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Design of Energy Independent Remote Monitoring System for Cargo Wagons

Master's thesis

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- define technical conditions and parametres for the system
- analyze suitable technologies for realization of the system
- design the architecture of the system
- design and construct the subsystem installed in the wagon and verify it by practical testing (data consumption in different modes of work, reliability, ...)

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Student's name and signature

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Declaration

I hereby submit for the evaluation and defence the master's thesis elaborated at the CTU in Prague, Faculty of Transportation Sciences.

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CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Transportation Sciences

DESIGN OF ENERGY INDEPENDENT REMOTE MONITORING SYSTEM FOR CARGO WAGONS

Master's thesis

May 2017

Jakub Ryšavý

Key Words

Cargo, Freight, Wagon, Car, Railway, Internet of Things, Telecommunications, GNSS, Low Energy, Sensors

Abstract

The subject of this master thesis is to sum up the current work in the field of railroad smart cargo wagon, design the system's architecture and analyse suitable technologies for realization of the system. It includes the author's smart wagon device construction and testing.

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2 LIST OF ABBREVIATIONS

Abbreviation	Definition
3GPP	3rd Generation Partnership Project
A/D	Analog/Digital
AT&T	American Telephone and Telegraph
BTS	Base Transciever Station
BTS	Base Transceiver Station
C/A	Coarse/Acquisition
CCTV	Closed-Circuit Television
CDMA	Code Division Multiple Access
CO	Carbon monoxide
CPU	Central Processing Unit
DCS	Digital Cellular System
DCS	Digital Cellular System
EC	European Comission
EDGE	Enhanced Data rates for GSM Evolution
EEPROM	Electrically Erasable Programmable Read-Only Memory
EGNOS	European Geostationary Navigation Overlay Service
ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
EU	European Union
FDMA	Frequency Division Multiple Access
GLONASS	Globalnaja navigacionnaja sputnikovaja sistěma
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Groupe Spécial Mobile
GSM	Groupe Spéciale Mobile
GSMA	Global System for Mobile Communications Alliance
GSM-R	GSM-Railway
GSM-R	Global System for Mobile Communications – Railway

H_2	Dihydrogen
HSPA	High Speed Packet Access
HTML	HyperText Markup Language
I/O	Input/Output
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IP	International Protection
ISP	In-system programming
ITS	Intelligent Transportation Systems
ITU-R	International Telecommunication Union - Radiocommunications
LE	Low Energy
LoRa	Low Radiation
LoRaWAN	Low Radiation Wide - Area Network
LPG	Liquified Petroleum Gas
LPWAN	Low-Power Wide-Area Network
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MIMO	Multiple - Input Multiple - Output
MIPS	Million Instructions Per Second
NB-IoT	NarrowBand Internet of Things
PHP	Hypertext Preprocessor
PSTN	Public Switched Telephone Network
QAM	Quadrature amplitude modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAM	Random-Access Memory
RF	Radio Frequency
RF	Radio Frequency
SBB	Schweizerische Bundesbahnen
SIG	Special Interest Group
SIM	Subscriber Identification Module
SIM	Subscriber Identification Module

SPI	Serial Peripheral Interface
SQL	Structured Query Language
SRAM	Static Random Access Memory
SWOT	Strengths Weaknesses Opportunities Threats
TCN	Train Communication Network
TCP/IP	Transmission Control Protocol/Internet Protocol
UMTS	Universal Mobile Telecommunication System
USA	United States of America
USB	Universal Serial Bus
USSR	Union of Soviet Socialist Republics
WAN	Wide Area Network
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

3 INTRODUCTION

The aim of this thesis is to develop the idea of a smart cargo wagon, design the most suitable architecture and choose the right technologies and settings with respect to identified constraints.

Using geolocation systems and some sensors, it is possible to track the transported goods and its condition in real-time. Road cargo operators usually already have at least GPS trackers on their cars, whereas rail cargo operators don't. This paper will deal with the issues of application of GPS and different sensors into the specific environment of rail cargo.

So far, the only known application of this technology is in Switzerland, where the Swiss Federal Railways (SBB) cooperate on the project with Bosch. [1]

This thesis has two main parts. The first part will be dealing with the problem theoretically. System architecture will be designed and suitable technologies will be discussed and compared.

In the second part, a functional prototype of a smart cargo wagon device is described and tested in terms of energy and data consumption, two main limiting factors.

4 THE CONCEPT OF SMART WAGON

“The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.” [2]

The concept of smart wagon aims to allow the cargo freight wagons to transmit data relating to their position and cargo to a central control centre. As a result, the company can deliver goods faster and provide the customers with more detailed information about their goods. [3]

To achieve that, the wagons are equipped with sensors that collect data on their current position as well as the condition of wagons and the carried goods. Connectivity hardware wirelessly transfers this data to a remote server, which makes it available to the rail operator. Knowing the real-time information about the position of the wagons and condition of the goods, the organization of transport can be faster and more efficient, logistic processes optimized, and transportation costs reduced. An anticipatory condition-monitoring feature notifies users of wear on components so that upcoming repairs can be planned well in advance and according to requirement. [3]

Figure 1: Bosch and SBB smart wagon concept. [3]

4.1 CURRENT SOLUTIONS AND PROPOSALS IN THIS FIELD

So far, there is only one real application of this technology, and that is being tested by SBB and Bosh. There are also some academic papers dealing with this topic.

4.1.1 SBB AND BOSCH

Swiss Federal Railways cooperate with Bosch on the application of a smart freight wagon. Bosch use their sensors from automotive industry to deliver the solution. The project is currently being tested on a few freight wagons, eventually they want all the company's 7000 freight wagons to be connected to the Internet.

The wagon is equipped with sensors monitoring temperature, humidity, vibrations, door closure, brakes and freight condition. Every wagon also carries a GPS module.

The more distant sensors communicate with the main module via Bluetooth. The main module is connected to the Internet via GPRS. Bosch claims that their solution can work up to 6 years on one battery charge.

The data are collected from the sensors and send to a cloud database. There they are processed and the goods recipient can view where the goods currently are. SBB can also see where their wagons are. With all the information from the sensors, they can ensure that the condition of goods during transport were as required. By precise recording of operational performance, maintenance can be optimized by better scheduling.

They believe that this system will help to transport goods to its destination more quickly, safely, efficiently and will reduce the transport cost, too. [4] [5]

4.1.2 AT&T AND MAERSK

This is not a railway project, but it is very similar. Moller-Maersk Group is a company operating more than 290 000 refrigerated containers. AT&T is an American telecommunications conglomerate investing heavily in the Internet of Things.

The solution they are working on for Maersk will allow Maersk to monitor the temperature inside their containers, ensuring that whatever's inside doesn't fall out of a set range. When the temperature drops near a problematic level, operators get a warning, and when it goes above that level they get a series of gradually-increasing alerts. These alerts are also documented in a computer system, creating a record that can be reviewed and analysed.

A secondary benefit is that if the container goes astray it could be tracked. Containers tend to fall of into the ocean during big storms and there is a surprising amount of undocumented loss associated with accidents like that.

The in-container device contains a cellular 3G SIM card, a GPS unit and a ZigBee radio and antenna, as well as multiple interfaces for connecting into the refrigerated container's controller. The device can operate with two-way connectivity from almost anywhere in the world. [6]

4.1.3 IEEE PAPERS

Mr. Joffrey Clarhaut, Mr. Said Hayat and Mr. Hamza Tahiri from Lille University and French Institute of Science and Technology for Transport, Development and Networks developed a concept of a railroad smart wagon. They focused on safety functions. They were trying to develop a system that would prevent or mitigate damages caused by the accidents that occur inside the freight wagons.

As examples, they chose two railroad accidents – the Eurotunnel Shuttle 7539 from 1996 and the Iron Highway CP-121 from Canada, 1997. In the Eurotunnel incident, the train got stuck in the tunnel with a fire on board. The fire was extinguished with difficulty because of the confined environment in the tunnel. The tunnel and the train were badly damaged and the entire infrastructure along 1 km had to be rebuilt. In the Iron Highway accident, a trailer transported on the train became unlocked and moved into a position in which it was in excess of the width of the wagon. As the train rolled under a road bridge, the trailer struck the bridge support columns. The trailer was extensively damaged and operators had to close the road for several days because many columns of the bridge were damaged. [7] [8]

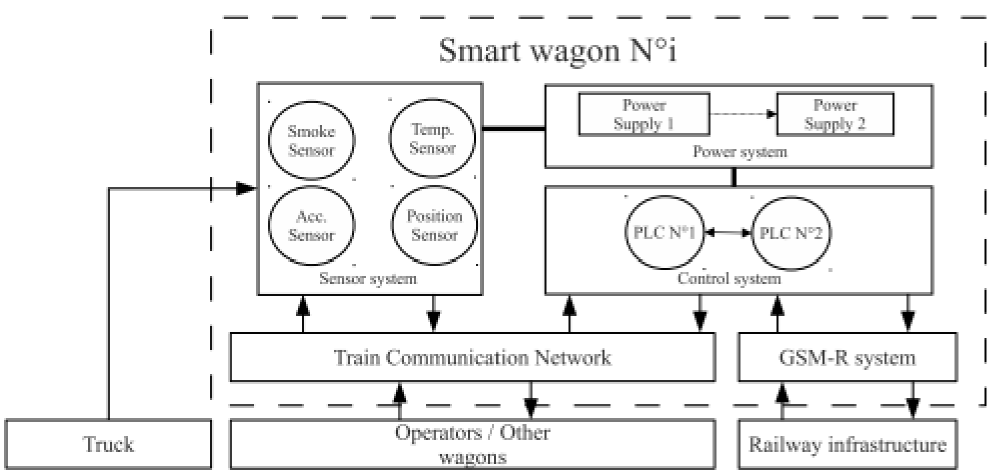

Figure 2: Smart wagon architecture by French Institute of Science and Technology for Transport. [7]

Their proposed infrastructure is designed for a truck or a trailer carried by the wagon, therefore it includes an interface for communication with the truck. The system architecture is depicted in Figure 2. This concept uses GSM-R to connect the wagon to the Internet and Train Communication Network (TCN) defined by IEEE 1473 standard. This standard is designed for wired connections in passenger trains. The wagon to truck interface is realized through IEEE 802.11p, a special version of technology known also as Wi-Fi that was modified for purposes of vehicle-to-vehicle communication. [7] [8]

5 METHODOLOGY

When designing the system, I will follow the footsteps of FRAME, the European ITS Framework Architecture.

"An ITS architecture is the conceptual design that defines the structure and/or behaviour of an integrated Intelligent Transport System (ITS)." [9]

ITS architectures help to ensure that the resulting ITS deployment:

- Can be planned in a logical manner
- Integrates successfully with other systems
- Meets the desired performance levels
- Has the desired behaviour
- Is easy to manage
- Is easy to maintain
- Is easy to extend
- Satisfies the expectations of the users [9]

5.1 FRAME SYSTEM ENGINEERING PROCESS

The system engineering process consists of several parts, as depicted in Figure 3.

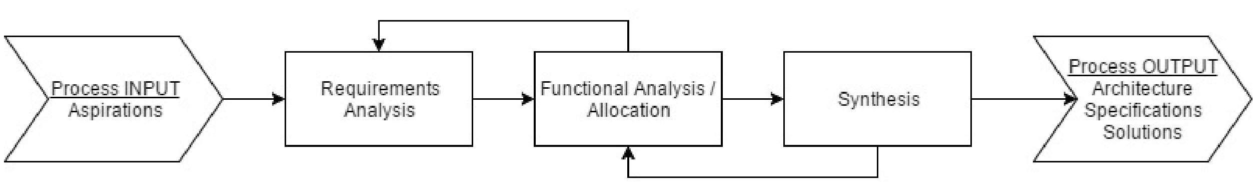

Figure 3: System Engineering Process. [10]

5.1.1 ASPIRATIONS

Aspirations are aggregated from many different sources. Focused, specific and comprehensive requirements are essential for generating an integrated solution. Examples of aspiration sources are:

- Customers
- Legacy systems
- Design constrains
- Performance
- Maintenance
- Operational Issues
- Measures of effectiveness
- Missions and environment
- Training
- End users [10]

5.1.2 REQUIREMENT ANALYSIS

Requirement Analysis sets and refines requirements in the context of system goals and characteristics. Three main areas of requirements are:

- Performance requirements
- Functional requirements
- System constraints

During the requirement analysis process, user needs and models are defined. User needs are derived from stakeholder aspirations and should be unambiguous, testable with objective tests, traceable, singular, unique and allocated to at least one user.

User needs are summarised in a User Needs Table. [10]

5.1.3 FUNCTIONAL ANALYSIS

Functional analysis is an iterative process successively defining low-level functions. Functional architecture is defined in this phase. [10]

5.1.4 SYNTHESIS

Defines logical sets of functions and allocates them to portions of deployment. Also defines internal and external interfaces. Physical and communicational architectures are created during synthesis.

The relations between FRAME products are depicted in Figure 4. [10]

5.2 USING THE FRAME ARCHITECTURE

The FRAME Architecture was developed by the EC project KAREN (1998-2000) and first published in October 2000. Since then, the architecture has been constantly kept up to date.

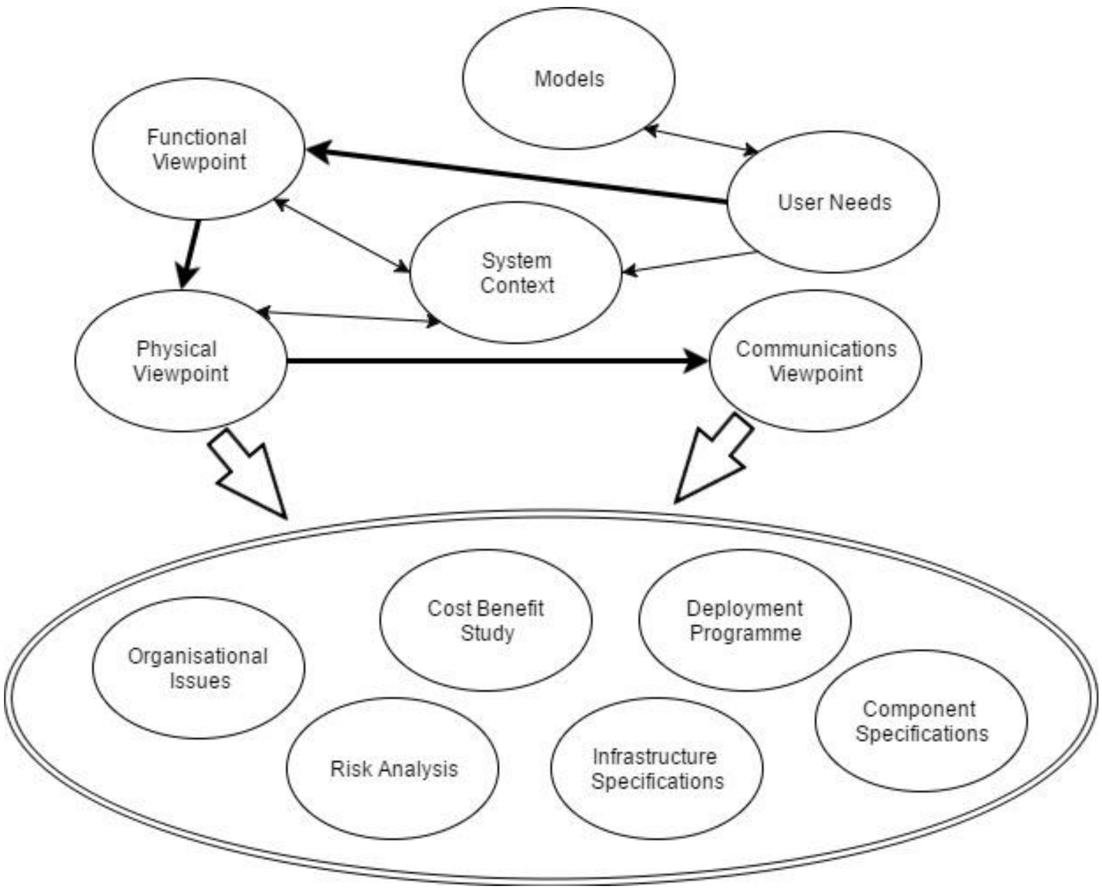

Figure 4: Relations between FRAME products. [10]

FRAME Architecture covers the first two phases of the system development process – User Needs and Functional Viewpoint. It contains pre-defined user needs for different areas of ITS deployment. In order to keep the number and size of the User Needs to manageable proportions, many details have been omitted. Some of these are in the descriptions of the corresponding functions, whereas others are options to be defined by the system purchaser or supplier. [11]

6 USERS

This chapter will identify users of this system and list their typical user stories and needs.

User groups that can benefit from having real-time information about wagon location and condition are depicted in Figure 5.

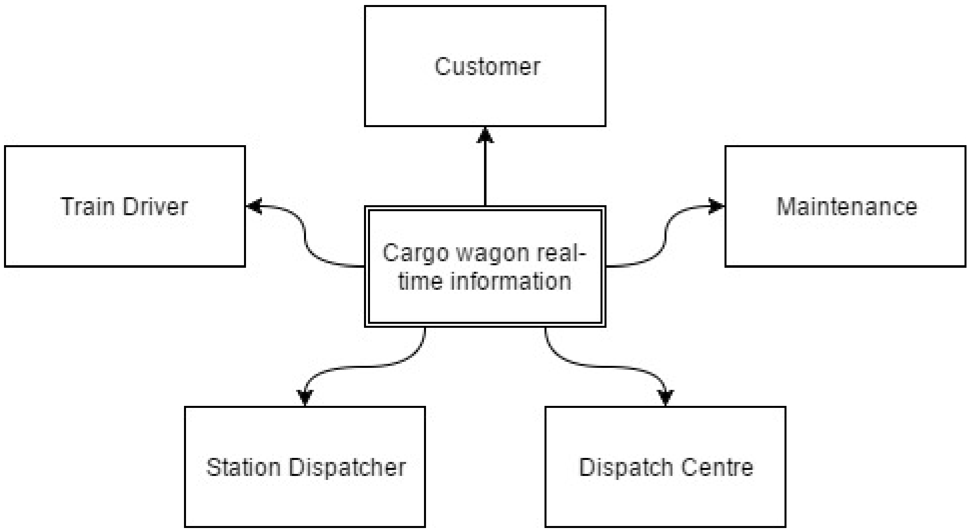

Figure 5: Users of smart cargo wagon technology.

6.1 USER STORIES

User stories are written from the perspective of end system user. A user story is a natural language description of one or more features of a system. User stories for each identified user group are listed in Table 1

User Group	User Story
Dispatch Centre	Dispatch centre coordinates company's fleet. Without smart wagon technology, they must rely on station dispatchers' information about wagon movement between stations and have very limited information about wagons on their way between terminal stations. Having the smart wagon technology implemented, the dispatch centre's overview about the fleet is much more detailed and up-to-date. The dispatch centre can react faster and make more informed decisions. Dispatch centre is the only user group to have full access to all available data from the system.
Station Dispatcher	Station Dispatcher controls his railway station. Accepts, builds and dispatches trains. Without smart wagon technology, he must verify each inbound and outbound wagon manually. He also must manually mark down where he puts the wagon in the railyard of his station.

	With the smart wagon technology, none of these manual tasks are required. Wagons report their positions automatically and using geofencing, list of wagons present in any particular station is generated automatically. And with the geolocation accuracy down to metres, the station manager knows exactly where the wagon is located at any given moment, which helps him to find any wagon in the railyard easier and faster. The dispatcher also receives alarms when something wrong happens in wagons located inside the station.
Train Driver	Train driver is responsible for the train he drives. Having its wagons equipped with the smart wagon technology, he receives alarms from the wagons if something goes wrong. Together with dispatch centre operators, who receive the same alarms, they can find the best solution for critical situation.
Maintenance	Maintenance workers keep the company's fleet serviceable through regular service inspections. Having information from sensors monitoring wagon condition, service intervals could be extended or shortened depending on the wagon's wear and tear. The use of smart wagon technology would both increase efficiency of wagon's maintenance and improve the safety of its usage.
Customer	Customers entrust their goods to the rail cargo company. The only thing they know about their goods during its transfer is the estimated time of delivery. With smart wagon technology, the customers could be allowed to track their goods almost in real-time, with information about goods condition included. The time of arrival to destination can be estimated more accurately, and from the sensors installed inside the wagon, the customers can make sure their goods were treated as required.

Table 1: User stories.

6.2 USER NEEDS

FRAME provides general user needs for all ITS projects, but specific user needs still need to be defined for each particular project.

6.2.1 FRAME USER NEEDS

There are several different user need groups based on the ITS system deployment listed in the Appendix C to the E-FRAME document [11]. The relevant group for an independent remote monitoring system for cargo wagons is Group 9 (Figure 6), Freight and Fleet Management, specifically Group 9.5.1, Road Freight Management.

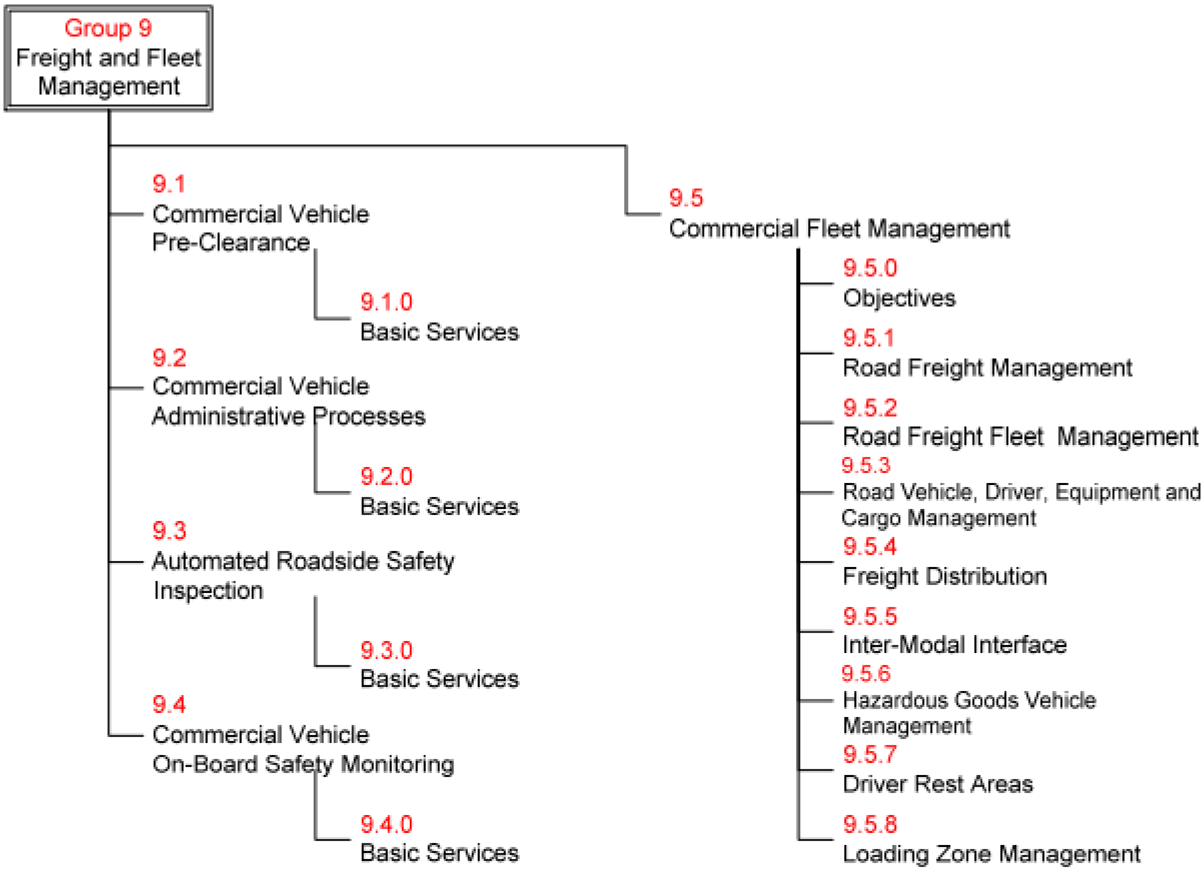

Figure 6: FRAME User Needs group. [11]

For Group 9.5.1, following user needs are listed in [11]:

Group	No.	Description
9.5.0 Objectives	9.5.0.1	The system shall support fleet and freight operations for all sizes of operators, including single vehicle companies.
	9.5.0.2	The system shall be able to incorporate additional regulations as and when required, and provide an indication of compliance.
9.5.1 Road Freight Management	9.5.1.1	The system shall enable the exchange of information, e.g. market enquiries, offer and supplier evaluation data, contracts, invoices, payments etc. between parties, e.g. consignors, consignees etc.

	9.5.1.2	The system shall be able to provide information about a cargo, (e.g. loading status, contents, delays, delivery status, disputes etc.) to the fleet management centre in real time.
	9.5.1.3	The system shall be able to prepare and update official documents, e.g. transport orders, customs declarations, hazardous goods declarations, notices of dispatch etc. in a controlled manner, and assist the process of checking them.
	9.5.1.4	The system shall be able to exchange official documents (e.g. transport orders, customs declarations, hazardous goods declarations, notices of dispatch etc.) between vehicles, the fleet management centre and the relevant authorities in a controlled manner
	9.5.1.5	The system shall be able to transfer any information about a journey (e.g. route, (hazardous or oversize) cargo, etc.) to the relevant authorities (e.g. traffic control centres, traffic information centres etc.) when required.
	9.5.1.6	The system shall be able to track the physical (e.g. temperature) and administrative status (e.g. shipment status, delivery status, etc.) of a cargo throughout its journey.
	9.5.1.7	The system shall enable the consignee to receive information, (e.g. delivery note, invoice etc.) directly from the vehicle.
	9.5.1.8	The system shall enable the shipper to receive information (e.g. destination, contractual data etc.) directly from the vehicle.
	9.5.1.9	The system shall be able to confirm electronic documents with electronic signatures.
	9.5.1.10	The system shall be able to reconstitute the route taken by any item, and the contracts that have been fulfilled (tracing function).
	9.5.1.11	The system shall be able to analyse the costs and performance of the freight and fleet management) operations.
	9.5.1.12	The system shall be able to transfer any data that has been recorded on a vehicle to the home base and/or any other authorised third party.

Table 2: FRAME User Needs. [11]

Besides Group 9, user needs from Group 1 relate to this system. Group 1 contains user needs related to general requirements on ITS systems in terms of architectural properties, data exchange, adaptability, constraints, continuity, cost/benefit, expandability, maintainability, quality of data content, robustness, safety, security, user friendliness, special needs privacy and communications. The whole list of these requirements can be seen in [11], pages 72-80.

6.2.2 SPECIFIC USER NEEDS

Specific user needs are derived from the environment, purpose and other circumstances of the system deployment.

Group	No.	Description
1 On-board devices	1.1	The system shall use communication technologies that are available along the railroad.
	1.2	The system's on board devices shall be able to operate for at least a year without an external power source.
	1.3	The system's on board devices shall be resistant to vibrations caused by the motion of vehicles along the railway.
	1.4	The system's on board devices shall be protected by a case meeting IP68 requirements (complete protection against dust and protection against long immersion periods and water pressure).
	1.5	The system shall be modular to accommodate different types of sensors for different types of wagons.
2. Interface	2.1	The system shall provide customers with real-time tracking information
	2.2	The system shall use geofencing to list wagons currently located in a defined area (station) for station dispatching purposes.
	2.3	In case of detection of danger from smoke or chemical sensors, the system shall inform the train driver and the dispatch centre.
	2.4	The system shall provide all gathered data to the dispatch centre in real-time.

Table 3: Specific user needs.

7 FUNCTIONAL VIEWPOINT

A Functional Viewpoint shows the functionality that will be required to fulfil the User Needs, and hence the Stakeholder Aspirations. When using the FRAME Architecture, the Functional Viewpoint is shown as a Data Flow Diagram that contains Functions, Data Stores and Terminators, and the Data Flows between them. [12]

The system receives data through sensors. On-board devices collect the data and upload them to an online database. Data is processed and if a danger (e.g. smoke on smoke detectors) is detected, the dispatch centre and the train driver are alerted.

Different types of interfaces with different rights to access the data are provided to user groups. These user groups can view data relevant for their use cases.

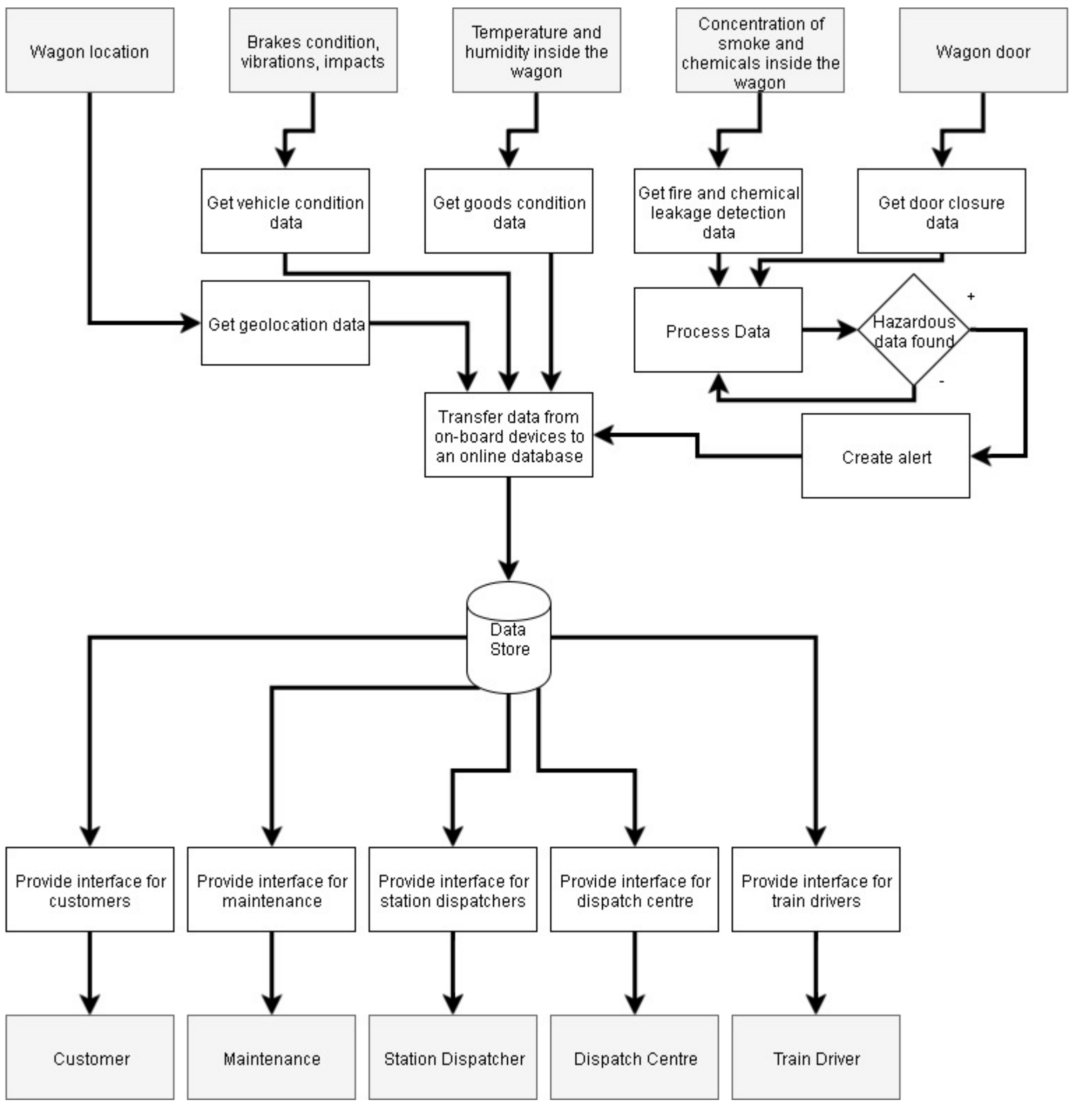

Figure 7: Functional Viewpoint.

8 PHYSICAL VIEWPOINT

Once the Functional Viewpoint is complete, each function and data store needs to be located, either within a sub-system, or within a module that is part of a sub-system. Once this has been completed, the component specifications can be created from the definitions of the functions and data stores within them.

In this case, functions are distributed between two sub-systems: the on-board devices and the web server, as seen in Figure 8.

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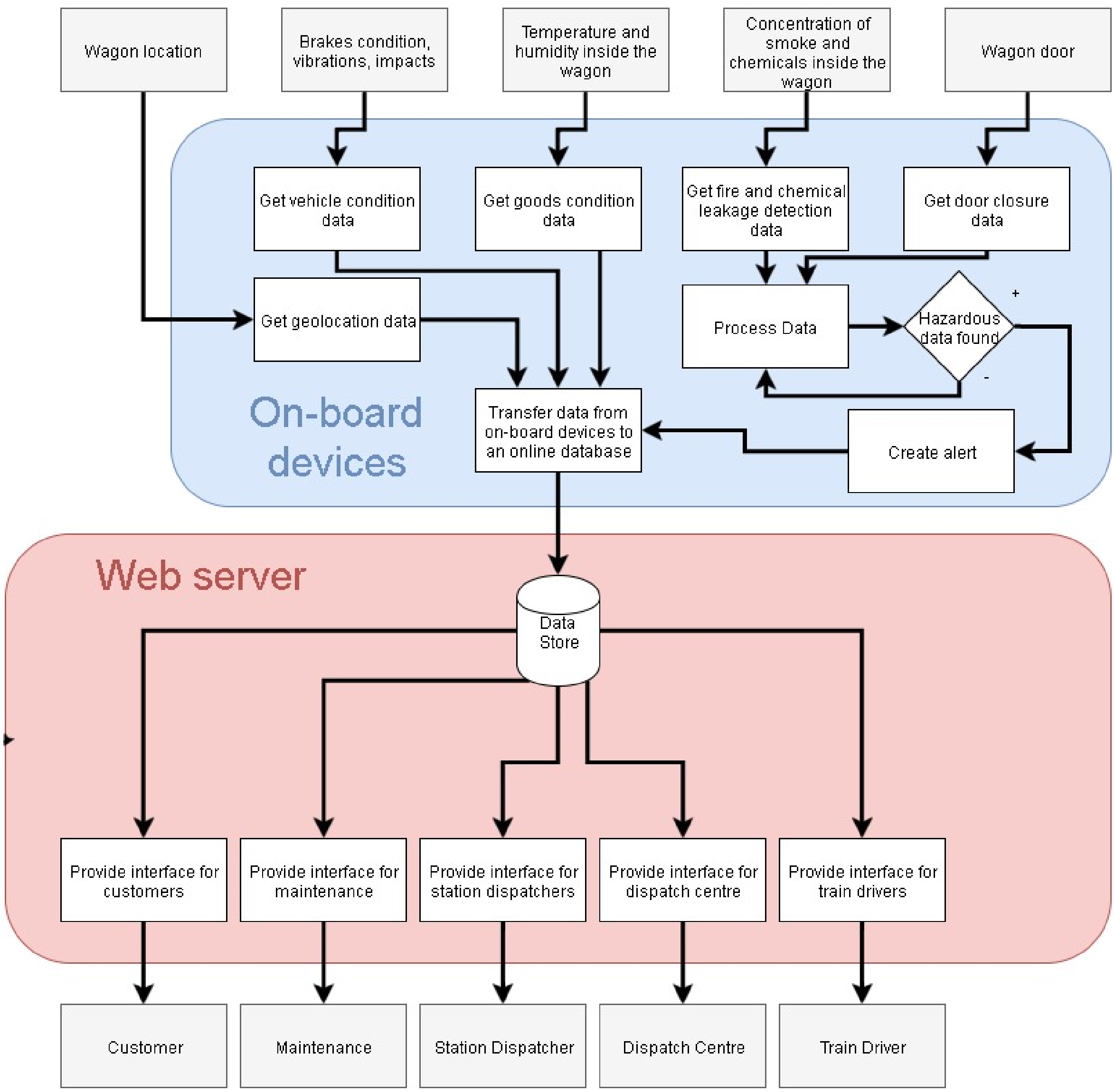


Figure 8: Physical Viewpoint.

9 COMMUNICATIONS VIEWPOINT

The system collects data from the wagons and their surroundings. Depending on the type of the wagon and typical carried goods, following data should be collected:

Data	Sensor	Frequency	Required sensor quality
Latitude	GNSS sensor	Medium	Determine on which one of neighbourhood rails the wagon is
Longitude	GNSS sensor	Medium	Determine on which one of neighbourhood rails the wagon is
Temperature inside the wagon	Temperature sensor	Medium	Medium
Humidity inside the wagon	Humidity sensor	Medium	Medium
Door closure	Door closure sensor	Medium	High
Chemical leakage	Chemical sensor	High (event-triggered reporting)	Low, but reliability of detection required
Smoke	Chemical sensor	High (event-triggered reporting)	Low, but reliability of detection required
Brakes condition	Brakes condition sensor	Low	Medium
Vibrations	Accelerometer	Medium	Medium
Impacts	Accelerometer	High (event-triggered reporting)	Medium

Table 4: Data collected by on-board devices.

There is no need for smoke and chemical leakage data when the concentration of the chemicals is low. However, the concentration must be frequently (at least every few minutes) monitored and when smoke or chemical leakage is detected, the data must be immediately sent to the web server together with the wagon’s geolocation data. The system doesn’t need to know the accurate concentration of the chemical, but it must reliably detect any over-limit concentration.

The same goes for impacts. When a big impact is detected by the accelerometer, it must be reported immediately. Collecting vibration data from the accelerometer could be useful for determining the state of the rail surface and the wagon’s wheels.

For goods monitoring, the geolocation data, temperature and humidity must be updated at least several times an hour. For the purposes of station dispatchers, having the geolocation data accurate enough to determine on which rail the wagon is located in the railyard would be useful. Most today’s temperature and humidity sensors provide sufficiently accurate data for the purpose of informing the customer about their goods condition.

A door closure sensor is a very simple device that must work correctly. When the system detects door open and wagon movement at the same time, an alert must be triggered.

The system’s Data Flow Diagram can be seen in Figure 9.

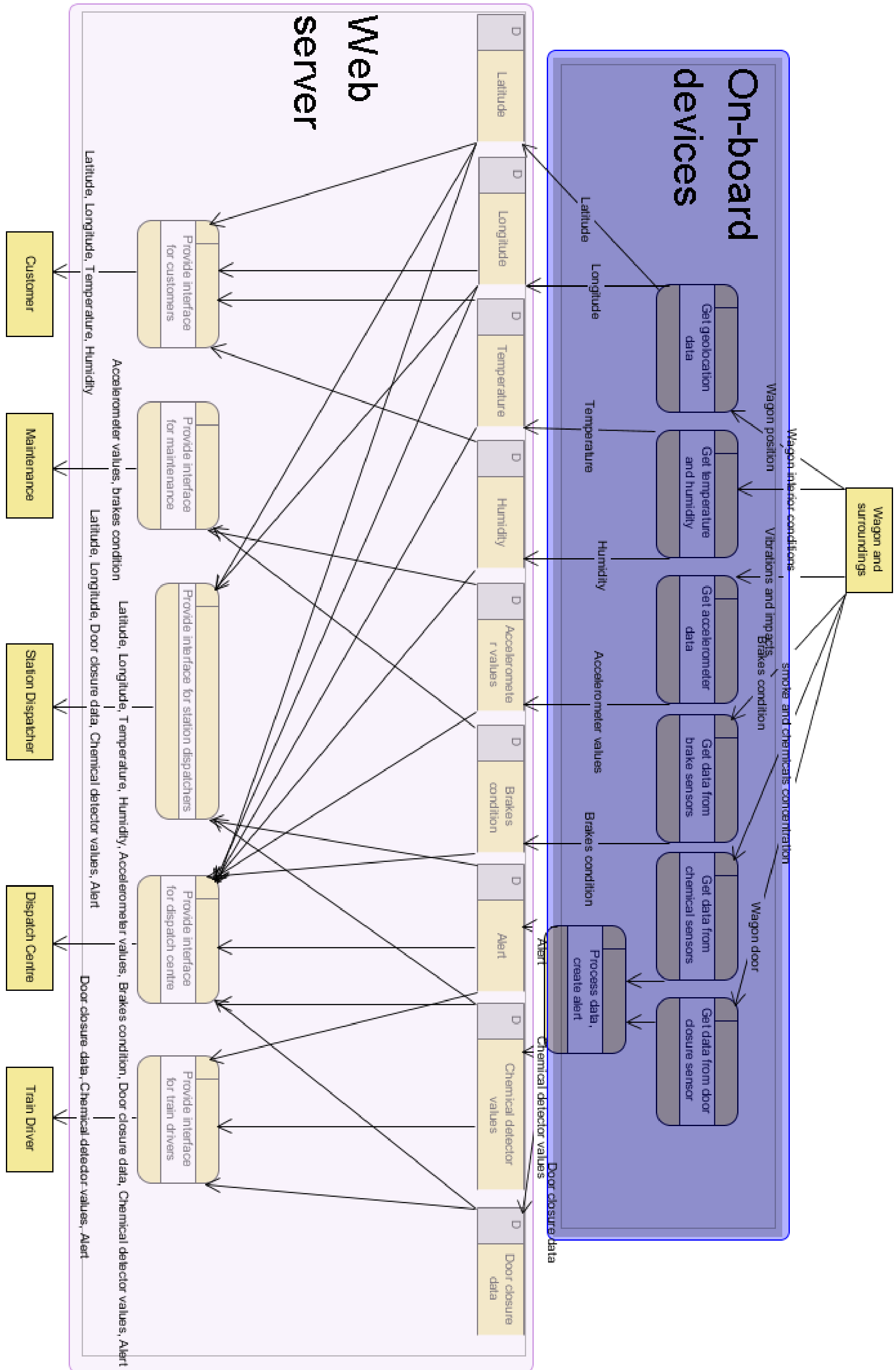


Figure 9: Data Flow Diagram

10 ON-BOARD DEVICES

The minimal list of components for an on-board device is:

- Processing unit
- Sensors
- Device for communication between the processing unit and sensors
- Device for communication between the processing unit and the web server
- Battery
- Case

10.1.1 SENSORS

Many different sensors can be placed on a freight wagon. The choice of sensors depends on the type of the wagon and carried goods. Possible sensors are:

- **Global Navigation Satellite System (GNSS) receiver –** GPS, GLONASS, Galileo Compass or other GNSS receiver for obtaining the wagon's latitude, longitude, altitude and velocity.
- **Temperature and humidity sensors –** for goods quality monitoring
- **Door closure sensor**
- **Chemical sensors –** radiation, gas sensors for gas leakage monitoring
- **Fire detectors –** temperature and smoke sensors
- **Brake condition sensors**
- **Accelerometer –** vibrations and impacts

10.1.2 PROCESSING UNIT

There are two main requirements that must be taken into consideration when choosing a suitable microcontroller for the on-board devices. The first aspect is the microcontroller's energy consumption, and the other one is its computational power. These two parameters must be balanced.

The microcontroller must be able to handle a GPS device, a module for cellular communication and sensor communication simultaneously. These tasks don't require microprocessors known from today's computers or mobile phones. These microprocessors would be unnecessarily expensive for this application and would consume too much energy. A simple microcontroller with just a few MHz of operating frequency and with low energy consumption is required. One of the most used microcontrollers of these specifications is Atmel ATmega328P, described in detail in the following chapter.

10.1.2.1 ATMEGA328P

ATmega328P is an 8-bit microcontroller with 32 KB of in-system programming (ISP) flash memory with read-while-write capabilities, 1 KB of electrically erasable programmable read-only memory (EEPROM), 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, a byte-oriented 2-wire serial interface, SPI serial port, a 6-channel 10-bit A/D converter, programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts. It has 4 different operating speed grades: 0 - 4 MHz with input voltage 1.8 – 5.5V, 0 – 10 MHz with input voltage 2.7 – 5.5 V and 0 – 20 MHz with input voltage 4.5 – 5.5 V. [13]

Parameter Name	Value
Program Memory	32 KB
CPU Speed in MIPS	20
RAM	2 B
Data EEPROM	1024 B
Temperature Range	-40 to 85 °C
Operating Voltage Range	1.8 to 5.5 V
Pin Count	32

Table 5: Atmel ATmega328P specifications. [13]

The power consumption of ATmega328P depends on input voltage, clock frequency and the used clock source. With Low Power Crystal Oscillator (LP), the microcontroller consumes less energy than with the Full Swing Crystal Oscillator (FS) – as seen in Table 6. [14]

Frequency	mA @ 5V	mA @ 3.3V
1 MHz	6.75	0.92
8 MHz	11.68	4.16
16 MHz (LP)	16.32	7.40
16 MHz (FS)	17.52	7.94
20 MHz (LP)	19.71	8.86
20 MHz (FS)	21.12	9.46

Table 6: Atmel ATmega328P energy consumption. [14]

10.1.2.2 ALTERNATIVES

There are several other manufacturers producing microcontrollers that are similar to ATmega328P, such as Microchip PIC, Intel 8051 series Freescale (Motorola) or Texas Instruments.

11 GNSS

GNSS stands for Global Navigation Satellite System and is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. [15] The GNSS era started during the Cold War, as a product of the competition between the Soviet Union and the United States of America. The first two launched systems were Navstar GPS (the first satellite was launched in 1978 by the U.S. military) and GLONASS (the first satellite launched in 1976 by the USSR). After the dissolution of the USSR, GLONASS was continued by the Russian Federation and formally declared operable in 1993, the same year as GPS. [16] [17]

GNSS systems weren't originally intended for civilian use, but after the Korean Air Lines Flight 007 tragedy, the Reagan administration changed their minds and allowed worldwide access to the then-called Navstar GPS. [16]

There are currently 4 GNSSs in the world in different stages of development:

- GPS (USA)
- GLONASS (Russia)
- BeiDou (China)
- Galileo (EU)

11.1 GNSS PRINCIPLES

All GNSSs determine location by trilateration. Trilateration is similar to triangulation. The difference is that whereas triangulation is only possible in 2-D space, trilateration works in 3-D.

All satellites broadcast signals consisting of their current location and accurate time. All signals spread in the same speed into the area of a sphere with the sending satellite being in the centre of the sphere. The receiver receives multiple signals from the satellites and knowing the time of receiving the signal, the time of sending the signal and the location of the satellite when sending the signal, it can determine its distance from a certain point in the space. The set of all points equidistant from that point (all possible locations of the receiver related to one single satellite) is a sphere.

Having the signal from at least 4 satellites, the receiver can identify its location anywhere on the Earth and in the troposphere. [18]

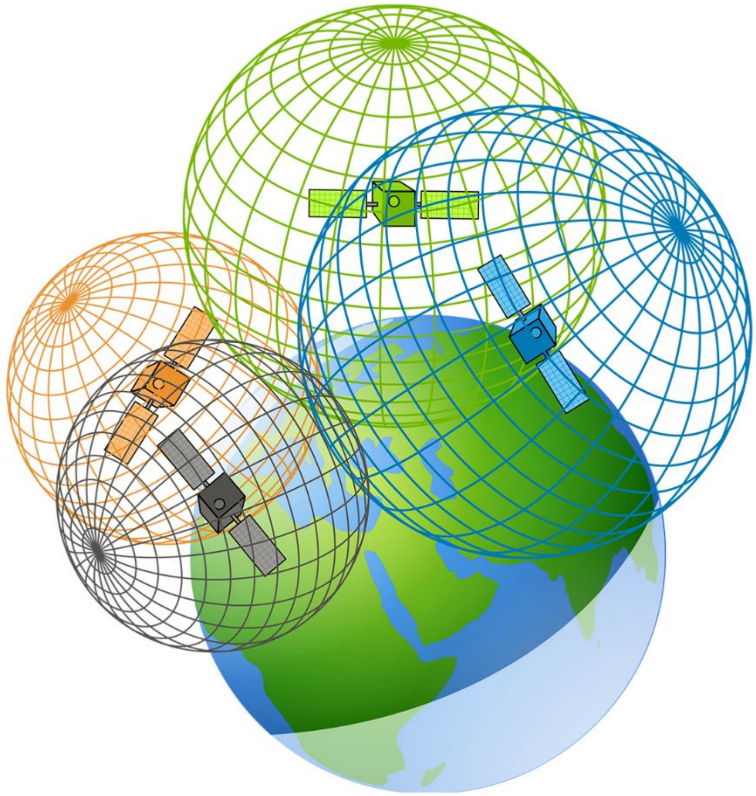


Figure 10: Trilateration. [18]

11.2 CRITERIA

The on-board device's integral part will be a GNSS module. The choice of the system will depend on the application-specific criteria, out of which the most important is **availability**. The selected GNSS must cover the area of operation of the freight cars.

The secondary criterion is **accuracy**. The selected GNSS must be accurate enough to determine on which rail in the railyard the wagon is located. This information is valuable for the station dispatcher. The basic axis distance of two rail tracks in a station is 5m. [19] The tolerated error must be smaller than half of the distance to reliably determine which track the train is on.

The accuracy of a GNSS varies depending on many different factors, one them being coverage by an augmentation system. Some countries have built their own augmentation system to enhance the GPS performance.

Performance of GNSS systems is also determined by **continuity** (the ability of the total system to perform its function without interruption during the intended operation)

[20] and **integrity** (the measure of the trust that can be placed in the correctness of the information supplied by a navigation system). [21]

Other aspects that must be taken into consideration are:

- The **possibility of the system's shutdown by its owner** - e.g. in the case of GPS the system could be shut down by the U.S. Ministry of Defence in case of war.
- **Maintenance** - satellites have a certain lifespan and need to be continuously replaced. When the budget is tight, the system loses its satellites that are not replaced by new ones, which affects negatively both the availability and the accuracy of the whole system. This happened to GLONASS at the end of the 1990s.

There are receivers that can combine signals from different GNSS systems to achieve better accuracy and availability.

11.3 GPS

The GPS is the GNSS operated by the U.S. Department of Defence. GPS satellites transmit signals to the earth at two frequencies, designated L1 and L2. The main carrier signal is L1. It has frequency on 1575.42 MHz and is modulated by two codes: the coarse/acquisition (C/A) code also known as civilian code and the precision/secure (P/Y) code, reserved by cryptographic techniques to military and authorized civilian users. The L2 signal has frequency of 1227.6 MHz and only contains the precise code. It was established to provide a second frequency for ionospheric group delay correction.

The GPS underwent modernization starting in 2005. Since then, two new signal have been transmitted: L2C for civilian users and M code – a new military signal transmitted in both L1 and L2 to provide better jamming resistance than the Y code.

Each GNSS also needs an accurate and well-defined Time References and Coordinate Frames, where positions are computed from signal travel time measurements and provided as a set of coordinates. For this purpose, the U.S. Department of Defence developed the World Geodetic System WGS-84, which is an unified terrestrial reference system for position and vector referencing. The GPS System Time is synchronized with the UTC at nanosecond level.

GPS provides two different positioning services:

- **The Standard Positioning Service (SPS)** – is provided on GPS L1 frequency. The L1 frequency contains a C/A code and navigation data message. This service is available to all GPS users. It provides positioning and timing service.

- **The Precise Positioning Service (PPS)** – is available on both L1 and L2 frequencies. They contain a precision (P) code signal with navigation data message that is reserved for authorized use by the use of cryptography. It is a highly accurate positioning, velocity and timing service reserved for military purposes.

The performance of GPS varies around the world as different countries use different augmentation systems in aaddition to GPS. The levels of performance for GPS without augmentation systems are around 5-10 m (95% of time) for C/A code receivers. [16] [22]

+	−
Already working	Military controlled – risk of switching off by owner
With EGNOS good accuracy	
Low risk of maintenance problems (running out of funding)	

Table 7: Pros and cons of GPS.

11.3.1 EGNOS

European Geostationary Navigation Overlay Service is the European satellite-based augmentation system. It enhances the performance of GPS in Europe. The system was launched in 2009. It provides three different services:

- The **Open Service** – free to use by the public in Europe
- The **Safety of Life Service** – provided to all communities of Safety of Life users over Europe
- The **Commercial Data Distribution Service** – provided to customers who require enhanced performance for commercial and professional use

With EGNOS, the performance level of GPS improves to 3 m (95% of time) in lateral direction. Its availability is higher than 99% in almost whole Europe, as seen in Figure 11. [23]

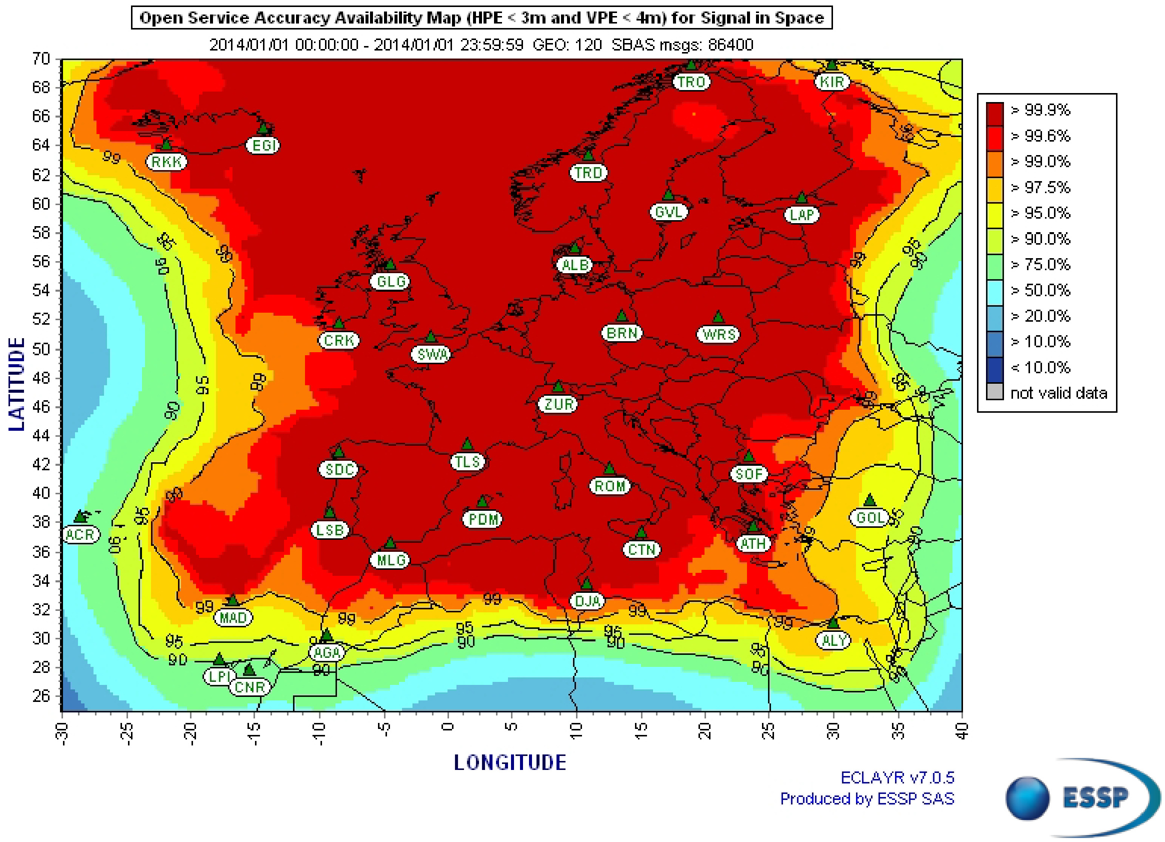


Figure 11: Availability of EGNOS in Europe. [23]

11.4 GLONASS

GLONASS is the Russian alternative of GPS. The system was originally called "Cicada". It was formally operational in 1993 and fully operational in 1995. Following the completion, the system fell into a state of disrepair with the collapse of the Russian economy and the reduction in funding for space industry. But after Vladimir Putin took charge in the early 2000s, the funding was restored to sufficient amounts, so that the system could be restored. In 2007, the system was released for public use.

Unlike other navigation systems that rely on CDMA modulation, GLONASS uses FDMA. That means that each satellite transmits navigation signals on its own carrier frequency.

Two services are available from GLONASS system:

- The **Standard Positioning Service** – free of charge for worldwide users
- The **Precise Positioning Service** – for military and other authorized users

The performance level of GLONASS is nowadays similar to the one of GPS. The availability is >99.9% in most parts of the world and the experienced lateral accuracy is usually less than 3m. Compared to GPS, GLONASS performs better in higher latitudes due to different orbits of the system's satellites. But overall, according to accuracy comparisons provided by the Russian System of Differential Correction and Monitoring, GLONASS is slightly less accurate than GPS. [17] [24]

+	−
Already working	Military controlled – risk of switching off by owner
	Medium risk of maintenance problems (running out of funding)
	Worse accuracy than GPS and Galileo

Table 8: Pros and cons of GLONASS.

11.5 BEIDOU

BeiDou-2 is the Chinese satellite navigation system that is intended to provide positioning, navigation, and timing services to users around the world. The evolution of the Chinese regional navigation system towards a global solution started in 1997, was formally approved in 2006 and is expected to provide global navigation services by 2020. BeiDou offers two services, the Open Service which is open to all users worldwide, and the Authorized Service. The information about the Authorized Service is not clear yet. [25]

The system is designed to provide a position accuracy of 10 metres in case of the Open Service. [26]

+	−
Low risk of maintenance problems (running out of funding)	Military controlled – risk of switching off by owner
	Worse accuracy than GPS and Galileo
	Incomplete

Table 9: Pros and cons of BeiDou.

11.6 GALILEO

Galileo is a project of the European Union. It provides a guaranteed global positioning service. Unlike all the other GNSS systems, Galileo is under civilian control. It's the only GNSS that is not controlled by the military. It started its initial services to public authorities on 15th December 2016. The system is interoperable with GPS.

With the same receiver, any user will be allowed to take a position from any satellite in any combination. Galileo intends to deliver real-time positioning accuracy down to the meter range by offering dual frequencies as standard. It will guarantee availability of the service under the most extreme circumstances.

The following services are planned to be provided by Galileo:

- **Open Service** – intended for motor vehicle navigation and location-based mobile telephone services. Positioning is accurate to one metre and the service is free to use. It doesn't guarantee integrity.
- **Commercial Service** – accurate down to centimetres and encrypted, for commercial use
- **Public Regulated Service** – restricted to government-authorised users, designed to provide high level of service continuity and encrypted
- **Search and Rescue Service** – should help to forward distress signals to a rescue coordination centre by detecting emergency signals transmitted by beacons and relaying messages to them
- **Safety of Life Service** – for aviation to enable aircrafts make approaches with vertical guidance [27]

+	−
Best stated accuracy out of all GNSS systems	Incomplete
Not military controlled – low risk of switching off	High risk of maintenance problems (running out of funding) because of the EU instability

Table 10: Pros and cons of Galileo.

11.7 GNSS COMPARISON

Galileo seems to be the best performing system in terms of accuracy and is the only GNSS that isn't controlled by the military, which means lower risk that the owner of the system decides to switch the service off for civilians. The biggest concern with Galileo is that the EU may fall apart. Should it happen, the future of Galileo will be uncertain. To an extent, similar could be said about all the other GNSS systems, next in line being probably GLONASS. In addition, Galileo isn't fully operational yet. The same applies to BeiDou. Neither BeiDou nor GLONASS perform better than

GPS in terms of accuracy and therefore it would make little sense to pick any of them as the only GNSS system for the application in the European smart wagon. Furthermore, the availability of BeiDou receivers in Europe is questionable. GPS receivers are easy to get, GLONASS receivers too. GPS is interoperable with Galileo, and Galileo-enabled GPS receivers are already on market, only requiring a minor software update to receive signals from Galileo satellites.

The following table sums up GNSS system and underlines their differences:

	GPS	GLONASS	Galileo	BeiDou
Owner	USA	Russian Federation	European Union	People Republic China
Satellites (full constellation / currently operational)	24/31*	24/24	30/18	35/20
Access Scheme	CDMA	FDMA	CDMA	CDMA
Status	Operational	Operational	In deployment, full operation expected in 2020	In deployment, full operation expected in 2020

**24 satellites needed for full operation, 31 currently in orbit and operational, target number is currently 33*

Table 11: GNSS comparison.

GPS is currently by far the most used GNSS by civilians. Even though it's military controlled, the USA are stable and the risk of drained funding is low.

A combination of GPS and GALILEO, which is possible with just one receiver, would provide the best possible accuracy, coverage and availability. It's also a robust solution for the case when one of the services becomes unavailable for whatever reason.

12 TELECOMMUNICATIOS

Different communication schemes come to mind when thinking about the possibilities of the transport of information from sensors placed all along the train to the central database. Thinking about the wagons only as part of a train, today's technologies would allow solutions such as having only one GPS and long-range communicator (the two most demanding devices in terms of energy consumption) on board of the engine and the other sensors (temperature, humidity, smoke, chemical sensors) reporting to this central unit using a low-energy wireless communication technology. Such application would be cost and energy efficient. This solution, however, would be relevant only when the engine and the wagons belong to the same company and when all this company's wagons and engines were equipped with this technology. But in reality, engines of different companies drag wagons that belong to other companies very often. Also, with this communication scheme, it would be difficult to obtain data from wagons when standing in a station. And finally, if the device on the engine in this communication scheme breaks down, it means losing the information from all wagons. It would be possible to use this communication scheme if the technology got standardized, but as far as I'm concerned, there are no plans for the standard right now.

For the above discussed reasons, the most robust solution is to think about every wagon as an independent unit that is connected to the Internet via a WAN technology. Because it's impractical and in some cases even impossible to use wires to connect sensors placed all along the wagon to the central wagon unit (consisting of a microcontroller, a WAN communication device and a GNSS receiver), a short – range energy efficient technology is also required.

The maximal length of a freight train in Europe is limited to 740m. One freight wagon is usually 10-20 metres long.

12.1 SHORT - RANGE COMMUNICATION

A short – range communication technology is needed for communication between the sensors and the central unit. Since the data flows in this application are minimal, the two main criteria in the choice of the technology are **range** and **energy consumption**.

The required range of the telecommunication technology is derived from the length of the wagon. The standard length of a freight wagon doesn't extend over 20 metres, which is the minimal required reach for the short – range communication technology.

The most spread technologies with this communication range are Wi-Fi and Bluetooth, but Wi-Fi is designed for high data throughputs and consumes a lot of energy, therefore it's inappropriate for this application.

Technologies nowadays used in IoT are ZigBee, Z-Wave and ANT.

12.1.1 BLUETOOTH

Bluetooth is covered by the IEEE 802.15.1 standard. It was developed in the 1990s as a replacement for cable connections. The initial objective was to cover a limited area of about 10 m, consume little energy and handle moderate data rates. In 2010, a low energy consumption and IoT suitable Bluetooth version 4 was introduced. The specifications of the Bluetooth Low Energy were further improved in 2016 with the release of Bluetooth version 5.

Bluetooth operates in the 2.4 GHz band and supports ad-hoc communication or small networks that contain up to 7 nodes per 1 master in star topology. It allows to connect up to 10 master nodes to create a scatternet (a network of master nodes, each of them having its own piconet consisting of slave nodes).

The first three versions of Bluetooth are nowadays called “Bluetooth Classic” and are not compatible with the newer versions (V4.0, V4.1, V4.2 and V5) called “Bluetooth Low Energy”. The most important feature of Bluetooth Low Energy is, as indicated by its name, low energy consumption. This is mostly achieved by the device being 99.9% of the time inactive. [28]

It is maintained by Bluetooth SIG, a global community of more than 30,000 companies. This consortium estimates that by 2020, 1 in 3 wireless products shipped will include the Bluetooth technology. [29]

12.1.1.1 BLUETOOTH LOW ENERGY

The Bluetooth Low Energy series started with Bluetooth V4.0. This version has transfer speed up to 1 Mbit/s and range up to 100 metres. Bluetooth 4.1 solved the problem of interference of V4.0 with LTE networks, allowed Bluetooth devices to act as both hub and end point simultaneously. That allowed to eliminate the hub from the communication and let peripherals communicate directly. V4.1 also allowed the manufacturers to set the reconnection timeout intervals of their devices, which improved its power management. Bluetooth V4.2 introduced several new improvements over the V4.2. The most significant one was allowing the chips to use Bluetooth over IPv6 for direct Internet access. Currently, the last version is Bluetooth V5.0. It was introduced in 2016 and features higher data rates, extended range and greater throughput compared to the previous version. [28] [30]

12.1.2 ZIGBEE

ZigBee is covered by the IEEE 802.11.4 standard. It was established as an alternative to Wi-Fi and Bluetooth in the late 1990s. It was intended to be simpler, more flexible and less expensive than either Wi-Fi or Bluetooth.

In Europe, it operates in the 2.4 GHz band and in the 868 MHz band, which offers better signal propagation through walls, windows, floors and so on. It supports ad-hoc communication, peer-to-peer communication and star or mesh networks with up to 65,536 nodes. If a node can’t communicate with another node directly, they may communicate through the network as others who act as repeaters. Should a device fail or be removed, the autodiscovery feature of such a mesh network will recognize the fact and find an alternative path.

Data rates depend on the selected frequency band. At 868 MHz, raw data rate is 20 kbps (1 channel), and 250 kbps at 2.4 GHz (16 channels). Distances range from 10m to 100m+, depending on frequency, output power and environmental characteristics.

It is maintained by the ZigBee Alliance, a consortium of more than 220 companies. [31] [32]

12.1.3 Z-WAVE

Z-Wave was developed by Zen-Sys, a Danish startup, and acquired by Sigma Design in 2008. Unlike other standards, Z-Wave is a proprietary wireless standard. It is not open, but it is available to Sigma Design customers.

The Z-Wave technology enables any node to talk to other adjacent nodes directly or indirectly through available relays in its mesh network. A master controller node controls any additional nodes. The nodes communicate directly with one another if they're within a range. If two nodes that want to communicate aren't within a range, they can link with another node that both can access and exchange information.

In Europe, it operates in the 868 MHz band. And one Z-Wave network contains up to 232 nodes. [31]

12.1.4 ANT+

ANT+ is a wireless protocol similar to Bluetooth. It is designed for collection and transfer of sensor data. It is maintained by an alliance owned by Garmin. It operates in the 2.4 GHz band. Nowadays, it is used mainly in sport and health monitoring applications (for example all Samsung and Sony mobile devices support ANT+ for connection with devices such as heart rate belt). It supports P2P, star, tree and mesh topology and up to 50 slaves under one master node. [33]

12.1.5 TECHNOLOGY COMPARISON

Bluetooth and ZigBee are widespread and open technologies, which gives them a huge advantage in terms of availability compared to Z-Wave and ANT+, which are controlled by one single company.

As seen in Table 12, none of these technologies have problems with range for the intended application, which requires a range of at least 20 m. Data transfer rates are also sufficient.

Technology	Band	Range	Maximum Data Rate
Bluetooth LE	2.4 GHz	30 m	1 Mbit/s
ZigBee	868 MHz / 2.4 GHz	100 m	250 kbit/s
Z-Wave	868 MHz	30 m	40-100 kbit/s
ANT+	2.4 GHz	60 m	1Mbit/s

Table 12: Short range communication technologies comparison. [34] [33]

The decision therefore depends on energy consumption. Table 13 depicts the energy consumption of selected short - range telecommunication technologies in different modes of operation.

Technology	Sleep (μW)	Receive (Rx) power (mW)	Send (Tx) power (mW)
Bluetooth LE	8	53	60
ZigBee	4	84	72
Z-Wave	3	65	70
ANT+	3	75	110

Table 13: Energy consumption in different modes of operation. [34]

Bluetooth LE performs the best in energy consumption both when sending and receiving data, but its sleep consumption is by far the highest. However, this data is from 2014 when only Bluetooth V4.0 was available. Since then, newer versions with better power management have appeared. Also, in the paper called “Power Consumption Analysis of Bluetooth Low Energy, ZigBee, and ANT Sensor Nodes in a Cyclic Sleep Scenario” by Mr Artem Dementyev and co. from 2013 [35], Bluetooth LE is found the lowest power consuming technology, followed by ZigBee and ANT.

Also in this paper, they found out that the parameters that dominated the power consumption were not the active or sleep current, but rather the time required after each sleep cycle to wake up, and to what extent the RF module slept between the individual RF packets. In terms of time required for a designer to configure the cyclic sleep routine, in our evaluation ZigBee was the quickest, ANT took the longest, and Bluetooth LE was in between the two.

12.2 LONG – RANGE COMMUNICATION

To transfer the data from the wagons to the database, the project needs to implement a WAN communication technology. With data flows in this project being minimal, data transfer rates of available technologies are not the main criteria of the choice. An essential criterion is the **coverage** of the communication technology, especially along the European railways. Other important aspect is **energy consumption** of the end device.

This is a competition between traditional cellular networks (2G, 3G, 4G, 5G) and new emerging LPWAN networks that are designed for simple and low energy machine-to-machine communication.

12.2.1 MOBILE NETWORKS

Most mobile telecommunication networks are cellular. In this type of networks, signals carrying voice, text and digital data are transmitted through a global network of transmitters and receivers.

The cellular design means that a mobile phone network is divided into thousands of overlapping geographic areas – cells. A typical cellular network can be envisioned as a mesh of hexagonal cells, each with its own base station at the centre. The cells overlap at the edges to ensure that users always stay within the range of a BTS. A cellular network example is depicted in Figure 12. RF signals transmitted by individual phones are received by the base station and then, via central switching centres, by another base station and from there to another phone. The diameter of the coverage area of a BTS varies from several hundreds of metres in urban areas to several kilometres in rural areas. [36] [37]

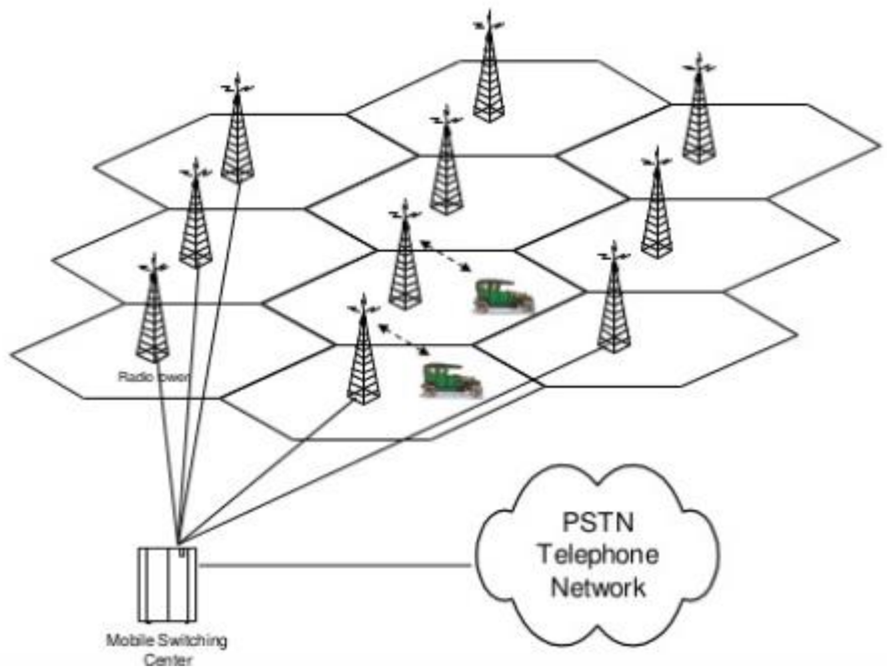


Figure 12: Cellular network. [37]

12.2.1.1 2G AND 2.5G – GSM, GPRS AND EDGE

The first generation cellular telephony systems were analogue and weren't designed for data transmission. The second generation is digital and nowadays dominates the cellular telephony world.

GSM, originally known as Groupe Spéciale Mobile, was first introduced in 1991 as the standard for pan-European cellular systems. It operates in the 800, 900 1800 and 1900 MHz bands. Generally, data throughput is limited to 9.6 kbps. Users log in to the GSM network using a SIM card. This card contains user profile data, a description of access privileges and features, and identification of the mobile operator that hosts the home registry. There are more than 475 GSM network in more than 190 countries, predominantly in Europe and Asia. In Europe, GSM is also the basis for DCS 1800. It is an upbanded version of GSM, which operates in the 1800 MHz band.

GPRS specifications were developed in 1997 by ETSI, which has since passed the responsibility for its development to 3GPP. GPRS is a packet-switched service that supports TCP/IP packet protocols with QoS. It's an evolution of GPS which enables mobile data usage sufficient for Internet browsing and e-mail. The theoretical transmission rate of GPRS is up to 171.2 kbps, but in reality, it's limited to 115.2 kbps and typical transmission rates are usually between 30 - 60 kbps.

EDGE is a 2.5G standard developed by ETSI in 1999 as the final stage of development of GSM. It supports data rates up to 473.6 kbps thanks to improved modulation technique. Maximum transmission rates are, however, typically in the range of 75-150 kbps. [32]

The coverage of 2G technology is illustrated in Figure 13 on the map of T-Mobile coverage of the Czech Republic (pink). I couldn't find any map of European mobile networks coverage, so I used the maps of T-Mobile CZ because I'm using their network in my project (described at the end of the thesis). The coverages of the other operators in the Czech Republic are very similar for all network technologies. The maps don't guarantee coverage along the railroads. Railroad tunnels, at least, are not covered by commercial operators' networks.

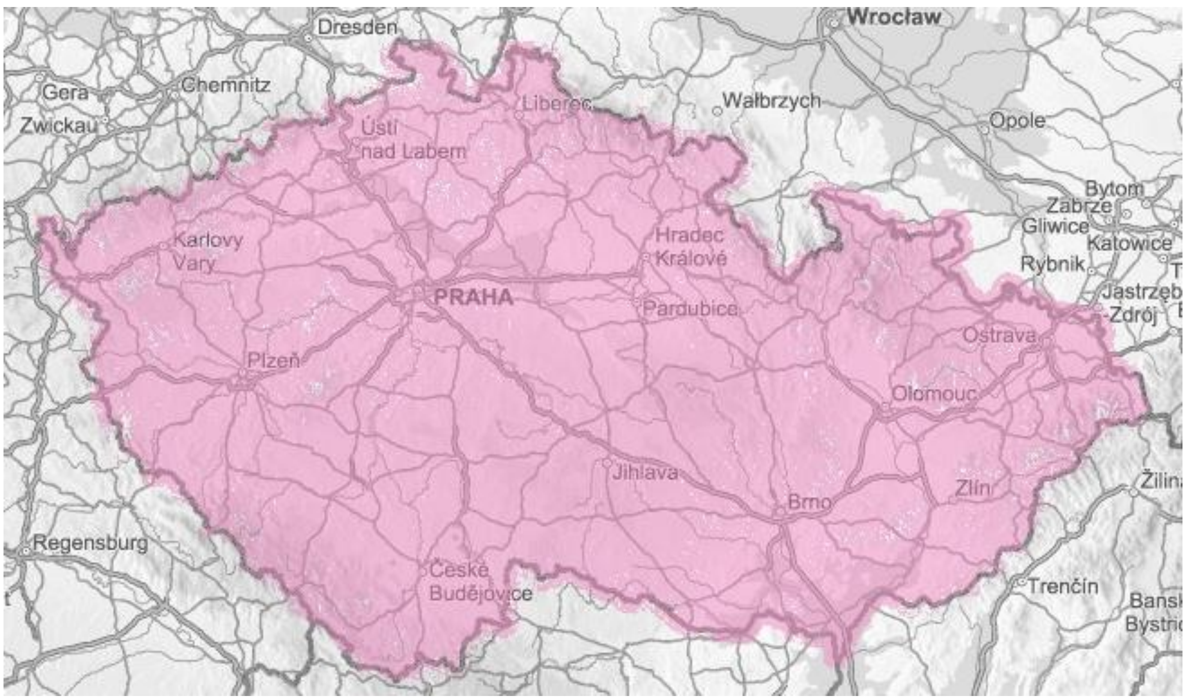


Figure 13: T-Mobile 2G coverage of the Czech Republic. [38]

12.2.1.2 GSM-R

GSM-R is not a public network. It's designed for the use of ETCS, the European signalling, control and train protection system that aims to replace the current incompatible safety systems installed along European railways. It's being built along important railway corridors. The aim is to reach 100% coverage along these tracks (including tunnels) because Safety of Life applications are using the network. GSM-R can transfer both voice (train driver to control centre communication) and data. GSM-R uses all public GSM bands and also additional frequencies in the 900 MHz band.

In the future, GSM-R is expected to evolve towards LTE. GSM-R networks working with LTE-based equipment have potential to reduce costs while improving latency and data speeds. [39] [40]

Figure 14 shows intended GSM-R coverage of Czech Republic in 2020. Pan-European corridors are painted red, tracks connecting these corridors are painted blue. The price for data transfers in GSM-R networks hasn't yet been specified in the Czech Republic.

Figure 14: GSM-R coverage of Czech tracks, 2020 plan. [41]

12.2.1.3 3G – UMTS, HSPA

To be considered a true network of the third generation, any network must have data rates of at least 2 Mbps in stationary speed, 384 kbps for slow moving devices, and 128-144 kbps for fast moving devices. Better data rates compared to 2G and 2.5G are achieved thanks to a more efficient modulation. It was first deployed in Japan in 2000. It's compatible neither with 2G nor with 2.5G. [32]

With HSPA, the possibilities of 3G expanded well beyond the initial 3G requirements. Compared to UMTS, which uses QPSK modulation (4 phases), HSPA uses 16-QAM (16 phases) for download. This provides for maximum data rates of 28 Mbps in downlink and 11 Mbps in uplink. HSPA also has lower latency than UMTS. 3G HSPA can compete with LTE and LTE-A. In terms of maximum data speed, however, its spectral efficiency is not so high. [42]

Figure 15 depicts T-Mobile 3G coverage of the Czech Republic (yellow).

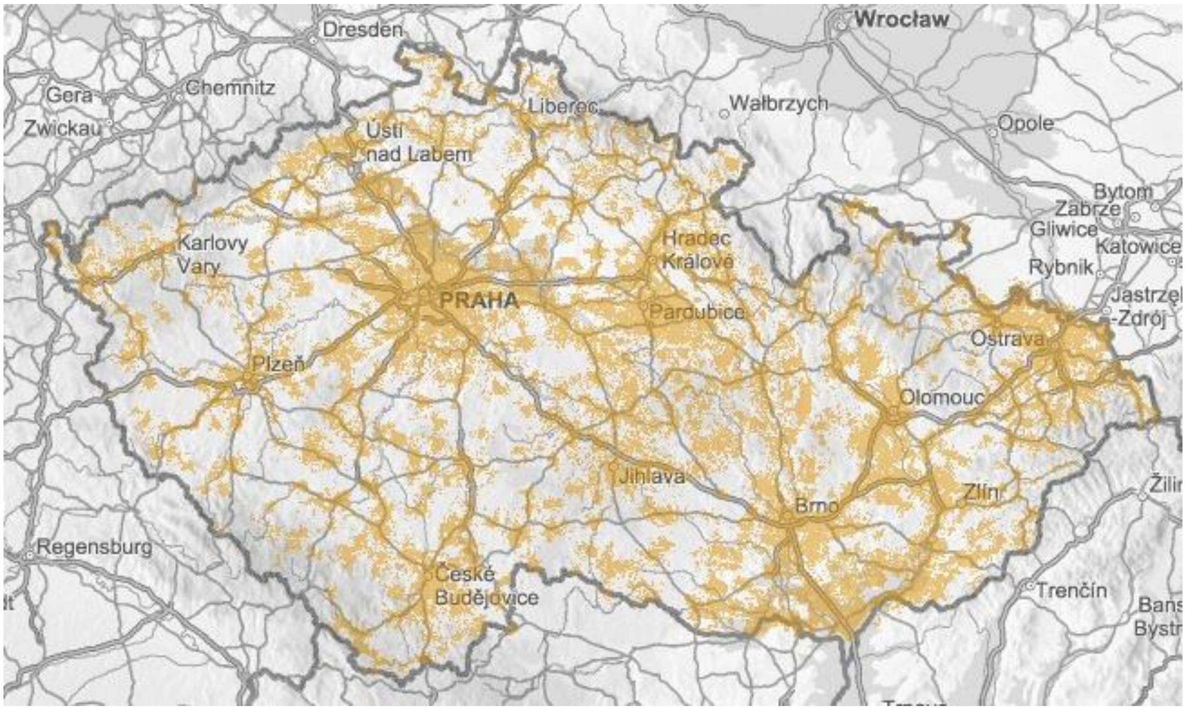


Figure 15: T-Mobile 3G coverage of the Czech Republic. [38]

12.2.1.4 4G – LTE AND LTE-A

LTE is the successor to 3G UMTS and HSPA. Similarly to the previous technologies, it was developed by 3GPP. It provides much higher data download speeds and sets the foundations for LTE-A.

The first LTE version is not a true 4G network. It only meets the requirements for 3G network, but it's marketed as 4G (ITU-R 4G requirements are peak data rates of 100 Mbps for a user on a highly mobile network and 1 Gbps for a user with local wireless access). Peak downlink speed is 100 Mbps for single-input single-output technique. LTE also supports multiple-input multiple-output technique. Using MIMO, the peak uplink speed rises to 326 Mbps. Peak uplink speed depends on used modulation – 50 Mbps for QPSK, 57 Mbps for 16-QAM and 86 Mbps for 64-QAM. [43]

LTE is an all IP based network. It supports both IPv4 and IPv6. There was originally no basic provision for voice transfer, but later Voice over LTE was added. It uses many different frequency bands in different countries. In Europe, it's usually 800 MHz band for rural areas and 1800 MHz or 2600 MHz in urban areas.

The true 4G network is LTE Advanced. The goal of LTE-A is to provide very high data transfer rates and high levels of mobility. Peak data rates are set at 1 Gbps for downlink and 500 Mbps for uplink. Its spectrum efficiency is 3x greater than standard

LTE's. Latency improved from 10 ms to 5 ms. LTE Advanced devices are compatible with LTE networks.

Comparison of LTE and LTE-A with HSPA+, the most advanced 3G technology, is in Table 14.

	HSPA+	LTE	LTE-A
Max downlink speed	28 Mbps	100 Mbps	1 Gbps
Max uplink speed	11 Mbps	50 Mbps	500 Mbps
Latency round trip time (approximation)	50 ms	10 ms	5 ms
Approximated year of initial roll out	2008/09	2009/10	2014/15

Table 14: HSPA+, LTE and LTE-A compared. [44]

The specifications of LTE-A are rivalled by WiMAX, which also provides very high data rates and good mobility, but it's unlikely that WiMAX will be adopted as the 4G technology. [44]

Figure 16 depicts T-Mobile LTE coverage of the Czech Republic (red).

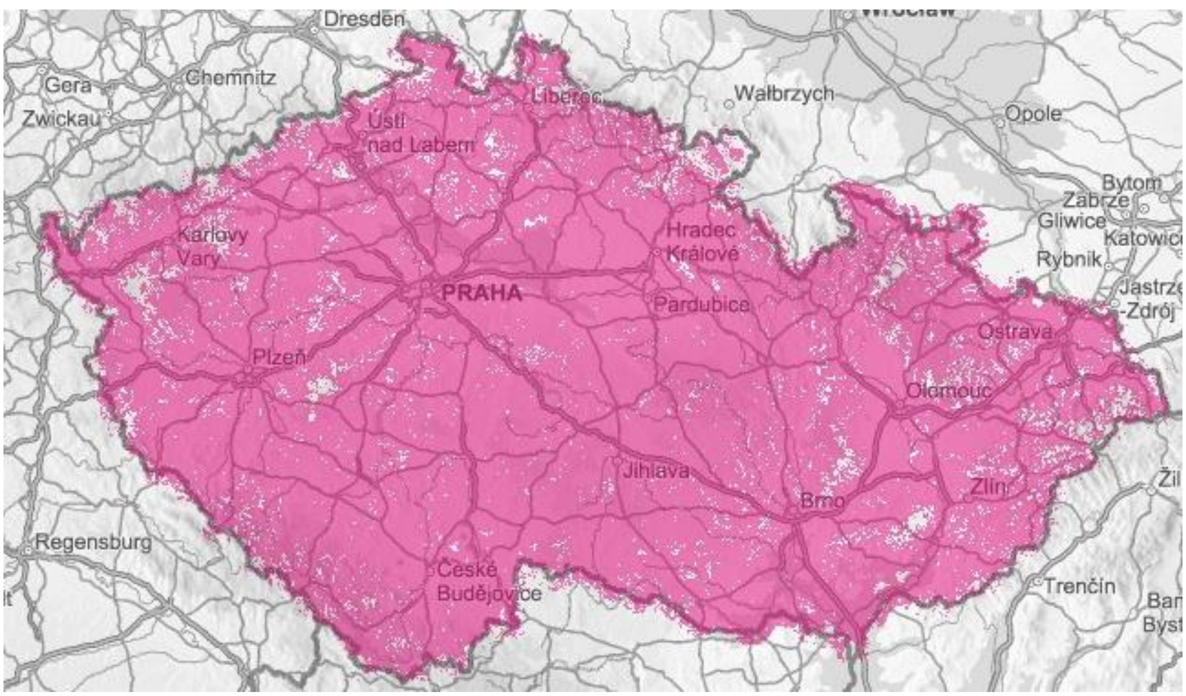


Figure 16: T-Mobile LTE coverage of the Czech Republic. [38]

12.2.1.5 LTE-M

LTE-M is the abbreviation for LTE Category M1. This technology is for Internet of Things devices to connect directly to a 4G network. It is specified as an enhancement to LTE Advanced Pro (also nicknamed 4.5G) in 3GPP Releases 13 and 14. Its peak data rate is 1 Mbps.

The three basic principles of LTE-M are:

- **Low Cost** – Devices can connect to 4G networks with chips that are less expensive to make.
- **Long Battery Life** – Devices can enter a "deep sleep" mode called Power Saving Mode or wake up only periodically while connected. That mode is called Extended Discontinuous Reception (eDRX).
- **Low Service Costs** – Because the maximum data rate is very low compared to traditional 4G networks, the carriers should offer service plans closer to old 2G pricing than 4G pricing.

LTE-M was specified by 3GPP Release 13 with these design goals:

- 10 years battery life on a 5 WH battery
- Device cost comparable to GPRS based IoT devices
- Extended coverage
- Variable data rates (to enhance coverage) [45]

12.2.1.6 5G

No standards have been developed for 5G network yet. But in 2014, the GSMA outlined eight criteria for 5G. A network should meet a majority of these requirements in order to qualify as 5G:

- 1-10 Gbps connection end-to-end in the field (not just theoretical maximum)
- Latency of 1 millisecond on end-to-end round trip
- 1000x bandwidth per unit area compared to 4G
- 10x-100x number of connected devices compared to 4G
- 99.999% availability
- 100% coverage
- 90% reduction in network energy use compared to 4G
- Up to 10 years battery life for low power machine-type devices

Looking at the requirements on number of connected devices and battery life for low powered machine-type device, it's clear that 5G is designed for the Internet of Things.

New frequency spectrum will be required because those used by 3G and 4G are already overcrowded. The new spectrum will need to be in high frequency bands in order to deliver the envisaged data speeds.

There have been some tests of the technology in the past couple of years, but as of yet, there is no network meeting the 5G requirements in the world. However, Huawei is planning to launch the first pilot 5G network with its partners in 2018, same as Ericsson, who is planning to demonstrate 5G at the Winter Olympics in South Korea (as is Samsung) and at the FIFA World Cup in Russia. Both these events take place in 2018. Commercial launch is expected in 2020. [46]

From transportation point of view, 5G is important because it will also provide features for V2X communication – for both in-coverage and out-of-coverage scenarios. That means that 5G will support direct device-to-device communication on distance of hundreds of metres. Additional device-to-device communications intended for 5G include e.g. multi-hop. The model example of multi-hop is that the signal can go from a BTS to a mobile phone and from there, via multi-hop, to a smart watch. [47]

12.2.2 LPWAN

LPWAN stands for Low-Power Wide-Area Network. It's a wireless wide area technology that is specialized for interconnecting devices with low-bandwidth connectivity and focused on range and power efficiency. Thanks to using narrower bands than traditional mobile networks, LPWANs have less noise in their channels, which enables them to achieve better range with lower energy consumption. LPWAN technologies are designed for machine-to-machine communication with focus on budget. The devices connected to this type of networks are much simpler than those connected to new generations of cellular networks, and therefore are much cheaper and consume less power.

LPWAN data transfer rates are very low, as is the power consumption of connected devices. The networks are also designed to support more connected devices over a large coverage area and have better bi-directionality. [48]

These technologies are currently booming and there are many of them competing against each other right now. In recent history, 3GPP, the standards body which is responsible for the 3G, 4G and 5G mobile standards, omitted development of a replacement for GPRS (2G), which is responsible for most of today's machine to machine communications. 3G and 4G are designed for high speed connection, but they also consume lots of power. Several private companies such as Sigfox or Semtech (LoRaWAN) identified the hole in the market and have been developing low cost, low speed, low power communication options. Challenged by these new technologies, the 3GPP ultimately also developed their own standard in this field – the NB-IoT.

12.2.2.1 NB-IOT

NarrowBand IoT is a radiotechnology designed for the Internet of Things. It is standardized by the 3GPP. The NB-IoT technology was frozen at Release 13 of the 3GPP specification in 2016.

It can be deployed in the spectrum allocated to LTE, or in another dedicated spectrum, possibly in today's GSM spectrum when GSM gets shut down.

The peak downlink data rate is 250 kbps, uplink data rate may vary from 20 kbps to 350 kbps. It has a high latency of 1.6 - 10 seconds. It promises up to 50 000 connected devices per cell, 10 years of battery life, low cost terminals, high reliability and high carrier-class network security. It is also claimed that NB-IoT aims to have better coverage than GSM, because many possible IoT devices could be installed in remote locations where there is currently no coverage at all. [49]

12.2.2.2 LORAWAN

The name LoRaWAN is a combination of LoRa and WAN (Wide Area Network). LoRa is an abbreviation for low range, low power wireless platform. The technology is being developed by LoRa alliance. Networks using LoRaWAN offer a solution to serve battery-operated IoT applications. The first standard of LoRaWAN was released in June 2015.

Data transfer rates of LoRaWAN range from 0.3 kbps to 50 kbps for both uplink and downlink. In order to optimize the battery life of end-devices and network capacity, the LoRaWAN network server manages the data transfer rate for each connected device via an algorithm, known as Adaptive Data Rate algorithm. In Europe, it uses the unlicensed 868 MHz band. The range of one gateway is 2-5 km in urban area and up to 15 km in rural area.

LoRaWAN networks are currently being built all around Europe. [50]

12.2.2.3 SIGFOX

Sigfox was founded in France in 2009. Their wireless network is designed to connect wireless low-energy objects. For using their technology, Sigfox charges €1 per year per device.

Uplink data rate is 100 bps and any device has a limited number of sent messages per day – it can only send 140 messages per day, no message can be bigger than 12 bytes. It is practically a one-way communication network, because downlink is even more limited – the network only allows four 8-byte messages per device per day. The range of one gateway is 3-10 km in urban areas and 30-50 km in rural areas. In Europe, it uses the unlicensed 868 MHz band. It has a very long latency, it takes between 1-30 seconds for a device to send a message. [51]

Sigfox network in Western Europe is almost complete and is spreading further East very fast, as seen in Figure 17. Already covered areas are painted blue, purple indicates countries under roll-out.

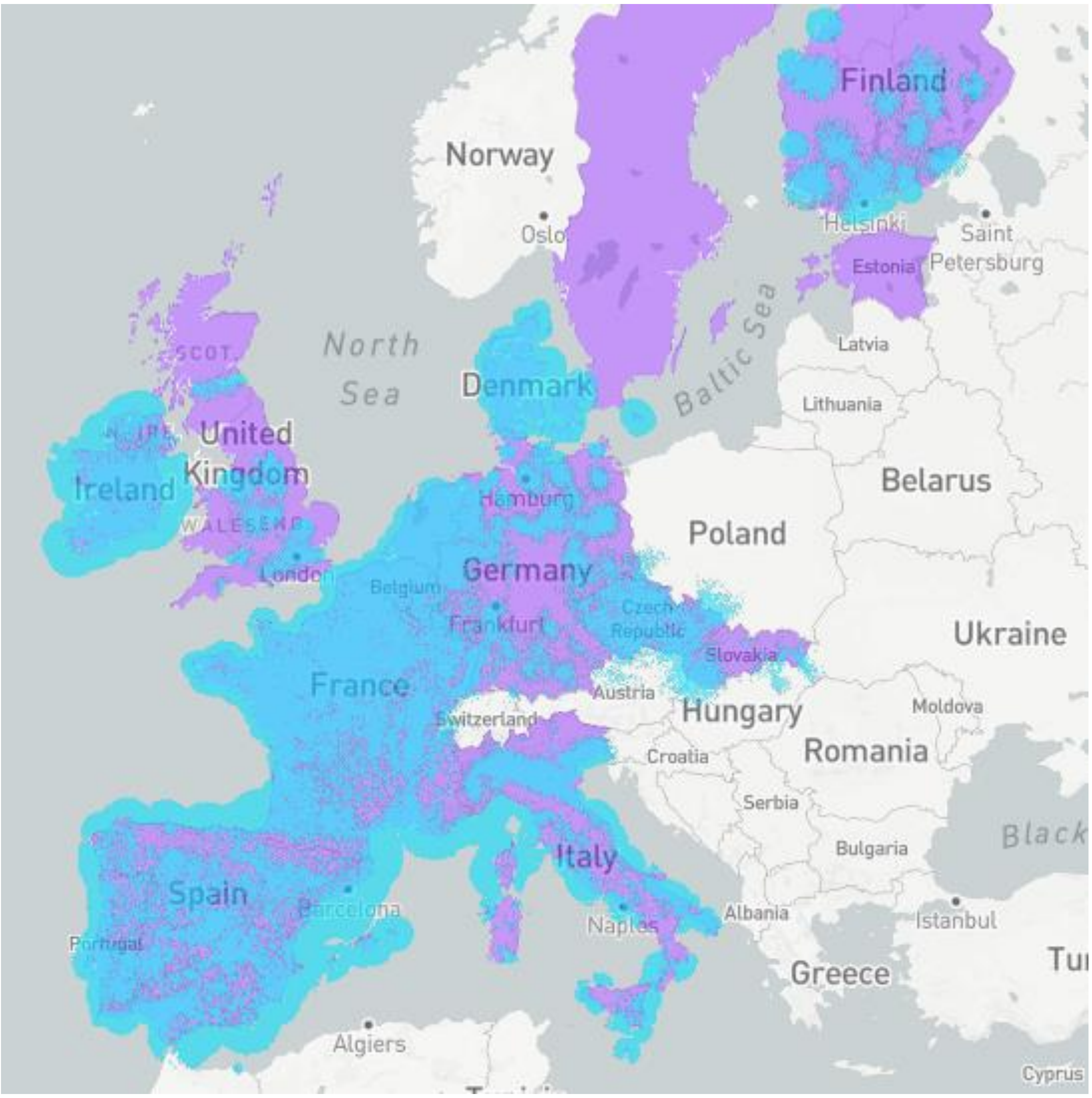


Figure 17: Sigfox coverage in Europe. [52]

12.2.3 CHOICE

At the moment, it's difficult to pick one best suitable technology for the smart wagon application. On the one hand, there are technologies that are already built and have a great coverage, but consume too much energy. On the other hand, there are technologies that are only being implemented, but if they reach the coverage they promise, their specifications are much more suitable, namely in terms of power consumption and price.

Out of the above mentioned technologies, only one can't be considered a real contender – the 3G. 3G networks never reached the coverage of 2G and never will. From the performance point of view, 3G can't compete with 4G. Despite being newer, 4G also already has better coverage than 3G in most European countries. Rumours are that 3G might even be shut down earlier than much older 2G in order to re-use its frequency bands for other applications.

The comparison between GPRS and LTE is a matter of choice between the old one and the new one. GPRS has better coverage, modules cost less and for sending small amounts of data once in a while, as it stands, it also consumes less energy. However, LTE's coverage will only get better. Different versions of LTE are interoperable and their update to new versions is only a matter of software, hardware doesn't need to be replaced. LTE-M and NB-IoT devices will also be much cheaper than the current 4G devices. And, of course, energy consumption of these devices will substantially improve and will be much better than that of the GPRS devices. There is almost no doubt that GPRS network will eventually be shut down earlier than LTE. At the moment, GPRS is a better choice. However, it's clear that LTE will overleap it in a very near future.

The million dollar question is how the development will look like in the LPWAN market. Mr. Nick Hunn, an expert in this field, makes an insight in his blog post "NB-IoT is dead. Long live NB-IoT". [53]

According to him, the 3GPP entered the market late, which left space for other players to enter the field and currently are well ahead of 3GPP and their NB-IoT. But these IoT–ready networks are not a lucrative field. For example, Sigfox is selling their modules for $3 and already have data plans that charge as low as $1.50 per year. SK Telecom, using LoRaWAN technology, charges $0.30 per device per month. For comparison, operators currently get $50-$200 from their current machine-to-machine contracts.

His prediction is that despite the low cost of network devices (anyone can become an IoT network operator by purchasing LoRaWAN gateway for €250 and cover a radius of around 5km), projects like LoRaWAN and Sigfox won't thrive financially and eventually, when 3GPP sort their issues with NB-IoT and implement it in their existing LTE networks, most IoT manufacturers will probably migrate to it because no one else will be able to guarantee a stable network for the next 15-20 years and the NB-IoT will eventually wipe out any remaining alternatives. However, he believes that that NB-IoT won't be globally implemented before 2023.

Hunn's final words in the article are as follows: *"The irony is that we now have a set of different LPWAN options which look as if they do support a ten year battery life, but it's unlikely that any of them will still be operating in ten years' time."* [53]

Each technology has its pros and cons. Since all LPWAN technologies are very similar, I summed took them as a whole and compared them to the most relevant mobile network technologies – GPRS and LTE – using SWOT analysis.

GPRS	Helpful	Harmful
Internal origin	**Strengths:** • Current coverage	**Weaknesses:** • obsolete
External origin	**Opportunities:** •	**Threats:** • Could be switched off soon

Table 15: SWOT analysis for GPRS.

LTE	Helpful	Harmful
Internal origin	**Strengths:** • Coverage	**Weaknesses:** • Device cost • Power consumption
External origin	**Opportunities:** • Future development (LTE-M and 5G) • Low risk of end of support in near future	**Threats:** •

Table 16: SWOT analysis for LTE.

LPWAN	Helpful	Harmful
Internal origin	**Strengths:** • Power consumption • Pricing (device, data plan)	**Weaknesses:** • Current coverage

External origin	**Opportunities:** • Big coverage plans	**Threats:** • Funding • Maintenance

Table 17: SWOT analysis for LPWAN networks.

13 POWER SUPPLY

There is usually no power source available on a freight wagon. But there are ways to continuously recharge the device's battery from environmental resources.

13.1 SOLAR ENERGY

Solar energy is a popular alternative source of energy. It is harvested through solar panels. Solar panels consist of photovoltaic cells. Each photovoltaic cell is basically a sandwich made up of two slices of semi-conducting material – usually silicon. To work, photovoltaic cells need to establish an electric field, which occurs when opposite charges are separated. To achieve this, other materials are added into the silicon layers, giving each layer of the sandwich a positive or negative electrical charge. Phosphorus is used for the top layer to add extra electrons and give it a negative charge, whereas boron is added into the bottom layer. That gives the bottom layer a negative charge. When the top layer has a negative charge and the bottom layer has a positive charge, an electric field is established between these two. Then, when a sunlight photon hits the photovoltaic cell, it knocks an electron free, the electric field pushes the electron out of the silicon junction. Metal conductive plates on the sides of the cell collect the electrons and transfer them to wires. There they flow as any other source of electricity. [54]

The most efficient solar panels in the world are capable of 40 to 50% efficiency, however, most used solar panels are around 10 to 20% efficient. The Sun dumps ~1,000 W/m^2 at sea level on a clear day. [55] Simple calculation says that a 15% efficient panel will generate 150 Wh per sunny hour per $1m^2$ of its surface.

Solar panels' energy production depends heavily on its exposure to the Sun. In winter, when the sunshine is not that intensive and days are short, the panel generates substantially less power than in summer.

13.2 VIBRATIONS

Another option is to use the energy resource provided by railway movement very generously – vibrations. Energy can be harvested from vibrations through piezoelectric materials. Piezoelectric Effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. Piezoelectric effect is reversible, meaning that materials exhibiting the direct piezoelectric effect (the generation of electricity when stress is applied) also exhibit the converse piezoelectric effect (the generation of stress when an electric field is applied). When piezoelectric material is placed under mechanical stress, a shifting of positive and negative charge centres in the material takes place, which then results in an external electrical field. When reversed, an outer electrical field either stretches or compresses the piezoelectric material. [56]

Because the piezoelectric generator itself is very fragile, it must be covered in a robust case to keep it protected from environmental impacts. To optimize the energy output of the harvester, we must know the frequency of the vibrations it is supposed to be exposed to. Manufacturers provide different harvesters peaking in efficiency at different frequencies. Another parameter the harvester's output depends on is the acceleration amplitude.

Exposed to the frequency of vibrations the harvester is designed to, it can generate between 0.1 and 10 mW. The harvester's dimensions are roughly 70x50x1 mm. [57]

13.3 CHOICE

A solar panel needs direct sunlight to harvest energy, whereas a piezoelectric generator needs motion. These technologies don't compete against each other and could be implemented both at the same time. In fact, they could quite efficiently complement each other. If we simplify the conditions to the sunlight being available/unavailable and the wagon moving or not, the only case in which the battery is not being recharged is the wagon standing in a station with no sunlight available.

If I had to pick only one of these technologies, I'd choose piezoelectric generators because it would be easier to install them on most types of wagons, and also because they are designed for use in railway environment. Vibrations and dust from railway transportation could affect solar panels' efficiency and service life.

14 MY WORK

To explore the possibilities of the IoT, I created a device that could be used as a smart wagon device and tested some of its abilities. My device has a GPS receiver, a temperature and humidity sensor and a smoke/gas detector. It uploads data from these sensors to a web server via GPRS. The data is stored in a MySQL database and presented to users using HTML, PHP and JavaScript. A simplified communication scheme of this project is depicted in Figure 18.

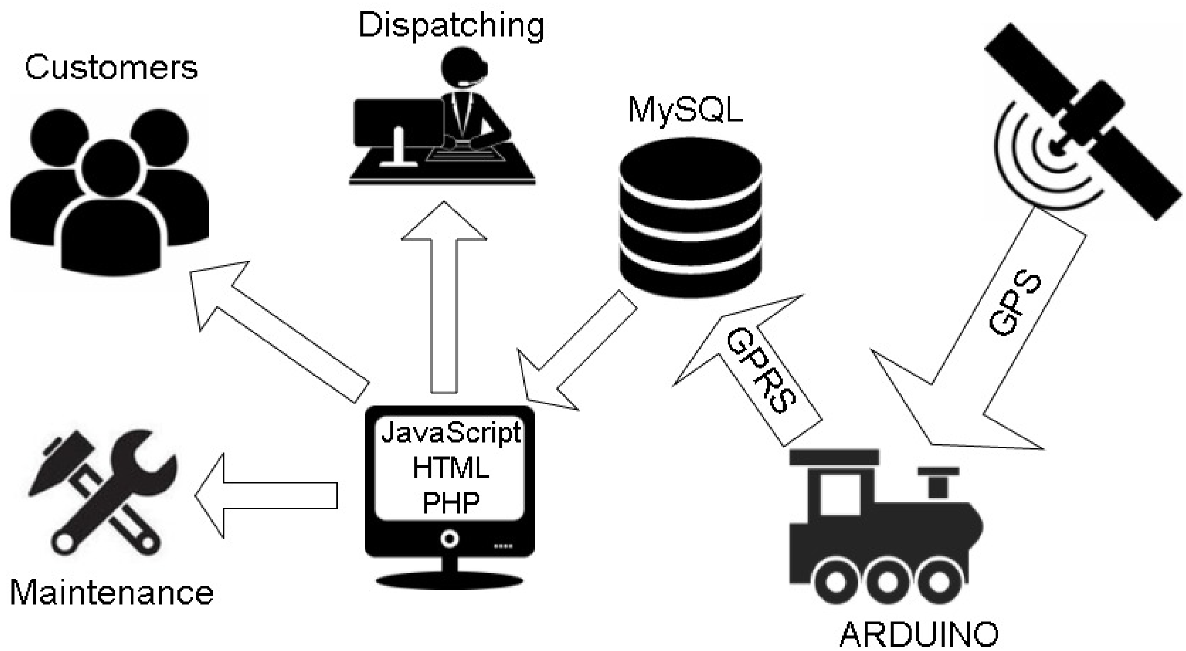


Figure 18: Simple communication scheme of my project.

I also measured the device's power and data consumption with various intervals between each data collection to get an idea about what battery capacity (possibly with some recharging option described in Chapter 13 Power Supply) will be needed for the project. The data consumption was measured to get an idea about required data plan for the smart wagon device.

14.1 THE DEVICE

The components I used are:

- Arduino Uno R3
- Libelium shield with SIM 908 module (GPS and GPRS)
- DHT 22 Temperature and Humidity Sensor
- MQ-2 Smoke and Gas Detector
- 12V 3000 mAh rechargeable Li-Ion battery (originally for CCTV camera)
- GPS antenna
- GPRS antenna
- SIM card (mobil.cz)

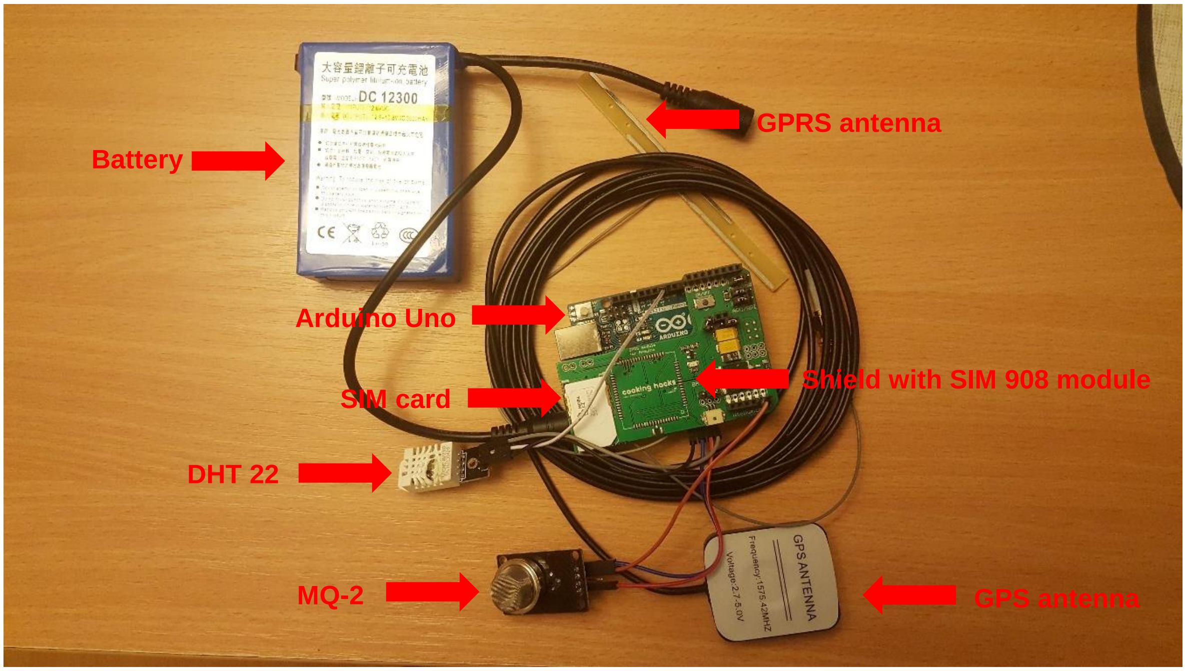


Figure 19: My device.

14.1.1 ARDUINO

Arduino is the cornerstone of my project. It's an open-source electronics platform based on easy-to-use hardware and software. It was developed at the Ivrea Interaction Design Institute in Italy in 2003 as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As it reached greater popularity, it started changing to adapt to new challenges, such as the Internet of Things or 3D printing. [58]

There are several different Arduino versions serving different purposes. The version I used in my project is Arduino Uno R3. It is based on the Atmel ATmega328P microcontroller, which is described in 10.1.2.1 ATmega328P. These tasks don't require microprocessors known from today's computers or mobile phones. These microprocessors would be unnecessarily expensive for this application and would consume too much energy. A simple microcontroller with just a few MHz of operating frequency and with low energy consumption is required. One of the most used microcontrollers of these specifications is Atmel ATmega328P, described in detail in the following chapter.

It has 14 digital I/O pins, 6 analog input pins, operating voltage of 5V and recommended input voltage of 7-12V. The flash memory is 32 KB.

14.1.2 SIM908

SIM908 can receive GPS signal and communicate via GPRS network in 850/900/1800/1900 MHz bands as a GPRS Class 10 device (4 time slots for download, 2 timeslots for upload, downlink speed up to 85.6 kbps). It can operate in temperatures from -40°C to +85°C. The required supply voltage is 3.2 ~ 4.8 V for GPRS and 3.0 ~ 4.5 V for GPS. The GPS module receives GPS L1 C/A code. The Time-To-First-Fix is 30s for cold start and 1s for hot start. Horizontal accuracy is <2.5m (95% of the time). [59]

In my case, the SIM908 module was built into an Arduino shield supplied by Libelium. The shield communicates with the Arduino using its ICPS ports. To perform the required function, the shield needs connected a SIM card, a GPS and a GPRS antenna. Both antennas were provided in the set with the SIM 908 shield, but the default GPS antenna was too weak and had problems with signal acquisition, so I replaced it with an external car navigation system antenna.

14.1.3 DHT22

DHT22 is a digital-output relative humidity and temperature sensor. It has an operating range of 0-100% humidity and -40~80 °C. The accuracy of this sensor is +-5% for humidity and +-0.5 °C for temperature. Its requires power supply between 3.3 and 6 Volts DC. The sensing element is a polymer capacitor. [60]

14.1.4 MQ-2

The gas sensor MQ-2 is useful for detecting gas leakage and smoke. It can detect H_2, LPG, methane, propane, alcohol, CO and smoke. It reacts to concentrations of combustive gases ranging from 300 to 10000ppm. It requires 5V AC or DC voltage. [61]

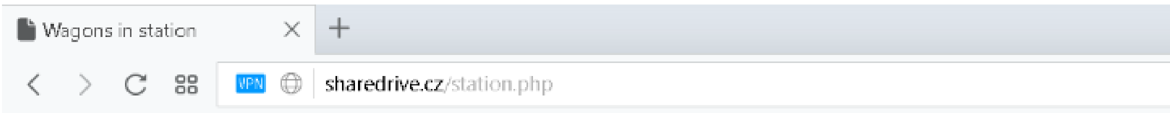
14.2 THE WEBSITE

The website is available under domain http://sharedrive.cz and consists of different scopes displaying different data obtained from the device.

14.2.1 GOOGLE MAP

There are two different scopes available for the Google map. The http://sharedrive.cz/map.html displays all wagons on one map for complete overview of company's fleet. The map is modified to highlight transit lines (including railways) and visibility of roads is switched off.

The other scope is for a specific station. A railway station can be defined by geofencing and when a wagon is in the area of the station, it is displayed in the table above the map as present in the station. List of defined stations is available at http://sharedrive.cz/stations.php .



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wagons in Wien Floridsdorf

code	latitude	longitude	last reported
CD_007	48.26943200	16.41801000	2017-01-19 01:41:08
CD_008	48.26550400	16.41185200	2017-01-19 18:24:12
CD_009	48.26681100	16.41371800	2017-01-19 02:52:26

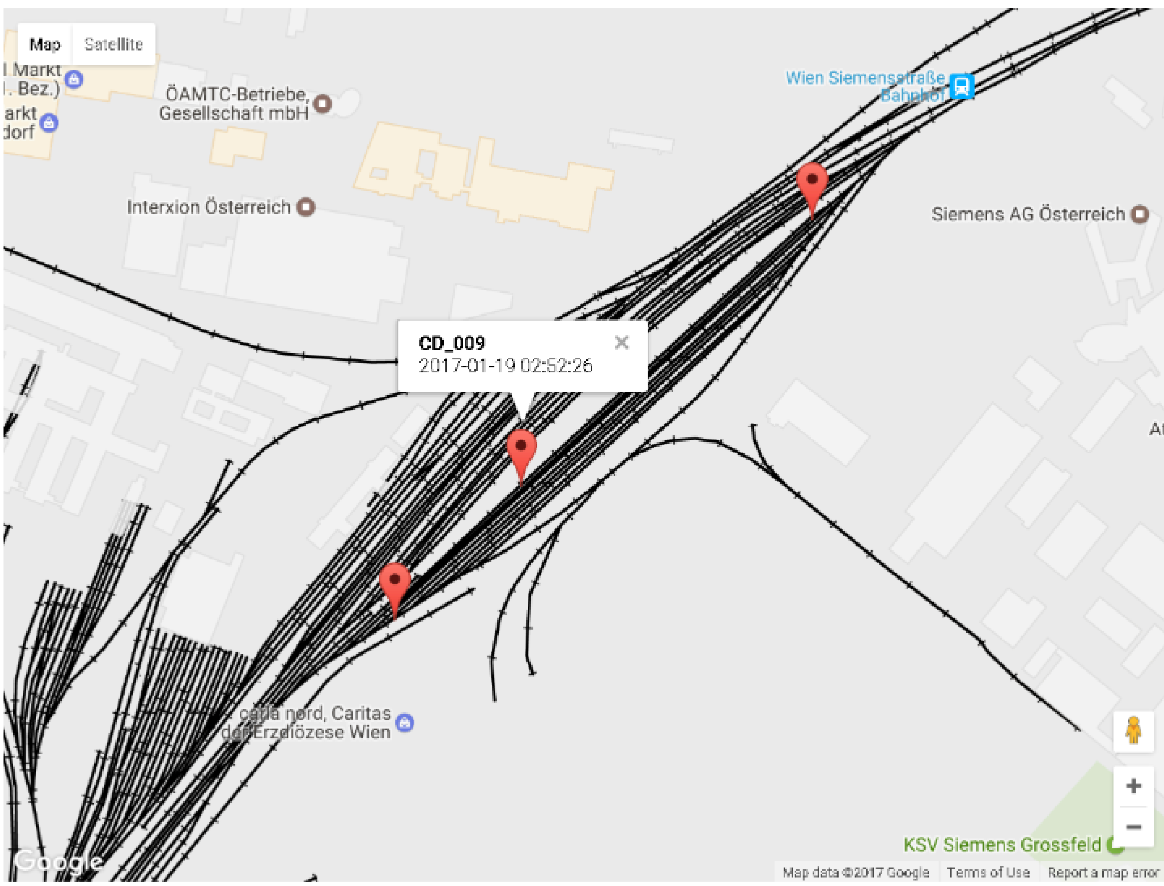


Figure 20: Google map and list of wagons in Wien Floridsdorf.

14.2.2 DATA FROM TEMPERATURE AND HUMIDITY SENSOR

This data is available at http://sharedrive.cz/temperatureandhumidity.html . And after choosing time range for the data (date and time range picker is using code from daterangepicker.com), a chart containing the required data is displayed. The chart uses a JavaScript library called Chart.js.

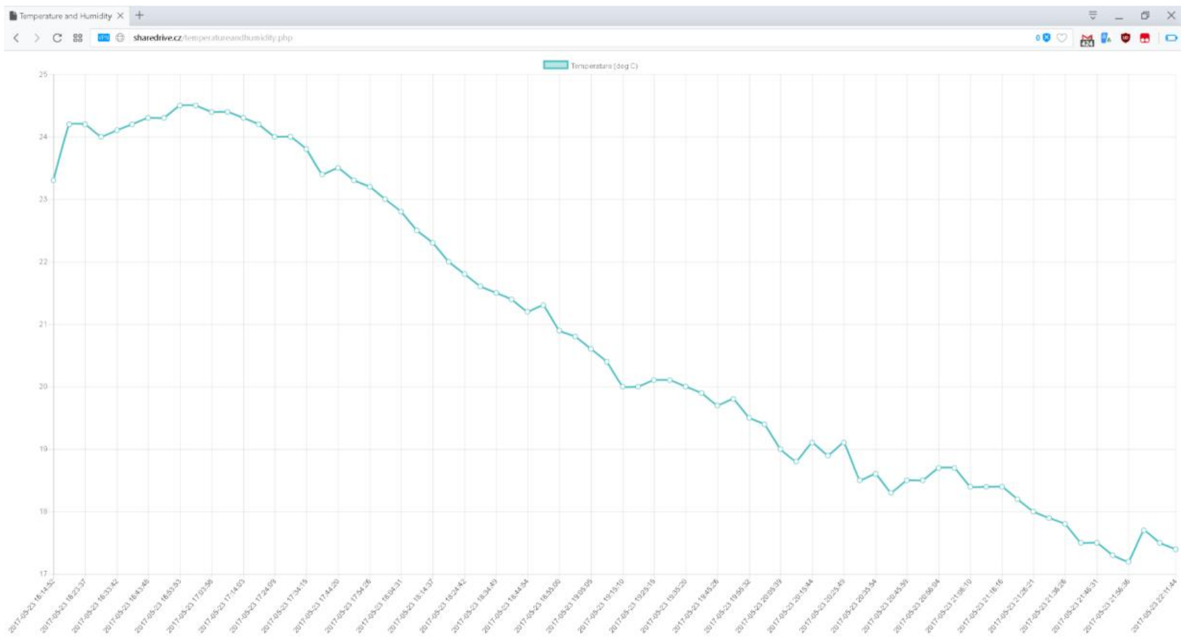
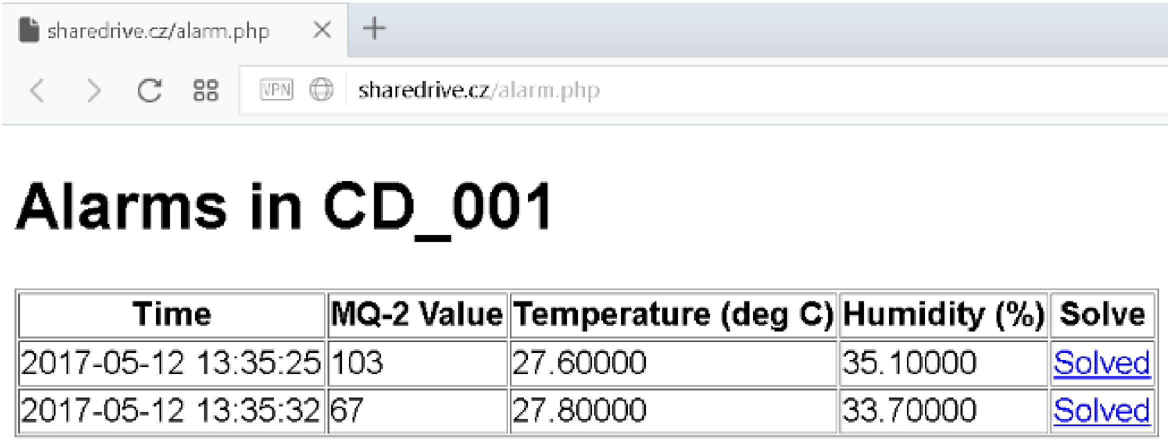


Figure 21: Chart representation of temperature data (sampling period 5 minutes).

14.2.3 ALARMS FROM SMOKE AND GAS DETECTOR

The smoke and gas detector’s output is just a simple analogue value representing the overall presence of all chemicals the sensor is able to sense in its surroundings. After a few experiment measures with butane from a lighter, I decided to set the threshold value to 60. When the value from the MQ-2 detector surpasses 60, it is displayed in the table at http://sharedrive.cz/alarm.php .



Alarms in CD_001

Time	MQ-2 Value	Temperature (deg C)	Humidity (%)	Solve
2017-05-12 13:35:25	103	27.60000	35.10000	Solved
2017-05-12 13:35:32	67	27.80000	33.70000	Solved

Figure 22: Alarms table.

14.3 POWER AND DATA CONSUMPTION TESTING

The aim of the testing is to find a compromise between sampling frequency, energy consumption and data plan of the device.

14.3.1 ENERGY CONSUMPTION

For power consumption test, I used a USB tester and a 230V USB power adapter. The USB power adapter's output is 5.5V and gives up to 2A. The USB tester works with voltages between 3-30V and currents ranging from 0-5.1A. It is able to detect charging current, voltage and consumed energy (in Wh and Ah). The manufacturer claims that the tester's accuracy is ±1%.

Figure 23: USB power adapter and USB tester.

14.3.2 DATA CONSUMPTION

Data consumption was measured via my operator’s data consumption monitoring. The operator measures data transferred per day and rounds to kilobytes.

14.4 TESTING RESULTS

My Arduino was taking the data from the sensors with different intervals (1 minute, 5 minutes and 30 minutes). For each of these modes, I measured energy consumption and transferred data. The results were as follows:

Sampling frequency	1 minute	5 minutes	30 minutes
Duration [hours]	4	6	6
Samples	234	71	11
Consumed energy [Wh]	6.438	9.096	9.345
Discharge at ~5.5 V [mAh]	1165	1647	1692
Data measured by operator [kB]	188	57	10

Discharge calculated for 24 hours of operation [mAh]	6990	6588	6768
Data consumption calculated for 30 days [MB]	33.0	6.7	1.2

Table 18: Measurement results.

Arduino uses about 45 mA current. [62] GPS on SIM908 takes 76 mA in the continuous tracking mode and 77 mA in the acquisition mode. [59] Consumption of GPRS module depends on many factors. It toggles between two modes, the GPRS standby mode and the GPRS data mode depending on whether data is currently being transferred or not. Power consumption depends (among other aspects) on network settings, GPRS configuration and the signal strength in the area of the receiver. It could be said that a GPRS module consumes 30-50 mA when inactive and up to 1800 mA during data transmission. [63] The MQ-2 sensor consumes up to 150 mA at 5V. [64] The consumption of DHT22 is negligible, typically around 1.5 mA. [60]

Device	Current consumption [mA]
Arduino	45
GPS	76/77
GPRS	30-50 inactive/1800 during transmission
Gas Detector	(up to) 150
Temperature and Humidity Sensor	1.5

Table 19: Current consumption of each module.

When I was observing the energy consumption of the device, it was consuming between 250-300 mA when inactive and the value rose almost up to 1000 mA when sampling.

From the table, it’s clear that as it stands, my device is energetically far too inefficient for the IoT application. My device wasn’t put into sleep mode between the samplings. As a result, there was almost no influence of sampling frequency on the overall power consumption. It went as far as to the point when the device consumed more energy with 30-minute sampling frequency than with 5-minute sampling frequency. The possible reasons for this phenomenon might be:

- Error on the cheap USB tester
- Different configuration of GPRS network

- The MQ-2 sensor – In order to take samples, the sensor needs to warm up to about 60°C. The day I was measuring the consumption for 5-minute sampling frequency, the weather was warm and the sensor was under direct sunlight. That might have resulted into lower powering requirements on the sensor's heating.

In mobile data plan measures, the data consumption is very low. It fits better into the LPWAN data plan bracket.

14.5 FUTURE WORK

The device I made is currently useless due to its power consumption. Its power management must be improved. A sleep mode must be implemented and the power consumption between sampling must be reduced to minimum. The issue with the sleep mode is that the device would lose the GPRS and GPS connection. From my experience, it takes about a minute to obtain the GPS data on a cold start. Even with a better power management, it's worth considering extending the sampling frequency. In my opinion, the ideal sampling frequency is between 0.5-2 hours.

It will also be necessary to physically separate the processing unit from the sensors and implement a short – range communication technology to replace the wires. Then each of the sensors will need its own battery.

The development of LPWAN technologies will be very important. If any one of the technologies reaches a good coverage, it will be ready to replace the GPRS. And depending on the technology's receiver cost and power consumption, it would also be possible to leave out the short – range communication and make each sensor communicate with the web server directly.

It would also be interesting to explore the possibilities of energy harvesting on cargo wagons, especially from piezoelectric generators. To find the optimal piezoelectric generator, we need to know the frequency of vibrations of a moving wagon.

15 CONCLUSION

Smart wagon technology is a real challenge, but it will take another couple of years until it truly booms. Over the last few years, the idea has developed from an academic concept suggesting the use of Train Communication Network (IEEE 1473 standard for wired communication is passenger trains) for short - range communication and GSM-R for long – range communication in 2010 to a real application by Bosch and SBB using Bluetooth for short – range communication and GPRS for long – range communication.

I don't think smart wagons will boom using these technologies. Bluetooth LE meets all the criteria for smart wagon application, but I don't consider GPRS the ideal technology for smart wagons. It's becoming obsolete and won't be in use forever. In terms of energy management and consumption, it can't compete with the emerging Low-Powered WAN networks such as LoRaWAN, Sigfox or NB-IoT. These technologies are destined to replace GPRS in machine-to-machine communication. Their networks are currently being built and the question is which ones will be able to raise enough funds to cover the whole European area and maintain the network because it's almost certain that some of them will eventually fail to do so.

But the ones that will succeed will offer better energy consumption, cheaper devices and data plans compared to GPRS. It is not difficult to predict that the real boom of IoT won't happen until these networks are completed.

Since the GPS became widespread in the late 1990s, there has been no real competition for it. The only real competition, GLONASS, was hit hard by the dissolution of the USSR and couldn't compete in either accuracy or availability. But times have changed, GLONASS is competitive again and there are two other GNSS systems on their way to completion – Galileo and BeiDou. For future application, if Galileo is able to provide the specifications it promises, it will certainly be worth considering its receivers instead of GPS-only receivers (Galileo receivers will be able to receive signals from Galileo, GPS and GLONASS satellites at the same time).

The device I constructed to test the possibilities of smart wagon devices is based on Arduino and uses GPRS for data transfers, GPS for geolocation and contains also a temperature and humidity sensor and a smoke and gas detector. I also created a website presenting the obtained data. The website is available under domain http://sharedrive.cz .

I tested the device's power and data consumption with different data sampling frequencies. The result is that the data consumption is low, but the energy consumption is very high and the device needs to improve its power management by implementing a sleep mode.

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