INTELLIGENT ROAD


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This document is created in a project called Intelligent Road. The project is financed by EU:s INTEREG IV A North program for interregional cooperation.
Executive Summary

Project Intelligent Road is a common effort of four main partners: Rovaniemi University of Applied Sciences (RAMK), Luleå Technical University (LTU), Finnish Meteorological Institute (FMI), Kaakkois-Suomen ELY-keskus (KaS ELY) – and representatives of business sector of the region. The overall objective of the project is to support the development of business community in Northern Scandinavian region by testing and improvement of existing innovative products concerned with road safety provision in Nordic weather conditions. The specific objective of the project is to create a demo of sustainable and marketable Intelligent Road System providing location-based short-term road weather information to the road user passing by the area. Target Groups, which are directly and positively affected by the project are businesses and above mentioned project partners. All these actors have exclusive know-how in the area and are each equally important for the implementation of the project and its success. Final beneficiaries of this project are business community of the Northern Scandinavian Region; Ministry of Transport and Communications of Finland, represented by KaS ELY and Finnish Transport Safety Agency; Swedish Ministry of Enterprise, Energy and Communications; and of course local municipalities, as Luleå Municipality, and road users.
CONTENTS

Executive Summary ................................................................................................................. 1

CONTENTS .............................................................................................................................. 2

Glossary & Terminology ......................................................................................................... 5

1 SYSTEM REQUIREMENTS AND SPECIFICATIONS .............................................................. 6

1.1 INTRODUCTION .............................................................................................................. 6

1.2 VEHICULAR NETWORKING ............................................................................................. 6

1.2.1 Overview ....................................................................................................................... 6

1.2.2 Cooperative ITS .......................................................................................................... 8

1.2.3 3G/4G .......................................................................................................................... 10

1.2.4 Bluetooth ................................................................................................................... 10

1.2.5 ZigBee .......................................................................................................................... 11

1.2.6 Comparison of methodologies ..................................................................................... 11

1.3 Existing road weather services ......................................................................................... 12

1.3.1 ELY’s road condition service ...................................................................................... 12

1.3.2 Finnish Transport Agency’s road condition service ..................................................... 13

1.3.3 Destia’s Varopalvelu .................................................................................................. 14

1.3.4 Liukasta.info –service ............................................................................................... 15

1.4 Intelligent Road requirements ........................................................................................ 15

1.4.1 Overview ....................................................................................................................... 15

1.4.2 General Objectives ..................................................................................................... 16

1.4.3 Site-specific requirements .......................................................................................... 16

1.5 Requirements Specification ............................................................................................. 17

1.5.1 Overview ....................................................................................................................... 17

1.5.2 Rovaniemi site ............................................................................................................ 17

1.5.3 Sodankylä site ............................................................................................................. 21

1.5.4 Luleå site ..................................................................................................................... 24

1.5.5 Co-operation activities ............................................................................................... 26

1.6 Conclusions ...................................................................................................................... 27

2 SYSTEM DESIGN .............................................................................................................. 28

2.1 INTRODUCTION .............................................................................................................. 28
2.1.1 Objective ................................................................................................................. 28
2.1.2 Intelligent Road system ......................................................................................... 28
2.2 HARDWARE ARCHITECTURE .................................................................................. 29
  2.2.1 Vehicle data acquisition system ........................................................................... 29
  2.2.2 DAVIS weather station ......................................................................................... 36
  2.2.3 Road Weather Station ......................................................................................... 38
  2.2.4 Road Weather Station data distribution to the road users .................................. 40
2.3 SOFTWARE ARCHITECTURE ................................................................................... 42
  2.3.1 Vehicle data acquisition system ........................................................................... 42
  2.3.2 Road Weather Station ......................................................................................... 50
  2.3.3 Road weather data distribution systems ............................................................. 53
  2.3.4 IR Mobile application ......................................................................................... 53
2.4 SERVER ARCHITECTURE ......................................................................................... 55
  2.4.1 Big picture ........................................................................................................... 55
  2.4.2 Database design .................................................................................................. 55
  2.4.3 Client-server communication .............................................................................. 56
  2.4.4 Data processing methods ................................................................................... 56
  2.4.5 Data types .......................................................................................................... 57
3 SYSTEM TESTING AND VALIDATION ...................................................................... 62
3.1 INTRODUCTION ....................................................................................................... 62
  3.1.1 The purpose of the Intelligent Road system ....................................................... 62
  3.1.2 Validation ........................................................................................................... 62
  3.1.3 Presentation ....................................................................................................... 63
  3.1.4 Testing ................................................................................................................ 63
3.2 SYSTEM VALIDATION ............................................................................................ 63
  3.2.1 Optical sensors .................................................................................................. 64
  3.2.2 Weather and road forecast ............................................................................... 65
  3.2.3 Communication ................................................................................................. 65
  3.2.4 Presentation ....................................................................................................... 65
3.3 SYSTEM TESTING ................................................................................................ 65
  3.3.1 Sensors and data collection ............................................................................... 65
# Glossary & Terminology

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSMA/CA</td>
<td>Carrier-Sense Multiple Access with Collision Avoidance</td>
</tr>
<tr>
<td>C2C-CC</td>
<td>Car 2 Car Communication Consortium</td>
</tr>
<tr>
<td>CCK</td>
<td>Complementary Code Keying</td>
</tr>
<tr>
<td>DSSS</td>
<td>Direct Sequence Spread Spectrum) and</td>
</tr>
<tr>
<td>ELY</td>
<td>Centre for Economic Development, Transport and the Environment</td>
</tr>
<tr>
<td>ETSI</td>
<td>The European Telecommunications Standards Institute</td>
</tr>
<tr>
<td>FTA</td>
<td>Finnish Transport Agency</td>
</tr>
<tr>
<td>IEEE</td>
<td>The Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IR</td>
<td>Infrared</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation Systems</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunications Union</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>MIB</td>
<td>Management Information Base</td>
</tr>
<tr>
<td>OFDM</td>
<td>Orthogonal Frequency-Division Multiplexing</td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle-to-Infrastructure communications</td>
</tr>
<tr>
<td>V2R</td>
<td>Vehicle-to-Roadside communications</td>
</tr>
<tr>
<td>V2V</td>
<td>Vehicle-to-Vehicle communications</td>
</tr>
<tr>
<td>VANET</td>
<td>Vehicular Area Networking</td>
</tr>
<tr>
<td>WAVE</td>
<td>Wireless Access in Vehicular Environments</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>Wireless Fidelity</td>
</tr>
<tr>
<td>WiMAX</td>
<td>Worldwide Interoperability for Microwave Access</td>
</tr>
</tbody>
</table>
1 SYSTEM REQUIREMENTS AND SPECIFICATIONS

1.1 INTRODUCTION

This document presents the specification of requirements in Intelligent Road project. It also gathers together the work conducted in Work Package 1. The objectives in the WP1 are the definition of measurement parameters, the measurement of parameters, analysis of available sensors and technologies for the measurements and the definition of user needs. This document is not covering the measurement procedures themselves, but otherwise aims to fulfill all the requirements stated for WP1.

The document is structured as follows. The brief state-of-the-art review for the related vehicular networking and short-range wireless communication research is presented in the following chapter. State-of-the-art review for the existing road weather services is presented in the chapter 3. In the chapter 4, the requirements of Intelligent Road project are presented both in general level and in site-specific form. In the next chapter, the specification of requirements is presented in detail, site by site. Finally the conclusions are drawn in the chapter 6.

1.2 VEHICULAR NETWORKING

1.2.1 Overview

Vehicular Ad Hoc Networks (VANETs) have grown out of the need to support the growing number of value added wireless services such as vehicle safety, automated toll payment, traffic management, enhanced navigation, location-based services such as finding the closest fuel station, restaurant or travel lodge and infotainment applications such as providing access to the Internet.

As mobile wireless devices and networks become increasingly important, the demand for Vehicle-to-Vehicle (V2V) and Vehicle-to-Roadside (V2R) or Vehicle-to-Infrastructure (V2I) communication will continue to grow. VANETs can be utilized for a broad range of safety and non-safety applications. Over the last few years, we have witnessed many research efforts that have investigated various issues related to V2I, V2V, and V2R areas because of the crucial role they are expected to play in Intelligent Transportation Systems (ITSs).

In the first approaches for VANET system the straightforward approach was to rely on traditional wireless networks, the system called Wireless Fidelity (Wi-Fi). The approach has many benefits, the most important one being the compatibility with home networking equipment, making it nowadays very price-competitive and rather efficient. However, as Wi-Fi has been designed for the static nodes typically located in office environment, problems arises in vehicular networking environment. The rapidly moving vehicles and complex roadway environment present challenges at the physical level. Also the communication reliability requirement all the time with safety-related services is an important aspect. Nonsafety applications also require fast and efficient connection setups with roadside stations providing services (e.g., weather and road data update) because of the limited time a car spends within the station coverage area. The IEEE 802.11 standardization
body has finished a new amendment, IEEE 802.11p, to address these concerns. The IEEE 802.11p medium access control standard is part of the WAVE standards (wireless access in vehicular environments), containing also IEEE 1609 standard family for the architecture, communications model, management structure, security mechanisms, and physical access for wireless communications in the vehicular environment. In Europe IEEE 802.11p is used as a basis for the ITS G5 standard, supporting the geonetworking protocol for vehicle to vehicle and vehicle to infrastructure communication. ITS G5 and geonetworking is being standardized by ETSI ITS, with close co-operation with Car 2 Car Communication Consortium (C2C-CC). The IEEE standardization forum is U.S counterpart for ETSI standardization forum, but in this particular case IEEE and ETSI have been working in close co-operation, aiming to have a global system usually referred to as cooperative ITS. The cooperative ITS is nowadays the primary approach for the vehicular networking.

Even if cooperative ITS is the specially tailored and generally approved approach for the vehicular networking, one can also use general purpose communication approaches for vehicular networking. Mobile communication networks are currently widely relying on 3G communication methodology, nowadays slowly moving into 4G communications, respectively. Both of these approaches provide appropriate communication capabilities for the major part of the vehicular networking services envisioned, except the safety related services.

It is possible also to employ general purpose short distance communication systems (in addition to Wi-Fi) for the vehicular networking. The data capacity and range are seriously limited in these approaches, but as an advantage one gains solution and device simplicity and low price. Such kinds of approaches are Bluetooth and ZigBee, among others.

In the following sub-chapter the most important vehicular networking approaches (mentioned above) are presented in detail.

1.2.1.1  IEEE 802.11
The IEEE 802.11 standard (originally published in 1997) defines wireless LAN MAC and physical layer (PHY) specifications. The fundamental access method for the MAC is carrier sense multiple access with collision avoidance (CSMA/CA). The services realized via MAC messages are the core of the standard.

The original IEEE 802.11 standard defined three different radio systems: 2.4 GHz FHSS (Frequency-Hopping Spread Spectrum), 2.4 GHz DSSS (Direct Sequence Spread Spectrum) and IR (Infrared). DSSS is the most common approach and is used in the extensions of the standard defined later. The data rates are 1 Mbps and 2 Mbps. Lots of extensions to the standard are produced, the most common ones being nowadays 802.11b and its downward compatible followers 802.11g and 802.11n, presented in the following sub-chapter.
1.2.1.2 IEEE 802.11 b/g/n
IEEE 802.11b was the first backward compatible enhanced version of 802.11. The frequency band is the same 2.4 GHz, as well as the CSMA/CA based MAC. 802.11b provided new data rates of 5.5 Mbps and 11 Mbps. The CCK (Complementary Code Keying) modulation method enables the possibility to achieve higher data rates. Otherwise the IEEE 802.11b had only minor differences to the original standard.

The next advanced version was IEEE 802.11g standard extension providing an 802.11a type system (capacity up to 54 Mbps) in the 2.4 GHz frequency (802.11a was designed to 5 GHz band). The modulation scheme used in 802.11g is orthogonal frequency-division multiplexing (OFDM) copied from 802.11a with data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s, and reverts to CCK (like the 802.11b standard) for 5.5 and 11 Mbit/s. Even though 802.11g operates in the same frequency band as 802.11b, it can achieve higher data rates because of its heritage to 802.11a.

IEEE 802.11n is the latest amendment to the IEEE 802.11 Wi-Fi standard to improve network throughput with a significant increase in the maximum net data rate from 54 Mbit/s to 600 Mbit/s (slightly higher gross bit rate including for example error-correction codes, and slightly lower maximum throughput) with the use of four spatial streams at a channel width of 40 MHz. It has standardized support for multiple-input multiple-output and frame aggregation, and security improvements, among other features.

1.2.2 Cooperative ITS
1.2.2.1 WAVE - IEEE 802.11p and IEEE 1609.x
The 802.11 standardization forum noted that former 802.11 standards (b,g) were not optimal for fast nodes. The time a vehicle stays in the area of the base station is rather short for initiating the connection and carrying out data exchange. Also, Wi-Fi system with carrier sense multiple access with collision avoidance (CSMA/CA) is not especially tailored for the quick connection creation of high-speed nodes. The forum started tackling the issue of vehicular communication, especially in the 802.11p standardization work, based on the IEEE 1609 standard family. The underlying protocol structures behind all of these activities are IEEE WAVE (Wireless Access in Vehicular Environments) standards, IEEE 802.11p for lower communication protocol layers and IEEE 1609 standard family for the upper layers, respectively. IEEE 802.11p is the standard for vehicular networking. The underlying technology in this protocol is Dedicated Short-Range Communication (DSRC), which essentially uses the IEEE 802.11a standard OFDM based physical layer and quality of service enhancements of IEEE 802.11e, adjusted for low overhead operations. The IEEE 802.11p uses an Enhanced Distributed Channel Access (EDCA) MAC sub-layer protocol designed into IEEE 802.11e, with some modifications to the transmission parameters. DSRC is a short-range communication service designed to support communication requirements for enhancing public safety applications, to save lives and to improve traffic flow by vehicle-to-vehicle and infrastructure-to-vehicle communications. WAVE is the next generation technology, providing high-speed vehicle to-vehicle and vehicle-to-infrastructure data transmission. The WAVE system is built on IEEE 802.11p and IEEE
1609.x standards operating at 5.850-5.9250 GHZ with data rates supports between 3 and 27 Mbps with 10 MHz channel and 6-54 Mbps in 20 MHz channel, respectively. Up to 1000 m range in variety of environments (e.g., urban, suburban, rural and motorways) is supported, with relative velocities of up to 110 km/h, with either 10 MHz or 20 MHz channel bandwidth.

The IEEE 1609 Family of Standards defines an architecture and complementary, standardized set of services and interfaces that collectively enable secure vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless communications. IEEE 1609.1 - Trial-Use Standard for WAVE Resource Manager, describes the key components of the WAVE system architecture and provides the resource manager for this wireless system. IEEE 1609.2 - IEEE Trial-Use Standard for WAVE Security Services for Applications and Management Messages defines the secure message formats and processing. It also defines the circumstances for using secure message exchanges and how those messages should be processed base upon the purpose of the exchange. IEEE 1609.3 - IEEE Trial-Use Standard for WAVE Networking Services defines the network and transport layer services, including addressing and routing, in support of secure WAVE data exchange. It also defines Wave Short Messages, providing an efficient WAVE-specific alternative to IPv6 (Internet Protocol version 6) that can be directly supported by applications. Furthermore, this standard defines the Management Information Base (MIB) for the WAVE protocol stack. Finally, IEEE P1609.4 - IEEE Trial-Use Standard for WAVE Multi-Channel Operations provides enhancements to the IEEE 802.11 Media Access Control (MAC) to support WAVE operations.

1.2.2.2 C2C-CC and ETSI G5

The Car 2 Car Communication Consortium (C2C-CC) is an organization comprising European vehicle manufacturers that is open for providers, research associations and other partners. The C2C-CC started trials in 2001 and demonstrated the use of IEEE 802.11 WLAN technologies in order for the vehicles to communicate with each other within the range of a few hundred meters.

The Car2Car communication trials are focusing on driver assistance using new wireless technologies, design and development of active safety applications, the floating car data which operates by updating the service center which holds data relating to individual vehicles parameters, as well as user communication and information services. C2C-CC is a key contributor to the V2V and V2I validation trial processes.

C2C-CC also has the objective of contributing to the European standardization bodies and in particular ETSI TC ITS (European Telecommunications Standards Institute: Technical Committee: Intelligent Transport Systems). Standard process called ETSI G5, more specifically ETSI ES 202 663, is in practice the European counterpart for vehicular networking standardization. The ultimate goal is to maintain the compatibility between the American oriented IEEE 802.11 and European ETSI standardization, respectively.
1.2.3 3G/4G

3G is the third generation technology which is mainly used in mobile communication. It supports data throughput up to 2 Mbps for stationary users and 384 Kbps for moving vehicles. The peak downloaded rate achieves 100 Mbps and peak uploaded rate is 50 Mbps. It includes services like Code Division Multiple Access (CDMA) 2000 and Universal Mobile Telecommunications System (UMTS). The defined network destination is a cell based wide area. The frequency band oscillates between 1.8-2.5 GHz.

Third generation technology is geared toward cellular telephone technology and Internet access. Especially it is designed to download efficiently the information from the Internet or sending and receiving large multimedia files. The devices using 3G are considered to support also broadband applications like mobile-tv, video on demand, video conferencing, tele-medicine or location-based services.

4G is the fourth generation technology which provides much higher data rate than 3G. The standard uses Orthogonal Frequency-Division Multiplexing (OFDM) which provides high throughput in the range of 100 to 300 Mbps. The data are downloaded with peak rate of 1 Gbps and uploaded in peak with 500 Mbps. The frequency band is between 2.0-8.0 Ghz. The supported services are Worldwide Interoperability for Microwave Access (Wimax) Advanced and Long Term Evolution (LTE). They guarantee IP-based architecture, multi antenna techniques and network scalability.

The International Telecommunications Union (ITU) specified that 4G must provide networks without interruptions and loss of signals. It provides the high demands of the user applications like live mobile video, mobile portable gaming, cloud-based applications, emergency response and tele-medicine.

1.2.4 Bluetooth

The widespread use of Bluetooth in mobile phones, PDAs, head sets, and tablets make Bluetooth an interesting technology to when interaction with a human user is important. Bluetooth allows up to seven devices to form a local wireless network called a Piconet. The maximum bandwidth of Bluetooth is around 2 Mbit/s, which is adequate for streaming high-quality music, file transfer of smaller files such as business cards etc., and the use of Bluetooth-based Human-machine interfaces (HMI) such as mice and keyboards. Bluetooth can also be used for TCP/IP networking through of the of the Bluetooth Personal Area Network (PAN) profile. By using the PAN profile, a device such as a mobile phone can share its Internet-connection to other devices.

Bluetooth can also be used for sensor networks, where small devices uses sensors to monitor a certain physical property, i.e. temperature, vibrations, humidity, position, etc., and can send sensor data to the Internet using the PAN profile and a standard consumer device such as a mobile phone.
Bluetooth, or IEEE 802.15.1 as it is formally called, is maintained by the Bluetooth Special Interest Group (SIG). The SIG organization performs interoperability tests, sets standards and promotes the use of Bluetooth worldwide.

1.2.5 ZigBee

ZigBee, or IEEE 802.15.4, is a standard for low-bandwidth wireless communication. It resembles Bluetooth, but allows much large networks to be formed and can be used in a multi-hop (mesh) configuration. The bandwidth of IEEE 802.15.4 is much lower than that of Bluetooth, but the power consumption is also much lower. IEEE 802.15.4 was designed for sensor network applications with often battery-powered nodes. The primary use is in the context of wireless data acquisition.

The IEEE standard 802.15.4 is used as a base for a multitude of wireless technologies. Some examples are:

- ZigBee.
  The name ZigBee is actually a software layer on top of the IEEE 802.15.4 standard. ZigBee defines a number of profiles for devices, and handles routing, low-power and other features.
- 6LoWPAN
  When using TCP/IP over 802.15.4, the use of ZigBee is not optimal though ZigBee now supports the use of IP-based communication. The term Internet of Things (IoT) is today closely coupled with wireless communication suing IEEE 802.15.4 even though other technologies also are supported, such as powerline communication. 6LoWPAN is a specification for compression of IPv6 packets on top low-bandwidth communication links, such as IEEE 802.15.4.
- WirelessHART
  The use of wireless technologies in industrial application often involves HART-based communication. WirelessHART is an adaptation of the older cable-based HART protocol to use 802.15.4 as a medium.

1.2.6 Comparison of methodologies

The comparison between presented methodologies is not easy pull out, as they have been designed for slightly different purposes. However, the main features of the presented methods are listed in the Table I below.

<table>
<thead>
<tr>
<th>Communication method</th>
<th>Theoretical data</th>
<th>Mobility</th>
<th>Architecture</th>
<th>Connection delays</th>
<th>Theoretical range</th>
</tr>
</thead>
<tbody>
<tr>
<td>WirelessHART</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZigBee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6LoWPAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I: The main features of the communication methods related to vehicular networking
<table>
<thead>
<tr>
<th>Service Type</th>
<th>Rate</th>
<th>Coverage</th>
<th>Quality</th>
<th>Cellular Status</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional WLAN; IEEE 802.11g</td>
<td>54 Mbps</td>
<td>Low</td>
<td>Local</td>
<td>Low</td>
<td>140 m</td>
</tr>
<tr>
<td>Conventional WLAN; IEEE 802.11n</td>
<td>600 Mbps</td>
<td>Very low</td>
<td>Local</td>
<td>Low</td>
<td>250 m</td>
</tr>
<tr>
<td>V2V (vehicle-to-vehicle)¹</td>
<td>3-54 Mbps</td>
<td>Good</td>
<td>Local</td>
<td>Very low</td>
<td>1 km</td>
</tr>
<tr>
<td>V2I (vehicle-to-infrastructure.)¹</td>
<td>3-54 Mbps</td>
<td>Good</td>
<td>Local</td>
<td>Very low</td>
<td>1 km</td>
</tr>
<tr>
<td>GPRS cellular data</td>
<td>56–114 kbit/s</td>
<td>Good</td>
<td>Cellular</td>
<td>Moderate</td>
<td>unlimited³</td>
</tr>
<tr>
<td>3G cellular data</td>
<td>0.2 Mbps</td>
<td>Moderate</td>
<td>Cellular</td>
<td>Moderate</td>
<td>high³</td>
</tr>
<tr>
<td>LTE/4G cellular data</td>
<td>300 Mbps</td>
<td>Moderate</td>
<td>Cellular</td>
<td>Moderate</td>
<td>low³</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>2 Mbps</td>
<td>Very low</td>
<td>Local</td>
<td>High</td>
<td>100 m</td>
</tr>
<tr>
<td>ZigBee/IEEE 802.15.4</td>
<td>250 kbps</td>
<td>Very low</td>
<td>Local</td>
<td>High</td>
<td>50 m</td>
</tr>
</tbody>
</table>

¹ based on IEEE 802.11p networking  
² with maximum data rate mode  
³ commercial cellular systems range is not defined as range of one cell but the coverage of operational systems in 2013

1.3 Existing road weather services

This chapter introduces few existing road weather services in Finland (and Sweden).

1.3.1 ELY’s road condition service

The Finnish Centre for Economic Development, Transport and the Environment (ELY) is producing a road condition web service called “ELY ajokeli”. Web page for the service can be found from http://keli.foreca.fi/production/app.fi.html (figure 1). Service offers real-time information and forecasts about the road conditions and weather. It covers all the main roads in Finland and classifies the road condition into normal, poor and very poor driving conditions with the green, yellow and red color, respectively. The roads and the road weather cameras are shown on the map. Users can click the camera figures on the map to see the picture of the current road condition on
the spot. By clicking the road user sees the current temperature and wind situation on the road and also the forecast for the next few hours.

ELY’s road condition service shows the same road condition and the forecast even for over 100 km long road stretches. The real situation at the road is not measured. Comparing to the Intelligent Road project system where the vehicles are collecting the real time data from the roads and sending them to the main server, the ELY’s service is far more inaccurate.

![Figure 1. ELY’s road condition service.](image)

### 1.3.2 Finnish Transport Agency’s road condition service

The Finnish Transport Agency (FTA) is producing an automated road condition forecasts on a public map service. Functionality and the appearance are consistent to the ELY’s road condition service described in the previous chapter (3.1). Web page for the service can be found from [http://www2.liikennevirasto.fi/alk/english/keliennuste/](http://www2.liikennevirasto.fi/alk/english/keliennuste/) (figure 2). Service is delivered for the FTA as a turnkey solution by the Finnish GIS-company Karttakeskus. Karttakeskus is producing overall service management, 24/7 monitoring and maintenance of the web service. Forecasts and weather model for the service are produced by the Finnish Meteorological Institute (FMI). The road
condition data is retrieved from the FMI servers to the web map service. Observations and road weather camera pictures, which are retrieved from the Digitraffic interface, are updated every 15 minutes and the forecasts are updated every hour.

![Map of road conditions](image)

Figure 2. Finnish Transport Agency’s road condition service.

1.3.3 Destia’s Varopalvelu

The Finnish infrastructure and construction service company Destia and Finnish Meteorological Institute (FMI) are producing road condition service called “Varopalvelu”. Service warns the road users for disturbances in the traffic and changes at the road conditions by a sms, a smartphone application or a wap browser. The service tells the sudden changes in the road and weather conditions or the traffic disturbances like accidents, thundershowers, snowstorms or local slipperiness on the road to the driver. The service includes a route forecast service in which user can define the route.
1.3.4 Liukasta.info –service

Liukasta.info is a service, provided by Iriba and Teconer companies, offering users an opportunity to browse road slipperiness measurements conducted on the road network during the last 24 hours. Web page for the service can be found from liukasta.info (Figure 3). The µTec mobile software solution is used for road slipperiness measurement and the results are presented in real-time on the map as well as the slipperiness information from the road weather stations of the Finnish Road Administration.

1.4 Intelligent Road requirements

1.4.1 Overview

In this chapter the requirements stated for the Intelligent Road project are described.
1.4.2 General Objectives

The general objective of the Intelligent Road project is to implement a demo system which provides information of local road and weather conditions for road users. Information is also available for other service providers who can utilize it in their own services.

1.4.3 Site-specific requirements

1.4.3.1 Rovaniemi

Rovaniemi (RAMK/Arctic Power) focuses on implementing data acquisition systems (DAQ) for test vehicles equipped with measurement devices. These vehicles are delivery trucks and normal passenger vehicles. Delivery trucks are owned by Kuljetus Kovalainen Oy and passenger vehicles will be pointed out by LTU later on. Measurement devices are used to measure road conditions and optionally selected CAN-bus data while vehicles are driving. DAQ-system sends real-time data to Intelligent Road data server. The server handles data storage and processing and makes data available for other users via different interfaces. Wireless data exchange between trucks and Sodankylä RWS will be tested also. Use of alternating traffic signs to inform road users about road conditions on Rovaniemi-Sodankylä road will be investigated and implemented if found possible.

Requirements for completing the objectives are:

- real-time collection of road condition along with position information (GPS) and other data
- data exchange between vehicle and RWS
- data transfer between vehicle and IR data server
- data transfer between IR data server and traffic signs
- data visualization
- interfaces to data for different users/authorities

1.4.3.2 Sodankylä

Operations in Sodankylä are built around FMI experimental intelligent Road Weather Station (RWS) located in Petäjämaa, 7 km distance from Sodankylä and 600 m direct distance to FMI facilities in Sodankylä. The RWS produces an extensive set of weather related measurements, constructed partially with Intelligent Road project funding and partially through other research projects.

Within the Intelligent Road project, the main objective is to provide and deliver the wireless weather related services to vehicles bypassing the RWS, and at the same time collect the vehicle oriented data in order to enhance the accuracy and quality of these services, respectively. Nowadays such kinds of communication and/or data collection devices are not installed (or in operation) in traditional vehicles, and therefore we are mainly providing the services in conceptual level, as the only vehicles fully compatible with our equipment are our own research vehicles. However, some parts of the RWS services can be achieved from www site and with traditional Wi-Fi communication equipment sometimes on board in vehicle, or in the mobile phone on board in vehicle, respectively. Based on these presumptions, the main site-specific requirements are:
• real-time collection of RWS data, both for the RWS host computer (to be delivered directly to vehicles) and FMI data servers (to be used in Internet-based services)
• data delivery capabilities from RWS to bypassing vehicle
• development of enhanced local weather services based on RWS local data

1.4.3.3 Luleå

Luleå Tekniska Universitet (LTU) focus on local weather forecast. This forecasts will be based on Trafikverkets RWS located in the surroundings of Luleå, weather data and road condition data form the vehicle mounted road condition monitoring sensor Road eye and a IR-temperature measurement. The sensor equipment will also include a small weather station mounted in a roundabout close to the university. LTU will also focus on evaluate the system in cooperation with Luleå Municipalities road maintenance division. Within the Intelligent road project daily measurements in the surroundings of Luleå will be carried out in combination with daily road weather forecast to investigate the possibility of improving the resolution of road condition forecast based on present road conditions. These measurement will also be validated through continuously tire to road friction measurement and video recordings.

Requirements for completing the objectives are:

• real-time collection of road condition along with position information (GPS) and other data
• real-time collection of tire to road friction along with position information (GPS)
• Video recording of present road conditions in combination with brake tests
• daily road weather forecasts
• data transfer between vehicle and IR data server
• data visualization
• interfaces to data for different users/authorities

1.5 Requirements Specification

1.5.1 Overview

The requirements of Intelligent Road project are gathered from project pre-conditions, expected usage needs and site-specific equipment needs. The requirements are specified site-by-site, describing the whole project instrumentation with necessary background information and parameters.

1.5.2 Rovaniemi site

1.5.2.1 Main objectives

Rovaniemi (RAMK) focuses mainly in implementing data acquisition systems for vehicles and providing the IR data server interfaces as described in chapter 4.3.1.
Requirements for completing the main objectives are:

- real-time collection of road condition along with position information (GPS) and other data
- data exchange between vehicle and RWS
- data transfer between vehicle and IR data server
- data transfer between IR data server and traffic signs
- data visualization

1.5.2.2 Required road/weather information

The required road/weather information consists of:

- Road condition (from optical measurement)
- Road friction (from optical measurement)
- Road temperature (from IR-thermometer/RWS)
- Information available from RWS

1.5.2.3 Road user instructions / Directives

The required road/user instructions/directives consist of:

- Warning about upcoming road conditions
- Warning about upcoming weather conditions
- Instructions how to adjust driving style to conditions

1.5.2.4 Required equipment

**Optical friction measurement sensor**

Friction measurement is needed to sense road condition and friction. This sensor should have at least following specifications:

- Suitable for outdoor use, operating temperature range at least -20 to +40 °C
- Operating voltage +12 VDC
- Digital output (RS232, CAN or some other bus)
- Measurement data should consist of at least:
  - Information of road condition (wet, dry, icy etc.)
  - Numeric data
- Sensor must be possible to mount to a car or a truck

**Data acquisition device (DAQ)**

Device to acquire data from optical measurement sensor and CAN-bus and send collected data to Intelligent Road system server is required. DAQ device should have at least following specifications:

- Suitable for outdoor use, lowest operating temperature at least -30°C
- IP6x classification
• Operating voltage +12 VDC
• GSM/GPRS connections
  o Antenna included
• SIM-card slot, card must be user replaceable
• Integrated GPS-receiver
  o Time to first fix in cold start must be less than 1 minute
  o Antenna included
• 1 RS232 interface
• 1 CAN-bus interface
  o High speed
  o Supported baud rates must range at least from 125 kbps to 1 Mbps
  o Supports 2.0A/B formats
• 1 Ethernet interface
• 1 ZigBEE radio transceiver
  o Antenna included
• Python programmable

**IR-thermometer**

Infrared thermometer is needed to measure road surface temperature while vehicle is driving. Minimum requirements for the IR-thermometer are:

• Suitable for outdoor use, lowest operating temperature at least -20 °C
• IP6x classification
• Operating voltage +12 VDC
• Digital output (RS232 or CAN-bus) or analog output 0-5 VDC
• Measurement range at least -20 to +100 °C
• Fast response time (<= 150ms to 90% response)

**Temperature/humidity sensor**

Temperature/humidity sensor is required to measure outdoor temperature and humidity conditions. The sensors will be mounted to the test vehicles. Minimum requirements for the sensor are:

• Operating temperature at least -40 to +80 °C
• Temperature measurement range at least -40 to +80 °C
• Humidity measurement range 0 to 100 % RH
  o Temperature range at least 0 to +40 °C
• Accuracy at least ±0.4 °C and ±3 % RH (full range)
• 2xAnalog output 0-5 VDC
  o One channel for temperature and one for humidity
• Operating voltage +12 VDC
• IP6x classification for housing
Analog to CAN converter (required for temperature/humidity sensors and optionally required for IR-thermometers)

The analog to CAN converter is required to convert the signals to digital form suitable for the DAQ-device. Minimum requirements for the analog to CAN converter are:

- Suitable for outdoor use, lowest operating temperature at least -30 °C
- IP6x classification
- Operating voltage +12 VDC
- At least three analog inputs suitable for 0-5 VDC signals
- Resolution must be at least 16 bits
- Supported CAN-bus baud rates must range at least from 125 kbps to 1 Mbps
- Size should be smaller than 60x60x60 mm

802.11p (DSRC/WAVE) compatible network device (OBU)

DSRC compatible network device is required to test and demonstrate vehicle to RWS communication. Vehicle to vehicle communication could be demonstrated also with these devices. Minimum requirements for the device are:

- Operating temperature range at least -30 to +40 °C
- Operating voltage +12 VDC
- Integrated 802.11p transceiver
- 802.11p compatible antennas included
- 1 Ethernet interface
- 1 RS232 interface
- Compatible with Sodankylä RWS 802.11p device (RSU)

Intelligent Road system server

Main part of the Intelligent Road demo system is the system server which receives and stores the data from different subsystems. It must also communicate with different subsystems and provide interfaces to data. The server will be located in the premises of Rovaniemi University of Applied Sciences. Minimum requirements for the system server are:

- 2,4 GHz multicore processor
- 4 GB RAM
- 1 TB hard drive (RAID preferred)
- Operating system Windows Server 2012 or Linux
- MySQL-database
- Daily backup plan for critical parts of the system
- Interfaces to different subsystems
• will be programmed by RAMK/pLAB in cooperation with RAMK/Arctic Power and other partners

1.5.2.5 Other remarks
No other remarks identified.

1.5.3 Sodankylä site

1.5.3.1 Main objectives
Main objectives of Sodankylä site are closely related to the requirements are mainly listed in chapter 4.3.2. The key issue is to provide and deliver the wireless weather related services to vehicles bypassing the RWS, and at the same time collect the vehicle oriented data in order to enhance the accuracy and quality of these services, respectively. The main objectives are:

• real-time collection of RWS data, both for the RWS host computer (to be delivered directly to vehicles) and FMI data servers (to be used in Internet-based services)
• data delivery capabilities from RWS to bypassing vehicle
• development of enhanced local weather services based on RWS local data

1.5.3.2 Required road/weather information
The required information in the Sodankylä site are the data collected from RWS measurements. This information consists of:

• Road surface temperature (from the surface sensors and optical measurement
• Road friction (from optical measurement)
• Road condition (from optical measurement)
• Visibility information
• Air temperature
• Traffic counting

1.5.3.3 Road user instructions / Directives
The required road/ user instructions/directives consist of:

• Warning about upcoming road conditions
• Warning about upcoming weather conditions

1.5.3.4 Required equipment
Road Weather Station (RWS)

Requirements listed below are fulfilled with FMI constructed research RWS located in Sodankylä.

RWS is expected to provide extensive set of road weather related measurements. DSRC and Wi-Fi compatible network devices are required to test and demonstrate vehicle to RWS communication. Vehicle to vehicle communication could be demonstrated also with the station. Minimum requirements for the system are:
• Operating temperature range at least -30 to +40 °C
• Operating voltage +12 VDC
• Integrated 802.11p transceiver
• Integrated Wi-Fi (at least IEEE 802.11g) transceiver
• 802.11p and 802.11g compatible antennas included
• Road friction measurement
• Road condition
• Optical road surface temperature
• Road surface temperature
• Visibility
• Temperature (air)
• Wind, speed and direction
• Frost level
• Traffic camera
• Traffic counting

802.11p (DSRC/WAVE) compatible network device (OBU)

Requirements listed below are fulfilled with NEC Linkbird-MX radio receivers, owned by FMI.

DSRC compatible network device is required to test and demonstrate vehicle to RWS communication. Vehicle to vehicle communication could be demonstrated also with these devices. Minimum requirements for the device are:

• Operating temperature range at least -30 to +40 °C
• Operating voltage +12 VDC
• Integrated 802.11p transceiver
• 802.11p compatible antennas included
• 1 Ethernet interface
• 1 RS232 interface

Wi-Fi compatible network device (OBU)

Requirements listed below are fulfilled with Wi-Fi equipment (both vehicular and laptop PCs), owned by FMI.

Minimum requirements for the device are:

• Operating temperature range at least -30 to +40 °C
• Operating voltage +12 VDC
• Integrated 802.11g/n transceiver
• 802.11g/n compatible antennas included
• 1 Ethernet interface
• 1 RS232 interface

**Optical friction measurement sensor**

Requirements listed below are fulfilled with Teconer RCM 411 optical road condition monitor, owned by FMI.

Friction measurement is needed to sense road condition and friction. This sensor should have at least following specifications:

- Suitable for outdoor use, operating temperature range at least -20 to +40 °C
- Operating voltage +12 VDC
- Digital output (RS232, CAN or some other bus)
- Measurement data should consist of at least:
  - Information of road condition (wet, dry, icy etc.)
  - Numeric data
- Sensor must be possible to mount to a car or a truck

**IR-thermometer**

Requirements listed below are fulfilled with Teconer RCM 411 optical road condition monitor, owned by FMI.

Infrared thermometer is needed to measure road surface temperature while vehicle is driving. Minimum requirements for the IR-thermometer are:

- Suitable for outdoor use, lowest operating temperature at least -20 °C
- IP6x classification
- Operating voltage +12 VDC
- Digital output (RS232 or CAN-bus) or analog output 0-5 VDC
- Measurement range at least -20 to +100 °C
- Fast response time (<= 150ms to 90% response)

**Temperature/humidity sensor**

Temperature/humidity sensor is required to measure outdoor temperature and humidity conditions. The sensors will be mounted to the test vehicles. Minimum requirements for the sensor are:

- Operating temperature at least -40 to +80 °C
- Temperature measurement range at least -40 to +80 °C
- Humidity measurement range 0 to 100 % RH
  - Temperature range at least 0 to +40 °C
- Accuracy at least ±0.4 °C and ±3 % RH (full range)
- 2xAnalog output 0-5 VDC
1.5.3.5 Other remarks

No other remarks identified.

1.5.4 Luleå site

1.5.4.1 Main objectives

Main objectives of Luleå site are closely related to the requirements that are listed in chapter 4.3.3. The key issue is to collect data and validate the data to be able to develop a simple road condition forecast based on present road condition with high resolution.

1.5.4.2 Required road/weather information

The required road/weather information consists of:

- Road condition (from optical measurement)
- Road friction (from optical measurement)
- Road temperature (from IR-thermometer/RWS)
- Information available from RWS
- Video recording
- Continues tire to road friction measurement
- Daily road weather forecast
- Weather data

1.5.4.3 Road user instructions / Directives

The required road/user instructions/directives consist of:

- Warning about upcoming road conditions
- Warning about upcoming weather conditions

1.5.4.4 Required equipment

**Optical friction measurement sensor**

Friction measurement is needed to classify road condition and friction. This sensor should have at least following specifications:

- Suitable for outdoor use, operating temperature range at least -20 to +40 °C
- Operating voltage +12 VDC
- Digital output (RS232, CAN or some other bus)
- Measurement data should consist of at least:
  - Information of road condition (wet, dry, icy etc.)
  - Numeric data
• Sensor must be possible to mount to a car or a truck

Data acquisition device (DAQ)

Device to acquire data from optical measurement sensor and CAN-bus and send collected data to Intelligent Road system server is required. DAQ device should have at least following specifications:

• Suitable for outdoor use, lowest operating temperature at least -30°C
• IP6x classification
• Operating voltage +12 VDC
• GSM/GPRS connections
  o Antenna included
• SIM-card slot, card must be user replaceable
• Integrated GPS-receiver
  o Time to first fix in cold start must be less than 1 minute
  o Antenna included
• 1 RS232 interface
• 1 CAN-bus interface
  o High speed
  o Supported baud rates must range at least from 125 kbps to 1 Mbps
  o Supports 2.0A/B formats
• 1 Ethernet interface
• 1 ZigBEE radio transceiver
  o Antenna included
• Python programmable

IR-thermometer

Infrared thermometer is needed to measure road surface temperature while vehicle is driving. Minimum requirements for the IR-thermometer are:

• Suitable for outdoor use, lowest operating temperature at least -20 °C
• IP6x classification
• Operating voltage +12 VDC
• Digital output (RS232 or CAN-bus) or analog output 0-5 VDC
• Measurement range at least -20 to +100 °C
• Fast response time (<= 150ms to 90% response)

Tire to road friction measurement apparatus

Tire to road friction apparatus measuring the friction while vehicle is driving. Minimum requirements for the friction measurements are:

• Suitable for outdoor use, lowest operating temperature at least -30 °C
• Operating voltage +12 VDC
• Digital output (RS232 or CAN-bus) or analog output 0-5 VDC
• Measurement range at least -20 to +100 °C
• Friction measurement between 0-1 with a resolution of 0.01µ

Road Weather Station (RWS)

Requirements listed below are fulfilled by the Swedish Trafikverkets VVIS stations and collected using Datex II.

RWS is expected to provide extensive set of road weather related measurements:

• Air temperature
• Road surface temperature
• Humidity
• Wind speed
• Wind direction
• Precipitation type
• Precipitation amount
• Dew Point

Local weather forecasts

Providing road weather forecast for the Luleå area for the time 08:00-16:00 regarding the parameters:

• Air temperature
• Road surface temperature
• Humidity
• Wind speed
• Clouds
• Precipitation type
• Precipitation amount
• Dew Point

1.5.4.5 Other remarks

No other remarks

1.5.5 Co-operation activities

1.5.5.1 Use-Cases

The co-operation activities are built around the activities presented above. The main use cases are

• real-time collection of road condition along with position information (GPS) and other data with Teconer RCM411
• real-time collection of road condition along with position information (GPS) and other data with Road Eye
• data exchange between vehicle and RWS
• data transfer between vehicle and IR data server
• data transfer between IR data server and traffic signs
• data visualization

1.5.5.2 Main objectives
The main objectives in co-operation use cases are

• combining different test sites data and measurements into a single data service
• harmonizing the measurements as well as possible
• offering the data service to the public use and testing
• evaluation of service

1.6 Conclusions
This document presented the specification of requirements in Intelligent Road project. The objectives in the WP1 are the definition of measurement parameters, the measurement of parameters, analysis of available sensors and technologies for the measurements and the definition of user needs. This document is not covering the measurement procedures themselves, but otherwise aims to fulfill all the requirements stated for WP1.

This deliverable consists of the state-of-the-art review of related the vehicular networking and short-range wireless communication research and the introduction of the requirements of Intelligent Road project are presented both in general level and in site-specific form. The specification of requirements is presented in detail, site by site. Based on the document specifications, the ultimate pilot systems in each site are constructed.
2 SYSTEM DESIGN

2.1 INTRODUCTION

2.1.1 Objective

The objective of this document is to describe the design of the Intelligent Road system presented in Figure 4. Each partner will describe the main functionality and architecture of their subsystems so that all partners have a common understanding of the whole IR system.

2.1.2 Intelligent Road system

Intelligent Road system is described in Figure 4. The system consists of several subsystems that work together to measure, process, analyse and exchange real-time data to create useful road condition information for the road users. Main server is the heart of the system. It receives and processes data and makes it available for road users in different ways. Road condition and weather data from mobile or stationary systems is delivered to the server utilizing GPRS, DSRC/WAVE and several other methods.

This document describes the hardware and software design of these different subsystems at high level. Detailed descriptions of different subsystems will be written by or in cooperation with each partner that is responsible of the certain subsystem.

Figure 4. High level description of the Intelligent Road system showing interaction between the subsystems.
2.2 HARDWARE ARCHITECTURE

2.2.1 Vehicle data acquisition system

Data acquisition (DAQ) system is designed to collect, process, transmit and receive real-time data from different sensors and data sources as described in Figure 4. Data acquisition system consists of several devices which have different functionality and purpose. It is crucial that all data is GPS-positioned and timestamped. Central point of the system is the ConnectPort X5 which is a python programmable device. It is programmed by RAMK/Arctic Power to handle the data acquisition and transmitting tasks. There are also devices to provide I/O connectivity for X5 as well as sensors to measure different parameters like friction, temperature and humidity.

![Diagram of vehicle data acquisition system](image)

**Figure 5. Test vehicle data acquisition system high level hardware description.**

The DAQ-system will be installed to three Kuljetus Kovalainen Oy delivery trucks and to one Luleå University of Technology (LTU) and one Luleå Municipality vehicle. LTU vehicle called RT3 is equipped with both RoadEye and Teconer sensors. Additionally RT3 has onboard a tire road friction measurement system (TRF) which is custom built and designed by LTU. RT3 will be used as a research vehicle to compare and validate the performance of different friction sensors in real conditions. Luleå Municipality will use the system in their maintenance vehicle to compare how visually observed and measured road conditions differ from each other.

More detailed hardware description of the vehicle data acquisition system is described in a separate document “Vehicle Data Acquisition System”. All vehicle installations (named IR1-IR6) are
documented separately because each system has their own details. These documents are stored to the project folder.

2.2.1.1 Main components

ConnectPort X5

ConnectPort X5 (Figure 6) is a python programmable data acquisition (DAQ) device with a wide variety of wired and wireless connection interfaces. It meets all the requirements specified in the Requirements Specification document chapter 5.2.4. The X5 is used to acquire data from different sensors of the IR-system and send measured and GPS-positioned data to IR-server.

![ConnectPort X5](image)

Figure 6. ConnectPort X5 data acquisition device can be seen on the left (www.digi.com). On the right the X5 is installed to a Kovalainen truck.

The X5 is a rugged, IP67-classified, device and therefore it can be mounted without special enclosure to a suitable place in the vehicle. GPS/GSM antenna should be installed so that it has a clear view of the sky.

Teconer RCM411

RCM411 (Figure 7) is an optical friction measurement sensor with serial port connectivity and it meets all the requirements specified in the Requirements Specification document chapter 5.2.4. RCM411 is used to measure road surface conditions and friction. Figure 7 shows the sensor’s tow bar installation frame which is replaced with a custom made frame in truck installations. The frame in Figure 7 is mainly used in passenger vehicle installations.
Figure 7. Teconer RCM411 installed to its original frame on the left. On the right the RCM411 is installed to a custom frame used in Kovalainen trucks.

Teconer RCM411 is recommended to be installed to a height of 50-80cm from ground. Installation angle to the road surface should be 10°-20° from the vertical direction. After the installation height is selected, the sensor parameters must be recalculated to get correct measurement results.

**RoadEye SD**

RoadEye SD (Figure 8) is an optical friction measurement sensor with serial port connectivity. It meets all the requirements specified in Requirements Specification document chapter 5.2.4. RoadEye SD is used to measure road surface conditions and friction.

Figure 8. RoadEye SD optical friction measurement sensor. The truck installation can be seen on the right.

RoadEye is recommended to be installed to a maximum height of 80cm from the ground. The height is measured from the main body of the sensor. Installation angle to the road surface should be 45 degrees. The measurement spot size the beam creates on the road surface is about 2*2cm. The sensor body is installed in to a plastic tube to protect the sensor and its lenses from the environmental conditions.
IR-thermometers

The selected thermometers meet all of the requirements specified in the Requirements Specification document chapter 5.2.4. The IR-thermometers are used to measure road surface and optionally air temperature. The measured information is used to enhance the readings of the RoadEye SD and RCM411.

Figure 9. RTS411 on the left is installed in a metal enclosure. Raytek MI on the right is installed in a plastic enclosure.

Teconer RCM411 uses RTS411 IR-thermometer (Figure 9) which is supplied by Teconer. Thermometer is installed to the same frame as RCM411. RoadEye SD uses Raytek MI IR-thermometer (Figure 9) to measure road surface and air temperature. It also meets all the aforementioned requirements. The plastic cover shown in Figure 9 is only an adapter to fit the sensor in a longer plastic tube to protect the IR-probe from dust and water.

Analog to CAN interface

A-CAN-DG-V2 is an analog to CAN interface manufactured by Texys International. It meets all the requirements specified in Requirements Specification document chapter 5.2.4. It is used to add I/O connectivity to DAQ for temperature/humidity and other sensors. The small size of the interface makes it easy to install into existing enclosures.
Tire road friction – RT3 measurement system

Tire road friction measurement system is a Halliday RT3 Curve mounted on LTU research vehicle a Volvo XC90 and the system is installed in the rear of the car. It sends data via serial port and meets all the requirements specified in the Requirements Specification document chapter 5.4.4.

VBOX 3i

VBOX 3i is a high speed GPS data logger from Racelogic. It has several I/O-channels and possibility to use Inertial Measurement Unit (IMU) to make accurate testing possible in areas with obstructed view of the sky. It is installed in the LTU’s research vehicle.

Serial port interface

Serial port interface device in this application is Digi PortServer TS 4 H MEI. It meets all the requirements defined in Requirements Specification document chapter 5.2.4. It has 4 serial ports to make it possible to connect all necessary devices to the X5 in the RT3 installation. PortServer
interfaces multiple serial devices to X5 using a single Ethernet connection and a selectable protocol (UDP/TCP etc.).

Figure 12. Digi PortServer TS 4H MEI unit (www.digi.com) can be seen on the left. On the right the unit has been installed as a part of DAQ system.

802.11p OBU and RSU devices

The 802.11p compatible On Board Unit (OBU) and Road Side Unit (RSU) from Componentality Oy are used in the Vehicle to X communication testing. These devices meet all of the requirements specified in the Requirements Specification document chapter 5.2.4. These devices are compatible with the FMI RWS described later in chapter 2.2.3.

Figure 13. 802.11p RSU and antenna on the left and OBU on the right. (www.componentality.com)
2.2.1.2 Connectivity

Vehicle data acquisition system hardware connectivity is described on high level in Figure 15. Detailed hardware layouts and diagrams are described in the “Vehicle Data Acquisition System” document. There is also specific documentation for each individual installation.

Power supply connections are intentionally left out from the Figure 15 because they are subject to change according to the vehicle type. For example in truck installations (Figure 14) there is a 24V main battery that is used to power the DAQ-system and other components. However, it must be used along with a suitable 24V-12V DC/DC-converter, because the system is designed to operate on 12VDC.

On passenger vehicles, 12V supply is available and therefore no DC/DC-converter is needed.

![Figure 14. Junction box installed in a Kovalainen truck containing DC/DC-converter and other electronics.](image)

CAN, RS-232 and Ethernet cabling is and must be selected specifically to suit the needs of those buses. The specific cable types and possible CAN-bus termination resistor positions and other relevant details are described in the “Vehicle Data Acquisition System” document.
2.2.2 DAVIS weather station

The weather stations are used to monitor present weather conditions locally at selected sites. The DAVIS Vantage Pro II is selected because it has enough functionality at a reasonable price. It is also easy and quick to install. Normally it is installed to a 2 meter metal pole on surface or on the roof.

2.2.2.1 Components

DAVIS Vantage Pro II consists of a weather station and a console (Figure 16). Weather station can be equipped with a variable selection of sensors.

Figure 15. Hardware connectivity of the basic vehicle DAQ system.

Figure 16. DAVIS Vantage Pro II consists of a weather station, console and some selectable sensors.
Weather station unit can be equipped to monitor various environmental parameters such as rain, temperature, solar/UV-radiation and wind to mention few. It is also possible to add solar panels and wireless communication to the weather station system.

**Console**

Weather station console is used to monitor various parameters onsite. User can configure weather station settings using the console. It is recommended to install the console indoors or to a heated enclosure due to operating temperature limitations (0° to 60°C).

**Data acquisition unit**

Weather station data must be acquired and sent to the IR-server. The implementation of acquisition is done case-by-case. Current implementations in use are GPRS-modems and PCs depending on the installation location.

### 2.2.2.2 Connectivity

Figure 17 shows the hardware connectivity options of a DAVIS weather station unit. The station is connected to either a modem or a PC using RS-232 connection. The modem and PC have software installed which handles the data acquisition and transfer to the IR-server. There are variety of sensors available for the DAVIS stations and each station can have a different set of sensors.

![Figure 17. Hardware connectivity of a DAVIS weather station unit.](image)
2.2.3 Road Weather Station

Finnish Meteorological Institute (FMI) has established a combined RWS (Road Weather Station) and RSU (Road Side Unit) station into E75 highway Petäjämaa (N67.36217, E26.61740) in Sodankylä, nearby FMI facilities in Sodankylä. This infrastructure has been built to be a test bed for different research projects related to vehicular networking, road weather services and snow research. It consists of road weather station with extended set of professional weather measurements combined with intelligent vehicle-to-infrastructure communication capabilities. Intelligent Road project is one of the projects exploiting the measurements and methodologies installed to the station. The combined RWS and RSU is presented in the Figure 18 below.

![Figure 18. Combined RWS and RSU located in Sodankylä.](image)

2.2.3.1 Components

The station consists of professional meteorological measurements combined with intelligent wireless networking systems, supplemented with additional traffic related measurements and infrastructure. FMI possess also some equipment for the measurements and communication conducted in vehicles bypassing the station, which are not so much related to Intelligent Road project work, but listed here anyway. The roughly categorized list of equipment is as follows.

**Road weather measurement instrumentation:**

- Air temperature (2m), Vaisala PT100
- Relative humidity (2m), Vaisala HMP45D
- Air temperature and humidity (4,5m), Vaisala HMP155
- Wind speed and direction (6,5m), Thies Clima 2D Ultrasonic Anemometer
- Wind speed and direction (6,3m), Vaisala WINDCAP Ultrasonic Wind Sensor WMT703
- Road surface state and temperature (0cm), Vaisala DRS511
- Visibility (6m), Vaisala PWD 22
- Visibility (2,4m), Vaisala PWD 22 (for snow drifting special case)
- Soil temperature and moisture (Road frost) (0-300 cm), Stevens Hydra Probe II sensors
- Soil temperature (Road frost)(0-300cm), LISTEC SEC 15 sensors
• Soil temperature under the road lane (-40cm), Vaisala DTS12
• Road surface state (remote), Vaisala DSC111
• Road surface temperature (remote), Vaisala DST111
• Road weather camera with internal infrared light, Zavio B7210 Full HD

**Vehicular networking/Wireless Communication instrumentation:**

• IEEE 802.11p communication, NEC Linkbird-MX v3 with dual Larsen antenna adjusted for 5.3-5.9 GHz operation
• IEEE 802.11n communication, PCE-N15 with semi-directive antenna
• 3G communication, Telewell TW-EA510 + Huawei E1552 USB Modem, Viola 3G router

**Available vehicle instrumentation:**

• Sunit C7 Vehicle PC with gyroscope and GPS, 3G and Wi-Fi
  o embedded external temperature sensor
• Sunit D7 Vehicle PC with gyroscope and GPS, 3G and Wi-Fi
• Wi-Fi communication laptops
• IEEE 802.11p capable NEC Linkbird MX v3 units
• IEEE 802.11p capable Componentality units
• µTEC friction measurement software
• ublox GPS evaluation kits

**Facility parameters:**

• Operation hut 5 m² with warming, electricity and light
• Fence
• 6 meter fixed mast (with laddering)
• 5 meter tilting mast
• Vaisala data logger QML201C
• Moxa IA240-T-LX embedded computer
• Lenovo Edge desktop computer
• Road weather display

2.2.3.2 Connectivity

The Road weather station hardware connectivity is described in Figure 19.
2.2.4 Road Weather Station data distribution to the road users

The selected set of the RWS data is developed into road weather service and provided to the road users via android application (figure xx). In addition a bus operating between Ivalo-Rovaniemi and two taxes operating in Sodankylä area are equipped with Sunit vehicle PC’s and screens to share the RWS data to the customers. Taxi systems with 7” touch screen includes possibility to customers to evaluate the service.

Data to the road weather service application is updated mainly with the 3G communication, when vehicle bypasses the RWS and is within range of a Wi-Fi communication data is updated through the Wi-Fi connection.

Another way of distributing the road data to users is using a road side display presented in Figure 21. This has a clear advantage of not requiring any devices from road users, but the trade of is the
limited amount of possible data that can be delivered in the short time the car has the display in view.

![Road weather station display](image)

**Figure 21. Road weather station display**

### 2.2.4.1 Components

System includes the RWS pictured in the chapter 2.3 and the vehicle equipment. The vehicle equipment can be for example smart phones, tablets or laptops with the 3G and/or Wi-Fi connection. Bus and taxi installations consist of power system that may include DC/DC power converter, Sunit vehicle PC (figure xx) and screen (figure xx) and antennas for Wi-Fi and 3G connection (figure xx). The 3G antenna includes GPS. The screen size on the bus is 22” and 7” in a taxi.

![Sunit vehicle PC and screen](image)

**Figure 22. Sunit vehicle PC on the left and Sunit 22” screen on the right.**
2.2.4.2 Connectivity

The Sunit system hardware connectivity in the bus and taxis is described in the Figure 24 below.

As can be seen from the Figure 24 the system has only a few hardware components. Antennas, power source, display and a computer-unit are the only things that are needed for a Sunit-vehicle computer system.

2.3 SOFTWARE ARCHITECTURE

2.3.1 Vehicle data acquisition system

Figure 25 presents the high level operation logic of the vehicle DAQ system. Software consists of several modules which operate in parallel and send data to data storage. DAQ-software module
reads current values from the data storage and queues them to be sent outward to the IR-server. Not all software modules are described in the Figure 25.

More detailed software description of the vehicle data acquisition system is described in a separate document “Vehicle Data Acquisition System”.

![Vehicle DAQ software description](image)

**Figure 25. Vehicle DAQ software description.**

### 2.3.1.1 Software components
Describe software components and their main functionality here. Detailed description is in “Vehicle Data Acquisition System” document.

### 2.3.1.2 Data formats
**DAQ output**

ConnectPort X5 data acquisition device sends data outward using GPRS-connection and HTTP POST method. There are data packet formats for each available sensor, CAN-bus data and diagnostic data. All packets contain GPS-data. Temperature/humidity sensor data and IR-thermometer data is included in optical friction measurement sensor data packets. Each data packet contains a packet specific identification ID in the data field 1 and a device specific identification in the data field 2. These identification codes are described in the chapter X.X.

The data packets are sent in the following string format:

$$1+2+3+4+...+n$$
Multiple data packets can be combined into same output string. The packets are separated by a semicolon “;”.

Here is an example multi-packet string:

```
1+2+3+4+...+n;1+2+3+4+...+n;1+2+3+4+...+n
```

**RCM411 data packet format**

The data packet format for the RCM411 is described in the Table 1. Please note that data fields 21, 23, 28, 29 and 30 can vary due to different device selections. If an RTS411 is used, data fields 21 and 23 represent air temperature and surface temperature. If a third party IR-thermometer is used, the data field 28 is used to represent thermometer’s value. If Vaisala or other third party temperature/humidity sensor is used, data fields 29 and 30 contain temperature and humidity information.

Detailed description of how the data packet is built can be found from separate document “Vehicle data Acquisition System”.

<table>
<thead>
<tr>
<th>Data field</th>
<th>Variable name</th>
<th>Example data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dataID</td>
<td>1</td>
<td>Data packet identification number</td>
</tr>
<tr>
<td>2</td>
<td>deviceID</td>
<td>2</td>
<td>Device identification number</td>
</tr>
<tr>
<td>3</td>
<td>timestamp</td>
<td>2013-03-07 11:59:00.123456</td>
<td>YYYY-MM-DD HH:MM:SS.6f</td>
</tr>
<tr>
<td>4</td>
<td>fix_time</td>
<td>09:59:00.0</td>
<td>HH:MM:SS.1f (UTC)</td>
</tr>
<tr>
<td>5</td>
<td>fix_status</td>
<td>1</td>
<td>gps fix status, 1 = Fix / 0 = No fix</td>
</tr>
<tr>
<td>6</td>
<td>latitude</td>
<td>66.5469</td>
<td>Latitude</td>
</tr>
<tr>
<td>7</td>
<td>latitude_hemisphere</td>
<td>N</td>
<td>Hemisphere for latitude, N/S</td>
</tr>
<tr>
<td>8</td>
<td>longitude</td>
<td>25.8209</td>
<td>Longitude</td>
</tr>
<tr>
<td>9</td>
<td>longitude_hemisphere</td>
<td>E</td>
<td>Hemisphere for longitude, E/W</td>
</tr>
<tr>
<td>10</td>
<td>speed_over_ground</td>
<td>48,1305</td>
<td>Ground speed, km/h</td>
</tr>
<tr>
<td>11</td>
<td>course_over_ground</td>
<td>50.41</td>
<td>Course, °</td>
</tr>
<tr>
<td>12</td>
<td>fix_date</td>
<td>03/07/13</td>
<td>date of current gps fix, UTC</td>
</tr>
<tr>
<td>13</td>
<td>num_satellites</td>
<td>9</td>
<td>Number of visible satellites</td>
</tr>
<tr>
<td>14</td>
<td>altitude</td>
<td>118.4</td>
<td>Altitude, m</td>
</tr>
<tr>
<td>15</td>
<td>hdop</td>
<td>4.33</td>
<td>Horizontal dilution of precision</td>
</tr>
<tr>
<td>16</td>
<td>signal1</td>
<td>35.08</td>
<td>S1, Measurement signal 1</td>
</tr>
<tr>
<td>17</td>
<td>signal2</td>
<td>44.98</td>
<td>S2, Measurement signal 2</td>
</tr>
<tr>
<td>18</td>
<td>signal3</td>
<td>2.061</td>
<td>S3, Measurement signal 3</td>
</tr>
<tr>
<td>19</td>
<td>friction</td>
<td>0.45</td>
<td>S4, Friction</td>
</tr>
<tr>
<td>20</td>
<td>surface_condition</td>
<td>1</td>
<td>S5, Surface condition (1-6)</td>
</tr>
<tr>
<td>21</td>
<td>temperature</td>
<td>16.3</td>
<td>S6, Internal temperature (air if RTS411), °C</td>
</tr>
<tr>
<td>22</td>
<td>variable7</td>
<td>250.0</td>
<td>S7, N/A</td>
</tr>
<tr>
<td></td>
<td>surface_temperature</td>
<td>5.0</td>
<td>S8, Surface temperature if RTS411, °C</td>
</tr>
<tr>
<td>---</td>
<td>----------------------</td>
<td>-----</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>24</td>
<td>variable9</td>
<td>828.7</td>
<td>S9, N/A</td>
</tr>
<tr>
<td>25</td>
<td>variable10</td>
<td>1136.7</td>
<td>S10, N/A</td>
</tr>
<tr>
<td>26</td>
<td>variable11</td>
<td>0.750</td>
<td>S11, N/A</td>
</tr>
<tr>
<td>27</td>
<td>water_layer_thickness</td>
<td>0.035</td>
<td>S12, Water layer thickness, mm</td>
</tr>
<tr>
<td>28</td>
<td>road_temperature</td>
<td>5,467</td>
<td>Road temperature (Infrared sensor), °C</td>
</tr>
<tr>
<td>29</td>
<td>air_temperature</td>
<td>6,789</td>
<td>Air temperature (Vaisala), °C</td>
</tr>
<tr>
<td>30</td>
<td>air_humidity</td>
<td>35,66</td>
<td>Relative humidity (Vaisala), RH %</td>
</tr>
</tbody>
</table>

Table 1. RCM411 data packet format.

**RoadEye data packet format**

The data packet format for the RoadEye sensor is described in the Table 2. Please note that data fields 19, 20, 21, 22, 23 and 24 can vary due to different device and measurement selections. Data fields 19-21 will be populated by data calculated from the measurement signals. When a third party IR-thermometer is used, the data field 22 is used to represent thermometer’s value. If Vaisala or other third party temperature/humidity sensor is used, data fields 23 and 24 contain temperature and humidity information.

Detailed description of how the data packet is built can be found from separate document “Vehicle data Acquisition System”.

<table>
<thead>
<tr>
<th>Data field</th>
<th>Variable name</th>
<th>Example data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dataID</td>
<td>1</td>
<td>Data packet identification number</td>
</tr>
<tr>
<td>2</td>
<td>deviceID</td>
<td>2</td>
<td>Device identification number</td>
</tr>
<tr>
<td>3</td>
<td>timestamp</td>
<td>2013-03-07 11:59:00.123456</td>
<td>YYYY-MM-DD HH:MM:SS.6f</td>
</tr>
<tr>
<td>4</td>
<td>fix_time</td>
<td>09:59:00.0</td>
<td>HH:MM:SS.1f (UTC)</td>
</tr>
<tr>
<td>5</td>
<td>fix_status</td>
<td>1</td>
<td>gps fix status, 1 = Fix / 0 = No fix</td>
</tr>
<tr>
<td>6</td>
<td>latitude</td>
<td>66.5469</td>
<td>Latitude</td>
</tr>
<tr>
<td>7</td>
<td>latitude_hemisphere</td>
<td>N</td>
<td>Hemisphere for latitude, N/S</td>
</tr>
<tr>
<td>8</td>
<td>longitude</td>
<td>25.8209</td>
<td>Longitude</td>
</tr>
<tr>
<td>9</td>
<td>longitude_hemisphere</td>
<td>E</td>
<td>Hemisphere for longitude, E/W</td>
</tr>
<tr>
<td>10</td>
<td>speed_over_ground</td>
<td>48,1305</td>
<td>Ground speed, km/h</td>
</tr>
<tr>
<td>11</td>
<td>course_over_ground</td>
<td>50.41</td>
<td>Course, °</td>
</tr>
<tr>
<td>12</td>
<td>fix_date</td>
<td>03/07/13</td>
<td>date of current gps fix, UTC</td>
</tr>
<tr>
<td>13</td>
<td>num_satellites</td>
<td>9</td>
<td>Number of visible satellites</td>
</tr>
<tr>
<td>14</td>
<td>altitude</td>
<td>118.4</td>
<td>Altitude, m</td>
</tr>
<tr>
<td>15</td>
<td>hdop</td>
<td>4.33</td>
<td>Horizontal dilution of precision</td>
</tr>
<tr>
<td>16</td>
<td>signal1</td>
<td>35.08</td>
<td>S2, Measurement signal 1</td>
</tr>
<tr>
<td>17</td>
<td>signal2</td>
<td>44.98</td>
<td>S3, Measurement signal 2</td>
</tr>
<tr>
<td>18</td>
<td>signal3</td>
<td>2.061</td>
<td>S4, Measurement signal 3</td>
</tr>
<tr>
<td>19</td>
<td>friction</td>
<td>0.45</td>
<td>Friction (calculated by DAQ)</td>
</tr>
<tr>
<td>20</td>
<td>surface_condition</td>
<td>1</td>
<td>S1, Surface condition (1-5), (DAQ converts)</td>
</tr>
</tbody>
</table>

GPS + Roadeye data packet
Table 2. RoadEye data packet format.

**OBU – RSU data packet format**

OBU-RSU data packet format(s) will be described in this section. These data packets are not yet defined.

**RT3 data packet format**

RT3 data packet format is described in the Table 3 below.

<table>
<thead>
<tr>
<th>Data field</th>
<th>Variable name</th>
<th>Example data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dataID</td>
<td>6</td>
<td>Data packet identification number</td>
</tr>
<tr>
<td>2</td>
<td>deviceID</td>
<td>2</td>
<td>Device identification number</td>
</tr>
<tr>
<td>3</td>
<td>timestamp</td>
<td>2013-03-07 11:59:00.123456</td>
<td>YYYY-MM-DD HH:MM:SS.6f</td>
</tr>
<tr>
<td>4</td>
<td>fix_time</td>
<td>09:59:00.0</td>
<td>HH:MM:SS.1f (UTC)</td>
</tr>
<tr>
<td>5</td>
<td>fix_status</td>
<td>1</td>
<td>gps fix status, 1 = Fix / 0 = No fix</td>
</tr>
<tr>
<td>6</td>
<td>latitude</td>
<td>66.5469</td>
<td>Latitude</td>
</tr>
<tr>
<td>7</td>
<td>latitude_hemisphere</td>
<td>N</td>
<td>Hemisphere for latitude, N/S</td>
</tr>
<tr>
<td>8</td>
<td>longitude</td>
<td>25.8209</td>
<td>Longitude</td>
</tr>
<tr>
<td>9</td>
<td>longitude_hemisphere</td>
<td>E</td>
<td>Hemisphere for longitude, E/W</td>
</tr>
<tr>
<td>10</td>
<td>speed_over_ground</td>
<td>48,1305</td>
<td>Ground speed, km/h</td>
</tr>
<tr>
<td>11</td>
<td>course_over_ground</td>
<td>50.41</td>
<td>Course, °</td>
</tr>
<tr>
<td>12</td>
<td>fix_date</td>
<td>03/07/13</td>
<td>date of current gps fix, UTC</td>
</tr>
<tr>
<td>13</td>
<td>num_satellites</td>
<td>9</td>
<td>Number of visible satellites</td>
</tr>
<tr>
<td>14</td>
<td>altitude</td>
<td>118.4</td>
<td>Altitude, m</td>
</tr>
<tr>
<td>15</td>
<td>hdop</td>
<td>4.33</td>
<td>Horizontal dilution of precision</td>
</tr>
<tr>
<td>16</td>
<td>distance</td>
<td>1200</td>
<td>S1, Travelled distance, m</td>
</tr>
<tr>
<td>17</td>
<td>left_wheel</td>
<td>0.35</td>
<td>S2, Left wheel,</td>
</tr>
<tr>
<td>18</td>
<td>right_wheel</td>
<td>0.45</td>
<td>S3, Right wheel,</td>
</tr>
<tr>
<td>19</td>
<td>mean</td>
<td>0.4</td>
<td>S4, Mean (Left/Right)</td>
</tr>
<tr>
<td>20</td>
<td>speed</td>
<td>50</td>
<td>S5, Speed, km/h</td>
</tr>
<tr>
<td>21</td>
<td>steering_angle</td>
<td>45</td>
<td>S6, Steering angle, 0-360 degrees</td>
</tr>
</tbody>
</table>

Table 3. RT3 data packet format.

**VBOX 3i data packet format**

VBOX 3i data packet format is described in Table 4 below.

NOTE: Data field 24 is scaled and mapped to the RoadEye data packet data field 22.

Table 4. VBOX 3i+IMU+AI data packet format.
<table>
<thead>
<tr>
<th>Data field</th>
<th>Variable name</th>
<th>Example data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dataID</td>
<td>7</td>
<td>Data packet identification number</td>
</tr>
<tr>
<td>2</td>
<td>deviceID</td>
<td>2</td>
<td>Device identification number</td>
</tr>
<tr>
<td>3</td>
<td>timestamp</td>
<td>2013-03-07 11:59:00.123456</td>
<td>YYYY-MM-DD HH:MM:SS.6f</td>
</tr>
<tr>
<td>4</td>
<td>fix_time</td>
<td>09:59:00.0</td>
<td>HH:MM:SS.1f (UTC)</td>
</tr>
<tr>
<td>5</td>
<td>fix_status</td>
<td>1</td>
<td>gps fix status, 1 = Fix (&gt;3sats) / 0 = No fix (&lt;3sats)</td>
</tr>
<tr>
<td>6</td>
<td>latitude</td>
<td>66.5469</td>
<td>Latitude</td>
</tr>
<tr>
<td>7</td>
<td>latitude_hemisphere</td>
<td>N</td>
<td>Hemisphere for latitude, N/S</td>
</tr>
<tr>
<td>8</td>
<td>longitude</td>
<td>25.8209</td>
<td>Longitude</td>
</tr>
<tr>
<td>9</td>
<td>longitude_hemisphere</td>
<td>E</td>
<td>Hemisphere for longitude, E/W</td>
</tr>
<tr>
<td>10</td>
<td>speed_over_ground</td>
<td>48.1305</td>
<td>Velocity, Ground speed, km/h</td>
</tr>
<tr>
<td>11</td>
<td>course_over_ground</td>
<td>50.41</td>
<td>Heading, Course, °</td>
</tr>
<tr>
<td>12</td>
<td>num_satellites</td>
<td>9</td>
<td>Number of visible satellites</td>
</tr>
<tr>
<td>13</td>
<td>altitude</td>
<td>118.4</td>
<td>Altitude, m</td>
</tr>
<tr>
<td>14</td>
<td>vertical_velocity</td>
<td>0.01</td>
<td>Vertical velocity, m/s</td>
</tr>
<tr>
<td>15</td>
<td>status_byte1</td>
<td>5</td>
<td>Status byte 1</td>
</tr>
<tr>
<td>16</td>
<td>status_byte2</td>
<td>5</td>
<td>Status byte 2</td>
</tr>
<tr>
<td>17</td>
<td>distance</td>
<td>0.000078125</td>
<td>Distance, m, corrected to trigger point</td>
</tr>
<tr>
<td>18</td>
<td>longitudinal_acceleration</td>
<td>0.01</td>
<td>Longitudinal acceleration, G</td>
</tr>
<tr>
<td>19</td>
<td>lateral_acceleration</td>
<td>0.01</td>
<td>Lateral acceleration, G</td>
</tr>
<tr>
<td>20</td>
<td>distance_reset</td>
<td>2567.000078125</td>
<td>Distance travelled since VBOX reset, m</td>
</tr>
<tr>
<td>21</td>
<td>trigger_time</td>
<td>25.23</td>
<td>Time from last brake trigger event, s</td>
</tr>
<tr>
<td>22</td>
<td>trigger_velocity</td>
<td>75.29</td>
<td>Velocity at brake trigger point, km/h</td>
</tr>
<tr>
<td>23</td>
<td>velocity_quality</td>
<td>0.05</td>
<td>Velocity quality, km/h</td>
</tr>
<tr>
<td>24</td>
<td>analog_input1</td>
<td>0.12345</td>
<td>S12, Analog input 1</td>
</tr>
<tr>
<td>25</td>
<td>analog_input2</td>
<td>0.12345</td>
<td>S13, Analog input 2</td>
</tr>
<tr>
<td>26</td>
<td>analog_input3</td>
<td>0.12345</td>
<td>S14, Analog input 3</td>
</tr>
<tr>
<td>27</td>
<td>analog_input4</td>
<td>0.12345</td>
<td>S15, Analog input 4</td>
</tr>
</tbody>
</table>

Table 4. VBOX 3i data packet format.

Diagnostic data packet format

Diagnostic data packet format (Table 5) contains general information about data acquisition system and its components.

<table>
<thead>
<tr>
<th>Data field</th>
<th>Variable name</th>
<th>Example data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dataID</td>
<td>4</td>
<td>Data packet identification number</td>
</tr>
<tr>
<td>2</td>
<td>deviceID</td>
<td>2</td>
<td>Device identification number</td>
</tr>
<tr>
<td>3</td>
<td>timestamp</td>
<td>2013-03-07 11:59:00.123456</td>
<td>YYYY-MM-DD HH:MM:SS.6f</td>
</tr>
<tr>
<td>4</td>
<td>fix_time</td>
<td>09:59:00.0</td>
<td>HH:MM:SS.1f (UTC)</td>
</tr>
<tr>
<td>5</td>
<td>fix_status</td>
<td>1</td>
<td>gps fix status, 1 = Fix (&gt;3sats) / 0 = No fix (&lt;3sats)</td>
</tr>
<tr>
<td>6</td>
<td>latitude</td>
<td>66.5469</td>
<td>Latitude</td>
</tr>
<tr>
<td>7</td>
<td>latitude_hemisphere</td>
<td>N</td>
<td>Hemisphere for latitude, N/S</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>----------------------</td>
<td>----------</td>
<td>----------------------</td>
</tr>
<tr>
<td></td>
<td>longitude</td>
<td>25.8209</td>
<td>Longitude</td>
</tr>
<tr>
<td>9</td>
<td>longitude_hemisphere</td>
<td>E</td>
<td>Hemisphere for longitude, E/W</td>
</tr>
<tr>
<td>10</td>
<td>speed_over_ground</td>
<td>48.1305</td>
<td>Ground speed, km/h</td>
</tr>
<tr>
<td>11</td>
<td>course_over_ground</td>
<td>50.41</td>
<td>Course, °</td>
</tr>
<tr>
<td>12</td>
<td>fix_date</td>
<td>03/07/13</td>
<td>date of current gps fix, UTC</td>
</tr>
<tr>
<td>13</td>
<td>num_satellites</td>
<td>9</td>
<td>Number of visible satellites</td>
</tr>
<tr>
<td>14</td>
<td>altitude</td>
<td>118.4</td>
<td>Altitude, m</td>
</tr>
<tr>
<td>15</td>
<td>hdop</td>
<td>4.33</td>
<td>Horizontal dilution of precision</td>
</tr>
<tr>
<td>16</td>
<td>power_on_count</td>
<td>10</td>
<td>Number of times CPX5 has started</td>
</tr>
<tr>
<td>17</td>
<td>supply_voltage</td>
<td>12,88</td>
<td>ConnectPort X5 supply voltage</td>
</tr>
<tr>
<td>18</td>
<td>internal_temperature</td>
<td>20.88</td>
<td>ConnectPort X5 internal temperature</td>
</tr>
<tr>
<td>19</td>
<td>http_post_error_count</td>
<td>0</td>
<td>HTTP post request error count</td>
</tr>
<tr>
<td>20</td>
<td>http_post_ok_count</td>
<td>0</td>
<td>HTTP post request success count</td>
</tr>
<tr>
<td>21</td>
<td>http_post_unknown_count</td>
<td>0</td>
<td>HTTP post request unknown count</td>
</tr>
<tr>
<td>22</td>
<td>http_post_invalid_count</td>
<td>0</td>
<td>HTTP post request invalid count</td>
</tr>
<tr>
<td>23</td>
<td>cpu_utilization</td>
<td>20</td>
<td>ConnectPort X5 CPU utilization</td>
</tr>
<tr>
<td>24</td>
<td>free_memory</td>
<td>14423424</td>
<td>ConnectPort X5 free RAM memory</td>
</tr>
<tr>
<td>25</td>
<td>uptime</td>
<td>2332</td>
<td>ConnectPort X5 uptime since reboot</td>
</tr>
<tr>
<td>26</td>
<td>mobile_rssi</td>
<td>5</td>
<td>Mobile connection received signal strength indication</td>
</tr>
<tr>
<td>27</td>
<td>mobile_quality_value</td>
<td>1</td>
<td>Current mobile connection signal quality value</td>
</tr>
<tr>
<td>28</td>
<td>mobile_rstat_code</td>
<td>1</td>
<td>Mobile connection registration status</td>
</tr>
</tbody>
</table>

Table 5. Diagnostic data packet format.

### 2.3.1.3 Communication protocols

**Teconer RCM411**

RCM411 communicates with other devices via serial port. When powered on, RCM411 sends “RCM411 V 2.52 2013-01-04” initial string to the serial port. It can take up to 10 seconds before the device starts sending data periodically. No commands are needed to initialize data transfer. Data sampling interval is configured by default to 1 Hz. This can be changed but is not recommended by the manufacturer. Adjusting sampling to be faster will add noise to the data.

RCM411 serial port settings are described in the Table 6.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RCM411 - Serial port settings</strong></td>
<td></td>
</tr>
<tr>
<td>Baud rate</td>
<td>38400 bps</td>
</tr>
<tr>
<td>Stop bits</td>
<td>1</td>
</tr>
<tr>
<td>Parity</td>
<td>None</td>
</tr>
<tr>
<td>Flow control</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 6. Serial port settings for RCM411.

After the initial string RCM411 starts to send data in ASCII form. Data string consists of twelve (12) comma separated values followed by a CR (Carriage Return) as a termination character.
Termination character can be used to identify different data packets when reading and parsing serial data.

Example string format: “S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12CR”

RCM411 serial data format is described in Table 7.

<table>
<thead>
<tr>
<th>RCM411 - Serial data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
</tr>
<tr>
<td>S2</td>
</tr>
<tr>
<td>S3</td>
</tr>
<tr>
<td>S4</td>
</tr>
<tr>
<td>S5</td>
</tr>
<tr>
<td>S6</td>
</tr>
<tr>
<td>S7</td>
</tr>
<tr>
<td>S8</td>
</tr>
<tr>
<td>S9</td>
</tr>
<tr>
<td>S10</td>
</tr>
<tr>
<td>S11</td>
</tr>
<tr>
<td>S12</td>
</tr>
<tr>
<td>CR</td>
</tr>
</tbody>
</table>

Table 7. RCM411 serial data formatting.

Some of the parameters described in Table 7 are not in use in current version of the RCM411. These are marked with N/A (Not Available).

**RoadEye**

RoadEye communicates with other devices via serial port. Serial port settings are described in the Table 8.

<table>
<thead>
<tr>
<th>RoadEye - Serial port settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud rate</td>
</tr>
<tr>
<td>Data bits</td>
</tr>
<tr>
<td>Stop bits</td>
</tr>
<tr>
<td>Parity</td>
</tr>
<tr>
<td>Flow control</td>
</tr>
</tbody>
</table>

Table 8. Serial port settings for RoadEye.

Serial data format for RoadEye is described in Table 9. Friction and water layer thickness are calculated from measurement signals by DAQ device. Calculation formula is developed by LTU.

Example string format: “S1, S2, S3, S4”

<table>
<thead>
<tr>
<th>RoadEye - Serial data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
</tr>
<tr>
<td>S2</td>
</tr>
<tr>
<td>S3</td>
</tr>
<tr>
<td>S4</td>
</tr>
</tbody>
</table>
Table 9. Serial data format for RoadEye.

**RT3 tire friction measurement system**

RT3 system is connected to a control hub which is used to display values for the driver in the car. The hub can be used to configure RT3 parameters. The hub has a serial port which is used to interface the RT3 to other systems for data logging. RT3 serial port settings are described in the Table 10.

<table>
<thead>
<tr>
<th>RT3 - Serial port settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baud rate</td>
</tr>
<tr>
<td>Data bits</td>
</tr>
<tr>
<td>Stop bits</td>
</tr>
<tr>
<td>Parity</td>
</tr>
<tr>
<td>Flow control</td>
</tr>
</tbody>
</table>

Table 10. Serial port settings for RT3.

When the RT3 and hub are powered ON, the hub starts to send messages to the serial port in the format described in Table 11. The RT3 doesn’t send any start messages to the serial port when powered ON.

Example string format: “S1, S2, S3, S4, S5, S6”

<table>
<thead>
<tr>
<th>RT3- Serial data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
</tr>
<tr>
<td>S2</td>
</tr>
<tr>
<td>S3</td>
</tr>
<tr>
<td>S4</td>
</tr>
<tr>
<td>S5</td>
</tr>
<tr>
<td>S6</td>
</tr>
</tbody>
</table>

Table 11. Serial data formatting of RT3.

**802.11p OBU and RSU**

Data packet(s) for 802.11p communication are yet to be defined.

**GPS**

GPS receiver is integrated to the ConnectPort X5 and the GPS-data is read in NMEA format. GPS-data is added to every data packet and therefore GPS data doesn’t have a separate data packet.

2.3.2 **Road Weather Station**

The road weather station has multiple scripts for controlling data recovery and data transmission. But two main scripts are the most important: the weather information saving script that just saves weather values once every minute and the sending script that delivers the data to passing vehicles. The DHCP-client list is used during individual Wi-Fi connections for checking connected client IP-addresses.
2.3.2.1 Software components

Software scripts run on top of python 2.7.3 and its associated libraries. Also basic Linux programs like wget and hostapd are used for fetching pictures and listing client IP-addresses.

2.3.2.2 Data formats

Sending of weather information to the road users through Wi-Fi or 802.11p is done with simple UDP/TCP messages presented in the Table 12 below. During the 3G-connection the program fetches the data from the RWS-website.

<table>
<thead>
<tr>
<th>RWS UDP-message</th>
<th>Data field</th>
<th>Variable name</th>
<th>Example data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Message number</td>
<td>000010359</td>
<td>Used in testing</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Time Server</td>
<td>763.135 (Seconds)</td>
<td>used in system testing</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Temperature</td>
<td>4.0</td>
<td>Celsius</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Wind speed</td>
<td>3.0</td>
<td>m/s</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Wind direction</td>
<td>221</td>
<td>degrees</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Surface status 1</td>
<td>24</td>
<td>Three numbers explain road condition</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Surface status 2</td>
<td>325</td>
<td>Three numbers explain road condition</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Road temperature 1</td>
<td>-0.1</td>
<td>Celsius</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Road temperature 2</td>
<td>-0.2</td>
<td>Celsius</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Visibility</td>
<td>20000</td>
<td>metres</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>NWS</td>
<td>0</td>
<td>Current weather code in NWS</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>WMO</td>
<td>0</td>
<td>Current weather code in WMO format</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>TCP/WLAN/Delay</td>
<td>001</td>
<td>First number TCP 1(on) 0(Off). Second is WLAN(1) 802.11p(0) and last delay time</td>
<td></td>
</tr>
</tbody>
</table>

Table 12. RWS UDP-message

In special cases (e.g. during testing) the Sunit-vehicle pc saves the GPS data as well.

<table>
<thead>
<tr>
<th>Data field</th>
<th>Variable name</th>
<th>Example data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Time sunit</td>
<td>763.136</td>
<td>seconds</td>
</tr>
<tr>
<td>2</td>
<td>Message number</td>
<td>000010359</td>
<td>integer</td>
</tr>
<tr>
<td>3</td>
<td>Latitude</td>
<td>67.3608111667</td>
<td>Latitude</td>
</tr>
<tr>
<td>4</td>
<td>Longitude</td>
<td>26.6188428333</td>
<td>Longitude</td>
</tr>
<tr>
<td>5</td>
<td>Height</td>
<td>163.4</td>
<td>metres</td>
</tr>
<tr>
<td>6</td>
<td>Sat number</td>
<td>9</td>
<td>Number of vis. Satellites</td>
</tr>
<tr>
<td>7</td>
<td>speed</td>
<td>91.0</td>
<td>km/h</td>
</tr>
<tr>
<td>8</td>
<td>Direction</td>
<td>341</td>
<td>degrees</td>
</tr>
<tr>
<td>9</td>
<td>Message number</td>
<td>000010359</td>
<td>integer same as above</td>
</tr>
<tr>
<td>10</td>
<td>Time Server</td>
<td>763.135</td>
<td>ms</td>
</tr>
<tr>
<td>11</td>
<td>Temperature</td>
<td>4.0</td>
<td>Celsius</td>
</tr>
<tr>
<td>12</td>
<td>Wind speed</td>
<td>3.0</td>
<td>m/s</td>
</tr>
<tr>
<td>13</td>
<td>Wind direction</td>
<td>221</td>
<td>degrees</td>
</tr>
<tr>
<td>14</td>
<td>Surface status 1</td>
<td>24</td>
<td>Three numbers explain road condition</td>
</tr>
<tr>
<td>15</td>
<td>Surface status 2</td>
<td>325</td>
<td>Three numbers explain road condition</td>
</tr>
<tr>
<td>16</td>
<td>Road temperature 1</td>
<td>-0.1</td>
<td>Celsius</td>
</tr>
<tr>
<td>17</td>
<td>Road temperature 2</td>
<td>-0.2</td>
<td>Celsius</td>
</tr>
<tr>
<td>18</td>
<td>Visibility</td>
<td>20000</td>
<td>metres</td>
</tr>
<tr>
<td>19</td>
<td>NWS</td>
<td>0</td>
<td>Current weather code in NWS</td>
</tr>
<tr>
<td>20</td>
<td>WMO</td>
<td>0</td>
<td>Current weather code in WMO format</td>
</tr>
<tr>
<td>21</td>
<td>TCP/WLAN/Delay</td>
<td>001</td>
<td>First number TCP 1(on) 0(Off). Second is WLAN(1) 802.11p(0) and last delay time</td>
</tr>
</tbody>
</table>

### 2.3.2.3 Communication protocols

Communication between the RWS and passing cars relies mostly on simple UDP-packets.
2.3.3 Road weather data distribution systems

Sunit vehicle program is presented in the Figure 27. The program uses either Wi-fi or 3G depending on the GPS coordinate of the car. If the car is near the road weather station Wi-fi is used further away 3G.

![Figure 27. Sunit program diagram](image)

2.3.3.1 Software components

Standard windows connection programs for establishing 3G-connection / Wi-Fi connection and a python-Kivy script for displaying / fetching the data from RWS and determining the distance to the Road Weather station.

2.3.3.2 Data formats

The Sunit system captures the same packets as in Table 12 in addition to fetching the RWS-data / pictures from the RWS-website when no Wi-Fi connection is available.

2.3.3.3 Communication protocols

Wi-Fi and 3G are the main communication channels in delivering data to users.

2.3.4 IR Mobile application

The Intelligent Road mobile application has been made for Android OS platform version 4.0 (API lvl 14). The purpose of the application is to display road condition data for the driver. The application
has similar look (Figure 28) as the map view of the web interface of the IR-server (http://data.intelligentroad.eu/vis) described later in the chapter 2.4.5.7.

![Figure 28. The map view of the IR mobile application.](image)

### 2.3.4.1 Functionality
The application shows real-time location specific road condition data for the user. The display is split into two sections: map view and text view. In the map view data is displayed as a colored line where the color indicates the current value of the selected parameter. The blue arrow indicates the current location of the Android device. The current location is always centered on the screen. The map is rotated as the driving direction changes, as is usually done in GPS-navigation devices.

Geofencing is utilized to warn user of the application about dangerous road conditions ahead. At the moment surface condition and friction data is used in generating the warning messages.

### 2.3.4.2 Data formats
The IR mobile application uses data formats described in 2.3.1.2.

### 2.3.4.3 Communication protocols
The application has two communication options: Android device’s own network connection or direct Wi-Fi communication with the ConnectPort x5 (DAQ) installed to the vehicle. If the vehicle has the DAQ and sensor installed, application offers network connection to the DAQ via Wi-Fi.
Hotspot. The Android device must be configured correctly to make the direct (hotspot) connection possible.

If there is no DAQ installed to the vehicle, the application communicates, using Android device’s network connection, with the IR-server to get the real-time data for the current location if available.

2.4 SERVER ARCHITECTURE

2.4.1 Big picture

High level definition of the server architecture and functionality is described in Figure 29. Multiple data sources send data packets to the IR-server. Server receives and processes the data packets according to the data and device identification codes and stores it to the database.

Acquired and processed data is visualized and presented at http://plabdev.ramk.fi/intelligentroad/vis. Data processing and visualization are described in chapters 2.4.4 and 2.4.5.6. It is possible to add interfaces to IR-data for third parties to utilize the data in their services.

Detailed description of server implementation is described in a separate document “XXX”.

2.4.2 Database design

Production database is built on MySQL database server. Database structure itself is generated by Django’s ORM tools.
Database consists of generic Django databases for session, users and permission handling. There are also separate databases for different data formats. Each data format has its own table in the database which is used to store the data.

### 2.4.3 Client-server communication

Client-server communication is implemented using certain data packet formats described earlier in chapter 2.3.1.2 for vehicle data acquisition and chapter X.X.X for data XX.

Server itself is running on Debian Linux operating system. HTTP-server is Apache. Intelligent Road software is implemented with Python which is run by WSGI module on Apache. Intelligent Road software also uses Django Framework to make software development easier and faster.

Following graph in Figure 30 demonstrates the software and their relations on the server.

![Diagram](image)

**Figure 30.** Relations of different software on the server.

### 2.4.4 Data processing methods

Data processing is described in Figure 31. Server receives the POST data from data collectors (weather stations, road vehicles etc.). The POST data is then identified by data ID and server selects the correct data processor. Each data row is then processed and validated. If the data is valid it is then saved into correct data table in the MySQL database.
2.4.5 Data types

Server receives the POST data from data collectors (weather stations, road vehicles etc.). The POST data is then identified by data ID and server selects the correct data processor. Each data row is then processed and validated. If the data is valid it is then saved into correct data table in the MySQL database.

2.4.5.1 Road vehicle data

This data is collected from moving road vehicles. There are several types of data depending of the devices used on the vehicle. Sensors and the according data types are: RCM411, RoadEye, RoadEye Algorithm, RT3 + GPS, VBOX 3i + IMU + AI. Each data type has its own table in the MySQL database.

2.4.5.2 Weather station data

Intelligent Road software receives multiple weather station data. The weather station data types are VVIS data, Davis Vantage Pro data and Digitraffic Data.

VVIS Data is the road weather station data from the Northern Sweden and it's fetched from the Swedish Transport Administration’s (Trafikverket) servers. Davis Vantage Pro data is received from Lapland University of Applied Sciences’ own weather stations and LTU’s weather stations.
Digitraffic data is fetched from the Digitraffic service. It contains the road weather station data from the Finnish road weather stations. Only the northern part of Finland is used and visualized on the map interface.

2.4.5.3 Road Camera data
Road camera data is also received from the Digitraffic service. Each available road camera picture is downloaded two times in an hour and saved on the Intelligent Road server. Old pictures are not saved at the moment. New images will replace the old pictures on the server.

2.4.5.4 FMI Forecast data
The weather forecast data is received from Finnish Meteorological Institute. This forecast data consists of the friction, surface temperature and warnings for the slippery and rain. This data is calculated on the FMI’s server and then sent to the Intelligent Road server. This data is also visualized on the map.

FMI forecast data is calculated for predefined routes. Forecast will be made for predefined locations. The forecast is generated for 8 hours and is available for every 15 minutes.

2.4.5.5 Diagnostic Data
Diagnostic data is received from the road vehicles and saved for debugging use. It’s not visualized on the map.

2.4.5.6 Interfaces

2.4.5.7 WWW
The Intelligent Road WWW-interface ([http://data.intelligentroad.eu/vis](http://data.intelligentroad.eu/vis)) shown in Figure 32 consists of 2 views for the data: a list view and a map view.

The list view has tabs for different types of data. Vehicles tab has tables for all the different sensors installed. Weather tab has a list of different types of road weather stations and the latest data from them. Diagnostic tab shows some diagnostic data from the vehicles equipped with the DAQ-systems and sensors. Most of the latest data can also be browsed in a list which is sorted by the time of the data. These lists can be opened, if available, by clicking the link in the ID column of the row in the table in the list view.
Figure 32. List view of the Intelligent Road www-interface.

The list view also has a login button and when pressed, it shows a login form. When inserted with valid username and password, it opens up a control panel. Within the control panel is the possibility to change the text forecasts for Luleå-city.

“Latest data on map” -link opens the map view of the data.

Figure 33. Map view of the Intelligent Road www-interface.

Map view (Figure 33) has a control panel and a map. Control panel has options for changing the dates or hours and the type of the data rendered on the map. The data is shown on the map with lines of different colour. The colour of the line depends on the currently selected data type and the
value of the data. Each data type has its own legend which helps to determine the value of the coloured line. Depending on the selected vehicle there is also a text forecast panel for Luleå city.

The map view has also an options panel with the following options:

- **Show markers**
  - Adds the collected measurement points to map
- **Show road weather stations**
  - Adds road weather stations to the map
- **Show road weather cameras**
  - Adds road weather cameras to the map
- **No optimization**
  - Toggles optimization of the data off. All saved and valid markers will be fetched from the server and shown on the map. This will be memory and CPU consuming.
- **Show forecast**
  - Adds forecast to map and opens up forecast panel.

Because of the performance limitations of web browsers, the data on the server must be optimized before it is sent to the browser. Optimization removes any unnecessary data points which are not required when representing the data on the browser. For example, the straight lines can be represented with two data points in each end of the line and all data points can be removed from between these two points. Optimizing the data helps to render the website faster and the browser to use less memory which helps creating a more responsive user interface.

The collected weather station and road camera data is also shown on the map interface (Figure 34). User can enable these markers on the left side of the interface by checking the checkboxes. When this data is enabled the following markers will be shown on the map.

![Figure 34. Close-up of map view showing weather station and road camera icons.](image)
If user clicks on a weather station icon, an information popup shown in Figure 35 will be opened. This popup contains the latest information for the selected weather station as shown in the Figure 35. If there are multiple weather stations on selected locations, all of the weather stations are shown on the list.

![Figure 35. Information popup on the map view containing weather station data on the left and road camera picture preview popup on the right.](image)

User can also view the latest road camera pictures by clicking on the camera icon. Only the latest road camera pictures are available as described in the chapter 2.4.5.3. Road camera popup (Figure 35) will show the preview images of all the cameras in the selected location. A larger version of the camera pictures can be viewed by clicking one of the shown images. The larger picture will be shown in its own frame as can be seen in Figure 36.

![Figure 36. Full image view after the user has clicked on one of the available preview images on the road camera popup window.](image)
If there are multiple road camera pictures on the selected location, the pictures can be browsed by clicking on the left or right side of the picture. Details of the picture will be shown at the bottom of the picture. Details include the location and the timestamp of when the picture was fetched from the Digitraffic service.

2.4.5.8 OTHER
The data from the server to the browser is achieved with predefined URLs for the data. The Intelligent Road -application has 4 types of data: vehicle data, weather station data, weather camera data and forecast data. Each data type has a predefined URL to fetch the data from the server. The data URL is built from base URL and arguments which consists of e.g. date of data, area of data and type of data. Browser application makes calls to these URLs and presents the data to users. These URLs can be used to fetch data from the Intelligent Road -database to use for other applications. The data is provided in JSON format for the web user interface.

3 SYSTEM TESTING AND VALIDATION

3.1 INTRODUCTION

3.1.1 The purpose of the Intelligent Road system
The reason to validate the Intelligent Road system is to answer the question ‘Does the system serve the purpose it was first intended to?’ The main goal of the Intelligent Road system is to provide road-users with accurate information of the road condition both in real-time and as road condition forecasts. Many accidents involving vehicles are caused by hazardous road conditions. If information about slippery road conditions could get more local and accurate some of these accidents could be avoided or mitigated. The Intelligent Road system is based on vehicle mounted optical sensors for road surface condition and temperature measurements in combination with data from stationary Road Weather Stations (RWS). These sensors are used to make more local and accurate road condition measurements and forecasts for road users and road maintenance to increase traffic safety during difficult road conditions.

3.1.2 Validation
When presenting road conditions to road users, it is important that the information is relevant and correct. Otherwise the road user will ignore or misjudge the information. Road friction is dependent on the road surface, type and age of the vehicle, the weight/load of the vehicle and the type, as well as the pressure of the tires in use. Only measuring the road condition meaning, i.e. determining if the asphalt is dry, wet, icy, slushy, moist or snowy, will not give a complete friction measurement, as the friction coefficient is defined when two surfaces are sliding against each other. But it will however give friction estimation. Therefore, the validation of the optical road condition sensors needs to be thorough, both for correctness and against actual tire to road friction measurements to acquire more valid friction estimation.
3.1.3 Presentation

By using vehicle-based sensors a large amount of data is collected. It is a challenge to present this data in a way that is fast and easy for the user to comprehend. Hence, it is important to evaluate and test alternatives for data presentation. In the Intelligent Road project the data is made available through different user applications such as a webpage and navigation application for Android tablets by using a range of communication methods such as 3G and WLAN.

To be able to deliver a slippery road condition warning that has an effect on the road-user, it needs to be correct, location specific and appear at the right time. Most of all, the warnings need to be presented in a non-distractive way. On top of road users, road maintenance entrepreneurs planning their work (e.g. plowing and salting) could use the road condition information. This means that the requirements for the presentation of data changes, for example presenting the different road conditions and friction estimations in color scales gives a comprehensive picture of the situation on a larger area with roads that require maintenance.

3.1.4 Testing

In order to measure and forecast different road conditions, it is necessary to collect data from a large number of sensors. Within this project the idea was to use new sensors for road condition monitoring, making it necessary to test them together with already available sensors in order to validate their performance. Therefore testing of the sensor system and the communication methods for the sensors was one of the most important issues creating a reliable system. Hence the system was tested during a longer period to cover as many road situations and weather conditions as possible.

The testing has been carried out in several steps during the project making progress between the two measuring periods, winter 2012/2013 and 2013/2014. The testing have been focusing on different issues depending on the project partner, where Lapland University of Applied Sciences (Lapland UAS) has focused on data collection (vehicle-to-cloud) and data presentation, Luleå Technical University (LTU) has focused on the correctness, response time and robustness of the road condition measurements and The Finnish Meteorological Institute (FMI) has focused on the intelligent RWS and vehicular networking, sending information from stationary RWS to passing vehicles and communicating data between vehicles.

3.2 SYSTEM VALIDATION

When dealing with slippery road information data it is important that the information that is sent to the user is correct and within the right time frame, i.e. the information is useless if it is presented too late. Hence, validation of the correctness, availability, time response and resolution of the Intelligent Road systems optical sensors is important. For the weather forecast presentation and communication the correctness and the resolution is the most significant parameters as the forecast is not that dependent of the right position and time response in seconds.
3.2.1 Optical sensors

To evaluate and validate the optical sensors, Road Eye by Sten Lofving Optical Sensors and the RCM411 by Teconer, of the Intelligent Road system four parameters are investigated, correctness, availability, time response and resolution. The ways to evaluate the parameters are described below:

- **Correctness:**
  - Telling if the optical road condition sensors estimate the tire to road friction correctly.
  - **Method for validation:** The parameter is validated through continuous friction measurements with the Halliday RT3 Curve sensor or through video recordings combined with braking tests.

- **Availability:**
  - By examining the availability of data during a measurement sequence, the data rates and connectivity are controlled so that no relevant data gets lost.
  - **Method for validation:** Comparing the data logged by Intelligent Road system with data collected in real-time using the correct sampling rate in the test vehicle. This parameter is focusing on the data rates and connectivity but is also dependent on the resolution of the sensors (see Resolution below).

- **Time response:**
  - Time response tells how fast the real-time data is presented on a webpage. The time response should be short enough for the road condition data to be presented within a relevant time frame for the different users. The parameter is validated through investigation of time delay of the data presented on the webpage.
  - **Method for validation:** A test run is driven on a selected route. During this test run optical sensor data is measured real-time with a dedicated vehicle monitoring system along with the Intelligent Road system. Time response can be defined by stopping the vehicle and calculating the time until the stopping location is shown in the Intelligent Road system webpage.

- **Resolution:**
  - The sampling rate of the measurements resolution should be fast enough to find sudden changes in road conditions within a reasonable distance. Depending on the driving speed, distance resolution should be 5-25m which corresponds to 1-2 seconds.
  - **Method for validation:** The Halliday RT3 Curve measures the friction with a frequency of 1 Hz. The optical sensor measurements are synchronized with the RT3 curve measurements making it possible to compare the two signals. This allows the investigation of the optical sensors’ capability to track changes in friction.
3.2.2 Weather and road forecast

In addition to the validation of the sensors included in the Intelligent Road system, it is of interest to examine the outcome of the weather and road condition forecasts. For forecasts, it is only correctness that is validated. This is due to the road condition forecast being based on the measurements carried out with the Road Eye sensor. If the sensor delivers reliable data as input to the forecast, the forecast will also comply with specified requirements. Here it is important to note that if the optical sensors classify false conditions, this error will be propagated on the road condition forecast.

3.2.3 Communication

Today the optical sensors are quite expensive for an ordinary road user but the information from these sensors is still interesting for various road user segments. By utilizing vehicular networking schemes, it is possible to communicate the sensor data to road users. For validating the communication systems, tests of V2V and V2I systems have been carried out in order to measure data throughputs using especially the IEEE 802.11p WiFi standard.

3.2.4 Presentation

Validation of the presentation alternatives is done through interviews and surveys with both ordinary road-users and the entrepreneurs responsible for the road maintenance in Luleå Municipality.

3.3 SYSTEM TESTING

3.3.1 Sensors and data collection

To validate the Intelligent Road system the new sensors need to be tested in real life applications and data needs to be collected in various weather conditions. The input to the Intelligent Road system is weather forecasts and data coming from:

- Road Eye, vehicle mounted optical sensor for road condition monitoring and friction estimation
- Raytek MI, vehicle mounted infrared thermometer for road surface temperature
- Teconer RCM411, vehicle mounted optical sensor for road condition monitoring and friction estimation
- Teconer RTS411, vehicle mounted infrared thermometer for road surface temperature
- Web camera for recording of road conditions
- Halliday RT3 Curve, tire to road friction measurement apparatus
- Swedish VVIS road weather stations, delivering air and road temperature, humidity, wind speed and direction, dew point and precipitation amount and type
- Digittraffic (open data service); Finnish road weather stations, delivering weather camera images, air and road temperature, humidity, wind speed and direction, precipitation amount and type, road condition, salt amount and freezing point of the road
• FMI’s Intelligent Road weather station, delivering air and road temperature, humidity, wind speed and direction, road condition, soil moisture and temperature profile under the road, present weather and visibility
• FMI road friction forecast
• Local weather forecast for the Luleå area done by meteorologist forecasting: air temperature, road temperature, precipitation, precipitation type, wind speed and dew point.

The connection of the sensors to the server is presented in the WP2 System design documentation. As the two optical road condition monitoring sensors (Road Eye and Teconer RCM411) are rather new sensors on the market, these sensors needed to be evaluated regarding performance and availability in real life applications.

The optical road condition sensors use absorption and scattering of light to classify different road conditions. The weakness of these sensors is that they only measure the road surface giving a general estimate, not taking into account the tire of the vehicle. The advantages of the sensors are that they have a good resolution they are reasonable in price and they are rather small.

To collect data, the sensors were mounted on five different vehicles:

• Three Kuljetus Kovalainen Ltd. (a road transportation company) trucks of which two were equipped with Teconer RCM411 and Teconer RTS411 and one truck equipped with the Road Eye sensor. The trucks are carrying out measurements on three Finnish road stretches between Sodankylä-Rovaniemi-Oulu.
• One car equipped with a Road Eye sensor carrying out measurements in the Luleå area.
• One Volvo XC90 SUV equipped with a Road Eye, Raytek MI, Teconer RCM411, Teconer RTS411, Halliday RT3 Curve and a camera. Within Luleå area Measurements have been carried out in roads between Ersnäs-Luleå center and Porsön. This setup is used in the development of the friction estimation algorithms of the optical sensors.

In addition to these permanent installations, FMI has occasionally conducted optical road condition monitoring with two additional road condition monitors (RCM411) within the region of Sodankylä municipality and surrounding areas.

3.3.2 Road condition forecast
One of the objectives of the project was to investigate how the new road condition monitoring sensors in combination with local weather forecasts, could improve road weather and road condition forecasts for the upcoming 1-8 hours. Making a forecast based on road condition sensors the resolution is increased drastically compared with ordinary road weather forecast, i.e. from 0,5-1 km down to 10-30 m. The testing of the road condition forecast algorithm was carried out on the roads in the Luleå area, mainly between Porsön and Ersnäs. The algorithm calculates the upcoming road conditions based on the measurement and the weather forecast.
The testing was carried out according to following scheme:

- In the morning (around 08:00) a measurement was carried out on a defined road stretch with the optical road condition sensor. Simultaneously a weather forecast for the day was calculated for the area where the road stretch was located.
- In the afternoon (around 16:00) a measurement was carried out in the same road stretch. The calculated road condition forecast was then evaluated against this road condition measurement in order to find out its correctness.

3.3.3 Testing conditions

The Intelligent Road system has been tested during the winters 2012/2013 and 2013/2014 in the arctic regions around Rovaniemi, Sodankylä and Luleå. Although all three sites are in the arctic region the weather conditions differ. The Luleå site has coastal climate as it is close to the Gulf of Bothnia. Coastal climate is characterized by high humidity and quite small temperature differences during day/night in summer/winter due to large water mass that preserves heat energy. The coastal climate affects the road weather creating hazardous road conditions. As an example, in the autumn when the temperature decreases below zero and winds are coming from the open sea with a lot of humid air, there can be fast build-ups of frost on the roads. Frost is one of the most hazardous road conditions as it is hard for the driver to detect and it is very slippery. Another specific weather condition for this coastal region is super cool rain that also creates slippery road conditions.

In the regions around Rovaniemi and Sodankylä the climate is more of a continental type resulting in larger temperature differences between day/night and summer/winter. This is due to absence of the large water masses absorbing and storing the heat from the sun. These differences between the test sites made it very suitable for winter road testing because a large variety of road conditions could be covered. It has to be noted that the winter 2013/2014 was exceptional due to the high temperatures, small amount of snow and with slushy road conditions, respectively.

3.3.4 V2X communication tests

3.3.4.1 Rovaniemi test site

In the pilot measurements in Rovaniemi two vehicles were used, the first one acting as an OBU and the other one as a RSU. Both vehicles contained the following devices: a GPS, a laptop, RSU/OBU and an inverter to power all the mentioned devices. All the devices were connected directly to the laptop. For UDP measurement, Iperf was used. GPS data was sent from the OBU to the RSU with a LabVIEW program, which basically captured the GPS data from the GPS device via RS-232 port and sent it to the RSU as a UDP-packet.
Figure 37 Test equipment before installation to a vehicle. RSU unit is not shown in this picture.

During the V2I-tests, the RSU-vehicle was parked near the road while the OBU-vehicle drove past it multiple times. Both Iperf and LabVIEW programs were running and saving the data from each run. Large pole antennas provided by Horizon were used in Rovaniemi measurements.

3.3.4.2 Sodankylä test site

Test locations
The tests were conducted on RWS vicinity area in Sodankylä. Tests were conducted in clear weather conditions with no rain.

Test setup and methods
IEEE 802.11p operation is initiated in RWS/RSU, to provide broadcast type RWS information in maximal delivery rate. Sunit vehicle PC is deployed in the vehicle, with communication software and user application. PC is also equipped with data capture software and Wireshark throughput analysis software. Vehicle bypasses RWS with 80 km/h and 100 km/h speeds, starting and ending at “out of range” position. The procedure is repeated 10 times with both speeds, and communication process is observed throughout the measurement, in order to ensure measurement success. In case of failure(s), more repeats for the measurements are required.

The data delivery between the Sodankylä intelligent RWS and vehicles has been tested with many different test scenarios using IEEE 802.11p which is the primary communication protocol in short range V2I communication. Communication between the RWS and the vehicles has also been tested with Wi-Fi and 3G and these protocols have been used for the road weather application using Sodankylä RWS data. The application has been implemented into Android based tablet and smartphone, and later on converted also into iPad tablet and Jolla Smartphone, respectively. Android
version has been exposed into long-term testing in several different (and different type of) user devices, while iPad and Jolla has only been exposed for the general operability test so far.

The pilot measurements in Sodankylä were conducted between combined RWS/RSU and bypassing vehicle. The RWS/RSU employs the radio communication infrastructure for IEEE 802.11p communication, traditional Wi-Fi communication with IEEE 802.11n/g and cellular communication in 3G network. The vehicle side HMI is constructed to laptop (mainly for reference), Sunit D7 vehicle PC, Android-system compatible tablet and Android smart phone, respectively. Optional approach was to provide support also to the iPad-tablet and Jolla-operated smart phone. Laptop and vehicle PC are supporting both IEEE 802.11p and IEEE 802.11n/g communication, while tablets and smart phones are employed with IEEE 802.11n and 3G communication, respectively. In this paper we focus on the IEEE 802.11p communication tests, as they were the primary interest in the project. Sunit vehicle PC was employed to host receive the data through separate IEEE 802.11p capable modem with dual Larsen antennas adjusted for 5.35-5.925 GHz and further capture the received data with Wireshark data capture software.

On the RWS/RSU side the host computer located in the station was employed to broadcast data for the bypassing vehicles in pre-defined packet size and interval, respectively. Many different combinations were briefly tested, until the optimal rate (1500 byte packets in 1 ms interval) was found and further used in the measurements.

3.3.5 System presentation

Today several vehicle brands have a small snowflake lit or a blinking temperature reading when the temperature drops below 3 degrees Celsius to warn for the possibility of slippery road conditions. When traveling in artic region during the winter it would mean that the snowflake would be lit all the time and after a while the driver would ignore the warning.

The information that is gathered in the Intelligent Road system is presented in the homepage but to get it even more accessible for the road user two apps for android platforms where developed. The first with focus on presenting the data recorded in the vehicle in real time for the driver and the second with focus on road maintenance and vehicle testing.

FMI also generated a specific user application for RWS data, and this application was converted to Android based tablet and smart phone, Sunit vehicle PC, iPad tablet and Jolla smartphone, respectively.

3.3.6 User evaluation

The pilot testing within the Intelligent Road project was carried out in two ways: firstly a survey was distributed to several road users both professional and personal, secondly the Intelligent Road results were presented to the Luleå Municipality road maintenance division to discuss, from a user perspective, the data of the Intelligent Road system and how the data was presented.
3.4 RESULTS

In this chapter the results of the system testing is presented.

3.4.1 Optical sensors

The optical sensors RCM411 and Road Eye are validated as described in the Validation section above.

3.4.1.1 Correctness

Figure 38 shows distributions of the Halliday Friction Number (HFN) for the road conditions classified by the Road Eye and the RCM411. The friction numbers are measured with the RT3 Curve and the HFN is divided by 100 to get a friction number representation. Notable is that the Dry and the Wet has some measurements that are below a friction number of 0.6. Some of these low values are caused by sharp turns and bumps in the road, the RT3 Curve is only able to handle curves with a 50 m radius without decrease in the HFN value the other are simply wrong classifications. For ice and slush there are some high friction numbers above 0.6, these are caused by wrong classifications.
To exemplify the method of evaluation of the correctness, one drive from Ersnäs to Porsön that includes all 5 road conditions, was chosen. From this run it is also possible to show examples of the other validation parameters. In Figure 39 the two optical road condition sensors are compared with the friction measurement of the RT3 Curve. It can be seen that both sensors differs well between road conditions with high and low friction. Notable is that Road Eye classify the high friction parts around the samples 150 and 1400 that RCM411 does not. For the correctness there are some false classifications mostly by the RCM411 but the overall classification is acceptable.

Another difference is the surface classifications for example between 350 and 700, where the Road Eye classifies ice and slush and the RCM411 snow. This is the most difficult part of using an optical road condition sensor - how to define the different surfaces? What is a snowy, icy or slushy road surface and when does it change from one to another? As these sensors are still new on the market this is a question that needs to be elaborated on with more research and it is not a subject in this project. This is also something that can be set by a user to get a satisfactory road condition measurement.

Figure 39 show the road condition classification from the two optical road condition sensors but what is more interesting is the friction estimation. To be able to evaluate the correctness of the estimated friction from the optical sensors the error between the friction estimate from the optical sensors and the RT3 measured friction is calculated.
Figure 40 Error distributions between the RT3 Curve and the Road Eye and the RCM411 sensors, respectively.

Figure 40 shows the distributions of the error, respectively for each sensor, for 23 measurements done on different road conditions during the winter 2013/2014. The Road Eye has a little better performance than the RCM411 for these measurements as the error distribution is closer to 0 and the standard deviation is narrower.

3.4.1.2 Availability

Figure 41 Availability of the data from the server, comparison of live recorded data and server data.

The availability of the data on the server is acceptable. As Figure 41 shows the fit of the two data complies. There is no data lost from the real-time measurement to the server and this is the case of all measurements. This of course is dependent on the internal memory in the communication apparatus in the vehicles that saves data when the connection to the server is lost.

3.4.1.3 Time response

The time response for the Intelligent Road system when connected to the 3G network is shown in Table 1.
Table 13 Length of driven distance and time delay for the position to be updated on the web page

<table>
<thead>
<tr>
<th>Length of driven distance (km)</th>
<th>3</th>
<th>21</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time delay on web page (min)</td>
<td>0.08</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

As can be seen for road maintenance the time response is no problem but for in-vehicle presentation the time response is too long. If the connection is lost the time response of course could be longer because much data then needs to be sent afterwards. Therefore a connection, via for example Bluetooth, between the communication box in the vehicle and a smart phone or a tablet would be preferable for presentation of the real time data to the driver of the vehicle.

### 3.4.1.4 Resolution

![Comparison and validation of the optical sensors against RT3 measurement](image)

The resolution of the Intelligent Road system is important to evaluate, as one of the most important features of the optical sensors is to classify slippery road patches that are hard for the driver of a vehicle to detect, for example a short patch of ice on a wet road. Therefore the resolution, i.e. sample rate of the sensors, needs to be investigated. In Figure 42 the classification of both optical sensors is shown in the same graph. For both sensors there are classifications that are just one sample (samples 50-100). Compared with the friction measurement shown in the bottom of Figure 42 the resolution of the optical sensors are enough as they can classify a small ice or slush patch on a snowy road.

### 3.4.1.5 Calibration of the Road Eye sensor

In previous projects where the Road Eye has participated the calibration of the sensor have been done manually. Within this project several vehicles were equipped with Road Eye sensors, all sensors sent data to the server where the classification algorithm was programmed. As the signals of
the Road Eye sensors are dependent on the distance and angle to the road the signal required a calibration to enable a correct classification.

By making a static measurement against a white paper and record the values for the three wavelengths and then divide the signals with this value, respectively, the sensor is calibrated. Figure 43 shows the difference between two Road Eye sensor measurements for two different mounting positions with different distance and angle. The measurement is done with two sensors mounted on one vehicle pointing at the same spot on the road. In the top of Figure 43 the un-calibrated measurement is shown where there is a large deviation between the two signals, making it impossible to use the same algorithm for classification. In the bottom of Figure 43 the calibrated signals are shown, here we can see that the signals have much better convergence. Enabling the use of the same algorithm.

### 3.4.2 Forecasts

Within the Intelligent Road project the forecasts of the weather parameters is of high importance as the correctness of the weather forecast is crucial for the road condition forecast. The road condition forecast is also dependent of the Road Eye measurement correctness. If the start values of the road condition are wrong this error will propagate further to the road condition forecast.
### 3.4.2.1 Weather

The left side of Figure 44 shows three weather parameters measured by the RWS around the city of Luleå in Sweden during the winter 2013/2014. Notable is that the air temperature is centered near 0°C, i.e. the temperature of the winter 2013/2014 has been above normal in Luleå. What is also notable is that because of the high temperature the precipitation has been rain instead of snow, making the road conditions Wet and Slush the most common. The left part of Figure 44 shows the forecasted parameters for the winter 2013/2014. Making a comparison between the measured and the forecasted parameters it can be seen that though the forecasted parameters are much less in amount the distributions are similar, i.e. the forecast have been close to the reality.

### 3.4.2.2 Road condition forecast

![Comparison of Road Eye measurement, Road weather forecast and RT3 Curve measurement for the three friction values High (Black 0.6-1 μ), Medium (Yellow 0.3-0.6 μ) and Low (Red 0-0.3).](image)
Figure 45 shows a Road Eye and RT3 measurement together with the road condition forecast done 2014-01-15. The GPS coordinates are shifted to get a better view of the three measurements. The results of the road condition forecast show that there are possibilities using optical road condition sensors in cooperation with ordinary road weather forecast to make road condition forecast. On smaller road with less traffic this simple road condition forecast worked better, see the start and end of the plotted routes in Figure 45. For larger roads that are salted and have a larger vehicle flow, for example the E4 highway that passes through Luleå, the wrong classification was higher and therefore also the forecast. This is mostly because parameters as salt and vehicle flow needs to be incorporated into a road weather forecast algorithm.

![Figure 45 Rainfall, Air and Road temperature, Wind speed](image)

Figure 46 Weather parameters and forecasted parameters for 2014-01-15

The left part of Figure 45 is the measurements from 08:00 in the morning and the right is from 15:30 the same day. The weather parameters for this day are shown in Figure 46, where it can be seen that the forecast and the measurements complies and it can be seen that the day start with some snow and wind and with temperatures between -15 - -20, then during mid-day the snow decreases but starts again during the afternoon. This implies snowy road condition but due to the wind and the heating from the vehicles the large roads practically never stay snowy.

To enable a computation of the wrong classification of the road conditions from the road condition forecast, it is transformed into the following friction values: Dry=0.85, Wet=0.8, Slush=0.5, Ice=0.25, Snow=0.3. Consequently all three friction results are sorted into three larger representation categories, high (Black 0.61-1, i.e. Dry and water), medium (Yellow 0.31-0.6, Slush) and low (Red 0-0.3, Ice and snow) to enable comparison. Presenting the friction in this way makes the information easy and fast to understand for the road-users. In this case high means good grip, medium means risk for slippery roads and low means slippery roads, be careful.
Looking at Figure 45 we see that the snow seems to blow off the main roads as both the Road Eye and RT3 sensors estimates that there is high friction in the largest extent. However, the forecast incorrectly classify that it is a low friction on a road section, actually having a high friction. This is also the case for the forecast six (6) hours later. This is caused by the wrong classification of the Road Eye sensor propagates on to the forecast. Also notable is that there are several cases where the Road Eye sensor finds road sections with low friction values. Sensing road spots with low friction is actually one of the most beneficial features of the sensor.

When investigating a larger number (23) of runs the false road condition classification for the Road Eye sensor is around 30% and for the forecast 40%. If also the classifications where the Road Eye and forecast underestimate the friction, meaning that it warns for slippery roads be careful and the correct warning should be risk for slippery roads, the wrong classification decreases to 20% for both the sensor and the forecast. For both the cases the road users need to be careful and as mentioned in previous sections this is something that the user of the system can set.

3.4.3 V2X communication

3.4.3.1 V2I results

The V2I field tests were conducted both in Sodankylä and Rovaniemi. The general results of these measurements are viewed in the Figures 11-13. Figure 11 presents the results with 60 km/h only conducted in Rovaniemi, Figure 13 results with 100 km/h only conducted in Sodankylä, and Figure 12 results with 80 km/h conducted in both places. It can be seen that in each of the speeds the communication window is rather harmonized, obviously faster speed resulting in communication window.

In Rovaniemi measurements there is more fluctuation observed in momentary throughput, but on the other hand the connection window is slightly longer. Other vehicles between the OBU and the RSU cause lower performance due to blocking the direct line of vision between them, occurring also in Sodankylä measurements. Lower performance also happens when there is no direct vision due to slope (which can be seen in all V2I tests conducted in Rovaniemi). There was also a notable difference between the OBU going south and north. In V2I tests when the OBU drives north, the connection time is longer than going south. This phenomenon is also clearly caused by the surface shape affecting differently in opposite direction. In Sodankylä measurements this effect was removed by doing all the test measurements to one direction only.
Figure 47 – Data throughput from combined RSU to vehicle, bypassing the station with 60 km/h speed.

Figure 48 – Data throughput from combined RWS/RSU or RSU to vehicle, bypassing the station with 80 km/h speed.
The cumulative average throughput during the communication window was 67 MB in Rovaniemi tests with 80 km/h and 58 MB in Sodankylä tests, respectively. In 60 km/h tests in Rovaniemi the cumulative average throughput was 97 MB and 48 MB with 100 km/h speed in Sodankylä, respectively. Larger antennas used in Rovaniemi tests are clearly providing better performance in terms of range and cumulative throughput. Nevertheless, the size of the communication window in all the measurements is clearly large enough for the Intelligent Road project service scenarios.

3.4.3.2 V2V results

In the V2V measurements two vehicles were passing each other with constant speeds of 60 km/h, 80 km/h and 100 km/h, respectively. The configuration details were similar with V2I, except the fact that roadside unit counterpart was replaced with duplicate vehicle OBU configuration, acting as data broadcasting unit. Again the measurements were conducted in Rovaniemi with 60 km/h and 80 km/h, and in Sodankylä with 80 km/h and 100 km/h speeds.

The main results of these measurements are viewed in the figures 14-16. Again, Figure 14 presents the results with 60 km/h only conducted in Rovaniemi, Figure 8 results with 100 km/h only conducted in Sodankylä, and Figure 15 results with 80 km/h conducted in both places, respectively. It can be seen that in V2V communication the connection window is anything but harmonized, lot of variation is occurring in all the measurements.
Also there are notable differences between connection window lengths in similar measurements, e.g. in 60 km/h measurements the variation is between 40 and 60 seconds. The main reason for this
behavior is unpleasant communication environment of two high-speed objects passing by each other, making the communication entity as unstable as possible. Minor effect might also be caused by the fact that the vehicles did not accelerate in the same way, causing the meeting points to be slightly different between the measurements. The use of different antennas had more dramatic effect in V2V measurements. Especially in the Figure 18 where both Sodankylä and Rovaniemi measurements are presented in the same graph, one can see clear difference between 10 Sodankylä measurements each shorter than 20 seconds and 5 Rovaniemi measurements, varying between 27 and 40 seconds.

The cumulative average throughput during the communication window of V2V measurements was 43 MB with 60 km/h vehicle speeds, 15 MB with 80 km/h speed, and 9 MB with 100 km/h speed. Even if the variations are high and there are some unexpected patterns in the data, it is clear observed that also in V2V communication scenario the size of the communication window is clearly large enough for the Intelligent Road project service scenarios. For example, the size of the package containing all the combined RWS/RSU up-to-date road weather data is only 0.4 MB.

3.4.4 Presentation

![Figure 53](https://www.intelligentroad.eu)

The data from the vehicle sensors and the RWS-station is presented in tables on the web [www.intelligentroad.eu](http://www.intelligentroad.eu) or as coloured lines on a map as shown in Figure 53. Where each road condition (dry, moist, wet, snowy, icy, frost or slushy) represent a certain colour. The road conditions are coloured as:

- Dry=Green
- Moist = Light green
- Wet = Yellow
- Slush = Orange/(Red)
- Ice = Red
- Snow = Blue
- Unknown = Black

Also friction estimations and the friction measurements from the RT3 Curve has been presented as coloured lines on Google maps as:

- Red for friction between 0.00-0.15
- Orange for friction between 0.15-0.30
- Yellow for friction between 0.30-1.00

As a requirement from the ELY-centre of Lapland, also more detailed friction estimation values between 0.00 – 0.30 are visualized. This is due to the fact that friction below 0.30 still has huge variations from real conditions to relatively normal winter driving conditions. In the more detailed view, the friction is presented with the following values:

- Light green 0.30-1
- Green 0.28-0.30
- Turquoise 0.25-0.28
- Light blue 0.22-0.25
- Blue 0.20-0.22
- Dark blue 0.15-0.20
- Violet 0.0-0.15

A revision of colours in the detailed friction scale will be still considered.

Also seen in Figure 53 is the RWS stations from which it possible to get weather parameters as air temperature, road temperature, dew point, average wind speed, humidity, visibility and friction.
Figure 54 Comparison of resolution of road weather forecast and optical road condition measurement. Also shown is the road camera application.

Integrated into the webpage is also a road weather forecast from FMI. This can be seen as the green markers to the right in Figure 54. By setting a time parameter, visible to the left in Figure 54, it is possible to get a forecast for a certain time of interest. Notable in Figure 54 is also the resolution of the measurement with an optical sensor to the left and the road weather forecast to the right, were the measurements have a much higher resolution. Visible in Figure 54 is also a road weather camera application that shows current road status live in the webpage, these camera is mounted along the road in combination with the RWS.

3.4.4.1 Presentations for tablets

![Figure 55 The road weather application for tablets](image)
An application for vehicle PC, tablets and smartphones was presented during the Intelligent Road project, see Figure 55. The purpose of the application was to provide a local road weather service for the road users in the Sodankylä area. The service uses data gathered in the Sodankylä RWS and shares the measurement data with the road users. The provided dataset includes real time road weather camera picture, road surface state (friction and condition) information, the current air and road temperature, humidity, wind speed and direction, visibility and frost depth in the road area.

Two taxis and a bus operating in the Sodankylä area were equipped with vehicle PC's and screens to provide the service to the customers. A few Android tablets and smartphones as well as one iPad and Jolla smartphone were also equipped with the same application, and tested by the FMI crew themselves.

All of these applications (except Android tablet) were in full operation rather late, so any extensive analysis of the user experience could not investigated. Some general observations were made however.

Taxi application (Sunit vehicle PC)
- The system was constructed in a way that it had to be re-started after engine start. It would be better if it would start automatically.
- The data presented on the screen was mainly “too scientific” for general passengers
- The tablet computer would be more convenient. At least in Sedan-type taxi, where the power cable of Sunit PC was inconvenient.
- The brightness of the screen should be able to scale, the current model was too bright in the dark time.

Bus application (Sunit vehicle PC)
- The subpages are not too easy to browse
- Screen availability is not the best possible, generally only one passenger can exploit the data and service

Driver application (Android tablet, Android smart phone, iPad tablet, Jolla smartphone)
- Generally suitable for professional drivers (trucks etc.) as additional screen
- As a primary vehicle screen, the main information should be coming from the navigator, this data is only “supplemental”

At LTU also a tablet application was developed called Navigator++. The idea was to incorporate the Road Eye measurements and the road weather condition forecast into a navigation application. So the Navigator shows current road status ahead of the vehicle when driving. Another application that also is implemented into the navigator is for planning of trips. Where the road condition forecast is used to show road status at different times. The reason for this is that in the northern part of Sweden and Finland the traffic flow is not as high as in the southern part so instead of using
V2V communication for road status information ahead of the vehicle the Navigator+++ in combination with the road condition forecast would be an alternative.

Within the concept of the Navigator+++ a schedule for maintenance is also programed. This means that the driver of the snow plough or the salt truck will get instructions in which order they should execute the maintenance. When the Navigator+++ application detects that the vehicle is at the right position the driver is able to cross the task, in this way the commissioner of the work can see when the work is completed.

3.4.5 User evaluation

3.4.5.1 Presentation and discussion with Luleå Municipality

The project results, i.e. the intelligentroad.eu homepage, were presented to the Luleå Municipality personal responsible for the winter road maintenance. Also the Navigator+++ prototype for maintenance use was presented. The main points of the meeting was:

- The map and the visual presentation of the road conditions are good and the uses for the Luleå Municipality are several. Mainly regarding an objective way of measuring friction.
- The Luleå Municipality also suggested that in the future there would be good to mount the sensors on five to ten busses to get a larger fleet for data collection. With this deployment the system would be attractive from a maintenance perspective.
- A larger fleet would mean that the focus of the Luleå Municipality vehicle could be changed from the main roads to the bicycle and walkways, reducing the slippery roads for the
- Another point of view was that it would be an advantage to have a live reading of the sensor mounted on the Luleå Municipality's vehicle during the maintenance evaluation.
- The Navigation+++ could also be used to send instructions to the vehicles that are putting sand or salt on the roads so it gets more effective to prevent slippery road conditions.

3.4.5.2 Road-user needs

In the autumn 2013, a survey was conducted as a part of the project to different segments of road-users. Their incitements in using such real-time road weather information system were investigated along with the particular information they would like to receive while being on the road and their evaluation of a technical application displaying this on-spot specific data.

The information was gathered by using a mixed methods approach, embracing surveys, semi-structured interviews and an online poll. The primary data source is quantitative in a form of online surveys. In total 229 responses were received, composing of 217 responses from everyday drivers and 12 professional drivers.

The overall findings suggest that the distinct user groups consider it generally very important to acquire real-time and location specific road weather information. Approximately the same proportions of interested respondents were willing to employ a technical solution displaying the
information. Most important pieces of information were road condition information, state of road’s winter maintenance and slipperiness warnings.

**Would you use technical applications/solutions, which provide accurate and real-time information about road weather and driving conditions?**

(Answers in %)

<table>
<thead>
<tr>
<th></th>
<th>Local everyday road users (n=217)</th>
<th>Professional drivers (n=12)</th>
<th>Total sample (n=229)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yes</strong></td>
<td>86</td>
<td>75</td>
<td>86</td>
</tr>
<tr>
<td><strong>No</strong></td>
<td>14</td>
<td>25</td>
<td>14</td>
</tr>
</tbody>
</table>

**How important do you rate to receive the following weather and road condition information in real-time?** (Answers of local everyday road users; multiple answers possible)

- **Road condition (icy/ snowy/ wet)**
  - **Very important**: 182
  - **Important**: 27
  - **Irrelevant**: 9

- **Winter maintenance (plowing/ sanding/ salting roads)**
  - **Very important**: 136
  - **Important**: 65
  - **Irrelevant**: 17

- **Slipperiness warnings**
  - **Very important**: 124
  - **Important**: 72
  - **Irrelevant**: 21

- **Sight**
  - **Very important**: 123
  - **Important**: 77
  - **Irrelevant**: 18

- **Warnings of traffic slowdowns (accidents/ traffic jams/ weather)**
  - **Very important**: 108
  - **Important**: 93
  - **Irrelevant**: 14

- **Air temperature**
  - **Very important**: 84
  - **Important**: 106
  - **Irrelevant**: 24

- **Road temperature**
  - **Very important**: 75
  - **Important**: 92
  - **Irrelevant**: 47
As it can be concluded from the responses, the so-called everyday drivers would like to obtain accurate road-weather information and most preferably through a smartphone application. In the survey it was also inquired about other possible solutions on informing the drivers on real-time weather and road conditions. A clear majority of these open-ended questions suggested an open homepage showing the necessary data as shown in the table below.

### What would be a suitable technical option for receiving real-time information about weather and road conditions while driving? (Answers of local everyday road users; multiple answers possible)

<table>
<thead>
<tr>
<th>Technical Option</th>
<th>Amount of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphone application</td>
<td>141</td>
</tr>
<tr>
<td>Navigator</td>
<td>132</td>
</tr>
<tr>
<td>Bord computer displays</td>
<td>86</td>
</tr>
<tr>
<td>Radio announcements</td>
<td>86</td>
</tr>
</tbody>
</table>

### Amount of responses

As it can be concluded from the responses, the so-called everyday drivers would like to obtain accurate road-weather information and most preferably through a smartphone application. In the survey it was also inquired about other possible solutions on informing the drivers on real-time weather and road conditions. A clear majority of these open-ended questions suggested an open homepage showing the necessary data as shown in the table below.

<table>
<thead>
<tr>
<th>Response themes of open-ended question</th>
<th>Number of responses citing the theme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homepage with real-time road weather information, which drivers can consult before starting a trip</td>
<td>22</td>
</tr>
<tr>
<td>Short message</td>
<td>3</td>
</tr>
<tr>
<td>Map program for tablets (Ipad)</td>
<td>3</td>
</tr>
<tr>
<td>Warnings for the driver through signal sounds</td>
<td>3</td>
</tr>
<tr>
<td>E-mail</td>
<td>1</td>
</tr>
<tr>
<td>Social media</td>
<td>1</td>
</tr>
<tr>
<td>TV</td>
<td>1</td>
</tr>
</tbody>
</table>
3.5 DISCUSSION AND CONCLUSIONS

The conclusion from the testing and validation of the Intelligent Road system is that:

- The tests with the optical sensors Road Eye and RCM411 generally give the same result, this is because they use the same physical phenomena in order to distinguish the different conditions but by different techniques. By adjusting certain parameters, the results can be even more equal. This is also a question for a user of the Intelligent Road system - how sensitive should the system be? One example is slush, where the RCM411 is programmed to detect slush with high friction and the Road Eye with low friction. This is something that can be adjusted to a user’s preferences.

- The optical sensors are operating with a correctness that is acceptable for a friction estimation sensor, where the Road Eye sensor has a less error and standard deviation than the RCM411 for these measurements. The availability, resolution and response time for both optical sensors are also acceptable as it enables classification of short slippery road patches. One way to increase the correctness of the optical sensor Road Eye would be adding a surface temperature sensor.

- Based on the performance of the optical sensor and the manual local weather forecasts the road condition forecast is performing acceptable and can definitely be used for slippery road information. As this is a first trial incorporating the optical sensors into road weather forecast there is potential for improvement, for example by using the data from the RWS to adjust the weather parameter forecast. Larger models for the weather forecast together with information about traffic flow and information about when and how much salt is deployed on the roads, would also improve the road condition forecast.

- According to the survey among road users and in the interview with Luleå Municipality it is primarily the road condition that is interesting for the users. This agrees well with the information presented by Intelligent Road system. The selected presentation alternatives, a website and application for tablets and smartphones, is also in good agreement with the responses we have received.

The main conclusion of the Intelligent Road project is that the Intelligent Road system is of great interest both for local authorities as Luleå Municipality and international where the traffic agencies in both Sweden and Norway have showed interest in the optical sensors and their applications. The Intelligent Road project has also lead to interest in the Road Eye sensor meaning that large vehicle automotive component manufacturers are evaluating the sensor within their own companies for production.
INTELLIGENT ROAD

2012 – 2014

Project partners

LAPIN AMK
Lapland University of Applied Sciences

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