Provision of Electronic Healthcare Services via DVB-RCS Satellite Communication Technology

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Abstract

The advent of broadband communications technologies has paved the way to the wide application of innovative, yet resource-demanding electronic healthcare services like real time telemedicine or high bandwidth store and forward transmission of medical data from underserved locations. Satellite broadband communications technologies, such as the Digital Video Broadcasting with Return Channel via Satellite (DVB-RCS) technology, attempt to offer wide-area broadband connectivity comparable to the terrestrial broadband technologies, when the available data rates and costs are considered, even in geographically remote areas where the terrestrial technologies really suffer. This paper describes a wide-area tele-medicine platform, specially suited for homecare services, based on the DVB-RCS and Wi-Fi communications technologies. The presented platform combines remote medical data collection and transmission, patient monitoring and tele-conference services. Possible operational scenarios involving the aforementioned system and test results regarding tele-monitoring and medical data transfer are also presented.

Keywords

Tele-medicine, Digital Video Broadcasting with Return Channel via Satellite (DVB-RCS), Satellite Interactive Terminal (SIT), Return Link (RL), Homecare, Wi-Fi, Patient Tele-monitoring, Remote Site (RS), Regional Access Point (RAP), Center Node (CN)

1. Introduction

Broadband connectivity is rapidly evolving around the globe using a diversity of means involving wire-line (e.g. Asynchronous Digital Subscriber Line - ADSL), wireless (e.g. Wi-Fi, WiMax) and satellite interconnections. Multimedia-rich services provided via broadband connections can potentially change the way of communicating ideas, doing business, or even thinking in the modern world. In this framework, European Space Agency (ESA) has developed the Digital Video Broadcasting with Return Channel through Satellite (DVB-RCS) technology enabling almost all potential locations, even the most geographically dispersed and isolated ones, to gain access to broadband services using low-cost Satellite Interactive Terminals (SITs). Today the DVB-RCS technology is a mature broadband communications technology with comparable implementation and operational costs to the other broadband technologies, effectively satisfying the Quality of Service (QoS) requirements of the existing applications.
DVB-RCS (see ETSI EN 301 790 and ETSI EN 300 468) is an ETSI standard that specifies the provision of the interaction channel for interactive (two-way) satellite networks using Return Channel Satellite Terminals referred to as RCST or simply SITs. It is essentially based on the DVB-S (S: Satellite) technology broadly used today for satellite digital TV broadcasting and utilizes the MPEG transport stream standard as the transmission platform towards all SITs.

The topology of a typical interactive satellite network is star with the central gateway, known simply as DVB-RCS Hub, at its center and the SITs around the DVB-RCS Hub. The DVB-RCS Hub manages the network operation; enables SIT access to the satellite network, assigns bandwidth to SITs, relays traffic between SITs inside the satellite network and between the SITs and other networks (e.g. Internet) and also monitors the operation of the SITs. Note that data communication between two SITs can only take place through the DVB-RCS Hub, thus effectively being a two-hop communication. For the sake of simplicity in this paper from this point forward, the transmission from the DVB-RCS Hub towards all SITs will be referred to as Forward Link (FL) and the transmission from each SIT towards the DVB-RCS Hub will be referred to as Return Link (RL). Network access on the RL is based on the Multi Frequency Time Division Multiple Access (MF-TDMA) technology. Data rates on the FL can reach 45 Mbps and data rates on the RL can reach 2 Mbps. Bandwidth allocations on both FL and RL can be guaranteed (constant rate) or dynamic, depending on the available bandwidth at certain time periods.

Telemedicine applications span the areas of emergency health care, patient telemonitoring, telecardiology, teleradiology, teledermatology, telepsychiatry and telesurgery (Kyriacou et al, 2004) (Maglogiannis et al, 2004). Such applications enable the availability of prompt and expert medical care at understaffed areas like rural health centers, ambulance vehicles, ships, trains, airplanes as well as for home monitoring (Homecare) (Pattichis et al, 2002) (Shimizu, 1999) (Istepanian et al, 2004). Mobile/Satellite telemedicine is a new and evolving area of telemedicine that exploits the recent development in mobile/satellite networks. Satellite systems are considered an attractive networking solution for telemedicine platforms, since they have the advantage of worldwide coverage and offer a variety of data transfer speeds, even though satellite links require high operating costs.

In this paper an integrated, wide-area tele-medicine platform for homecare services based on the DVB-RCS and Wi-Fi technologies is presented. The described system can support all or a number of the following services:
1) Videoconferences between patients at home and medical personnel, such as doctors and nurses, located at a remote hospital or medical center.
2) Tele-monitoring of patients at home with or without movement problems.
3) Acquisition of medical data, such as (in-blood) glucose measurements, heart pulse measurements, weight measurements etc. and transmission of this data to a hospital or medical center for further process and/or archiving.

The topology of the proposed tele-medicine system and its complete operation are analytically described in Section 2. In Section 3, two possible operational scenarios are presented. In Section 4, tests regarding tele-monitoring and medical data transfer are presented. The objective of the tests was to validate the transmitted video quality, considering various data
rates and combinations of satellite capacity allocation, involving guaranteed and dynamically allocated bandwidth, while medical data transfer takes place. Finally, Section 5 concludes the paper.

2. Description of the Integrated Satellite Tele-medicine Platform

The general topology of the proposed tele-medicine platform is depicted in Figure 1. The system consists of one or more Remote Sites (RSs) placed in several remote areas. Each RS has access to a wireless access point. Every RS can be equipped with a special communication unit, essentially being a videoconference unit/ videophone or a tele-monitoring unit. Optionally, the communication unit at the RS may have the capability to connect to medical data acquisition units that collect various medical measurements and vital signals, such as the level of glucose, heart pulse, weight, electrocardiogram (ECG) etc., Every RS is connected to a Regional Access Point (RAP) (e.g. RAP Y1) using the Wi-Fi technology (IEEE 802.11g), and communicates through the corresponding (at site) DVB-RCS SIT and the available DVB-RCS Hub to the Center Node (CN), being a hospital or a medical center. The range of communication between a RS and a RAP is generally less than 1 km. The locations of the RSs, RAPs and CN are assumed to be random. Further information about the RSs, RAPs and CN is provided in the following sub-sections.

![Figure 1 - Topology of the proposed tele-medicine system](image)

2.1 Required Infrastructure at each Remote Site (RS)

In each RS the following equipment is required:
- One (1) communication unit, usually being a videophone or a special videoconference/medical data collector unit. The videophone is supplied with Ethernet
(IP) interface and with the push of a button it is possible to make video calls to the medical personnel of the CN. The video is projected onto a Liquid Crystal Diode (LCD) monitor on the device. Alternatively, there is the ability to install a special integrated videoconference and medical data acquisition unit (Scotty Group, 2006). This device is also equipped with Ethernet (IP) interface and it can be used as a gateway for video and medical data. In fact, it can be connected to special health check equipment, like a glucose meter, a stethoscope, a weight scale, a blood pressure meter, a vital signs monitor, a pulse oximeter etc. The medical personnel, through the embedded teleconference capability of the device, can communicate with the patients using real-time video, as with a simple videophone, even permitting the realisation of regular and irregular medical examinations from distance. Considering the characteristics of the aforementioned device, glucose and blood pressure measurements, supervision of injuries, monitoring and/or confrontation of hypoglycaemia or hyperglycaemia symptoms, monitoring and/or confrontation of possible heart attack incidents, as well as monitoring of the respiratory system of patients can easily be performed using the proposed tele-medicine system, always in collaboration with the medical staff of the CN.

- A simple IP camera or a video server, connected to an analogue camera, could be also used just for visual monitoring of patients with or without movement problems. More details on video servers exist in Section 4.
- One (1) wireless access point that uses Wi-Fi technology (IEEE 802.11g). This appliance is connected through Ethernet (IP) interface to the aforementioned communication unit. The video transmission and/or the transfer of medical data to the neighbouring RAP will take place via the wireless access point. The wireless access point is connected through an RF cable to an omni-directional antenna installed on the roof of the building where the RS is located.

### 2.2 Required Infrastructure at each Regional Access Point (RAP)

- One (1) wireless access point that uses Wi-Fi technology (IEEE 802.11g). This device is connected via Ethernet (IP) interface to the SIT located at the RAP. The wireless access point is connected through an RF cable to an omni-directional antenna installed on the roof of the building that hosts the RAP.
- One (1) SIT to communicate (always via the DVB-RCS Hub) with the CN.

### 2.3 Required Infrastructure at the Center Node (CN)

- One (1) data Collector Personal Computer (C-PC). This PC is used to communicate with the special videoconference/medical data collector units located at the RSs. Special software will consolidate and process all the medical data coming from the aforementioned units and it will update the medical records of the patients. The data collection will be realised sequentially, whereas the software will communicate with the videoconference/medical data collector units of the RSs one-by-one. The user of the C-PC may be a properly trained nurse. Note that the C-PC could be also used for viewing or recording video from an IP camera or a video server located at a RS. For video viewing, a web browser on the C-PC is enough; for video recording, special software is required.
- One (1) Database Computer (DB-PC). This PC is used in order to communicate with the C-PC and will support the database, where the medical history data of the patients will be
contained. In order to ensure system reliability and security, two identical DB-PCs may be used, operating in cluster configuration.

- One (1) Multipoint Conference Unit (MCU). The MCU will manage videoconferences between patients reside at the RSs and the medical staff located at the CN. The MCU supports multiple videoconference sessions, essentially organised as doctor-to-one-patient or doctor-to-many-patients sessions. The MCU is based on a videoconference hardware and software combination. The MCU can be easily operated by the medical personnel.

- Two (2) or more Videoconference Units (VCUs). Each VCU will be connected to a TV. The VCU gives the opportunity to the doctor at the CN to communicate with his patient (or patients) using real-time video. Two doctors may handle two different sessions simultaneously, e.g. one session regarding a cardiological incident and one session regarding a human respiratorial incident; each of the sessions will be represented by one teleconference session organised as a doctor-to-one-patient session or a doctor-to-many-patients session. Alternatively, two physicians of the same area of expertise (e.g. pathologists) could handle the same session of incidents, if this is required. Each patient will see his doctor on the LCD monitor of his videophone or special videoconference/medical data collector unit, while the doctor will see his patient on the TV connected to his VCU. The communication with the patients will be performed either sequentially that is in a one-by-one basis, or simultaneously in the case that there is a number of patients with the same health problem, if this is possible.

- Two (2) or more TV monitors connected to the utilised VCUs may be used.

- One (1) Ethernet Hub or Switch. This device will be used for the implementation of a Local Area Network (LAN). The aforementioned applications will operate through this LAN.

- One (1) SIT to communicate (always via the DVB-RCS Hub) with the RAPs.

3. Typical Operational Scenarios

3.1 Operational Scenario 1

Suppose that Mr. A. located at RS X1 and equipped with a videophone, is having a difficulty in breathing. By pressing a button on his videophone, a direct connection is made with the doctor at the CN. According to the symptoms described by Mr. A., following to the doctor’s questions, the doctor provides appropriate advise to the patient in order to address his health problem and decides if further medical attention is needed (i.e. if an ambulance has to be sent to the home of Mr. A. or not) based also on the medical records of the patient.

3.2 Operational Scenario 2

Assume that Mr. P. suffers from saccharoid diabetes. Mr. P. is located at the RS X2 and he is equipped with a videoconference/medical data collector unit, connected to a glucose meter. Mr. P. has hypoglycemia symptoms (e.g. abstractness, ephidrosis). Then by pressing a button on the aforementioned unit, a direct connection is made with the doctor at the CN. At the same time, with the assistance of the attached glucose meter on his videoconference/medical data collector unit, the level of blood glucose of Mr. P. is measured. The results are sent to the CN and they are collected from the C-PC. The doctor gains access to them and he also retrieves the medical history of Mr. P. from the database. According to the examination results, the symptoms described by the patient following to the doctor’s questions and the
patient’s medical history, the doctor decides if further medical attention is needed (i.e. if an ambulance has to be sent to the home of Mr. P. or not) and then provides appropriate advice to Mr. P. in order to address his uncomfortable condition.

4. Experimental Tests and Results

Regarding the experimental setup, two (2) SITs were used, which were communicating with each other (Sites X and Y) through the DVB-RCS Hub that the Hellenic Aerospace Industry (in Tanagra, Greece) owns and operates. The HellasSat satellite was used to provide SIT and DVB-RCS Hub interconnection. The tests presented in this paper essentially involved patient (video) tele-monitoring and medical data transfer. The SIT at Site X was connected to a PC, while the SIT at Site Y was connected to the output of a video server device.

Site X simulates the CN, while Site Y simulates a combination of RS and RAP. The input of the video server at Site Y was connected to one Close Circuit TV (CCTV) analogue camera. The video server device transforms the analogue TV signal at its input(s), coming from one or more tele-monitoring cameras, to one or more IP packet video streams, which are then sent to a LAN. Basically, the video quality provided by a video server depends on the utilised video compression format (e.g. MPEG-2, MPEG-4) and frame size/resolution (e.g. 4CIF - 768x576 pixels, 2CIF - 640x480 pixels, CIF - 380x240 pixels, QCIF - 176x144 pixels). Note that during the tests, the video server was connected to one CCTV camera only.

Moreover, the SIT at Site Y was connected to a PC during the tests and it produced a continuous data stream, essentially simulating blood pressure (transfer rate: 10 kbps) and audio stethoscope (transfer rate: 10 kbps) data transmission, towards the PC at Site X. The total data stream rate was 20 kbps. The utilised numbers, referring to blood pressure and audio stethoscope data transmission rates, were acquired from Table 1, which presents typical data rates for transmission of biosignals. Actually, the client version of the Iperf testing software (Iperf Team, 2003) was running to the PC at Site Y, while to the PC at Site X the server version of the Iperf software was running. The client version of Iperf sends a constant User Datagram Protocol (UDP) data stream, which simulates a medical data stream (see above), to the server version of Iperf. The server version of Iperf records packet loss for the transmitted data stream and the utilised bandwidth by the stream. The test topology is illustrated in Figure 2.

The basic objective of the tests was to validate the video quality perceived at Site X, while sending both video and simulated medical data (biosignals) from Site Y, considering various transmission data rates and combinations of satellite capacity allocation, involving guaranteed and dynamically allocated bandwidth for the SIT at Site Y. The packet loss for the data stream and the utilised bandwidth by the stream were continuously monitored during all tests. The video quality is defined considering the quality of illustration. Actually, the quality of the video is not good when the image is not sharp enough, squares and/or blurred areas appear inside the image frame, the sequence of video frames is not constant but stops and starts again, the colours are not properly displayed etc. The transmitted data rate from a SIT can be guaranteed (Constant Rate Assignment - CRA) or dynamic (Volume Based Dynamic Capacity - VBDC), depending on the available bandwidth, or combination of the above two bandwidth allocation schemes.
Table 1: Typical Medical Data Transmission Rates

<table>
<thead>
<tr>
<th>MEDICAL DATA TYPE</th>
<th>DATA RATE REQUIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Blood Pressure Monitor</td>
<td>&lt; 10 kbps</td>
</tr>
<tr>
<td>Digital thermometer</td>
<td>&lt; 10 kbps</td>
</tr>
<tr>
<td>Digital audio stethoscope &amp; integrated electrocardiogram</td>
<td>&lt; 10 kbps</td>
</tr>
<tr>
<td>Compressed and full motion video (e.g. ophthalmoscope, etc)</td>
<td>384 kbps to 1.544 Mb/s (speed)</td>
</tr>
</tbody>
</table>

Figure 2 - Topology of the test network

During the tests, video and medical data transfer from the video server and the PC at Site Y towards the PC at Site X took place considering different RL rates for the SIT at Site Y. The FL rate for the SIT at Site X was 2 Mbps in all tests. Note that for the tests, the video resolution was CIF (380x240 pixels) and the video compression format MPEG-4 was used with 20% compression, that is the 20% of the totally produced information about colours and brightness was finally sent from the video server. No restrictions to the upper and down limits of the video rate produced by the video server were imposed. Video viewing on the PC at Site X took place using an ActiveX-enabled web browser (Microsoft Internet Explorer). Note also that the total rate for the medical data transmission was 20 kbps. The test results are depicted in Table 2.

As shown in Table 2, best video quality, with also best frame rate and throughput, were acquired when the RL rate was 1024 kbps (or more) and it was all CRA. However, this value for the RL rate is not realistic and affordable, especially when networks with many RSs are
considered, since the satellite capacity (and thus the RL rate/bandwidth) is expensive and its availability is usually limited. So, lower RL rates are required in real conditions. As it can be understood from Table 1, satisfactory video quality, with also acceptable frame rate and throughput, were acquired when the RL rate was 384 kbps and it was all CRA. This value of RL rate is much more affordable and realistic. It is obvious from the tests that the throughput basically depends on the value of CRA; decrease of CRA eventually caused lower throughput, worse video quality and smaller frame rate. Even when large values of VBDC (above 512 kbps) were available during the tests, but the CRA was less than 256 kbps, the video quality and particularly the frame rate were not satisfactory.

Table 2: Test Results

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Video Quality *</th>
<th>RL rate for the SIT at Site Y (kbps)</th>
<th>Frame rate (fps)</th>
<th>Throughput (kbps)</th>
<th>Medical Data Stream Packet Loss (%)</th>
<th>Medical Data Stream Utilised Bandwidth (kbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>1648 – CRA</td>
<td>25</td>
<td>900</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>1024 – CRA</td>
<td>25</td>
<td>900</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>512 – CRA</td>
<td>25</td>
<td>420</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>384 – CRA</td>
<td>25</td>
<td>310</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>256 – CRA</td>
<td>25</td>
<td>190</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>128 – CRA</td>
<td>10</td>
<td>90</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>64 - CRA, 64 - VBDC</td>
<td>10</td>
<td>60</td>
<td>0</td>
<td>–20</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>64 – CRA, 192 - VBDC</td>
<td>10</td>
<td>70</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>64 – CRA, 448 - VBDC</td>
<td>12</td>
<td>140</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>128 - CRA, 128 - VBDC</td>
<td>12</td>
<td>100</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>128 - CRA, 256 - VBDC</td>
<td>12</td>
<td>120</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>128 - CRA, 384 - VBDC</td>
<td>12</td>
<td>140</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>256 - CRA, 256 - VBDC</td>
<td>12</td>
<td>230</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>14</td>
<td>3</td>
<td>256 - CRA, 768 - VBDC</td>
<td>13</td>
<td>240</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>4</td>
<td>512 – CRA, 512 - VBDC</td>
<td>25</td>
<td>450</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

*Best: 5, Very Good: 4, Good: 3, Bad: 2, Very Bad: 1

For the transmitted data stream that simulates the transfer of biosignals, no packet loss appeared and the utilised bandwidth was constant, basically reaching 20 kbps, in all tests as shown in Table 2. Even when the RL allocated capacity was small (e.g. Test 7) the medical data transfer was normal and stable, without packet losses. So, video transmission did not affect medical data transmission at any case. Besides, medical data transmission was not affected by the different values of CRA and VBDC, for the SIT at Site Y, considering all tests. So, medical data transfer can be well served using dynamic capacity allocation schemes, that is VBDC, without the need for, rather expensive and limited, guaranteed capacity (CRA).

5. Conclusions

This paper presents an integrated, low-cost, wide-area tele-medicine system, with emphasis to patient monitoring/homecare services. The topology of the described system is hierarchical, involving an access network based on the Wi-Fi technology and a core network based on the DVB-RCS satellite communications technology. The monitored patients can be located practically anywhere, even in geographically dispersed and isolated areas, where normally there is no terrestrial communications infrastructure capable of supporting similar services.
Considering the characteristics of the utilised equipment in the framework of the proposed tele-medicine system, teleconference with the patients, tele-monitoring, glucose and blood pressure measurements, supervision of injuries, monitoring and/or confrontation of hypoglycaemia or hyperglycaemia symptoms, confrontation of possible heart attack incidents as well as monitoring of the respiratory system of patients can be efficiently performed using the proposed tele-medicine system. A set of tests is also included in this paper, which is related to tele-monitoring and medical data transfer. The experimental results show that SIT transmission rates at 384 kbps are enough to support tele-monitoring, providing satisfactory video quality and frame rate. Also, the transmission of biosignals can be performed with no packet losses using dynamically allocated capacity, without the need for expensive guaranteed capacity. Besides, medical data transfer was not affected by video transfer and it was constant during all tests. Future developments involve the incorporation of more communications technologies, such as WiMax and GSM/3G, and the incorporation of more medical services.

6. Acknowledgment

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7. References

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