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Adaptation Layer Based Architecture For Vehicular Hybrid Communication

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Abstract
Communication is an integral part of today's Intelligent Transport Systems (ITS). There are many contenders for the communication technology, namely IEEE 802.11p (ITS G5), cellular 4G and 5G, millimeter Wave etc., each with its security mechanism and services, resulting in in different data accuracy, confidence, trust level. Thus it becomes necessary to combine multiple of these technologies into a hybrid communication system. To benefit from the capabilities of multiple communication technologies, it is important to design vehicular communication architectures to be flexible but also reliable enough. In this paper, an adaptation layer based communication architecture is presented with multiple variations of the layer structure. The paper discusses key functions of an adaptation layer, identifies and defines criteria for judgment of the best variation, and then concludes by comparing these variations. As a result of the comparison the paper identifies the optimal architecture for vehicular hybrid communication.

KEYWORDS
Hybrid Communication, Communication Architecture, Adaptation Layer

Introduction
Driving safety and comfort are areas where automotive industry has been going through a revolution for some time. This has been driven by great advancements in environment perception technologies. With ever powerful on-board sensors and cooperative ITS (C-ITS) using vehicle-to-everything (V2X) communication, it has been possible to detect objects more efficiently, to get information about traffic jams, and much more. That's why, starting with a variety of Advanced Driver Assistance Systems (ADAS), cars are now moving towards being ready to be fitted with automated driving functions.

Communication makes a big part of ITS and automated driving. There are, however, different communication technologies that are being used to achieve similar objectives. For vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, IEEE 802.11p based ITS-G5 (Europe) and WAVE (America) standards have been standardized and tested extensively in various field operational tests and pilot programs. Cellular 2G, 3G and 4G has been used for vehicle-to-network (V2N) connectivity to access (and provide) quasi real-time traffic data. Additionally, some projects have explored the benefits of Mobile Edge Computing (MEC) over cellular to detect vulnerable road users (VRUs) [1], or for vehicle to vehicle communication [2]. Now, there are new contenders for vehicular communications like LTE-V2X [3] and 5G including millimeter wave etc.

With multiple technologies for vehicular communication, each offering certain advantages over the other, a hybrid communication paradigm is foreseen to be used. This solves a number of problems, namely – redundancy in case of failure of one technology, better (combined) deployment penetration etc. Obviously, this comes at an expense of higher complexity, increased cost for integration and material, and most likely increased cost for operation. There are also new questions in front of the system designers.

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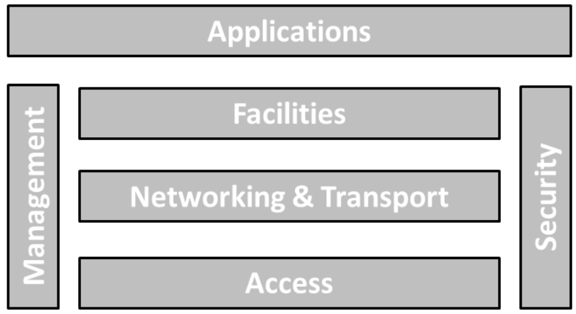

Figure 1: ETSI ITS communication architecture

For example

- How to manage different levels of trust in data received from different sources over different technologies?
- How to match the latencies in data received over different communication technologies?
- How to coordinate usage of multiple media to address application and service requirements? (use them in parallel, alternating, prefer one over the other, …)
- How to realize failover (probably with altered capabilities) in case one communication medium becomes unavailable?

These questions can be addressed by architecture related solutions. In this case, the trust levels, latencies and other parameters of different communication technologies need to be matched. Additionally, dynamic coordination and management of communication media should be provisioned. This can be realized by a dedicated entity in the communication architecture. This paper introduces an adaptation layer based communication architecture to perform the above functions. A number of variations of this architecture will be presented and compared over a set of qualitative criteria.

The remainder of this paper is organized as follows. The next section discusses related work, followed by an overview of hybrid communication. Subsequent sections provide a description of the adaptation layer based approach, and an introduction to and comparison of different architecture configurations. Finally it concludes by summarizing the results.

Related Work

The ETSI ITS communication architecture standard [4] specifies access-technology agnostic communication architecture as shown in Figure 1: ETSI ITS communication architectureFigure 1. This architecture contains cross-layer elements for management and security, facilities to link applications to network and transport, and an access layer to accommodate for multiple communication media. However, the standard does not specify how multiple media can be combined in a hybrid communication approach (as defined below).

The German public funded research project Converge defined an architecture combining ITS-G5 with cellular communication [5]. The project developed a concept that facilitates ITS-G5 like services over cellular networks (geo-messaging over cellular using a GEO server). Both communication technologies are combined to achieve the best possible dissemination of messages over desired dissemination areas.

The present paper introduces an adaptation layer based communication architecture approach that addresses dynamic communication resource management as well combining incoming data from different sources. It takes the ETSI ITS architecture as starting point and extends it with elements providing the above functionality.

Hybrid Communication

The term hybrid communication was used first in 2014 in the report “C-ITS Deployment in the Netherlands” [6]. It was then brought forward to the European Commission C-ITS Platform discussions in 2015 resulting in adopting it as a key element in the support for further developments of new ITS services

[7]. As no clear definition was in place the term was interpreted differently by different stakeholders. Most commonly, a hybrid communication system was considered a system with more than one communication technology (e.g. GSM, LTE, WiFi, Bluetooth, ITS-G5 and DAB+) where applications have to choose one or the other. Other views considered hybrid communication as a combination of LTE and LTE-V2X. It is expected that the European Commission C-ITS Platform II will have established a common view on hybrid communication within its upcoming second C-ITS Platform report (publication expected before fall 2017).

This work considers hybrid communication as more than simply having multi communication technologies available for applications to choose from. A hybrid communication system should combine these technologies in order to improve information sharing in terms of availability, validity, accuracy, and quality. This will allow improvement of safety and efficiency related decision making by road users in general and vehicle automation in particular.

Hybrid communication as defined above aims at

- Optimizing the usage of (dynamically) available communication resources to achieve maximum effectiveness in information sharing.
- Evaluating and combining received information to achieve best availability, validity, accuracy, and quality

Optimizing the usage of (dynamically) available communication resources requires information transfer from the access layers to upper layers. This information includes general capabilities of the communication technology and the communication medium's current state. The required information flow is visualized in Figure 2. Evaluating and combining received information consists of, firstly, format matching, and secondly, attribute matching for information from different sources.

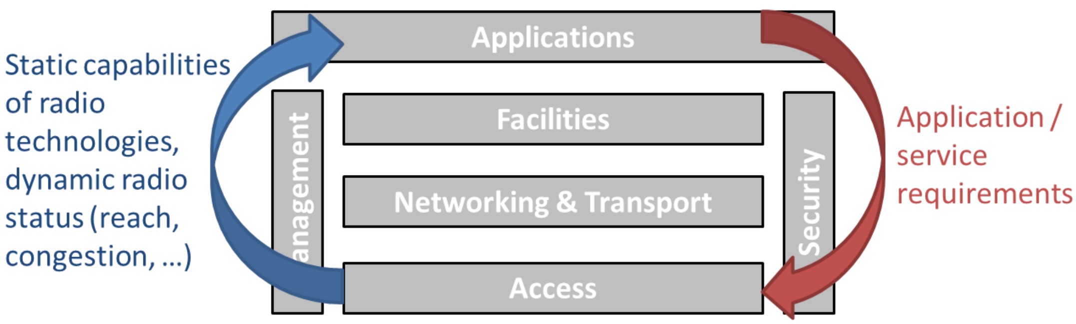

Figure 2: Hybrid Communication architecture information flow

It is envisioned that in hybrid communication will improve the communication robustness and efficiency and provide means to improve the possibility to judge the value of information received. It is evident that for interoperability reasons several standards will have to be developed.

Adaptation Layer based Communication Architecture

One approach to realize hybrid communication as described above is the use of an adaptation layer within the communication architecture. The adaptation layer 'adapts' data from different sources into one common format for the whole system to understand for incoming data and carries out dynamic communication media management for outgoing data as shown in Figure 3. The layers above and below in Figure 3 are depicted as dashed as the adaptation layer can be located at different locations within the layered model of the stack depending on implementation.

To fulfill the goals of hybrid communication as introduced in the previous section, the following functions are required to be provided by an adaptation layer

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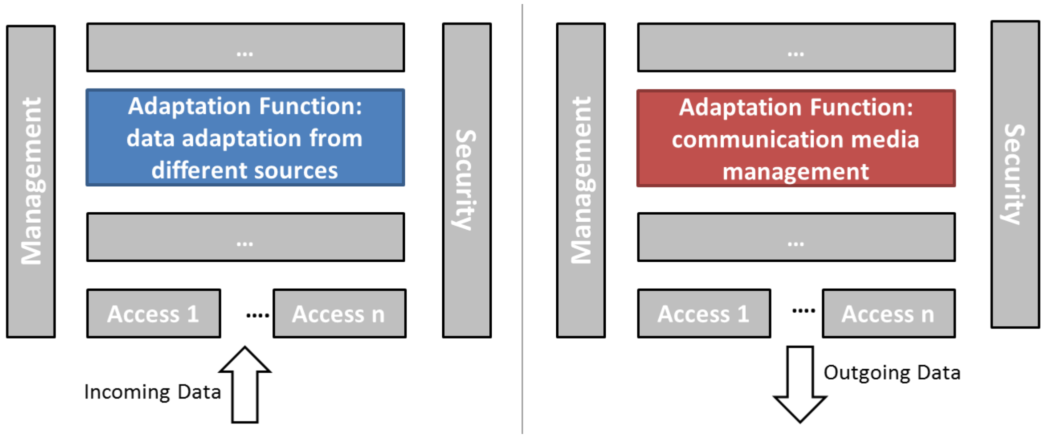

Figure 3: Adaptation layer functions

- *For incoming data*
  - Convert data from different sources (possibly over different technology) into a common format
  - Match the latencies, if different, between similar data received over different technologies
  - Match the confidence / accuracy of similar data received over different technologies
  - Match the trust level of data received over different technologies
- *For outgoing data*
  - Coordinate sending of data over multiple media in parallel according to application or service requirements
  - Schedule sending of data alternating over multiple media in line with application or service requirements (possibly alleviating channel load)
  - Choose one communication medium over the other due to capabilities
  - Realize failover (probably with altered capabilities) in case one communication medium becomes unavailable

As mentioned above, the adaptation layer can be realized at different layers within the communication architecture. The following section will study three different configurations and discuss advantages and disadvantages in detail

Communication Architecture Configurations

As a baseline for practical analysis, this paper takes the following assumptions

1) The vehicle on-board communication system supports the following communication technologies – IEEE 802.11p based V2X, Cellular based V2X (C-V2X) (LTE-V2X or later on eV2X), Mobile Edge Computing (MEC) over cellular, and backend connectivity over cellular.
2) IEEE 802.11p uses the C-ITS protocol stack as defined by ETSI, Basic Transport Protocol (BTP) and Geo-networking (GNW) [8] [9].
3) Networking and transport protocols for C-V2X are unknown at the moment (they are assumed to use similar protocols / variations of the protocols of the C-ITS protocol stack, which are yet to be specified).
4) MEC can use IP and TCP/UDP networking and transport protocols respectively but it may also use Basic Transport Protocol (BTP) and Geo-networking (GNW) as defined in ITS G5.
5) Backend connectivity uses standard TCP/IP.
6) The facility layer(s) provide the functions of message encoding/decoding and specific functions like Cooperative Awareness Message (CAM) periodic transmission service etc.

With these assumptions, this work compares three configurations of communication architecture according to the following criteria

- *Data correlation*: best adaptation of similar data from different sources
- *Resource management*: ease of management of communication resources
- *Redundancy in design*: repeated functionality

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- *Modular structure*: ease of adding or removing a communication technology
- *Expansion possibilities*: possibility of expanding functionality of modules with minimum effort
- *Ease of implementation*: how simple or complex the implementation is

Configuration 1 (C1)

In this configuration, the adaptation layer lies above the facilities layer, as shown in Figure 4. The facilities layer is realized with separate modules tailored to the individual protocol stacks of the communication media. The adaptation layer receives the decoded data over different communication technologies and performs the adaptation functions. Message transmission on the individual media are either automatically managed within the facility layers (e.g. in case of CAMs over 802.11p), or triggered from the adaptation layer. One of the key benefits of this configuration is that existing implementations for dedicated communication media can be reused as is. Adding new communication media requires development and integration of a complete stack up to / including facility layer.

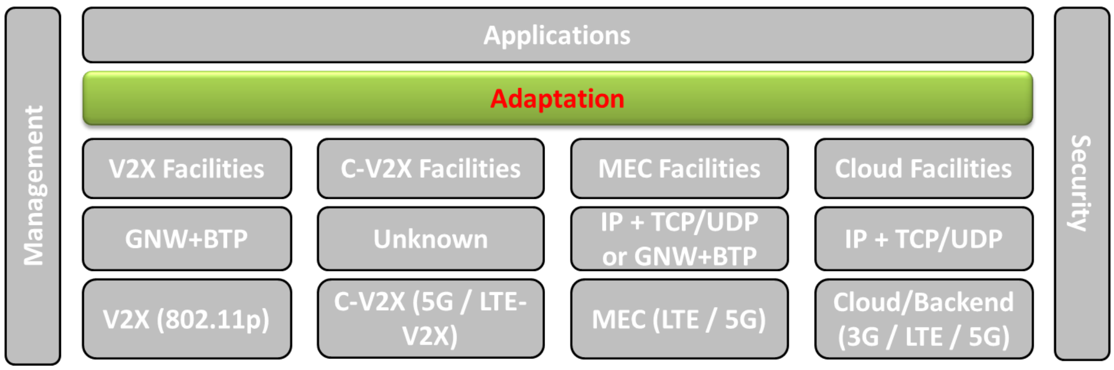

Figure 4: Architecture Configuration C1

In addition to the base configuration as depicted above, multiple variations of function distribution between adaptation layer and facilities layer can be considered as sub-configurations for selected communication media. One potential variation is omitting the facilities layer for backend connectivity. As backend connectivity is an IP and TCP/UDP based communication, there is no need to have a separate facilities layer and the adaptation for it can be done directly in the adaptation layer. Similarly, if MEC uses IP and TCP/UDP instead of GNW and BTP, the MEC facilities can be omitted and the adaptation for it can be done directly in the adaptation layer.

Table 1 summarizes the evaluation of this configuration C1 according to the criteria previously introduced and provides reasoning.

Table 1: Configuration C1 Evaluation

Criterion	Configuration 1	Reasoning
Data Correlation	Good	Well defined and understood input from tailored facilities layers for each communication medium.
Resource management	Moderate	Independent operation of each facility on the other simplifies but also limits resource management
Redundancy in design	Bad	Facility layers have high degree of redundancy for similar functions / communication media
Modular structure	Good	High degree of modularity because each technology is operating independently.
Expansion possibilities	Moderate	Simple to add new communication media, but dedicated facilities layer has to be added
Ease of implementation	Good	Simplicity of adaptation layer due to tailored facilities, existing facilities implementations can be reused

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Configuration 2 (C2)

In this configuration, the adaptation layer lies below the facilities layer as shown in Figure 5. The adaptation manages the communication media directly. It is responsible for aggregating incoming data from and distributing outgoing data over the different media. The facilities functions are common for all communication media (they are medium agnostic), resulting in no redundancy at facilities layer and a single direct interface towards the applications.

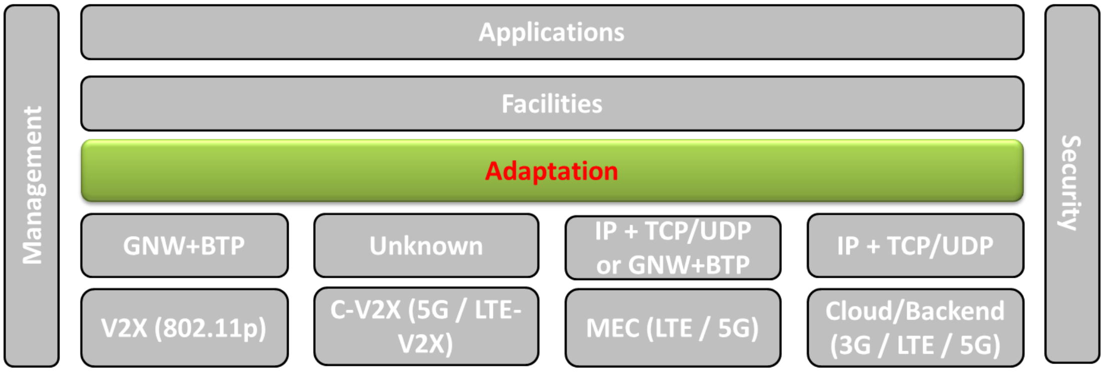

Figure 5: Architecture Configuration C2

Table 2 summarizes the evaluation of configuration C2.

Table 2: Configuration C2 Evaluation

Criterion	Configuration 2	Reasoning
Data Correlation	Moderate	One common data representation to the application layer due to common facilities layer.
Resource management	Good	Adaptation layer lies close to access layer and can coordinate between facilities and access layer.
Redundancy in design	Good	No redundancies in facilities and adaptation layer
Modular structure	Bad	Limited due to common facilities and adaptation layers.
Expansion possibilities	Moderate	Adaptation layer has to be extended to add new communication media
Ease of implementation	Moderate	Simplicity of facilitates layer, on the expense of complexity of adaptation layer

Configuration 3 (C3)

In this configuration, the adaptation layer is contained within the facilities layer (as shown in Figure 6) because adaptation is considered just another facility. Facilities layer interfaces with all communication media as well as applications layer directly. This configuration supports fast and additive implementation, especially if only a small and limited number of communication media are to be used.

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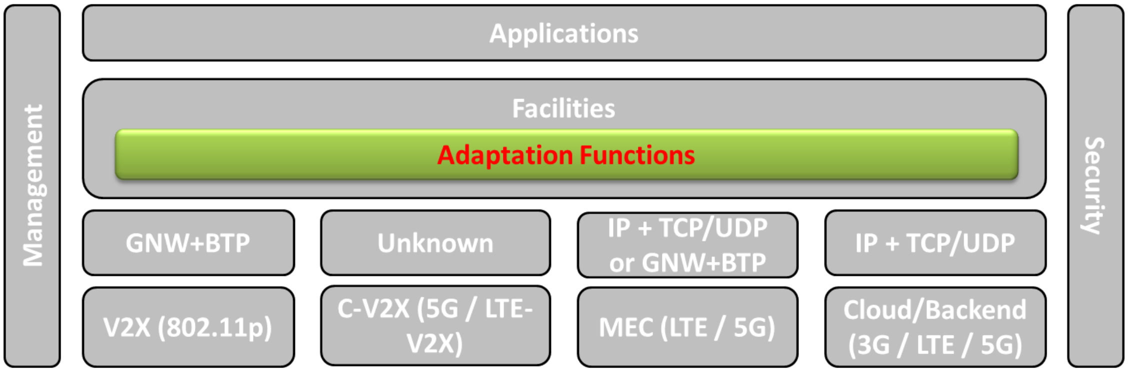

Figure 6: Architecture Configuration C3

Table 3 summarizes the evaluation of configuration C3.

Table 3: Configuration C3 Evaluation

Criterion	Configuration 3	Reasoning
Data Correlation	Bad	Limited correlation due to sideways adaptation and facilities functions.
Resource management	Bad	Adaptation function has limited to no influence on communication resource management.
Redundancy in design	Good	No redundancies in facilities layer and adaptation functions
Modular structure	Bad	Facilities and adaptation functions in a single layer / block
Expansion possibilities	Bad	No clear abstraction boundaries between upper layers, making it difficult to change the design later on
Ease of implementation	Good	Supports 'additive development' i.e. starting with one component and keep on adding others

Comparison

Table 4 compares the qualitative merit of the three architecture configurations. As per the definition and interpretation of the comparison criteria in this work, Configuration 1 presents the optimal compromise. It not only provides good data correlation but also the ease of adding or removing a communication medium due to its modular structure. The modularity comes at an expense of redundancy.

Table 4: Comparison of configurations C1, C2, and C3

Criterion	Configuration 1	Configuration 2	Configuration 3
Data Correlation	Good	Moderate	Bad
Resource management	Moderate	Good	Bad
Redundancy in design	Bad	Good	Good
Modular structure	Good	Bad	Bad
Expansion possibilities	Moderate	Moderate	Bad
Ease of implementation	Good	Moderate	Good

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Conclusions

Advancements in onboard sensors and ITS have made it possible for vehicles to transition from ADAS to automated driving. Communication in ITS is considered to be an enabling factor for this transition. Its evolution shows a clear trend to use multiple communication technologies in parallel. In order to benefit from the capabilities of different communication technologies in most efficient way, a hybrid communication approach is required.

This work investigates adaptation layer based communication architectures that are flexible and effectively combine multiple communication technologies to improve reliability. It discusses key functions of an adaptation layer and presents three variations of the layer structure. Furthermore, it identifies and defines criteria for judgment of the best variation, and then compares the described variations. As a result of the comparison, Configuration 1 is adjudged the best based on the performance criteria. It does have redundant facilities layers for each communication technology but this very feature makes it easier to add new communication technology in future.

Future work will report on our ongoing activities of quantitative performance evaluation using actual hardware in a prototype system. Beyond that, it is planned to complement the work on prototypes with simulations.

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