# TESHEALTH: An Integrated Satellite/Terrestrial System for E-Health Services

# TESHEALTH: An Integrated Satellite/Terrestrial System for E-Health Services

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*Abstract*—**This paper aims at investigating the integrated satellite/terrestrial interactive e-health system, which 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. The implementation of a secure, scalable and flexible heterogeneous network capable of providing the appropriate infrastructure, is analysed, focusing on the end to end QoS solution, that satisfies the quality level required by the telemedicine applications. Moreover the developed interactive Service Platform, which aims at sharing health information among the different applications and services (Self-Care and Assisted Services) and includes real-time audio and video interactions among patients, specialists and health service providers, is described.**

## I. Introduction

In the last few years the role of ICT (Information and Communication Technology) in the health system has been one of the main investigated research area [1] [2] [3]. In this context the design of an integrated interactive system for telemedicine services is required both for clinical studies and for self-care purposes: in fact the integration of distributed medical competence and clinical information contributes to the quality of medical care. Although *Prevention* is in all Governments Agenda as the strategy to intervene on population life style and behaviour and to maintain as long as possible people in healthy conditions, nowadays there are very few *population management* programs that try to intervene on the lifestyle and behaviour modification. In fact, the *Acute people* are about 20% of the population and represent the cause of the 80% of the healthcare expenditure, while the *remaining population* is responsible for about 20% of the healthcare expenditure.

This paper proposes an integrated satellite/terrestrial system for e-health services addressing both to the consumer market through the development of interactive applications used by the individual at the Health Point to do a general health status assessment (Self-Care services) and to the professional market through clinical study applications for healthcare professionals cooperation (Assisted services). Such a system has been developed within the framework of the European Space Agency (ESA) project TElemedicine Services for HEALTH (TESHEALTH).

The paper is organized as follows: in Section II the overall system architecture is introduced; in Section III the defined e-Health services and applications are described; in Section IV the physical and logical network architecture are analysed, highlighting the proposed QoS solution. Finally concluding remarks are reported in Section V.

## II. Overall System Architecture: TESHEALTH Reference Scenario

In order to give an overview of the TESHEALTH system architecture, in the following, both the network architecture and the services platform solution are briefly described.

It is worth highlighting that this system comes from an accurate analysis of the user's (citizens and physicians) needs, which is carried out thanks to the collaboration with national hospitals. In detail, the steps followed to implement the overall e-Health infrastructure are: definition and development of the services platform in compliance with the user's inputs; identification of the network requirements (minimum guaranteed bandwidth, acceptable latency and drop probability, traffic flows priority) to support the defined services; design of the network architecture able to satisfy the network constraints, exploiting different technologies characteristics and capabilities; security and end-to-end QoS solution implementation through network devices configuration.

*Network Architecture:* The provision of e-Health services through the implementation of an interactive service platform, which includes real-time audio and video interactions among patients, specialists and health service providers, requires the deployment of an interconnected system based on an integrated and interoperable telecommunication network, which consists of both terrestrial and satellite segments. Fig.1 depicts the overall TESHEALTH network architecture able to satisfy the quality of service required by the considered e-health applications, optimizing and minimizing the offered service cost. As shown in Fig.1, both citizens or physicians can access the interactive Service Platform from different locations (e.g. Health Points, Hospitals, Home), regardless of the chosen access technology, either satellite or terrestrial (Section IV).

*Service Platform:* The TESHEALTH Service Platform aims at sharing health information among different applications and services (Self-Care and Assisted) and it is based on the Health Integration Engine (HIE). This module guarantees the information exchange between the TESHEALTH subsystems (Personal Health Media (PHM), Electronic Health Record (EHR), Electronic Clinical Research Form (ECRF), Clinical

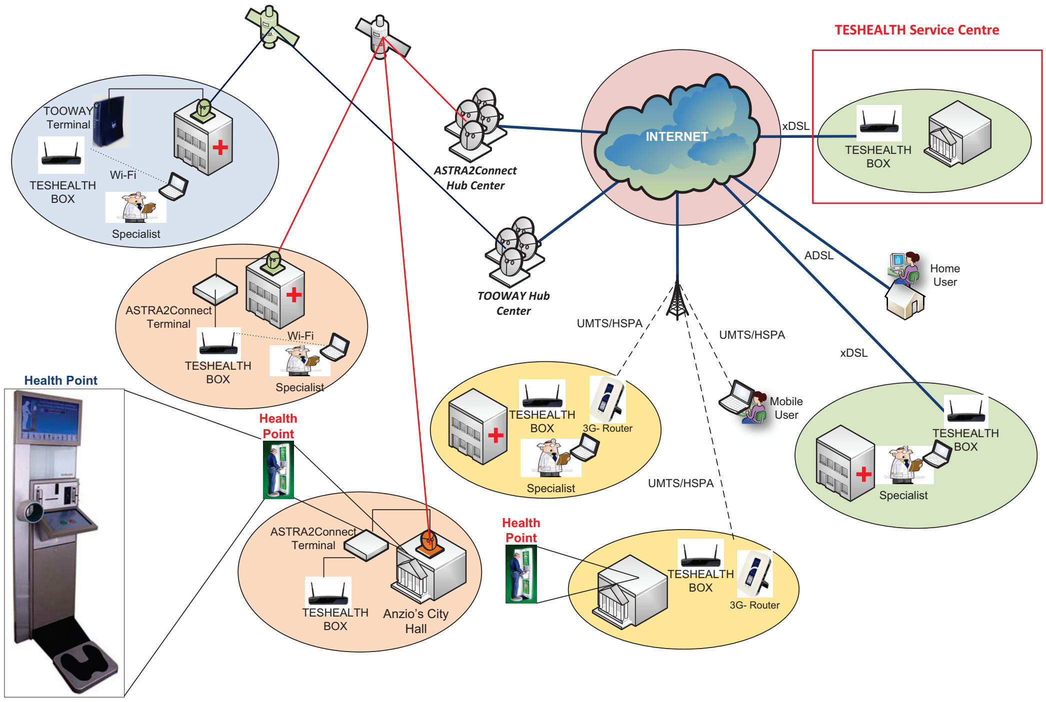


Fig. 1. TESHEALTH Overall Network Architecture

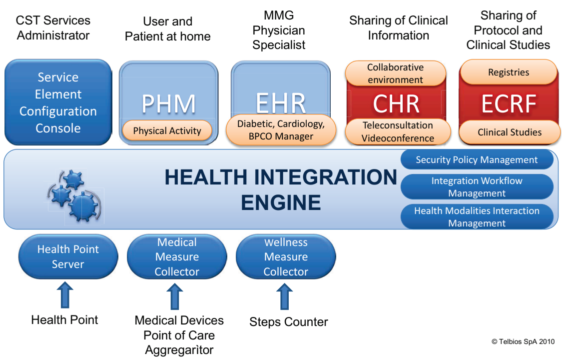


Fig. 2. TESHEALTH Service Platform: the Health Integration Engine.

Health record (CHR)), creating work-flows and rules in order to acquire, manage and route health data (Fig.2). HIE emulator implements SOA (Service Oriented Architecture) paradigm and all messages incoming and out-coming from the HIE are compliant with the HL7 (Health Level Seven) [4].

## III. Application Layer: Telemedicine Services

With the aim to propose an innovative mix of customer oriented technologies and services, TESHEALTH uncovers a new opportunity in the marketplace providing people unprecedented easy access to health and well-being related services. In the following subsections the TESHEALTH services are described, starting from an accurate analysis of both the state of art of the available services and applications and the user (patient and specialist) requirements. In particular both the Self-Care and Assisted services are analysed, highlighting their objectives, functionalities and technical aspects.

### A. *Self-Care Services*

Primary Prevention represents a big opportunity for *interactive* systems, with respect to the traditional information campaign, allowing to guide people in adopting right life styles, by knowing patients feelings, concerns, habits and relationship with their illness.

The Self Care Services offer a range of tools, functionalities and services supporting the behaviour of change of the user, finalised to the lifestyle improvement and wellness. The goal of changing can be reached by means of tools able to convince the user about the value of this change of behaviour and with the capabilities of supporting him through an easy and attractive change process. The user-system interaction level can be decided by the user, who can: only give essential information to the system or make some biometrics measurements to assess his health status or to be an active user by adhering to specific care plans. The tools involved in the Self-Care services are: the PHM and the Health Point.

The PHM is designed with the aim to help people to better know their body and adopt right life style. As a tutor the PHM (Fig.3) supports people in planning little daily actions, thanks to an updated logbook dedicated to specific activities (e.g. check some parameters, make physical exercises, etc). In order to achieve the previous objectives the PHM includes a repository of care plans for primary prevention, which involves both the adoption of an alerting system (via SMS or email) for planned activities and a reporting system to make people aware of their results. Moreover to enable people to share clinical information with the doctor, relatives and friends it provides a documents and data storage. In detail, the PHM

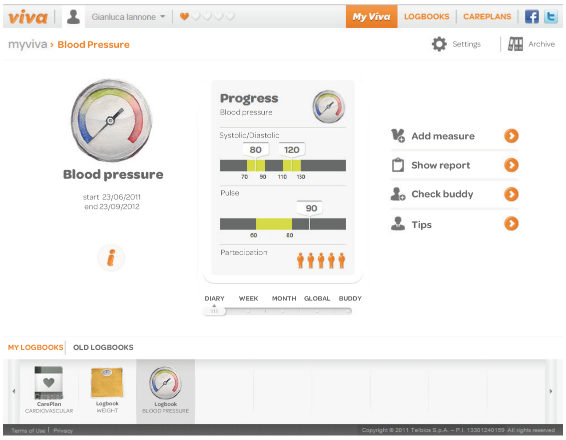


Fig. 3. Personal Health Media

is a J2EE (Java 2 Enterprise Edition) platform based on a three tiers architecture (Data layer, Back-End layer and Front-End layer). The platform is designed according to the project objectives, which include technological features such as scalability, modularity, integrability, configurability, standards and security. In detail, the *Front-End layer* is composed by a Web Server (Apache Web Server) that hosts a web application named PHM Web Application. It represents the interface between user and the PHM system managing the graphical and textual messages. The *Back-End layer* is composed by an Application Server (JBoss Application Server) that hosts J2EE applications offering services to the Front-End layer. Finally, the *Data layer* is composed by a database server used to store all data managed by the PHM application. The communication between FE and BE is implemented using JSON (JavaScript Object Notation) technology and standard REST (Representational State Transfer).

The Health Point is a remote device (kiosk), that can be located in public buildings like pharmacies, allowing users to check autonomously some biometrics measurements. In fact, it permits to accurately measure: blood pressure, cardiac frequency, weight, body mass index and body fat. Moreover, the cardiovascular risk evaluation can be performed. These information are sent information to the PHM in order to update the user health record (using the HIE module and HL7 protocol).

### B. Assisted Services

Considering *Prevention* a big opportunity for Healthcare system to reduce the impact of chronic disease on the population, there is a growing demand of technological solutions that can: support the increasing number of chronic diseases; increase ICT integrated systems for easy fruition, exchange and management of clinical data, supporting the medical staff, providing easy access to health data; reduce raising number of medical errors and Adverse Drug Effects (ADE).

TESHEALTH project, answering these demands, provides two different services to support physicians and healthcare professional activities in this environment: e-clinical studies and tele-consultation services.

*E-clinical studies services* make easier and more efficient the work carried on by the experts in e-trials thanks to the continuous monitoring and management of incoming clinical data, which include the use of cryptography for privacy enforcement. The application scenario of these services is based on ECRF platforms and it enables a multi-centric study, which includes a *core lab* as study monitor and several peripheral clinical centres as contributors to the study (i.e research centers). In particular, it involves the exchange of data among ECRFs (through the HIE) of a patient monitored in a multi-centric study between two hospitals. As an example, this permits to perform a study of a group of patients with cardiac chronical problems, by gathering a broad set of homogeneous data in a specifically dedicated database, which includes data collected during standard clinical examinations. Patients enrolled in the protocol are followed up with periodical exams in hospitals and periodical controls, performed by operators, at home. Collected data are transferred to the ECRF to perform controls and verify the protocol.

The ECRF application is constituted by three logical tiers:

- Presentation Tier: it implements the User Interface (UI), communicating with the Application and Data tier through secured Web Services (HTTPS) and UDP for interactive multimedia. It includes the ECRF Web framework and the integrated collaborative video client, based on MPEG4/H.263.
- Application and Data Tier: it represents the backend of the application, including the Web and the collaborative video servers. It also implements the application business logic.
- HIE Tier: it provides the bi-directional exchange of data between the ECRF application and the other TESHEALTH subsystems. The adopted transport protocols are XML-based, following the SOA paradigm.

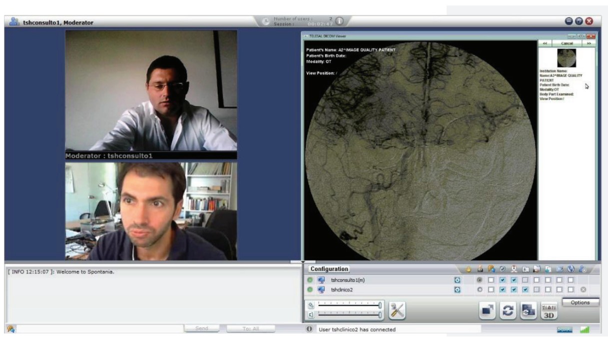

Fig. 4. Tele-consultation services

*Tele-consultation services* enable healthcare professionals to share patients data for precocious diagnosis and clinical cases discussion, allowing people to access periodical clinical check-up for prevention and avoiding medical institutions congestion.

A teleconference module includes a set of functions as data storage and forwarding, collaborative working, virtual meetings, session scheduling, on-line video transmission and video-education. Direct communication between users at different locations is provided. For example an expert could have a patient whose data need to be discussed with other centers (Fig.4). A virtual board enables all participants to exchange messages in a chat area and share images performing zoom actions and basic drawing as pointers, references, texts, highlighters or frames can be performed.

## IV. Access and Network/Transport Layers: Heterogeneous Network Architecture

In the following subsections, both the physical and logical network topology, considered in the implementation of the overall e-Health system, are described.

### A. Physical Network Topology

The heterogeneous network architecture, which involves the integration of the satellite and the terrestrial components, permits to exploit the advantages and overcome the disadvantages of both systems.

*Satellite Component:* It consists of two different space segments: TOOWAY and ASTRA2Connect segments. The network configuration for both segments is defined as *Satellite Two Way Interactive* configuration, which means that the forward and the return channel are provided through a satellite link. A star topology, which includes a hub station (network control center) and several user terminals, is considered. In detail, each user terminal has a dedicated point-to-point link only with the hub station, while a point-to-multipoint connectivity in the forward channel and multipoint-to-point connectivity in the reverse channel are supported.

The first satellite system is based on the S-DOCSIS (Satellite-Data Over Cable Service Interface Specification) standard and it is operated by Eutelsat with the service name TOOWAY. While the second one is based on the Newtec Sat3Play platform and it is provided by SES-ASTRA with the service name ASTRA2Connect. The considered satellite clusters connect the users to the Service Center enabling the transmission of different kind of traffic flows in a scalable and flexible way.

*Terrestrial Component:* It consists of wired and wireless segments. In particular, those considered are: Wired, UMTS/(Universal Mobile Telecommunications System)/HSPA (High Speed Packet Access) and Wi-Fi segments. The wired and the UMTS/HSPA segments provide long range connectivity, whereas Wi-Fi segments provide only local connectivity (enabling the use of portable terminals as laptops) and they are supported by another technology in order to communicate with the Service Centre.

It is worth highlighting that the lowest level (Access Layer) allows the end-user connectivity to the network, regardless location, mobility and capacity of the terminal user through the different satellite and terrestrial access technologies, providing a joint interface to the Network and Transport Layer based on the IP protocol.

### B. Logical Network Topology: IP QoS Solution

In order to implement a secure, flexible and scalable network, providing an adequate QoS solution the Network and Transport Layer tasks are analysed.

The management of the quality of service and security required by the different services is achieved through advanced network control mechanisms implemented on IP routing devices (Boxes). Such devices, able to perform the required traffic classification and conditioning and advanced routing functions, are provided with Wi-Fi and Ethernet interfaces and play the double role of: Wi-Fi Access Point and network device for managing the provision of the Quality of Service at the boundaries of the QoS Domain.

In detail Cisco 871 Ethernet to Ethernet Wireless Router is used as a Box and in order to meet the network requirements, which mapped the e-health services needs, the network configuration integrates the following different technologies: Virtual Private Network (VPN) with IP Security (IPSec) and Network Address Translation Transparency (NAT-T) and Differentiated Services (Diff-Serv or DS) solution.

*IPSec VPN and NAT-T:* To configure and secure the connection between the Service Platform users (remote clients) and the Service Center, the tunnel mode VPN solution is adopted. The Boxes act as VPN gateways and they are responsible for the VPN protection. In particular, in order to protect traffic across the Internet, the IPSec Layer-3 protocol is used to encrypt data and different encrypted tunnels are defined, allowing the management of the transmission of sensitive data, securely (data confidentiality, integrity and authentication), across an unsecured network.

As depicted in Fig.5, the Boxes are logically connected in a star network topology, which involves one central Box (INGRESS Node) and many peripheral ones (EGRESS Nodes). In particular, the Box placed at the Service Center plays the role of the INGRESS Node and represents the only QoS protected way to reach the services source. Whereas the others play the roles of EGRESS Nodes and represent the clients and destinations of the services. To connect remote clients to the server, the Cisco Easy VPNs are used, therefore the Boxes acting as EGRESS nodes represent the Easy VPN Clients, while the one acting as INGRESS node represents the Easy VPN Server. For a highly secure and scalable connectivity for remote access VPNs, the Dynamic Virtual Tunnel Interfaces (DVTIs) are configured, providing an on-demand separate virtual access interface for each VPN session. Moreover, to implement a very flexible network configuration able to overcome the uncontrolled NATs that there are along the path between the INGRESS and the EGRESS Nodes, the IPSec NAT Transparency feature is used, guaranteeing the independence from any particular satellite or terrestrial network configuration.

*Differentiated Services Solution:* Among various well-known QoS approaches, the Diff-Serv strategy [5] turns to be the most suitable approach able to create a very flexible network. In fact, Diff-Serv is a coarse-grained, class-based method for traffic management, based on a mechanism to

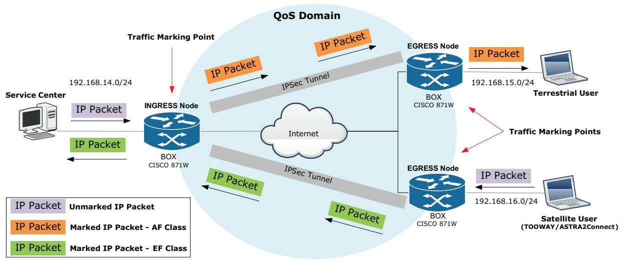


Fig. 5. IPSec-VPN Logical connection and Traffic Marking Points in the Differentiated Service QoS Architecture

classify and mark packets as belonging to a specific class. The traffic entering the network, is classified and conditioned (through metering, marking, shaping, and policing functions) in the nodes at boundaries of the network, (INGRESS and EGRESS Nodes), and assigned to different behaviour aggregates, identified by a single DS code-point (DSCP).

In particular, three different DS classes are taken into account in order to manage the different e-health services: two Assured Forwarding PHB (AF22 for web based services and AF31 for TCP-based streaming services) and an Expedited Forwarding PHB (EF for video conference services). The recommended DSCP encoding is used to mark the defined traffic classes [6]. In detail the traffic is marked both at the INGRESS and the EGRESS Nodes, allowing the protection of the critical traffic flows transmitted from each end point of the network architecture (Fig.5). Regardless the application traffic marking, the Boxes re-mark all the packets destined to the Service Platform network, allowing to control and manage all the traffic flows through the priority given to the protected ones and assignment of the Best Effort class to the others. Moreover, to ensure an appropriate QoS level for each DS class, a minimum guaranteed bandwidth is defined. Therefore in case of high data traffic the capacity is assigned according both to the associated packet forwarding properties and to the defined bandwidth value.

As an example of the QoS implementation, in TABLE I the test report of the unidirectional link between the satellite user and the Service Center, through the satellite TOOWAY segment (satellite uplink), is shown. The UDP traffic flow sent to the 8200 port (belonging to the EF DS class) has a higher priority with respect to the one sent to the 5001 port (best effort). Moreover, although the test is performed in case of link congestion (the satellite uplink available bandwidth is 256 Kbits/s and two flows of 250 Kbits/s are transmitted), the reported network parameters highlight the QoS effect.

To conclude, in TABLEII the IP QoS solutions implemented to meet the services requirements are summarized, highlighting the advantages of the main adopted technologies.

TABLE I
LINK: SATELLITE USER → SERVICE CENTER. SATELLITE UPLINK QOS PERFORMANCE EVALUATION TEST REPORT

| **Port** | ***5001*** | ***8200*** |
|---|---|---|
| **Time Interval** | 0.0-92.0 s | 0.0-93.0 s |
| **Transfer** | 1.42 MBytes | 2.57 MBytes |
| **Bandwidth** | 129 Kbits/s | 232 Kbits/s |
| **Jitter** | 133.076 ms | 17.259 ms |
| **Loss/Total Datagrams** | 903/ 1915 (47%) | 81/ 1915 (4.2%) |

TABLE II
SERVICES REQUIREMENTS AND IP QOS SOLUTIONS.

| **Services Requirements** | **IP QoS Solutions** |
|---|---|
| User-Service Center secure connection regardless of uncontrolled NAT points | *VPN-IPsec (DVTI) with NAT-T*: Security, Scalability, Internet Access Control and Flexibility |
| *Self-Care Services:* Medium bandwidth, low latency | *AF22 DS class* [7]: Medium drop precedence |
| *Assisted Services:* High bandwidth, low latency | *EF* [8] and *AF31 DS classes*: Low drop precedence |

## V. CONCLUSIONS

The proposed integrated satellite/terrestrial interactive e-health system opens a new frontier in the way people relate to their health, their lifestyle and well-being in general. TESHEALTH system provides a technological platform that allows: to identify the personal health behaviour and medical history of each individual, to improve care and outcomes on a patient-by-patient basis, to enable connected health programs and to meet patients where they live, with tools and services that help them manage their own health, leveraging the health-care system. In particular the implemented heterogeneous network architecture enable the user to access the Service Platform through different kind of technologies, providing the appropriate infrastructure that satisfies the quality level required by the telemedicine applications and that promotes the use of satellite communications.

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