Vehicular networking and road weather related research in Sodankylä

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Abstract

Vehicular networking and especially safety-related wireless vehicular services have been under intensive research for almost a decade now. Only in recent years, also the road weather information has been acknowledged to play an important role when aiming to reduce traffic accidents and fatalities via Intelligent Transport Systems (ITS). Part of the progress can be seen as a result of Finnish Meteorological Institute's (FMI) long-term research work in Sodankylä within the topic, originally started in 2006.

Within multiple research projects, FMI Arctic Research Centre has been developing wireless vehicular networking and road weather services, in co-operation with FMI meteorological services team in Helsinki. At the beginning the wireless communication was conducted with traditional Wi-Fi type local area networking, but during the development the system has been evolved to hybrid communication system of combined Vehicular Area Networking (VANET system with special IEEE 802.11p protocol and supporting cellular networking based on 3G commercial network, not forgetting support for Wi-Fi –based devices also. For the piloting purposes and further research, we have established a special combined road weather station (RWS) and roadside unit (RSU), to interact with vehicles as a service hotspot. In the RWS/RSU we have chosen to build support to all major approaches, IEEE 802.11, traditional Wi-Fi and cellular 3G. We employ road weather systems of FMI, RWS and vehicle data gathered from vehicles, into the up-to-date localized weather data delivered in real-time. IEEE 802.11p vehicular networking is supported with Wi-Fi and 3G communications.

This paper briefly introduces the research work related vehicular networking and road weather services conducted in Sodankylä, as well as the research project involved in this

work. The current status of instrumentation, available services and capabilities are presented in order to formulate the clear general view of the research field.

1 Introduction

The vehicular networking related research work in Sodankylä started within the Eureka Celtic Carlink (Wireless Traffic Service Platform for Linking Cars) project (Sukuvaara, 2009), established in 2006. The architecture development basis combined both vehicular ad-hoc network and infrastructure-based networking with roadside fixed network stations. The conceptual idea of multiprotocol access networking was used for combining Wi-Fi (Wireless Fidelity) and GPRS networking. As a result, the Carlink project designed and piloted one of the first operating vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication architectures.

The concept of hybrid vehicular access network architecture were successfully studied, developed and evaluated in the Carlink project. The general idea of the continuation project Eureka Celtic Plus WiSafeCar (Wireless traffic Safety network between Cars) (Sukuvaara, 2013) was to overcome the limitations of communications by upgrading communication methodology. Wi-Fi was upgraded with the special vehicular WAVE (Wireless Access in Vehicular Environments) system based on IEEE 802.11p standard amendment (IEEE Std. 802.11p, 2009) and GPRS with 3G communication. The architecture was employed with a set of more sophisticated services, tailored for traffic safety and convenience. The set of example services was also adjusted to be compliant with services proposed by the Car-2-Car Communication Consortium (C2C-CC) (Baldessari, 2007) and ETSI standardization for the "day one set of services" (ETSI, 2010). Especially the newly-found IEEE 802.11p based vehicular access network system underwent an extensive set of test measurements, both with V2V and V2I communications. The measurements demonstrated that the IEEE 802.11p has clearly better general performance and behaviour in the vehicular networking environment, compared to the traditional Wi-Fi solutions used for this purpose. The pilot platform deployment proved that the new system operates also in practice, and the pilot services defined can be provided properly. In the deployment, the overlay cellular network (3G) played an important role, and this hybrid method would be an attractive solution for the ultimate commercial architecture. The WiSafeCar project drew an outline for the commercially operating intelligent vehicular access network architecture, with a general deployment proposal.

Even if the commercial deployment did not take place, the developed system served as the basis for a more advanced project, Eureka Celtic Plus CoMoSeF (Co-operative Mobility Services of the Future) project (Sukuvaara et al, 2015), along with other intelligent traffic related research. The focus in the CoMoSeF project was on near-the-market services and multi-standard communication. The aim was to not only to serve vehicles, but also exploit vehicle-originating data to ultimately enhance the same services. Similarly, RSUs are not just serving the vehicles as connectivity points, but also host RWS capabilities to provide additional data for the services. Both of these properties are combined in the Finnish Meteorological Institute approach to employing vehicular networking architecture to provide route weather information for vehicles passing our combined RWS/RSU. The enhanced RWS/RSU was also studied in NPP-funded SNAPS (Snow, Ice and Avalanche applications) project, where it represented the winter traffic data and enhanced service source for bypassing vehicles as well as online customers of local stakeholders. The Sodankylä RWS is equipped with up-to-date road weather measurement instrumentation, compatible with (but not limited to) the equipment of operational RWS. The procedure was to design, develop and test both the local road weather service generation, and the service data delivery between RWS and vehicles. The vehicle passing the combined RWS/RSU is supplemented wirelessly and automatically with up-to-date road weather related data and services, and at the same time possible vehicle-oriented measurement data is delivered upwards to database, to be used as part of weather information. IEEE 802.11p is the primary communication protocol, but also traditional Wi-Fi communication is supported, together with cellular 3G access as a backbone. Furthermore, the winter traffic data gathered from the vehicles was studied in Interreg IV A Nord Intelligent Road project. More advanced road weather services to be delivered directly to vehicles were intensively studied in EU FP7 project FOTsis (European Field Operational Test on Safe, Intelligent and Sustainable Road Operation). As the result of all these projects and research work, the interactive RWS station, together with research vehicles, forms the pilot system in Sodankylä, acting as a real-life test bed for the present and yet to come demonstration systems.

2 Research Road Weather Station

FMI has constructed a special combined Road Weather Station and Road Side Unit (RWS/RSU) to the Northern Finland, nearby its facilities in Sodankylä. The station, viewed in the Figure 1, is equipped with up-to-date road weather measurement instrumentation. The general objective is to design, develop and test both the local road weather service generation and the service data delivery between RWS and vehicles. The collection of RWS measurements is listed in the Figure 2.

The IEEE 802.11p VANET standard is used as the primary communication entity. Traditional Wi-Fi (IEEE 802.11g/n) and cellular networking (3G) are used as reference methods for the existing operative solution and as the alternative communication methods if VANET network is not available.

The interaction between vehicle and RWS represents the typical V2I communication. The vehicle passing the RWS/RSU is supplemented wirelessly and automatically with up-to-date road weather related data and services, and at the same time possible vehicle-oriented measurement data is delivered upwards. As seen in Figure 3, the local server in RWS/RSU is hosting the station operations. It is linked with NEC Linkbird-MX modem for IEEE 802.11p communication attempting, but it has also internal Wi-Fi modem, and both of these communication channels are actively seeking the passing vehicle communication systems. The local server is also gathering measurement data from two different measurement entities, Vaisala Rosa road weather measurement system and FMI weather station measurements. The data from these sources, together with vehicle-oriented data is sorted and further delivered to FMI local facilities through 3G communication link. The advanced services are developed in FMI facilities and delivered back to the RWS/RSU, to be further delivered to vehicles. The messaging system and operational procedure is presented in simplified format in the Figure 4. The same software entity maintains the data delivery between RWS and vehicles and RWS and FMI site, while gathering and updating the local weather data of RWS/RSU.

The communication system, originally presented by Mäenpää (2013), supports the operations in IEEE 802.11p, traditional Wi-Fi and 3G environments. The communication software has been generated with Python general-purpose, high-level programming language. The Python version 2.7.3 has been used throughout our development process. All the operations are running in parallel Python .py-modules. Basically all the communication elements are using same operation module, presented in the Figure 4. Depending on the usage profile (RWS, vehicle in V2I, vehicle in V2V) different kind of initiation process is required. The RWS/RSU has an infinite-loop Python operation procedure, which has been initiated before starting any other elements. Therefore it is expected to perform to specialized eternal loop of its network operations already before any vehicle is about to initiate communication. One module generally supports only one communication protocol, so in order to enable parallel operation of 802.11p and 802.11n one must initiate parallel modules for this. Finally, the 3G communication can't be initiated in this manner, as it is not practical to broadcast data in cellular network, and ultimately not allowed by the commercial network operators. The 3G operation is arranged simply by forcing end users to fetch up-to-date RWS data in pre-defined intervals from the RWS stations nearby. Therefore, RWS only needs to ensure that the up-to-date data is always stored in the RWS download folder.

Figure 5 presents the devices and their connections in V2I communication. The operational procedure for the communication can be presented in the following steps:

0. All programs are initiated both in RWS and in the vehicle. Devices are connected according to the Figure 5.

1. Vehicle radios are constantly searching for nearby IEEE 802.11p/Wi-Fi networks.

2. When one is found the vehicle radio form a connection and the data exchange between the computers in RWS and vehicle can begin.

    a. Neither RWS nor the vehicle knows anything about the IEEE 802.11p/Wi-Fi network status. They can only see if the IP address is "real" and active or not.

3. When the connection between vehicle and RWS devices has been established and the IP of the vehicle PC is visible for RWS host computer, the latter starts pushing messages to vehicle PC's IP at a constant rate.

4. When the connection is lost the IP-address disappears and messages will not be sent anymore.

5. Up-to-date RWS data is stored and updated regularly to download folder, in order to support 3G based data fetch by the vehicles out of range.

After this procedure the cycle begins again and vehicle radio starts searching for the nearby IEEE 802.11p/Wi-Fi networks.

Server software is the same for both Wi-Fi (IEEE 802.11n) and IEEE 802.11p communication. In the software only minor difference exists between the protocol procedures, in terms of different IP and message delivery rate. The complete server side code is presented in the Figure 4. As stated before, different protocols are launched in the parallel Python software modules. During the communication tests only UDP-messages have been used, but the TCP messages are supported as well. 3G communication is purely based on TCP-messages.

There are two threads that run at all times inside the RWS server; A weather condition monitoring script and a message sending script. The weather monitor just reads the data and saves it into a table that the messaging script can read. This is done in order to speed up the sending of messages.

Vehicle computer is using the same Python communication modules as RWS, presented in the Figure 4. When starting the vehicle application program the user chooses the transmission protocol (UDP/TCP), the communication protocol (Wi-Fi/802.11p), the delay between messages and the delay for the program startup. Mac list is only checked if the servers internal Wi-Fi is chosen as the messaging platform. The messages received from the vehicles passing the RWS are currently only being printed to the screen.

In the Client side we have two to three threads running at the same time:

1. The Wi-Fi connection is only used during IEEE 802.11n communication.

2. For the system evaluation purposes, the GPS values are constantly being monitored and saved into a GPS-table. This table is used when a message is received in order to pinpoint the location where the message was received. We can also monitor the speed and direction from the GPS data and see how many messages are lost during transit from the numbers that are included in each message.

3. The 3G communication is conducted by the vehicle. Vehicle PC has a simple Python module running in parallel with other modules, which fetches the nearest RWS data in pre-defined intervals. Time stamps of the different data contents are compared to select the most recent one.

3 The vehicular measurements

In order to fulfil the concept of serving vehicles and exploiting their data, the measurements are also conducted in vehicles and the data collected from there. Our vehicle data consists of mainly pilot-type service data like accident warning information, with more systematic measurement data of friction measurements, external temperature sensors and vehicle telematics data collected from CAN-bus. The accident warnings are simply initiated by pushing emergency button in vehicle computer unit, to be later on integrated to the vehicle internal systems. The friction measurements and telematics data represent more sophisticated vehicle observations.

FMI is using two different optical friction monitoring sensors in its road weather services. Vaisala DSC 111 friction monitoring instrument is tailored for fixed friction measurements. It has been deployed permanently into the Sodankylä special RWS, introduced in the previous chapter. From the mobile friction monitoring perspective, it serves as a reference measurement.

The mobile friction monitoring is conducted with Teconer RCM 411 instrumentation (viewed in the Figure 6). RCM411 has been designed for quality control and optimization of winter maintenance. RCM411 is also suitable for runway condition reporting. The sensor can be installed to a vehicle in order to monitor the surface conditions in real time. RCM411 detects all typical surface states like Dry (green line color in the map), Moist (light blue), Wet (dark blue), Slushy (violet), Snowy (white) and Icy (red). RCM411 also measures water and ice layer thicknesses in fractions of millimeters up to 3 mm. A model based on the surface type and amount is used to estimate coefficient of friction. Acceleration based µTEC Friction Meter can be integrated to the same user interface installed in a cell phone.

Friction monitoring is occurring on the measuring vehicle continuously. The friction measurement data is collected from the measuring vehicle in pre-defined intervals through 3G communication or through IEEE 802.11p or Wi-Fi communication whenever entering in the range of Sodankylä RWS. Friction data of other vehicles or from the RWS can be delivered back to the vehicle as reference data. Currently there is no application deployed for this purpose, and this is not in the scope of the project.

Telematic data collected from vehicle CAN-bus has been recently employed for our vehicle data contents. At the moment only the temperature data exploited, but the possibilities to use vehicular telematics data as a source or at least an indicator of meteorological services is actively seek.

In addition to existing vehicular data sources, also the Taipale Telematics Sensior system is processed, which can be used to fusion the data of different external data sources. At the moment only the navigation and temperature data is gathered from the Sensior, but the additional sensor instrumentation is under consideration.

4 Measurement data

Vehicular networking and road weather related measurements generated in Sodankylä RWS and supporting infrastructure consists of operative example RWS services as well as specially tailored pilot measurements.

The operative RWS services are gathered into our public RWS website, found from http://sodrws.fmi.fi and viewed in the Figure 7. The historical data series captured from the RWS are presented in our public local database, in http://litdb.fmi.fi/rws.php. The website contents are tailored also to the mobile devices of Android-based operating system as well as iPhone and Jolla, aiming to present our vision of road weather services user interface scalable for different environments. In addition to this, the measurement data is gathered into historical time series, to be exploited in the future research. An example of such data set, road frost data from the winter 2014-2015, is presented in the Figure 8. The frost measurement is conducted with multiple temperature sensors buried in different depths, indicating frost when temperature below zero. In the warm periods and at the end of winter season, frost is melting first from the ground level, which can clearly be seen in the Figure 8.

As an example of the pilot measurements in Sodankylä, the data throughput estimation measurements conducted between combined RWS/RSU and passing vehicle are presented in the Figures 9 and 10. In this measurement the focus was on the IEEE 802.11p based VANET (Vehicular Area Networking) communication, comparing it to the traditional Wi-Fi based communication in the same environment and conditions (based on IEEE 802.11g standard). On the RWS/RSU side the host computer located in the station was employed to broadcast data for the passing 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. Figure 9 presents the results with

80 km/h vehicle speed, Figure 10 results with 100 km/h, respectively. The green colored line is the Wi-Fi measurement average and the lighter green lines are the Wi-Fi measurements. Similarly the solid orange is the IEEE 802.11p average measurement and the lighter orange are the measurements.

It can be seen that in both speeds the communication window is rather harmonized with IEEE 802.11p, obviously faster 100 km/h speed resulting as shorter communication window. The cumulative average throughput during the communication window for 802.11p was 467 Mb in tests with 80 km/h vehicle speed and 382 Mb with 100 km/h speed. In additional singular test with larger antennas clearly better performance was achieved in terms of range and cumulative throughput. The cumulative average throughput for Wi-Fi communications had a larger fluctuation than the IEEE 802.11p measurements, but the window for 80 km/h Wi-Fi was 602 Mb and 488 Mb for 100 km/h. The predictable performance of 802.11p is more important advantage compared to smaller absolute capacity. Nevertheless, the size of the communication window in all the measurements is clearly large enough for supporting our combined RWS/RSU scenario. The details of the measurements, analysis as well as architecture deployment strategies based on the results are presented in Sukuvaara (2009), Sukuvaara (2013), Sukuvaara et. al. (2015) and Sukuvaara (2015).

5 Conclusions

This paper has been introducing the research work related vehicular networking and road weather services conducted in Sodankylä, binded to our concept of interactive road weather station as a service hotspot road weather services and data collection. FMI's combined Road Weather Station (RWS)/Road Side Unit (RSU) is acting as a central infrastructural element of such V2V and V2I communication platform, supported with areal infrastructure and observing vehicles. The aim is to employ road weather systems of FMI, RWS data as well as the data gathered from vehicles, into the up-to-date localized weather data delivered to the vehicles in real-time. IEEE 802.11p based vehicular networking is the primary channel, supported with parallel traditional Wi-Fi and 3G communications. In the future, 4G and 5G communication will be employed and tested as well.

Our research shows that our approach of hybrid communication offers considerable approach for serving vehicles with real-time weather and traffic information. An extensive set of road weather measurements has also been conducted, to be exploited as part of road weather services of FMI as well part of vehicular networking research. Detailed and more specific data contents with local area weather data can be delivered to vehicles in service hotspots located beside road. Whenever outside the range of any RWS, 3G cellular data ensures that the most critical information related to weather and traffic is always up to date. As a summary, our approach of combined RWS/RSU represents our imagination of merging modern road weather services and vehicular intelligence, and stands for respectable test bed for the future road weather and networking services as well.

FMI's combined Road Weather Station (RWS)/Road Side Unit (RSU) in Sodankylä is the unique research platform combining very advanced road weather measurements with versatile collection of the most common wireless communication methodologies used in vehicular environment. Together with harsh, arctic road weather conditions it represents incomparable development environment and pilot RWS station within the field of ITS (Intelligent Transport Systems) and vehicular networking.

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Figure 1. Combined RWS/RSU-system.

Parameter	Sensor	Measurement height/depth	Measurement period
Temperature	PT100	2 m	Oct. 2011 →
Humidity	HMP45D	2 m	Oct. 2011 →
Wind speed and direction	Thies Clima 2D Ultrasonic Anemometer	6.5 m	Oct. 2011 →
Soil moisture profile	Stevens Hydra Probe II	-1,-5,-10,-20,-30,-50,-100,-200,-300 cm	Oct. 2011 →
Soil temperature profile	Stevens Hydra Probe II	-1,-5,-10,-20,-30,-50,-100,-200,-300 cm	Oct. 2011 →
Present weather and visibility	Vaisala PWD22	2.4 m (Oct. 2012 - 7.9.2012: 2.6 m)	Oct. 2011 →
Road weather camera	Axis 221 camera		Oct. 2011 – Oct. 2013
Road surface state (remote)	Vaisala DSC111		Nov. 2012 →
Road surface temperature (remote)	Vaisala DST111		Nov. 2012 →
Road surface state and temperature	Vaisala DRS511	0 cm	Sept. 2012 →
Wind speed and direction	Vaisala WA15	6.3 m	Nov. 2012 →
Air humidity	Vaisala HMP155	4.5 m	Sept. 2012 →
Air temperature	Vaisala HMP155	4.5 m	Sept. 2012 →
Soil temperature	Vaisala DTS12	-40 cm	Sept. 2012 →
Present weather and visibility	Vaisala PWD22	6 m	Sept. 2012 →
Infrared camera	Zavio B7210 Full HD		Nov. 2012 →
Soil temperature profile	LISTEC SEC 15 d-LIST Sensor	0-3m	Nov. 2013 →

Figure 2. Collection of RWS measurements

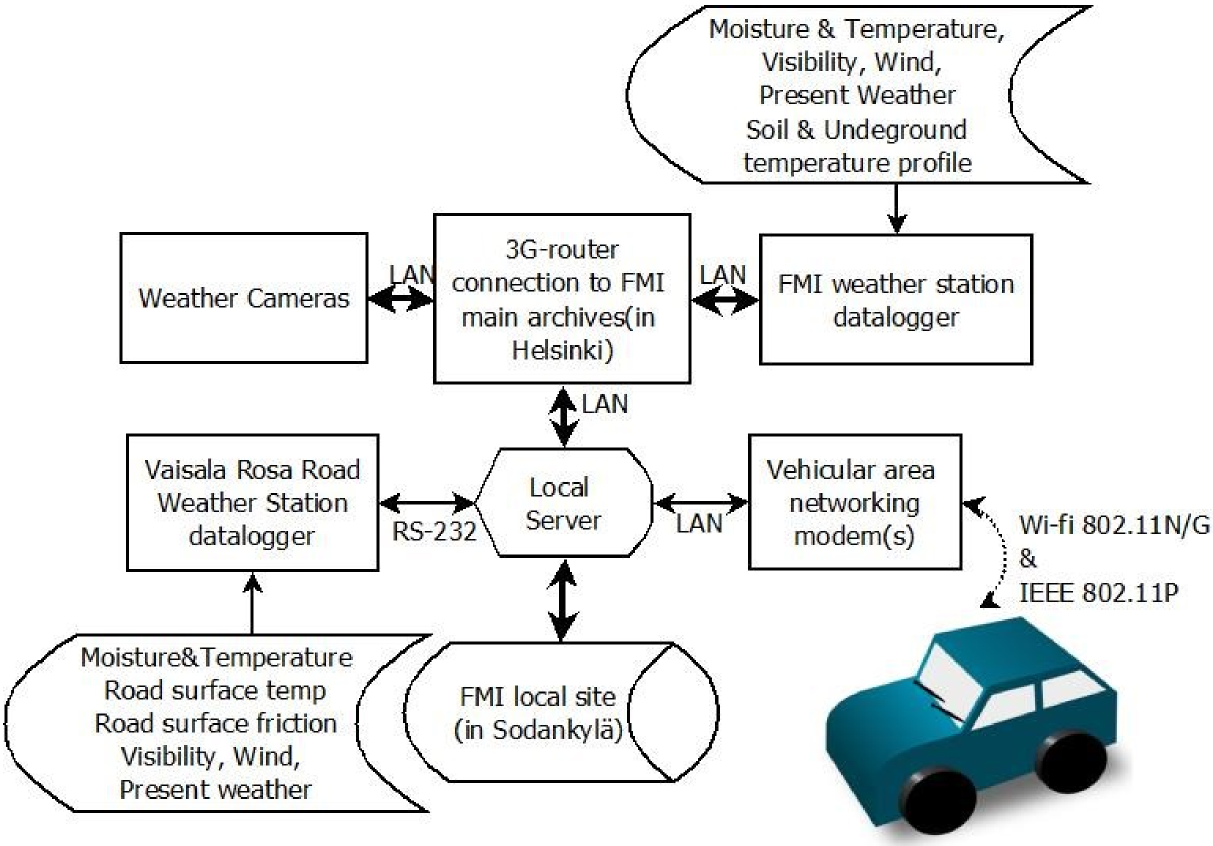

Figure 3. Communication entity of RWS/RSU.

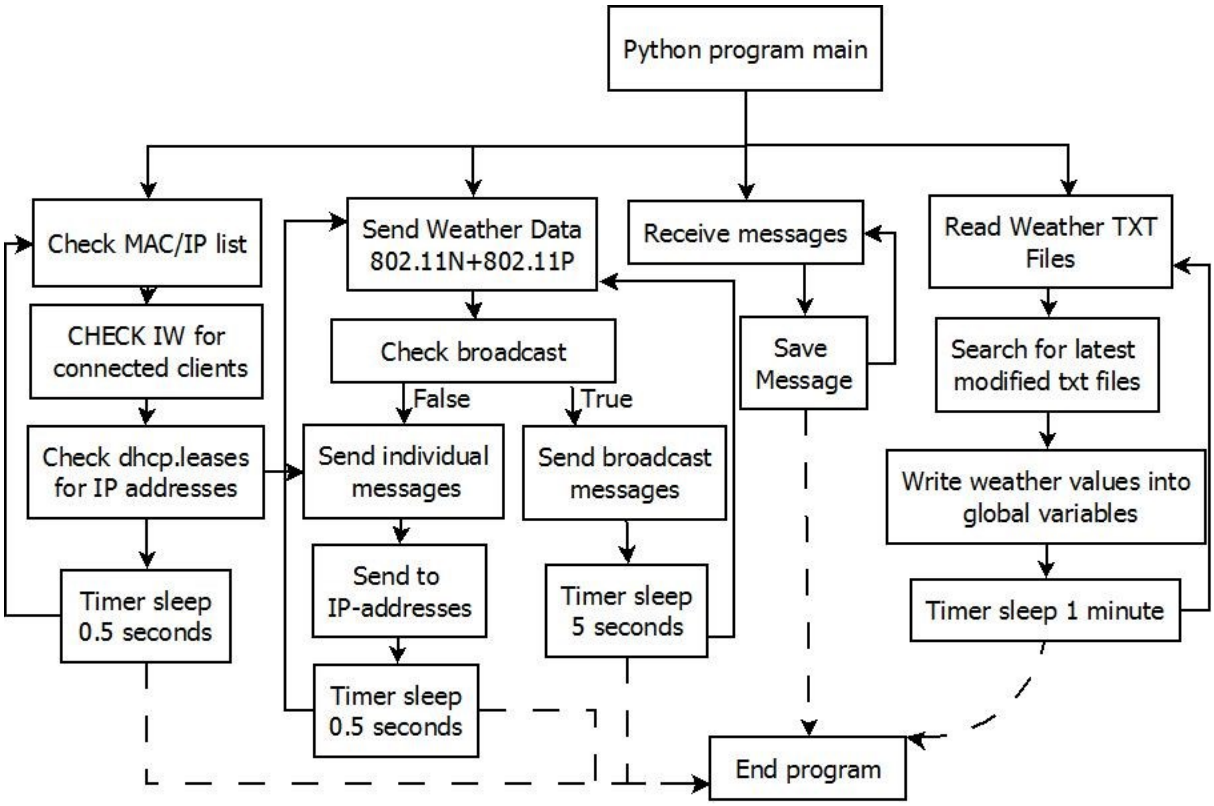

Figure 4. Operational process in RWS/RSU.

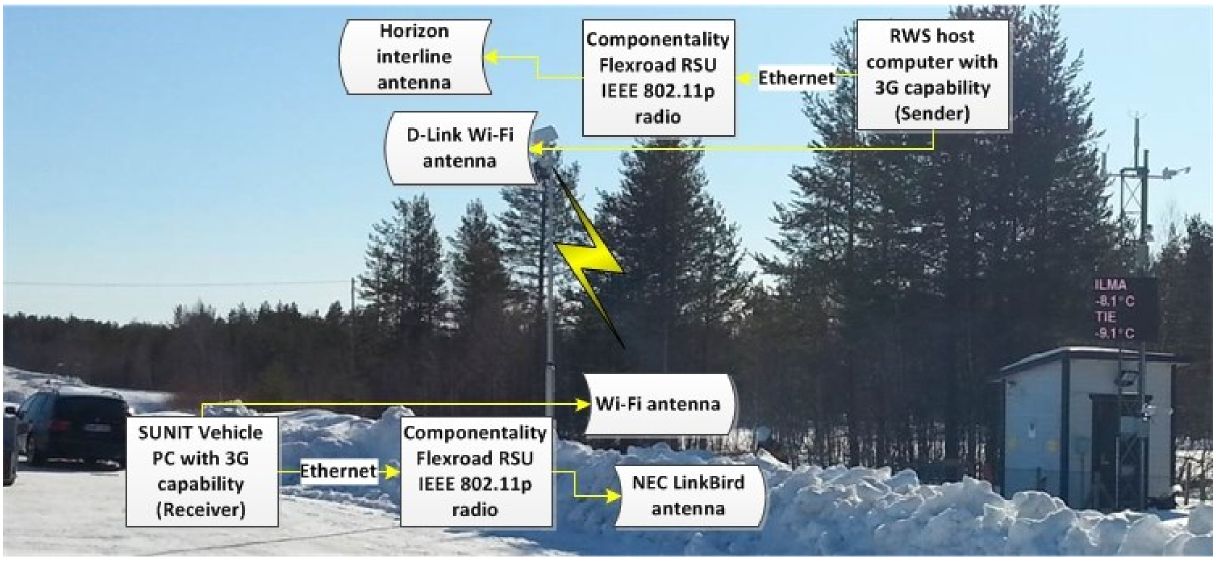

Figure 5. Devices and their connections in IEEE 802.11p communication.

Figure 6. -Teconer friction measurement instrument mounted into the vehicle.

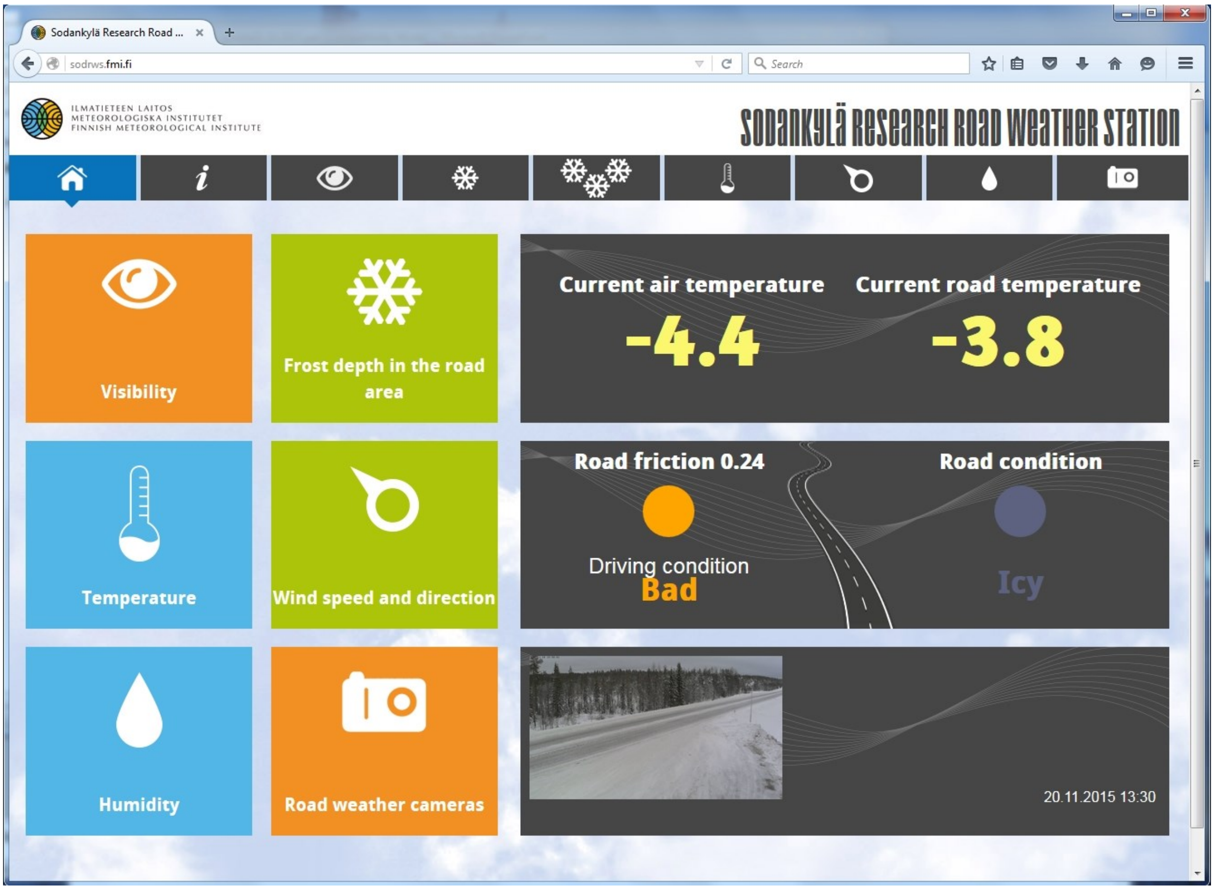

Figure 7. Road weather station website at http://sodrws.fmi.fi.

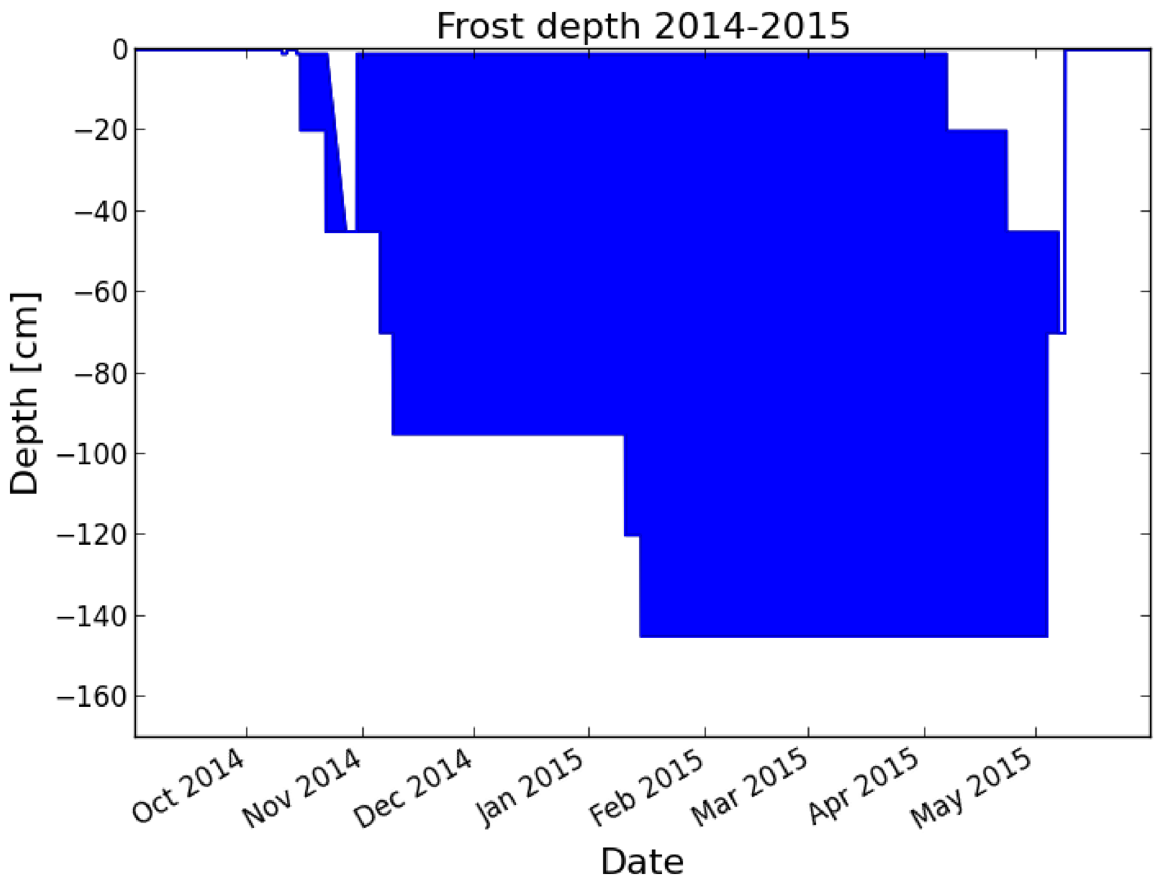

Figure 8. Frost depth data from the RWS measurements

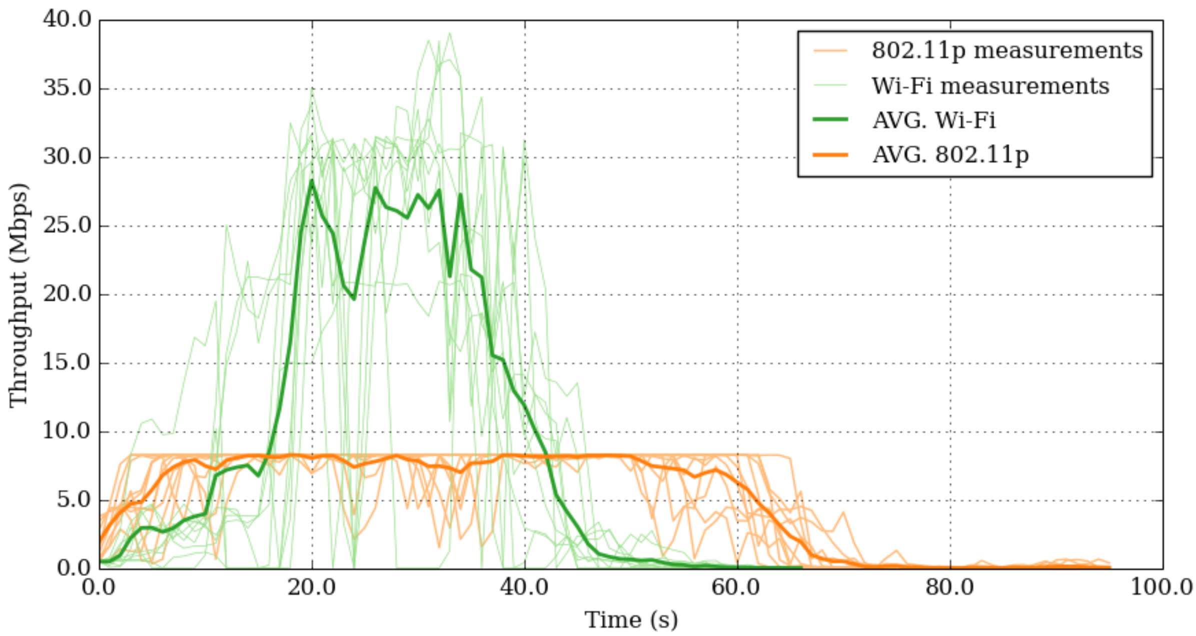

Figure 9. Data throughput from combined RWS/RSU to vehicle with 80 km/h speed.

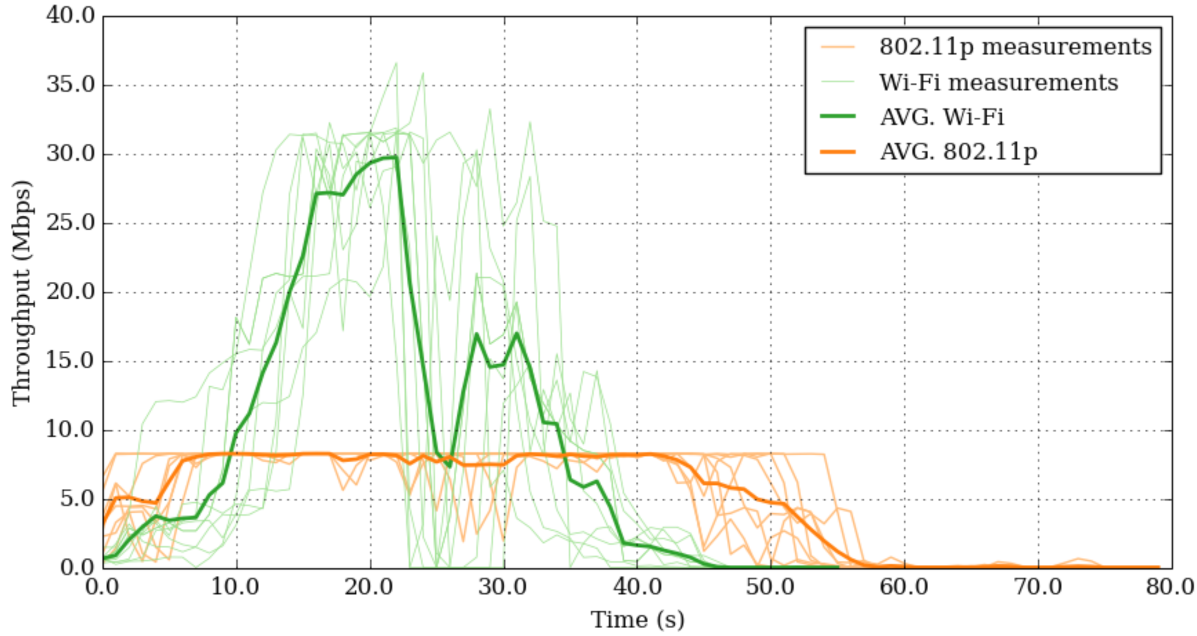

Figure 10. Data throughput from combined RWS/RSU to vehicle with 100 km/h speed.