Enhancing TETRA with capabilities exploiting MIPv6 and IEEE 802.21 MIH services

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Abstract — **The private mobile radios (PMRs) play a key role in public safety, emergency and rescue missions, patrolling and military operations, allowing the fast deployment of robust and effective communication networks able to cover a wide area of interest. Unfortunately, they do not offer high performance in terms of throughput and QoS if compared with well-established and emerging wireless technologies such as WiFi, IEEE 802.11s, LTE, WiMaX, etc. Since modern terminals are equipped with multiple wireless interfaces it is reasonable to suppose a close cooperation among PMRs and the above mentioned networks, according to the concept of Always Best Connected (ABC) paradigm, that is in a multiple access technology scenarios it is desirable that the mobile node be always connected through the access technology which best fulfill user and network needs. Moving from this idea, we explore the possibility of extending the capabilities of a well known PMR, i.e. TETRA, by exploiting Mobile IPv6 and IEEE 802.21 Media Independent Handover services.**

Keywords: Private Mobile Radio, TETRA, Mesh network, IEEE 802.21, Mobile IPv6, Vertical handover, Heterogeneous networks, Command and Control.

I. INTRODUCTION

Public safety, rescue missions, patrolling and military operations are some of the most important scenarios in which a rapid deploying of a robust communication infrastructure is a critical issue. In all of these scenarios, the Private Mobile Radios (PMRs) play a key role in managing communications among users, thanks to their capability to be fastly and easily deployed in a wide area, their robustness and the availability to allow group communications among network users. Having a secure, robust and safe communication network is essential in reaching the success of an operation. As a proof, the emerging concept of network-centric environments [1] shows how is important to have an efficient communication network in which all users and mission partners can safely access any information everywhere and anytime. Although PMRs are widely used in several applications, there are some features that a PRM cannot guarantee. As traditional PMRs do not offer high transmission rates, there are some features, i.e. video streaming and video conferences, that the network cannot support. Hence, to provide the users with better services, new network approaches need to be analyzed. Nowadays, thanks to the technology development, network radio technologies such as WiFi, WiMAX, and UMTS/LTE allow their users to enjoy high transmission rate by accessing the internet through their smart-phone or tablets. Moreover, modern wireless terminals are equipped with several wireless interfaces and can manage by themselves handover procedures in order to being always best connected [2] while the users are moving. Therefore, is not unreasonable and unfeasible to suppose an interaction between PMRs and new emerging networks.

In this work, we address the problem of extending a well known PMR technology, i.e. TErrestrial Trunked Radio (TETRA) [3][4], by implementing vertical handover capabilities in order to realize a full and seamless interoperability between TETRA technology and other widely developed standards, such as IEEE 802.11. In order to manage and guarantee the full interaction between these two standards, the IEEE 802.21 framework [5], combined with Mobile IPv6 [4], is exploited to perform seamless vertical handover. As we will show in next Sections, the cooperation between PMR and 802.11-based networks leads to several improvements:

- a) wide radio coverage area guaranteed by the TETRA base station;
- b) high performance in terms of throughput, delay, jitter and packet loss rate, guaranteed by employing a wireless mesh network deployed near the headquarters;
- c) high security against tampering as network devices which are composing the backbone are deployed near the headquarters and unreachable by an attacker (this feature is an essential requisite in case of military and peace keeping missions or in all of those scenarios in which the infrastructure deployment represents a critical issue);
- d) easiness in use guaranteed by exploiting a single device with two or more network interfaces seamless and fully inter-operable.

The remainder of the paper is structured as follows. MIPv6 and IEEE 802.21 MIH services are described in Section II; in Section III we present a realistic application scenario in which it is desirable to introduce the interoperability of TETRA and WiFi technologies in a single multi-interface device; in section IV we describe our proposed framework; section V presents the simulation framework we adopted to test the handover mechanism and related results; finally, in section VI, future works and improvements will be summarized.

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II. RELATED WORK

Our proposal is based on two well known protocols, able to guaranteeing an effective and seamless handover among different radio technologies such as IEEE 802.11 and TETRA: the IEEE 802.21 protocol and the Mobile IP v6 protocol. In the following sections we briefly explain these two mechanisms before presenting our integrated proposed solution.

A. IEEE 802.21 overview

In this Section we describe the IEEE 802.21 framework, also known as Media Independent Handover (MIH), a protocol layer enabling vertical handover, that is the process thanks to which a mobile terminal, allowing IP-based services and provided with multiple interfaces, can connect to different radio access points and/or base stations exploiting the always best connected paradigm, i.e. always selecting the interface with the best features according to the implemented policy.

This standard defines extensible IEEE 802 media access independent mechanisms which enable the optimization of handover between heterogeneous IEEE 802 networks and facilitate handover between 802 networks and other networks. The purpose of the standard is limited to the initialization and preparation of handover phases. Therefore, it helps to discover and select a new target network, negotiate the handover procedure and set up a new Layer 2 (L2) connection with it.

This is done introducing a Media Independent Handover Function (MIHF), that is an intermediate layer located between L2 and L3, enabling the information sharing among the Mobile Node (MN) and other network entities supporting vertical handover.

The IEEE 802.21 standard introduces three Service Access Points (SAPs):

- a media independent SAP, called MIH SAP, that supplies the MIH users (L3 and higher layers) with services of the MIHF;
- a media dependent SAP, called MIH LINK SAP, enabling the communication among the MIHF and each L2 layer technology of the mobile device, in order to control and monitor the different radio links;
- a network-level interface, called MIH NET SAP, enabling the communication and the information sharing among the mobile node and the other network entities involved in vertical handover procedures.

Moreover, the implementation of the IEEE 802.21 standard provides for three main entities:

- the ***Media Independent Event Service (MIES)***, which provides higher layers with event classification, filtering and reporting corresponding to dynamic changes in link characteristics; when a node turns on, the L3 protocols has to register to the services provided by the MIES in order to manage the data flow and decide if and when performing the handover procedure; the list of notifications and events supported by the MIES and adopted in our framework is illustrated in Table 1.
- the ***Media Independent Command Service (MICS)***, which enables MIH users to manage and control links behavior in order to schedule the handover procedures according to the implemented handover policies and to the notifications sent by the Media Independent Handover Function.
- the ***Media Independent Information Service (MIIS)***, which defines a framework for acquiring, storing, and retrieving information useful for handover decision. Note that this information can be acquired from a local or remote *Information Server* holding a database of available network in the area of interest.

Event	Description
MIH-Link-Detected	Link of a new access network has been detected.
MIH-Link-Up	L2 connection was established and link is available for use.
MIH-Link-Down	L2 connection was broken and link is not available for use.
MIH-Link-Going-Down	Link conditions are degrading and connection loss is imminent.

Table 1: List of notification sent by the MIES to upper layers.

B. Mobile IPv6 overview

Mobile IPv6, or MIPv6, is a communication protocol which allows MNs to move within heterogeneous or homogeneous networks by maintaining the same IPv6 address. Each MN is provided with at least two IPv6 address, a Home Address (HoA) and a Care-of Address (CoA). The first one is a fixed address univocally assigned to a node by its Home Network (HN), whereas the CoA is a temporary address depending on the network the MN is currently attached to. As a MN can move towards a Foreign Network (FN), a foreign agent assigns a CoA to each node entering the FN. When a node enters a foreign network a Binding Update (BU) is performed in the node's home agent. Thus, if a Correspondent Node (CN) sends a packet to a node MN, CN sends a packet addressed to the HoA of MN. After reaching the home network of MN, the packet is captured by the home agent handling the MN, say HA. If MN is still inside its home network, HA delivers the packet to MN, otherwise the home agent perform a tunneling to the foreign network the MN is attached by using the CoA assigned to MN in the foreign network. To reduce latencies introduced by tunneling operations, each correspondent node maintain a binding cache containing mobile nodes' bindings. Such an approach let the CN to firstly check if its binding cache contains the binding for a given MN, if this is the case, CN forwards the packet directly to the CoA of MN, otherwise CN sends the packet to the home network of MN.

III. SCENARIO OVERVIEW

A typical scenario, suitable to illustrate the proposed framework, is depicted in Figure 1.

Figure 1: Scenario overview.

The figure shows a wide area suitable to give hospitality to great public events, such as political congresses, sports manifestations, exhibitions and similar. Securing this kind of events is a very hard task involving several monitoring/detecting technologies that need connectivity towards a command and control (C2) operational centre that we indicate in the map as Headquarters and placed in the centre of the area of interest. Usually, to provide connectivity to all the devices deployed in the field, a wireless mesh network is used as backbone following the network organization represented in Figure 1.

Besides sensor/detector/monitoring devices placed near the main building, police patrolling is expected in order to cover the whole zone. Usually, in such a scenario, security employs a private mobile radio (PMR) for individual and group voice call with the headquarters and/or other users; furthermore, frequently it is desirable that security can transmit to the C2 operators other information such as position, biometric data, video surveillance streaming, etc. If this is the case, TETRA PMR is not suitable for transporting this kind of information and security operator is provided with a second device using WiFi technology to communicate.

In this paper we propose the use of a multi-modal device equipped with two radio technologies, i.e. TETRA and WiFi, the first able to guarantee a wide coverage area with low bit rate, the latter suitable for short range communication with a high data rate supporting real time and time critical C2 applications. In such a way, security operators can transmit data towards the Headquarters without changing the device. Scope of the paper is showing, with the support of simulation, that the IEEE 802.21 protocol can play a key role in enabling multi-modal technologies device particularly suitable for operating in the context of patrolling, monitoring, and home landing operations such that depicted in our demonstration scenario.

IV. PROPOSED FRAMEWORK

Several research works appear in the last years with the aim of illustrating the capabilities of IEEE 802.21 protocols in enabling seamless and effective vertical handover among different communication technologies belonging to the 802 products family [7][8]. In this work we want to apply this framework to TETRA devices in order to provide an effective and flexible device to military, security and/or sanitary operators working within an interest area not covered by a preexistent network infrastructure. The proposed architecture is illustrated in Figure 2, where we can notice how the media independent function acts as an intermediate layer in the device's protocol stack, managing the two available interfaces, i.e. WiFi and TETRA radios, on the base of information gathered by the MIHF services.

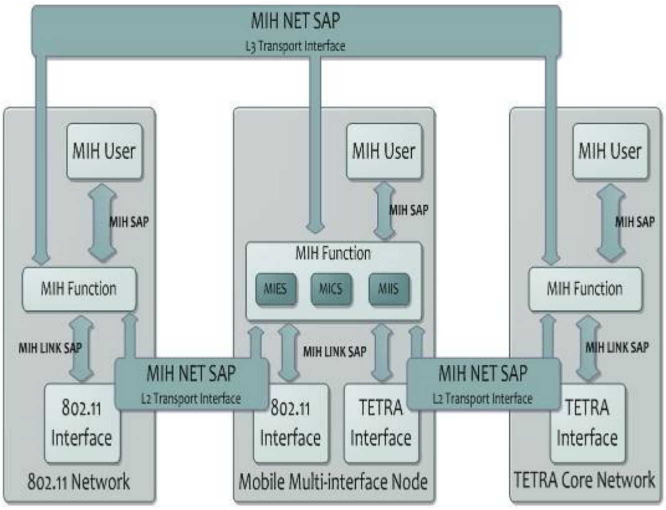

Figure 2: MIHF elements and SAPs.

When a new point of attachment (PoA) is detected, the MIH user establishes if the new PoA is better or not respect with the interface actually in use. Several research papers appear with the aim of investigating the more suitable selection criteria but this aspect is out of the scope of our paper. Thus, in our simulation, we choice to select the PoA on the base of two simple criteria:

1) *the received signal/noise ratio (SNR);*
2) *the available bandwidth.*

Furthermore, according to the IEEE 802.21 framework, two handover politics have been taken into consideration:

- *Case 1*: the MIHF makes use of the *link-down* event, triggered when the Mobile Node (MN) exits from the coverage area of the current Base Station (BS) it is connected to; in such a case the MN must lose the signal before starting the handover procedure;
- *Case 2*: the MIHF exploits the *link-going-down* event to avoid packet loss; in such a case the MIHF periodically checks the received signal-to-noise ratio related to the working interface and, when it is under a prefixed threshold, the MIHF starts the handover procedure before losing the connection.

We notice that, TETRA is not an IP-based network so, in the design of the new protocol stack, we have chosen to interface the MIHF not directly to the L2 (logical link + MAC layers) but to the *Sub Network Dependent Convergence Protocol* (SNDCP) layer, that is the protocol layer enabling the transmission of IP packets over the TETRA MAC frame or multi-frame. At the light of this consideration, the modified protocol stack of the mobile multi-interface node is shown in Figure 3. Figure 4 shows the procedures, events and messages exchanges related to the above mentioned case 1 and case 2.

V. PERFORMANCE EVALUATION

In this Section we describe the performance results obtained with simulations. More specifically, in Section V-A we provide a brief description of the simulation environment together with the general settings we used in order to obtain the results we will present in Section V-B.

A. Simulations descriptions and settings

In order to validate the feasibility of the proposed framework we run several simulations in NS-2.29 [9] jointly with: the 802.21 NIST add-on module [10][11], the Neighbor discovery NIST add-on module [12], and the NIST extension of MAC 802.11 module [13].

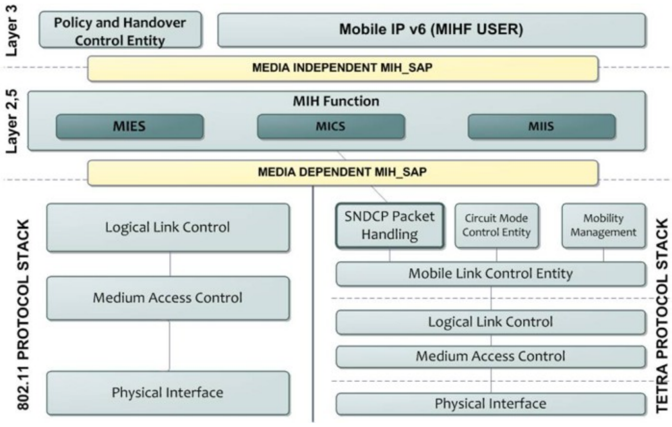

Figure 3: The new mobile node's protocol stack.

Furthermore, at the best of our knowledge, a TETRA module for NS-2 platform is missing, thus we needed to implement a new NS-2 module in order to simulate the lower layers of the PMR protocol, with particular emphasis on the MAC and SNDCP layers, in order to manage the IP packets transmission. Additionally, the above cited layers have been modified in order to guarantee the interoperability with the MIHF layer and the Neighbour discovery module provided in the NIST add-on patches.

We considered a scenario of 4 Km^2, as depicted in Figure 5, where we deployed $N_{APs} = 7$ access points with a coverage area of $R = 200$ *meters*, $N_{BSs} = 1$ TETRA base station placed

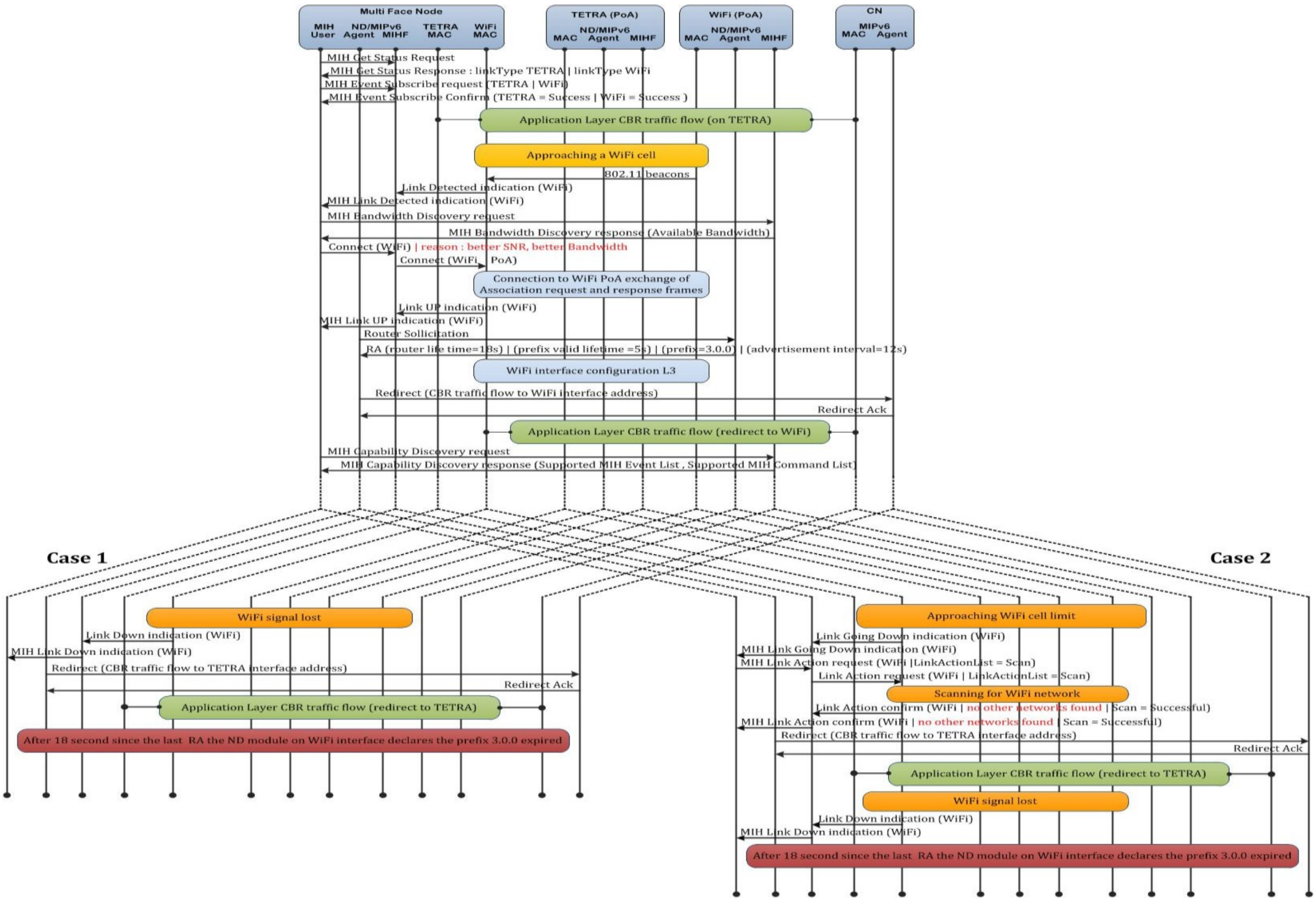

Figure 4: Handover messages.

near the headquarters with a radio coverage radius suitable to cover the whole area of interest, $N_{MNs} = 1$ mobile multi-interface (TETRA + 802.11) node (MN), exploiting the IEEE 802.21 capabilities to carry out the vertical handover between the two different radio access technologies, and $N_{CNs} = 1$ correspondent node (CN), i.e. the command and control server, placed in the headquarters and connected with both TETRA and wireless mesh network.

In our simulation, we assume that the MN equips a mobile surveillance van or a security/safety operator moving within the area of interest and traversing both the centre of the area, near the headquarters, and the boundary zone. During its movement, the MN transmits to the C2 server biometric and/or other sensor/detection data, video surveillance streaming, short messages and similar. In the area near the headquarters the MN exploits the wideband connection provided by the APs deployed in the field; when it moves out of the range of WiFi infrastructure, instead, thanks to the MIHF it will be able to maintain the connection with the C2 server by exploiting the narrowband connection provided by the TETRA interface. In such a way, nevertheless it is impossible to transmit video surveillance streaming because of the low throughput guaranteed by the TETRA radio access, the operator will be always capable to send sensors' data and messages to the headquarters without changing device and in a seamless and user-transparent manner.

With the aid of the Network Simulator 2, we evaluate how the handover procedures work and what is the impact of handover latencies on performance. In the next section, we will present measures related to the instantaneous available bandwidth, the number of packets lost during the handover procedure, i.e. during the change of the access point, and the handover latency, i.e. the time interval necessary to complete the handover procedures redirecting the IP flow towards the new IP Care-of-Address. Regarding the performance evaluation, two different handover policies have been planned according to the case 1 and case 2 cited above.

Parameter	Value
Coverage Radius	> 1.5 Km
Carriers for BS	4
Frame length	4 time slots
Time slot length	0.014167 s
Bit Rate	28.8 kbps
Back-off Timer	[0;1.27503]s
BS mode	Minimum mode
Release Time	4.590108 s

Table 2: TETRA module parameters.

Furthermore, for the sake of completeness, in Table 2 we report the configuration parameters related to the TETRA add-on module we developed for this research work.

A. Numerical results

As referred in the above section, we evaluate the proposed framework taking into consideration three performance metrics:

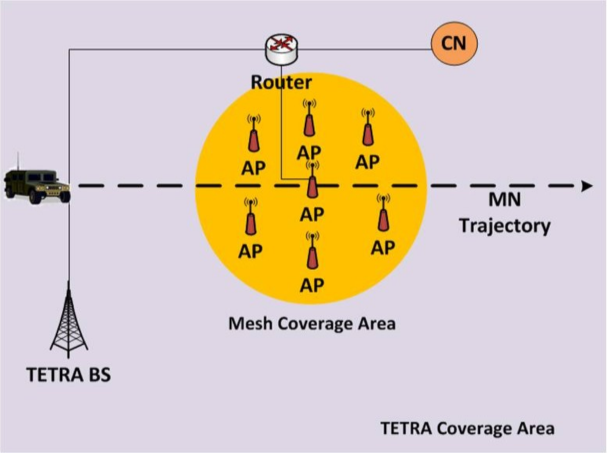

Figure 5: Simulation scenario.

a) ***Packet lost***: the number of packet lost during the procedure of handover, that is during the change of the radio access network during the mobile node movement;
b) ***Available bandwidth***: the instantaneous available bandwidth related to the radio access technology in use;
c) ***Handover latency***: the time occurring between the reception of the last packet from the old access router and the first packet received from the new access router, after completing the handover phase.

The mobile multi-interface node moves at 50 km/h passing from a TETRA coverage area, far to the headquarters, towards an area near the headquarters covered by both the TETRA base station and the wireless mesh network. In such a way, we are able to test the behavior of the mobile node when it crosses from the TETRA to the wireless mesh coverage area and, vice versa, when it passes from the mesh to the TETRA area. Figure 6 shows the number of packet lost during the handover procedures in both directions, TETRA-to-Mesh and Mesh-to-TETRA using the two different handover policies (case 1 and case 2) described before. As expected, case 2 performs better because of its proactive approach obtained by using the link going down event. Furthermore, we notice that the number of packets lost during the handover between TETRA and WiFi is the same for both the policies because the handover procedure is triggered as consequence of a new and better link detected event and not by a link down or link going down event.

Figure 7 represents the instantaneous available bandwidth; as expected the use of MIPv6 combined with MIH capabilities allows a seamless handover between the two involved technologies guaranteeing to the mobile terminal the best connection according to the available resources. Finally, in Figure 8 we represent the handover latencies during the migration from one radio access to the other one.

The results show that MIPv6 and MIHF represent a suitable solution for extending the capabilities of the TETRA private mobile radio, allowing the creation of a heterogeneous ad-hoc, secure, robust, fast deployable, effective and wide coverage range wireless networks.

VI. CONCLUSION AND FUTURE WORKS

In this paper we have investigated the capability of the IEEE 802.21 protocol in managing vertical handover among different radio access technologies such as TETRA and WiFi.

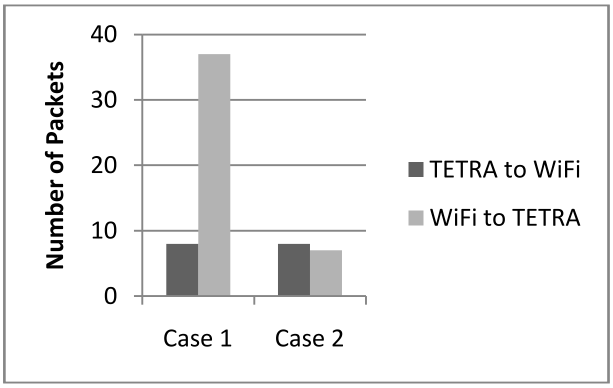

Figure 6: Number of packets lost during the handover phases.

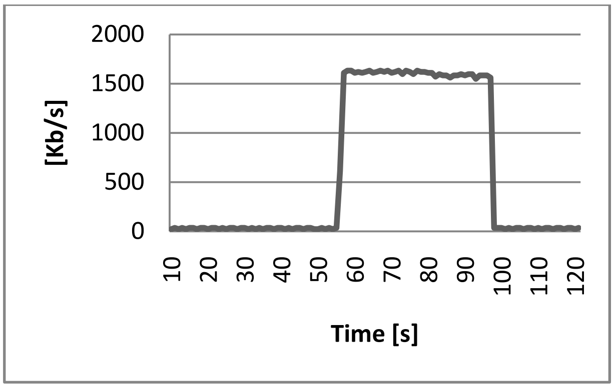

Figure 7: Instantaneous available bandwidth.

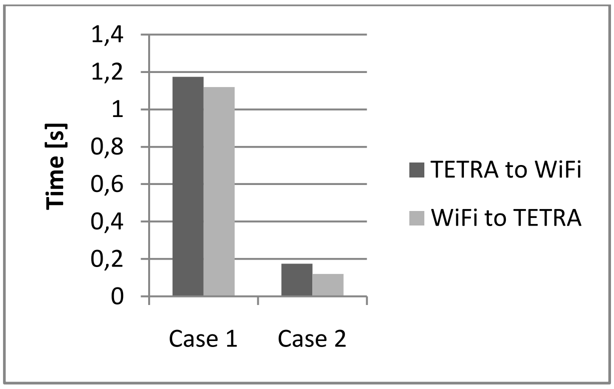

Figure 8: Vertical handover latencies.

We evaluated a multi-modal device provided with two network interfaces, TETRA and 802.11, showing that the IEEE 802.21 protocol is able to guarantee a seamless vertical handover between the two radio access technologies investigated. For this scope we used the Network Simulator 2.29, expanded with the NIST add-on modules, implementing the MIHF procedures able to manage the handover operations. Furthermore, we developed an additional module to simulate the TETRA medium access control protocol in the NS2 simulation framework. The obtained results show that the IEEE 802.21 represents a promising framework to obtain the plain interoperability among different communication technologies. Moreover, this work opens a wide range of research activities and, in particular:

- protocols for secure and fast authentication during the handover procedures, in order to reduce the L2 and L3 handover latencies;
- adaptive handover decision algorithms based on the application requirements and traffic priority;
- intelligent radio access point selection based on network load and guaranteed QoS;
- GPS aided target point-of-attachment selection.

Concluding, the proposed network architecture permits to combine fast network deployment, wide coverage area and efficient bandwidth utilization, increasing the TETRA capabilities, thanks to the application of the always best connected paradigm guaranteed by protocols such as MIPv6 and IEEE 802.21 MIH.

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