 165 bps.

Low-Earth orbit satellite communication systems use satellites which are in much lower orbits than geostationary satellites. Due to the low orbits, those satellites are not geostationary and orbit the Earth in 1.5 to 10 hours depending on the height. They provide a small geographic coverage and thus, more satellites are required if continuous coverage is desired. Due to the lower distance to the Earth, less intense and smaller transmitters are required - for both the satellites and the ground side systems. ORBCOMM[1] provides LEO communication systems with 35 satellites orbiting in a height of about 775 kilometres. As figure 2.3[2] illustrates, global coverage is not continuously. Short gaps in the coverage are closed by one of the passing satellites in a few minutes, providing global coverage with latency. The satellites operate at frequencies of 137.00-138.00 MHz (downlink) and 148.00-150.05 MHz (uplink). The downlink bitrate is at 4.8 kbps while the uplink is at 2.4 kbps.

[1] See ORBCOMM (2005)

[2] The illustration has been rendered by SaVi - Wood et al. (1996)

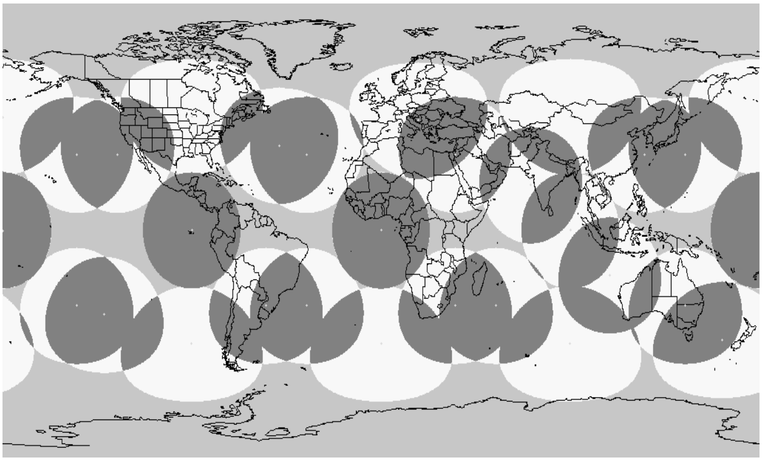


Fig. 2.3: Low-Earth satellite communication systems achieve global coverage only with latency

2.2.1.4 Dedicated Short Range Communication

Dedicated Short Range Communications (DSRC) is a short to medium range wireless communication technique specifically designed for automotive use, i.e. vehicle-to-vehicle and vehicle-to-infrastructure communication. Due to the short range of the signals, DSRC is particular useful to provide location based services. Today, the main application of DSRC is Electronic Toll Collection (ETC). In future, DSRC will also support safety critical communications such as collision avoidance and hazard warning. DSRC systems use infrared or the radio spectrum, particularly microwaves in the frequency bands 5.795-5.805 GHz and 5.805-5.815 GHz[1].

2.2.1.5 Broadcasting

Broadcasting is mainly used for the distribution of *traffic and travel information*. The *Radio Data System* (RDS) is a standard for sending small amounts of digital information using conventional FM radio broadcasts. RDS uses the technique of adding data at a bitrate of 1187.5 bps on an existing stereo transmission in a way that the data is carried inaudibly. The *Traffic Message Channel* (TMC) is a service of the RDS which provides traffic information coded according to the ALERT-C protocol[2]. TMC messages are processed by in-vehicle RDS-TMC receivers which use this information to give route guidance considering the current traffic and weather conditions.

Digital Audio Broadcasting (DAB) is a technology for broadcasting audio in digital form. DAB was developed within the Eureka 147 Project and is now standardised by the European Telecommunications Standards Institute (ETSI). DAB uses the

[1] See Electronic Communications Committee (2002)
[2] See International Organisation for Standardization (2003)

frequencies 47-68 MHz, 174-240 MHz and 1452-1492 MHz. The gross data capacity for the entire DAB signal is approximately 3 Mbps, of which approximately 2.3 Mbps can be used for data transmission. Considering redundancy in channel encoding, a net useful payload in the range of 0.6-1.7 Mbps is available[1]. As the bitrates are magnitudes higher than those available with RDS-TMC, more sophisticated traffic and travel information can be broadcasted using DAB.

2.2.2 Positioning systems

Determining the position of vehicles is a fundamental task in transportation. The knowledge of vehicle positions is important for autonomous navigation, collective traffic observation, and tracking of commercial vehicles. This section presents an overview of positioning systems which can be used in commercial vehicles.

2.2.2.1 Dead reckoning

If the vehicle's position is known at one point in time, the position can be continuously determined by advancing the known position using course, speed, time and distance travelled. This technique is known as dead reckoning.

The vehicle's speed and the distance travelled can be determined using wheel odometers. Each turn of the wheel is identified and the distance travelled can be determined by the circumference of the wheels. Odometer inaccuracies result from wear and slip of the wheels. The course can be determined using magnetic or gyroscopic compasses. As the magnetic field of the Earth is very weak, the accuracy of the course determined by magnetic compasses is subject to all kinds of magnetic perturbations. Gyroscopic compasses use mechanical or optical gyroscopes to determine the course of a vehicle. A mechanical gyroscope consists of a rapidly spinning wheel set in a framework that permits it to tilt freely in any direction or to rotate about any axis. The momentum of such a wheel causes it to retain its attitude when the framework is tilted. An optical gyroscope, laser or fibre, measures the interference pattern generated by two light beams, travelling in opposite directions within a mirrored ring or fibre loop, in order to detect very small changes in motion[2].

The advantage of dead reckoning is that it allows fully autonomous positioning within the vehicle. The main disadvantage of dead reckoning is its unbounded accumulation of errors. Thus, dead reckoning requires a method for position correction such that errors accumulated since the last correction can be eliminated. An extensive discussion of dead reckoning sensors as well as methods for position correction is out of scope of this work and can be found in Czommer (2000).

2.2.2.2 Satellite positioning

A *Global Navigation Satellite System* (GNSS) allows a mobile receiver to determine its exact position anywhere in the world. Currently, there are three GNSS among

[1] See Bower (1998)

[2] See Britannica Online (2005)

which only the first one is fully operational: the United States' *Global Positioning System* (GPS), the Russian Federation's *Global'naya Navigatsionnaya Sputnikovaya Sistema* (GLONASS), and the European Union's *Galileo*. All GNSS use trilateration to locate a mobile receiver through calculations involving information from a number of satellites.

Satellite positioning of vehicles relies on the knowledge of the exact position of satellites and the distance of the vehicle to those satellites. Let d_{vs} denote the distance of vehicle v to satellite s and let (x_s, y_s, z_s) denote the satellite's position in space. The position (x_v, y_v, z_v) of vehicle v can be calculated with the help of the following equation.

$$d_{vs} = \sqrt{(x_s - x_v)^2 + (y_s - y_v)^2 + (z_s - z_v)^2}$$

This equation has three variables and three satellites are sufficient to determine the position of the vehicle. As illustrated in figure 2.4, two spheres intersect in a circle. The intersection of three spheres results in two distinct positions. Only one of them is near the Earth's surface whereas the other is far in space and can be discarded.

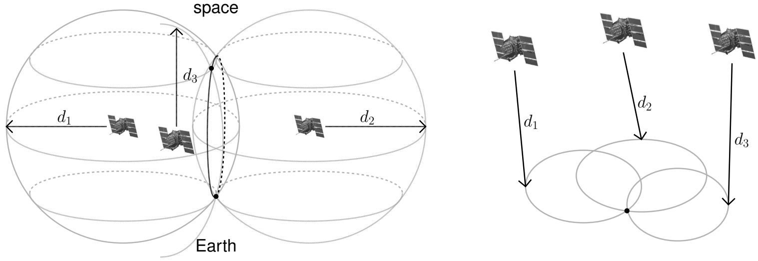


Fig. 2.4: Satellite positioning with three satellites

In an ideal scenario each satellite s sends a signal which includes the exact time t_s of transmission. The signal travels with the speed of light c (which is approximately 300 000 km/s) towards the receiver where it arrives at the time t_v. The distance between satellite and receiver is

$$d_{vs} = c \cdot (t_v - t_s).$$

In real-life, however, the clocks of satellites and receivers in the vehicles are not always running synchronously. Due to the high speed of light an error of 1 μs results in a difference of 300 metres. The clocks of the satellites are very precise and are regularly synchronised by ground control. The clocks of the receivers, however, are usually not as precise and are not synchronised with the satellite clocks. Fortunately, the precise time of the internal clocks of the receiver is not required. Instead, the time is calculated using a fourth satellite signal. Let $\tilde{t_s}$ denote the locally determined time of satellite s and let $\delta_s := \tilde{t_s} - t_s$ denote the time bias. Analogously, let $\tilde{t_v}$ denote the locally determined time of the receiver and let $\delta_v := \tilde{t_v} - t_v$ denote the time bias. The pseudo range $\tilde{d}_{vs}$ based on the locally determined time can be used to determine the position by

$$\begin{aligned}\tilde{d}_{vs} := c \cdot (\tilde{t_v} - \tilde{t_s}) &= c \cdot (t_v - t_s) + c \cdot (\delta_v - \delta_s) \\ &= d_{vs} + c \cdot (\delta_v - \delta_s) \\ &= \sqrt{(x_s - x_v)^2 + (y_s - y_v)^2 + (z_s - z_v)^2} + c \cdot (\underbrace{\delta_v - \delta_s}_{=:w_v}).\end{aligned}$$

As the clocks of all satellites are synchronised regularly each satellite s has approximately the same time bias δ_s. If $\delta_v - \delta_s$ is substituted by w_v the above equation has four variables and four satellites are sufficient to determine the position of the vehicle.

Accuracy

Satellite positioning is subject to several influences having effect on the quality of positioning. The accuracy of satellite positioning suffers from the following influences:

- Satellite clocks
  Although atomic clocks used in satellites are very precise, no clock is absolutely precise, and the clock error continuously grows between subsequent synchronisations by ground control.
- Satellite orbits
  Satellites are positioned in very precise orbits, however, slight shifts of the orbits are possible due to gravitation forces.
- Atmospheric effects
  Satellite signals do not travel at the vacuum speed of light as they transit the ionosphere and troposphere. Free electrons in the ionosphere as well as variations in temperature, pressure, and humidity contribute to the speed of radio waves.
- Multi-path effects
  Satellite signals can be reflected by high rise buildings and other obstacles. In urban areas the probability that satellite signals cannot reach the receiver on the direct line is very high, in particular, if the satellite is in a low horizon.

Differential GNSS[1] uses the fact that inaccuracies caused by those influences can be expected to be similar for receivers located near to each other. In order to improve the accuracy of positioning of a vehicle, a second receiver located at a fixed known position can be used. The second receiver is used to measure the signal error. This allows to calculate corrections which can also be applied to the position obtained by the vehicle. Let (x_b, y_b, z_b) denote the known position of the base station and $(\tilde{x}_b, \tilde{y}_b, \tilde{z}_b)$ denote the calculated position from the satellite signals. Analogously, let

[1] Differential GNSS is often referred to as *differential GPS* as today GPS is the only fully operational GNSS.

$(\tilde{x}_v, \tilde{y}_v, \tilde{z}_v)$ denote the calculated position of the vehicle. The difference between the measured position and the exact position can be expected to be the same for the base station as for the vehicle. The vehicle's position (x_v, y_v, z_v) can then be calculated by

$$(x_v, y_v, z_v) = (\tilde{x}_v + x_b - \tilde{x}_b, \tilde{y}_v + y_b - \tilde{y}_b, \tilde{z}_v + z_b - \tilde{z}_b).$$

This correction, however, is only effective if the same satellites are used for calculating the position. Correction data is usually transmitted via one-way broadcasting and thus, it is not known which satellite combination is used by the vehicle. As the number of satellite combinations which may be used for positioning is very high, it is not practical to transmit correction data for all satellite combinations to the receiver. Instead, correction data Δr_{bs} for the pseudo ranges of all satellites is transmitted. The pseudo ranges measured by the base station b and the vehicle are

$$\begin{aligned}\tilde{d}_{bs} &:= c \cdot (\tilde{t_b} - \tilde{t_s}) \\ &= d_{bs} + \underbrace{c \cdot (\delta_b - \delta_s) + \varepsilon_{bs}}_{=:\Delta r_{bs}}\end{aligned}$$

and

$$\begin{aligned}\tilde{d}_{vs} &:= c \cdot (\tilde{t_v} - \tilde{t_s}) \\ &= d_{vs} + c \cdot (\delta_v - \delta_s) + \varepsilon_{vs}\end{aligned}$$

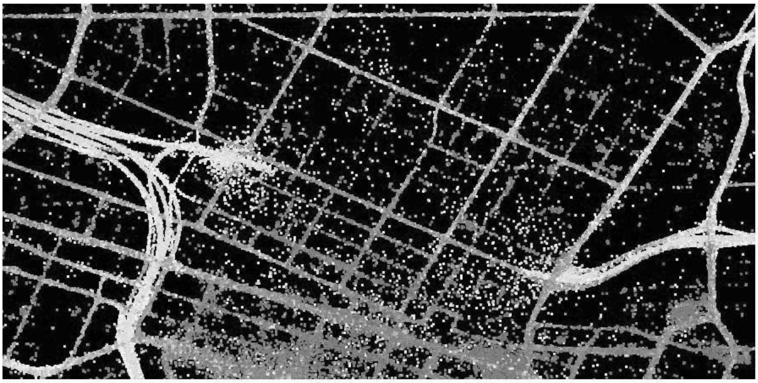
where ε_{bs} and ε_{vs} denote the error due to the various influences. It is assumed that for nearby receivers the errors ε_{bs} and ε_{vs} are almost identical and that the position can be calculated using the adjusted pseudo ranges by:

$$\begin{aligned}\hat{d}_{vs} := \tilde{d}_{vs} - \Delta r_{bs} &= d_{vs} + c \cdot (\delta_v - \delta_s) + \varepsilon_{vs} - \Delta r_{bs} \\ &= d_{vs} + c \cdot (\delta_v - \delta_s) + \varepsilon_{vs} - c \cdot (\delta_b - \delta_s) - \varepsilon_{bs} \\ &= d_{vs} + c \cdot (\delta_v - \delta_b) + \underbrace{\varepsilon_{vs} - \varepsilon_{bs}}_{\approx 0} \\ &\approx d_{vs} + c \cdot (\delta_v - \delta_b) \\ &= \sqrt{(x_s - x_v)^2 + (y_s - y_v)^2 + (z_s - z_v)^2} + c \cdot (\underbrace{\delta_v - \delta_b}_{=:w_v}).\end{aligned}$$

Under the assumption that $\varepsilon_{bs} = \varepsilon_{vs}$ an equation with four variables has to be solved and four satellites are sufficient to determine the position.

Availability

Satellite positioning requires the "visibility" of the satellites. Due to tunnels, urban canyons, and other obstacles, vehicles cannot always receive the signals of four satellites. Furthermore, it is not always guaranteed that the signals received are sufficiently precise due to multi-path effects. As illustrated in figure 2.5, insufficient satellite visibility can result in poor positioning. Therefore, satellite positioning systems usually cannot be used to fully replace dead reckoning systems. Instead, they should be used in conjunction with dead reckoning systems in order to provide high availability of accurate positioning.



Source: Mason (2005)

Fig. 2.5: Obstacles such as tunnels hinder satellite positioning

2.2.2.3 Cellular communication based positioning

In cellular communication networks base stations are distributed throughout the covered area. There is a variety of ways in which a position can be determined in cellular communication networks such as GSM and UMTS. According to Drane et al. (1998), the most important techniques for positioning in cellular communication networks are cell of origin (COO), propagation time, time difference of arrival (TDOA), and angle of arrival (AOA) which are illustrated in figure 2.6.

Cell of origin (COO)

The simplest but also most inaccurate way is to approximate the vehicle's position by the position of the COO, i.e. the cell which is used for communication. The COO only gives an approximation of the vehicle's position and, as illustrated in figure 2.6, it is not guaranteed that the base station associated to the COO represents the closest base station to the vehicle. In the GSM network COO can give an accuracy of less than 100 metres in urban areas and up to 35 kilometres in rural areas.

Propagation time

This involves measuring the time it takes for a signal to travel between a base station and a mobile telephone or vice versa. Alternatively, this approach might involve the measurement of the round-trip time of a signal transmitted from a source to a destination which is then echoed back to the source, giving a result twice that of the one-way measurement. The former requires very stable and accurate clocks and the knowledge of the exact time of signal transmission. The latter does not rely on such synchronisation between the mobile telephone and the base station(s) and thus, is the more common means of measuring propagation time. Three base stations are required to give unambiguous positioning.

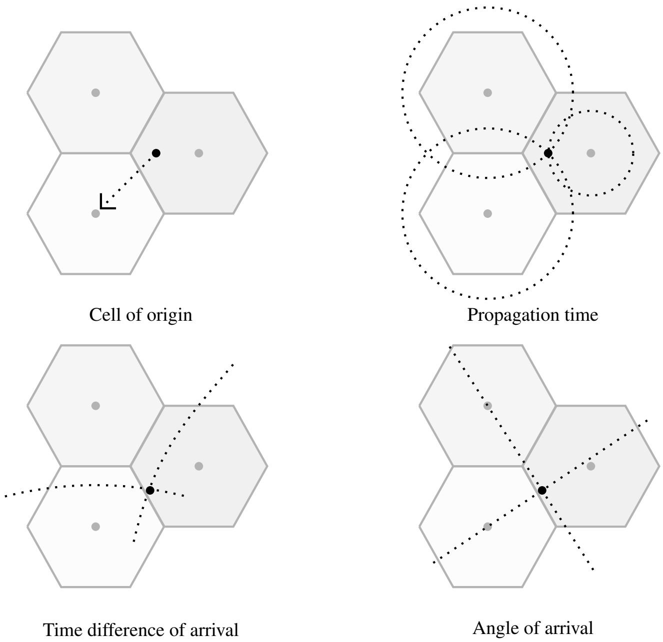


Fig. 2.6: Cellular communication based positioning

Time difference of arrival (TDOA)

A mobile telephone can listen to signals transmitted simultaneously by several base stations and measure the time difference between each pair of arrivals. Each TDOA measurement defines a curve on which the mobile telephone must be located. Let (x_A, y_A) and (x_B, y_B) denote the known positions of the base stations A and B and let Δt_{AB} denote the TDOA. The position (x_v, y_v) can be determined by

$$\sqrt{(x_A - x_v)^2 + (y_A - y_v)^2} + c \cdot \Delta t_{AB} = \sqrt{(x_B - x_v)^2 + (y_B - y_v)^2}.$$

Two or three TDOA measurements are required for unambiguous positioning. An important issue for TDOA systems is the need to have some means of establishing the synchronicity of the base stations. For self-positioning the base station must transmit the signal at the same time (or with a known time offset), for remote positioning the signal transmitted from the mobile telephone is received by several base stations and there must be a known time relationship between the receiver clocks.

Angle of arrival (AOA)

This involves measuring the AOA of a signal from a base station at a mobile telephone or the AOA of a signal from the mobile telephone at a base station. In either case a single measurement produces a straight line. If the mobile telephone is not on the direct line through two different base stations, both lines intersect at the vehicle's position.

2.2.2.4 Signpost systems

Signpost systems can be used for positioning of vehicles as they pass roadside beacons. Vehicles and beacons are equipped with DSRC devices and when a vehicle passes a signpost, it receives encoded locational identifier information from the signpost. Positioning using signpost systems relies on a sufficient number of signposts located along the roads. As deploying the required infrastructure for widespread areas is very expensive, signposts are primarily used if other positioning methods cannot be used or if the accuracy is insufficient, e.g. in covered areas and roadways.

2.2.3 Geographical Information Systems

Geographical Information Systems (GIS) are systems for capturing, storing, checking, manipulating, analysing, and displaying data which are spatially referenced to the Earth[1]. Among the most important applications of GIS are *Geographical Information Systems for Transportation* (GIS-T)[2]. This section gives a brief introduction into GIS-T and its applications.

2.2.3.1 Data collection

Transport related data can be captured using airborne or land-based methods. Although satellites and aeroplanes can be used to obtain aerial images of the Earth's surface at relatively low cost, road mapping information required for GIS-T databases can often only be obtained by land-based methods.

Aerial images

It is possible to identify some transport related data, e.g the road network, using aerial images[3]. This of course, is only possible if the geographical features are visible from the sky. Hence, aerial images do not lend themselves well to mapping roads in dense urban canyons and tree canopy areas. Furthermore, prevailing traffic regulations cannot be identified using aerial images as road signs can not be captured.

Mobile mapping

Mobile mapping involves the use of a vehicle equipped with sensors and cameras to capture transport related data while driving. This ensures fast and low-cost data acquisition. In principle, all information that a participant in traffic is able to see can be acquired[4]. The required processing of raw data, e.g. for road sign recognition, can be done in real-time or after the collection of the raw data.

[1] See Department of the Environment (1987)
[2] See Miller and Shaw (2001)
[3] See Baumann (2002)
[4] See Benning and Aussems (1998)

2.2.3.2 Data representation

Two fundamental geographical data models, the raster model and the vector model[1], are used for representing geographical data.

Raster model

In a raster representation, the Earth's surface is divided into an array of cells that are usually square or rectangular. All persistent geographical variation is expressed by assigning attributes to these cells. These attributes can represent the type of the cell, e.g. building or road. When information is represented in raster form all details about variations within the cells are lost and the cell's attributes can only represent a simplification. For a precise representation the cell size has to be small enough in order to minimise the amount of information lost. However, a small cell size dramatically increases the storage memory required for the raster representation. Data encoded using the raster data model are particularly useful as a backdrop map display because they look like conventional maps and can communicate a lot of information quickly to humans. However, the raster representation is not very useful for computerised analysis of the road network.

Vector model

In the vector model, each object in the real world is classified into a geometric type: point, line, or area. Points are recoded by their coordinates, lines as points defining the vertices of the line, and areas as a series of lines that close to form a polygon. The vector representation of the road network is particularly useful as it is very storage efficient and well suited for various applications. Most transport related applications, e.g. route calculations, are based on a vector data model of the road network, e.g. the *Geographic Data File*.

2.2.3.3 The Geographic Data File

The *Geographic Data File* (GDF) is a standard used to describe and exchange road network-related data. Major map vendors such as TeleAtlas and NAVTEQ provide maps in GDF. The current GDF version 4.0 was published as an ISO standard in 2004[2]. The conceptual data model of GDF identifies *features, attributes* and *relationships* which are defined in catalogues[3]. The *Feature Catalogue* provides a definition of real world objects such as roads and buildings. The *Attribute Catalogue* defines a number of characteristics of features and possibility of relationships. The *Relationship Catalogue* describes relations between features that may be used, e.g. to indicate the right-of-way.

The GDF structure is organised in three levels which are illustrated in figure 2.7. In level 0 the fundamental geometrical and topological entities used are described.

[1] See Longley et al. (2001)
[2] See International Organisation for Standardization (2004)
[3] See Comité Européen de Normalisation: Technical Committee 278 (1995)

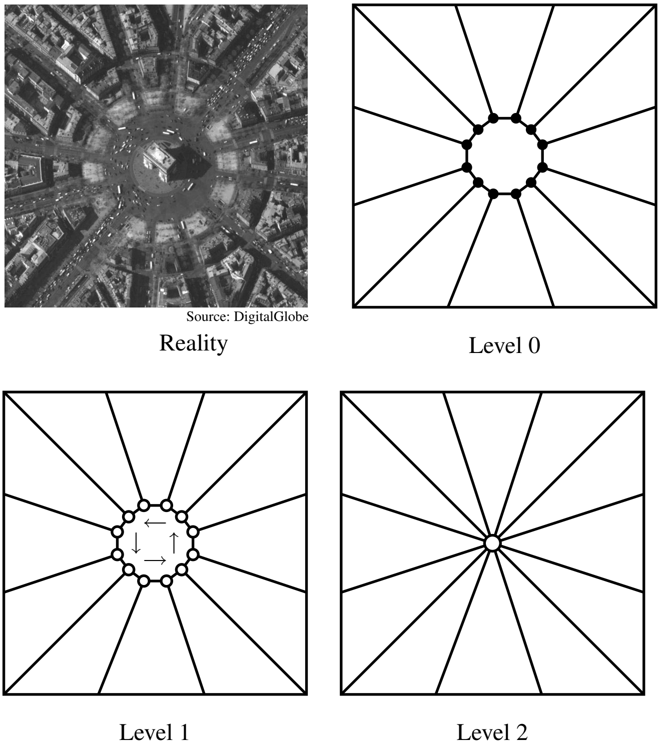


Fig. 2.7: GDF levels

The entities are nodes (0-dimensional), edges or polylines (1-dimensional) and faces or polygons (2-dimensional). Level 1 adds the possibility to describe real world geographic objects with their characterising properties. The *simple features* in level 1 use the level 0 entities as their geometrical and topological representation and combine them with attributes and relationships. Examples for simple features are signposts, junctions, road elements, and address areas. The features can have attributes such as number of lanes and permissible direction of travel. Relationships between junctions and road elements can be used to model prohibited manoeuvres, e.g. those indicated by *"no left turn"* road signs. In level 2 simple features can be aggregated to describe *complex features*. Examples of complex features are roundabouts and highway junctions.

Depending on the kind of application different levels are used. As guidance through complex junctions requires a high level of detail, level 1 is required for route guidance applications. Level 2 is more appropriate for the calculation of shortest routes, as it is not required to consider the full complexity of how to traverse complex junctions and roundabouts.

2.2.3.4 Applications

Among the fundamental applications in GIS-T are geocoding, route calculation, and map matching.

Geocoding

Geocoding is the process of assigning geographic coordinates, in particular longitude and latitude, to address information. Address information typically includes country, city, street name, and house number. Usually a postal code is added which significantly eases finding the approximate location corresponding to the address. Although address information uniquely defines a certain location, the representation is not very well suited for computerised processing. Geographic coordinates are particular important to determine approximate distances between two points A and B, e.g. between the current position of a vehicle and its destination. For points which are near to each other the Euclidean distance can be calculated by

$$d_{AB} :=\| x - y \|_2 = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}$$

whith (x_A, y_A) and (x_B, y_B) denoting the coordinates of A and B. The Earth's curvature has to be considered when calculating the distance between points which are far apart, see figure 2.8. Let (λ_A, μ_A) and (λ_B, μ_B) denote longitude and latitude of

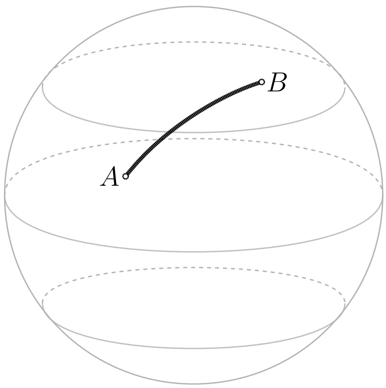


Fig. 2.8: Distance between A and B on the Earth's surface

A and B and let the Earth's diameter of approximately 6370 km be denoted by R. The distance on the Earth's surface can be approximated by

$$d_{AB} := R \cdot \arccos\big(\sin\mu_A \cdot \sin\mu_B + \cos\mu_A \cdot \cos\mu_B \cdot \cos(\lambda_A - \lambda_B)\big).$$

In road transport vehicles cannot travel on the direct line between two points, instead, they travel along the road network. As the distance travelled along the road network is usually longer than the direct line, a fix multiplier[1] is often used to approximate the travel distance.

Route calculations

One of the most important applications in transportation is the calculation of the least cost route from one point A to another point B. Alternatively, the route with the shortest distance, fastest travel time, etc. can be calculated. This problem is known as *shortest path problem* in directed networks, see figure 2.9. The shortest path problem is the problem of finding a path from one point to another minimising the sum of all costs c_{nm} associated to the arcs in the path. The shortest path problem can be solved using the well-known *Dijkstra* algorithm or the A^* algorithm, see Ahuja et al. (1993).

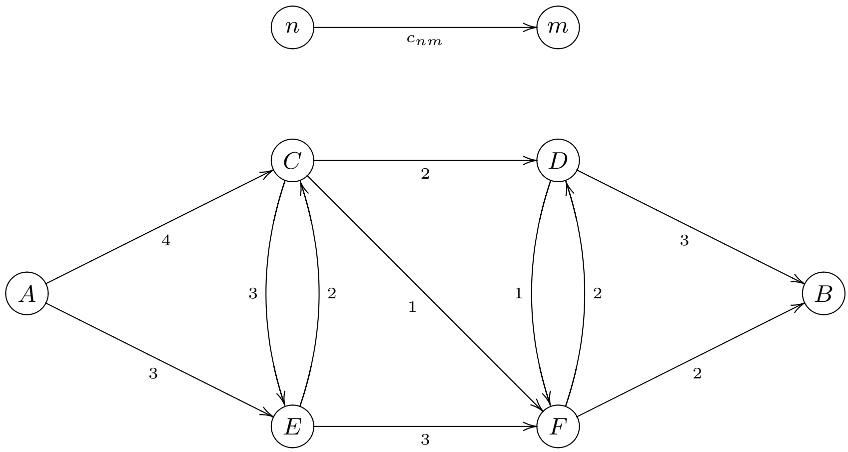


Fig. 2.9: Shortest path problem in a directed network

Map matching

Map matching is the problem of matching a given (set of) estimated location(s) with the corresponding position(s) in the digital representation of the real world, i.e. the digital map. The goal is to match the estimated location of a vehicle with an arc in the network, and then determine the street and the position on the street that corresponds to the vehicle's actual location. Map-matching algorithms are used to reconcile inaccurate locational data with an inaccurate digital map. They can be classified into *point-to-point*, *point-to-curve*, and *curve-to-curve* methods:[2]

[1] This multiplier is typically between 1 and $\sqrt{2}$ (the maximum deviation according to the *Manhattan distance*).

[2] See Bernstein and Kornhauser (1996)

- point-to-point matching: a single vehicle position is matched to the closest node in the road network
- point-to-curve matching: a single vehicle position is matched to the closest point on an arc in the road network
- curve-to-curve matching: a set of vehicle positions is matched to the best "fitting" path in the road network and the vehicle positions are accordingly matched to points on that path

Of course, it is not necessary to determine the distance to every node, arc or path in the road network. Instead, one can first identify those nodes, arcs or paths that are "reasonable" and then only calculate the distance to those nodes, arcs, or paths.

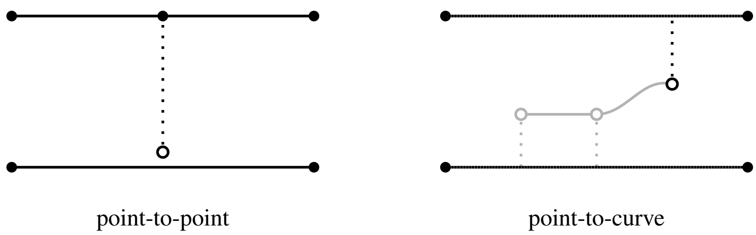


Fig. 2.10: Problems with point-to-point and point-to-curve map matching

As illustrated in figure 2.10, point-to-point map matching encounters problems originating in the way in which the map was digitised, i.e. roads which are digitised in more detail are more likely to be matched. The fact that neither point-to-point nor point-to-curve map matching use any historical information leads to further problems of these methods. Curve-to-curve map matching makes use of historical information and thus, is less sensitive to outliers. Curve-to-curve map matching can be further improved by adding topological information to the algorithm. A thorough discussion of map matching techniques is out of scope of this work and the reader is referred to Czommer (2000), White et al. (2000), and Quddus et al. (2003) for further information.

2.3 Transport telematics

According to Gillette (1988) the *"combinations of computers and telecommunication devices to form new infrastructures are as important to national economies in the twentieth century as the combination of steam engines and carts to form railroads in the nineteenth"*. It is only natural that the combination of transportation and telematics is an important task in the twenty-first century as transportation, computers, and telecommunications are of fundamental importance to every economy. *Transport telematics* concerns the use of telematics with focus on transport organisation, information, and control[1]. The term transport telematics is often used synonymously

[1] See Prognos AG (2001)

Traffic and travel information	• Pre-trip information • On-trip driver information • On-trip public transport information • Personal information services • Route guidance and navigation
Traffic management	• Transportation planning support • Traffic control • Incident management • Demand management • Policing/enforcing traffic regulations • Infrastructure maintenance management
Vehicle-related	• Vision enhancement • Automated vehicle operation • Longitudinal collision avoidance • Lateral collision avoidance • Safety readiness • Pre-crash restraint deployment
Commercial vehicles	• Commercial vehicle pre-clearance • Commercial vehicle administrative processes • Automated roadside safety inspection • Commercial vehicle on-board safety monitoring • Commercial vehicle fleet management
Public transport	• Public transport management • Demand responsive transport management • Shared transport management
Emergency management	• Emergency notification and personal security • Emergency vehicle management • Hazardous materials and incident notification
Electronic payment	• Electronic financial transactions
Safety	• Public travel security • Safety enhancement for vulnerable road users • Intelligent junctions

Fig. 2.11: Fundamental TICS services

to the terms *Intelligent Transportation Systems* (ITS) and *Transport Information and Control Systems* (TICS), however, ITS and TICS are more general and certain applications related to transportation are also termed ITS or TICS applications if they provide transport related use of computer technology - even if no telecommunication is involved. A composite taxonomy of TICS services, as standardised by International Organisation for Standardization (1997), is shown in figure 2.11. A detailed description of all of these applications can be found in PIARC Commitee on Intelligent Transport (1999).

Some transport telematics applications are already widespread and well-known to many transportation professionals and private users. For example, many new (private) cars are equipped with on-board navigation systems considering real-time traffic and travel information. According to a study by Frost & Sullivan[1] the number of commercial vehicles equipped with telematics devices will rise from 75 550 in 2001 to over 5.4 million in 2009. Total market revenues are anticipated to grow from € 169.5 million in 2001 to € 4.7 billion by 2009. As commercial vehicles will be increasingly equipped with telematics devices, the market for telematics services will increase from € 84.3 million in 2001 to just under € 3.2 billion by 2009. It is anticipated that one of the main application of services demanded will focus on logistics and transportation management.

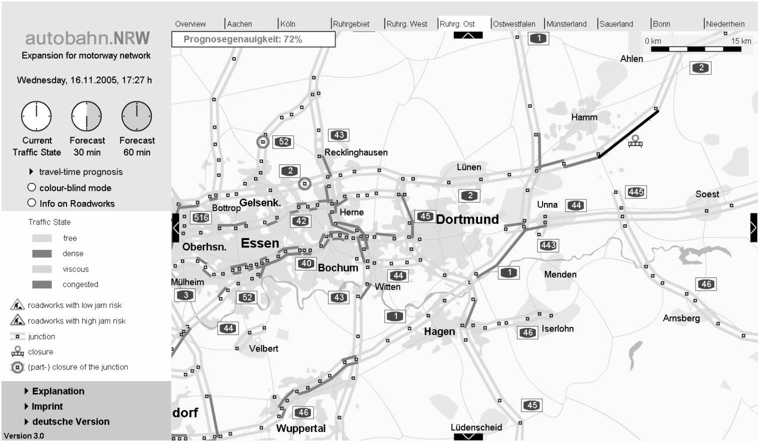
This section gives a short introduction into the major transport telematics applications concerned with commercial vehicle operations.

2.3.1 Traffic and travel information

Traffic and travel information includes information about prevailing and current conditions and regulations concerning the transport infrastructure, points of interest, traffic, and weather. This information is usually categorised into pre-trip and on-trip information. Pre-trip information is used to plan the transport. The transport demand, i.e. the decision whether a transport is done or not, may depend on pre-trip information concerning travel distances and times, tolls, and multi-modal interchange possibilities such as roll-on/roll-off on piggy-back trains or ferries. On-trip information is used to react on the dynamism of transport related issues. Route guidance can be provided dynamically including arrival time estimations considering current traffic and weather conditions. Route guidance instructions are given by acoustic and/or visual turn-by-turn driving instructions. Location based services such as information about nearest truck stops, gas stations, maintenance and repair facilities, etc. can be provided when the vehicle is en-route.

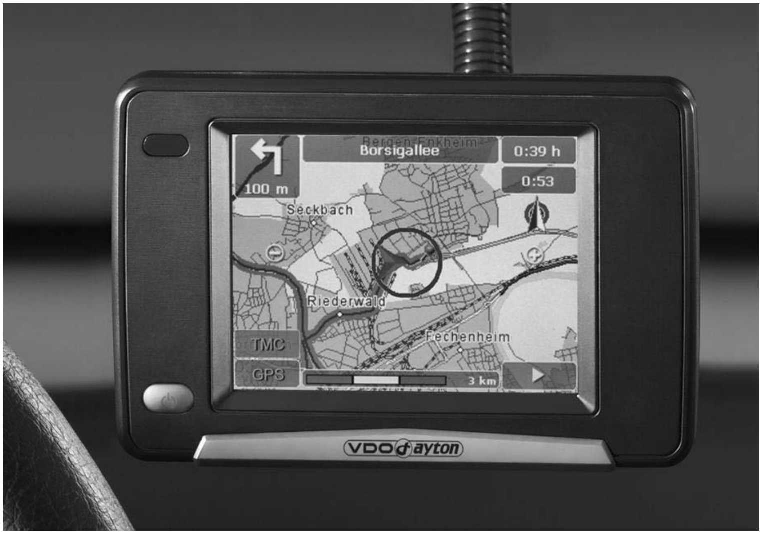
Traffic and travel information are often collected by the transport infrastructure provider and can be disseminated through a variety of media[2]. In North Rhine-Westphalia, for example, traffic forecasts are provided in the Internet, see figure 2.12. Another example is the *Traffic Message Channel* (TMC), a service using the *Radio Data System* (RDS) for sending traffic and travel information using conventional FM

[1] See Frost & Sullivan (2002)
[2] See Kopitz and Marks (1999)



Source: Autobahn NRW (2005)

Fig. 2.12: Traffic forecasts in the Internet



Source: VDO Dayton

Fig. 2.13: On-board navigation system using the TMC

radio. Navigation systems can use this information to calculate shortest routes considering delays due to congestion. Figure 2.13 shows an on-board navigation system using the TMC.

2.3.2 Vehicle-related safety

Vehicle-related telematics applications primarily aim at improving the safety. The European Union initiative to half the number of traffic fatalities until 2010[1] has lead to several projects concerning the use of vehicle-to-vehicle communications based on Dedicated Short Range Communication to improve traffic safety, for example, *Inter-Vehicle Hazard Warning*[2], *FleetNet - Internet on the Road*[3] and *CarTALK 2000*[4]. Vehicle-to-vehicle communications can improve road traffic safety and efficiency by expanding the driver's perception and enabling cooperative driving and platooning[5].

2.3.3 Commercial vehicles

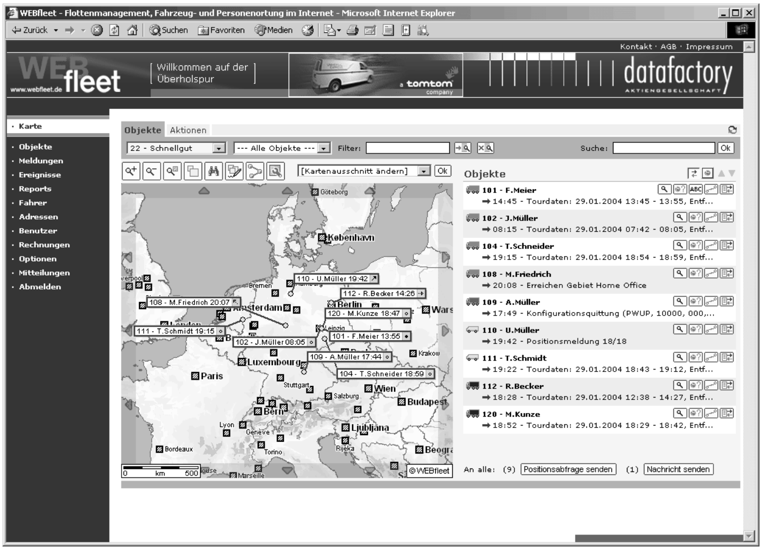
2.3.3.1 Pre-clearance and safety inspections

Control of credentials and other documents, safety status, and weights causes delays for commercial vehicles which increase the cost of transportation. Transport telematics can help in minimising the length and quantity of such stops. Pre-clearance systems enable commercial vehicles to have credentials, other documents, safety status, and weights checked automatically at normal road speeds and without lengthy controls.

2.3.3.2 Fleet telematics

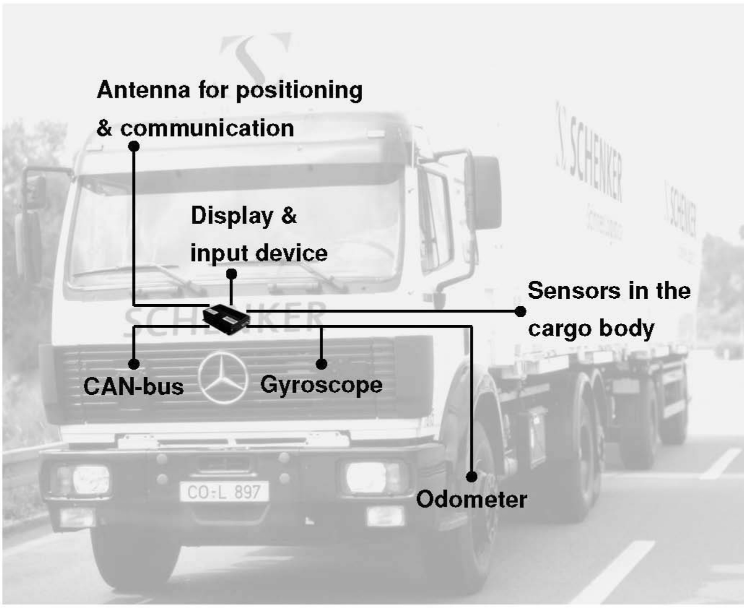
Fleet Telematics Systems (FTS) allow the information exchange between a commercial vehicle fleet and their central authority, i.e. the dispatching office. A FTS typically consists of mobile Vehicle Systems (VS) and a stationary Fleet Communication System (FCS). The FCS may be a stand alone application maintained by the carrier or an internet service running by the supplier of the system. The FCS usually includes a data base in which all vehicle positions and messages are stored. Digital maps are often included which allow to visualise vehicle positions and traces. Figure 2.14 shows an example of such a FCS. Typical components of VS are illustrated in figure 2.15. The communication with the FCS is realised by trunked radio, cellular, or satellite communication. Positioning of vehicles is usually realised by satellite positioning systems and/or dead reckoning using gyroscope and odometer. Usually, the VS is equipped with a simple input device allowing drivers to send predefined

[1] See European Commission (2001)
[2] See DEUFRAKO (2002)
[3] See Hartenstein et al. (2003)
[4] See Reichardt et al. (2002)
[5] See Tsugawa (2005)



Source: datafactory AG (2005)

Fig. 2.14: Fleet Communication System



Source (Background image): Schenker AG

Fig. 2.15: Vehicle System

status messages. Drivers may add simple content, e.g. numeric values, but usually cannot enter arbitrary text. Besides of the messages sent by drivers, some VS can also automatically submit messages, e.g. the vehicle's position, data from sensors in the cargo body, or vehicle data from the CAN-bus. In 2002 major European commercial vehicle manufacturers, namely Daimler Chrysler, MAN, Scania, DAF, IVECO, Volvo, and Renault, have agreed to give third parties access to vehicle data using the CAN-bus as a connection. The *Fleet Management Standard* (FMS) is an open standard allowing, dependent on the vehicle equipment, access to vehicle data such as fuel consumption, engine data, or vehicle weight[1].

2.3.4 Emergency management

Telematics systems can provide notifications in case of emergencies, also known as Mayday services. Emergency notifications can be initiated manually, e.g. by the driver pushing a panic button, or automatically, e.g. triggered by airbag, front impact, side impact, and rollover sensors. Vehicle position and the type of damage are transmitted to the service centre. After receiving and verifying the emergency message, the operator at the service centre initiates appropriate measures in co-operation with relevant external organisations, such as police, fire brigades, or medical services. Access to additional information can be provided to the emergency service, e.g. driver-specific information concerning medical data and name of doctor, or data on the nature and condition of hazardous goods. According to Xu (2000) emergency management systems can reduce rescue times by as much as 30 per cent.

2.3.5 Electronic Toll Collection

Electronic Toll Collection (ETC) systems enable drivers to pay tolls automatically on a no-cash basis without stopping at toll stations. ETC systems enable transactions to be undertaken at expressway traffic speed. They are usually based on Dedicated Short Range Communication. However, some ETC systems are also based on satellite positioning and cellular communication techniques. The German TollCollect system[2], for example, uses GPS/GSM and DSRC as a supplement for streets where satellite positioning is likely to be too inaccurate or impossible, e.g. in tunnels.

[1] See FMS-Standard Working Group (2002)
[2] See TollCollect (2005)

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