An enhanced vertical handover decision algorithm designed for vehicular networks

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Abstract—
Nowadays automotive industry is taking advantage of the latest developments offering On-Board Units, which are powered by advanced processors, GPS devices, sensors, and multiple wireless access technologies such as Wi-Fi, WiMAX and UMTS. Users within vehicular networks will be able to access content from the Internet at high speeds while moving from one place to another, switching among multiple access points with heterogeneous coverage areas, as well as with different Quality of Service (QoS) levels offered. To maintain data connections alive in such dynamic conditions, Vertical Handover techniques are required. In this paper we present a Vertical Handover Decision Algorithm designed for dynamic environments. The decision making process is optimized by combining networking information, obtained by the services of the IEEE 802.21 standard, with geolocation, map information, surround context information and route calculation, thereby improving the handovers' performance.

Keywords— **Vertical handover, IEEE 802.21, Wi-Fi, WiMAX, UMTS, ns-2, GPS, vehicular networks.**

I. Introduction

Due to the wide deployment of wireless broadband systems, nowadays vehicles are being improved to use telecommunications not only for sending safety-related messages, but also for infotainment services. Therefore, the QoS must be guaranteed in order to fulfill the application requirements. Different solutions in the Vehicular Networks (VNs) area have been proposed, but they only consider a single wireless technology as the main underlying network, as is the case of Universal Mobile Telecommunications System (UMTS) due to its wide coverage area, or IEEE 802.11 in the Vehicular *Ad-hoc* Network (VANET) case. However, when considering multiple wireless access network candidates to hand over to, a Vertical Handover Decision Algorithm (VHDA) must evaluate the most suitable network among them in order to maintain connectivity with the highest quality possible. The automotive industry is taking advantage of the latest developments of the different embedded systems and communication technologies, thus building fully featured On-Board Units (OBUs) powered by fast and reliable processor units, Global Positioning System (GPS) based navigation systems, Wireless Fidelity (Wi-Fi), UMTS, and even Worldwide interoperability for Microwave Access (WiMAX) interfaces to reinforce the communication system of the vehicles [1]. Since there are different alternatives for communication among vehicles, and between the vehicles and the infrastructure, on highways and metropolitan areas, the industry must face the downside issues when heterogeneous wireless technologies are used in highly dynamic environments such as VNs. Therefore, in order to provide continuous communication among heterogeneous wireless networks while maintaining certain QoS levels, the IEEE 802.21 standard [2] has been released.

In this paper we propose a novel VHDA called **MACHU (Multi-ACcess network Handover Algorithm for vehicUlar environments)**, which combines GPS-based geolocation, map information, surround context information and route calculation, with the functionality of the IEEE 802.21 standard. For the decision-making process, MACHU takes advantage of both current and future geolocation of the vehicle (within the route and map layout), along with the networking information provided by the different services of the IEEE 802.21 standard. The purpose is to choose the most suitable access network along the route when following the pathway from one location to another.

The rest of this paper is organized as follows: Section II presents related proposals found in the literature. An overview of the Vertical Handover (VHO) process and the IEEE 802.21 standard is provided in Section III. The design and considerations of MACHU are presented in Section IV. Section V describes the simulation environment used for the evaluation of the VHDA, while Section VI presents the experimentation results. Finally, Section VII presents the conclusions of this research work, as well as the future work.

II. Related Work

Horizontal handovers assisted by GPS information have been already studied and proposed by different authors [3], [4] presenting the advantages of geolocation within a single type of wireless network. Recently, works considering GPS support for the decision-making process when performing VHO among multiple access technologies were presented. Ylianttila *et al.* [5] proposed using the GPS in order to manage the current location of the mobile device to hand over among Wi-Fi and UMTS cells, performing the decision-making based on the Received Signal Strength (RSS).

A more recent proposal is presented by Gu *et al.* [6] using a Position Prediction Mechanism (PPM) in order to predict the future position of the mobile device, and obtaining network information for the decision-making process from the advertisement packets. However, authors propose predicting the

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future position based on GPS information alone.

Concerning network information, as far as we know, none of the previous proposals collects the networking information using the Media Independent Information Service (MIIS) offered by the IEEE 802.21 standard. The MIIS offers very powerful and detailed information about the Points of Attachment (PoAs) (*i.e.* Base Stations (BSs) and Access Points (APs)), network preferences, billing information, and handover policies.

In our proposal we not only use GPS-based coordinates, but also combine coordinates, maps, surround context information and routes to dynamically calculate and recommend the optimal pathway from one place to another. That information is then used as an input to the IEEE 802.21 services to select the best network to hand over to along the proposed pathway.

III. VHO & the IEEE 802.21 standard

Diverse processes are required in order to perform a Vertical Handover (VHO). The complete VHO process is divided into three phases [7]: i) Handover information gathering, ii) Handover decision, and iii) Handover execution.The information gathering phase is in charge of collecting relevant information from diverse context sources, such as network capabilities, access points, user equipments, and user preferences. The most critical element in a VHO process is the decision phase since, depending on the network candidate chosen, the performance of the system could improve or decrease. Once the information is gathered, the VHDA is in charge of making a decision about *When*, and *Where* to trigger the handover. This decision should consider several parameters in order to choose the best candidate network to hand over to. Concerning the VHDA, there are several proposals considering techniques such as fuzzy logic, pattern recognition and neural networks, among others [8], [7]. The execution phase is in charge of committing the VHO itself. In this process the User Equipment (UE) leaves the current network and gets attached to a new network in a seamless manner, experiencing low latencies and minimal packet loss.

The IEEE has been making significant efforts in order to develop a protocol which may be able to homogenize VHO processes among heterogeneous networks. In that sense the IEEE 802.21 standard [2] has been released with the aim of regulating the handover process.

The Media Independent Handover Function (MIHF) protocol, defined by the IEEE 802.21 standard, establishes the messages exchanged between peer MIH entities for handover, offering a common message payload across different networking media (802.3, 802.11, 802.16, Cellular). The standard refers as *lower layers* to the technology dependent components, and as *upper layers* to the requesting modules. Lower layers can be accessed by different functions to retrieve information to detect, prepare, and execute the VHO, while the upper layers demand that information; therefore, the latter are also referred to as *Media Independent Handover User (MIHU).* The MIHF offers to both lower and upper layers a Service Access Point (SAP) in order to exchange the service messages. The basic services offered by the MIHF are briefly described below:

The **Media Independent Event Service (MIES)** detects the changes on the lower layers, e.g., changes on the physical and data link layer. The MIHF notifies events occurring in the lower layers to the MIHUs according to their requests. The MIES covers events such as state change events (link up, link down, and link parameter changes), predictive events (link going down), and network initiated events (load balancing, and operator preferences).

The **Media Independent Information Service (MIIS)** allows the MIHF to discover its network environment by gathering the information required by upper layers to make decisions. The information elements refer to the list of available networks, location of PoA, operator ID, roaming partners, cost, security, QoS, PoA capabilities, and Vendor specific information, among others.

The **Media Independent Command Service (MICS)** allows the MIHU to take control over the lower layers through a set of commands. With the information gathered by the MIES and MIIS, the MIHU decides to switch from one PoA to another. The commands allow not only to execute the handover, but also to set different parameters in the lower layer elements. Typically, the commands used by the MICS are: i) *MIH Handover Initiate*, used between networks and mobile devices, ii) *MIH Handover Prepare*, used between the old network and the new network, iii) *MIH Handover Commit*, used between networks and mobile devices, and iv) *MIH Handover Complete*, used between networks and mobile devices, as well as among networks.

IV. Overview of the MACHU VHDA

Concerning Vehicular Networks (VNs), when a vehicle passes through different PoAs along the route, a VHDA could decide to join/leave different coverage areas for a very short period of time due to the speed and route chosen to reach the destination. Thus, an adequate VHDA for vehicular environments must evaluate all the surrounding PoAs (cell information and coverage) not only to choose the one whose performance best fits the applications' requirements, but also the one which offers a more reasonable coverage within the route to make the VHO worthwhile.

Our proposal (MACHU) takes the most of the current OBUs, such as continuous power supply, multiple networking interfaces, GPS information, maps and routes, combining the different data sources with the network information provided by the IEEE 802.21 standard. Figure 1 presents the flow diagram of the MACHU Algorithm, which is mainly divided into three independent and parallel components: Networking, Neighborhooding, and Decision-making branches. We now proceed to describe each branch.

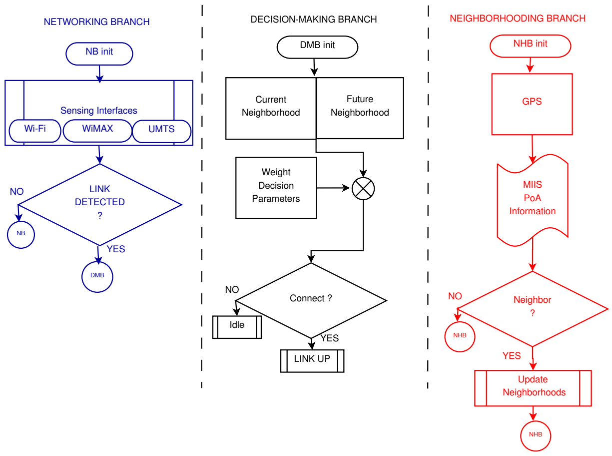

Fig. 1. MACHU Algorithm.

A. *Networking*

The networking branch is in charge of sensing the different wireless network interfaces available at the OBU. This process is done by a process that periodically sends and receives information about the network status (*e.g.* Router Advertisement (RA) and Router Solicitation (RS)). To interact with the interfaces, MACHU uses the IEEE 802.21 services, *i.e.* Media Independent Event Service (MIES) and Media Independent Command Service (MICS) to check the link status and received reports. When an event occurs in the physical/link layer, the interfaces receive a trigger event (LINK DETECTED) launching different sequence processes (decision-making, VHO execution); through the MIES, different events are notified to upper layers in order to execute the different actions associated with a VHO process. Moreover, any further actions defined by the upper layers are executed by the lower layers using the primitives defined by the MICS.

B. *Neighborhooding*

The Neighborhooding branch introduces novel features by considering surround context information. All the surrounding information is gathered into two data storage elements: Current Neighborhood and Future Neighborhood. Each of these storage elements are periodically filled-in with information about the current and future PoAs available (cell information and coverage), respectively. Every $SensingPeriod$ seconds, the branch executes a query to the GPS module requesting the current geolocation and the future geolocation within the next $PredictionWindow$ seconds. The response contains a geolocation within the map with the route that the vehicle is taking to reach the destination. Based on those geolocations a request is performed to the PoA information database, powered and made available by the Media Independent Information Service (MIIS) of the IEEE 802.21. A list of current and future available PoAs is retrieved and locally stored at the OBU to be used by the decision-making branch. The MIIS PoA information database offers information such as the ID of the network, the ID of the PoA, its geolocation, coverage, monetary cost per MB, and BW offered. The local data storage containing current and future neighborhood information is filled-in with information about PoAs only if the current and future geolocation, within $PredictionWindow$ seconds, are inside the coverage area described in every PoA registry. To determine the coverage condition, Equation 1 is used.

$$d = \sqrt{(X_{vehicle} - X_{PoA})^2 + (Y_{vehicle} - Y_{PoA})^2} \quad (1)$$

A major issue when performing a VHO is the latency taken by the whole VHO process, since a high latency could mean packet loss and service disruption, thus downgrading the performance of active applications. Equation 2 describes the different latencies associated with a VHO process, where VHO_{L2} is the latency referred to the association process at the link layer, and VHO_{L3} is related to the Internet Protocol (IP) level processes (*i.e.* IP address negotiation among the interface and the PoA). Finally, VHO_{MIP} is the time taken by the Mobility for IP (MIP) protocol for notifying and upgrading the home and foreign IP addresses when managing the mobility database.

$$VHOLat = VHO_{L2} + VHO_{L3} + VHO_{MIP} \quad (2)$$

The MACHU algorithm takes $VHOLat$ into account as a main decision parameter. In order to perform an adequate neighborhood discovery task, the most adequate values for the $SensingPeriod$ and the $PredictionWindow$ variables must be selected. Therefore, based on Equation 2, we made the following considerations:

i) To guarantee an accurate decision-making process, MACHU must gain awareness of, at least, some minimum future neighborhood information within the time frame defined by Equation 3, where α is the relative percentage of the Useful Coverage Time during which the system is able to tolerate the adverse effects of VHO (which implies both packet loss and latency).

$$CellCoverageTime_{min} = \frac{VHOLat_{max}}{\alpha} \quad (3)$$

ii) An optimum $SensingPeriod$ must be smaller than the $CellCoverageTime$, as show in Equation 4.

$$SensingPeriod_{opt} < CellCoverageTime_{min} \quad (4)$$

iii) Based on the $SensingPeriod$, Equation 5 presents a minimum $PredictionWindow$ which guarantees an accurate process of Neighborhooding.

$$PredictionWindow_{min} = 2 \cdot CellCoverageTime_{min} \quad (5)$$

However, depending on the features and performance of the OBU, the optimum $PredictionWindow$ can be considered as in Equation 6, where β is a multiplier that can be tuned according to the OBU and the performance of each particular system.

$$PredictionWindow_{opt} = \beta \cdot PredictionWindow_{min} \quad (6)$$

By taking all the aforementioned parameters into account, the Current and Future Neighborhood shall offer precise and coherent information.

C. Decision-making

Finally, the selection of the destination network (by choosing a PoA to handover to) is made at the decision-making branch. This process evaluates all the gathered information and, based on an Multiple Criteria Decision-Making (MCDM) evaluation, the candidate PoA which best fits the application requirements is chosen. For testing purposes, MACHU currently considers the cell coverage information (stored locally as the Current and Future Neighborhoods) in order to allow or deny the VHO execution (*i.e.* LINK UP IEEE 802.21 primitive). The main MACHU's decision logic, which considers the cell coverage time, allows handovers to take place only when the $VHOLat$ time is lower than α percent of the Useful Coverage time. Remember that α, as mentioned before, is the maximum relative time during which system supports handover-related losses.

Finally, when a VHO process takes place, the new address is notified to the different network elements involved by using Mobility support for Internet Protocol v.6 (MIPv6), which manages the mobility issues.

V. Simulation Environment

A. Simulation tools

The National Institute of Standards and Technology (NIST) has developed a Network Simulator (ns-2) [9] add-on for seamless mobility [10]. The *NIST mobility package for the ns-2*, in conjunction with EURANE [11], offers many capabilities and features to simulate Wi-Fi, WiMAX, and UMTS technologies, and to perform VHO among them. Furthermore, the NIST add-on also enables the MIES and MICS services of the IEEE 802.21 standard to interact with heterogeneous network interfaces under homogeneous standard primitives. Since our proposal requires the third IEEE 802.21 service: the Media Independent Information Service (MIIS), we have developed (by extending the NIST add-on) a MIIS considering local and remote databases which store the PoA container information, being able to read and write information via XML files, strictly following the IEEE 802.21 standard. Our proposal also considers the capability of updating the status of the PoA container via notifications performed by the vehicles, as suggested by Andrei *et al.* in [12]. We have also implemented a Global Positioning System (GPS) add-on module for the ns-2 which manages the GPS coordinates, maps, and routes, to select a pathway to travel from the current geolocation to any destination. The GPS module also translates the geolocation coordinates into traveling time, in order to allow the MACHU algorithm to know *where* the vehicle is expected to be at any moment in the future.

B. Simulation scheme

For our experiments we have devised a simulation scheme considering vehicles moving at 32 Km/h from Universitat de Valencia Campus (Source) to Universitat Politecnica de Valencia Campus (Destination) in the city of Valencia, Spain. Figure 2 shows the route from one geolocation to another, involving a distance of 5.5 km in an 3.75 km^2 area. Our GPS module manages all the coordinates of the route. Moreover, the MIIS provides information about the available networks and its respective PoAs within the simulated area, as shown in Figure 3. Table I summarizes the main configuration set for the experiments. As observed, there are 1 UMTS, 8 Wi-Fi, and 3 WiMAX PoAs covering different areas with distinct bandwidth capacity. It is important to point out that UMTS covers the whole scenario, meaning that the UMTS technology is always the backup connectivity technology for this set of experiments. The $VHOLat$ considered for each technology has been extracted from real measurements of Wi-Fi handovers done at the Universitat Politecnica de Valencia Campus, while the WiMAX handovers have been done at the Universidad de Murcia Campus; these measurements agree with the ones presented in [13], [14]. For the α value, we have set the system to allow up to a 5% of the Useful Coverage Time to be associated with handover-related losses, and β is set to 1 to verify whether the minimum $PredictionWindow$ is good enough to guarantee the correct functionality of MACHU. The OBU demands a 1.48 Mbps Constant Bit Rate (CBR) video traffic stream. We focus on video streaming traffic since it allows performing a fair evaluation when considering the different evaluation parameters at the VHO events due to the characteristics of this type of traffic. For evaluation purposes, the available networks are working under "best-case" conditions, so there is no other traffic in the network that could interfere or compromise our evaluation of the MACHU algorithm. So, the purpose of this set of experiments is to evaluate the performance of the MACHU algorithm rather than evaluating the network performance itself.

TABLE I
VHO SCHEME COMPONENTS.

Component	**Wi-Fi**	**WiMAX**	**UMTS**
Access Point	8	3	1
Theoretical Bw (Mbps)	54	70	5
Bw offered (Mbps)	28.2	16.3	2.7
VHO latency (ms) [13], [14]	1080	2665	-
Advertisement Interval (ms)	100	5000	-
Coverage (m)	500	1000	5000

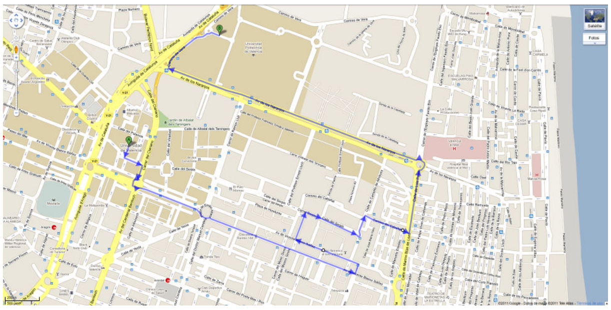

Fig. 2. Map and route layout.

VI. MACHU performance evaluation

To evaluate MACHU, we have performed several experiments in order to assure its accurate performance. For comparison purposes, we also have performed experiments evaluating the simulation scheme under a different VHDA. In particular, we have used the Technology-aware VHDA proposed in [15], which is a VHDA that considers the technology availability, and, as a main decision parameter, takes the bandwidth offered into account.

Results show that the experiment with the Technology-aware VHDA performs a VHO every time a new coverage area offering higher bandwidth is detected, since its decision-making process does not consider the surrounding context nor the useful coverage areas. Thus, it often joins PoAs that are abandoned after a very brief period of time, performing unnecessary VHO processes with their inherent latency and packet loss. In general, missing context information may lead to wrong decisions, as demonstrated in [16]. Table II shows that the experiment adopting the Technology-aware VHDA performed 18 VHO events, which resulted in 64816 lost packets. Figure 4 presents the active wireless interfaces at the OBU of the vehicle while moving within the pathway (throughout the simulation time). Figure 5 presents the active interfaces under the MACHU algorithm for comparison. We can clearly observe that there are less VHO events performed with MACHU than with the Technology-aware VHDA, avoiding to join worthless PoAs due to their reduced Useful Coverage Time, and thus reducing unnecessary VHO events and their adverse effects. Table II presents a summary of the main performance results for both VHO decision algorithms. As observed, MACHU introduces less VHO processes, reducing up to 55% the VHO events required and achieving an improvement of up to 32% in terms of packet loss, while maintaining the QoS demanded by the video streaming session. Finally, Figure 6 presents the technology dwell usage time, describing the amount of time that every type of wireless interface has been active during the experiments. We can observe that, when using the Technology-aware VHDA, the UMTS, WiMAX and Wi-Fi interfaces are active the 12.5%, 37.14%, and 50.3% of the time, respectively; under the MACHU VHDA, their activity changes to the 30.21%, 54.3% and 12.44% of the time, respectively. The differences detected highlight the different choices made; in particular, we find that MACHU avoids unnecessary VHO events when reaching Wi-Fi hotspots that, due to their small useful coverage areas, will at times cause only adverse effects rather than improve the overall performance through higher bandwidth capacity.

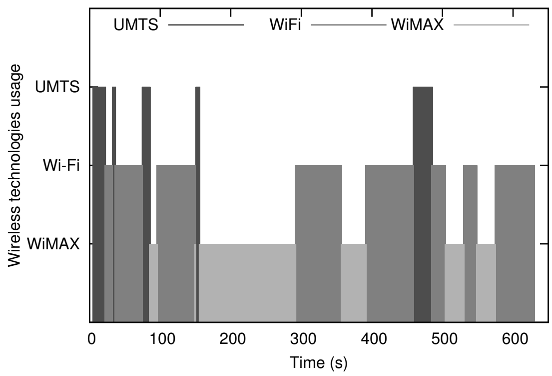

Fig. 4. Wireless technologies usage when adopting the tech-aware VHDA.

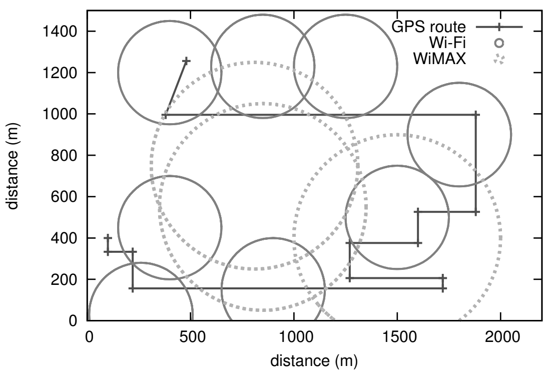

Fig. 3. Wireless technologies coverage areas.

VII. Conclusions

In order to evaluate our algorithm, we have used the ns-2 simulator powered by the NIST add-on, which offers an implementation of the MICS and the MIES services of the IEEE 802.21 standard. We have developed a GPS module to manage geolocation, map information, and route calculation within the ns-2, and we have also extended the NIST add-

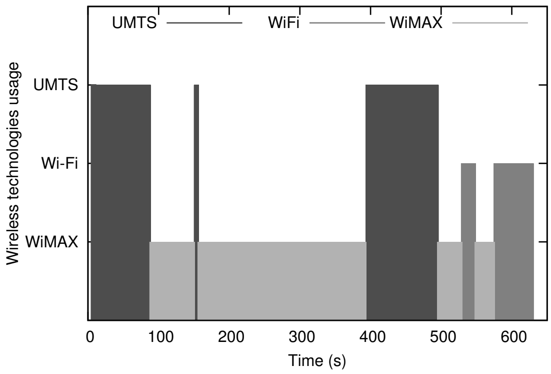

Fig. 5. Wireless technologies usage when adopting the MACHU VHDA.

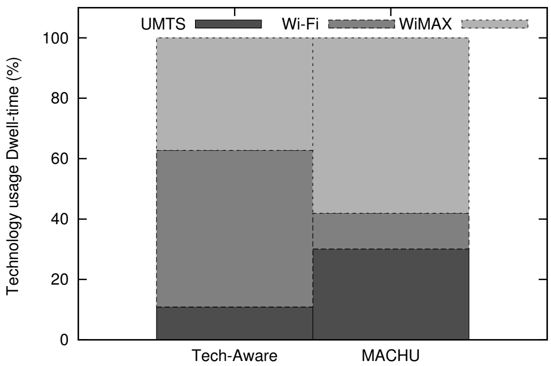

Fig. 6. Wireless technologies usage.

on in order to be able to use the MIIS of the IEEE 802.21, thereby taking context into account for making the best VHO decisions.

Through a set of experiments, we have validated the correctness of our algorithm, and we compared it against a Technology-aware algorithm already studied in previous works. Results showed that MACHU avoids performing worthless VHO processes, thus reducing their adverse effects such as the increase of packet loss.

As a future work we plan to enhance our algorithm by combining several parameters from different sources (*i.e.* network, user preferences, and context information).

Acknowledgments

This work was partially supported by the *Ministerio de Ciencia e Innovación*, Spain, under Grant TIN2011-27543-C03-01.

TABLE II
VHO results.

Parameters	**Tech-aware**	**MACHU**
VHO events	18	8
Packet loss	64816	21348
Throughput (Mbps)	1.471	1.477
Unnecessary VHO events	10	0

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