Vehicular Networking Road Weather Information System Tailored for Arctic Winter Conditions

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Abstract: Winter conditions are dominating the road traffic platform in the Northern Scandinavia, and the weather services play an important role in successful winter road traffic operations. Intelligent Road project is contributing towards tackling this challenge and aims to support the development of business community in Northern Scandinavian region by road safety provision via vehicular networking based services in Nordic weather conditions. FMI's combined Road Weather Station (RWS)/Road Side Unit (RSU) is acting as a central infrastructural element of such vehicle-to-vehicle and vehicle-to-infrastructure communication platform, supported with areal infrastructure and third party vehicles equipped with weather measurement and communication infrastructure. The aim is to employ road weather systems of FMI and furthermore exploit RWS data as well as the data gathered from vehicle instrumentation. The resulting up-to-date and localized weather data is then delivered to the stakeholders, tourists and even the vehicles in the operating area in real-time. IEEE 802.11p based vehicular networking is the primary communication channel, supported with traditional Wi-Fi and 3G communications.

Keywords: VANET, IEEE 802.11p, road weather, road weather station, road safety, ITS.

1. Introduction

European Union Interreg IV A Nord program's Intelligent Road [1] is a project aiming at increasing safety of the arctic roads in Northern Scandinavia. By using the innovative technology of the northern businesses, Intelligent Road presents a system that can provide road-users with short-term road weather information data. The testing and system implementation is carried out by combining the exclusive arctic know-how and testing conditions of the project partners in Finland and Sweden. In this paper we present common work of FMI (Finnish Meteorological Institute) and Lapland UAS (Lapland University of Applied Sciences) in creating the service concept, service demonstration and communication field tests of such a system in Northern Finland. An essential part of the project development and field testing was conducted by our third main partner Luleå Technical University (LTU), but in this paper we limit the focus for the work conducted in Northern Finland. Vehicular networking has an essential role, as the rapidly changing road weather and road surface condition data needs to be collected, combined and delivered back to vehicles and road users as rapidly as possible. According to our studies in the Intelligent Road project, even 87% (n=217) of local everyday road-users rate it important to receive real-time road weather and road condition information while driving. The most crucial pieces of information are the status of the

road surface, winter maintenance status and slipperiness information, preferably communicated through a smart phone application, variable message sign or a navigator system add-on [2]. Finland is an arctic country and Lapland in Northern Finland is its northernmost, and most the arctic, region. Arctic winter conditions create challenges in road transport. The Figure 1 shows that between 2004 and 2006, Lapland has had slushy or icy road conditions in 92% of the traffic accidents which have had damages, injuries or fatalities. This percentage was notably the highest in Lapland when comparing all road maintenance areas in Finland. In fact, due to the changing climate, freezing rain in the northernmost parts of Finland is even expected to increase and it will create even more treacherous road conditions in the future [4].These treacherous conditions result into incidents on the roads. In Finland in 2004, a head-on collision, involving a heavy vehicle combination and charter coach, resulted in 22 passengers perished. The location had very low local friction [5].
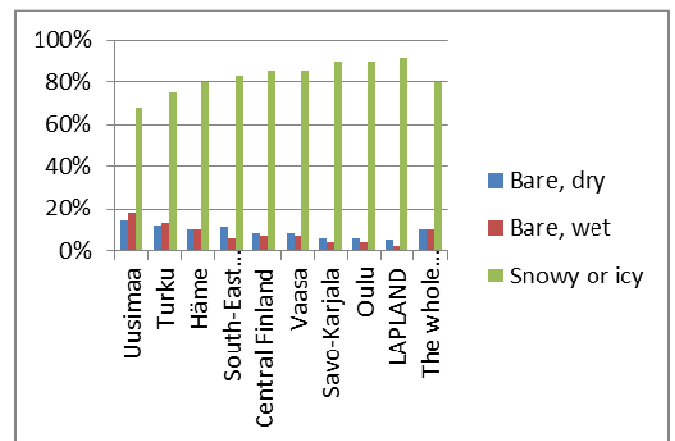

Figure 1. Distribution of road conditions in traffic incidents in Finland among road maintenance areas in years 2004-2006. Modified from the original source [3].

Tailoring the Intelligent Road system to the arctic winter conditions means that the road-users are able to receive f.ex. local and high-resolution road condition warnings to avoid accidents. Currently, the areal weather information or in-vehicle ambient temperature measurements are insufficient especially when delivering accurate surface condition information to road-users. 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).

2. Related work

In the field of wireless telecommunications the main standard approach followed worldwide has been IEEE 802.11 standard family, containing IEEE 802.11a approach for 5.8 GHz wireless networking and popular Wireless Fidelity (Wi-Fi) standards IEEE 802.11 b/g/n. 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. Wireless Access to Vehicular Environment (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. Either 10 MHz or 20 MHz channel bandwidth can be chosen [6],[7].

Vehicle-to-Infrastructure communication means a Vehicular ad-hoc network (VANET) created between moving vehicles and a static infrastructure beside the road. V2I communication is usually employed to deliver information from road operators or authorities to the vehicles. Roadwork warning is a typical example of a V2I service; vehicular access network transceivers are deployed into the roadwork area, informing the vehicles approaching the area about the exceptional road operability. One particularly important advance is the ability for traffic signal systems to communicate the signal phase and timing (SPAT) information to the vehicle in support of delivering active safety advisories and warnings to drivers. One approach for traffic-light optimizing is the Shortest-Path-Based Traffic-Light-Aware Routing (STAR) protocol for VANETs [8]. Both of these services are broadcast-type, lacking the use of an uplink channel. On the contrary, the RSU with a road weather station employed in [9] not only delivers the weather and warning data for the passing vehicles, but also gathers the weather and safety related observations from the vehicles to further update the data.

V2I communication has certain similarities to a wireless link between the mobile node and access point in a traditional wireless network. Just as an access point, RSU is a static element within moving vehicles, like the mobile nodes in a traditional wireless network. Due to its fixed nature, RSU possesses superior resources in terms of signal strength and therefore data capacity, just like access point. However, due to the temporary nature of V2I communication, RSU cannot provide continuous backbone network connectivity for the vehicles. Instead, RSU can merely act as service hotspot, delivering a pre-configured high-band service data exchange between the vehicle and fixed network whenever in the vicinity area of an RSU. One example of such a data dissemination network is introduced in [10].

The V2V communication approach is mostly suited for short-range vehicular communications. The general idea is that moving vehicles create a wireless communication network between each other, in an ad-hoc networking manner and on a highly opportunistic basis. The communication architecture is distributed, as individual vehicles are communicating equally, in an ad-hoc manner. The data exchange between passing vehicles is typically of the unicast type, but also multicast (for example in case of a platoon of vehicles exchanging traffic information) and broadcast (in the case of accident warnings) transmissions are employed. A pure V2V network does not need any roadside infrastructure. Therefore it is the primary communication candidate for real time safety applications in vehicles. One of the key motivations for V2V communications is the opportunity to enable cooperative vehicle safety applications that will be able to prevent crashes [11],[12].

Similar types of field measurements as presented in this paper have been conducted widely. In [13] authors present very comprehensive series of empirical experiments and analysis of DSRC characteristics under freeway, rural, suburban and open field environments. Combined DSRC-compatible radio and GPS-receiver with embedded DSRC protocol stack and some applications were deployed into the fleet of 3 vehicles and huge amount of measurements observing data rate, RSSI, DSRC reliability etc. were conducted.

The authors of [14] have constructed a real-word testbed for research and development in vehicular networking with DSRC (IEEE 802.11p), Wi-Fi (IEEE 802.11 a/b/g/n) and cellular interface (3G/4G), respectively.

In [15] the field measurement equipment was closely related to ours. NEC Linkbird-MX v3 units were deployed to four vehicles, to generate IEEE 802.11p beaconing service (by two vehicles) and the receivers (two other vehicles). In two very long measurements (1260 km per vehicle) campaigns they measured packet delivery rate and packet inter-reception, with small 100B payload. Some of the authors of this work have been conducting similar kind of measurements presented in [16] and [17]. Older work worth mentioning can be found from [18] which is also closely related to this work. These measurements were conducted using older IEEE 802.11a protocol modified to emulate DSRC standard. Furthermore, the DOME test-bed [19] was in operation for more than 5 years, providing multi-standard vehicular communication system using Wi-Fi standards,

GPRS and 3G combined together. For further reading, a brief survey of vehicular networking platforms is presented in [20], and more comprehensive one from [11], respectively.

The routing between vehicular network nodes is typically arranged in contention basis, simply letting the first node to be served first, with no limitations. More intelligent resource sharing can be employed, like the overhead-controlled contention based routing [21], or some of the variety of general wireless ad-hoc network protocols, introduced in [22]. In this work, we are focusing on one-hop wireless network distance, and therefore are not employing any particular routing method.

3. Intelligent Road objectives and service structure

Intelligent Road is exploiting vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), vehicle-to-cloud (V2C) and their combination, but the main focus is on V2I communication. The general idea of communication system is presented in the Figure 2, based on the automotive network domain presented in [6]. The in-vehicle shortest range of communication emerges in in-vehicle communication, where the wireless devices inside the vehicle form the network. In our work we use in-vehicle communication only to pass information between our sensors and host vehicle computer/device. Vehicle-to-vehicle communication consist of data exchange with passing vehicle, networking between vehicles travelling in the same direction and emergency data broadcasting to the other vehicles nearby. In this work, we only consider the measurement data exchange between vehicles. Additionally, vehicle-to-infrastructure communications employs the roadside infrastructure for data exchange and networking with the car. The roadside infrastructure usually has a permanent link to the fixed network, hypothetically allowing Internet connectivity at least on a temporary basis. Vehicle data is gathered into the combined road side units or our special combined road weather station and road side unit, while the up-to-date (weather oriented) service data is delivered into the opposite direction, respectively. A vehicle can also have a direct connection to the fixed network infrastructure through cellular network systems (typically mobile phone networks) allowing continuous connectivity. We are employing 3G communication for this purpose.
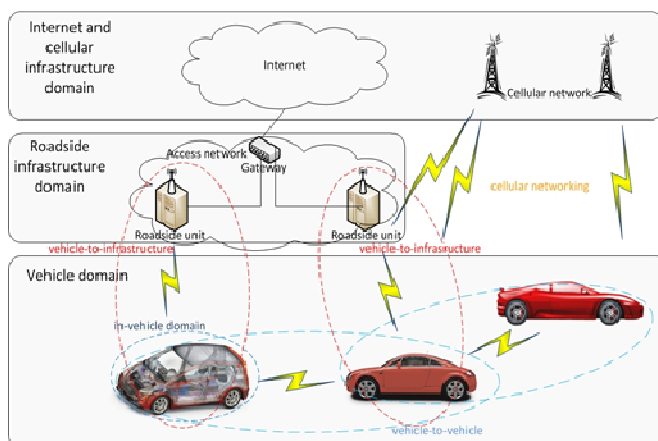
Combining these different networking types (excluding in-car communication) into a single architecture is one of the key objectives in this work. As the focus is on local weather services, road weather stations are essential and especially our concept of the combined road weather station and roadside unit (RWS/RSU) is the key data source, together with public road weather stations in the surrounding area (equipped with somewhat lighter instrumentation). FMI meteorological systems obviously draw the large scale meteorological data, but instrumentation within the road infrastructure is used to bring more local perspective. Furthermore, the vehicles themselves are also employed in data sensing process. Due to the tight restrictions for accessing vehicle internal data, we have only been able to achieve the temperature information from an ordinary car so far. However, we have implemented special instrumentation for on-board friction and road condition measurements in several vehicles. We have envisioned that a special road stretch can be appropriately monitored with underlying meteorological system supplemented with few RWS stations (our RWS/RSU and few general RWS) and several vehicle units providing additional in-situ road surface data. In order to fully exploit the local real-time information, the resulting service data also needs to be delivered directly and instantly into the vehicles travelling in the area. Therefore, we also need to employ vehicular networking between the vehicles and roadside infrastructure. As the density of RWS stations is expected to be rather low, we must employ supplemental 3G cellular network communication. Combined RWS/RSU is our service hotspot, allowing delivery of all the road weather data and related material during the bypass. Elsewhere, we only deliver the critical supplemental weather data elements to the vehicles, with lower capacity allowed by 3G, but with wide coverage within our road stretch. The vehicle bypassing 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. The communication system is presented in the Figure 3. IEEE 802.11p is the primary communication protocol, but also the traditional Wi-Fi communication is supported. The RWS/RSU is linked with IEEE 802.11p for communication attempting, but it has also internal Wi-Fi modem, and both of these communication channels are actively seeking the bypassing vehicle communication systems.
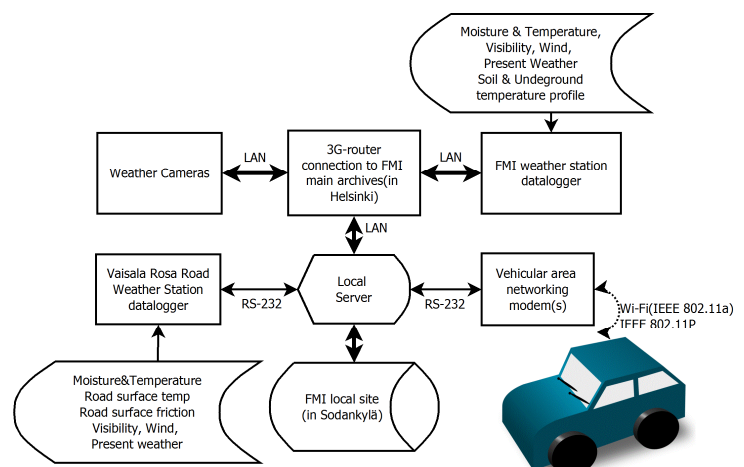

Figure 2. Vehicular networking entity.

Figure 3. Overview of RWS/RSU.

The IEEE 802.11p communication is the primary channel, and whenever it is not available the Wi-Fi is activated. Eventually when the vehicle fails to achieve data with 802.11p and Wi-Fi, it will use 3G cellular link to fetch the up-to-date data from the nearest RWS in pre-defined intervals. The data measured in the RWS/RSU (Vaisala Rosa RWS data in parallel with FMI weather station data and weather camera data, all of them collected to local server), together with vehicle-oriented data (also stored in local server) 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. We have also deployed the customer devices into few busses and taxis, so the public transport passengers will also be able to browse the service data. More detailed information about the communication system can be found from [24] and [12].

4. In-vehicle data acquisition

Vehicles have been used in the Intelligent Road project as a moving measurement platform equipped with various sensors to monitor road condition related information. It was one of the project requirements to find a way to gather and forward this measurement data to use it in other systems and applications and to make it available for the road users.

The in-vehicle data acquisition (DAQ) system described in the Figure 4 has been designed and developed by Lapland UAS Arctic Power research unit in the Intelligent Road project to collect, process, transmit and receive real-time data. The heart of the system is ConnectPort X5, a rugged IP67-class remote telemetry device with wide operating temperature enabling it to function in arctic conditions. It has several interfaces to connect sensors and measurement instruments. These interfaces are CAN, RS-232, Ethernet, Wi-Fi, XBee, GPRS, GPS and digital I/O. There are also additional modules connected to the DAQ to provide analog I/O and IEEE 802.11p interfaces. The X5 also features a 3-axis accelerometer enabling accident condition alarming. The X5 is fully programmable in Python and it can be updated over- the-air (OTA) making it adaptable for different measurement scenarios. The OTA capabilities along with sophisticated cloud-based management software, makes it possible to easily maintain a large fleet of probe cars equipped with DAQ systems.
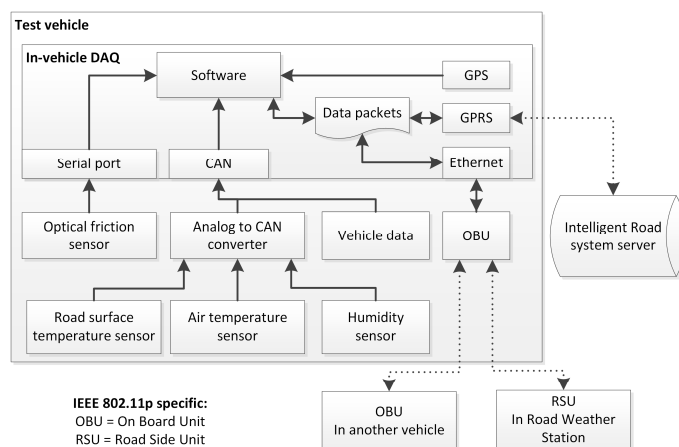

Figure 4. Description of the in-vehicle DAQ system setup.

The management software also displays real-time information of the health of the fleet DAQs including battery voltage, temperature and CPU along with several other parameters.

The main data sources of the DAQ are friction measurement devices such as Teconer RCM411, Road eye and Halliday RT3 Curve. These devices measure road friction, road surface condition, road surface temperature and other related parameters. The X5 is also able to read probe vehicle's CAN-bus enabling acquisition of additional data from the vehicle's sensors.

All of the data DAQ acquires is time and GPS stamped and transferred to the Intelligent Road main server for further processing and visualization. The DAQ software is programmed to use a tailored data format in server communication. If the network connection to the server is unavailable, the software has a circular buffer to keep the measurement values until connection to the server can be re-established. The values are also kept in buffer in case the server is not responding for some reason. Each data packet is coded with identifier fields enabling IR-server to recognize the data source and type.   If a sensor or device is malfunctioning, the DAQ software notices it and replaces their measured values with error flag values before sending. The IR-server receives these data packets with error values normally but doesn't visualize them. The error values are stored for debugging and maintenance purposes.

Each friction sensor is sampling multiple times per second up to 100Hz of Halliday RT3 Curve used in LTU's research vehicle. The running averages of the measurement values are calculated and sent to the IR-server to be processed further, stored and visualized. For Road eye data, it is also possible to use a road surface condition algorithm developed by LTU [24] to enhance the accuracy of the Road eye sensor.

The main difference between these sensors is the measurement technique as both RCM411 and Road eye are optical sensors sensitive in NIR-wavelengths while RT3 is a traditional tire-road friction measurement device. The principles to determine the road surface condition using NIR-spectroscopy is discussed in [25].

Probe vehicle's V2X communication is possible using the DAQ's Ethernet to interface with IEEE 802.11p compatible networking device (OBU). Acquired data can be broadcasted in real-time to the 802.11p network. This method can also be used in the implementation of the previously envisioned special road stretch to provide in-situ data from the vehicle to the RWS/RSU stations and other vehicles.

The in-vehicle DAQ's Wi-Fi interface enables local information and monitoring systems. One such application called IR Mobile has been developed by Lapland UAS in the Intelligent Road project to display real-time in-vehicle data from DAQ to the driver using Android tablet. The IR Mobile app communicates also, via cellular network, with the IR-server to receive latest data of the surrounding area. This feature enables the use of the app in every vehicle, not only in the probe car with WiFi and DAQ installed. The app has similar visualization functionality as described later in the chapter V. In addition it is capable of updating the route and map view while driving and alarming the driver using geofencing when the car is entering an area with bad road conditions.

5. Data visualization

Data visualization, developed by Lapland UAS Software Engineering Laboratory, combines several data sources into one visual presentation of the data. When the data is sent to the server, it is immediately available to be visualized on the map or as tabular data. The weather data from road weather stations is visualized on a map as weather station markers and user can view the detailed data by clicking the marker location. This data is updated every 20 minutes. FMI road weather forecast is updated every 30 minutes. The weather forecast is visualized as three different states depending on the friction. Third data type is the road condition data from moving vehicles which is delivered to the server to store all the gathered information. The road condition data is then visualized on a map layer based on the GPS coordinates of the data and the time when the data is collected. From the road condition data, the determined condition (wet, slush, ice etc.) and friction value can be visualized on the map.

When visualizing large amounts of data on an internet browser, there are some limitations to consider. Large amounts of data causes the browser application performance to decrease. To reduce the data sent to the browser, there are some optimization algorithms implemented. First objective is to get rid of repetitive and unnecessary data, for example when vehicle is not moving by checking if the vehicle has not moved enough and if the data value is the same as previous data.

Second optimization is used when the vehicle is driving on a road and the data value is not changed. If the road is straight enough and the road condition does not change, that part of road can be visualized with only two data points. This method is based on the deviation and distance from the last accepted data point and the road condition data analyzed from the road surface. When the data point is far enough from the previous accepted data point or far enough from the middle of the road, a new data point is added to the optimized data set. In most cases this optimization can be made real time when the browser application requests the
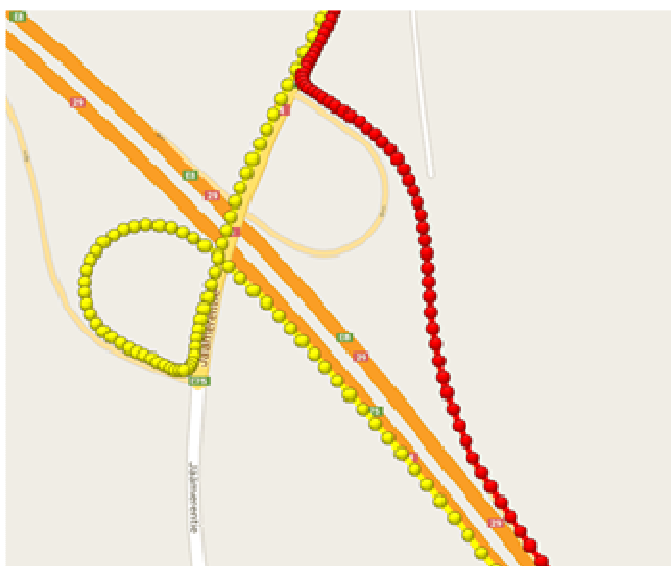

Figure 5. Raw surface condition data without optimization visualized on the map.
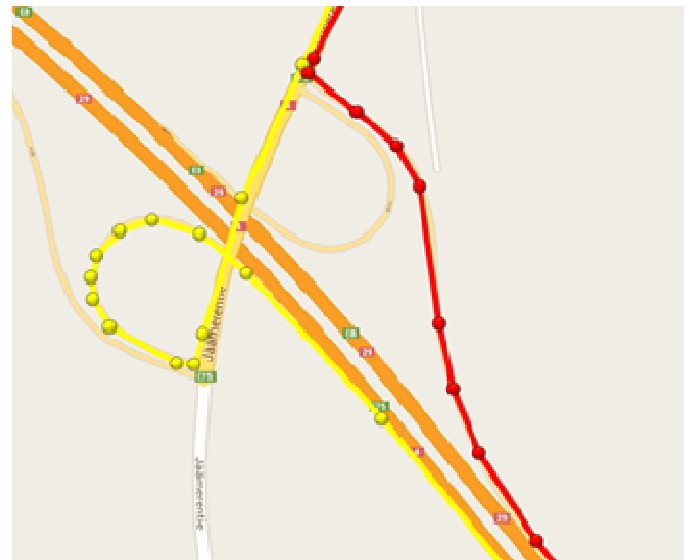

Figure 6. Optimized data visualized on the map.

data for a certain area. Figures 5 and 6 demonstrate the difference in the amount of data points before and after the optimization. By optimizing data the visualization can be drawn much faster on the browser. If a user wants to view all of the data, browser interface has an option to view all of it without optimization. In the case described in the Figures 5 and 6, the data sent to the browser is reduced by about 85%. To further optimize the data visualization speed, some experiments with open Finnish road network data have been made. By using open data of all roads in Finland we could create persistent locations for the data and then map the collected data to these predefined locations. However this way of saving the data was quite slow because of the geospatial mapping of the data points. Also the visualization speed was slower.

6. Communication system field test

In order to ensure the general operability of the vehicular networking system, we needed to conduct a series of test measurements. The measurement procedures were adapted from the earlier VANET field tests conducted in Sodankylä [16]. The main focus was on V2I communication testing, as this scenario mainly employs the combined RWS/RSU and general RSUs, but also the V2V scenario was set under the communication testing. The main focus in the test measurements was to find general capacity limitations for the V2I communication system, with V2V extension as an extension option. The underlying operative environment is based on the model presented in Figure 2; Vehicles exchange data with RSU during the bypass or whenever in communication range with it, and the vehicle can further deliver the service data achieved from RSU for the vehicles it meets outside the range of RSU. The capacity was estimated in terms of linear data throughput and packet delay.

6.1 Vehicle-to-infrastructure

The V2I field tests were conducted both in Sodankylä and Rovaniemi. 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.

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. During the 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.

The general results of these measurements are viewed in the figures 7-10. Figure 7 presents the results with 60 km/h only conducted in Rovaniemi, Figure 10 results with 100 km/h only conducted in Sodankylä, and Figure 8-9 results with 80 km/h conducted in both places, respectively.
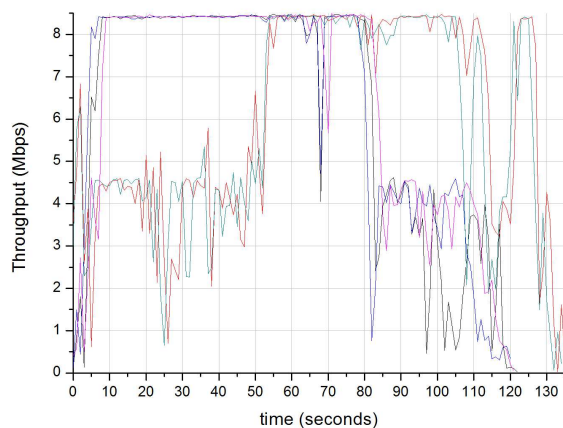

Figure 7. Data throughput from combined RSU to vehicle, bypassing the station with 60 km/h speed.

Figure 8 presents the Sodankylä measurements and Figure 9 Rovaniemi measurements. It can be seen that in both speeds the communication window is rather harmonized, obviously

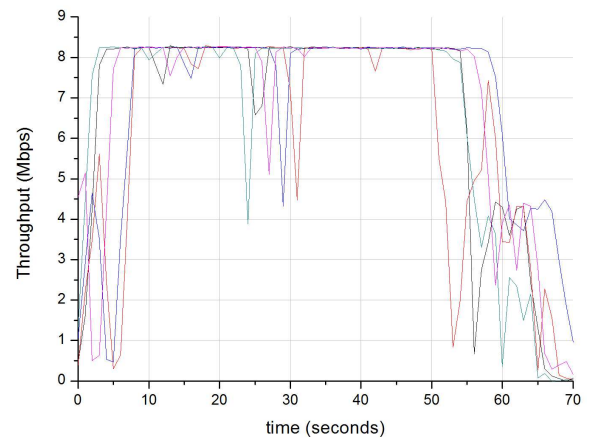faster 100 km/h speed resulting as shorter communication window.

Figure 8. Data throughput from combined RWS/RSU to vehicle in Sodankylä, bypassing the station with 80 km/h speed.

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.
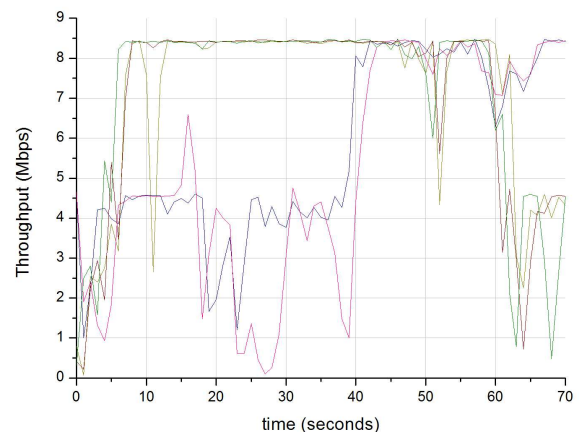

Figure 9. Data throughput from RSU to vehicle in Rovaniemi, bypassing the station with 80 km/h speed.

The cumulative average throughput during the communication window was 539 Mb in Rovaniemi tests with 80 km/h and 467 Mb in Sodankylä tests, respectively. In 60 km/h tests in Rovaniemi the average total throughput was 777 Mb and 382 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.
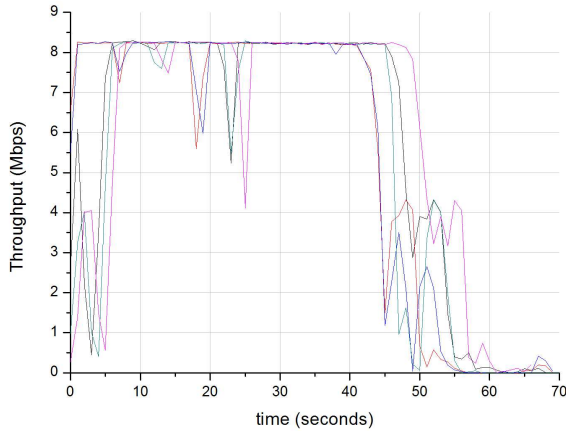

Figure 10. Data throughput from combined RWS/RSU to vehicle, bypassing the station with 100 km/h speed.

6.2 Vehicle-to-vehicle

In the Sodankylä 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.

The main results of these measurements are viewed in the figures 11-14. Again, Figure 11 presents the results with 60 km/h only conducted in Rovaniemi, Figure 14 results with 100 km/h only conducted in Sodankylä, and Figures 12-13 results with 80 km/h conducted in both places, respectively.
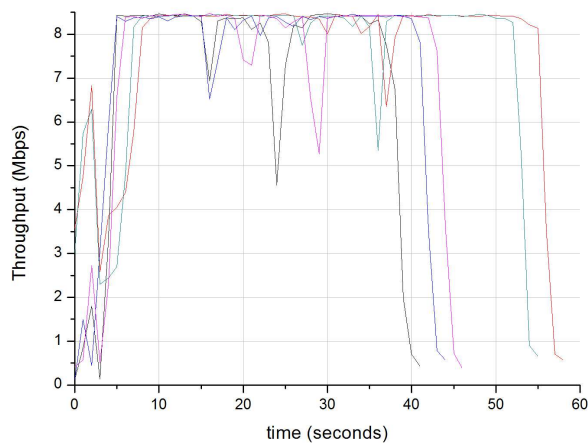

Figure 11. Data throughput in Rovaniemi V2V measurements with 60 km/h speed.

Figure 12 presents the Sodankylä measurements and Figure 13 Rovaniemi measurements. It can be seen that in V2V communication the connection window is anything but harmonized, lot of variation is occurring all the time in all kinds of 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

entity as unstable as possible, and minor effect 60 seconds, respectively.
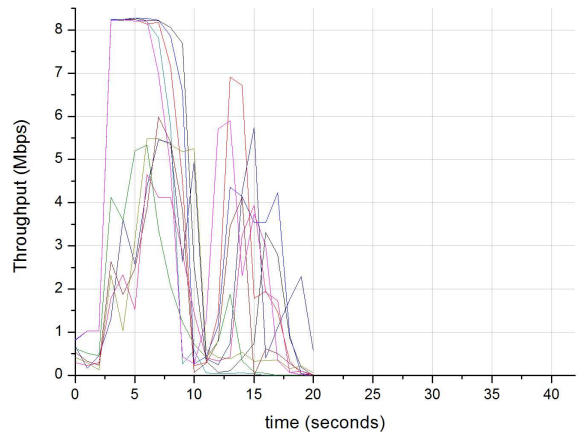

Figure 12. Data throughput in Sodankylä V2V measurements with 80 km/h speed.

The main reason for this behavior is unpleasant communication environment of two high-speed objects passing by each other, making the communication 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 Figures 12-13 where both Sodankylä and Rovaniemi measurements are presented in comparable manner, one can see clear difference between 10 Sodankylä measurements each shorter than 20 seconds and 5 Rovaniemi measurements, varying between 27 and 40 seconds, respectively.

The cumulative average throughput during the communication window of V2V measurements was 346 Mb with 60 km/h vehicle speeds, 122 Mb with 80 km/h speed, and 72 Mb with 100 km/h speed, respectively. 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.
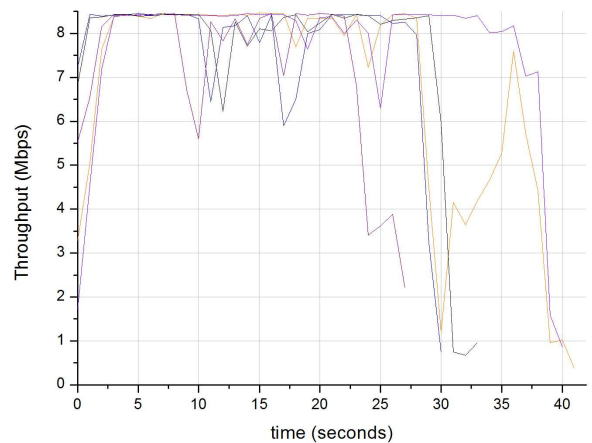

Figure 13. Data throughput in Rovaniemi V2V measurements with 80 km/h speed.
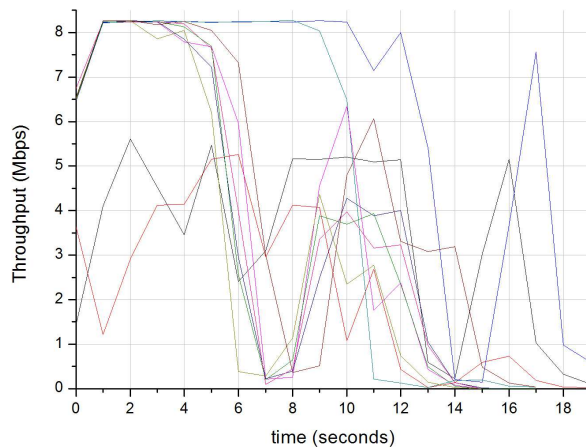
Figure 14. Data throughput in Sodankylä V2V measurements with 100 km/h speed.

7. Demonstration deployment and operation

To validate the Intelligent Road system it needed to be tested in real-life environments and in as many weather situations as possible. For that purpose, the Intelligent Road web service was constructed, to host the services and maintain the data gathered from different sources. The web service data consisted of Road eye (with Raytek MI) and Teconer RCM411 road condition, road friction and temperature monitors, Haliday RT3 Curve, tire to road friction measurement apparatus, Swedish VVIS RWS stations data, Finnish Digitraffic, RWS stations data and FMI Intelligent RWS data. The user services provided were FMI   road weather forecast in Finland and local weather forecast for the Luleå area, and real-time friction map.

The vehicle sensors were mounted on five different vehicles: three Kovalainen trucks, two equipped with Teconer RCM411 and RTS411 and one truck equipped with a Road eye sensor, travelling on the roads between Sodankylä-Rovaniemi-Oulu. One car was equipped with a Road eye sensor, and the other with a Road eye, Raytek MI, Teconer RCM411, Teconer RTS411, Haliday RT3 Curve and camera, both of them driving in the Luleå area. In addition to these permanent installations, FMI was conducting optical road condition monitoring in temporary basis with two additional road condition monitors, within the region of Sodankylä municipality and surrounding areas.

The web service construction and design details are presented in [1]. The service was constructed into public Internet location, and is still available in this location. The service operability was evaluated by the project partners, and with specific feedback questionnaire designed and requested from the project test users as well as independent users. Based on questionnaire data, the service was found useful, although many development needs and requirements were issued also. Based on the project team evaluation, the system was also found adequate for the specified need, especially if one takes into account the very limited resources we had available to pull out such a pilot system.

8. Conclusions

This paper presents the traffic service concept for Northern Scandinavia, developed in Intelligent Road project. The aim was to support the development of business community in Northern Scandinavian region by road safety provision via vehicular networking based services in Nordic weather conditions. The specific objective of the project was the demonstration of sustainable and marketable Intelligent Road System providing location-based short-term road weather information to the road user passing by the area. In this paper we have presented developed service concept and evaluated its general usability via IEEE 802.11p-based V2I and V2V communication field tests. Finally we have presented the demonstration deployment and operation of the concept system. Based on our analysis and evaluation, this service concept could be deployed to the Northern Scandinavia and in that position it would enhance traffic safety and benefit both professional road traffic as well as winter-time tourism around the North Finland and Sweden. In general it would generate added value in terms of safety and convenience in any geographical area experiencing harsh winter conditions.

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