Hybrid Satellite/Terrestrial Telemedicine Services: Network Requirements and Architecture

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Abstract—This paper proposes a novel, interactive telemedicine platform, providing real-time audio and video interactions among patients, physicians and health service provider. Such a system has been developed within the framework of the European Space Agency (ESA) project TElemedicine Services for HEALTH (TESHEALTH) in collaboration among industry, academia, and hospitals. In particular, in the framework of the project, all citizens from many different sites have the same opportunity to access services promoting disease prevention and healthy life style, and professional users (specialists, physicians, operators) can exploit the platform to accomplish clinical studies and medical research. In such a context, an IP-based heterogeneous network architecture, composed of both satellite and terrestrial components, is considered in order to provide properly the TESHEALTH services.

The paper presents the network parameters, the user requirements, and the hybrid satellite/terrestrial network architecture of the TESHEALTH platform. In addition, the platform offers Quality-of-Service, tailored to the individual user profiles and services, as well.

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1. INTRODUCTION

Background

Advances of new information and communication technologies makes it possible to connect the patient with medical equipment and the health care center at a distance. Important fields of application for telemedicine are i) the *emergency scenario*, in which time is a crucial factor to prevent morbidity or even mortality of the patient, and ii) the *remote scenario* with lacking communication infrastructure and insufficient stationary medical professionals.

An overview of currently available terrestrial telemedicine services can be found in [1] and an effective test trial demonstration of multimedia satellite telemedicine service is described in [7]. Although rudimentary telemedicine has existed for several decades, the focus has moved to i) security technology, by assuring data integrity, confidentiality, and availability ii) privacy, by protecting confidential information on the patient and iii) Quality-of-Service, by guaranteeing particular performance of the communication link [2].

In the USA, a first telemedicine service to Alaska via satellite was established in 1971 [2].
In Japan, research activites started with Hanshin-Awaji earthquake in 1995, killing 5488 people within 7 hours after disaster, mainly due to disruption of the communication infrastructure [3]. As a consequence, the first satellite-based telemedicine service was launched in 1997, and more than 1000 telemedicine projects were conducted until 2004.
In China, the first real-time telesonsultation between China and the USA occured via satellite in 1997. In the same year, a mainly terrestrial military telemedicine network, comprising one satellite channel was established, to connect up to 114 military hospitals with 60 telemedicine satellite stations in remote military camps [4]. A secondary military project in 2004 mainly used satellite communications and provided services such as teleconsultation, remote educations, and videoconference [5].
In contrast, India launched its own satellite-based telemedicine

network through Indian Satellite System (INSAT) in 2001, which now includes more than 300 hospitals. In particular, more than 270 remote/rural hospitals and health centers are connected to more than 40 superspecialty hospitals in major cities [6].

In Europe, a number of activities have been initiated in Europe by national and international organisations with the purpose of demonstrating and promoting the use of satellite communications in the field of telemedicine since the mid 1990's. The European Space Agency (ESA) has funded satellite based telemedicine since then. For example, in the project TelAny (Telemedicine anywhere), medical, software and telecommunications professionals got connected to test three different scenarios: i) accessing life signals of patients by using devices implanted in their bodies ii) treating emergencies on board ships in Norway and iii) making a medical database that consulting specialists could access.

Contribution

This paper presents first outcome of the ESA project TESHEALTH (TElemedicine Services for HEALTH) in collaboration among industry, academia, and hospital.

The TESHEALTH project aims at: i) specifying and developing an integrated system of e-health applications and services to increase the patient s safety by providing instruments and service for self-care and by creating a link between the individual and the physician anytime and anywhere; ii) assuring exchange of heterogeneous health data among different healthcare providers; iii) automatizing the complex healthcare workflow iv) deploying an integrated heterogeneous telecommunication network with focus on satellite.

The scenario comprises one or a few interactive user satellite terminals; a terrestrial wireless link between "Health Points" and user satellite terminal, and a satellite link between satellite terminal and a GEO satellite which provides IP connectivity. The health point might be accessible by the general public or, by selected individuals only. Internet access is established by commercial satellite providers.

The paper concentrates on the communication network architecture in TESHEALTH. The satellite network ensures uniform coverage over large areas, guaranteed Quality-of-Service (QoS), scalability of service provision, and centralized network management.

In contrast to previous contributions, the paper proposes an *IP-based* telemedicine service with point-to-multipoint connectivity in the forward channel and multi-point to point connectivity in the reverse channel.

Organization

Section 2 deals with the network parameters and defines the user profiles. Section 3 proposes the (heterogeneous) network architecture along with the features at the respective network layers in Section 4. A QoS strategie for the proposed system is outlines in Section 5.

2. Network Parameters and User Requirements

In the following the common measurements used to characterize network connection performance are summarized:

Bandwidth/Throughput - bandwidth effectively describes the "size of the pipe" required for the application to communicate over the network. A connection needing a guaranteed service has certain data-rate requirements and requires the network to allocate a minimum bandwidth specifically for it. In fact, due to the fact that different users share the same network resources, the throughput capacity (of a given medium, protocol, or connection) provided to a data stream could not be enough for the related service.

Bandwidth/Throughput variation - the communication network could be heterogeneous in time and space, therefore bandwidth/throughput could be variable. Effects of bandwidth/throughput heterogeneity on the network performance have to be identified in order to optimally utilize a heterogeneous communication network.

Latency - a packet takes some time to reach its destination due to different reasons, i.e. it cannot take a direct route to avoid congestions or it can be stopped in long queues. All packets in a flow usually experience different delay in the network due to the variable network conditions. Three different types of delay can be identified for each hop of the network:

- *Serialization/Transmission delay* - is the time it takes for a device to clock a packet at the given output rate. This kind of delay depends on the connection bandwidth and on the size of the packet being clocked.
- *Propagation delay* - is the time it takes for a bit to get from the transmitter to a end-receiver. This delay is a function of the distance and the media but not of the bandwidth. For Wireless Area Network links, propagation delays of milliseconds are normal while delays of 250 milliseconds are experienced for geostationary satellite connections.
- *Switching delay* - is the time it takes for a device to start transmitting a packet after the device receives the packet. This delay is typically less than 10 μs.

Jitter - this effect is experienced at the receiver side and is due to the fact that packets from the source reach the receiver with different delays; jitter affects the quality of streaming applications (i.e. audio/videoconference) and the receiver can offset the jitter by adding a receive buffer to store packets.

Table 1. Network parameters for Basic and Premium user profiles.

Network User Profile	Network Parameter	Numerical Values
Basic	Bandwidth	16-320 kbps
	Bandwidth variation	50 %
	Latency	150-500 ms
	Jitter	30-50 ms
	Packet loss	1-5 %
Premium	Bandwidth	420 kbps
	Bandwidth variation	20 %
	Latency	150-400 ms
	Jitter	30-50 ms
	Packet loss	0.1-3 %

Packet loss - is the number of packets being lost by the network during transmission. Packet loss can be due to a packet drop or packet error. Packet drops generally occur at congestion points when incoming packets exceed queue size limit at the output queue or there is an insufficient input buffers on packet arrival. Packet errors occur when packets are misdirected, or combined together, or corrupted. A loss of packets waste network resources, so the network has to be designed in order to minimize this effect.

Out-of-order delivery - when a collection of related packets is routed through a network, different packets may take different routes, as a result each packet has a different delay. Therefore packets arrive in a different order than they were sent; this requires protocols able to rearrange out-of-order packets.

Two different network user profiles are defined in order to enable users to access to the TESHEALTH services: *a*) the Basic user profile which gathers the minimum requirements to access to the TESHEALTH services and it can be identified with a residential internet connection, and *b*) the Premium user profile which represents the minimum requirements to access to the TESHEALTH services that include teleconsultation applications.

Network requirements have been divided on the basis of their applicability to the network user profiles; in Table 1, network parameters are reported both for Basic and Premium profiles.

3. Heterogeneous Network Architecture

The definition of the network requirements gives the input for the high level design of the TESHEALTH network architecture. The users are professionals such as specialists, physicians, operators, who exploit the platform to accomplish clinical studies and medical research. The services, provided by the TESHEALTH project, promote diseases prevention and healthy life style. All citizens from many different sites shall have the same opportunity to access services.

The network architecture is heterogeneous, composed of both satellite and terrestrial components, shall be considered to reach above objectives. The paragraph analysis both satellite and the terrestrial technologies with respect to technical, contractual, network management and deployment aspects. Finally, the proper technology is selected for each TESHEALTH context and services. The high level structure of the TESHEALTH overall architecture is depicted in Fig. 1. In particular, an integrated and interoperable telecommunication network has been considered and five main network segments have been identified and classified depending on the access technology and the network component, either satellite or terrestrial, they belong to. The network segments are:

- Satellite TOOWAY™ Segment;
- Satellite ASTRA2Connect™ Segment;
- Wired Segment;
- Wi-Fi™ Segment;
- UMTS (Universal Mobile Telecommunications System)/HSPA (High Speed Packet Access) Segment.

In the following subsections the satellite and the terrestrial components are described, highlighting the key access technology, the specific system selected for the TESHEALTH network and the network topology of each segment.

Satellite Component

The satellite component is composed of two different space segments: TOOWAY™ and ASTRA2Connect™ segments. Both are interactive broadband GEO (Geostationary Orbit) satellite systems.
The network configuration for both considered systems is defined as Satellite Two Way Interactive configuration, which means that both the forward and the return channel are provided through a satellite link. In particular a star topology, which includes a hub station and several user terminals, is considered. In this kind of network, the user terminal allows the end user to receive and transmit the desired information through the satellite, while the hub station is the network control center with both traffic and management capabilities. It is equipped with a larger antenna size and a more powerful power amplifier with respect to the user terminals and its function is to receive data from all transmitting user terminals and to convey the desired information to all user terminals. In this topology each user terminal has a dedicated point-to-point link only with the hub station. Besides, point-to-multipoint connectivity in the forward channel (from the hub station to the user terminals through the satellite) and multipoint-to-point connectivity in the reverse channel (from each user terminal to the hub station through the satellite) are supported. It is worth highlighting that the satellite component assumes a specific key role thanks to its unique features in terms of management and technical issues as well as its many peculiar characteristics which are particularly suitable for the TESHEALTH scenario.
In the design of the TESHEALTH network and technical specifications two satellite systems, characterized by different features and capabilities, have been considered. The first satellite system is based on the S-DOCSIS (Data Over Ca-

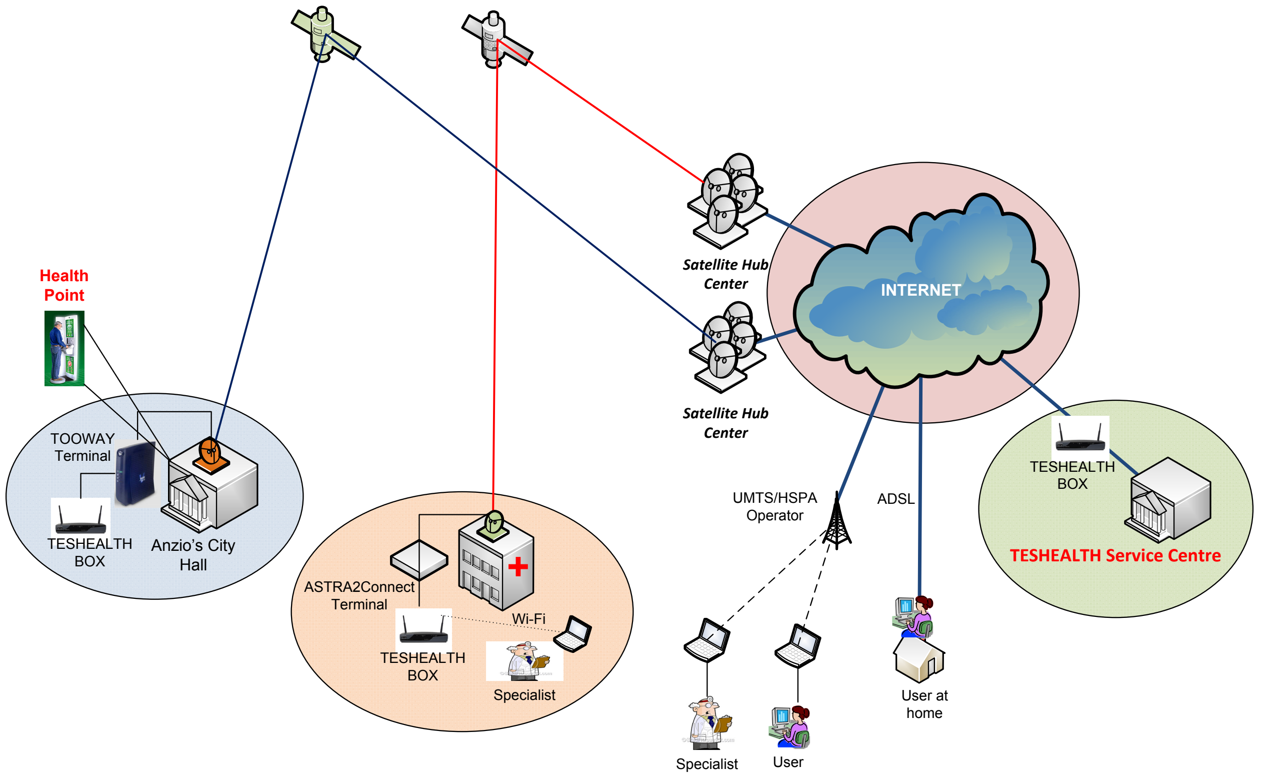

Figure 1. Overall TESHEALTH Architecture

ble Service Interface Specification) standard and is called SurfBeam®, provided by Viasat Inc. and, in Europe, it is operated by Eutelsat with the service name ***TOOWAY***™. TOOWAY™ is a proprietary broadband satellite system designed for the use with geostationary spot-beam based satellites in Ka (20/30 GHz) band and provides the user with a broadband IP access comparable to that currently offered by terrestrial ADSL service providers. Although the upper layer protocols are all based on the cable standard DOCSIS, the physical layer has been modified to accommodate the unique challenges of the satellite-land channel which can be affected by deep fading periods.

The second satellite system, which is considered in the building of TESHEALTH network, is based on the Newtec Sat3Play® platform. It is provided by SES-ASTRA with the service name ***ASTRA2Connect***. Astra2Connect is a two-way satellite broadband, providing an always-on, high-speed Internet access. It is designed to complement terrestrial broadband services, especially in remote areas of Europe where DSL (Digital Subscriber Line) or cable services may be limited or non existent. In particular in the ASTRA2Connect™ forward link, the IP data are embedded in a DVB-S2 (Digital Video Broadcasting - Satellite - Second Generation), while in the return channel the SAT-MODE technology is used for modulation and coding scheme at Physical Layer and the DVB-RCS (DVB-Return channel over satellite) standard for the access scheme at MAC Layer. In the TESHEALTH context, both TOOWAY™ and ASTRA2™ Connect clusters are considered to connect health points as well as hospitals and core labs to the TESHEALTH Service Center. Such links can enable the transmission of flows of the different applications used for self-care and assisted services in a scalable and flexible way. The coverage area provided is much wider than that offered by other terrestrial networks and, for example, the location of health points can be defined and modified without taking into account problems of connectivity. And also the number of hospitals involved in using TESHEALTH services can be several and spread over the country displaced in all national (and not only) area. In such satellite links the solution for managing the Quality of Service provision in the TESHEALTH heterogeneous network, based on the *Differentiated Services* paradigm is also implemented (see Section 5).

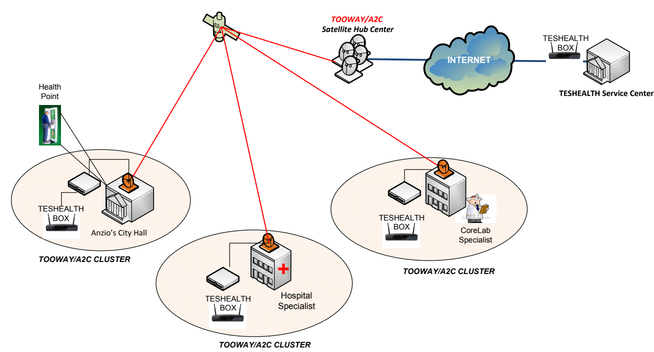

Figure 2. TESHEALTH Satellite Component

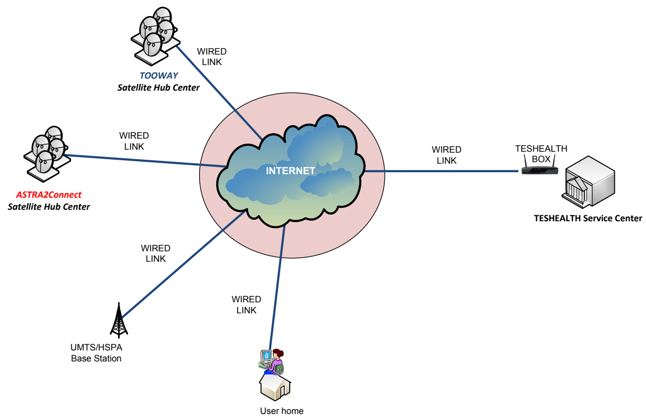

Figure 3. TESHEALTH Wired Links

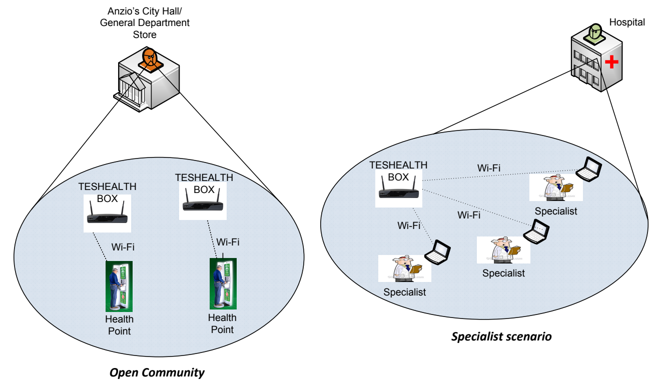

Figure 4. TESHEALTH WiFi Links

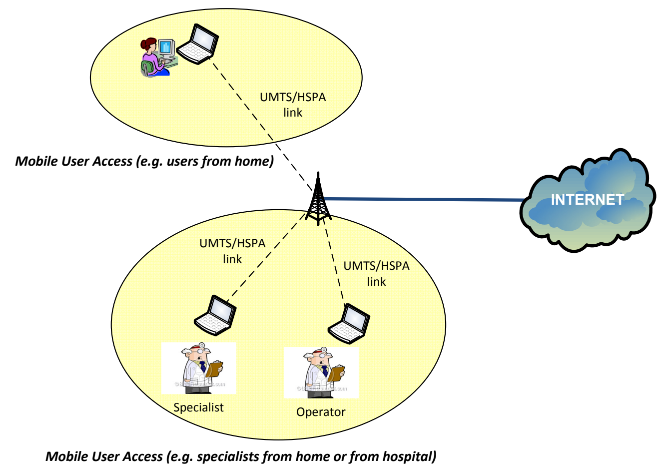

Figure 5. TESHEALTH UMTS/HSPA Links

Terrestrial Component

The terrestrial component of the TESHEALTH network consists both of wired and wireless segments. Terrestrial segments can allow to extend the capability of the network, by connecting the users involved in the TESHEALTH platform. Through the use of a large variety of technologies, which all converge to a joint IP-based interface, Health Points, specialists and users present in the TESHEALTH network can be connected to the TESHEALTH Service Centre. In particular the terrestrial segments considered in the TESHEALTH architecture are the: Wired, Wi-Fi and UMTS/HSPA segment. The ***Wired segment*** can be subdivided into:

- the *Core* segment, which can be identified with *core* internet links provided by xDSL or optical fibre technology.
- the *End-user* segment, which can be identified with the residential internet connection provided by ADSL (Asymmetric DSL) technology to final users.

The ***Wi-Fi segment*** enables users having portable terminals as laptops, to connect to the TESHEALTH platform. In particular, the Wi-Fi links are used for:

- the connection between satellite terminals and Health Points which can, therefore, be located within the range of 50/100 m from the satellite terminal. Such Wi-Fi links allow giving more flexibility to the installation of the satellite user terminal since it should not be too close to the health point and it does not need to install a cable connection between the satellite user terminal and the Health Point;
- the connection between satellite terminals located in a specific area at the hospital and specialists working there.

The ***UMTS/HSPA segment*** enables users having UMTS/HSPA mobile phones, to connect to the TESHEALTH platform. The UMTS/HSPA links are considered mainly for mobile users who want to access to TESHEALTH services through the Internet connectivity offered by such a technology.

4. Network Functional Layers

The general network architecture is designed through the definition of three functional layers, as shown in Fig. 6:

- the Access Layer
- the Network and Transport Layer
- the Application Layer

Each layer is characterized by some specific features that define its role within the general architecture of the network.

Access Layer

Starting from the lowest level, the tasks assigned to the Access Layer can be summarized as follows:

- To allow the end-user connectivity to the network, regardless of location, mobility and capacity of the terminal user through the different satellite and terrestrial access technologies considered in the TESHEALTH project.
- To translate the service levels required by upper layers in the classes of traffic characteristics of the adopted access technology.
- To implement the actions for the control and monitoring of the link.

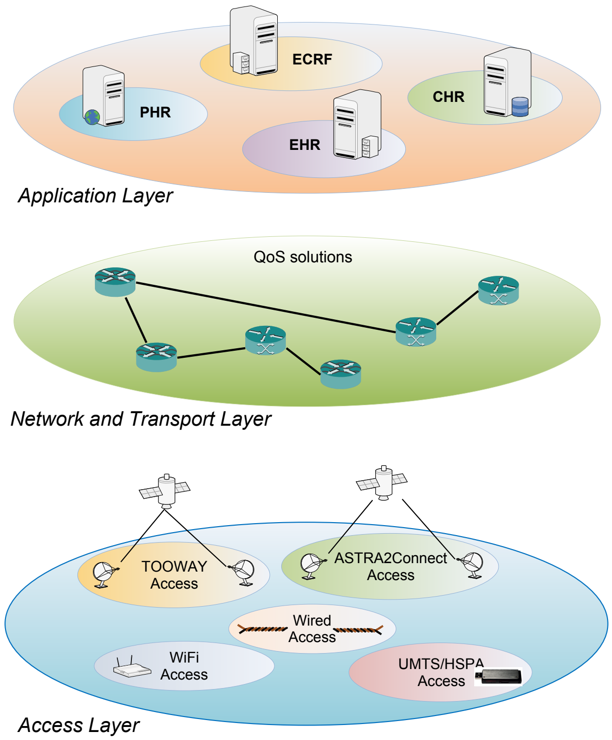

Figure 6. Network Functional Layer

- To provide a joint interface to the Network and Transport Layer based on the IP protocol.

Network and Transport Layer

In a similar way, the tasks of the Network and Transport Layer can be defined as follows:

- To support the IP protocol.
- To identify the geographical components of the network (Relay nodes, AAA Servers, Users) by providing a routing path based on the IP protocol.
- To provide adequate capacity to provided services, managing unexpected congestion situations, non-availability of links and degradation of the Quality of Service.
- To provide a mechanism for monitoring the QoS to the upper layer by classifying traffic into the appropriate classes of service.

Application Layer

Finally, the tasks of the Application Layer can be the following:

- To provide the contents of various TESHEALTH services.
- To define the interfaces among the different TESHEALTH applications.
- To provide location primitives and discovery of TESHEALTH services required.
- To provide functions of authentication, authorization and accounting for the provided TESHEALTH services.

The effectiveness of the whole network infrastructure is heavily bound by the interoperability of these functional layers.

5. Network Solutions for QoS support

The heterogeneous network architecture, considered to access to the TESHEALTH network, is composed of different segments which makes it cumbersome to be controlled by an end-to-end Quality-of-Service (QoS) solution. Hence, starting from the analysis of network requirements and the overall TESHEALTH scenario, the QoS solution adopted takes into account only the critical segments of the network, i.e. the satellite component (TOOWAY and ASTRA2Connect segments). Therefore, the QoS Domain considered in the TESHEALTH network is that depicted in Fig 7 with the realistic assumption that links on internet do not impact the prioritization of traffic operated on satellite segments. This means that the bandwidth capacity on internet links is assumed to be much larger than that of the satellite link. It is worth clarifying that the QoS provided through the adoption of the Fair Access Policy by the service provider is different from the QoS solution that the paper proposes through the configuration and the use of IP routing devices (subsequently called "TESHEALTH boxes").

In particular, among various well-known QoS approaches, the Differentiated Services (Diff-Serv) strategy, has been chosen to be implemented in the TESHEALTH network infrastructure because the class-based mechanism in Diff-Serv is the most suitable approach in a very flexible network. The Diff-Serv solution considered in the TESHEALTH network envisages the implementation in the TESHEALTH boxes of different Per-Hop Behaviours (PHBs) which define the packet forwarding properties associated with corresponding traffic classes.

In detail, three different Diff-Serv classes are taken into account in order to manage the different TESHEALTH services:

- AF22 class for Web based services;
- AF31 class for Streaming services;
- EF for real-time services such as Video-conference ones.

Currently, the advanced network control mechanisms are implemented on IP routing devices, the TESHEALTH boxes, that are able to perform the required traffic classification, conditioning and advanced routing functions. The TESHEALTH boxes are equipped with Wi-Fi and Ethernet interfaces that have twofold functionality: i) to act as **Access Point** for the setting up of Wi-Fi clusters and ii) **Network device** for managing the provision of the QoS at the boundaries of the TESHEALTH QoS Domain. Concerning their role as routers, in particular, they aggregate several advanced Traffic Engineering and routing functions useful for the correct delivery of the TESHEALTH services. Since their function is located at Layer 3, the integration with the other network seg-

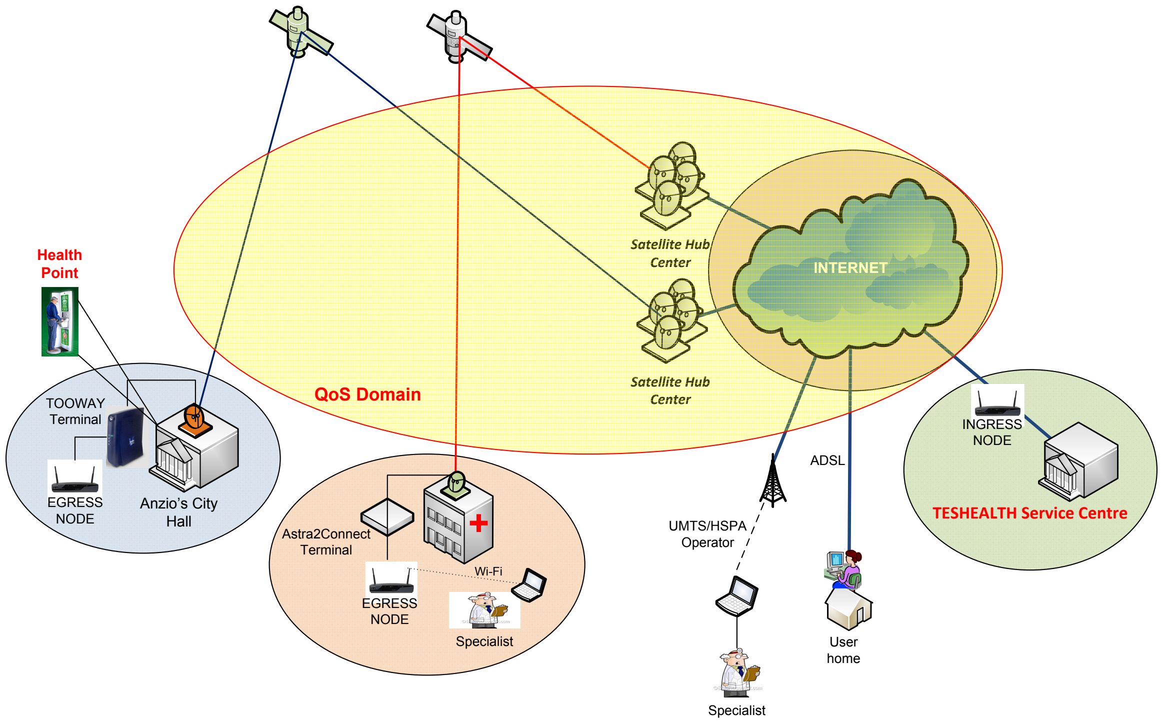

Figure 7. QoS Domain in TESHEALTH Network

ments is operated through the IP protocol. The QoS functions, provided through the DiffServ paradigm, are obtained through classification, marking and scheduling of incoming traffic both at the INGRESS and the EGRESSES nodes of the DiffServ Domain (QoS Domain in Fig. 7). Routing devices such as Cisco 870 Series Integrated Services Routers turn out to be a feasible solution in order to satisfy the network requirements. In particular, Cisco 871 Ethernet to Ethernet Wireless Router (CISCO8711W-G-E-K9) is used as TESHEALTH box. Such device, in fact, has wireless capabilities and implements QoS and Multicast features which are envisaged in the deployment of the network. It is worth highlighting that the TESHEALTH boxes manage end-to-end links. Therefore the QoS functions, provided through the DiffServ paradigm, will be implemented end-to-end by the TESHEALTH box placed at each end of the critical links of the overall network (at the boundaries of the QoS Domain).

In particular, in the TESHEALTH network architecture, the TESHEALTH boxes will be placed:

- close to Health Points, allowing the Health Point access to the TESHEALTH services;
- in the hospitals, allowing access to specialists;
- at the TESHEALTH Service Center.

Based on its function the TESHEALTH box placed at the TESHEALTH service center represents the INGRESS node (the server or the source of the TESHEALTH services), while the ones placed at the Health Points and hospitals represent the EGRESS nodes (the clients or the destination of the TESHEALTH services).

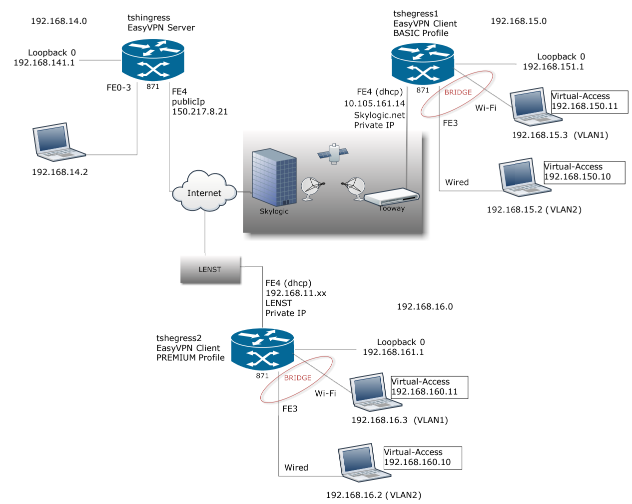

Figure 8. Network configuration of the proposed network architecture (laboratory version).

The (operating) laboratory version of the proposed network architecture is sketched in Fig. 8. The TESHEALTH boxes are labeled as “871”.

6. Conclusions

We have proposed a novel interactive telemedicine platform in collaboratrion with industry, academia, and hospitals. Integration of quality-of-service for users with different profiles makes it possible for the platform to support various real-time audio and video services, to promote disease prevention and healthy life style, as well as emergency care.

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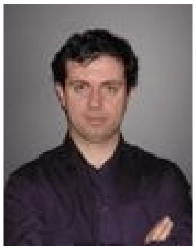
BIOGRAPHY

Alexander Kocian received the Dipl. Ing. degree (with distinction) from Vienna University of Technology, Austria, in 1997, and the Ph. D. degree from Aalborg University (AAU), Denmark, in 2003, both in electrical engineering. In 2001, AAU sponsored him a 6-month Visiting Research Scholarship at the Wireless Systems Laboratory, Georgia Institute of Technology, Atlanta, GA, USA. After serving the Digital Communications Laboratory at AAU as Assistant Professor for another two years, he joined the Department of Electronics Engineering of the Muscat branch in the Sultanate of Oman of Birla Institute of Technology (BIT), India, as Reader/Associate Professor. Since 2008 he has been Research Fellow with the Department of Electronics Engineering, University of Rome "Tor Vergata", Italy. He has consulted for Elektrobit, RTX Telecom, IMT, the Italian ministry of university and research (MIUR), and European Space Agency (ESA).
His research interests include iterative information processing in multiple-access communication systems, analog signal processing for satellite communication payloads, characterization of multiple-input multiple-output (MIMO) channels, and networking.

Mauro De Sanctis received the "Laurea" degree in Telecommunications Engineering in 2002 and the Ph.D. degree in Telecommunications and Microelectronics Engineering in 2005 from the University of Roma Tor Vergata (Italy). From the end of 2008 he is Assistant Professor at the Department of Electronics Engineering, University of Roma "Tor Vergata" (Italy), teaching "Information and Coding Theory". He was with the Italian Space Agency (ASI) as holder of a two-years research fellowship on the study of Q/V band satellite communication links for a technology demonstration payload, concluded in 2008. He was involved with the University of Rome "Tor Vergata" in several satellite missions of the Italian Space Agency (ASI): DAVID satellite mission (DAta and Video Interactive Distribution) during the year 2003; WAVE satellite mission (W-band Analysis and VErification) during the year 2004; FLORAD (Micro-satellite FLOwer Constellation of millimeter-wave RADiometers for the Earth and space Observation at regional scale) during the year 2008. In 2006 he was a post-doctoral research fellow for the European Space Agency (ESA) ARIADNA extended study named The Flower Constellation Set and its Possible Applications. From January 2004 to December 2005 he was involved in the MAGNET (My personal Adaptive Global NET) European FP6 integrated project and in the SatNEx European network of excellence. From January 2006 to June 2008 he was involved in the MAGNET Beyond European FP6 integrated project as scientific responsible of WP3/Task3. He is/was involved in several Italian Research Programs of Relevant National Interest (PRIN): SALICE (Satellite-Assisted LocalIzation and Communication systems for Emergency services), ongoing; ICONA (Integration of Communication and Navigation services) from January 2006 to December 2007, SHINES (Satellite and HAP Integrated NEtworks and Services) from January 2003 to December 2004, CABIS (CDMA for Broadband mobile terrestrial-satellite Integrated Systems) from January 2001 to December 2002. In 2007 he was involved in the Internationalization Program funded by the Italian Ministry of University and Research (MIUR), concerning the academic research collaboration of the Texas A&M University (USA) and the University of Rome "Tor Vergata" (Italy). In autumn of 2004, he joined the CTIF (Center for TeleInFrastruktur), a research center focusing on modern telecommunications technologies located at the University of Aalborg (Denmark). He was co-recipient of the best paper award from the 2009 International Conference on Advances in Satellite and Space Communications (SPACOMM 2009). He is serving as Sector Editor for the Space Systems area of the IEEE Aerospace and Electronic Systems Magazine. His main areas of interest are: wireless terrestrial and satellite communication networks, satellite constellations (in particular Flower Constellations), resource management of short range wireless systems. He co-authored a book entitled Information and Coding: Theory Overview, Design, Applications and Exercises and about 40 papers published on journals and conference proceedings.

Tommaso Rossi graduated in Telecommunications Engineering at the University of Rome Tor Vergata (URTV) in 2002. He gained a Master of Science degree in Advanced Communication and Navigation Satellite Systems in 2004 and a Ph.D. in Telecommunications and Microelectronics Engineering at the University of Rome Tor Vergata in 2008. Currently he is a member of a research group leaded by Prof. Marina Ruggieri and assistant professor in Telecommunications, teaching digital signal processing. His research activity is focused on Space Systems, EHF (Extremely High Frequency) Satellite Telecommunications, Satellite and Inertial Navigation Systems, Digital Signal Processing and Satellite Constellations. He is member of scientific Team involved in the definition of European Space Agency "TDP#5" (Technology Demonstration Payload) experiment (to be embarked on Alphasat satellite). He is member of technical Team of URTV working on Italian Space Agency "FLORAD" small mission project; responsible for design, optimisation and analysis of a Flower Constellation of millimetre-wave radiometers for atmospheric observation. He is involved in European Space Agency EDRS (European Data-Relay Satellite System) project; responsible for EDRS-user segment visibility analysis and Q/V-bands link budgets system analysis. He is member of technical Team and Project Office of Italian Space Agency "WAVE" phase A2 project, feasibility study for W-band satellite telecommunication payloads; responsible for small-LEO mission definition and payload design activities. He is technical member of URTV Team involved in Italian Space Agency "TRANSPONDERS" phase A2 project, feasibility study for Q/V-band satellite telecommunication payloads. He is member of URTV Team working on European Space Agency's "Multi-purpose Constellations" project; responsible for identification of conventional and innovative constellations concepts to be applied to multi-purpose architecture. In 2006 he worked on ESA research project on Flower Constellation Set and Its Possible Applications as responsible for the design, optimisation and analysis of Flower Constellations for communication, navigation and Earth/space observation applications. From 2005 to 2007 he worked on PISTA project, funded by TECNO.TIB.E.R.I.S. and University of Rome Tor Vergata for the development of low-cost inertial and GPS integrated navigation system, as responsible for the design of a data-fusion Kalman filter. From 2004 to 2005 he has been a member of technical and Project Office Team of ASI WAVE phase A project, feasibility study for W-band satellite telecommunication payloads; furthermore he has been responsible of URTV activities within the ASI TRANSPONDERS phase A project, feasibility study for Q/V-band satellite telecommunication payloads. He is co-chair of IEEE Aerospace Conference Session 2.07 "mm-Wave and Quasi Optic Aerospace Technologies" and author of more than 30 papers, on international journals and proceedings of international conferences.

Enrico Del Re was born in Florence, Italy. He received the Dr. Ing. degree in electronics engineering from the University of Pisa, Pisa, Italy, in 1971. Until 1975 he was engaged in public administration and private firms, involved in the analysis and design of the telecommunication and air traffic control equipment and space systems. Since 1975 he has been with the Department of Electronics Engineering of the University of Florence, Florence, Italy, first as a Research Assistant, then as an Associate Professor, and since 1986 as Professor. During the academic year 1987-1988 he was on leave from the University of Florence for a nine-month period of research at the European Space Research and Technology Centre of the European Space Agency, The Netherlands. His main research interest are digital signal processing, mobile and satellite communications, on which he has published more than 300 papers, in international journals and conferences. He is the Co-editor of the book Satellite Integrated Communications Networks (North-Holland, 1988), one of the authors of the book Data Compression and Error Control Techniques with Applications (Academic, 1985) and the editor of the books Mobile and Personal Communications (Elsevier, 1995), Software Radio Technologies and Services (Springer, 2001), Satellite Personal Communications for Future-Generation Systems (Springer, 2002), Mobile and Personal Satellite Communications 5-EMPS2002 (IIC, Italy, 2002) and Satellite Communications and Navigation Systems (Springer, 2008). He has been the Chairman of the European Project COST 227 "Integrated Space/Terrestrial Mobile Networks" (1992-95) and the EU COST Action 252 "Evolution of satellite personal communications from second to future generation systems" (1996-2000). He has been the Chairman of the Software Radio Technologies and Services Workshop (2000), the Fifth European Workshop on Mobile/Personal Satcoms (2002) and the Satellite Navigation and Communications Systems (2006). He received the 1988/89 premium from the IEE (UK) for the paper "Multicarrier demodulator for digital satellite communication systems". He is the head of the Digital Signal Processing and Telematics Laboratory of the Department of Electronics and Telecommunications of the University of Florence. He has been Director of the Italian Interuniversity Consortium for Telecommunications (CNIT) and is now Vice-President. Professor Del Re is a Senior Member of the IEEE and a member of the European Association for Signal Processing (EURASIP).



Luca Simone Ronga received his M.S. degree in electronic engineering in 1994 and his Ph.D. degree in telecommunications in 1998 from the University of Florence, Italy. In 1997 joined the International Computer Science Institute of Berkeley, California, as a visiting scientist. In 1998 obtained a post-doc position in the engineering faculty of the University of Florence. In 1999 he joined Italian National Consortium for Telecommunications (CNIT), where he is currently head of research. Since 1997 he is author of several funded project in various Telecommunications fields. In 1997 leaded a national research group of the project ”Integration of Multimedia Services on Satellite Heterogeneous Networks” which successfully developed a Software Defined Radio satellite modem prototype. In 2001 has been leader of the international research group Access Network Aspects for the COST272 European action ”Packet Oriented Service Delivery via Satellite”. In 2001 has been involved as WP leader in the DAVID programme ”Small Missions for Science and Technology”. Hes has been project leader for the national project FormSat ”Development of CNIT academic learning satellite system on Italian Objective 1 Regions” in 2003. In 2004 has been involved in the EU SatNEx ”Satellite Communications Network of Excellence” as leader of an international group on ”Cognitive Radio”. Since 2007 he is responsible for the CNIT satellite network operations and the scientific activities on the platform which is currently one of the largest Ka band satellite networks in Europe. He is member Member of NATO task force IST-077 RTG-035 devoted to coordination of Cognitive Radio research activities among coalition partners. He is also ”Rapporteur” for technical standard ”MAMES” DTS/SES-00310 in the ETSI group SES-SatEC (Satellite for Emergency Communications) and Official CNIT delegate at ETSI, participating to ETSI SES-SatEC task force. He conducts research activity and project management in various telecommunications areas, mainly in the satellite and terrestrial wireless fields. He authored over 70 papers published in books, international journals and conference proceedings. He has been editor of EURASIP Newsletter. His interests range from satellite communications to Software Defined Radio and Cognitive Radio techniques.

Sara Jayousi received her M.S. degree in Telecommunications Engineering in 2008 from the University of Florence, Italy. From June 2008 to May 2009 she received a research grant from CNIT (National Inter-University Consortium for Telecommunications) on satellite communications topics, in particular her research activity concerned the study of cooperative strategies for integrated satellite/terrestrial communication systems. From the beginning of 2009 she is a Ph.D. student (Computer Science, Multimedia and Telecommunications Engineering Research Programme) at the Department of Electronics and Telecommunications of the University of Florence. Her research activity is mainly focused on: cooperative communications, relaying systems, diversity algorithms, hybrid satellite/terrestrial networks and QoS network management.

Rosalba Suffritti received her M.S. degree in Telecommunications Engineering from the University of Florence, Italy, in 2006, and, her Ph.D. in ”Computer science, Multimedia and Telecommunications” from the University of Florence, Italy, in 2010. Her research activity focuses on advanced topics in satellite communications: cooperative strategies in mobile environments, satellite emergency communications and cognitive radio technologies. She is IEEE member and member of ETSI SES- SatEC (Satellite Earth Stations and Systems - Satellite Emergency Communications) working group which carries out the activity of standardization on satellite emergency communications. She is author of about 20 papers on international journals and proceedings of international conferences.