Paper number ITS-2790

IDEA: a location-based system for innovative hybrid diesel engine applications

Alfredo Favenza[1]*, Claudio Rossi[1], Daniele Brevi[2], Guido Gavilanes[2], Gianluca Marucco[2]
1. Microsoft Innovation Center, Torino, Italy
2. Istituto Superiore Mario Boella, (ISMB), Torino, Italy
* via P.C. Boggio, 61 – 10138 Torino – favenza@ismb.it - tel: 011 2276425

1. Abstract

Intelligent Transportation Systems (ITS) represent nowadays a major transition in transportation on many dimensions, from traffic safety improvement and transportation efficiency, to air pollution reduction and energy efficiency.
European GNSS, together with vehicular communication, represent an opportunity to enhance ITS. Accurate positioning is crucial for the development of vehicular applications based on Location Based Services (LBS).
In this paper, the authors propose iDea (Innovative Diesel Engine Application): an architecture for a vehicular system that feeds the powertrain selection algorithm of a vehicle with hybrid engine configuration, with both diesel and electric fuelling. To demonstrate the feasibility of our approach, the authors implemented it on a real test-bed. Our final aim is to help automotive industries to implement innovative vehicular applications targeted at increasing safety and reducing air pollution.
Keywords: ITS, GNSS, V2X

2. Introduction

In the period ranging from 2013 to 2023, according to the Market Report (March 2015) of the GNSS European Authority (GSA), LBS will represent the largest market in GNSS (53.2%) followed by Road segment (38%). Moreover, thanks to a continuing cost reduction and performances increase of satellite navigation equipment, the dependence of these Intelligent Transport System applications on Satellite Navigation systems is expected to grow further, especially in the mass-market segment.
The main goal of our solution is to deliver an information service to support the management of a multimodal hybrid propulsion engine, that in its turn represents an emerging trend. The proposed solution relies on traffic, positioning and map information coming from different data sources. Collected data are processed, combined and sent to a vehicle embedded device that selects the optimal engine propulsion modality. This optimized setting acts as the vehicle on-board energy management system, which helps in reducing the power consumption.
To achieve this goal, the proposed architecture involves the use of the following technologies:

- Advanced satellite navigation systems, which rely on Satellite Based Augmentation Systems (SBAS), and integrity computation;
- Vehicular communication systems, such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I);
- Embedded systems and ad-hoc platforms able to collect and process information from heterogeneous sources;
- Cloud computing centralized system, based on the Platform as a Service (PaaS) paradigm.

The vehicular information processed within iDea belongs to two different classes:

- "Global information", such as traffic conditions forecasting, which can influence the route planning and have an effect on the engine trim at macroscopic level;
- "Local information", such as information coming from other vehicles in a limited area, (e.g. position and velocity) or from Advanced Driver Assistance Systems (ADAS), e.g. cartographic data. This information can enable a fine control of the engine parameters allowing the Electrical Control Unit (ECU) to operate in an optimized mode on the basis on the road morphology, the surrounding traffic, and the local traffic regulations. This approach responds to the indications of ETSI and the European scientific community that is strongly emphasizing the relevance of local traffic and environmental awareness of vehicular applications [1].

Thus, our system makes available the information needed to choose the best power source according to the specific scenario and environmental conditions.

3. Defined use cases

In order to test and validate the system, the authors have identified and selected four most significant use-cases applicable in urban and sub-urban road scenarios:

1. Fuelling automatic selection based on local traffic regulations;
2. Fuelling automatic selection based on real-time local vehicular traffic through Vehicle-to-Vehicle (V2V) communication;
3. Fuelling automatic selection based on planned path to destination (on-the-go power management);
4. Assisted braking.

Use-case 1: Fuelling automatic selection based on traffic local regulations.
In this scenario, the vehicle needs to change the power source based on its position. An example is the following: the vehicle can enter in a Limited Traffic Zone (LTZ) free or charge (or with a reduced fee) when using the electric engine and then producing zero emissions. If this information is available to the vehicle, the power source can be switched either automatically or giving a warning to the driver in order to operate the brake.
It is worth to notice that the system must ensure that, for all the time spent in the LTZ, the vehicle is being powered with the electric engine. All this information must be sent to a control centre in real time or when the user leaves the LTZ area in order to assess its driving behaviour and for billing as shown in Figure 1.

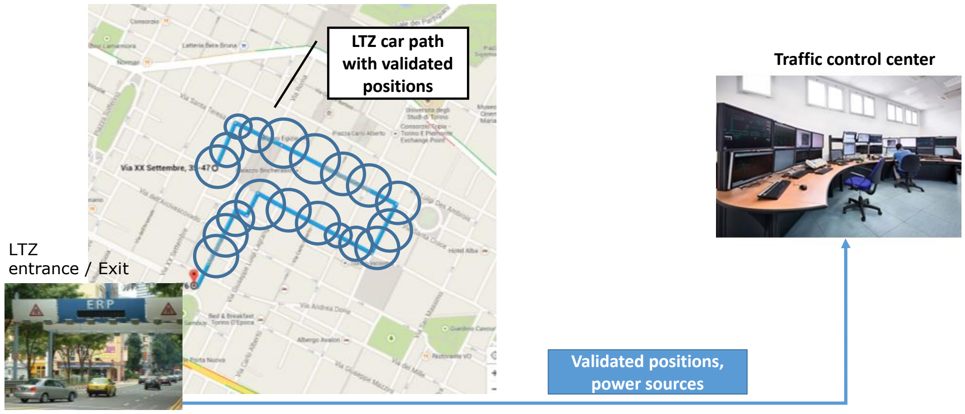


Figure 1 - V2I scenario in Use-case 1

Other examples involve the possibility to reward green driving behaviour e.g. for people that always uses electric engine near schools or other air-pollution sensitive places. Also in this case, validated position and communication through a fixed infrastructure are crucial.

Use-case 2: Fuelling automatic selection based on real-time local vehicular traffic through Vehicle-to-Vehicle (V2V) communication.
This scenario involves V2V communication only. The European Telecommunications Standards Institute (ETSI) standardized a set of Cooperative Aware Messages (CAM) to be exchanged through vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) with different purposes. The most important is related to safety but the exploitation of many others have been proposed in literature.
CAM messages allow all equipped vehicles to build a local dynamic map (LDM) with the position of all other vehicles (equipped with 802.11p [2] transceivers) within the radio range. This information can be used for realizing a security distance-maintaining system that can inform the system of a potential dangerous situation caused by trespassing the security distance of the vehicle ahead. For this type of service, the precise assessment of the position is cucial. In fact, the system must compute the distance between a vehicle and the preceding car and react (automatically adjusting the distance or with a warning to the driver) if it is smaller than the security distance, as shown in Figure 2.

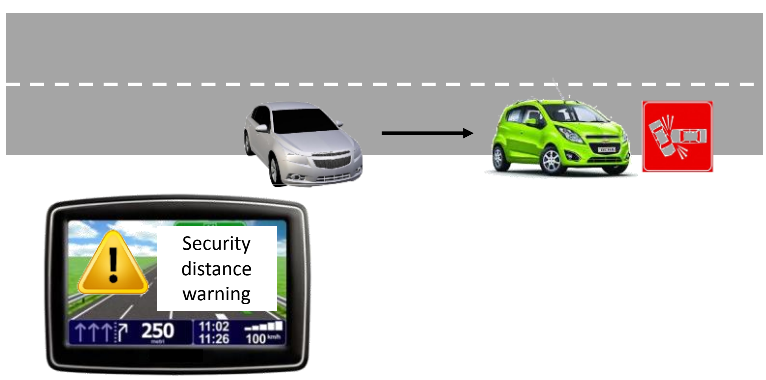


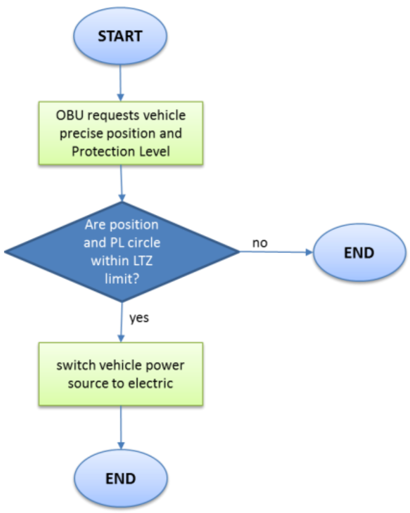
Figure 2 - V2V security distance warning

The embedded systems installed in the vehicle are empowered with the Advanced Positioning System. The vehicle on-board unit (OBU), which is connected with the embedded system, enquires to receive the vehicle position in order to change the type of propulsion.

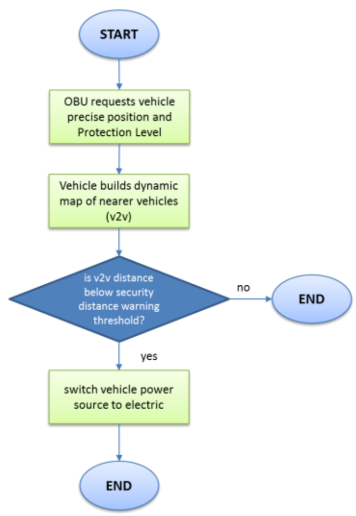
Use-case 3: Fuelling automatic selection based on planned path to destination (On-the-go power management)
The driver can request to the car Human Machine Interface (HMI) to calculate the planned path to a certain destination on the basis of start and destination geographic points. Starting from the path obtained by the navigator, the system can calculate the "Power Consumption Profile" (PCP) taking into account road segment distances and road slopes. This enables the vehicle to suggest the best type of propulsion for each segment.

Use-case 4: Assisted braking
While the vehicle is moving, the user is alerted when other vehicles trespass the eco-safety distance limit. This is necessary to minimize the possibility of sudden brakes with a low regenerative electrical power return. So the driver is warned about these non-eco-safe driving conditions.

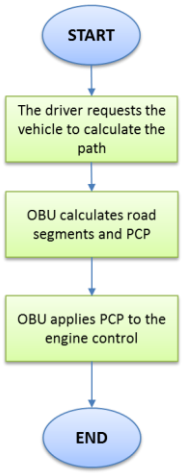
Figure 3 shows the flow chart diagrams of the four aforementioned use-cases.



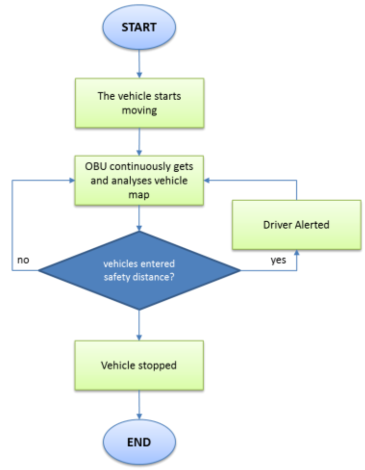
(a) Use-case 1



(b) Use-case 2



(c) Use-case 3



(d) Use-case 4

Figure 3 - Use-cases flow diagrams

4. EGNOS/EDAS

The European Geostationary Navigation Overlay Service (EGNOS) is the first pan-European satellite navigation system. It augments the satellite navigation systems (currently GPS), making them suitable for safety critical applications.

EGNOS provides corrections and integrity to GPS signal over a broad area centered in Europe. EGNOS is divided into four functional segments: the first is called ground segment, it is composed of the several stations and centres which are mainly distributed in Europe and are interconnected between themselves through a land network. 39 Ranging and Integrity Monitoring Stations (RIMS) receive the satellite signals and send this information to 4 MCC (control and processing centres), these generate correction messages to improve satellite signal accuracy and information messages on the status of the satellites (integrity). 6 NLES (Navigation Land Earth Stations) upload of the data stream to the geostationary satellites generating a GPS-like signal. This data is then transmitted to the European users via the geostationary Satellite. The second is EGNOS support segment, it performs the activities of system operations planning and performance assessment. The Space Segment is composed of three geostationary satellites, while the user segment consists in the EGNOS enabled user receivers.

The EGNOS corrections refer to: ephemeris and clock errors for each GPS satellite in view, and ionosphere delays. The EGNOS system can also warn the users in case anomalies in GPS data, which are detected in a constrained timeframe.

As told, users can benefit from the EGNOS system by receiving the signals broadcasted by the GEO satellites, also called the Signal-In Space (SIS), however, due to obstructions, as tall buildings, the user may not be able to receive the SIS, which happens very frequently in dense urban scenarios. The EGNOS Data Access Service (EDAS) [3], [4] provides the mean to deliver EGNOS data through general purpose ground-based networks. The high level architecture of EGNOS/EDAS is shown in Figure 6, which sketches the different delivery schemes of the systems.

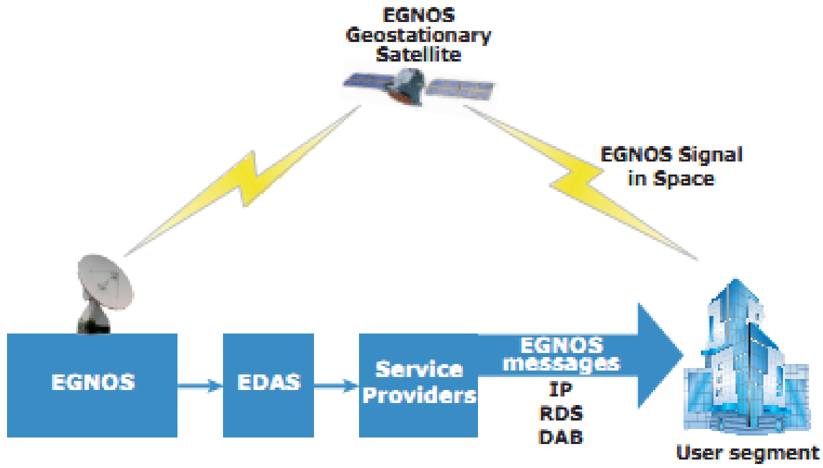


Figure 4 - EDAS high level architecture

EDAS can delivery two main types of data in real time:

- Augmentation information (including integrity), as normally received by users via the EGNOS geostationary satellites;
- Raw data collected by the EGNOS RIMS.

Within the frame of iDea, the EDAS service type is selected by the user as first step, while the second step, upon reception of the EDAS data, is the content parsing. It is demanded to a component called EGNOS Message Decoding Component, which extract all EGNOS messages based on the 6-bit message type identifier. After decoding, the receiver can decide to apply the corrections, , use the integrity information alone or in the frame of the augmented position computation. However, generally there are two modes of operation:

- Correction-only mode, in which EGNOS data are used to improve the accuracy of pseudoranges and satellite positions. Thus, the GNSS receiver computes a more accurate final Position Velocity Time (PVT) vector;
- Corrections-plus-integrity mode, the system uses the information from EGNOS also to calculate Horizontal and Vertical Protection Levels.

Figure 5 shows the flow chart of the operations performed by the EGNOS Message Decoding Component, from the decoding phase to the final output, while Figure 6 (a) sketches the Horizontal Protection Level (HPL) computed through EDAS. Figure 6 (b) shows the position errors with and without EDAS, obtained collecting one sample every second for several hours at a single known position. On average, the EDAS augmentation algorithm reduces by 0.18m and 2.78m the longitude and latitude error, respectively.

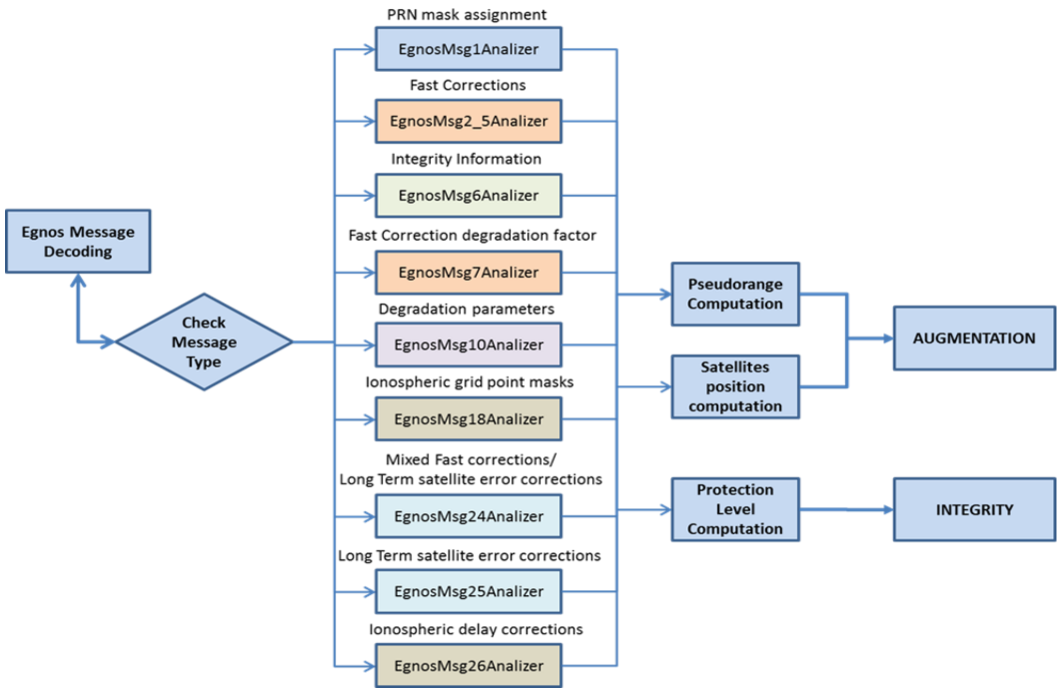
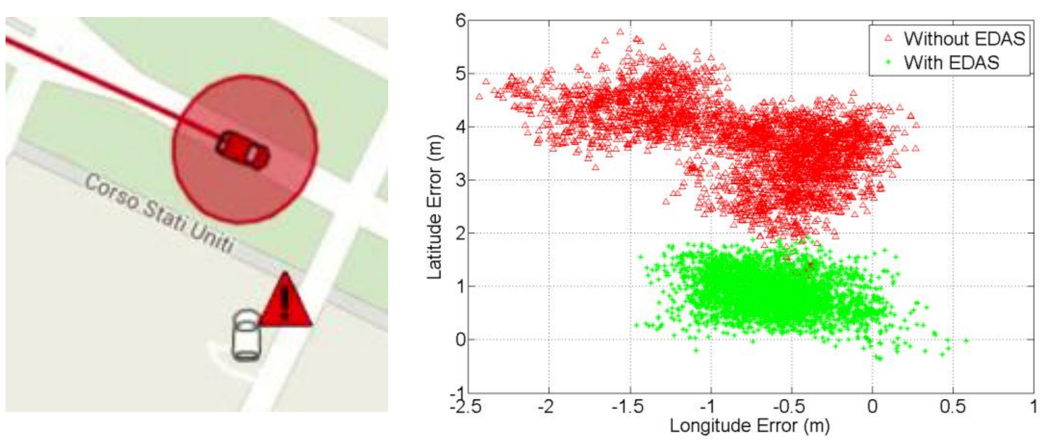


Figure 5 -High Level flow chart of the EGNOS Message Decoding Component



(a) HPL in practical for vehicles (b) Comparative positioning measurements

Figure 6 -EGNOS/EDAS Horizontal Protection Level

5. Idea Architecture

The iDea architecture is composed by three main subsystems, namely:

1. a Custom Embedded Device (CED) for location based service implementation that includes a GNSS receiver, an embedded computation board and a multimodal wireless interface;
2. a centralized backend for cloud-based EGNOS/EDAS augmentation;
3. Road Side Units (RSU) that supports the V2I communications locally or whenever there is a poor cellular coverage.

The CED is installed in the vehicle: it is needed to implement the location-based services considered in iDea.
The CED is interfaced with the Electronic Control Unit (ECU), which provides important information needed by the iDea applications: namely the battery and fuel level for the electric and for the diesel propulsion, respectively. The ECU is fed by the CED with the data necessary to switch the fueling or to perform an assisted brake according to the situation.
The CED is equipped with a multi radio wireless interface, featuring both a 802.11p compatible wireless card and a 3G/4G modem. Thus, the vehicle is assumed to be always connected to the internet through the cellular network, which is ubiquitous in all urban environments. In this way, costly Road Side Unit (RSU) deployments are not necessary to guarantee Internet connectivity. Furthermore, map APIs (Google Maps, TomTom, Bing, etc..) are used to obtain paths to any given destination, Limited Traffic Zones (LTZ) boundaries, traffic status, and more.
However, the authors foresee the presence of RSUs in locations where the cellular network is difficult, due to both poor coverage and/or to high peak of data traffic. Of course, RSU must be cabled with a separated backhaul, or rely on the backhaul of the building on which it is installed, to connect the vehicles to Internet and to the iDea back-end. Another advantage of using RSUs is the possibility to assess the presence of a vehicle in the neighboring area, as declared by the OBU, contributing to certify the driving behavior as necessary for the use-case 1.
The centralized back-end features an EDAS client, that fetches the EGNOS messages and stores them on a database using a cloud-based service. CEDs not featuring on-board EGNOS augmentation, can exploit a bespoke cloud service that receives HTTP augmentation requests and performs the augmentation on the cloud. Note that in this case the CED must be able to extract GNSS raw data from the receiver and include them in the request payload. Additionally, this service can be used also by CEDs having on-board EGNOS augmentation when the EGNOS Signal in Space is not available, which is common in urban scenarios.
Also, when the SIS is not available, the CED can decide to request the EGNOS data to the cloud back-end and perform the augmentation on board. To allow this, the cloud back-end provides a service to broadcast previously gathered EGNOS messages.
The cloud architecture enables robustness, flexibly and most of all scalability. Indeed, augmentation services may be used by a very big number of vehicles, requiring a service provisioned according to the real demand, which is achieved through the autoscaling capability of modern cloud systems, such as Windows Azure [5].
Figure 7 shows the iDea overall architecture, highlighting all main system components as well as the main information flows concerning positioning. The position is propagated with the PVT vector along with the associated Protection Levels (PLs), that define the validity boundaries of the position, thus implementing the concept of position integrity.

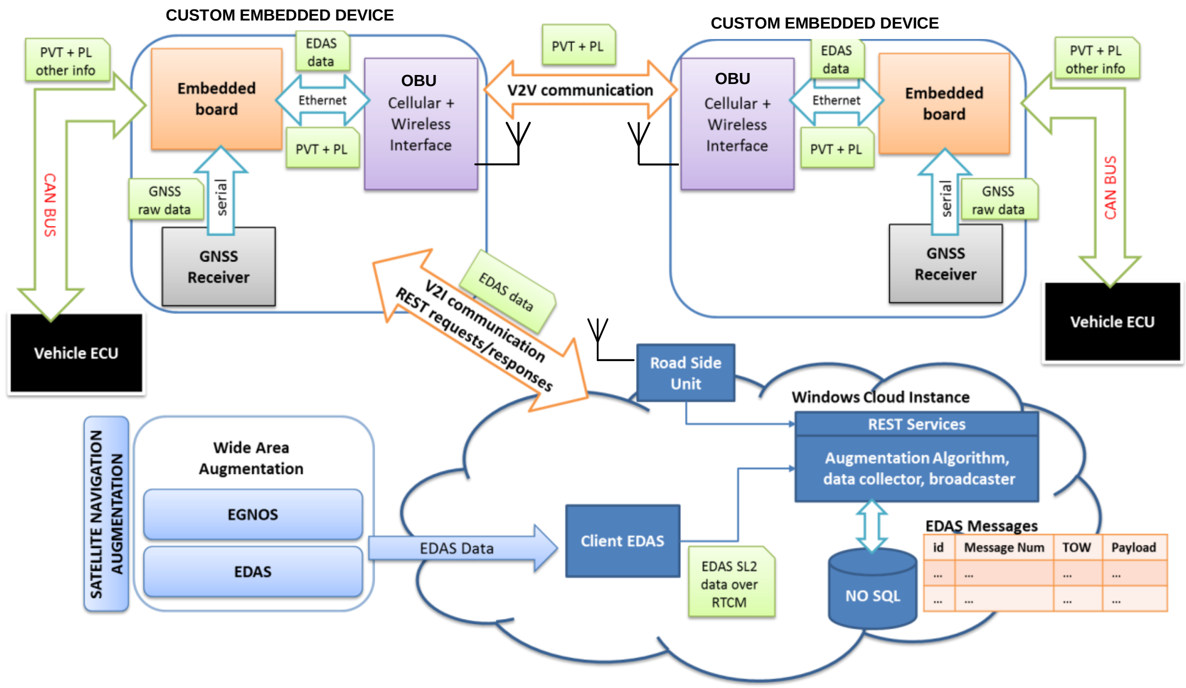


Figure 7 -Idea overall architecture

For the application considered within iDea, the only pieces of information that are exchanged between vehicles (V2V) are position and driving direction. Note that the driving direction is needed to determine the involved vehicles, discarding, for instance, vehicles going in the opposite direction. Since multi-hop communication is not needed, V2V information is broadcast without generating the well-known broadcast storm problem.

IDea exploits, the V2X communication messages standardized by ETSI, which have defined the Cooperative Awareness Application (CAA) for vehicular applications. The CAA uses two main messages: Cooperative Awareness Messages - ETSI TS 102 637-2 (CAM) and the Decentralized Environmental Notification Messages - ETSI TS 102 637-3 (DENM), which are both broadcasted in the so-called control channel (CCH).

The CAM messages are generated at a predefined repetition rate. Depending on data traffic and channel conditions, the CAM repetition rate can be adjusted to minimize congestion. CAM messages contains vehicle information, including, but not limited to, type of vehicle, position, speed, heading and even lights status. This information might be used by other vehicles to update their dynamic map containing the position of surrounding vehicles.

DENM messages are sent only after detection of abnormal situations that can cause an accident. The DENM is a high priority message, which has to be sent over with a higher priority than CAM messages. Within iDea, CAM messages propagate PVT information, because they do not directly manage emergency or safe-critical applications in real time.

6. Test-bed implementation

The following sections give a description of the design of each component of the aforementioned platform, providing a detailed view of the implementation choices taken for each system components.

6.1 V2X Communication subsystem

Nowadays only few commercial OBU products implement the IEEE 802.11p communication stack. These devices have high costs even for a single endpoint and do not offer the required degree of freedom to extend their functionality at the MAC level and the versatility to use them as complete communication units.

For this reason, an architecture based on a low-cost hardware and on open source software is proposed. Its main advantage is the possibility to fully embed the required communication applications and serve as a complete "plug and play" communication board. It is equipped with communication interfaces to interact with other embedded devices. It contains the required communication/routing protocols instantiated for the needs of the project. The open source software and operating system allow the customization of each layer.

6.1.1 Main Board

The hardware configuration is described as follows. An embedded PC is the core of the field test system, it manages the 802.11p communication card. It can be powered by any DC source between 10 and 20 V. The general purpose embedded PC board was chosen in order to have the freedom to use mini PCI peripherals, as the case of the 802.11p cards. The main board is an embedded PC Alix model 2D2 [6] produced by PC Engines, shown in the Figure 8.

Figure 8 - General purpose PC main board for communication

Figure 9 - On-board Integrated Multiple Antenna for V2X applications (model MGW)

Figure 10 - Sectorised Antenna for V2I applications (model PS)

This system board is an AMD Geode LX-based low-cost single board computer (SBC) for general applications. Its CPU runs at 500 MHz, features two miniPCI slots, which means it can house two wireless network cards; 2 Ethernet ports are available, one of them is PoE enabled, and two USB ports for peripherals. It uses a compact flash HDD as storage and a serial console for external management/debugging. Everything is packed in a 6x6 inch board.

6.1.2 V2X Network Card

The network cards proposed are built by Unex Technology. The model is a DCMA-86P2 [7] 802.11p miniPCI. The chipset used by the card is the well-known Qualcomm-Atheros AR5414A-B2B; the network card natively operates in the frequency range 5.85 –6.0 GHz, so, unlike other off-the-shelf cards, it is exempt from possible misbehaviours in the target frequency bands or interference with 2.4GHz-band channels. This is what is certified in the datasheet of the card and it was also confirmed in preliminary lab tests performed by the authors. Figure 9 and Figure 10 shows the used antennas.

6.1.3 Software drivers

Many of the required software drivers for communication devices are included as software packages of the Linux distribution, requiring only proper configuration, but in the case of the V2X interface, a special driver is required to initialize the network card. The network cards mentioned above work already with the open source Ath5k [8] driver present on Linux distribution for Wi-Fi-mode cards, but the driver can be modified to make the card to operate within the radio standard.

The open source driver for Atheros chipsets has been used as starting point. The driver is meant for classic Wi-Fi radios: so it needed some relevant (yet unavailable at the time of writing) customizations to make it compliant with 802.11p standard and compatible with UNEX cards.

The main differences between 802.11p and Wi-Fi, at physical layer, concern:

- The working frequency: 802.11p working frequency is shifted to the range 5.85 – 6.0 GHz band.
- Channel width: 802.11p has a default channel width of 10 MHz; former 802.11 standard channels are 20 MHz wide. This is meant to enforce reception, also with strong fading, thanks to the doubled symbol duration (that is higher per-symbol energy).

The driver was modified so to integrate both the custom 802.11p settings: in the new driver, both ITS channels and channel bandwidth can be easily selected as initial options of the driver protocols.

6.1.4 V2I System design

From infrastructure equipment perspective, the developed integrated RSU (Figure 11) consists in the hardware and software described above. It was integrated in a proper industrial case and connectors (IP65), in order to be placed outdoors on a roof with street visibility.

Figure 11 - Example of a real Road Side Unit equipped with two sectorised antennas

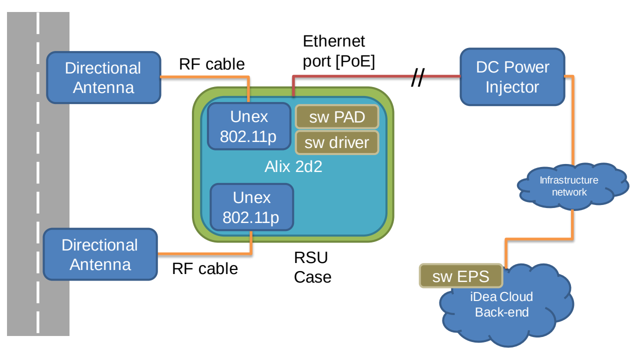


Figure 12 - Implementation scheme of a Road Side Unit

The RSUs are physically connected to the Cloud back-end via a fixed network. Inside, a series of interface services, called positioning assistance daemon (PAD), are running permanently on the RSU; the back-end is able to send EGNOS/EDAS data as a service to the vehicles within the radio range. EGNOS/EDAS Positioning Service (EPS) is a communication software entity that interacts with the back-end, gathering required data and forwarding necessary information to the vehicles requiring it. It constitutes the aggregation point connected to the PAD present on the RSUs. Figure 12 shows the RSU implementation scheme.

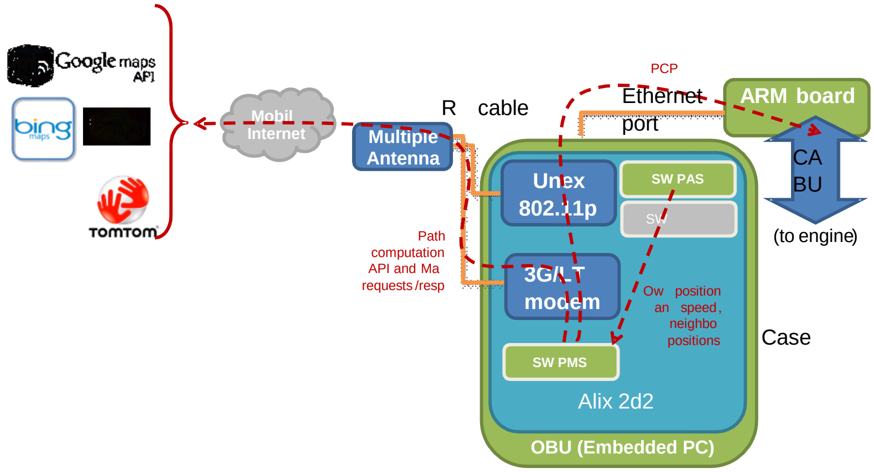


Figure 13 - Power management architecture

6.2 Power management computation architecture

The most relevant function of this architecture is to calculate the PCP, obtaining the path directions for a specific origin and destination of the vehicle. The directions can be introduced into the system via the vehicle main HMI and then the directions are calculated on an external service, such as the use of external APIs available on the internet, some of them publicly. In this case, the Power Management Service (PMS) gathers required information in order to obtain the PCP. The external services comprise either Google maps and API web services, Bing or TomTom services. The reasoning below these options is their public availability on the internet and therefore a strong developer support and documentation. The use of these external APIs is enabled by the 3G/LTE communication interface.

Once the path elevation profile is obtained, the PCP is calculated, which represents a set of waypoints with their driving distance, estimated time and road slope. The system communicates the PCP to the vehicle through the Embedded Board which sends it through CAN interface.

The PMS periodically queries the neighbor vehicle dynamic map (position and speed of all known vehicles) to the PAS in order to monitor the minimum safety distance threshold and in case issue the appropriate warnings on the driver’s HMI. In Figure 13 sketches the information flow of the PCP service.

7. Conclusion and future work

IDea proposes an architecture for vehicular systems that controls the powertrain selection of a vehicle with hybrid engine configuration to achieve energy efficiency and improve driver safety. To demonstrate the feasibility of this approach, a real test-bed was implemented based on four use-cases. The next step will be the roll-out of the performance evaluation of the system, including a complete study on the benefits brought by the EGNOS/EDAS augmentation system.

Acknowledgements: This work has been supported by IDEA project, financed by Piedmont Region in the framework of “Automotive Platform”.

8. References

[1] ETSI-TR-102-863

[2] "802.11p-2010 - IEEE Standard for Information technology - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments," [Online]. Available: http://standards.ieee.org/findstds/standard/802.11p-2010.html

[3] EC, "Data Access Service (EDAS) Service Definition Document (v2.0)", 2013.

[4] "The Radio Technical Commission for Maritime Services (RTCM) website," [Online]. Available: www.rtcm.org.

[5] Microsoft, "Microsoft Azure Cloud Computing Platform," http://www.microsoftazure.com.

[6] "Alix system boards," [Online]. Available: http://www.pcengines.ch/.

[7] "Unex wireless miniPCI for ITS V2X applications.," [Online]. Available: http://unex.com.tw/product/dcma-86p2.

[8] "Ath5k, The open source driver for Atheros chipset," [Online]. Available: http://wireless.kernel.org/en/users/Drivers/ath5k.