Devices and Wireless Interface Control in Vehicular Communications: An Autonomous Approach

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Abstract. During recent years, mobile communications have reached every aspect of our modern life. Multimode wireless terminals are about to be introduced in our vehicles, giving them the capability to communicate through different networks. However, it is hardly possible for the car device to control efficiently and adapt dynamically its connectivity according to its environment. The objective of this paper is to present the concept of an innovative technological framework for the autonomous control of multimode terminals in heterogeneous and non-federated wireless environments. The aim is to enable a self-configuring terminal to connect to independent networks, while respecting its applications requirements. The target scheme implies a strong level of abstraction and cross-layer design, taking into account constraints based on heterogeneous wireless systems, autonomous architectures and enabling generic services such as a smart access network selection. This scheme applies to the mobile terminal only, with mechanisms independent of the network infrastructure. The paper analyses how existing technologies are enhanced and combined with new features to achieve this objective and gives a description of the overall concept. A simulated model is used to assess the validity of the proposed framework, together with applications to real systems, highlighting the key benefits of the concept.

Keywords: Heterogeneous networks, wireless access selection, intelligent transport applications, MIH.

1 Introduction

In the recent years, mobile communications have been evolving and growing very fast, together with an exponential use of the Internet for all sorts of applications such as voice calls, video streaming or Mobile TV. Multimode terminals, capable to connect in heterogeneous networks have been introduced in every aspect of our modern lives and are now almost ready to be deployed in our vehicles, where they will provide additional safety, traffic efficiency and entertainment. One of the challenges to be addressed by these new systems, also called On-Board Units (OBUs), is the choice of the optimal access network according to the requirements and constraints of the executing

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applications. Currently, the software installed in smartphones prioritizes a Wi-Fi hotspot when one is detected, transferring all the data traffic on this access. When no Wi-Fi is available, the data traffic is transferred through the cellular network. This may lead to odd or unwanted behaviours. When it comes to OBUs, the constrained environment generates an additional level of complexity. Moreover, the OBU environment may rapidly change, especially due to the vehicle mobility, which implies a dynamic and autonomous adaptation of the device connectivity. It then becomes necessary to fine-tune dynamically the OBU connectivity on one or several of its network accesses according to the user's preferences or the needs of its applications. The current binomial and static solution is thus expected to become rapidly too limited and simplistic compared to the connectivity constraints foreseen in the near future, preventing safety applications which require very low latency to execute as initially planned. Techniques exist that partially address these requirements. First are the Media Independent Handover (MIH) services which provide mechanisms to handle multimode terminals when roaming across heterogeneous networks. Secondly, a new entity, the Connection Manager (CMGR) has been introduced to collect information about the device environment and apply algorithms optimizing the access network selection decision. A third technique comes from autonomous systems, which execute intelligent control loops, providing the ability to cope and adapt dynamically to unexpected situations according to decision policies. However, none of these techniques is able to provide a full solution by itself and efficiently take care of the diverse hardware devices located in the terminal. Our objective is thus to integrate them in a single framework which will provide the future systems with a flexible and optimized control of their multimode operation.

This paper is organised as follows. Section 2 exposes the challenge faced to connect efficiently and dynamically the vehicular devices and introduces the existing techniques which partially solve the issue: MIH services, access network selection and autonomous systems. Section 3 proposes an active and integrated framework which provides an intelligent control of the mobile terminal connectivity. It explains how this framework manages its various hardware devices and is organized to select autonomously the best suited access network. This is followed by an evaluation of the framework in section 4, together with its main results. The document is closed in Section 5 by a summary of the main contributions and the direction taken for future research.

2 Reference Technologies and Challenges

The section starts with an introduction of the specific challenges faced by vehicular communications. Then it presents existing technologies which partially address the issue of a dynamic and reliable adaptation of the wireless connectivity to heterogeneous access networks.

2.1 Vehicular Communications

A whole set of new technologies and applications are being designed [1] to enhance the quality of our travelling experience. This new domain constitutes a typical application case since car devices or OBUS can connect to at least three access technologies, including a specific wireless access derived from the Wi-Fi, also called the ITS (Intelligent Transport Systems) G5 technology, while they additionally receive information from the positioning system in the vehicle. The ITS architecture considers a varied set of devices: handheld terminals, cars, trucks, public vehicles and buses, but also traffic lights, variable message signs, traffic monitoring centres, etc. Accordingly, the new applications imply new constraints on the communications sub-system. Road safety applications developed to prevent car crashes require very low latency communications between the vehicles, achievable mainly with the ITS G5 access in V2V (Vehicle to Vehicle) mode. On the other hand, entertainment applications may require large bandwidths which can be obtained only with Wi-Fi or LTE (Long Term Evolution) cellular networks. As a consequence, the selection of the access network to be used depends not only on the radio signal level, but also on the application requirements and on other system parameters. Currently, the same application always uses the same type of access technology, whatever the context of the ITS Station. The terminal being multimode, each technology or modem requires the development of extensions to the control software in addition to the specific device drivers, which allows very little flexibility when moving between different environments. The ITS world is thus a typical case where a smart access technology selection algorithm, coupled with a strong level of abstraction for the monitoring and control of the different access technologies and mobile devices is required.

2.2 Media Independent Services

Operating multimode devices in heterogeneous networks can become very complex if each access technology has to be addressed directly and separately by the networking entities. To cope with this issue when executing access network handover, the IEEE 802.21 standard proposes three different Media Independent Services [2]. They offer to the upper layer management protocols some abstracted triggers, information acquisition and the tools needed to perform the handovers. The Event Service (MIES) provides the framework needed to manage the network events, and to report the dynamic status of the different links. The Command Service (MICS) allows controlling the links behaviour while the Information Service (MIIS) distributes the topology-related information and policies from a repository located in the network. A cross-layer architecture is defined where the MIH Function (MIHF), pictured in Figure 1, acts as a relay between *(i)* the media-specific Link layer entities connected by the MIH_LINK_SAP (Service Access Point) and *(ii)* the media-agnostic upper layer entities, or MIH-Users, connected over the MIH_SAP. The MIHF also handles the protocol that runs between the different network nodes to synchronize the MIH operations. This protocol provides rules for peer communications between the MIHF modules located in the different nodes and operates through the MIH_NET_SAP, using either Layer2 or Layer3 transport, according to the access network.

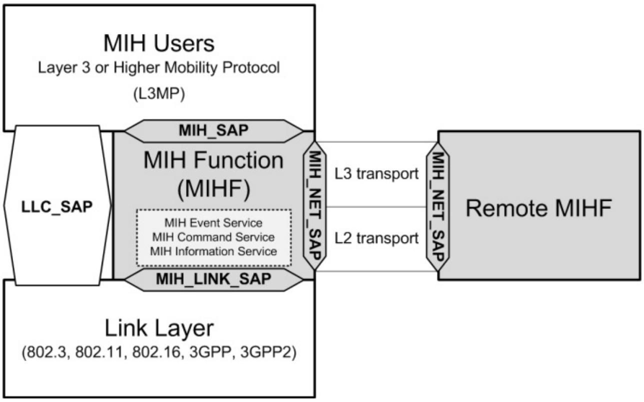

Fig. 1. Reference Model for Media Independent Handover

Currently, the IEEE 802.21 standard provides valuable mechanisms to control the network interfaces of a multimode terminal in a Media Independent and abstracted way. However, it involves several strong limitations. It only enables handover services and addresses exclusively network interfaces, ignoring the other devices present in the terminal which may reveal useful to control its connectivity. It thus offers the possibility to be developed to support an extended set of services and devices. This extension will be a main axis for the design of our solution.

2.3 Access Network Selection in Multimode Terminals

A research in literature on heterogeneous wireless network selection returns many studies and surveys for vertical handover management and optimization algorithms. A vast majority of them take the terminal point of view, optimizing network access selection in conjunction with mobility mechanisms. The main steps of the decision procedure are the input collection and the execution of a selection algorithm.

As explained in [3], the first step of the decision process consists in the collection of the appropriate information, according to a pre-defined list of criteria or attributes. In this survey, the attributes considered are all available from local resources, giving more importance to the user perspective: received signal strength, network connection time, available bandwidth, power consumption, monetary cost, security, and user’s preferences. The authors in [4] have the objective to optimize the performance of the system by selecting the best interface for a generic file download service. The decision is made locally to avoid any impact on the network, hiding from the application the complexity of spreading traffic over different access networks. The selection is performed using attributes related to the user context, QoS and mobility. Some information may also be provided by entities in the network, such as the MIIS or the ANDSF (Access Network Discovery and Selection Function) [5]. The latter contains the data management and control functionality necessary for providing network discovery and selection assistance data to the MT as per operators' policy.

When these inputs have been collected, a selection algorithm is executed. Algorithms range from simple comparisons where the best signal quality is chosen, to more complex ones which smartly combine the additional parameters from the end user, the application or the network context. The authors of [3] provide a survey of classical decision strategies in 4th Generation networks, classifying them based on the decision criteria. They show that the preferred input is usually the RSS (Received Signal Strength), sometimes combined with bandwidth information. Cost functions are more complex and combined algorithms the most reliable, but at the cost of larger handover delays. [6] analyses and classifies the different existing strategies, including user-centric strategies, taking into account user preferences in terms of cost and QoS, or strategies resolving a Multi-Attribute Decision Making (MADM) problem. The paper surveys well-known methods such as SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) or WP (Weighted Products). [7] defines a method based on a Markov Decision Process, using a link reward associated with the QoS achieved by the mobile connection and evaluated against the cost of handover signalling. The results show better handover performance than more classical methods, but the converging time of the algorithm is of the order of magnitude of minutes. Moreover, most of the proposed algorithms require a continuous execution and thus consume a lot of processing power. This is not convenient in a mobile device with limited power resources.

2.4 Autonomic Systems

Other conception studies of future architectures introduce a totally new cognitive plane, where the environment is sensed and observed, leading to the acquisition of knowledge which is exploited in a novel capability of self-management [8]. These Autonomous Systems (AS) are adaptable to cope with unexpected situations or dynamic changes occurring in their environment. They are in continuous variation at all levels, whether it be data, environment or goals. The self-management is performed primarily according to some internal policies and without requiring actions from a human user. The system operates by undertaking intelligent control loops [9]. It senses its operating environment, works with models that analyse its own behaviour in that environment, and, based on existing policies and learned knowledge, derives the appropriate actions to adapt and change the environment, its own state or its behaviour.

The AS architecture is structured according to a decision hierarchy and coordinated by an Orchestration Autonomic Manager (OAM). The OAM is assisted by a Manual Manager (or human user) and lower level Autonomic Managers. In their turn, they monitor and control the Managed Resources through a so-called Manageability Interface. A basic and shared knowledge source is installed at setup and further enhanced by self-learning in an evolutionary process through progressive steps. These concepts are introduced mostly in large computing systems and in a very basic and semi-empirical way in the existing CMGR implementations, to decide on which access network the mobile should connect. By mirroring the self-management architectures currently defined at network level, it sounds interesting to make an analogy and apply the same concept to the self-configuration of the MT, more particularly to the coordination of the different technologies involved in the solution to our problem.

3 Extending the Media Independent Services

Because the decision between networks operated independently has to be taken by the control entities in the car device, the main and innovative approach proposed here is to modify only the mobile terminal, leaving the network totally unaffected. Connectivity has to be maintained efficiently while remaining transparent to the applications. The system will also capitalize on an extension of the abstraction model introduced in the MIH standard.

3.1 The Connectivity Control Framework

According to these objectives, a layered system, the Connectivity Control Framework (CCF) pictured in Figure 2, has been designed. Some of the components, shown in the figure with hatched blocks, are present in existing terminals and remain unchanged. They include the applications, the Networking Services (NS, e.g., existing handover, security mechanisms or network statistics), the TCP/IP (Transmission Control Protocol / Internet Protocol) protocol stack and the devices or wireless accesses. The CCF is built around three main principles that guarantee a simple and flexible architecture, which could be summed up in a modification of the terminal operating system.

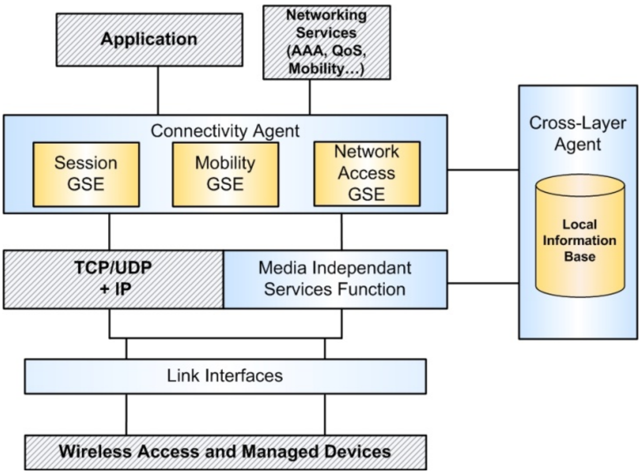

Fig. 2. Global architecture of the CCF

The main principle is to hide the heterogeneity and diversity of the devices and access networks behind an abstract interface which facilitates a range of services wider than handover management. This is achieved by the Media Independent Services Function (MISF) and the Link Interfaces. Another principle is to share the knowledge about the terminal context and its environment between the different components in a cross-layer fashion. This is achieved by the Cross-Layer Agent (CLA) which stores the configuration, policies and statuses in a Local Information Base (LIB). Finally, generic service enablers (GSEs), integrated in a Connectivity

Agent (CA) take care of dedicated basic service operations. They enhance the terminal operational behaviour for an autonomous and optimized connectivity, coping with dynamic changes and events in its environment.

3.2 MIS Functions and Managed Interfaces

The MISF is an abstraction layer which deals with the wireless multimodality of the terminal. It is a key component of the system, as it provides the means for the abstracted interaction between the wireless accesses or other devices and the upper layers, hiding their individual specificities. It is based on the MIH services, but is not restricted to handover. It provides a whole set of additional services, including monitoring of access networks, retrieving of system statistics and status, resource configuration with a certain level of Quality of Service (QoS), handling power sources, positioning device or enabling multicast and broadcast services.

At the lower layer, the Link Interfaces make the link between the MISF and the technologies device drivers. There is one Link Interface per type of device, completely specific to its implementation. Its main function is to translate the MIS commands and forward them downwards to the target driver. It acts as the endpoint for parameters retrieval in the upwards direction, possibly scheduling some periodic monitoring of the device. It receives the configuration MIS primitives and executes internal procedures to enable the reporting of measurements or subscribed events. Its location at the edge of the CCF minimizes the overall energy and processing power consumed by the framework. The Link Interfaces for the wireless devices control the access technologies present in the terminal. Nevertheless, a mobile terminal, whether it is a laptop, smartphone or OBU, includes devices other than the wireless interfaces, e.g. positioning systems, power supplies or tags and light sensors. In the same manner as the wireless interfaces, these devices can be controlled and monitored. When they relate to the mobile connectivity, they enhance its coordinated and integrated control through the CCF and the MISF, provided the availability of a specific Link Interface. Using this feature may prove very interesting as the OBU would be able to retrieve the speed of the car to eliminate the cells with small coverage, e.g., WLAN (Wireless Local Area Network) from the access selection decision.

A simplified set of primitives can be defined to make the MIS interactions generic. A Link_Action primitive carries a command from the upper layers. In the reverse direction, the Link_Report indicates an information from the Link Interface. The Link_Information is used by the MISF to exchange parameter values with the LIB, while the Link_Configure registers subscriptions for specific measurement reports from the device through the Link Interface. With these procedures, the MISF and the Link Interfaces bring to the framework the capability to manage, in an abstracted and flexible way, the various network interfaces and devices present in a terminal in order to achieve an optimized connectivity.

3.3 Network Access Selection

In the CA, the Network Access Generic Service Enabler (NAGSE) deals with aspects related to the monitoring of the networks availability, learning the characteristics of the unknown accesses and selecting the best network by running its algorithm on a set of parameters retrieved from the CLA. For the discovery and monitoring of available networks, it uses mainly the information received by the network interfaces, either to identify the availability of a known network or to learn the system information from an unknown network: radio technology, network name, signal quality, capabilities and available bandwidth.

The access network selection algorithm in the NAGSE may be invoked by the autonomous coordination function in the CA from several different states of the system. When the terminal starts, it is called to identify the initial network to attach to, without any running application. When a new application starts, it is requested to check whether the connected network is suitable. If several are available at once (in case of multi-homing for example), it evaluates which one is the most convenient. The objective is to apply an algorithm to a set of parameters and derive a configuration, in the form of the preferred ordered list of access networks, according to known policies. The criteria introduced by the policies govern the following metrics: better coverage, connectivity stability, load balancing, energy efficiency, application requirements in terms of bandwidth, QoS, technology or network support, capacity stability and network security. The most widely used algorithm, the SAW, is chosen here to compute the decision, because it is simple, converges in a limited amount of time and requires a reduced processing time since only one score value per access network has to be calculated. The score S_i of the current context for the i-th target network is determined thanks to a single calculation as

$$S_i = \sum_{j=1}^{n} w_j . r_{ij}$$

where w_j is the link reward of parameter j for the target application and the access network considered and r_{ij} is the measured value of the j-th parameter of the i-th network. The different scores allow to determine an ordered list of (access network, score) pairs. Because the algorithm depends on a combination of a discrete number of parameters and link rewards in a limited number of cases, it converges very rapidly. It allows using a larger set of attributes and thus reflects more closely the userand terminal context. Moreover, this algorithm is very flexible. It is easier to add a parameter than with “if then else” policies because it only requires that the new attribute get allocated link reward values. These values are determined by the CLA which is the component responsible of the learning process in the CCF. Based on the feedback from the user and the physical environment received through the other components, it analyses the values of parameters and policies that have been applied to determine the rewards that can optimize the operation of the CCF. With these functionalities, the NAGSE brings to the framework the capability to characterize the network environment in a very precise manner and to select the best access network for each application, taking into account several independent criteria in a flexible algorithm. The coordination of the MISF abstract interface with the NAGSE allows the system to operate in an autonomous and more dynamic manner.

4 Validating the Framework

To enable the evaluation of the benefits of the CCF operation, a prototype has been developed, using the OMNET++ platform [10], a discrete event simulation system. The simulation executes Ping connection tests or a web browsing application in a mobile terminal which moves randomly across a heterogeneous network playground, while the rest of the system parameters remain unchanged. This choice of applications allows demonstrating the dynamicity and efficiency of the framework. Figure 3 shows the network layout used for the simulation.

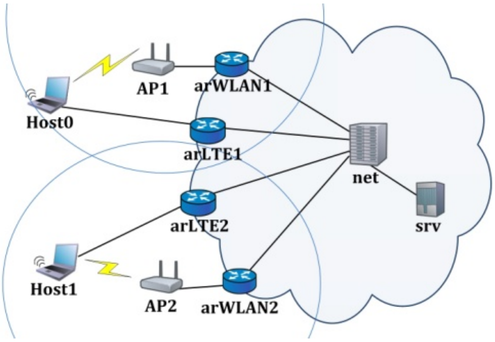

Fig. 3. Simulated network scenario

The LTE cell has a global coverage and provides an always-on access, while the WLAN availability is restricted to the circle shown in the picture around each access point. The results of the CCF prototype development are compared with two other cases: single technology (stationary WLAN) wireless terminal and mobile terminal equipped with a CMGR which fosters the WLAN access, in order to get the largest bandwidth and reduce the communication cost. The CCF module implemented strictly follows the architecture described in Section 3. Fifty simulation runs with random MT movements are executed for each test case in order to obtain a better confidence in the set of results. The main success criterion is the minimization of the number of broken sessions and packets lost, showing that the MTs obtained a suited connectivity at every position of the playground. The following metrics are collected: number of bytes transmitted and received by the applications, number of TCP connections opened / broken during the test, number of Echo Request packets sent and Echo Reply packets received back during the Ping test.

The results obtained are shown in Figure 4. Figure 4a pictures the measurements obtained with the Ping test. With the stationary WLAN, the terminal remains under the coverage of the wireless cell for the whole simulation, so no packet is lost. When the terminal moves and the CMGR switches the connectivity, between 3 and 7 packets, with an average of 3 packets, are lost for the time of the simulation. When the CCF replaces the CMGR, the loss rate drops to 0%, similar to the stationary WLAN use case. This result is due to the capability brought by the MISF to early report a vanishing network, and thus enable the upper layers to transfer immediately the connectivity to another available link before the older one is broken. Figure 4b shows the number of broken sessions (–BRK) according to the total number of opened sessions (–ALL) for the interactive web browsing application. With the stationary WLAN, 400 sessions are successfully started; the number of broken sessions is equal to zero. With the CMGR, fewer sessions can be established and several sessions are broken while they are executing. When using the CCF, the number of broken session is reduced to zero. All the sessions are successful. A very small amount of requests are retried by the application because the downlink packets were lost during the network change. These results confirm that the CCF terminal could adapt successfully to environment changes.

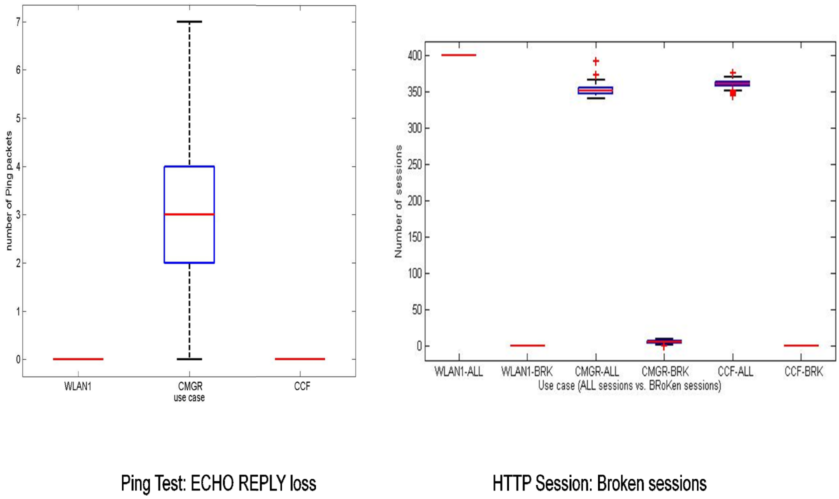

Fig. 4. Comparison of simulation results when using the CCF

In order to evaluate the impact of the CCF on the terminal processing time, a sample typical test has been made to measure the amount of discrete events involving the CCF and Link Interfaces components, vs. the total number of events for the whole simulation run. Table 1 shows the measured values for a specific test session. The additional number of discrete events introduced by the CCF remains under 0.2% of the total number of events.

Table 1. Measured processing time

	Number of events executed	Percentage
Total of the simulation	761839	
ccf contribution	409	0.0537%
Link Interfaces contribution	824	0.1082%

Another validation activity has consisted in applying the concept of abstraction from the technology specificities to real sub-systems, as described below.

In the first use case, the MIS have been implemented to support QoS resource allocation together with seamless mobility, targeting the integration in a beyond-3G cellular access. In this system, the upper layers were directly the Mobility management and the QoS controller and enforcement entities, showcasing the flexibility of the MISF abstraction. The performance parameters taken into account were the average delay, the packet loss and the jitter. During the tests, the average handover delay has been measured at around 6 seconds, with a non-significant disruption time. This result was expected because the new network attachment is performed before the old one is broken. For the same reason, it was confirmed that the packet loss was null during the handovers. Finally, the jitter measured at the MT during each handover was at the same level as the jitter obtained in a stable situation.

The second use case has addressed the Management layer of the OBU, a vertical cross-layer component, where the communication technology selection decides of the most suitable set of communication protocols and access technologies to carry the messages of a given ITS application. A specificity of ITS communications is that this decision must be made according to the type of the message or flow to transmit. It is closely related with the application which indicates its own requirements and the current context of the device. The global process is pictured in Figure 5.

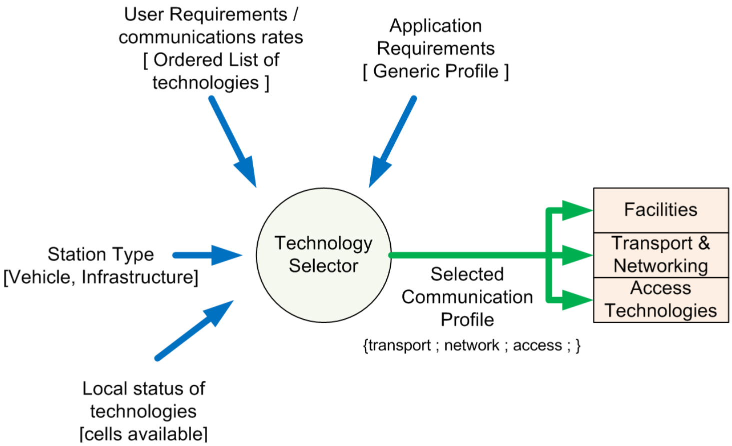

Fig. 5. ITS communications technology selection

The first input consists in the type of the originating and destination terminal. It may be a vehicle, a RSU (Road Side Unit) or a central traffic station. The second set of inputs is user-originated. Based on user preferences and subscription rates, the Management layer builds dynamically an ordered list of access networks. In the case of a central station, this list is built by matching the destination target area geography with the topology of transmitting stations (base stations or RSUs) covering that area. The process receives from the application the profile requirement associated to the message type. The same type of message (e.g., event notification) may have different values under different conditions or applications. The fourth and last input is built from the station context and contains the current status of the network accesses, observed locally, with parameters such as signal quality, radio coverage, network load or distance to the destination terminal. The objective of the decision is to choose the most suitable communication profile which includes the Transport protocol, the Network protocol and the Access technology.

This approach has been applied to the implementation of the communication technology selector in a simulation platform and has led to the definition of two procedures, the first one applied to the vehicle decision process and a second one applied to the global infrastructure (central station) decision process. They have provided very successful results.

5 Conclusion

A cross-layer and integrated framework for handling autonomously heterogeneous interfaces, the Connectivity Control Framework, has been proposed in this paper. The approach adopted here is that the CCF is restricted to the MT and has no impact on the mobile network infrastructure. It includes an abstraction layer which hides the network specificities to the rest of the framework and includes the support of other hardware devices such as positioning systems or sensors, for any type of control and not only handovers. The CA, acting as an upper layer of the MISF, coordinates the actions of GSEs. One of them, the NAGSE, specializes in the monitoring of access network availability and in making the decision of the optimal access to be selected by the OBU according to the executing application and its context. To assess its benefits, a simulation model has been developed, experimenting the framework behaviour in an heterogeneous wireless network testing environment. Even though these functionalities have been inserted in the MT, the additional power consumption is limited by putting the periodic polling functions at the edge of the system. Moreover, this framework has been applied to several application cases on real systems, enhancing existing access selection mechanisms for the upcoming vehicular communications. Future work will consist in refining the modality of storage for the context parameters and the evaluation of the link rewards for the decision algorithm that supports the autonomous operation of the device.

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