An ITS-based Architecture for Opportunistic Networking

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***Abstract*—For a smarter use of transportation systems, vehicles need to increase their environment awareness. This could be achieved by enabling vehicles to communicate with their environment. Once vehicles become connected, an ecosystem of applications and services could be developed around them, enabling the information exchange with other connected devices and contributing for a Cooperative Intelligent Transportation Systems (C-ITS). The environment of connected and cooperative vehicles is characterized by its heterogeneity, i.e., there are a wide variety of applications, a variety of users with different communication preferences. Moreover, countries may have specifics regulations. A single access technology to connect all these heterogeneity is impossible. For ubiquitous connectivity it is necessary to use existing wireless technologies (e.g., vehicular WiFi (ITS-G5, DSRC), urban WiFi, 802.15.4, and cellular). In such heterogeneous network environment, applications and services cannot take into account all technology particularities. It is necessary a communication architecture that hides the underlying differences of access networks from applications, providing seamless communication independently of the access technology. Based on the ITS architecture proposed by International Organization for Standardization (ISO) and European Telecommunications Standards Institute (ETSI), we propose a Decision Maker (DM) architecture that is capable to manage requirements and preferences from different actors (e.g., applications, users, administrators and regulators), it takes into account the short-term prevision about the network environment, it considers the context information (e.g., vehicle speed, battery level). And it also takes into account the route conditions between two communicating devices in order to make proactive decisions.**

***Keywords*—ISO TC 204; ETSI TC ITS; ITS station communication architecture; C-ITS; decision making.**

I. Introduction

The number of connected devices is growing fast around the world. These objects are components of a network known as the Internet of Things (IoT), where each object has the possibility to exchange data with others. This scenario enables the development of smart cities, where vehicles are supposed to be one of the communicating objects. According to Gartner research company, connected cars would be a major element of the IoT, representing 20% of all IoT devices [1].

For a smarter use of transportation systems, vehicles need to increase their environment awareness. This could be achieved by enabling vehicles to communicate with their environment. The connection could be local between nearby devices or global, i.e., connection over the Internet. Once vehicles become connected, an ecosystem of applications and services can be developed around them. Nowadays, we are connected to Internet through our computers and smartphones. In the future, the vehicles will be directly connected too, supporting a variety of applications (like smartphones do). For example, vehicles could connect to the Internet to enhance driver and passenger experience, e.g., improving the navigation and offering on-board Internet connectivity. Vehicles can to connect and exchange information with other devices in a smart city environment. In this context, users, devices and vehicles need to be connected anywhere, anytime with anything. Such connections will enable the information exchange between vehicles and their environment for a Cooperative Intelligent Transportation Systems (C-ITS).

However, a single access technology to connect all these heterogeneity of services and devices is impractical or even impossible. For ubiquitous connectivity it is necessary to use existing wireless technologies, such as vehicular WiFi (ITS-G5, DSRC), urban WiFi, 802.15.4, WiMAX, cellular (3G, 4G, and 5G under preparation) [2]–[4]. Each of these networks has specific characteristics in terms of bandwidth, data rate, security and others. Due to this network heterogeneity and its complementary characteristics, more connectivity opportunities are available. Mobile devices equipped with multiple communication capabilities could use multiple access technologies simultaneously in order to maximize flows satisfaction (e.g., to maximize communication bandwidth, to reduce latency, and others) and to satisfy communication requirements (e.g., security, monetary cost, traffic load balancing among available networks, and others).

The environment of connected and cooperative vehicles is characterized by its heterogeneity. For example, there are a wide variety of applications, each one with specific requirements. There are a variety of users with different preferences. Countries could have specifics regulations. There are a variety of access technologies, each one with specific characteristics in terms of bandwidth, data rate, security and others. Moreover, vehicles can move at high speed and frequently change its network environment.

In such heterogeneous and dynamic network environment, applications and services cannot take into account all technology particularities, unless they explicitly need it. The communication architecture has to hide the underlying differences of access networks from applications, providing seamless communication independently of the access technology. It should be capable to handle multiple access technologies simultaneously while select the most appropriate access network for each flow. Such an architecture should choose the path, i.e., the route between two communicating nodes that best meets the communication requirements (e.g., a local connection between nearby devices or a global connection over the Internet). Moreover, in such dynamic environment the communication architecture should perform proactive decisions taking into account the short-term prevision about the network availability.

Based on some research work and also based on the ITS architecture proposed by International Organization for Standardization (ISO) and European Telecommunications Standards Institute (ETSI), we propose a Decision Maker (DM) architecture. Such architecture is capable to manage requirements and preferences from different actors (e.g., applications, users, administrators and regulators), it takes into account the short-term prevision about the network environment, it considers the context information (e.g., vehicle speed, battery level). And it also takes into account the route conditions between two communicating devices in order to make proactive decisions. The proposed DM architecture is developed in an ISO/ETSI standard compliant way.

The remainder of this paper is organized as follows. Section II overviews the reference ITS station communication architecture proposed by ISO and ETSI. Section III reviews some related work. The proposed DM architecture is described in Section IV. And Section V concludes the paper and proposes future directions.

II. The reference ITS station communication architecture

In order to establish an harmonized communication-centric architecture for ITS, ISO and ETSI have proposed a reference ITS communication architecture supported by nodes called ITS Stations (ITS-S), where each ITS-S (e.g., vehicles) can handle its communication [5]. Such architecture is shown on Figure 1.

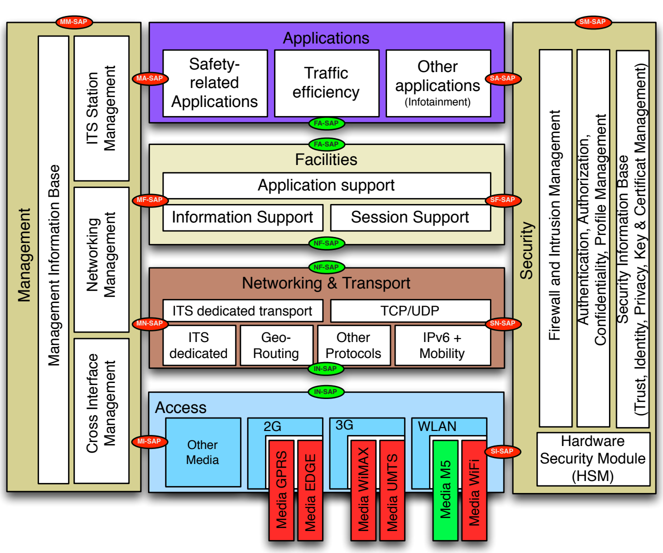

Figure 1. The reference ITS station communication architecture.

The concept of the ITS-S communication architecture is to abstract applications from both the access technologies and the networks that transport the information between communicating nodes. Therefore, applications are not limited to a single access technology, but they could take advantage from all available technologies. While the lower layers can be independently managed, without impacting applications.

In such architecture, two cross layers entities, i.e., “ITS Station Management” and “ITS Station Security” are responsible to station management functionalities and to provide security and privacy services, respectively. Since applications are developed regardless to communication networks, “ITS Station Management” entity is responsible to choose the best network interface for each application. In order to manage different process in the ITS-S, such cross layers entities communicate with the horizontal layers: “ITS Station Access Technologies” layer that is responsible for media access control and provides data transmission through different access technologies, such as vehicular WiFi (ITS-G5, DSRC), urban WiFi, 802.15.4, WiMAX, and cellular (3G, 4G, and 5G under preparation); “ITS Station Networking & Transport” layer, which is responsible to execute operations like packet routing, path establishment, path monitoring and Internet Protocol (IP) mobility; “ITS Station Facilities” layer that provides applications, information and communication supports (e.g., encode/decode message support, time-stamping and geo-stamping) and “ITS Station Application” layer that provides Human-Machine Interface (HMI).

Network Mobility Basic Support Protocol (NEMO) [6] has been chosen by several standardization bodies for IP-based mobility management, including ISO and ETSI. NEMO allows a Mobile Router (MR) to manage the IP mobility for all mobile network attached to it. The MR maintains a bi-directional tunnel (protected by IPsec) to a server in the cloud referred to as the Home Agent (HA), as shown on Figure 2. For the mobile network, it is allocated an IPv6 prefix identifying the mobile network in the IP addressing topology as permanently attached to the HA. Based on this prefix, the MR assigns unchangeable addresses to its attached nodes called Mobile Network Nodes (MNN). When a new network is available, MR generates a new auto configured IP address (Care-of-address (CoA)) within the new visited network and notifies them to the HA. Only the MR and the HA are aware of the network change, since MNNs remain connected to the MR through their permanent IP address.

MRs can be equipped with multiple communication interfaces. Multiple Care of Addresses Registration (MCoA) [7] is used to managed these communication interfaces simultaneously, as illustrated on Figure 2. MCoA enables the registration of several CoAs for a single MR. In this case, the MR could establish multiple tunnels through each of its communication interfaces and the HA.

The possibility of having multiple applications in an ITS-S simultaneously competing for communication resources leads to the need for a controlled access to these resources. In such a control, requirements and objectives presented by

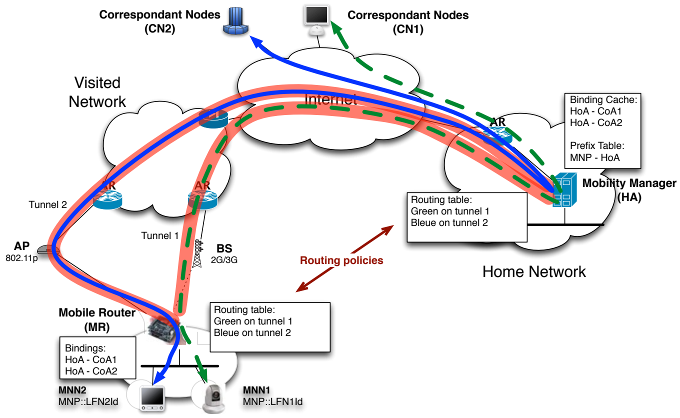

Figure 2. NEMO and MCoA.

application, user preferences, set of rules (e.g., regulations, network operator policies, etc.) and communication protocols' status are used by the ITS-S Management Entity (SME), from "ITS-S Management" cross layer, to select the best suited communication profile and path per communication source. The determination of the path implies the selection of the communication interface, the logical node in the access network to which the ITS station is locally attached (ingress anchor node) and the intermediary nodes in the network used to reach the destination node (egress anchor node). Aware about paths characteristics, the SME can choose the path that best meets the communication requirements (e.g., a local connection between nearby devices or a global connection over the Internet). The methods to determine the most appropriate path and to perform flow-interface mapping is implementation specific as it could be a competitive factor between stakeholders. It is thus not specified in the ISO standards.

III. Related work

Few researches have worked on the development of a DM architecture that consider the use of multiple access technologies simultaneously and routing flow per flow, i.e., spreading flows among different communication interfaces.

Authors of [8] proposed a modular architecture for multihomed mobile terminals. In such architecture, a middleware interacts with "higher-layers" and "low layers". The "high layers" gather the user and the administrator preferences, handle the applications' requirements, and detect the current terminal capabilities. The "low layers" detects the available networks and provides real-time information about the interfaces and access networks capabilities as well as it handles the selection execution process, i.e., it maps the application's flows on the preferred access network. It does not consider the path condition of a given flow between sender and destination nodes. And it does not consider the near future of the network environment, i.e., the short-term prevision about the availability of networks.

Paper [9] proposes a context-aware management solution to maximize the satisfaction of the applications while respecting the stakeholders policy rules. The proposed framework collect and combining policies from stakeholders (e.g., user, administrators and applications). Based on such policies and context information, it evaluates the network that better match the communication requirements. Once the best network is chose, the flow routing is enforced on the device using NEMO and MCoA. Such architecture does not consider the path condition experienced by a flow or the near future of the network environment.

Paper [10] proposes a framework for supporting network continuity in vehicular IPv6 communications. Such framework follows the ISO/ETSI guidelines for the development of cooperative ITS systems and is based on standardized technologies, such as NEMO protocol to provide an integral management of IPv6. However, it considers cooperation between mobile devices and networks based on the 802.21 standard (Media Independent Handover (MIH)), i.e., it considers that all networks support the specific functionalities from 802.21 standard [11].

IV. The ITS-based DM Architecture

This section describes the modular DM architecture for opportunistic networking in heterogeneous access network environment. The proposed architecture is based on the previously described ITS-S communication architecture and designed to meet the main challenges for communication profile and path selection in C-ITS environment.

A. *Expected properties*

As described by [12], the environment of connected and cooperative vehicles is characterized by a large heterogeneity. There are a wide variety of applications with different communication requirements. There are different wireless access technologies each one with specific characteristics in terms of bandwidth, data rate, security and others. In such an environment, the process to select the best suited communication profile and path for each data flow presents some challenges.

Different actors are able to present their requirements, preferences, constraints and policies in the decision making process. For example, applications can request a specific bandwidth, data rate or security level. Users can present their preferences, e.g., defining a priority or security level for a given message. Industrial and mobility service providers (i.e., operators) can present their policies, such as network constraints and particular billing procedures. Moreover, these wide variety of objectives could be contradictory. The DM architecture should be capable of managing these multiple objectives simultaneously.

The DM architecture should be able to monitor a variety of information in order to enable more accurate solutions in the decision making process. One essential piece of information to be monitored is the wireless networks availability as well as the performance of the networks in use. Moreover, it is necessary to monitor flows and their characteristics (e.g., used bandwidth, flow status).

Besides network monitoring, other significant parameters could be monitored. Vehicles would be able to take information from their environment, as vehicle's battery level, geographical position (e.g., GPS) or vehicle's speed in order to adjust the decision's strategies. For example, a power consuming network interface could be deactivated if the vehicle's battery level is under a certain threshold. Or a WiFi network could be privileged if the vehicle is stationary, while a cellular network could be preferred if the vehicle is moving.

The DM architecture should be capable of handling communication profile and communication path for each flow. A data flow is defined by ISO as an identifiable sequence of packets [13]. And packets are dependent upon applied protocols, links and nodes characteristics. For example, packets sent over different communication paths (routes) to the same destination node experience distinct network conditions/performances. Such distinct experiences are consequence of the applied protocol stacks (communication profile) and the specific characteristics of the traversed path (e.g., delay, throughput, security level, etc.). Therefore, on the Flow-Interface mapping process, it is not enough to indicate only what access network a given flow should use. In addition, according to flow requirements and paths characteristics it is necessary to determine the communication profile and path for each flow.

Moreover, due the vehicle's high speed the networks availability could change rapidly. In such highly dynamic mobility the decision making process should take into account the short-term prevision about the network environment condition. If the DM is aware about the near future of the network environment it can perform proactive and fine-grained decision. For example, it can decide to increase the data buffer for a given video streaming, if the vehicle is going to cross a wireless dead zone. Or, an on-board application could decide to delay a data transmission if it knows that a better network will soon be available.

The short-term prevision can be obtained in different ways. It can be obtained by cooperation with networks, e.g., using the IEEE 802.21 standard if the network support such protocol. The vehicle can store network information from a previous traversed route, e.g., for an user who uses the same route every day, the database could stores information about network conditions in such route. Or, the short-term information can be obtained by cooperation with neighbors vehicles. For example, two vehicles in opposite directions could exchange information about access points in their upcoming route. For this purpose, a vehicle stores the position of each access point in its traversed route, and give them to another passing-by vehicle.

B. Architecture design

To achieve the expected properties, we propose a modular DM architecture based on the ISO/ETSI standards. Figure 3 shows such proposed DM architecture.

For a better understanding, we split the DM architecture in five main parts, which are described below.

1) Requirement gathering: As mentioned before, different actors are able to present theirs requirements in the decision making process. In our proposed architecture we consider four main actors. *Applications* - it could request a specific bandwidth, data rate, security level and more. A middleware enables different applications to send their requirements to DM. *Users* - they can present their preferences through a Graphical User Interface (GUI), e.g., defining priority or security level for a given message. *Administrators*, i.e., industrial and mobility service providers - they could present their policies, such as network constraints and particular billing procedures. And *regulator* bodies - each country or region could define some specific rules, such as the prohibition of certain frequency ranges in certain areas. The requirements from all actors are stored in decision maker's databases and used by the DM to choose the communication interface that better matches the actors requirements.

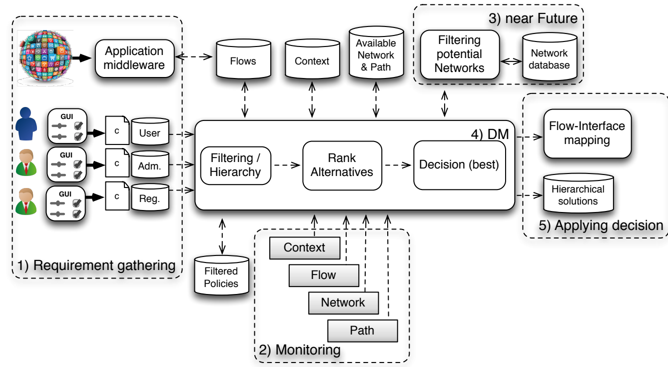

Figure 3. Proposed Decision Maker Architecture.

2) Monitoring modules: We defined four monitoring modules. *Network monitoring module* - in this process, the network monitoring module listens to the wireless interfaces and informs DM about the available wireless networks and their performances. Such monitoring module should be able to monitor network information even if no specific monitoring functionality, such as 802.21 [11], is implemented on the network side. *Context monitoring module* - this module is responsible for vehicle surrounding monitoring. It is responsible to monitor information like location of the neighboring vehicles, traffic jam, vehicle's speed, and others. These information are part of the Local Dynamic Map (LDM) functionalities, i.e., the conceptual data store located within an ITS-S as outlined in [14]. Therefore, we aim to rely this monitoring module on such conceptual data store. *Flow monitoring module* - this module should inform whether a flow is alive or not and evaluate flows' performance, like the currently used bandwidth, the currently latency, etc. *Path monitoring module* - this module is responsible to obtain various information (e.g., throughput, security level, latency, etc.) about the controllable end points where packets will be routed and to keep track of all the candidate and available paths.

3) Near Future: In order to take into account the short-term prevision about the network environment, we propose a network database that store the historical information about the access networks (e.g., network performance and access point location) and a filtering entity that is responsible to analyze such network database and, based on the context information of the vehicle (e.g., movement speed), to choose the potential networks to be considered in the decision making process.

4) Decision making process: The decision making process is responsible to take into account the application's requirements, user profiles, administrative rules (regulation and policies) as well as different monitored information in order to manage flows and paths. The decision making process is detailed in section IV-C.

5) Applying decision: In the applying decision process, the policies and information produced by the decision making process are applied in the system. In this process, the decision maker could interact with controlled entities in all layers of the ITS station communication architecture. Once the best access network and path is selected, i.e., the path and access network that better match the communication requirements, the DM request the "Flow-Interface mapping" module to enforce the flow routing decision. To enforce the decision's polices at the network layer in an IP-based environment, we are considering NEMO and MCoA. These protocols allow mobile routers to manage multiple access technologies simultaneously and to improve path and flow management.

Since the decision making process take into account the short-term prevision about the network environment, proactive decisions are enforced in order to maintain flows always best connected. However, unexpected changes can occur in a wireless environment (e.g., a given access network can drops). In order to adapt to the network conditions in real time, the DM maintain an hierarchical solution database with all sub-optimal solutions for each flow. This database is used by the "Flow-Interface mapping" module in case of emergency, i.e., when the best network solution drops unexpectedly and until the DM finds another better solution.

C. Decision Making Process

As mentioned before, the decision making process takes into account the application's requirements, user profiles, administrative rules as well as information from a variety of monitoring modules in order to manage flows and paths. We split our decision making process in three modules, as shown on Figure 3. Below we describe each one of these modules:

Hierarchy/Filtering: This module is responsible to receive and manage requirements, preferences, and policies from different actors. Since actors may have their own specific preferences and requirements, we need to "filter" (in Computer Science acceptation) the various values defined for the same parameter. Moreover, it is necessary to define a priority order between actors in order to manage contradictory objectives. For example, if the administrator sets a forbidden network for a user, and the user set the same access network to preferred, then it is necessary to define who has the priority. The output of such module is a list of filtered and hierarchical requirements.

Rank Alternatives: This module is responsible to find all alternatives for flow-interface mapping. It is a first filter to avoid forbidden networks or networks that do not match with flows' requirements. Such module receives the coherent list of requirements from "Hierarchy/Filtering" module, network information (e.g., networks availability and networks performance), and context information in order to find the potential solutions. The output of this module is a list of all potential solutions for each flow.

Decision Algorithm: This module receives the list of all potential solutions created in the "Rank Alternatives" module and apply decision making algorithm in order to evaluate the matching degree of communication requirements with networks and path characteristics. An utility function calculates a score, representing the matching degree for each solution. Higher the score, better is the solution. The solutions are sorted by descending order of score and stored on the hierarchical solution database. Such database is used by the enforcement module in case of emergency, i.e., when the best network drops unexpectedly, the "Flow-Interface mapping" module redirect the flow through the first available sub-optimal network while the DM finds a new better solution.

As described by [12], several decision making algorithms have been used in the network selection process. For example, the ones based on the game theory, the ones based on Multi-Objective Optimization (MOO) and the algorithm that uses Multi-Attribute Decision Making (MADM) techniques. The most used are the MADM methods (e.g., Simple Additive Weighting (SAW), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP)). Despite the MADM techniques present advantage as relative low computation complexity, this approach has some issues. For example, it is very difficult to choose the best weight for each attribute. Moreover, MADM algorithms could present ranking abnormality, i.e., change in one of the parameters of the objective function could determine a very different best solution. The design of a decision making algorithm is outside the scope of this paper. Such topic will be addressed in future works.

D. Integration in the ITS-S communication architecture

The ITS-S communication architecture functionalities could be implemented into a single physical unit, as the practical implementation showed on paper [15], or distributed into several physical units. Once applied to a vehicle, these functionalities could be performed by different modules in the vehicle's electric/electronic architecture.

Moreover, the NEMO environment mainly separate the applications and communications into MNN and MR. Therefore, the five functions described in Section IV-B can also be separated into such nodes. For example, the requirement gathering can be implemented in the MNN, the monitoring modules can be implemented in both MR and MNN, while the near future, the decision making process and applying decision are functions of the MR.

The proposed DM architecture is designed in an ISO/ETSI standard compliant way. Figure 4 shows one way how we can integrate such architecture in the ITS-S communication architecture.

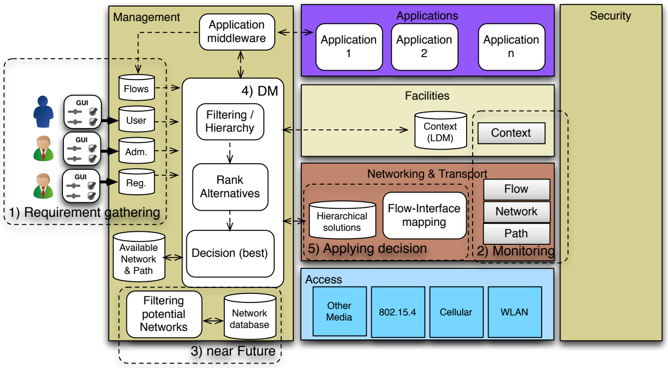

Figure 4. Integration of DM Architecture in the ITS-S communication architecture.

However, the standards give some guidelines to the developers, leaving some room in the way to implement the ITS-S communication architecture.

V. Conclusion and Future Work

In this paper, we proposed a modular decision maker architecture that is capable to choose the best available communication profile and path for each data flow in an heterogeneous and dynamic network environment. The proposed DM architecture is designed in an ISO/ETSI standard compliant way and we show how to integrate it in the ITS-S communication architecture.

Besides the access network selection, the proposed architecture is able to choose the best path for a given flow, i.e., the route between two communicating nodes that best meets the communication requirements (e.g., a local connection between nearby devices or a global connection over the Internet).

Different actors are able to present theirs requirements in the decision making process, e.g., applications, users, network administrators, etc. And this wide variety of objectives could be contradictory. The proposed DM architecture is capable of managing these multiple objectives simultaneously. Moreover, the DM receives information from a variety of monitoring modules (network, context information, path, and flows monitoring modules), that enable fine-grained decisions.

The proposed architecture address the short-term prevision about the network environment. This short-term prevision allows proactive decisions, which is very useful in vehicular environments that are characterized by highly dynamic mobility.

Once the best access network and path is selected for a given flow, the decision's polices are enforced at the network layer using standardized protocols, such as NEMO and MCoA. These protocols allow mobile routers to manage multiple access technologies simultaneously and to improve path and flow management.

We highlight the importance of the DM architecture validation. As future work, we will simulate the proposed architecture using different scenarios and existing decision making algorithms. We will also design and simulate a decision making algorithm capable to take advantage of the entire proposed architecture for smart and fine-grained decisions. Moreover, it is valuable to conduct such architecture in a real test-bed.

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