QOS STUDY PERFORMANCE OF AN INTEGRATED SATELLITE TELEMEDICINE PLATFORM

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ABSTRACT

This paper describes a wide-area tele-medicine platform, specially suited for homecare services, based on the DVB-RCS and Wi-Fi communication technologies. Implementation of DVB-RCS, utilizing dynamic assignment techniques mandated in the DVB-RCS specification, has been specifically designed and tuned for multimedia and high-speed data transfer. The monitored patients can be practically anywhere, even in geographically dispersed and isolated areas, where normally there is no terrestrial communications infrastructure capable of supporting similar services. The presented platform combines medical data acquisition and transfer, patient remote monitoring and teleconference services. Possible operational scenarios simulated and results regarding available data rates, Quality of Service (QoS) provision, and prioritization of tele-monitoring, videoconference and medical data transfer are provided and discussed in the paper.

I. INTRODUCTION

Multimedia-rich services provided via broadband connections can potentially change the way of communicating ideas, doing business, or acting in the modern digital world. In this framework, European Space Agency (ESA) has initiated the Digital Video Broadcasting with Return Channel via 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), effectively satisfying the QoS requirements of high demanding applications in electronic healthcare.

In the era of mobile computing the trend in medical informatics is towards achieving two goals: the availability of software applications and medical information anywhere and anytime and the invisibility of computing; computing modules are hidden in multimedia information appliances. The DVB-RCS technology seems capable of providing such pervasive e-health services. DVB-RCS [1],[2] is an ETSI (European Telecommunications Standards Institute) 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. The DVB-RCS Hub is vital for the operation of the DVB-RCS satellite communications network and essentially manages the network operation; it 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.

Tele-medicine applications span the areas of emergency healthcare, homecare, patient tele-monitoring, tele-cardiology, tele-radiology, tele-pathology, tele-dermatology, tele-ophthalmology, tele-psychiatry and tele-surgery [3]. These applications enable the provision of prompt and expert medical services in underserved locations, like rural health centers, ambulances, ships, trains, airplanes as well as at homes (homecare) [4]. Tele-medicine provided via satellite communications is an evolving area of healthcare services and provision of medical information, which utilizes the new developments in satellite networks such as DVB-RCS. In fact, satellite communication 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 rates, even though satellite links involve high operating costs [5]. However, with the application of the DVB-RCS technology, the operating costs of satellite links tend to be significantly reduced.

In the context of this paper, an integrated wide-area tele-medicine platform for the provision of homecare services, based on the DVB-RCS and Wi-Fi communication technologies, is presented and evaluated for the Region of North Aegean in Greece. The topology of the proposed tele-medicine platform and its functional operation are described in Section 2. In Section 3, two possible operational scenarios are presented, while in Section 4 the simulation of the proposed platform is presented and evaluated in terms of QoS parameters. Finally, section 5 discuss the findings and concludes the paper.

II. DESCRIPTION OF THE INTEGRATED SATELLITE TELEMEDICINE PLATFORM

The general topology of the proposed tele-medicine platform is depicted in Fig. 1. The platform can support all or a number of the e-health services, like videoconference or only VoIP communication between patients at home and medical personnel, such as doctors and nurses, located at a remote hospital or a medical center, video based tele-monitoring of patients at home with or without movement problems and biosignal based tele-monitoring. The platform's architecture is hierarchical, involving an access network based on the Wi-Fi technology and a core network based on DVB-RCS. The core DVB-RCS network can be provided by any company or organization that has purchased, invested and operates, like the one that Hellenic Aerospace Industry S.A. owns and operates at its premises in Greece. The DVB-RCS satellite core network can gain access by any satellite provider using the expensive but necessary satellite bandwidth (satellite transponder) in order to provide SIT and DVB-RCS Hub interconnection. The only limitation of the network is the satellite coverage footprint (coverage map) [6].

The platform may consist of one or more Remote Sites (RSs) placed in several remote areas. Every RS can be equipped with appropriate communication devices (i.e. videoconference units, videophones, patient tele-monitoring unit, IP phones etc). Optionally, the communication device at the RS may have the capability to connect to medical data acquisition units collecting various biosignals and physical data. Each RS has access (Ethernet IP connection) to a wireless access point that utilizes the Wi-Fi technology (IEEE 802.11g), through which the RS is wirelessly connected to a Regional Access Point (RAP). The range of communication between a RS and a RAP is generally less than 1 km. The RAP concentrates video/voice/data from a number of RSs and communicates through the corresponding (located at the site) DVB-RCS SIT, the utilized communication satellite and the available DVB-RCS Hub of the satellite network, with the Center Node (CN), essentially being a hospital or a medical center. Naturally, the equipment of the CN, among others, includes a SIT for communication with the satellite network. The medical personnel (physicians and nurses) at the CN can communicate and provide help to the patients with health incidents as well as potentially realize regular and irregular medical examinations from distance using the platform. The locations of the RSs, RAPs and CN are assumed to be random. Considering the characteristics of the equipment used in the framework of the proposed tele-medicine platform, teleconference/VoIP communication with the patients, tele-monitoring, glucose level and blood pressure measurements, supervision of injuries, monitoring and/or confrontation of hypoglycemia or hyperglycemia symptoms, confrontation of possible heart attack incidents as well as monitoring of the respiratory system of patients can be efficiently performed using the tele-medicine platform described in this paper.

Each Remote Site (RS) is equipped with a communication unit that utilizes a VoIP, a special integrated videoconference and/or a medical data acquisition unit. The medical personnel, through the embedded teleconference capability of the device, is able to communicate with the patients using VoIP, real-time video, as with a simple videophone, even permitting the realization of regular and irregular medical examinations from distance.

The required infrastructure at the Center Node (CN) consists of one data Collector Personal Computer (C-PC), one Database Computer (DB-PC), one Multipoint Conference Unit (MCU), two or more Videoconference Units (VCUs), two or more IP phones, two or more TV monitors, one Ethernet Hub or Switch and one SIT to communicate with the RAPs. The C-PC is used for the communication with the special videoconference/medical data collector units located at the RSs. Special software consolidate and process all the medical data coming from the aforementioned units and it will update the medical records of the patients. The DB-PC is used to facilitate the communication to the C-PC and support the database, where the medical history data of the patients will be contained. The VCU gives the opportunity to the doctor at the CN to communicate with his patient (or patients) using real-time video. The required infrastructure of the anticipated platform is depicted in Table 1.

Table 1: Required Infrastructure of the proposed platform at each node

Location	Required Infrastructure
Remote Site (RS)	- Communication Unit (VoIP, Videophone or Special Videoconference/Medical Data Collector Unit)
	- IP Camera or a Video Server Unit
	- Wireless Access Point
Regional Access Point (RAP)	- Satellite Interactive Terminal (SIT)
	- Wireless Access Point
Center Node (CN)	- Data Collector Personal Computer (C-PC)
	- Database Computer (DB-PC)
	- Multipoint Conference Unit (MCU)
	- Videoconference Units (VCUs)
	- IP phones
	- TV monitors
	- Ethernet Hub or Switch
	- Satellite Interactive Terminal (SIT)

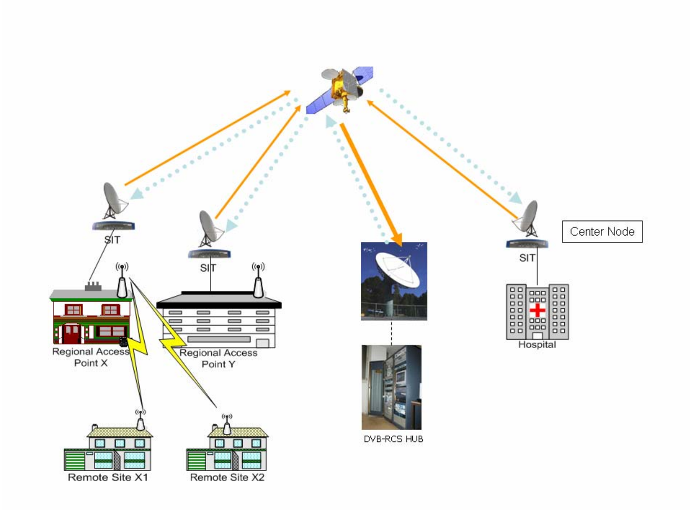

Fig. 1: Topology of the proposed tele-medicine platform.

III. The Platform in Practice – Two Typical Operational Scenarios

The implemented testbed used for our experiments consisted of two SITs, 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-2 satellite was used to provide SIT and DVB-RCS Hub interconnection. Site X simulates the CN, while Site Y simulates a combination of RS and RAP. The experiments essentially involve tele-monitoring, videoconference and medical/physical data transfer. Actually, two set of tests took place. The experimental results are discussed and evaluated in [7]. The first set involved (video) monitoring of the patients and medical data transfer, where 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. The second set involved videoconference between the two Sites jointly with medical data transmission from Site Y towards Site X. Note that two strict priority queues were defined in both SITs; the one had high priority weight and served video/voice transmission while the other one had low priority weight and served medical data transmission. We further discuss some indicative operational scenarios, which reveal the functionality of the proposed platform.

A. *Operational Scenario 1*

The first scenario concerns a patient, who recently was discharged from hospital after some form of intervention, for instance, after a cardiac episode, cardiac surgery or a diabetic comma. These types of patients are less secure and require enhanced care even at home. However, the home offers a considerably different environment than a hospital or a health unit. The patient or elder will mainly require except video surveillance, also monitoring of his vital signals (i.e., ECG, blood pressure, heart rate, breath rate, oxygen saturation and perspiration).

B. *Operational Scenario 2*

The second scenario concerns a patient, who suffers from saccharoid diabetes and he exhibits hypoglycemia symptoms (e.g. abstractness and ephidrosis). Supposing the patient is located at the RS X2, equipped with a videoconference / medical data collector unit, connected to a glucose meter, allowing a direct connection with a physician at a Center Node (CN), upon his request. The attached glucose meter measures the level of blood glucose and sends the results to the CN. The doctor gains access to these medical data and he also retrieves the patient's medical history from an EHR (Electronic Health Record) relational database system. 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 patent's home or not) and then provides appropriate advise in order to address his uncomfortable condition.

IV. PERFORMANCE EVALUATION USING SIMULATION

In order to verify the results of experimental setups demonstrated and discussed in [7], as well as to evaluate the performance of the DVB-RCS platform under different configurations, a simulation campaign is regarded as one of the optimum solutions [8], [9]. A simulation was developed to examine the aforementioned setup using OPNET. Some necessary simplifications were taken into account during the development of the platform. The most important among them is that the FL capacity is limited to an upper bound of 2 Mbps (instead of 45 Mbps), due to restrictions in computational power. Every set of simulation consists of one or more SITs corresponding to an equivalent number of monitored patients (source SITs), the DVB-RCS Hub, a satellite and one SIT corresponding to the CN (destination SIT). Both CRA and VBDC capacity allocations are examined, while three services have been modeled to be used by the SITs. The throughput and delay of each application under different network configurations are evaluated and depicted in the following graphs. It should be noticed that the buffers are considered to be infinite and no data discarding takes place (e.g. due to time expiration).

These applications are i) Medical data, comprising of a 20 kbps constant stream of data, ii) Voice application, encoded by G711 codec, generating a bit rate of 64 kbps and iii) Low quality video application, generating a bit rate of 120 kbps (25 frames/sec).

The simulation tests are divided into two major categories: i) Verification of the results of the experimental setup about the behavior of CRA and VBDC allocation algorithms and ii) Priority based handling of the applications data and comparison of the platform's performance.

A. *Verification of Results of Experimental Setup*

According to [7], when a specific bandwidth has been allocated to a SIT by the CRA algorithm, the application data rate of this SIT is a portion of the total allocated resources. The percentage of the useful bandwidth depends on the allocated capacity. As this increases, the percentage of useful bandwidth increases too, as headers and signaling are significant factors while allocated bit rate remains low. Experimental setup underestimates this portion, as an additional wireless link exists between the source and destination SIT. Reversely, simulation overestimates this portion because of the necessary simplifications assumed during its development. On the other hand, VBDC algorithm seems to be unsuitable for the management of the generated traffic. To examine CRA behavior a source SIT generating video traffic at a rate of 120 kbps, the DVB-RCS Hub, the satellite and one destination SIT have been implemented. Initially, exactly 120 kbps are allocated to the source SIT and for each following run this amount is increased by a step of 10 kbps. The whole amount of data reaches the destination at the third run, when the allocated bandwidth is 140 kbps. An excess allocation of 20 kbps is required (~17% of the video bit rate), in order to maintain the initial transmission rate through the network. Fig. 2 depicts the results of these runs.

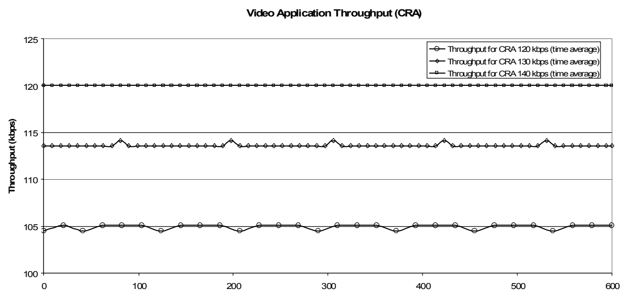

Fig. 2: Video application throughput, CRA algorithm

Furthermore, tests regarding the behavior of VBDC were conducted. The outcome was the anticipated one, since the experimental setup has explicitly indicated that VBDC could not manage the traffic. A source SIT generating video traffic at a rate of 120 kbps was inserted into a moderately loaded network and served by VBDC algorithm (120 kbps assigned). Simulation validates the experimental conclusion, showing that the allocation of resources with VBDC is unpredictable.

Considering the fact that video application is quite demanding, the conclusion that VBDC is inappropriate for handling real time data is extracted. The results are drawn in Fig. 3.

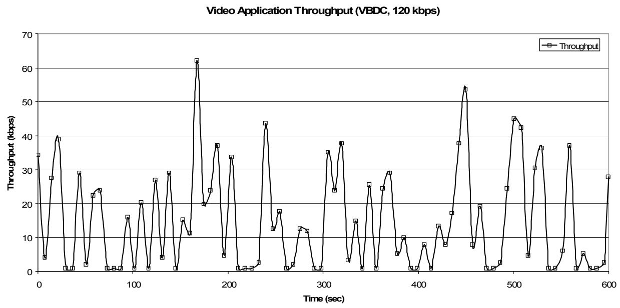

Fig. 3: Video application throughput, VBDC algorithm

B. *Performance study with Quality of Service*

The efficient utilization of the fixed and limited capacity of the DVB-RCS network is firmly associated with the concept of QoS. CRA is an algorithm that guarantees the QoS, at least to some extent. As described above, every SIT may run simultaneously up to three services (medical data, voice and video). Medical data is always of utmost importance, while voice and video may be complementary services for the monitoring of a patient. If the network is congested (or near the congestion point) medical data should be prioritized. In this phase of the simulation, several SITs are inserted into the network. There are seven SITs running all the services, two SITs dispatching medical and voice data and six SITs generating only medical data. The scenario parameters are summed at the following table. The total FL data rate is again limited to 2 Mbps and each SIT is assigned exactly the nominal transmission rate needed.

Table 2: Scenario's parameters.

SERVICE	NUMBER OF INSTANCES	TOTAL DATA RATE
Medical Data	15	300 kbps
Voice	9	576 kbps
Video	7	840 kbps

As can be derived from Table 2, the total data rate of the network is 1716 kbps, just above the congestion point (only a portion of the 2 Mbps is useful capacity). Medical data must be prioritized and this is the scope of the next two simulation runs. During the first run, no priorities exist. The second run utilizes a priority list, according to which applications are routed. Medical data are favored; voice application is in the middle, while video application is the last to be routed.

Fig. 4 to Fig. 9 compare the results from the two runs. For the first case, where no priorities exist, the graphs show that the throughput of all services is slightly below nominal (the network is just above congestion point), while the delay of each service is constantly increasing. On the other hand, for the second case, medical data and voice application reach their nominal throughput, resulting in the deterioration of video application's throughput.

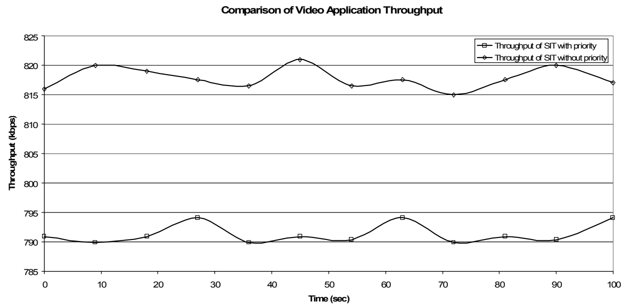

Fig. 4: Comparison of video application throughput

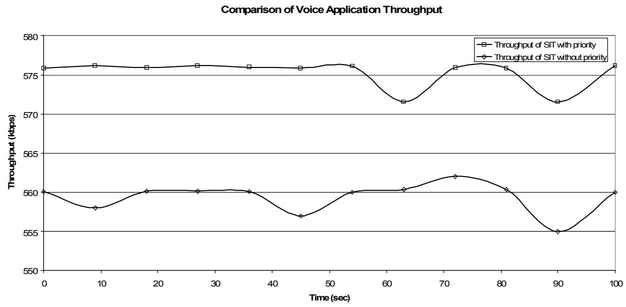

Fig. 5: Comparison of voice application throughput

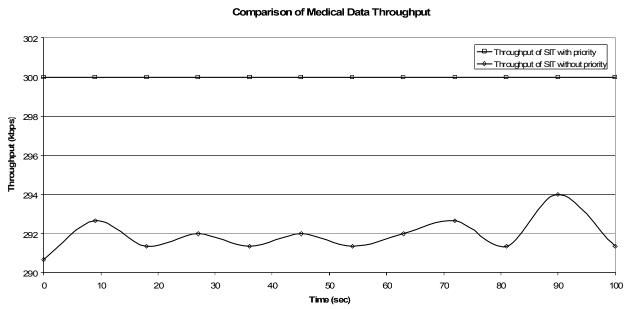

Fig. 6: Comparison of medical data throughput

Conclusively, setting medical data to a higher priority causes deterioration to the performance of video application. The extent of this effect is proportional to the congestion degree of the network under examination. Utilization of priority queues should be carefully considered before implemented, as it could seriously diminish the quality of the undermined services.

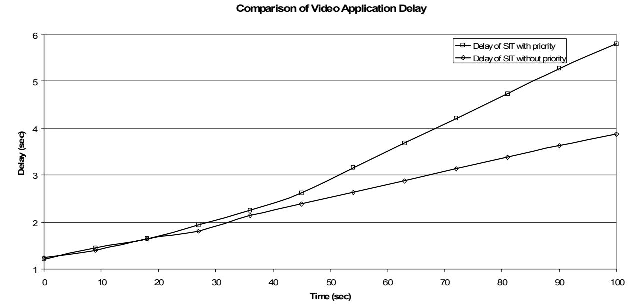

Fig. 7: Comparison of video application delay

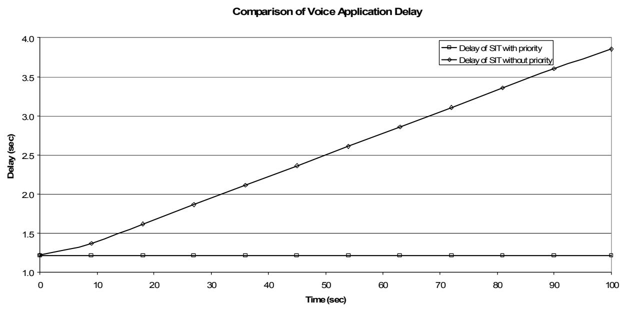

Fig. 8: Comparison of voice application delay

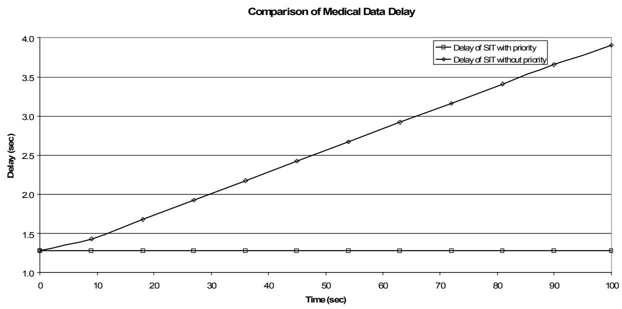

Fig. 9: Comparison of medical data delay

However, a possible scenario could be this: a patient's medical data arrive at the destination SIT (e.g. the hospital) and a health abnormality is detected. These patient's voice and video applications should automatically be prioritized, depending on the severity of the problem. Based on the previous scenario where a priority list exists according to the type of service routed, priority is added for a single SIT. Fig. 10 and Fig. 11 depict the results of this simulation.

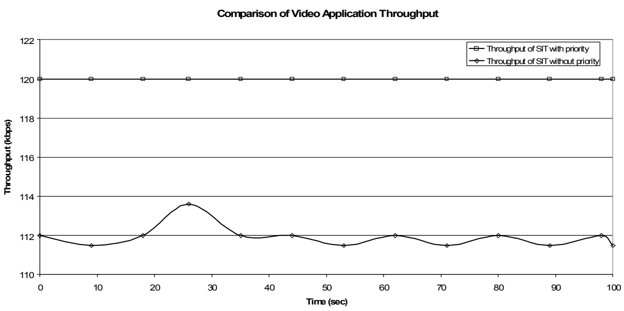

Fig. 10: Comparison of video application throughput

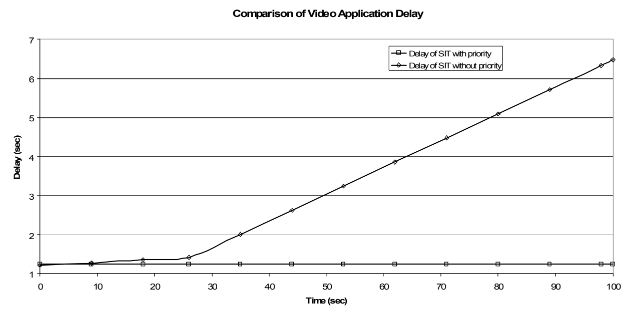

Fig. 11: Comparison of video application delay

Although the network is slightly congested, the video throughput of the prioritized SIT is equal to its nominal transmission rate, while the delay is kept low. Despite the fact that this solution is not the optimum (as it further degrades the QoS of the other SITs), it could act as a feasible way to momentarily serve more traffic than the network is able to handle in case of emergency.

V. CONCLUSIONS

This paper presents a novel, low-cost, wide-area tele-medicine platform, laying emphasis to patient monitoring and homecare services. The topology of the proposed platform is hierarchical, involving an access network based on the Wi-Fi technology and a core network based on the DVB-RCS satellite communications technology. Bearing in mind the proposed platform, simulation scenarios took place so as to evaluate the QoS parameters of the satellite system. The simulation involved medical data transfer, voice application and low quality video application. Prior to simulation results, there was a validation of the simulation platform due to experimental results and showing that the allocation of resources with VBDC is unpredictable. Prioritization for the transfer of medical data in case of a congested network, achieves excellent performance, but it should be carefully considered as it could seriously diminish the quality of the services. Automatically prioritized the applications for only one SIT (patient) in case of an emergency, the results are adequate even in a congested network.

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