Volvo Car Corporation

Enabling Technologies for Transport Efficiencies

Technical report

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Summary

ETTE was a collaboration project between the parts; Volvo Cars, AB Volvo, Actia, Smarteq and SP (SP Technical Research Institute of Sweden). The project was funded by FFI and run during the period from 2010-01-01 to 2013-09-15 with a total budget of 26,4 MSEK.

ETTE study make software implementation of dominant wireless technologies are IEEE 802.11(Wi-Fi) and 3G/LTE, where 802.11p is a “profile” of 802.11 for enabling cooperative intelligent transport system (C-ITS). As well as look in to establish a verification method development for this standards.

The work is planning to result in new functionality and services for after sales and product development that will come to a benefit for Volvo Cars and AB Volvo future customers. It is also an enabler to improve and rationalize product development for all partners.

The results have contributed in preparing the automotive business for the adoption to connectivity with a significant impact on participating parties' ability to understand automotive working environment. Knowledge not only regarding connectivity has been built up within the participating parties, also regarding electrical architecture. Knowledge invaluable for future work and collaboration. Team have done three video clip based on two defined usecase of 11p standard. There two vehicle communicate between each other over this standard.

This report will give an overview of all results and findings developed within the project.

Within project have publish three papers that have look in to repeatable, static validation method of 11p standard. One further paper is on the way out regarding antenna measurement between truck and car both active and passive measurement.

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1 Introduction

Nowadays communication is an important part of daily life, and customer expectation to be connected almost anywhere and anytime brings new challenges and new opportunities to vehicle manufacturers. On the other side the vehicle industry can use communication technology to make driving more pleasant, much safer and to seize opportunity for more aftermarket revenue.

Upcoming services in the connected car cannot be realized cost efficiently separately.

This will require a new approach; to create a cost effective platform the purpose of this project is to enable and verify synergies of the communications technologies within five areas:

• Service independent of the information carrier: a heuristic which optimizes resource efficiency with regards to factors such as reliability, capacity and payment model for different concurrent information carriers.

• Principles for antenna cluster integration in cars with regards to factors such as diversity, frequencies, and space constraints, while ensuring a basis for coexistence.

• Robustness towards interference between different communication paths for the current and future car communication solutions.

• Scalability and robustness of the combined system; concept where above areas utilizes each other's attributes, verification of the combined system.

• Integration of knowledge from above with car architecture.

The first function, as a result from this project, is plan to start to roll out from 2015 and forward.

1.1 Document purpose and structure

The intention with this document is to give the reader an overview of all activities and results performed within the project. It will also present information about what is left to do and interesting areas for further research.

The job has been divided in to seven different work packages. What was been done in these work packages are defined in the coming chapter "Work packages".

1.2 Background

Through Connected Vehicle by ETTE is should be possible to achieve new businesses and lower costs by providing new services, both for the end customer and for the internal organization. A key point to unlock this potential is to achieve a solution that cost efficiently integrates the wireless data transport of these services – and not looking at each service on its own. Looking at one of these services on its own the business case is not profitable for the foreseeable future. On the other hand, gathering the high number of services together, having them sharing their costs, utilizing the potential synergy between them, the complete business case instead will turn profitable.

Vehicles exchange information wirelessly to cooperatively avoid dangerous situations and enhance the overall road traffic situation, i.e., C-ITS. For example, the enormous accident that took place at *Tranarpsbron* outside Östra Ljungby, Sweden, in January this year could have been avoided or at least the damages could have been minimized if we already had C-ITS in place.

VCC and AB Volvo have signed a Memorandum of Understanding (MoU) with the OEMs within the Car-2-Car Communication Consortium (C2C-CC) to start deployment of C-ITS in 2015, among other OEMs.

In the VISAS project ACTIA (former Autoliv Connected Safety) together with VCC and Chalmers did study and developed safety and convenience services based on long and short range communication. The main focus for VISAS was the services while the focus for ETTE is the enabling technologies.

VCC, through different projects, working at different set parts of these services, and with the societal wireless services context, is at the threshold of providing the Connected Vehicle in a way that will achieve a new level of transport efficiency in the overall community:

- The SIGYN II project at VCC is studying security, safety, architectural and service aspects of the Connected Car for aftermarket and testing.
- The Next Generation Infotainment project (PLINTA) at VCC is among other infotainment related things handling in-car entertainment aspects of the Connected Car.
- Volvo Cars Customer Service is working on moving the VCC Web portal "Owner's Pages" to another level of amount of personalization with combined attributes unique to each specific end customer, aligning the development direction towards the vision of the Connected Car.

SP has together with e.g. VCC and AB Volvo been working with electromagnetic simulations and safe vehicle communication in PFF and IVSS projects. In a current project SP and among others Sony Ericsson is working with development of test methods and equipment for testing mobile phones in multipath environments (e.g. in cities).

Related to the subject of this project, AB Volvo has been involved as development partner in the following EU projects:

- Cooperative Vehicle-Infrastructure Systems (CVIS) (http://www.cvisproject.org/)
- SafeSopt (http://www.safespot-eu.org/)
- Pre-Drive C2X (http://www.pre-drive-c2x.eu/index.dhtml/344bf655821cc353880j/-/deDE/-/CS/-/) (See also description below in this chapter)

- EcoMove
- Freilot
- Sartre
- RelComH

The main goal for these projects is to provide a common communication and system platform (on-board and off-board) for improved transport efficiency.

1.3 ETTE objectives

The overall objective is to create a cost effective platform for connecting vehicles wirelessly through enabling synergies of the communications technologies within following areas:

- Having achieved a heuristic which optimizes resource efficiency with regards to factors such as reliability, capacity and payment model for different concurrent information carriers.
- Established principles for antenna cluster integration in vehicles with regards to factors such as diversity, frequencies, and space constraints, while ensuring a basis for coexistence.
- Robustness towards interference between different communication paths for the current and future vehicle communications solutions.
- Scalability and robustness of the combined system; concept where above areas utilizes each other's attributes. The combined system verified.
- Integrated knowledge from above with vehicle architecture.

This project aiming to demonstrate a complete system solution including antennas and telematics node in a vehicle, there two vehicle communicate between each.

1.4 Project organization

The ETTE project consisted of six partners; Volvo Car Corporation, AB Volvo, Actia Nordic AB, Smarteq Wireless and SP.

To fulfill the project goals described in the project application the project was divided into different work packages.

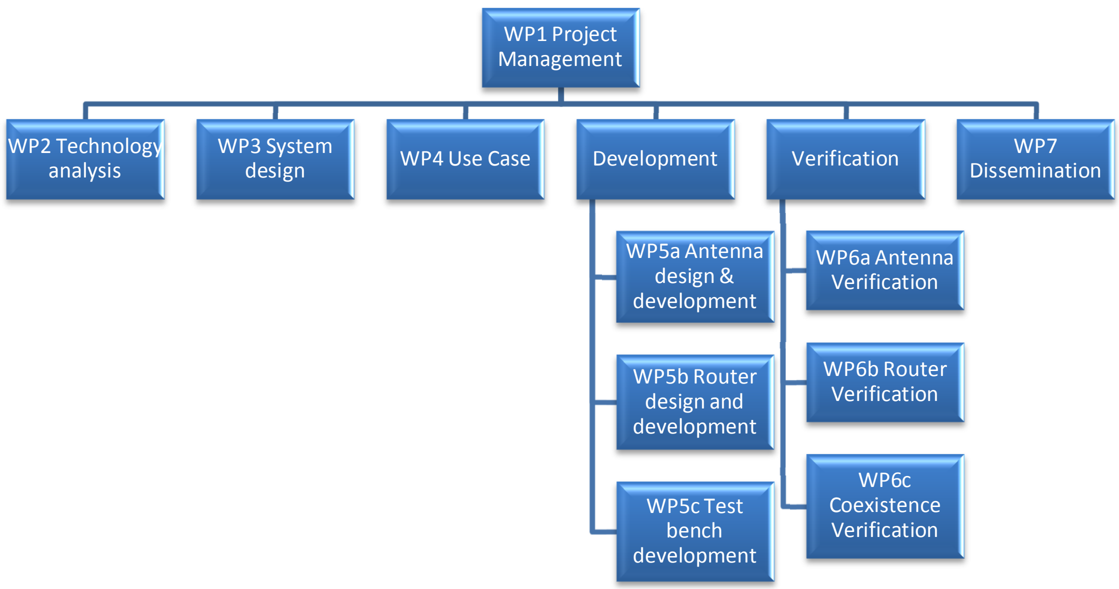

Figure 1: ETTE Project organization

The project manager has, on a regular basis had internal project meetings, reported progress and status to a steering committee consisting of members from each partner.

1.5 ETTE System overview

Principal installation in S60 car:

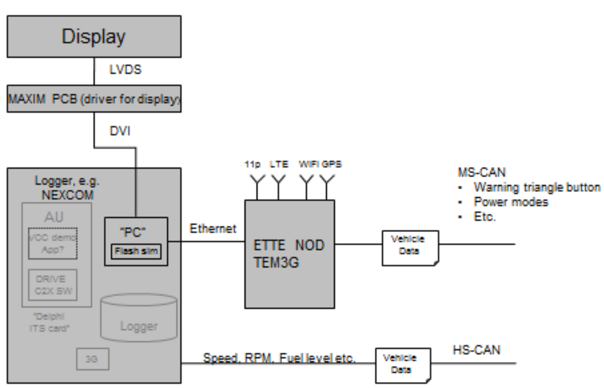

Figure 2: Car ETTE installation

Principal installation in FH truck:

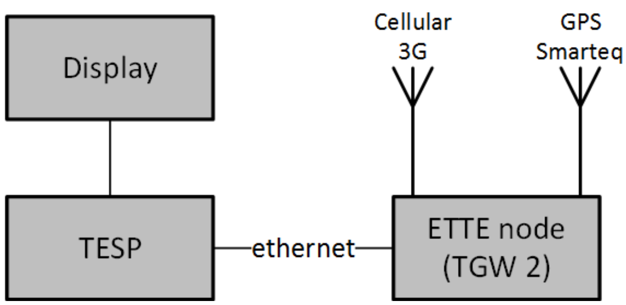

Figure 3: FH truck ETTE installation

2 Abbreviations

Abbreviation	Description
CAM	Cooperative Awareness Message
DENM	Decentralized Environmental Notification Message
ETTE	Enabling Technologies for Transport Efficiencies
ETSI	European Telecommunications Standards Institute
FMEA	Failure Mode and Efficient Analyze
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport Systems
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
PLINTA	Platform for safer INTegration
RSU	Rode Side Unit
SARTRE	Safe Road Trains for the Environment
SIGYN	Software In Global Yielding Network
SPA	Scalable Platform Architecture
TBD	To Be Defined
TBC	To Be Confirmed
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Vehicle/ Vehicle to Infrastructure
VCC	Volvo Car Corporation
VTEC	Volvo Technology
WP	Work Package

3 Work packages

Further description of each work packages and each objectives, activities and results.

3.1 WP1 Project management

3.1.1 Objectives

- To coordinate and administrate the complete ETTE project.
- Co-ordinate with other projects affecting or affected by ETTE
- Arrange project meetings.
- Report out technical status to steering committee meeting.
- Report out to Vinnova quality group.

3.1.2 Activities

The work within ETTE has been lead by the project manager to coordinated and synchronized time plans and activities between the work packages.

Regularly project meetings have been held with participants from all work packages both face to face and phone/ web conferences. The participants have varied during the project depending on the content of the different work packages for the time being.

Project status and results have been reported to the steering committee on a regular basis.

The work packages have been working for spreading project results. Project members have also participated at external conferences, both national and international.

Knowledge valuable for present vehicle project has continuously been handed over to respectively area of responsibility through participation in project meetings or workshops.

3.1.3 Method

Different methods have been used during the project depending on the art of the problem being studied. Each sub-project describes which methods that have been used within the different work packages. The development and implementation of the selected use cases have been performed iteratively within the ETTE project.

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3.1.4 Organization

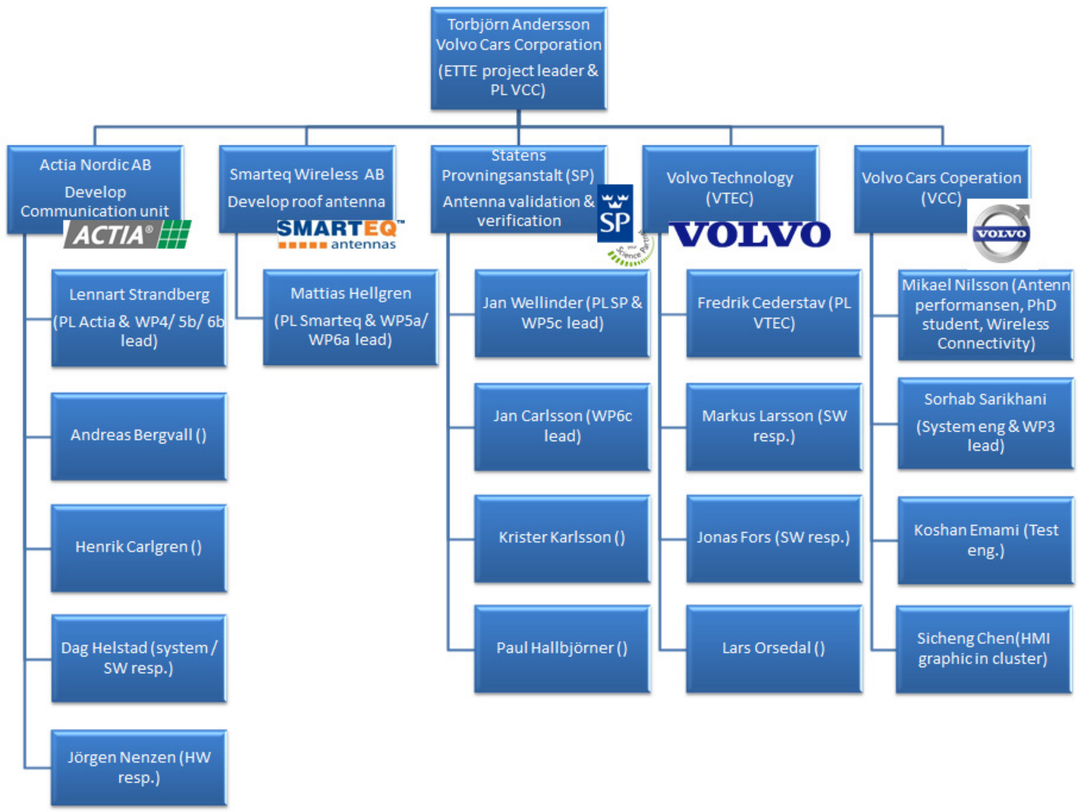


Figure 4: ETTE project organization

3.2 WP2 Technology analysis

3.2.1 Objectives

The information collected in this document will be used by the project for the next coming work packages.

The information shall be used to draw conclusions about which protocols, HW solutions etc. that should be used over time.

3.2.2 Activities

Have done a research of coming communication technologies. Accomplish a description of main attributes e.g. frequency, supported protocols, coverage, reach, performance cost & required hardware is also provided for each communication technology [1]

3.2.3 Results

The following two pictures conclude some of the above information.

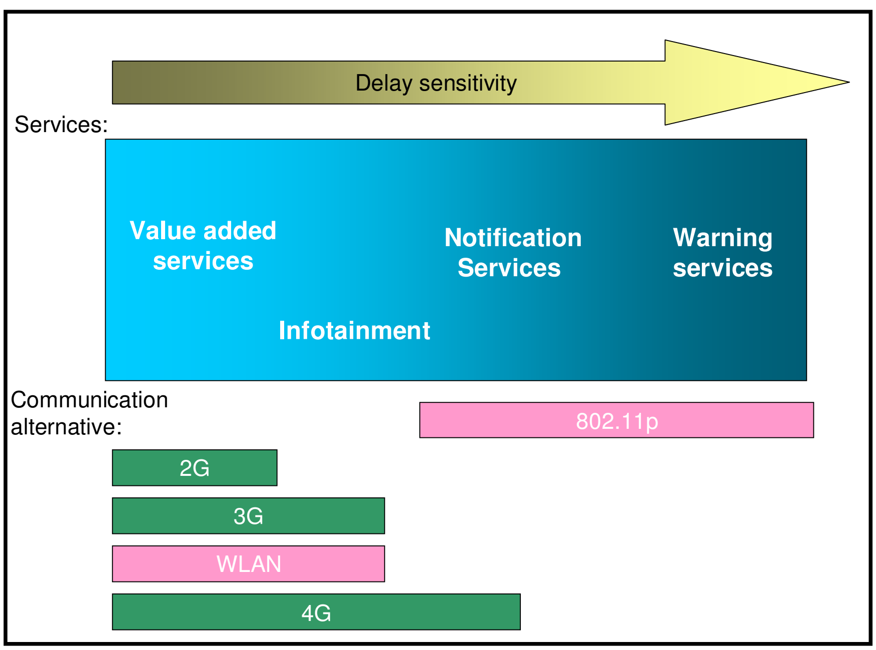


Figure 5: Proper communication carrier for certain service

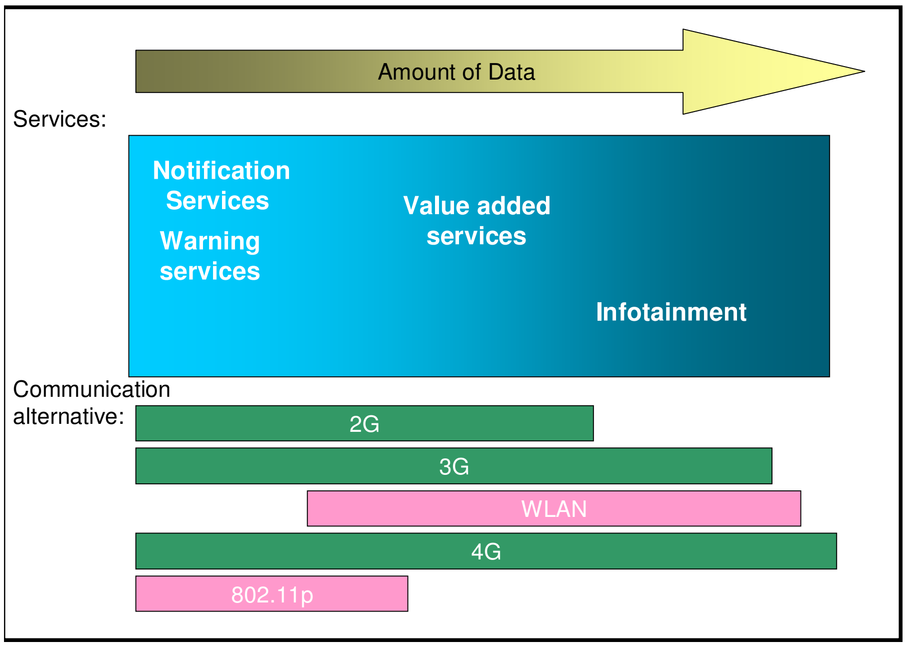


Figure 6: Able data for certain communication carrier

Based on this study in this work package, team decides to make further investigation in WiFi802.11p and 4G/ LTE technology.

3.3 WP3 System design

3.3.1 Objectives

This document describes these requirements on an overview level being defined in System Design Description.

3.3.2 Activities

Define a system description specification. Main criteria and requirements are defined in this system specification [2]:

3.3.2.1 ETTE node block diagram:

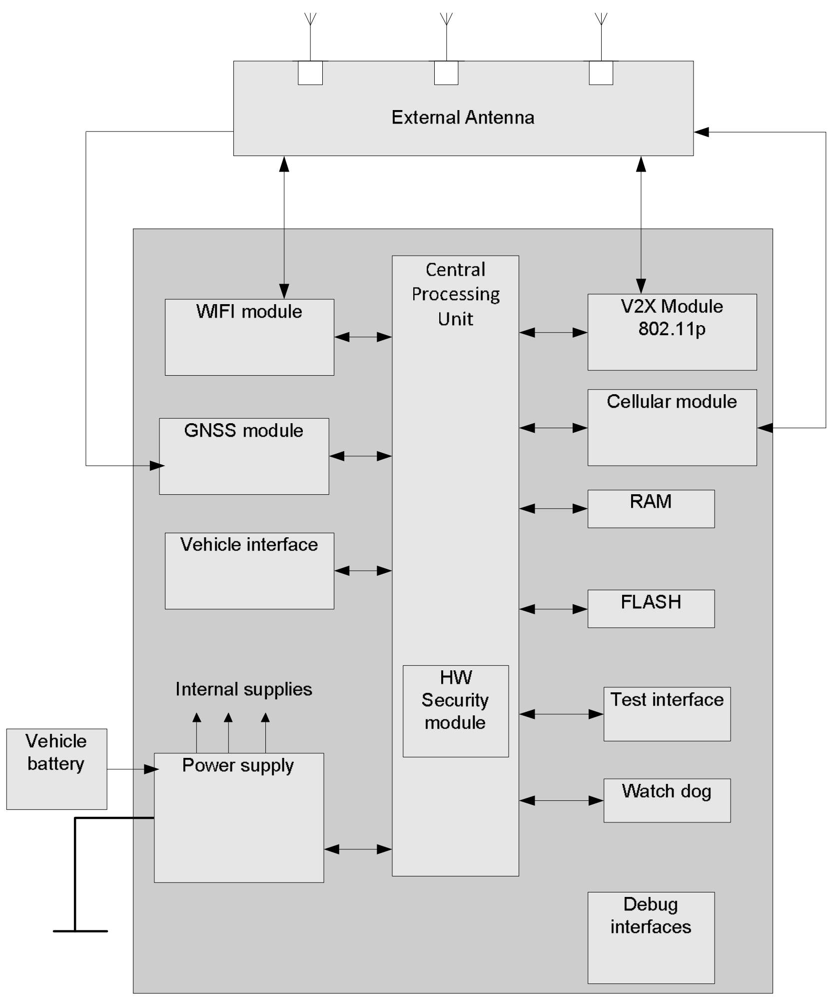


Figure 7: ETTE node hardware overview

3.3.2.2 Overview of the software architecture of ETTE node

The software of the ETTE node is built upon a layered architecture. The bottom layer is the operating system layer, which contains traditional operating system functionalities for connecting software of the upper layers to the hardware of the system. The operating system layer can contain both modules executing in user space and in kernel space. Next layer up is the vehicle abstraction layer, which exposes an API for accessing vehicle sensor data to the application. The ITS Facilities layer is a middleware layer for implementing functionalities needed for supporting the upcoming European standards on ITS, such as services for supporting cooperative awareness (CA), decentralized environmental notifications (DEN) and local dynamic map (LDM).
The top layer is the applications, which provides functionalities visible to the end user.

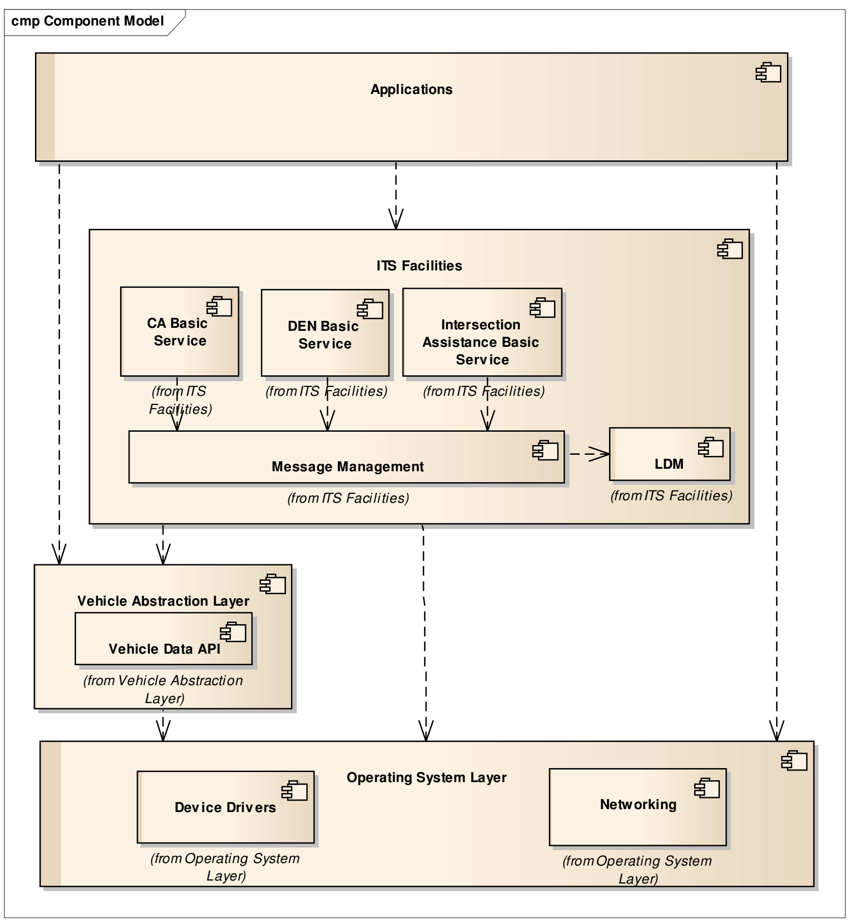


Figure 8: ETTE node software achitechture

3.3.2.3 CPU capacity analysis

The design shall be made on an ARM 926 based CPU running on 400- 450MHz, the CPU load shall be measured during the ETTE design phase in order to evaluate if the selected CPU gives sufficient performance. Especially latency requirement V2X shall be evaluated when several data streams are handled in parallel (WiFi, HSPA+, LTE etc.). At full load max 70% of the CPU power shall be used.

3.3.2.4 802.11p Transceiver concept

It is currently not defined if V2X will require a single or double radio concept.
It might be so that 2 radios is required for active safety application, with a 2 radios the system is able to receive simultaneously on two neighbored channels (one dedicated receiver channel for time critical emergency messages and one dedicated transmitter/receiver channel for critical road safety applications.
A disadvantage with a 2 radio concept is increased cost for the 802.11p Transceiver.

Note: In the ETTE NODE design the implication of a double radio concept shall be taken in account, even if the prototype might not be equipped with a double radio.

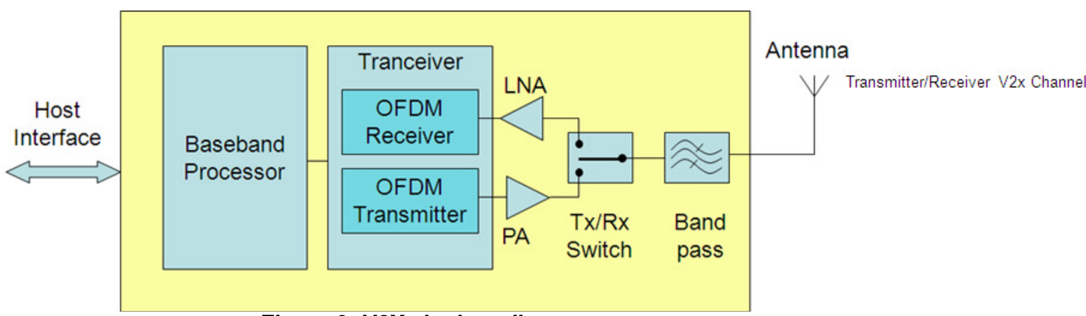


Figure 9: V2X single radio concept

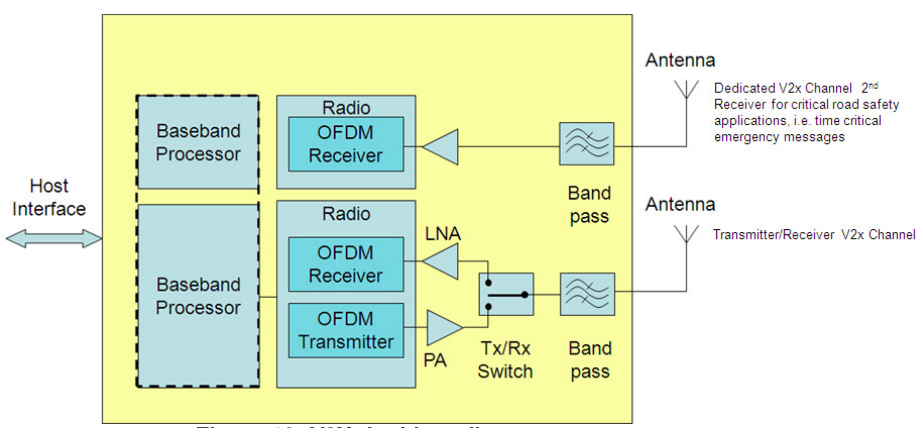


Figure 10: V2X double radio concept

3.3.2.5 Antenna system & description

The antenna should be a roof mounted antenna suitable for mounting on both trucks and cars.

Installation should be made from the outside of the vehicle and by means of standard tools.

The antenna is needed for telephone, navigation systems, active/passive safety systems, Car to car and Car to Infrastructure and entertainment system.

The antenna should be designed as a multifunctional/combination antenna containing functionality according to

3.3.2.5.1 ETTE antenna version number one

Antenna designed for demonstrator vehicle and ETTE node hardware.

Configuration

System	Standard	Frequency	Connector type	Connector Code
V2X	802.11P	5.85-5.925GHz	Fakra Female	I, Beige
WLAN	802.11b/g/n	2,4-2,485 / 4.915-5,825GHz	Fakra Female	(K, Curry) **tbd**
Cellular	3G/LTE-	824-960 / 1710-2690MHz	Fakra Female	D, Bordeaux
Cellular MIMO	LTE	2500-2690MHz	Fakra Female	H, Violet
GPS		1575,42MHz	Fakra Female	C, Blue

Figure 11: ETTE antenna configuration

3.3.3 Cross functional team Objective Oriented FMEA of system

A cross functional FMEA has been define there potential risk have been defined and reviewed. Boundary of this FMEA was as describe in picture below

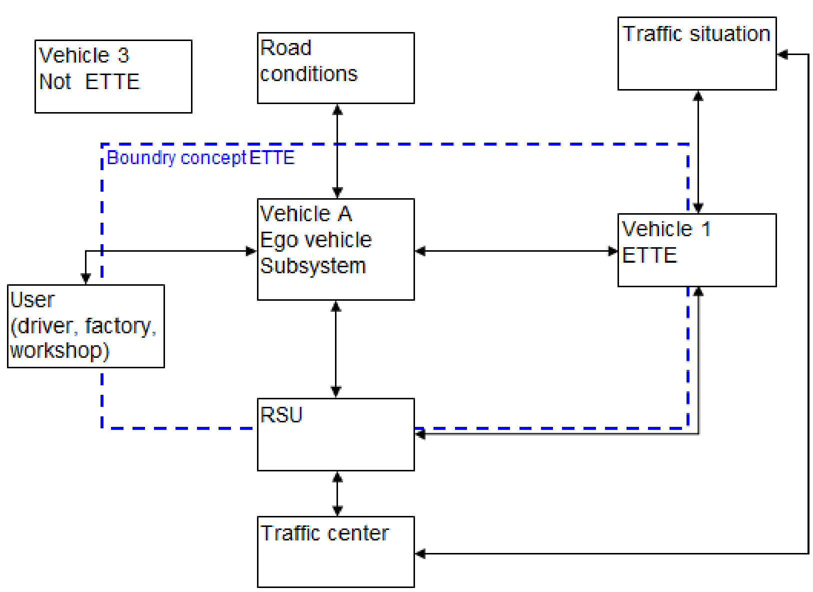


Figure 12: Boundary diagram of OOFMEA

Define what kind of logical object, physical object and attribute object that are in system and for estabished usecase (further detail about use case see chapter 3.4 Use Case)

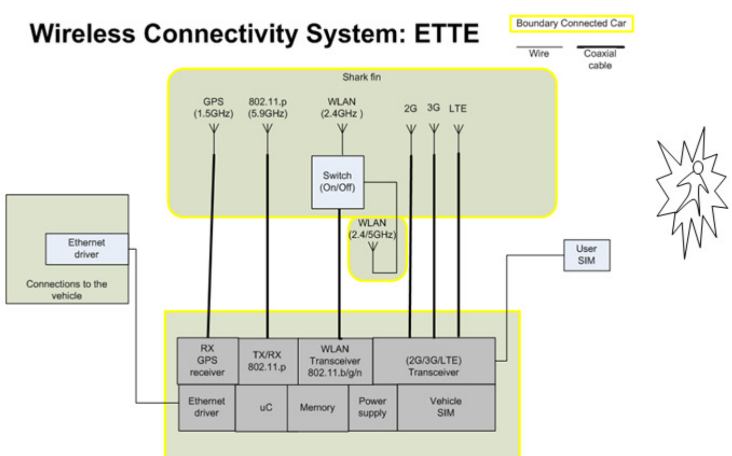
Example of logical break down of use case Stationary Vehicle Warning:

Stationary Vehicle Warning:
1- Decides if ego vehicle is stationary vehicle in order to send out warning message.
2- Collects required information in order to send out data.
3- Formats data in to DENM (Decentralized Environmental Notification Message) message.
4- Broadcasts DENM message.
5- Monitors DENM message from other vehicles / RSU.
6- Receives and decodes messages from not ego vehicles.
7- Decides if received message is relevant for ego vehicle.
8- Relays relevant message to in-vehicle nodes and/or broadcast message to other vehicle in zone.

Figure 13: Example of a logistic break down of a usecase

For each object we did brainstorming session of Potential Failure Mode, Potential Effects of Failure, Potential Causes/ Mechanisms of Failure as well as Recommended action.

Also define some potential failure on system level



With same object as above was reviewed.

Further details see [3].

3.4 WP4 Use case:

3.4.1 Introduction:

Use cases are used to capture the functional requirements of a system. Use cases describe the interaction between a primary actor—the initiator of the interaction—and the system itself, represented as a sequence of simple steps. Actors are something or someone which exists outside the system under study, and that take part in a sequence of activities in a dialogue with the system, to achieve some goal: they may be end users, other systems, or hardware devices. Each use case is a complete series of events, described from the point of view of the actor

3.4.2 Activities

Establish a report that define a overall description of each use case, actors, domain objects, preconditions, flow of events and data type/ range. [4]

3.4.3 Results

Seven different use cases was established for further analyze:

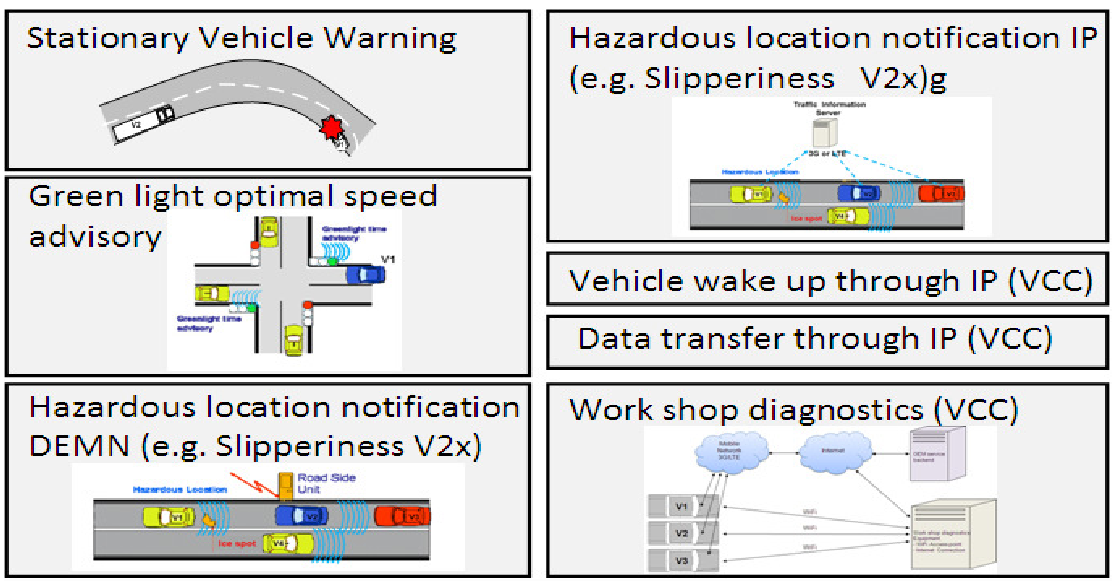


Figure 14: Defined use case within ETTE

Definitions:

CAM – The data exchange is based on periodically broadcasted awareness messages

DENM – The data exchange is based on event based broadcasted awareness messages

IP – The data exchange is based on individually addressed data from a known source to a known source.

Local – Required wireless communication range is defined as between 50-800m

Global – Required wireless communication range is defined as more then 800m

3.4.4 Further description information about Use Cases

The concept for Cooperative ITS (C-ITS) based on VANET Wireless V2X is that all vehicle broadcast a set of attributes (e.g. ego-position, heading, movement) to everyone else within range at all times. In Europe there is one message set standard that is the basic set of attributes called CAM - Cooperative Awareness Message and there is another set that is triggered by an event (such as slippery areas) called DENM (Decentralized Notification Message).

The frequency of these broadcasts may depend on over-air congestion and situation but in general, CAM is broadcasted at 10Hz.

It is important to note that the sender based on VANET never send warnings, it only send its awareness and its known information. Depending on the situation (e.g. speed, heading, position) of the receiving vehicle the received information may be turned into a warning or called to actions (e.g. breaking).

C-ITS VANET communication in Europe is based on the 5,9GHz band, the European profile of iEEE 802.11p is called ETSI ITS-G5 has a normal working range of 50-400m and max 800m.

3.4.4.1 Stationary Vehicle Warning

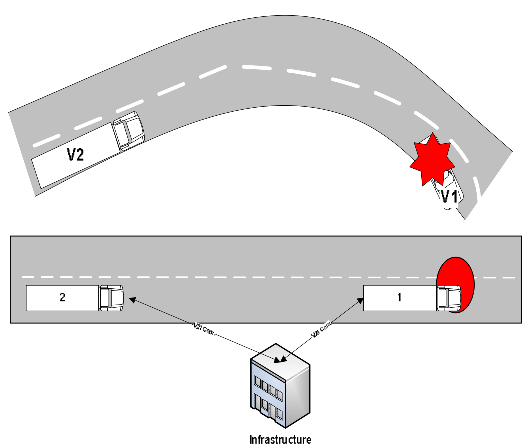


Figure 15: Stationary Vehicle Warning

Description:

This Use Case consist of any vehicle (V1) dangerously immobilized on the road (consecutive to an accident, a breakdown or any other reason) to alert other approaching vehicles (V2) of the risk for them associated to this dangerous situation.

The Vehicle (V1) periodically broadcast this information in all directions to any other approaching vehicle (V2) or infrastructure in range and the information shall be read by the approaching vehicles in all speeds (0-180 km/h).

3.4.4.2 Green light optimal speed advisory

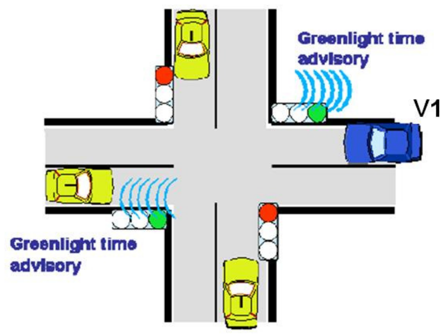


Figure 16: Green light optimal speed advisory

Description

This use case allows a traffic light to broadcast timing data associated to its current state (e.g. time remaining before switching between green, amber, red). Approaching vehicles (V1) receives traffic light timing and can adapt speed to optimize fuel consumption.

The traffic light RSU broadcast signal phase data in all directions to any approaching vehicle in range and the information shall be read by the approaching vehicles in all speeds (0-180 km/h).

3.4.4.3 Hazardous location notification DEMN (e.g. Slipperiness V2x)

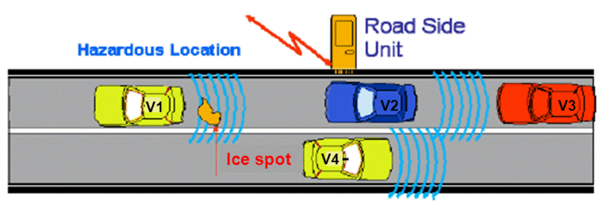


Figure 17: Hazardous location notification DEMN (e.g. Slipperiness V2x)

Description

This use case informs vehicles of any hazardous locations either temporary or permanent

The Vehicle (V1) recognizes slipperiness on the road (or other hazards for example "pot hole") and broadcast warning to alert approaching vehicles (V2, V3)

The Vehicle (V1) periodically broadcast this information in all directions to any other Vehicle (V2, V3, V4) and RSU in range, the information shall be read by the vehicles in all speeds (0-180 km/h).

The message is broadcasted during a defined time after that the hazard is detected

3.4.4.4 Hazardous location notification IP (e.g. Slipperiness V2x)

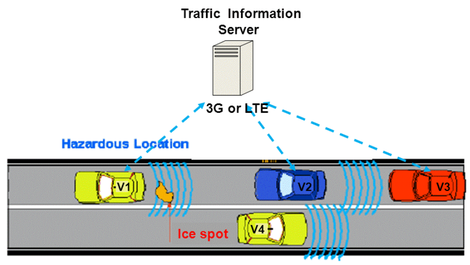


Figure 18: Hazardous location notification IP (e.g. Slipperiness V2x)

Description:

This use case informs vehicles of any hazardous locations either temporary or permanent.

The Vehicle (V1) recognizes slipperiness on the road (or other hazards for example “pot hole”) and transmits the information via 3G/LTE to a TIS (position, time and type of hazards).

The vehicle (V1, V2) is reports its position to the TIS via 3G/LTE, the TIS send Hazardous location notification the vehicles (V2, V3) when they are approaching hazardous location V3)

The information shall be read by the approaching vehicles in all speeds (0-180 km/h).

3.4.4.5 Data download through IP

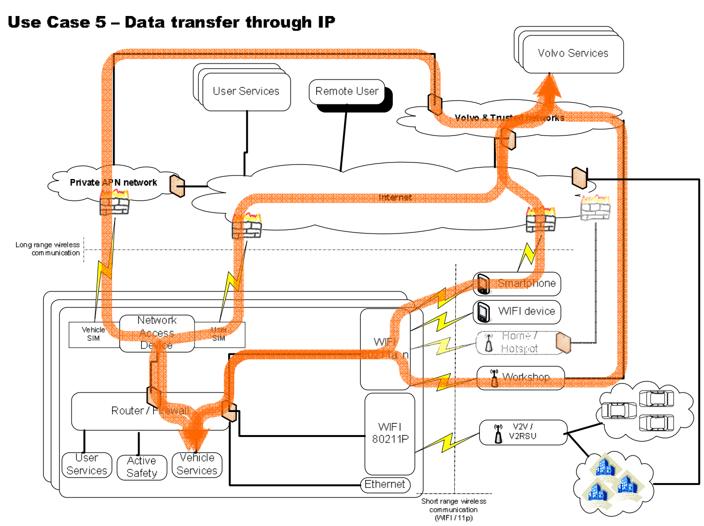


Figure 19: Data download through IP

Description:

This use case covers downloading of a data file to the vehicle. It starts where there is request/need to transfer a data file to the vehicle and this request/need is accepted by the system. The request/need is derived from any kind of functionality in the vehicle needing a data file, whether it is entertainment (e.g. video file), connected navigation (e.g. differential map update), or something else.

Large files via WiFi and / or LTE to might put specific requirement on router algorithm (for example how to re-establish down load session if connection is lost during down load), this must be considered in the use case design phase.

3.4.4.6 Vehicle wake up through IP

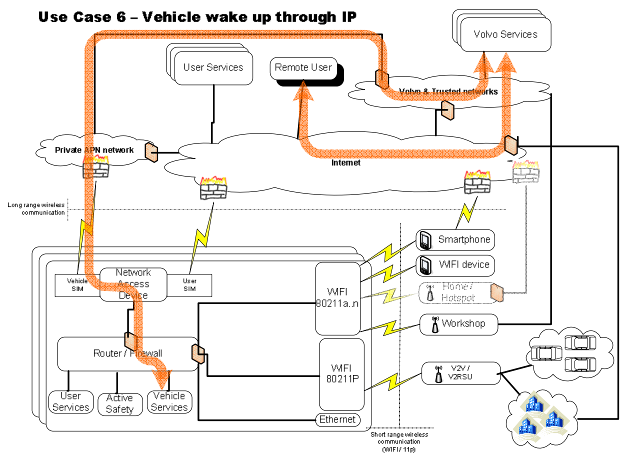


Figure 20: Vehicle wake up through IP

Description:
The purpose of this Use Case is to demonstrate vehicle wake up using an established IP data link over 3G/LTE which in waiting mode is transferring almost zero data per time, yielding decreased delays for remote services compared to wake up by SMS.

3.4.4.7 Workshop diagnostics

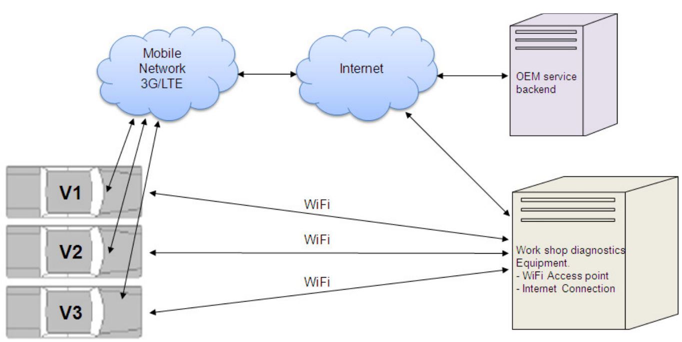


Figure 21: Workshop diagnostic

Description:
This use case covers remote diagnostics of a vehicle (V1,V2,V3) in a similar way as diagnostics via diagnose equipment connected to the vehicle OBD 2 connector but via WiFi (Local) or LTE/3G (Global).

WiFi is used as primary communication technology, if the vehicle not is within WiFi communication range LTE/3G shall be used.

3.5 WP 5a Antenna design & development

3.5.1 Objectives

- Identify antenna functionality needed to support ETTE-Node design with input from WP2 and WP3
- Create antenna specification with mechanical and Radio frequency demands such as Frequency range, Voltage Standing Wave Ratio, Antenna Gain, LNA Gain.
- Design an vehicle mounted combination antenna
- The antenna should be a roof mounted antenna suitable for mounting on both trucks and cars
- Installation should be made from the outside of the vehicle and by means of standard tools.
- Conclusions, lessons learned related to ETTE-Node antenna functionality in the antenna.
- Usability of the outcome of the project for Smarteq

3.5.2 Activities

Antenna component specification including:

- Frequency range / antenna function
- VSWR requirements / antenna function
- Gain requirements / function
- Voltage and current requirements
- Filter characteristics
- Mechanical interface to BIW

For each antenna functionality

- Define connector interface color and coding for each antenna function to be able to connect to ETTE-Node Poka-Yoke.
- Design iterations for each antenna function
  - CAD design of antenna/function
  - Create Board Layout and Board Assembly
  - Manufacturing of PCB antenna/function
  - RF testing antennas (VSWR, Gain, etc)
  - Re-Tuning of antennas

  Iterations are needed to finalize the antenna performance.
  - RF testing antennas (VSWR, Gain, etc)
- Evaluation of RF parameters on the antenna

- Evaluation of radio frequency characteristics for Personal vehicle versus truck installation
- Evaluation of radio frequency characteristics for different antenna locations on a vehicle

3.5.3 Result from Activities in WP5a

3.5.3.1 Radio frequency functions In ETTE_ANT enabling ETTE node functionality

System	Standard	Frequency	Connector type	Connector Code
V2X	802.11P	5.85-5.925GHz	Fakra Female	I, Beige
WLAN	802.11b/g/n	2,4-2,485 / 4.915-5,825GHz	Fakra Female	(K, Curry) **tbd**
Cellular	3G/LTE-	824-960 / 1710-2690MHz	Fakra Female	D, Bordeaux
Cellular MIMO	LTE	2500-2690MHz	Fakra Female	H, Violet
GPS		1575,42MHz	Fakra Female	C, Blue

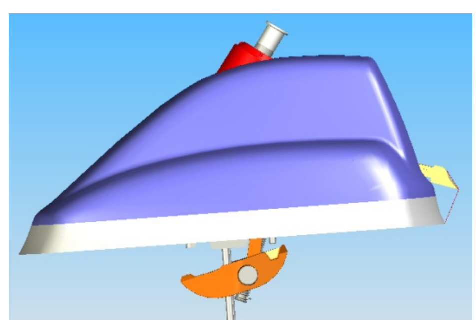
Figure 22: Radio frequency

3.5.3.2 General ETTE-antenna requirements and corresponding solution

- The antenna should be a roof mounted antenna suitable for mounting on both trucks and cars.
- Installation should be made from the outside of the vehicle and by means of standard tools.
- The antenna should be designed as a multifunctional/combination antenna containing functionality
  - GPS
  - Cellular MIMO (LTE)
  - Cellular (3G / LTE)
  - WLAN: WiFi 802.11b/g/n
  - V2X: WiFi 802.11p

3.5.3.2.1 Mechanical fastening

Mechanical fastening to the roof is made my means of a ”hook” latching arm operated from the outside of the antenna my means of a Torx 25. The position of the hook is guided so it can rotate-> consequently having one open position and one closed position.



Guiding pins in the antenna base plate enables correct alignment and also possibility for Poka_Yoke assembly on a vehicle if several antenna bases are mounted.

The ETTE antenna is designed to be mounted in a circular 30mm hole.

3.5.3.2.2 Combination antenna

Antenna functionality according to 3.8.1 is fitted together in a combination antenna. - Compromising an antenna base plate supporting all necessary antenna functions, plastic cover and suitable seal for water protection.

1: LTE MIMO antenna

2: GPS antenna

3: WLAN antenna

4: Mobile phone antenna

5: V2x antenna

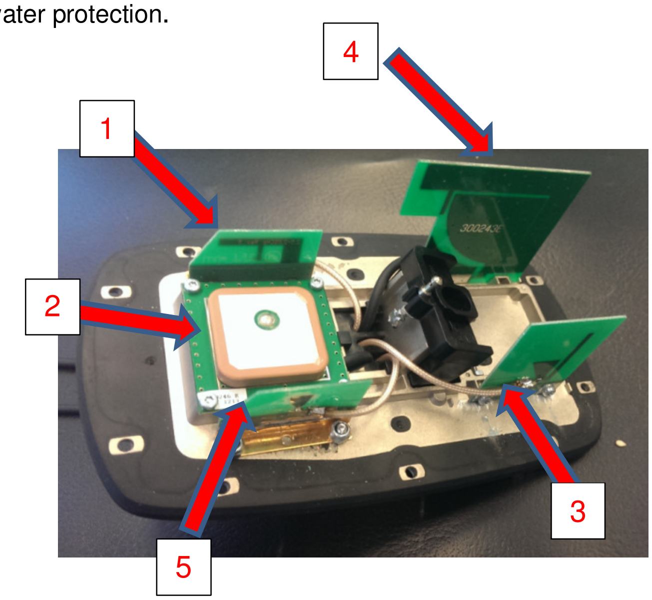


Figure 23: Antenna configuration

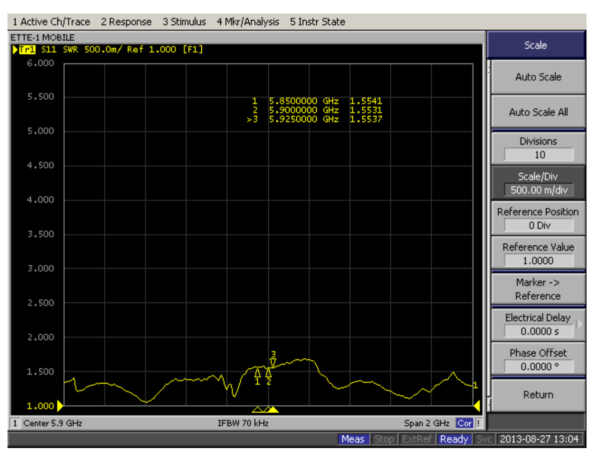
3.5.4 RF measurements

Several RF antenna measurements have been conducted during the project to evaluate and develop the ETTE-Antenna. Some of the test has been carried out in WP5a but also in WP6.

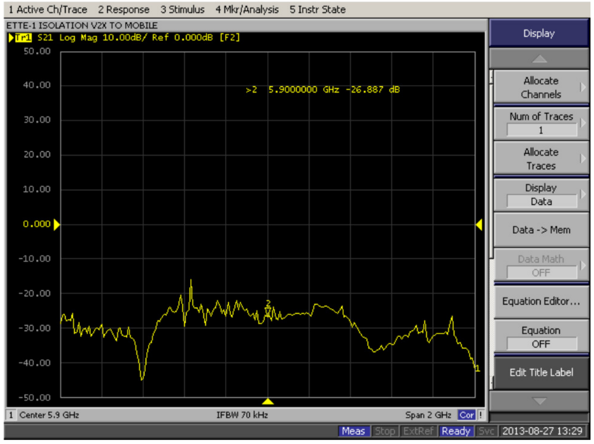
Below is a selection of tests and test result presented.

3.5.4.1 Frequency response and VSWR for V2X antenna (0489-0170)

Frequency response and VSWR of the V2X antenna is according to specification.



Isolation to other antenna functions inside of the ETTE-antenna ranges from 26-38dB



3.5.4.2 Radiation pattern evaluation for different antenna locations on a Volvo S60

During the project has 4 different antenna locations on a S60 been tested and evaluated in a RF perspective.

3.5.4.3 Conclusion of antenna measurement, different positions:

The S60 test vehicle is equipped with four units of a certain antenna module. The radiation pattern from each of these units is affected by the presence of the others. The antenna module is not symmetric, neither specially designed for the positions on which it is mounted.

Propagation from the antenna modules is affected by the non-perfect absorbers on the semi-anechoic chamber floor.

Conclusions from the measurement are listed below, conclusions which are based on diversity gain from 2D radiation patterns as described in chapter “Results-diversity gains”.

For the V2X antenna best diversity is achieved by combining position 1 with 2. Several other combinations achieve similar performance.

For MIMO LTE at 2600MHz realized by combining antenna elements Mobile and LTE-MIMO in same or separate antenna modules best diversity is achieved using both antennas in same antenna module on position 3.

At 5400 MHz the WLAN antenna works better on position 3 compared to position 1.

At 2100 MHz the Mobile antenna works better on position 3 compared to position 1

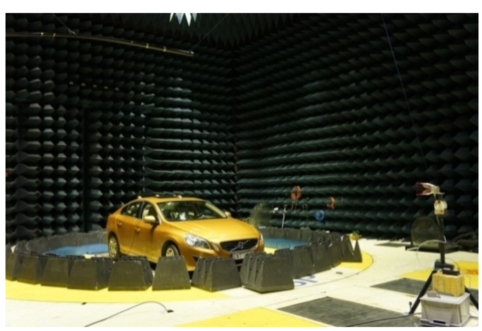


Figure 24: Car set up in chamber at SP

3.5.4.4 Radiation pattern for V2X on circular ground plane 1000mm

In order to characterize the ETTE-antenna without interference from the vehicle body is measurements conducted on a circular ground plane of 1000mm in diameter.

All antenna functions are measured and different antenna designs are evaluated during the project. Below is a typical radiation pattern in elevation cut presented for two different V2X antennas inside of the ETTE antenna.(Antenna sample N2 and N0)

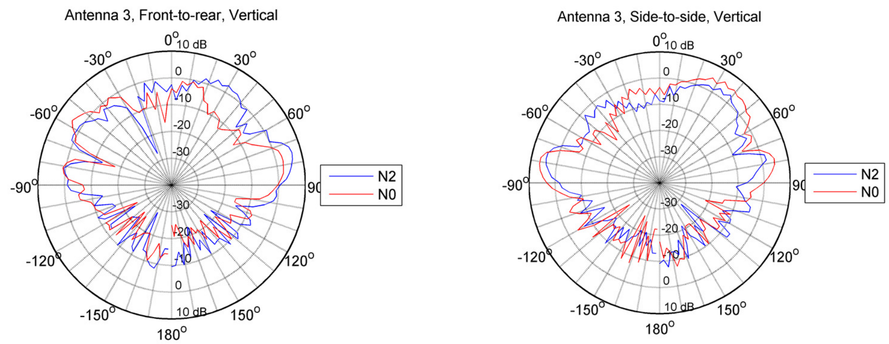
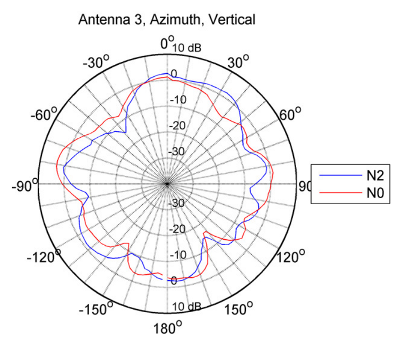


Figure 25: Radiation pattern for V2X in elevation cut



Radiation pattern in Azimuth cut
0degrees is in the forward direction

3.5.5 Result radiation pattern for V2X

Radiation pattern measurements for the V2X the antenna inside of the ETTE-multifunction antenna behaves as predicted. There is a clear lobe lift of ~ 30degrees and an asymmetrical gain in front to back side to side of the vehicle/antenna. Peak gain in front to back direction of the vehicle is 6,6dBi and for Side to Side of vehicle 6,5dBi. The asymmetrical pattern comes from nearby antenna functions inside of the antenna. (Antenna measured on circular GPØ1000mm)

3.5.5.1 Conclusion Radiation pattern for V2X on circular ground plane

The signaling in V2x is made in elevation angels between -5 to +10 degrees and traditional ¼ wave antennas has lobe lift that results in less gain at low elevation angles.

There is a need of designing the V2x antenna in such a way that maximum gain is achieved at lower elevation angles for optimum performance.

3.5.6 Cable losses (0489-0177)

The project has decided to measure loss on cables that could be used in automotive industry defined by diameter and cost. 18 cables where measured having a diameter range of 1.8 - 6mm

The project has identified one unique critical aspects that have a large impact on the RF system performance; Cable Losses for V2x operating at 5,9GHz. Traditional antenna cables experience high losses at these frequencies. The loss differs, on the tested cables, from 0.8dB/m to 3.8dB/m. A loss of ~3dB/m will lower the signal by a factor of 2.

3.5.6.1 Conclusion, cable losses

Using standard automotive RF-cables and cable routing for V2X is not recommended.

Cable losses will reduce the performance to a large extent. Example 5 meter of cable with a loss of ~3dB/m equals 15dB.

Traditional antenna installation on vehicles has approximately 5meter of cable

3.5.7 Lessons learned

1. Antenna position on the vehicle is important. Vehicle curvature on roof should be considered in the antenna design
2. V2X reception towards the back for trucks, with cargo, will be very limited
3. Keep RF-cables very short
4. There is a need of unique RF cables for V2X and WLAN, 4G (2600MHz) compared to traditional cables used today in the automotive industry due to high losses
5. Radiation pattern for V2X in elevation cut need be further evaluated due to that most of the signaling in V2x is made in elevation angels between -5 to +10 degrees.
6. A combination antenna with several antennas for different radio systems is time consuming and difficult to design, there is a need of many design iterations.
7. There might be an issue with isolation between different antennas. Isolation properties need to be addressed in overall system specification.

3.5.8 Related documents

Doc number	Description
0489-0568	GPS test instruction
0489-0391	GPS ESD test of LNA
0489-0116	GPS LNA test report
0489-0100	Anechoic chamber description
0489-0555	ETTE Antenna: VSWR

0489-0557	GPS Patch spec
0489-0170	VSWR and isolation on antenna functions
0489-0177	Cable losses
0489-xxx	Several radiation patter tests at WP6

3.6 WP5b Router design and development

3.6.1 Objectives

Design and develop the ETTE Node , the ETTE Node is designed in 2 versions:

1) VCC ETTE Node → Designed for integration in Volvo Cars

2) VTC ETTE Node → Designed for integration in Volvo Trucks

- VCC ETTE Node development main tasks Develop ITS-G5 stack (V2x)
- Develop V2x use cases for 802.11p
- Develop V2x use cases for 4G (LTE)
- Design and develop algorithm for “Stationary Vehicle Warning”, the purpose of the algorithm is to avoid warnings from vehicle that not are a “threat” for the approaching vehicle
- Integrate ITS-G5 ITS-G5 stack and use cases in Connetivity-CPU (C-CPU) SW (Linix OS)
- Adaptation of Telematics-CPU (T-CPU) CAN SW (Triggers for use cases)
- Adaptation of communication between T-CPU and C-CPU
- Develop end integrate HMI SW interface
- Develop daughter board
- Integrate 802.11p modem

VTC ETTE Node development main tasks

- Develop ITS-G5 stack (V2x)
- Develop V2x use cases for 802.11p
- Integrate ITS-G5 stack and use case in CPU (OSE OS)
- SW Adaptation for use case triggers
- Adaptation of HMI interface SW
- Integrate 802.11p modem in VTC ETTE node

3.6.2 Activities

The SW development (ITS-G5 stack and use cased) have been shared between ACTIA and VTEC, the figure blow gives an principle overview of the main responsibility of each company, for details see section “3.6.2.1 Components of the ETTE software”

Kapsch TrafficCom AB was selected as supplier of the 802.11p modem

ACTIA have developed the VTC and VCC ETTE Node hardware

As two different nodes (VTC and VCC) have been developed in the project interoperability tests between the nodes have been of great importance in order to verify that the Nodes is able to communicate in a correct way

Also vehicle integration test have been made during the development phase to secure that the Use case trigger commands via CAN is working properly.

In order to be able to test the uses case “Stationary Vehicle Warning” via 4G (LTE) a server application has been developed, the server is located in ACTIA premises in Linköping

In addition to the ETTE Node development also 2 special units and PC software for antenna measurement have been developed, the PC SW gives for example the possibility to measure 802.11p packet losses

3.6.3 Results:

Four VTC ETTE Nodes and five VCC ETTE Nodes have been built

Interoperability tests between the nodes have been successfully performed (including ASN1 coding)

During the vehicle integration tests in a Box Car at VCC issues with the interpretation off the Hazard signal via CAN (trigger for the use case “Stationary Vehicle Warning”) was discovered, after correction in VCC ETTE NODE SW the vehicle integration did work properly.

Use cases via 802.11p and 4G (LTE) have and HMI interfaces is working according to expectations (warning icons (symbols) appears in the HMI

3.6.4 HW Design:

3.6.4.1 VCC ETTE Node HW design

The VCC ETTE Node is based on the VCC TEM3G, Function blocks needed for ETTE have been added.

The figure below the shows VCC ETTE Node block diagram

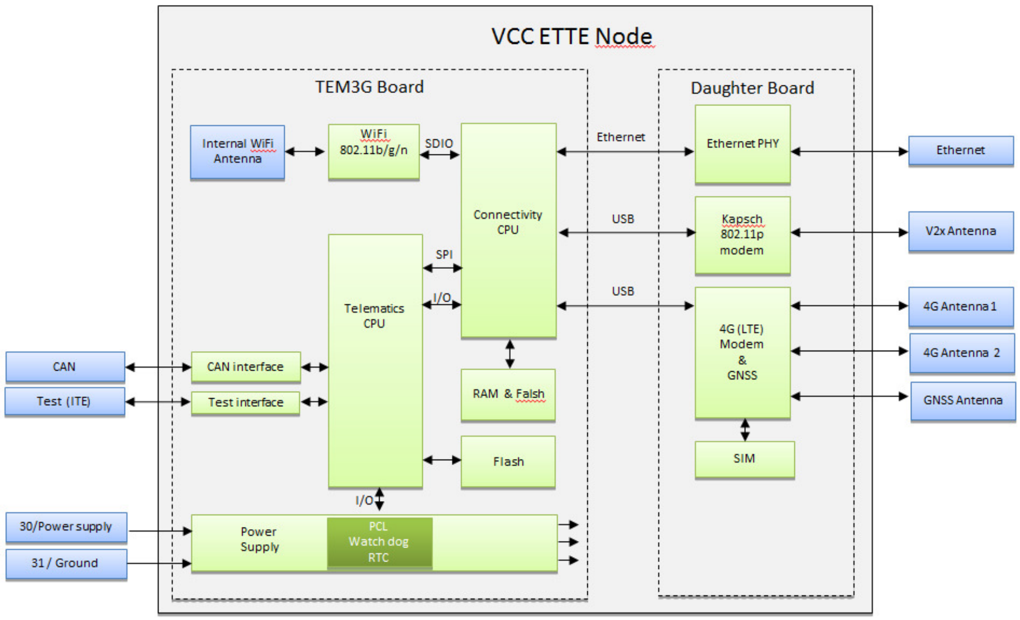


Figure 26: VCC ETTE Node block diagram

Telematics CPU:

- 32bit RISC type
- The clock frequency is set @ 144MHz during normal operation.

Connectivity CPU:

- ARM926
- The clock frequency is set @ 450MHz during normal operation

WiFi:

- Supported standards: 802.11b/g/n
- Frequency: 2.4 GHz operation - single band

4G (LTE):

- LTE data rates (category 3, MIMO)
  - 100 Mbps DL within 20 MHz bandwidth
  - 50 Mbps UL within 20 MHz bandwidth
- Circuit-switched data bearers (up to 64 kbps for GSM and UMTS)

- Quad-mode UMTS (WCDMA) / HSDPA / EDGE / GPRS operation
- HSDPA data rates up to category 20
- HSUPA data rates up to category 6
- GPRS multislot class 10
- EDGE multislot class 12

802.11P:

Overview:

The 5.9 radio modem is comprised of a single radio with a front end configuration supporting dual antenna ports. The radio is configured to support 10 MHz channels in the 5.9 GHz frequency band allocated for V2I and V2V communication in both US and Europe.

The 5.9 radio modem is comprised of two antenna ports, coupled to the internal patch antenna and external antenna port respectively. The default antenna for reception is configurable, and the antenna to be used for transmission is selected on a per-packet basis. The configuration for usage in the ETTE-project is that the external antenna port is selected as the default antenna for both reception and transmission.

5.9 Radio Characteristics:

Parameter	Details
Frequency Channels	Channel Frequency 172 5855-5865 174 5865-5875 176 5875-5885 178 5885-5895 180 5895-5905 182 5905-5915 184 5915-5925
Bitrates	3, 6, 9, 12, 18, 24, 27 Mbps The default bitrate is set to 6 Mbps
Output Power Range	2-16 dBm, configurable in steps of 1 dB.
Receiver Sensitivity dBm	**3Mbit/s 6Mbit/s 9Mbit/s 12Mbit/s 18Mbit/s 24Mbit/s 27Mbit/s** -92 -90 -88 -84 -82 -78 -76
Received Signal Strength Indication (RSSI)	The radio reports an indication of the received power, which is given as the strength of the signal relative to -100 dBm. The valid received signal range is "sensitivity level" to -30 dBm. I.e. the reported RSSI is valid in a range from approximately 10 to 70. The RSSI is reported with a resolution of 1 dB.

The values are given with reference to the antenna connector. Compensation for cable losses and antenna gain shall be handled by upper layers.

3.6.4.2 VTC ETTE Node HW design

The VTC ETTE Node is based on the VCC TGW2, Function blocks needed for ETTE have been added.

The figure below the shows VTC ETTE Node block diagram

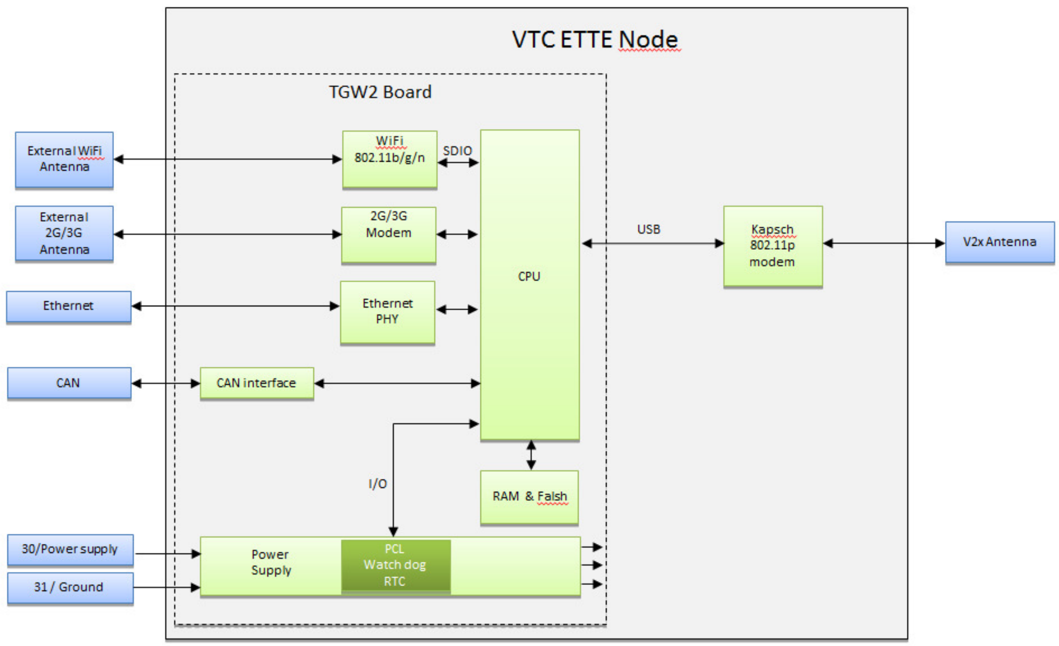


Figure 27: VTC ETTE Node block diagram

CPU:

- ARM926
- The clock frequency is set @ 400MHz during normal operation

WiFi:

- Supported standards: 802.11b/g/
- Frequency: 2.4 GHz operation - single band

2G/3G Modem:

Data features

HSPA

- Max uplink 5.76Mbps
- Max downlink 7.2Mbps

EDGE

- Multi-slot class 12(4 Down; 4 Up; 5 Total)

GPRS

- Multi-slot class 12 (4 Down; 4 Up; 5 Total)

CSD

- UMTS Max BR 64 Kbps
- GSM Max BR 14.4 Kbps

802.11P:

Same as VCC ETTE Node

3.6.5 Software Design

The software in an ITS station has three main purposes:

- To implement the GeoNetworking protocol, turning a vehicle or a road side unit into a GeoNetworking router. This includes packet routing and network management. Geographic routing is described in detail in ETSI x02 636-4 series of specifications.
- To provide a platform for development of ITS use case functionality. This includes a “Facilities Layer”, which includes message encoding / decoding, an event database, and helper functions for transmission of DEN / CAM messages.
- To implement applications, which realize the actual ITS functionality. Applications are responsible for detecting and triggering local events as well as handling events coming from remote ITS stations and determining whether the driver should be notified or not.

The ETTE software has been written to implement a few entire use cases, but it does not completely implement ETSI specifications at any level.

Since the ETSI specifications are still being developed (especially in the Facilities and Application layers), they’ve been hard to follow.

3.6.5.1 Components of the ETTE software

In the ETTE node, the ITS stack and the Vehicle Abstraction Layer is run in a single process. The software development was divided between VTEC / VCC and Actia as stated in the figure above. Yellow boxes were the responsibility of Actia.

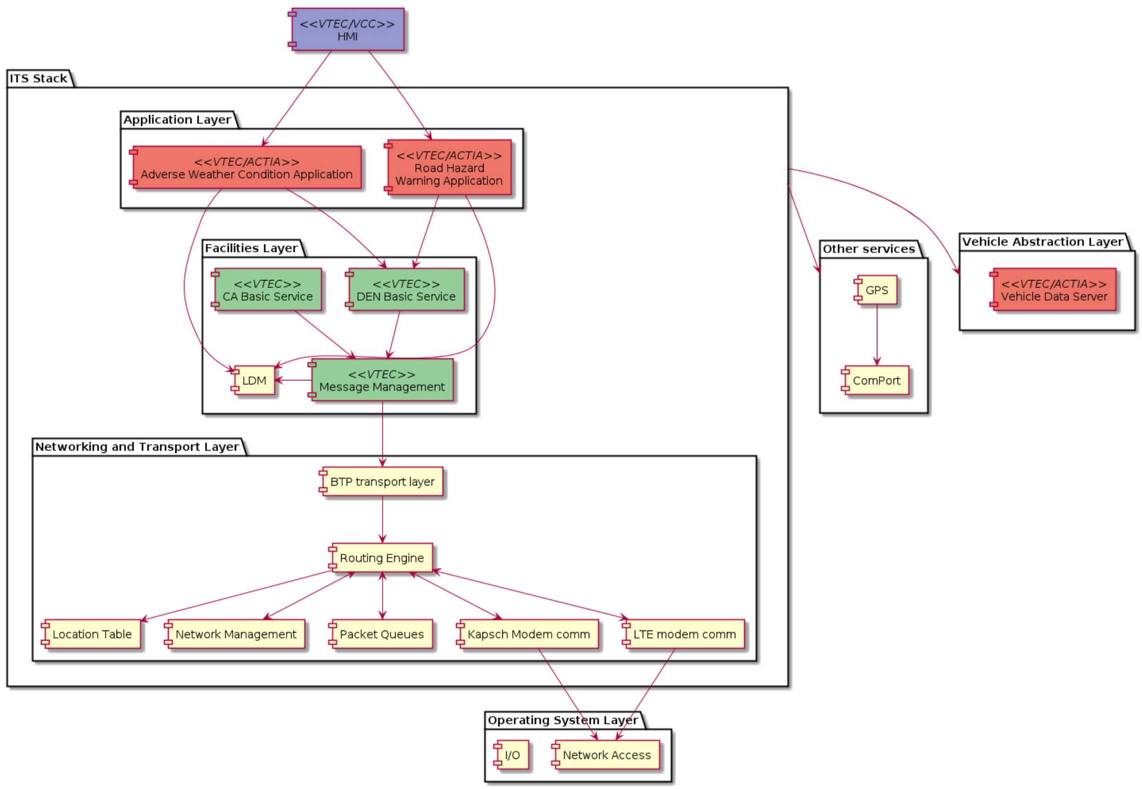


Figure 28: Component of the ETTE software

3.6.5.2 Use Case: Stationary Vehicle Warning

The functionality of the components in the figure above is easiest described using a concrete use case. In this case, we image a system of three ITS stations: originator, forwarder and receiver. The forwarder is included to demonstrate the functionality of a GeoNetworking router.

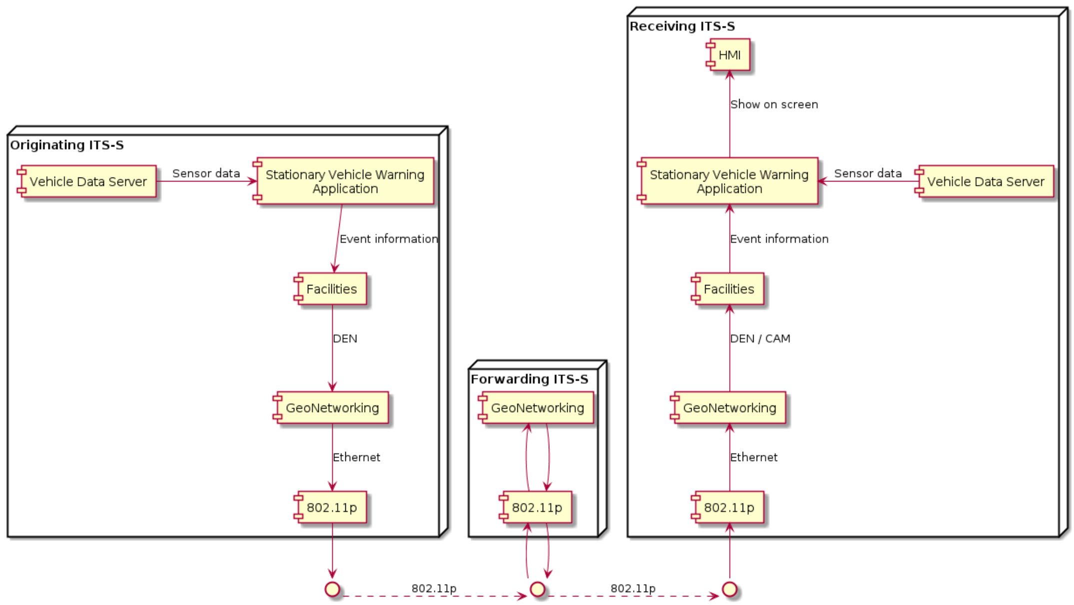


Figure 29: Software set of use case Stationary Vehicle Warning

1. The use case starts on the originating ITS-S. Speed and warning light status sensor data is processed by the Vehicle Data Server. Sensor data is probably read from the CAN network.
2. The SVW Application receives the sensor information.
3. The SVW Application sees that the speed is low and that the warning lights have been turned on and decides to trigger a SVW event.
4. The SVW Application tells the Facilities layer to start broadcasting a DENM/SVW message in the area around the local vehicle.
5. The Facilities layer adds some more information from the vehicle database, e.g. time stamps and an event ID. A DEN packet is created and encoded using ASN.1.
6. The Facilities layer sends the generated message to the GeoNetworking layer, asking it to transmit it as a GeoBroadcast.
7. The GeoNetworking layer uses its routing tables, the destination of the packet and the current location of the local vehicle to decide the next hop of the packet. In this case, it decides to broadcast it locally.
8. The GeoNetworking layer asks the 802.11p modem to broadcast the packet.
9. The 802.11p modem broadcasts the packet.
10. The packet is heard by the forwarding ITS-S. The 802.11p modem delivers the packet to the GeoNetworking layer of the forwarding node.
11. The GeoNetworking layer of the forwarding ITS-S decides to forward the packet to the receiving ITS-S. It updates some fields in the packet header (e.g. hop count) and sends it to the 802.11p modem.

12. The packet is heard by the receiving ITS-S. The packet is handled by the GeoNetworking layer. The local vehicle is within the target area of the packet, so it is passed to the Facilities layer.
13. The Facilities layer decodes the message and passes the event information to the receiving SVW Application.
14. The receiving SVW Application uses sensor data to decide whether the driver needs to be alerted. In this case, the driver is only alerted if the stationary vehicle is in the path of the local vehicle.
15. The driver is alerted through a warning in the HMI.

Figure 30: Stationary vehicle warning HMI in the ETTE Volvo car

3.6.5.3 Hazardous Location Use Case: Slippery Road

Note: throughout the ETTE project, this UC has been referred to as “Hazardous Location”, which in ETSI application terms isn’t correct. Hazardous locations denote obstacles and damages to the road, like pot holes, volcano eruptions (!) and landslides. For this use case, the actual event code being used is “AdverseWeatherCondition-Adhesion”.

The AWC use case (including Vehicle Data Server signals, HMI and the applications) was only implemented by Actia / VCC. Therefore, we could only test the use case between two cars, and not between car and truck.

AWC is implemented just like the SVW use case (see previous sections). The event is triggered on the originating ITS-S as soon as the DSTC warning lights are enabled. The warning is sent to all vehicles inside a circle around the originating ITS-S. On the receiving side, the driver is notified as soon as the receiving ITS-S enters the relevance area of the event. The vehicle’s speed and direction is not taken into account.

This is a very simplistic implementation which won’t work well in a production environment, but it was good enough for the demo.

3.6.5.4 ITS over LTE

The ETTE software also contains an alternative implementation of the physical and link layers, where 802.11p has been replaced by LTE.

Only the lowest layers have been changed. Instead of sending packets locally using 802.11p, GeoNetworking packets are wrapped in UDP / IP packets and are sent to a server on the Internet.

1. Application, Facilities and GeoNetworking layers work just like in the 802.11p case.
2. Instead of sending Ethernet packets over the 802.11p modem, the GeoNetworking packets are wrapped in IP / UDP and sent to the IP-ITS server.
3. The IP / UDP packets are received by the IP-ITS server.
4. The IP-ITS server now acts as a GeoNetworking router. It interprets the GeoNetworking protocols and determines the destination area of the packets.
    a. The database is consulted to find all ITS stations within the destination area.
    b. If the packet is topologically (as opposed to geographically) routed, all stations within a certain distance to the originator are selected
    c. The database information about the originating ITS station is updated
5. The packet is forwarded to all selected IP-ITS stations.
6. The receiving ITS station receives the packet. The LTE layer unwraps the the packet and sends it to the GeoNetworking layer. There, it is handled just as in the 802.11p case.

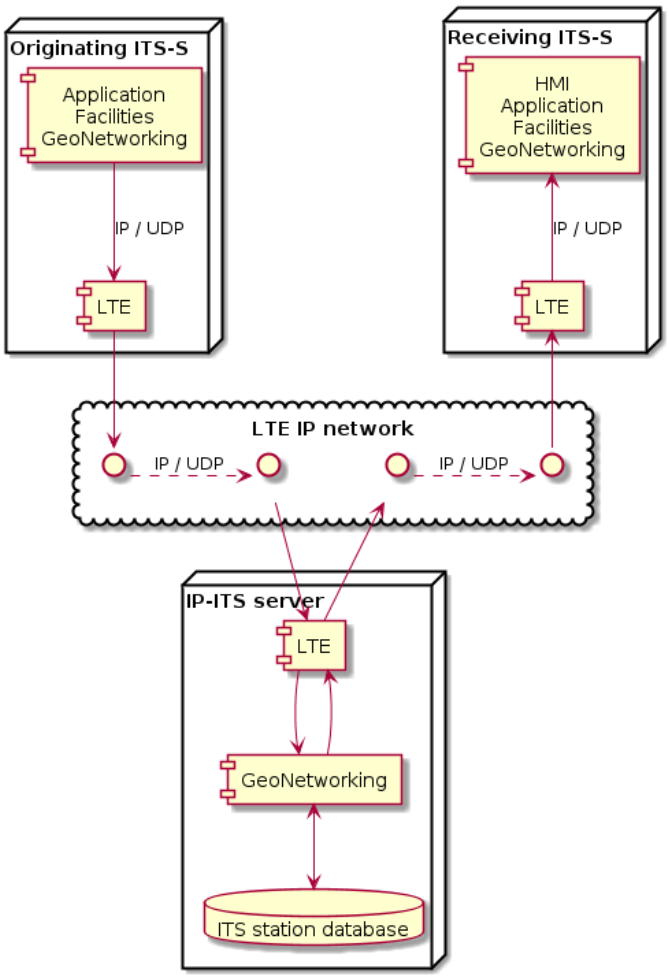


Figure 31: ITS over LTE

3.6.5.5 Software development

The development of the ITS stack was a collaboration between VTEC and Actia. The software was developed using C++. A great deal of focus was put on portability, since the ITS stack is run on OSE by VTEC and on Linux by Actia. The result was that the ITS stack can be run on virtually any POSIX compliant operating system. It has been run successfully on OSE, embedded Linux, desktop Linux and will run on Windows with a few minor updates.
VTEC and Actia agreed upon the software interfaces between the components, and then the different parts of the stack were implemented independently of each other. The components were then integrated at each company, effectively creating two different ITS stacks.
The most complex issue with this strategy was the fundamentally different development environments. At Actia, a traditional development environment was used, with platform

dependencies kept to an absolute minimum. At VTEC, a model based development environment was used, where the ITS stack became a part of a larger platform.
The tools used by VTEC (Rational Rhapsody) proved to be very weak at importing source code, which caused a lot of trouble at VTEC. For Actia, the code generated by the VTEC modeling tool was more or less unreadable, unmaintainable and full of dependencies to parts of the VTEC platform.

3.6.5.6 Vehicle integration

The vehicle integration was handled by VTEC and Actia separately with very little need or use for cooperation.
In the software, each implementation has two main integration points: the vehicle abstraction layer and the HMI device. The vehicle abstraction layer reads data from the CAN bus, and provides the data to the ITS stack in a standardized manner. The HMI device software interface was never standardized, so the differences in the HMI have been handled by writing specific applications for VTEC and Actia.

3.6.6 Other software produced

Apart from the ITS stack, a number of test tools were created. Most notably, a tool for testing 802.11p traffic throughput and signal quality was written by Actia. This tool was used for lab tests of the antennas developed as a part of ETTE and also for measurements done in Hällered and “real life” testing of signal quality.

3.6.7 Test results

The VTEC and Actia implementations were tested together at several occasions. The implementations proved to work well together most of the time.

3.6.7.1 802.11p tests

The main problems were caused by very limited signal reception. There had to be a clear line of sight between transmitter and receiver for 802.11p packets.

3.6.7.2 LTE tests

In LTE, the line of sight-problem experienced by 802.11p was no longer a problem.

As long as all vehicles had LTE connectivity, it worked very well. The round-trip time was measured continuously. In the normal case, a packet went from originating ITS-S, through the IP-ITS server and further on to the receiving ITS-S in around 35 ms. However, the round-trip time varied greatly. At irregular intervals, the round-trip could take more than 300 ms. The cause of this was never found.

3.6.8 Lessons learned / problems

- Joint software development can only be performed if both parts use similar development environment. Alternatively, have very well defined deliverables and interfaces.
- A very significant improvement of 802.11p transmitters / receivers is required, or else the ITS system will be useless.
- A lot of time was lost in cable trouble. Badly chosen USB cables caused all sorts of trouble. An expert on the chosen type of hardware should have been employed.
- Changing ETSI specifications created a moving target for the software development.

3.7 WP5c Test bench development

3.7.1 Objectives

The overall objective is to investigate the possibility of using a multipath propagation simulator (MPS) for external car communication tests. An MPS consists of an array of antennas encircling the test object, where each antenna simulates one signal propagation path. It also consists of a signal processing box that implements various signal imperfections in order to achieve a realistic channel.

3.7.2 Activities

The work is mainly experimental. It is broken down into several parts. First, an MPS equipment is designed, built, and calibrated for commonly used frequent bands, one of which is the V2X band at 5.9 GHz. It is set up at the "störmätplats" (SMP) at VCC. Passive measurements are performed in order to investigate the amount of disturbance and interference in the setup. Specifically, reflections and diffractions from the test object (car) are studied for three car models (C30, S60, XC90). Reflections from the ground and cover structure at the SMP are also studied. A few experiments with active signaling tests on 802.11p are performed, both as conductive measurements and over-the-air. A setup in a semi-anechoic room at SP is also tested, with passive measurements, similar to those at the SMP. Channel models, for 802.11p and cellular systems, are derived theoretically, and implemented in the MPS.

3.7.3 Results

The experiments have provided many results. They show that the MPS technique is indeed a viable technique for external car communication tests. Disturbances are at a fairly low level at the SMP, and at a very low level in the semi-anechoic room. This means that it is possible to accurately control the signal environment in the MPS, i.e. it is possible to implement various channels as desired. The passive measurements have also resulted in knowledge of what calibrations need to be performed on the MPS before each measurement.

The active signaling tests have showed that the MPS can be used to characterize a radio transmitter/receiver in a controlled way. Sensitivity to average power, time dispersion, and Doppler shift can be studied, individually or in combination.

3.7.4 Publications

N. Arabäck, P. Hallbjörner, "Serrodyne Frequency Translators for Doppler Shift in Multipath Propagation Simulators," Proceedings of the 7th European Conference on Antennas and Propagation (EuCAP), Göteborg, Sweden, 8-12 April 2013, pp. 967-969.

M. Nilsson, P. Hallbjörner, N. Arabäck, B. Bergqvist, F. Tufvesson, "Multipath Propagation Simulator for V2X Communication Tests on Cars – Design Aspects and Feasibility Experiments," Proceedings of the 7th European Conference on Antennas and Propagation (EuCAP), Göteborg, Sweden, 8-12 April 2013, pp. 1294-1298.

T. Ödman, P. Hallbjörner, "Vivaldi Antenna with Low-Frequency Resonance for Reduced Dimensions," Proceedings of the 7th European Conference on Antennas and Propagation (EuCAP), Göteborg, Sweden, 8-12 April 2013, pp. 2389-2391.

3.8 WP6a Antenna verification

3.8.1 Objectives

Good antenna design and accurate antenna placement are crucial for signal quality in wireless communications. Therefore the overall objective in this work package is to develop accurate and repeatable antenna verification methods enabling accurate verification during product development. Methods which can handle: the effect of ground plane reflection (two-ray path loss channels), antennas affected by the supporting vehicle (with radiating nulls and long far-field distance as result) and complex test structures (cars, cars with trailers, heavy vehicles, etc.).

3.8.2 Activities

Test objects were Smarteq antenna ETTE_ANT and a test monopole (from SP) mounted at several different positions at two different vehicles: ETTE S60 and FH truck. Measurements were performed with either passive measurement system or by the active radio from ACTIA.

Initial tests were performed in SPs large anechoic chamber (Faraday) November 2012 [6]. Results from this measurement are described in chapter 3.5.4. Measurement accuracy was to some extent affected by the high carrier frequency in combination with the size of the test object, which was a contributing reason why outdoor measurements were carried out at Hällered test track outside city of Borås in June 2013 [7].

Here tests were performed on two different test tracks: A test-surface named Skidpad (Hällered test track no. 12) which was used for a new type of radiation pattern measurements developed in this project and a straight road part of test track no. 23, which was used for range measurements.

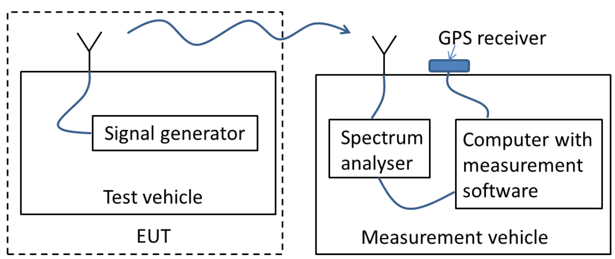


Figure 32: Test set up

Test setup. A signal generator located in the test vehicle (left) transmits a CW signal to the measurement vehicle equipped with spectrum analyzer (right). The measurement vehicle is also equipped with a GPS receiver for positioning and a computer with measurement software.

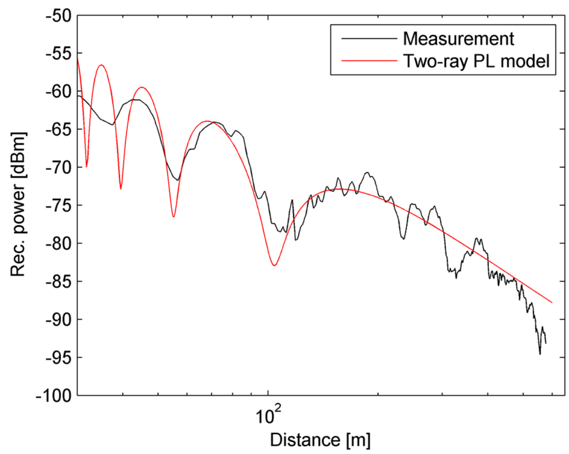


Figure 33: Range measurement between Volvo S60 with ETTE_ANT antenna and measurement vehicle. Measured data and theoretical two-ray model

3.8.3 Results

In both passive and active tests it turned out that coverage is strongly influenced by the vehicle on which the antenna is mounted and is very limited by large metallic objects such as the container of a truck.

It was also observed that during the range test, the received signal strength could be well approximated with the relatively uncomplicated channel model called two-ray path loss model. A model which combines the Line Of Sight (LOS) component with the ground reflection component (reflected in asphalt in this case).

Range and Skidpad measurements were performed at low speed implying long coherence times and almost no Doppler shift on the channel and should therefore be considered a best case result. Neither is there any traffic between the nodes disturbing the radio channel. On the other hand there were not much metallic objects around the test and measurement vehicles reflecting waves and in that way creating a multipath environment. The latter would possibly have extended the range.

Figure 34: Range Test object Volvo S60 in the middle of Skidpad and measurement vehicle driving around it following circle lines on different radiuses on the Skidpad. Upper right shows the measurement vehicle

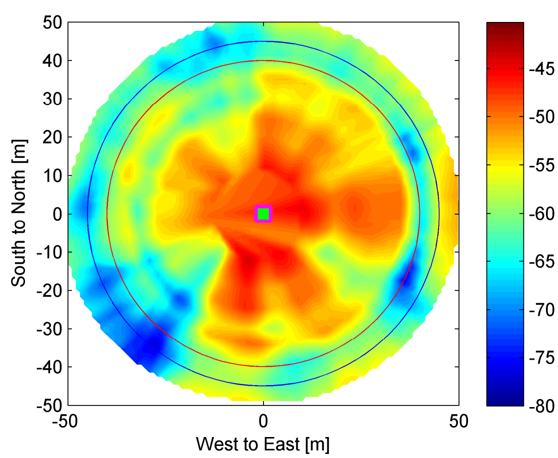


Figure 35: Example of results: received power at ETTE_ANT antenna mounted on Volvo S60. Colorbar unit: dBm.

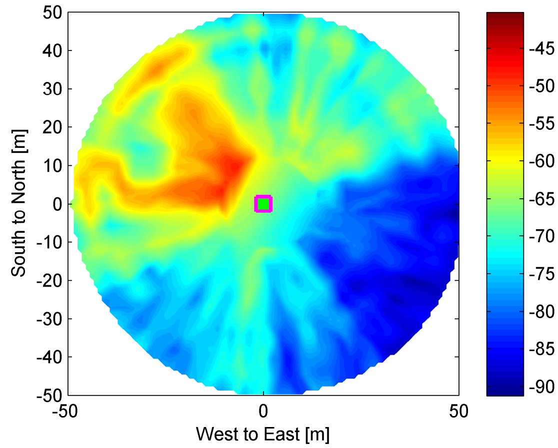


Figure 36: Example of results: received power at ETTE_ANT antenna mounted on FH Truck. Colorbar unit: dBm.

3.8.4 Publications

K. Karlsson, J. Carlsson, T. Andersson, M. Olbäck, L. Strandberg, M. Hellgren, “Distance Dependent Radiation Patterns in Vehcile-to-Vehicle Communications,” submitted to EuCap 2014, Hague, Netherlands, on 6-11 april 2014.

3.9 WP6b Router validation

3.9.1 Objectives

Validate the VCC and VTC ETTE node

The validation of the nodes was focused the following areas:

1. Performance test → measure the CPU load caused by the ITS-G5 stack (V2x), this test give important knowledge of the required CPU performance required in the next generation connectivity ECU:s
2. 802.11p radio communication range tests: measure the communication range achieved with the ETTE Node 802.11p RX and TX characteristics → give recommendations for the next generation connectivity ECU:s
3. V2x use case validation → validate the implemented uses cases on bench and in vehicle, interoperability tests between VCC ETTE Node and VTC ETTE Node
4. Validate the vehicle integration: HMI and CAN

3.9.2 Performance tests

Performance tests were performed by both Actia and VTEC.

3.9.2.1 Actia

The test was performed by running in a simulated but well controlled environment, consisting of four simulated ITS-S and one running on actual hardware.

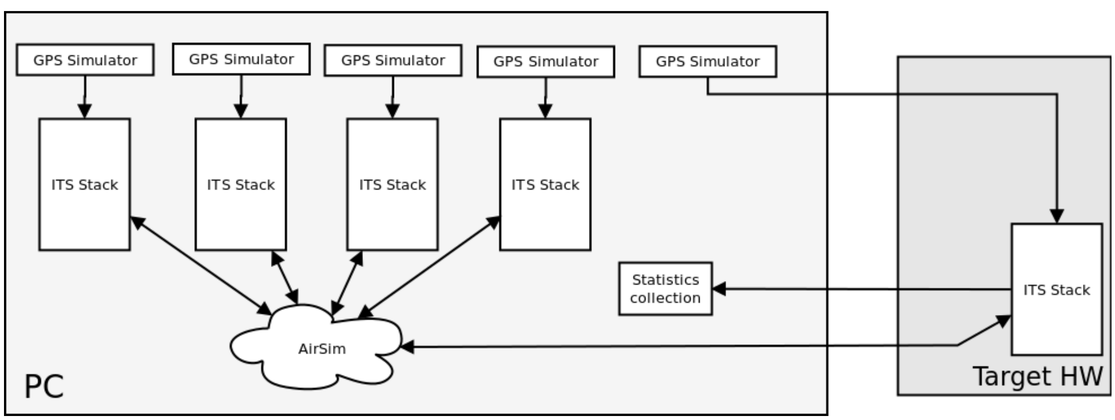


Figure 37: Performance test set up

All stacks were transmitting packets, loading the ETTE node. In the table below, the frequency is the number of packets sent by each node. Due to packet forwarding and routing rules and test inaccuracies, the approximate number of packets handled by the ETTE node is:

- @100 Hz: 750 p/s received, 320 p/s transmitted
- @50 Hz: 380 p/s received, 190 p/s transmitted
- @25 Hz: 190 p/s received, 100 p/s transmitted

Tests were performed with three different kinds of packets:

- Only GeoNetworking packets; GeoBroadcasting with no payload. Tests performance of OS/network/transport layers.
- DEN packets, unencoded: Like the first test, with the addition of DEN basic service and LDM.
- DEN packets, ASN.1 encoded: Like second test, but with DEN payload ASN.1 encoded. This is the most realistic case.

	GeoN	**DEN**	**DEN+ASN.1**
100 Hz	N/A	70%	N/A
50 Hz	35%	38%	53%
25 Hz	18%	19%	27%

Note: no tests have been made on encrypted / signed packets. However, introduction of cryptographic functions in the system will increase the CPU load very significantly, probably with a factor of at least 2.

The measurements above indicate that around 600 packets handled per second is the practical limit (50% CPU load) in the current hardware.

Due to the highly dynamic nature of the ITS packet routing, packet generation and a very weak state of the ITS application specifications, it's hard to estimate the actual number of packets sent / received by an ITS-S during a drive in a normal traffic environment.

3.9.2.2 *VTEC*

Reslut from Volvo Truck TGW2 unit with only DENM messages

Msg/sec per node	Idle	1 node sending	2 nodes	3 nodes	4 nodes
10	9%	15%	21%	25%	30%
10 (ASN1)	9%	19%	25%	30%	35%
20	9%	21%	30&	40%	49%
20 (ASN1)	9%	25%	36%	48%	60%

Predicted max number of notes with this setup:

- 16 nodes at 10 msg/ sec
- 9 nodes at 20 msg/ sec

3.9.3 802.11p Radio Communication range tests

The purpose of the radio communication range tests was to verify if the ETTE Node 802.11p modem TX power and RX sensitivity in combination with the ETTE vehicle integration (antenna cable attenuation, antenna gain) gives sufficient communication range.

3.9.3.1 Link budget calculations:

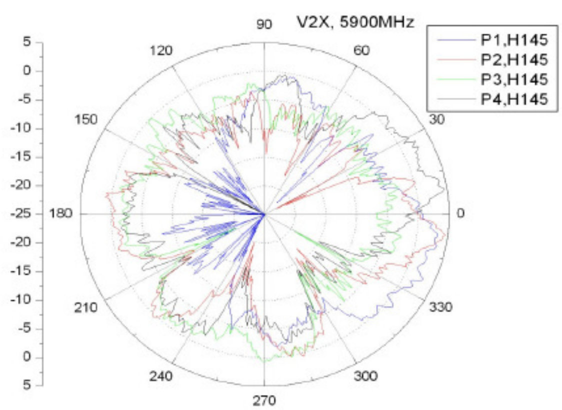
Modem specification:

- Receiver sensitivity: -90dBm
- Output power: 16dBm

Antenna Cable attenuation: 4dB
Connector attenuation: 1 dB

Antenna Gain:

	Volvo S60	
	P1	P4
Angle	Gain	Gain
0	1	0
15	-4	2
30	-5	2
45	-22	0
60	-7	-10
75	-3	-4
90	-3	-4
105	-9	-10
120	-10	-6
135	-15	-6
150	-15	-20
165	-20	-3
180	-20	-3
195	-15	-8
210	-15	-10
225	-25	-3
240	-25	-3
255	-5	-12
270	-5	-7
285	-5	-4
300	-5	-11
315	0	-10
330	1	-10
345	2	-5



The calculation below shows the link budget margin in dB with antenna position P1 with 2 vehicles located front to front

Communication distance [m]	Margin in [dB]
10	29
20	23
50	15
100	9
150	6
200	3

300	0

This calculation indicates that the expected communication range is 150 to 200 meter

This theoretical calculation is well in line with communication range that was achieved during field tests. In some cases the communication rage during field test was longer than expected (compared with the link budget calculation)
For a serial production system a communication range up to 800 most probably will be required.

This could be achieved by:

- Increased modem RF performance: Receiver sensitivity: -92dBm, Output power: 23dBm
- Reduced cable losses→ short distance between V2x modem and antenna
- Increased antenna gain

3.9.4 V2x use case validation

The following use cases were validated:

- Stationary Vehicle Warning
- Hazardous Location (Slippery Road)

The VTEC and Actia implementations were tested together at several occasions. The implementations proved to work well together most of the time.

3.9.4.1 802.11p tests:

The main problems observed were caused by limited signal reception (see section Link budget calculations). 802.11p @ 5.9GHz did require clear line of sight between transmitter and receiver.

Also tests with two approaching vehicles was performed, the individual vehicle speed was 80km/h. In this case the waning message was showed in the HMI in slightly before the vehicles was passing each other (very late).

3.9.4.2 LTE tests:

The Stationary Vehicle Warning was also tested with LTE (4G)

In LTE, the line of sight-problem experienced by 802.11p was no longer a problem.

As long as all vehicles had LTE connectivity, it worked very well. The round-trip time was measured continuously. In the normal case, a packet went from originating ITS-S, through the IP-ITS server and further on to the receiving ITS-S in around 35 ms. However, the round-trip time varied greatly. At irregular intervals, the round-trip could take more than 300 ms. The cause of this was not understood.

3.9.4.3 Use case stationary vehicle warning tests

3.9.5 ETTE use case test stationary vehicle warning

The cooperative function stationary vehicle warning was tested for eight scenarios with the ETTE S60 communicating with the FH truck on a straight road. Se Table I for definition of test vehicles: stationary or approaching, antenna location and direction of approaching vehicle. Results are shown in Table II [7].

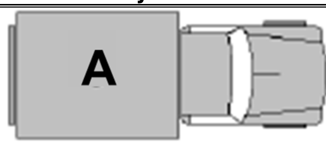
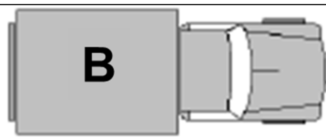
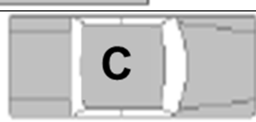
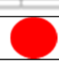
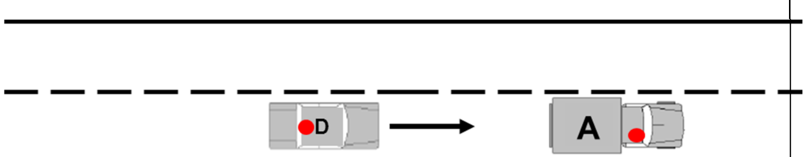
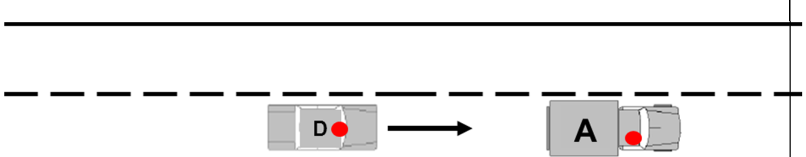
Symbol	Description
	Stationary FH Truck
	Approaching FH Truck
	Stationary ETTE S60
	Approaching ETTE S60
	Antenna location
	Approaching Vehicle driving direction

Figure 38: Definition

Test	Description	Result
1		Warning when D passes A.
2		Warning when D passes A.
3		Warning in D approximately 270 m before

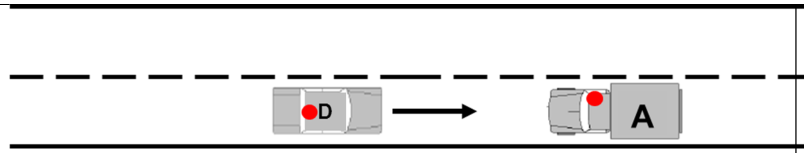
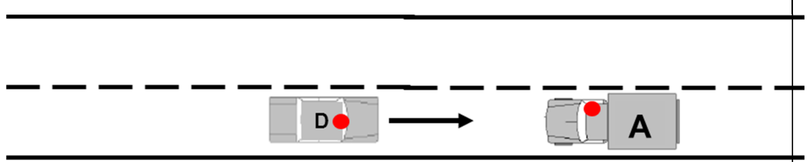
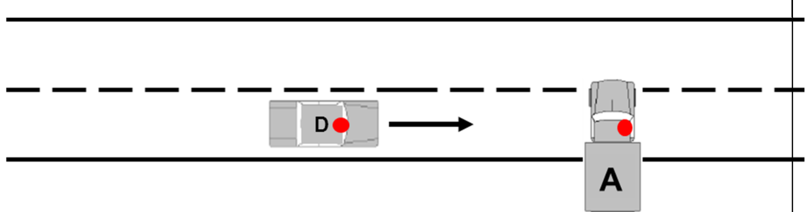
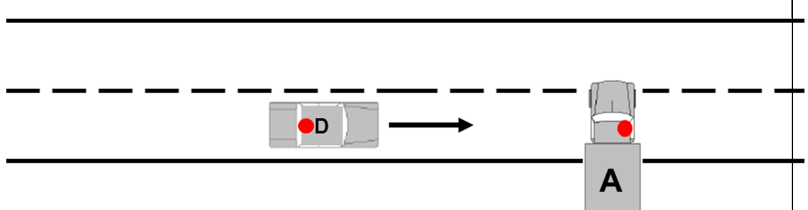
		A impact.
4		Warning in D approximately 410 m before A impact.
5		Warning in D approximately 10 m before A impact.
6		Warning when D passes A.

Figure 39: Test set up

3.9.6 Conclusions / recommendations

3.9.6.1 CPU performance:

The CPU performance test shows that an ARM926 CPU @ 400-450 MHz not gives sufficient performance for V2X, coexistence with other connectivity services will not possible.

There are different approaches to solve the CPU performance issue

- Use a CPU with significantly higher performance:
  The current ARM926 @ 450 MHz gives approximately 450 MIPS, an ARM Cotex A9 @

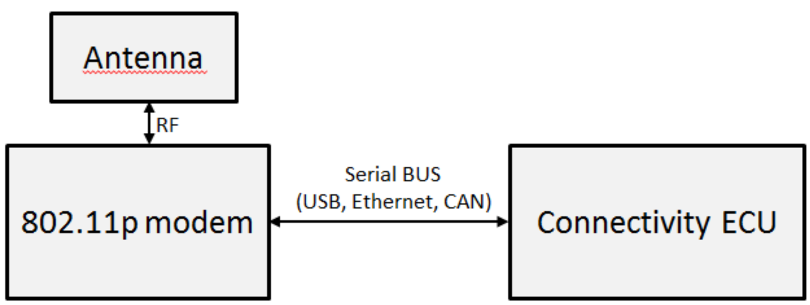
800MHz gives approximately 2000MIPS. There are also ARM Cortex A9 CPU:s with dual and quad core available

- Use Separate CPU for V2X (ITS-G5) and other connectivity services

3.9.6.2 Communication range issue:

The following recommendations is identified

- Keep the distance between the 802.11p modem and antenna as short as possible (minimize cable attenuation), this can be achieved by either locate the complete NODE (connectivity ECU) close to the antenna or by separating the 802.11p modem from the NODE (locate only the 802.11p modem close to the antenna).



- Minimize the number of connectors in the RF patch (minimize connector attenuation)
- Increased modem RF performance: Receiver sensitivity: -92dBm, Output power: 23dBm
- Increased antenna gain

3.10 WP6c Coexistence verification

3.10.1 Objectives

Verify coexistence between various antenna systems

3.10.2 Summary

Initial tests where co-existence between wireless systems LTE and IEEE 802.11p (11p) was tested.

3.10.3 Conclusions

Initial tests shows that 11p communication doesn't disturb LTE communication in the VCC_ETTE_Node.

Note: 11p interfered by LTE was not possible to test.

3.10.4 Possible next steps

Further tests require an autonomous radio node which can be placed inside an RF shielded box to avoid signaling directly to/from radio chip.

3.10.5 Test 1: LTE modem interfered by IEEE 802.11p communication

LTE settings:

- CMW 500 was connected to VTC_ETTE_Node via RF cable and step attenuator.
- 16 QAM modulation was selected, both in up and down link.
- Band 7, Channel 3000, 2645 MHz.

11p settings:

- VCC_ETTE_Node was connected to 11p ETTE_11p_modem via RF cable .
- Max output power from 11p modem in VTC_ETTE_Node.

The test was performed as follows: LTE modem was connected to CMW 500 and instrument was set to monitor throughput and BLER (BLock Error Rate). Step attenuator was increased until significant BLER occurred (approximately 40% and 55 dB attenuation).

11p modem was switched on and off, no degradation of LTE was observed.

3.10.6 Test 2: LTE modem interfered by IEEE 802.11p communication

Identical to Test 1, except communication via antennas. CMW 500 was connected to a broadband disc cone antenna and VTC_ETTE_Node to ETTE_ANT1.

11p modem was switched on and off, no degradation of LTE was observed

3.10.7 Test 2 IEEE 802.11p modem interfered by LTE communication

Neither step-attenuator method or isolation in ETTE_ANT1 was possible to test due to communication directly from radio chip.

3.11 WP7 Dissemination

3.11.1 Objectives

- Disseminate research results within participating organizations.
- Show that concept of some use case of 11p and LTE work in real life based on global ITS G5 standard.

3.11.2 Activities

- Make a physical integrate of required part to demonstrate concept in vehicles

3.11.3 Results

Have done three video clip to demonstrate car 2 car concept:

- Stationary vehicle warning. A Volvo FH truck standing still and Volvo S60 approaching. FH truck broadcast C2C message to S60 and show warning cluster display.
- Stationary vehicle warning. A Volvo S60 standing still and Volvo FH truck approaching. S60 broadcast C2C message to FH truck and show warning in a external display.
- Hazardous location notification. A Volvo S60 drive in front of another Volvo S60. When first car observe slippery road it broadcast C2C message to car behind and show slippery road information in cluster display

Have publish three paper at EuCAP 2013 and one more is plan to present at EuCAP 2014. Further detail appendix A.

4 How the project results will be used

The results will primarily be used in the following way:

VCC: Volvo Car Corporation is working on its next electrical architectural platform called SPA. This platform is planned to span a time period that needs to integrate the Connected Car. Part of project results from the ETTE project is plan to be transferred to one of first car programs on SPA-platform.

VTEC: ETTE has given valuable input to coming projects and decisions within the area of connected vehicles. It has given specific input for judging the maturity of the technology and input to product plans.

Findings from the project will form a foundation for hardware and software design of a commercialized V2x node, including the antenna system. This will also result in extra focus on C2C node capacity, reliability issues, antenna performance and placement of antennas. The result will also give feedback to C-ITS standardization

The experience gained from implementing the C-ITS services in ETTE, will be valuable for implementing the next generation of C-ITS services

Actia: Actia is developing, manufacturing and supplying Telematics control units to the vehicle industry (car, truck and special vehicle), the result from this ETTE project will be used to developing the next generation Telematics control units.

Smarteq: Smarteq is developing, manufacturing and supplying Antennas and RF-cables. The result from this ETTE project will be used to develop the next generation Antenna systems for vehicles. Also to get an understanding for limitations and opportunities when combining the needed antenna system/s on vehicles.

SP: SP is working with research and development in measurement technology for i.e. vehicle communication systems as well as providing advanced measurement facilities. ETTE has given SP a unique opportunity to test new ideas for measurement methods for various aspects of ITS systems that will be valuable input for other projects, especially WCAE.

5 Lessons learn

- For software development of ETTE node.
    - Based on current status of ETSI spec for ITS-G5 are not fully defined and open for own interpretation. Our question marks and comments have been feedback to ETSI. But it is really possible to get vehicle to communicate between each other base on same standard.
    - By this, software development have consume more time than expected

- Based on performed performance measurement of units CPU, today CPU power is not powerful enough to handle this C2C data broadcasting and receiving C2C messages.
- For high frequents as 802.11p (5.9 GHz) have high losses in antenna cables between antenna and receiver. For serie implementation have to move up intelligent & functionality closer to antenna, this going to be investigate in to FFI WCAE
- Antenna position are very sensitive i.e. angle and how good free line of site to transmitter.

6 Recommendations and Conclusions

- Based on vehicle range and performance measurement, this project have give good knowledge of this technology possibilities and challenges to deploy Car2Car according to signed MoU between vehicle OEMs and infrastructure.
- A car with curved roof, car need to have one antenna pointed forward and one on roof, to get required performance.
- For truck installation: It would be challenge to vehicle to vehicle/ infrastructure reward for trucks with cargo, when signal level reward will be very limited. This question will continue to look in to in EU project RealComH, there we have share some of our result.
- There is a need of unique RF cables for V2X and WLAN, 4G (2600MHz) compared to traditional cables used today in the automotive industry due to high losses.

7 How partners will use result

- VCC: This result will be one of many important piece in puzzle to reach a Connected Car and our vision with no serious injured human year 2020.
- VTEC: ETTE has given valuable input to coming projects and decisions within the area of connected vehicles. It has given specific input for judging the maturity of the technology and input to product plans.
- Actia: Actia is developing Telematics control units to the vehicle industry the result from this ETTE project will be used to developing the next generation Telematics control units
- SP: ETTE has given SP a unique opportunity to test new ideas for measurement methods for various aspects of ITS systems that will be valuable input for other projects, especially WCAE.
- Smarteq: The result from this ETTE project will be used to develop the next generation Antenna systems for vehicles.

8 Future work

Multipath Propagation Simulator
Continue the work from ETTE in to WCAE, by using six-sigma methods in devising design-of-experiments (DOE) tests and using measurement system analysis (MSA) to achieve confidence in the MPS repeatability performance. In doing this, the MPS hard- and software will be developed further into a useful tool in product development of cars

and heavy vehicles. Future measurements on various communication systems and vehicle models should also be performed. The goal is a set of verification methods for signaling tests of all systems used for external communication, on vehicles including the entire signal chain, i.e. signal environment, vehicle, antenna, radio transceiver, and cables. The verification methods should allow for the distinction between good and bad installation in vehicle, including transceiver, cables, and antenna, in a sense that is relevant to the quality perception of the end user. Within this goal, the methods will also allow simple pass/fail tests in a number of realistic scenarios, without necessarily establishing the performance limits of the radios/antennas.

Further break down of customer requirement to subsystem requirement
In ETTE the focus was to gain knowledge and proof of concept about the LTE and 802.11p technologies and in WCAE the next step will be taken. This means that the transfer function will be identified between customer needs and system level and from system level to component level so that the OEM can have confidence if that the supplier fulfill the component specification the customer needs will also be fulfilled. By having knowledge about the transfer functions and if there are non-linear input requirements that can be optimized towards the same output as before, but will less transmitted variance, means that the tolerances can be more relaxed on the input parameters and this saves cost.

Appendix A – Paper abstract

N. Arabäck, P. Hallbjörner, "Serrodyne Frequency Translators for Doppler Shift in Multipath Propagation Simulators," Proceedings of the 7th European Conference on Antennas and Propagation (EuCAP), Göteborg, Sweden, 8-12 April 2013, pp. 967-969.

M. Nilsson, P. Hallbjörner, N. Arabäck, B. Bergqvist, F. Tufvesson, "Multipath Propagation Simulator for V2X Communication Tests on Cars – Design Aspects and Feasibility Experiments," Proceedings of the 7th European Conference on Antennas and Propagation (EuCAP), Göteborg, Sweden, 8-12 April 2013, pp. 1294-1298.

T. Ödman, P. Hallbjörner, "Vivaldi Antenna with Low-Frequency Resonance for Reduced Dimensions," Proceedings of the 7th European Conference on Antennas and Propagation (EuCAP), Göteborg, Sweden, 8-12 April 2013, pp. 2389-2391.

K. Karlsson, J.Carlsson, T. Andersson, M. Olbäck, L. Strandberg, M. Hellgren ”Distance Dependent Radiation Patterns in Vehcile-to-Vehicle Communications. Plan to present at 8th European Conference on Antennas and Propagation (EuCAP), Göteborg, Sweden, 6-11 April 2014

Appendix B – Master thesis abstract

The Cooperative Intelligent Transport Systems (C-ITS) is a set of applications that aims to improve road safety and traffic efficiency as well as providing environmental benefits by enabling vehicles and roadside infrastructures to communicate with each other. This type of communication is mainly based on exchanging messages containing information such as speed, location and direction sent over an ad hoc local area network (IEEE 802.11p or ETSI ITS G5). However, the privacy of the users could be impaired by an adversary intercepting the exchanged messages between the ITS stations in an ad hoc vehicular network. Further, the lack of security requirements such as authentication and authorization allows unauthorized vehicles to get access to particular applications, services or privileges that should be only accessible by authorized vehicles. As an effort to validate and authorize the ITS stations in a Vehicular Ad hoc Networks (VANET), the European Telecommunication Standards Institute (ETSI) has introduced a security architecture that brings the pseudonymity, confidentiality, authenticity and integrity into the VANET communications by using Certificate Authorities (CAs) and identity management procedures.
As collaboration between Chalmers University of Technology and Volvo Cars Corporation, this master thesis aims at conducting vulnerability assessment on Secured Message and Identity Management Services in ETSI ITS C2C Communications by integrating sign/verification services into an already insecure implementation of the ETSI ITS communication system called ETTE.

Appendix C – List of deliverables

Ref no.	Deliverable	Delivery type		Reference:
[1]	Analysis Communication Technologies	Report		VCC Lotus Notes CPI
[2]	ETTE System Design Description	Report		VCC Lotus Notes CPI
[3]	OOFMEA_ETTE 1.0	Report		VCC Lotus Notes CPI
§	ETTE VP4 USE CASES	Report		VCC Lotus Notes CPI
[5]	ETTE antenna specification	Report		VCC Lotus Notes CPI
[6]	Radiation patterns at SP	Report		VCC Lotus Notes CPI
[7]	Propagation measurement at Hällered V1.2	Report		VCC Lotus Notes CPI