PERFORMANCE ANALYSIS OF WIRELESS SYSTEMS IN TELEMEDICINE

Hybrid Network for Telemedicine with Satellite and Terrestrial Wireless Links

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Abstract: Telemedicine services represent a valuable opportunity to provide medical assistance ensuring high flexibility and prompt set up and to significantly reduce costs. The use of hybrid networks based on satellites and terrestrial wireless systems can be extremely advantageous in terms of flexibility, capillarity and integration with modern medical equipment, in particular representing a suitable solution in case of disasters. In the paper such an architecture is described and key performance for some reference applications, evaluated through simulation, are shown and discussed.

1 INTRODUCTION

Nowadays telemedicine is gaining increasing interest, in particular in remote and disaster-struck areas where telecommunication infrastructure can be respectively missing or compromised.

The aim of this paper is to show feasibility and effectiveness of an hybrid network architecture for telemedicine, through performance evaluation carried out by simulations. The proposed hybrid network, selected also for the Telesal project (Arenaccio, Aversa and Luglio, 2006), is composed of a satellite core network, interconnected with terrestrial wireless tails using commonly available and consolidated wireless technologies.

Satellite systems are extremely suitable to represent the core infrastructure of the network for their capability to provide data access ubiquitously and in mobility over very large areas, including remote or impervious locations where typically terrestrial telecommunication infrastructures are not present or economically not viable. To complement such characteristics, terrestrial wireless systems can be fruitfully utilized realizing the terrestrial tails to ensure capillarity and to improve efficiency and flexibility (Luglio and Vatalaro, 2002).

Performances of some reference telemedicine applications will be evaluated using NS2 as simulation tool (Fall and Varadhan, 2007).

In section 2 an overview of the involved technologies is introduced, in section 3 the network architecture is described along with some telemedicine applications. In section 4 the simulations setup is presented offering some the simulation outputs summaries. Finally in section 5 conclusions are drawn.

2 TECHNOLOGY REVIEW

Different kinds of satellite configuration (geostationary and low orbit) can be utilized in the proposed hybrid architecture. As concerns terrestrial systems in particular WiMax, WiFi and Bluetooth looks the most suitable technologies for our scope.

2.1 Satellite Networks

Two kinds of satellite systems are considered:

a) wide band VSAT systems using a geostationary (GEO) satellite and
b) narrow band global communication system using a low orbit (LEO) satellite constellation.

VSAT systems (Very Small Antenna aperture Terminal) are characterized by the use of directional fixed or steerable (to allow mobility) dish antennas with a size of around 80-120 cm. They usually adopt star or mesh topology, using GEO satellites, which

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are suitable for multi-nation coverage area (usually at continental level). They can offer uplinks of up to 2 Mbit/s, with downlink up to 40 Mbit/s. Communications suffer of a physical delay of about 550 ms round trip, since the GEO satellite is placed in a 36000 km orbit. Star systems need a double hop to allow two terminals to directly communicate, from the terminal to the star-centre (called HUB) and from it to the other terminal, resulting in physical delay of four times 125-130 ms. Mesh systems, instead, allow direct communication between two terminals without crossing the HUB (physical delay of two times 125-130 ms).

For the specific scenario that have been simulated, DVB-RCS standard (ETSI EN 301 790, 2003), developed for VSAT systems, has been selected. The architecture referred to the standard usually applies to star topology, with a central HUB called NCC (Network Control Centre). Downlink channel is broadcasted to all users using DVB-S standards (ETSI EN 300 421, 1997), while return channel is shared with a MF-TDMA technique. DVB-RCS allows each terminal to negotiate capacity requests on demand for transmission on the shared return link according to pre-defined service level agreement:

- volume based dynamic capacity (VBDC), to issue bandwidth requests based on the actual volume of traffic needed;
- rate based dynamic capacity (RBDC), to issue bandwidth request based on the estimation of transmission rate;
- constant rate assignment (CRA), to obtain guaranteed bandwidth assignment.

Such an assignment scheme is called DAMA (Demand Assignment Multiple Access) and it is used to share the same upload channel dynamically and efficiently among several terminals. According to the request policy, different cost may by charged by the satellite operator.

On the other hand LEO constellations are composed of several satellites at low orbit (between 700 and 1500 km), which are in continuous movement with respect to terrestrial Earth surface. The system is designed to maximize the probability of user-satellite line of sight even at high latitudes and handover functionalities must be implemented in order to keep connection when changing serving satellite. LEO terminals use omnidirectional antennas and offer limited bit rate, usually dimensioned for voice communications (similar to GSM). Latency is limited to a few ms, but variable in time and affected to big spikes due to the handover execution.

Globalstar has been selected for the simulation campaign (http://www.globalstar.com/en/), due to its common availability in Europe.

2.2 Terrestrial Wireless Networks

To realize the terrestrial component PANs (Personal area networks), LANs (local area networks) or WANs (wide area networks) concepts can be adopted. The first two are usually associated to license free bands (IMS), with data throughput ranging from 1 up to tens of Mbit/s (with a coverage from few meters to some tens of meters). In particular Bluetooth (IEEE Std 802.15.1) and Wi-Fi (IEEE Std. 802.11) are representative technologies of PAN and LAN, respectively. A WAN is instead capable of long range coverage with higher throughput and it usually works either in licensed or free bands. WiMAX (IEEE Std. 802.16e-2005) is an example of WAN with allocation of commercial frequency bands around 3.5 GHz. HIPERLAN (ETSI EN 300 652, 1998) represents another example of WAN system working in the unlicensed band of 5.4 GHz.

For the purpose of our hybrid network proposal, only the license-free LAN and PAN technologies will be included, leaving to a future study a more comprehensive integration of WAN, LAN and PAN networks together with the satellite segment.

Wi-Fi is a widespread wireless technology that provides wired-LAN-like connection service to mobile devices in the range of around 100 m. Maximal bandwidth available on Wi-Fi variants ranges from 11 Mbit/s (standard 802.11b) to 54 Mbit/s (standard 802.11a or 802.11g). So far the infrastructure mode, with a central base station (called Access Point), has been widely deployed in most cases, although Wi-Fi foresees an ad-hoc direct connectivity. A set of base stations can serve up to 128 user terminal each, guaranteeing local mobility. Newer standard 802.11i and 802.11e are defining respectively stronger algorithms for security (WPA2) and QoS at MAC layer.

Bluetooth is a PAN ad-hoc wireless system which allows terminals to flexibly and autonomously configure themselves to communicate without a pre-existing infrastructure in a peer-to-peer fashion. Bluetooth Standard version 1.1 is the actual reference implemented in commercial products such as headsets, GPS devices, etc. It is designed to offer a total 1 Mbit/s data rate with a coverage of 10 meters maximum. When Bluetooth terminals get close enough, they can cluster into a piconet and temporarily designate one master unit to coordinate transmissions with up to seven slave units. The time needed to join a piconet and start service is in the order of some seconds.

Bluetooth is based on packet transmission and frequency hopping (FH) technologies to provide channelization among different piconets within the same area, to form the so called scatternets. Each Bluetooth service has a pre-defined QoS profile to announce during setup, and it is accepted in the piconet only if there are enough resources.

3 TELEMEDICINE NETWORK

The set up of a telecommunications network as support to telemedicine can be extremely difficult in remote or in disaster-struck areas. For instance, the installation of a single dedicated point to point radio link to restore or deliver GSM communication channels can take several hours. In this context, the use of satellite terminals can shorten this time to a few minutes, thanks to the intrinsic broad coverage of a satellite service. The core satellite network can be complemented by terrestrial wireless tails composed of Bluetooth piconets and Wi-Fi links.

3.1 Architecture

The proposed architecture is shown in Figure 1. Connection between satellite terminal and HUB is assumed to be alternatively realized with either DVB-RCS or Globalstar.

An application client on the disaster-struck area is assumed to be reached directly by the satellite terminal, or being part of a Bluetooth piconet. In both cases the connection with the Satellite Terminal can be wired or realized via a Wi-Fi wireless link (dashed line). Nodes of different segments are connected with Ethernet cables or with internal bus if integrated in the same hardware. In all cases connectivity is implemented at IP layer to leverage on IP built-in routing functionalities and address resolution.

Security and QoS must also be carefully considered in hybrid networks offering telemedicine services. QoS is a key issue for real time services, and must be offered end-to-end along the whole data path. This means that each segment must be coordinated centrally for its specific QoS management setup. Security and encryption, usually available for each technology independently, must be ensured also end-to-end, due to the sensitivity of data transmitted. End-to-end QoS and security could be handled at IP layer, since it can be considered too complex an adaptation of different QoS and security procedures offered by the different technologies at layer 2. Solutions like DiffServ and secure tunneling (VPNs) could be adopted.

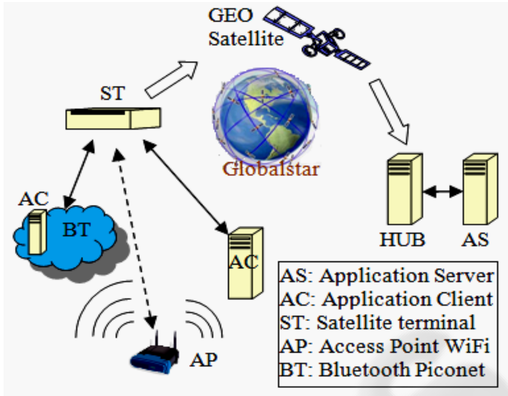

Figure 1: Network Architecture.

3.2 Reference Applications

Two kinds of applications, both real time and non real time, will be tested over the proposed network. Table 1 shows a list of these applications with the most significant characteristics. The last two rows show dimensions of representative files which can be transferred by non real time telemedicine applications.

Table 1: Telemedicine applications.

Real time			
Application	Protocol	Codec	Bitrate
Voice call	RTP	G729	8÷12 kbit/s
Video call	RTP	MPEG4	>384 kbit/s
Non Real time			
Application Data	Protocol	Size Raw	Size compressed
Radiography	FTP	5.7 Mbytes	380 kbytes
ECG trace	FTP	90 kbytes	45 kbytes

4 SIMULATIONS

Simulations have been performed using NS2 platform. The architecture introduced in section 3.1 has been set up and verified with the help of NAM (NS2's visual output), as shown in Figure 2. Application clients 4-6 have Bluetooth connectivity to the Home Gateway. The Home Gateway and the Application clients 7-8 have a Wi-Fi and wired Ethernet connectivity to the satellite terminal, respectively.

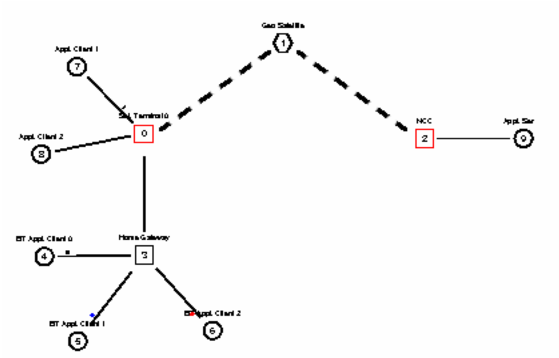

Figure 2: NAM output of NS2 simulation.

Traffic sources originated from Application Clients are compatible with the applications listed in Table 1. All the traffic is delivered from the application clients to the satellite terminal via a wired or wireless link, through the satellite (in alternative DVB-RCS or Globalstar) up to the application server at the other end of the network. The application server is representing the operative centre for emergency handling. TCP New Reno has been used as transport protocol for file transfer and standard UDP for real time traffic.

For simulations using DVB-RCS as satellite technology, a return link capacity of 512 kbit/s with the correct physical delay has been considered. For DAMA capacity requests, RBDC has been simulated according to (Roseti and Kristiansen, 2006) while CRA consists in a granted capacity, similar to a SCPC service (Single Channel Per Carrier, unshared uplink channel). For all the other technologies involved (Bluetooth, WiFi, Globalstar), common operational values as seen in section 2 have been used in NS2 simulated links.

Non real time application performances are summarized in Table 2. For this class of applications the performance index considered is the average time needed by the application on a Bluetooth node to send one data file (including reception and acknowledgement) to the application server at the other end of the network.

Table 2: Non Real Time Average Data Transfer Time.

Data	Globalstar	DVB-RCS w/ RBDC requests	DVB-RCS w/ CRA requests
Radiography RAW	Not performed	140s	115.6s
Radiography Compressed	333.5s	16s	12.5s
ECG trace RAW	79.6s	6.9s	4.9s
ECG trace Compressed	45.9s	4.8s	3.4s

Figures clearly show the differences in performances between GEO and LEO satellite system, and also between the two different request policies for DVB-RCS. The use of satellite to transfer medical data of limited size is acceptable under all conditions, while bigger size data transfer is not practical for narrow band Globalstar satellite system.

For real time applications, two different setup have been considered for the two alternative GEO and LEO satellite systems:

- When using DVB-RCS, a video call with five simultaneous voice calls with higher quality profile (12 kbit/s each) have been initiated from the Bluetooth nodes 4-6. Other two voice calls have been initiated from Application clients 7 and 8
- Over the Globalstar system, only one voice call originated by a Bluetooth node could be performed at the minimum codec rate (8 kbit/s)

In both cases the packet error rate has been verified to remain under 1%.

The one way average delay of RTP packets delivery from source to destination, measured at the two ends of the network, has been used as performance index for the real time applications. The averaged delay values are shown in Table 3.

Table 3: Real Time average packets delay (one way).

Data	Globalstar	DVB-RCS w/ RBDC requests	DVB-RCS w/ CRA requests
Voice Call	0.27s	0.48s	0.36s
Video Call	n.a.	0.61s	0.35s

Globalstar and DVB-RCS with CRA profiles show similar performances for the voice call average delay. In fact, in both cases there is no need for explicit bandwidth requests which introduce an additional access delay. RBDC request policy has a bigger average delay compared to the other two cases, because periodic requests based on estimated rate must be issued by the terminal to the NCC, thus increasing the perceived delay by an additional factor. RBDC is usually associated to a cheaper contract with satellite operator in comparison with CRA.

Jitter has resulted limited when simulation adopted the Globalstar network and the DVB-RCS with CRA profile. In particular some significant variations are present during LEO satellite handover, which was not simulated in our NS set up and usually occurs every 20 minutes in average.

Instead, when DVB-RCS system adopts RBDC access scheme, significant jitter variations are observed. Please note that RBDC allocation mechanism is not standardized by DVB and the reported effect might vary depending on the selected implementation.

In particular the jitter is due to voice calls packets pattern, a small packet each 10 ms, according to the codec standards. Small packets can trigger the request of a bigger capacity of the simulated DVB-RCS system which remains assigned to the terminal for a longer time (in this simulation 100 ms), resulting in temporary extra capacity. As consequence, the time needed for the delivery of packets decreases, resulting in a lower perceived rate needed. This vicious loop makes RBDC requests oscillating, together with system capacity assigned. This affects packet delivery delay too, which is shown in Figure 3 for a voice call.

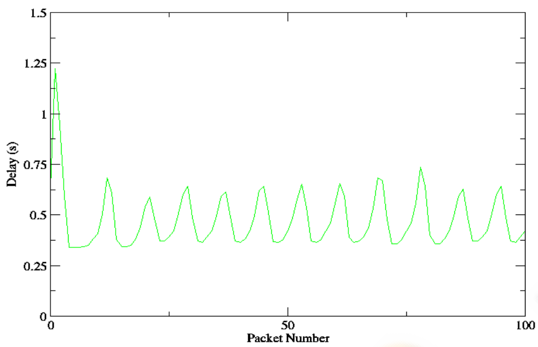

Figure 3: Packet delay oscillations on RBDC requests.

A proper de-jitter buffer (Ferrari and Verma, 1991) must be designed at receiver side in order to compensate the packet arrival latency variations for this case.

5 CONCLUSIONS

The paper describes a hybrid network for telemedicine applications adopting satellite networks and wireless technologies of different kinds. Both sample real time and non real time applications has been run in a simulated scenario including all the described network links, to assess performances.

The results obtained has proven the feasibility of such an hybrid network including satellite links. In particular positive results has been obtained with both GEO and LEO systems, taking into account limitations of LEO narrow band capacity. The main differences between different systems and the use of different request policies for DVB-RCS has been discussed.

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