Satellite and Wireless Links Issues in Healthcare Monitoring

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Abstract. Thanks to the facilities offered by telecommunications, telemedicine today allows physicians and clinicians to access, monitor and diagnose patients remotely. Telemedicine includes several applications such as remote monitoring of chronically ill patients, monitoring people in their everyday lives to provide early detection and intervention for various types of diseases, computer-assisted physical rehabilitation in ambulatory settings, and assisted living for the elderly at home. These new applications require a reliable, wireless communication link between the devices implanted in the patient's skin and a clinician. In this article, this issue is discussed and a list of performance criteria for the different communication links used is addressed, especially focusing on the satellite link.

Keywords: Vital sign monitoring, health-care monitoring, wireless sensor networks, wireless body networks, satellite, telemedicine.

1 Introduction

Nowadays, remote health-care is becoming increasingly attractive due to several advantages it brings: extending the health system coverage to rural and isolated areas, ensuring autonomy to chronic patients by letting them stay at home, allowing the clinicians to remotely diagnose and monitor their patients, ensuring real-time monitoring for critical illnesses, etc. Moreover, advances in key areas such as Wireless Sensor Networks (WSN) and Body Sensor Networks (BSN) are enabling technologies for the application domain of unobtrusive medical monitoring [1]. This field includes cable-free continuous monitoring of vital health signs in intensive care units, remote monitoring of chronically ill patients, monitoring people in their everyday lives to provide early detection and intervention for various types of diseases, computer-assisted physical rehabilitation in ambulatory settings, and assisted living for the elderly at home.

These innovative applications, where a pacemaker communicates the patient's health state and performance data to a base station, or a BSN integrating a number of devices, require a reliable wireless communication link between the sensing devices implanted in the patient's skin and a physician. Otherwise, the wireless link can be used to interrogate the implant at either irregular intervals, or on a regular basis, or to provide near permanent communication. A one-way wireless link may be used to

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obtain the patient's health information or performance data from the implanted device, while a two-way link allows external reprogramming of an implanted device [1]. Due to the critical and sensitive nature of the medical information transmitted through the wireless network, reliable data transfer for BSNs and network reliability are of paramount importance. In addition to wireless terrestrial networks, satellite link can (or have to) be used in some cases. For example, when the patient is outside of the cellular network coverage, the satellite network can be used to transmit data to the medical call center or to contact the patient for further information.

Network reliability directly affects the quality of the patient's monitoring, and in a worst-case scenario can be fateful when a life threatening event has gone undetected. However, due to the constraints on communication bandwidth and power consumption, traditional network reliability techniques such as the retransmission mechanism for TCP (Transmission Control Protocol) may not be practical for BSN applications, whereas they are used in satellite links despite their drawbacks (as in the OURSES [18] and URSAFE [17] projects that will be described later on below). With similar constraints on WSNs, researchers have proposed several methods for improving their reliability. One simple approach is to use limited retransmission where packets are retransmitted for a fixed number of times until an acknowledgment is received; however, retransmission often induces significant overhead to the network. Another approach is to form a multi-path network and exploit the multiple routes to avoid disrupted links. It is expected that this will be an area that will raise significant research interest in the coming years, particularly in exploring the autonomic sensing paradigm for developing self-protecting, self-healing, self-optimizing, and self-configuring BSNs.

Unlike typical wired or wireless network architectures in which the network configuration is mostly static and there are limited constraints on resources, the BSN architecture is highly dynamic, placing more rigorous constraints on power supply, communication bandwidth, storage and computational resources.

The remainder of this paper is organized as follows: the context of this work and its critical problems are discussed in section 2. Section 3 states the reliability problem and performance criteria for WBAN (Wireless Body Area Networks) and WSN links. Section 4 focuses on satellite link issues in telemedicine applications. In section 5, the main conclusions of our work are summarized, and a set of open issues and future directions is presented.

2 Context and Problem

TeSA laboratory conducted with its partners two projects in the context of remote health-care. These two projects are UR-Safe (Universal Remote Signal Acquisition For hEalth) and OURSES (Offer of Services using Satellite for Rural Usage).

2.1 UR-Safe Project Description

The UR-Safe project [18] aimed at creating a mobile telemedicine care environment for the elderly, thus helping mitigate the problems of health care provision observed in the Western societies caused by an aging population and the associated increasing costs. The adopted technological solution maximizes the concepts of autonomous living and quality of life for the patient, in alignment with the emerging models of health care provision, while at the same time addressing safety and alarm detection issues. The technological solution consists in placing medical sensing devices on the patient's body, all of them being connected via a short range Wireless Personal Area Network (WPAN) to a central, portable electronic unit called Personal Base Station (PBS). These wearable sensors enable to record electrocardiograms (ECG) and oxygen saturation level for instance, while a shock/fall detector sends an alarm when the patient falls or presses a button. Thanks to speech recognition algorithms, the PBS allows the exchange of simple spoken sentences with the patient in order to better analyze the patient's health condition. The pieces of information coming from the different sensors and from the shock/fall detector are gathered. Based on these data, preliminary computer-aided diagnosis is performed by the PBS. The data are then sent to a medical call center.

2.2 OURSES Project Description

The OURSES project [17] proposed three telemedicine applications related to services offered to elderly people. It focused on the use of satellites as a complement to terrestrial communication technologies to ensure the deployment of teleservices in areas where telecommunication infrastructure is lacking. These three telemedicine applications are described in the following.

A typical architecture of a remote telemedicine solution conjugates tree or four different communication technologies according to different wireless architecture links:

- The first link: the first link connects the medical nodes and the coordinator, in order to form a WBAN mainly using a star topology. The WBAN is often composed of a limited number of medical nodes (body sensors) connected to a coordinator (that may be a normal sensor node or a PDA (Personal Digital Assistant)).
- The second link: a second link exists between coordinators and a base station collector (local PC). The routing of information between the coordinators and the base station can be done in various ways and with different communications technologies: on the one hand, a WSN can be formed with all coordinators. The coordinators are also associated with environmental sensors that monitor the physical environment surrounding the patients (temperature, humidity, light,...). The information is then transmitted to the base station via a WSN mesh topology. On the other hand, centralized WiFi technology can replace the WSN by setting direct links between coordinators and access points to collect information.
- The third link: a last link is used to transmit data from the base station (local PC) to a remote physician. In the absence of wide-coverage terrestrial networks, a satellite link is used in this case.

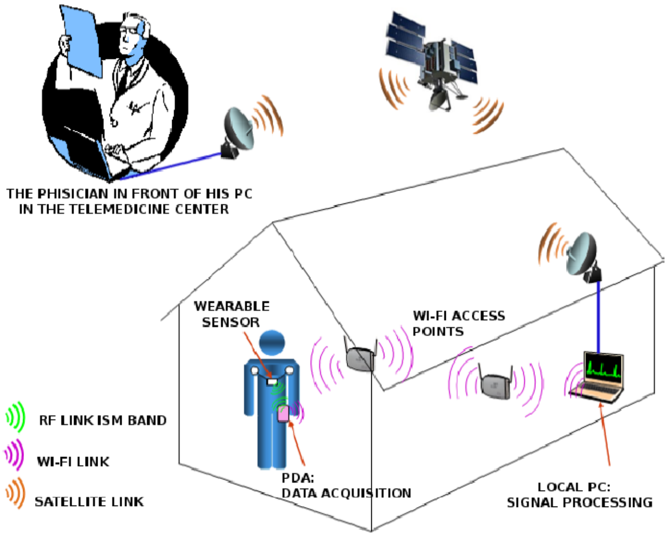

Fig. 1. Global scheme of ECG monitoring in OURSES project

Figure 1 shows a usage scenario on wireless vital sign monitoring using different technologies. This solution is based on a wireless wearable sensor which transmits ECG to a portable device in real time. The latter is then connected to a local PC which is located in the patient's house through a Wi-Fi link. ECG signals are then sent to the physician's office using a satellite link. When an abnormal event during an ECG analysis is detected by a specific automatic signal-processing-based diagnosis application running on the PC, an alarm is raised and sent to the physician's office.

2.3 Position of the Problem

The purpose of this paper is to join together different scientific communities involved in such challenging projects as telemedicine and biomedical vital signs remote monitoring, namely, the medical end-users (physicians, medical experts), the digital signal processing scientists from academia, and the telecommunication scientists and engineers from both academia and industry. Indeed, telemedicine projects include so wide and multidisciplinary technical and scientific expertise fields that a minimum of dialogue between the different disciplines should be sought for the sake of a better mutual understanding and a more unified and integrated approach.

More precisely, one peculiar problem arose in the experiments carried out in the framework of the aforementioned telemedicine projects: packet loss was observed at the physician's PC side on the satellite return channel downlink, which manifested itself in "hole" periods, that is, missing samples in the received ECG signal. In other words, a few ECG samples were missing due to undetected causes occurring somewhere in the wireless/satellite transmission chain that are attributed to the fact that the different links involved (fixed access network, mobile access network and satellite

DVB-RCS interfacing) are liable to inducing errors or loss on the transmitted data. Such data corruption/loss can occur anytime and anywhere. The timeout of several ARQ (Automatic Repeat Request) procedures was shown to induce packet loss: 1-2% for GPRS, and 8% for the satellite [24]. To cope with that problem, TeSA devised a recovering method which hybridized Papoulis-Gerchberg (PG) algorithm and an Auto-Regressive (AR)-based reconstruction algorithm.

The principle of the PG exact reconstruction algorithm lies in an interpolation of the missing samples using the band-limited property of the ECG signal, via an iterative process which allows to replace the missing part of the signal with the result of the Inverse Fast Fourier Transform (IFFT). The PG algorithm performs well with a reduced number of missing samples, but its drawback lies in the long convergence time of its iterative process. Therefore another ECG missing sample reconstruction method was proposed, namely, an audio signal reconstruction method based on AR modeling [24]. This method is used to predict forward and backward signal samples. The final step in the proposed reconstruction algorithm is to jointly use the two PG and AR methods, the AR algorithm being executed at initialization phase to be followed by the PG algorithm. The reconstruction performance was measured using the local signal to reconstruction error (noise) ratio given by:

$$SNR = 10log\left(\frac{\sigma_{xgap}^2}{\sigma_{(x-\hat{x})gap}^2}\right) \text{ in dB}$$

where σ_{xgap}^2 represents the variance of the original signal in the missing part and $\sigma_{(x-\hat{x})gap}^2$ represents the variance of the reconstruction error also restricted in the missing part. Tested on the MIT-BIH Arrhythmia Database, the combined method yielded better performance than the PG and AR algorithms for missing parts of up to 30 consecutive samples (120 ms).

The paper aims at identifying and qualitatively surveying all the different factors related to the wireless and satellite links that may be a cause of packet error or loss, and thus undermine the reconstruction performance of TeSA's algorithm, without any quantitative assessment at this stage. Packet errors and loss can be traced back to mainly three different sources: (i) general performance criteria of the transmission system; (ii) wireless issues; (iii) satellite link issues.

2.4 Performance Criteria

The performance criteria of wireless network links which have significant implications in the healthcare domain include the number of collisions, the energy consumption at the nodes, the network throughput, the number of unicast packets delivered, the number of packets delivered to each node, the signals received and forwarded to the Medium Access Control (MAC) layer, and the change in energy consumption with variation in transmission range, etc. Some of these criteria are described hereafter:

- ***The delay:*** The delay for data packets delivery is of paramount importance in health-care monitoring and its criticality depends on the way data traffic is transmitted. Indeed, the data can be transmitted on either a periodical basis or a non-periodical basis. A periodic transmission mode corresponds to the case where the traffic data packets collected by the body sensors are sent periodically, while a non-periodic transmission mode refers for instance to the case where an alarm is sent by a body sensor every time it detects an anomaly.
- ***The Packet Received Rate (PRR):*** In a health-care network solution, a high PRR is necessary so that the physician can make a good diagnostic. For instance, it may sometimes be difficult for him to interpret ECG data, which makes a diagnostic completely impossible.
- ***The Quality of Service (QoS):*** loss of data is more significant in BSNs, and may require additional measures to ensure QoS and real-time data interrogation capabilities.

3 Wireless Sensors and Body Networks in Vital Signs Monitoring

The advent of smart wireless sensors that are able to form a BSN would not be possible without the availability of appropriate and inexpensive low power short-range transceivers for low to moderate data rates. These are capable of transmitting real-time data with a latency of typically less than one second within a range of up to five meters.

Current standardization efforts affect most of the layers of a communication stack, starting from the Physical (PHY) layer, including the Medium Access Control (MAC) layer and reaching the higher layers, such as network or routing layers, and even sometimes the data representation and application layers. Different standardization bodies may work in a cooperative fashion, as is the case with ZigBee and IEEE 802.15.4.

The problems encountered in BSNs involved respectively on the first and the second links listed above are summarized as follows:

Energy Consumption: It is widely recognized that limiting energy is an inescapable issue in the design of wireless BSNs due to the strict constraints which it imposes on the network operations. In fact, the energy consumption is a crucial factor impacting the network lifetime that has become the prevailing performance criterion in this area. If the network is to operate as long as possible, these energy constraints require make a trade-off between various activities at both the node and network levels, so that the less energy consumed by the nodes, the longer the network lifetime to satisfy the running application [15].

Scalability: Scalability is an important factor in designing efficient WSN solutions. A good solution has to be scalable in the sense of being adaptable to future changes in the network topology. Thus scalable protocols should perform well as the network grows larger or as the workload increases.

Congestion: In healthcare WSN applications (particularly for medical emergencies or closely monitoring critically ailing patients), it is obviously desirable in the first place to avoid congestion, and should it occur, to reduce data loss due to congestion.

Mobility Issues: The wireless network solution must manage the mobility of equipments and mobility of persons in order to maintain a good connectivity.

3.1 IEEE 802.15.4 Solution

Although a wireless BSN is not always a lowest duty cycle application (such as continuous ECG streaming), the ZigBee/IEEE 802.15.4 framework appears to be the most intriguing and suitable protocol suite for it. The IEEE 802.15.4 MAC offers a number of valuable ingredients for BSNs: the MAC is optimized for low power and short messages and includes peer-to-peer network support, guaranteed time slots, etc. IEEE 802.15.4 is also likely to be chosen as the radio layer basis for IEEE P1451.5-based wireless sensors [27]. Highly integrated single-chip IEEE 802.15.4-compliant transceivers are already available from a number of IC manufacturers, yet they are a bit more power hungry than simple FSK (Frequency Shift Keying) transceivers because of DSSS (Direct Sequence Spread Spectrum), but they offer better robustness and better interoperability compared with FSK. Of course, the data rate is not sufficient to carry video data in ambient applications, but it could well convey pre-processed data, e.g. from a camera system that detects when a person is moving or falling. The IEEE 802.15.4a alternate PHY may add another interesting flavour to BSNs in the not-too-distant future. Worldwide interest in ZigBee-/IEEE 802.15.4-compliant products will inspire global creativity and keep costs down.

In [27], the authors present a usage scenario on wireless vital sign monitoring using IEEE802.15.4a standard. The 15.4a piconet is composed of one piconet controller (PNC) and a number of vital-sign sensors attached to the patient. The PNC, which plays the role of a data aggregator, is located at bedside; thus, the distances between the PNC and the sensors are generally shorter than 2 meters. Vital signs typically monitored in a patient's body can be categorized into two types: one type corresponds to continuous data, that is, data information (such as ECG) continuously transmitted from a sensor, and the other type corresponds to routine data, which is generated sporadically from the sensors including body temperature (BT), oxygen saturation (SpO2), and blood pressure (BP). For the continuous data type, wireless transmission which supports delay QoS maintenance is required because ECG waveform is a streamed data signal.

4 Satellite Issues in Telemedicine Applications

A satellite link raises several issues in a network deployed for telemedicine applications. Some of them may have a multifold impact on the biomedical signal in terms of: receive signal quality; signal reconstruction algorithm performance; quality of service (QoS) performance.

In the following, the focus will be placed upon, (i) the satellite channel itself in relation with propagation impairments in high frequency bands, and the nature of errors occurring in a satellite link; (ii) QoS issues with a special emphasis on performance requirements related to the transmitted IP-based traffic usable in telemedicine applications, (iii) and quite significant issues related to the TCP (Transmission Control Protocol) over the satellite link. The discussion is limited to geostationary satellites.

4.1 The Satellite Channel Issue

The satellite channel is a sensitive link in two respects:

- with regards to atmospheric impairments in high frequency bands, which can cause severe link outages;
- with regards to the error behavior, bit errors tending to cluster in bursts. An analysis and a thorough characterization of error patterns are required in order to assess the impact of bit errors on higher layers protocols.

These two aspects are detailed in the following.

Channel Impairments in High Frequency Bands: In high frequency bands above the Ka band, tropospheric effects in the satellite propagation channel may be strong, and thus detrimental to communications. Two categories will be considered [19]:

- Atmospheric attenuation due to gas, water vapor, clouds, the melting layer, and rain, the rain component being the prevailing factor for percentages of time lower than 1% (cf. figure 2). The rain attenuation component results in slow signal fading variations and can yield a magnitude of 20 dB for 0.05 % of an average year in Ka band. It represents the most serious limitation to the performance of satellite communication links in the millimeter wave domain. In addition, second order statistics of rain attenuation should also be taken into account in the design of a satellite communication system, since they directly relate to outage durations.
- Amplitude scintillation manifesting itself in the form of rapid signal fluctuations. Scintillation may impact the long term system availability (time percentages higher than 1%).

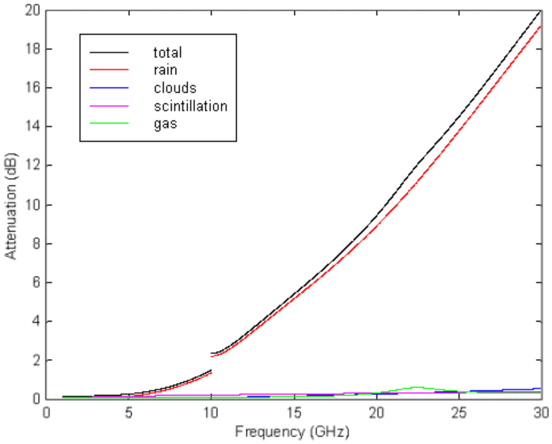

Fig. 2. Components of the atmospheric attenuation versus the frequency for 0.01% of the time

Channel Error Behavior Modeling: The numerous statistical propagation models that exist today for Ku band and above enable to estimate the degradation on a given link in terms of signal-to-noise ratio (SNR) C/N_0. Nevertheless, for new SatCom systems, C/N_0 loss does not directly relate to the degradation of the QoS offered to the end user. Thus, in order to be able to obtain a sound estimation of the QoS information, it becomes necessary to resort to methods that link the channel with higher layers mechanisms or more QoS-oriented parameters. In this perspective, an analysis and a modeling of the satellite channel error behaviour are also required.

a) Parametric analytical models: A first approach in that direction lies upon parametric analytical models. Most of the models built for the wireless fading channel use discrete-amplitude and discrete-time Markov chains, among which the two-state Gilbert model is a well-known one [33]. It was demonstrated that the error pattern can have a considerable impact on the performance of protocols at higher layers such as TCP or any ARQ-typed retransmission protocols [29], especially when errors occur in bursts. Combined with a broadened definition of outage events, different from the conventional definition as the exceeding of a threshold by a first order statistical parameter (such as the BER [Bit Error Rate] or the PER [Packet Error Rate] [35]), or with a peculiar framing strategy (for instance interleaving) [33], N-state Markov models enable to capture the intrinsic bit errors correlation and derive accurate predictions of the system performance when N increases.

b) Error performance methodology for ATM (Asynchronous Transfer Mode) by satellite after the ITU-R Rec. S.1062-1 WP-4B: The ITU-R Rec. S.1062-1 WP-4B constitutes a second approach towards the goal expounded above, that is, linking higher layers performance parameters to the physical layer parameters [3]. The recommendation defines a specific methodology to be applied when designing a satellite system using ATM with the purpose of satisfying the G.826 recommendation which addresses physical layer performance. The S.1062-1 WP-4B recommendation also links ITU I.356 QoS parameters at ATM layer with higher layers QoS parameters. It can be considered that the ITU-R S.1062-1 WP-4B recommendation provides a fruitful methodological framework for linking performance parameters located at different levels. These relations have been exploited in other contexts and studies [7, 8]. A same type of methodology should also be applied to assess the error performance of satellite links, and their deep and maybe subtle impacts on higher layers protocols such as TCP, which will directly translates into a level of biomedical signal restitution quality in our case of interest.

- *Errors model:* In order to properly study error performance in a satellite link, a valid model of error statistics is required. The most common model is that of random errors in which a sequence of statistically independent bits is observed from two possible Bernoulli outcomes: “errored” or “non-errored”. The number of errors during the observation period then follows a binomial distribution, but if the observation period is quite long and the bit error probability is very low, it can also be characterized by a Poisson distribution.
- *Statistical characterization of error bursts using lattice diagrams:* The random errors model is inappropriate when errors occur in bursts mainly because of the memory introduced by signal processing techniques in communication systems. It is possible to statistically characterize the patterns of the errors bursts (times and inter-arrival times of the bursts) at the output of the decoder by means of the lattice diagram of the coder, by invoking the concept of transfer function (Viterbi) of the convolutional code, and using an algorithm

that systematically and exhaustively collects all patterns of burst errors. The approach can be extended so as to characterize the effects of the scrambler, the descrambler, the interleaver and the concatenated coding, which are processes that are commonly used in DVB-RCS satellite communications.

- *Generic models of burst errors:* The characterization methods presented previously are specific to a particular coding scheme. Consequently their interest is limited for globally evaluating the performance parameters of digital satellite links. Therefore more generic models are based on a small number of statistical quantities such as typically the average length L of the bursts and the average number of errors per burst. Burst errors are generally assumed to follow a Neyman-A contagion distribution.

4.2 QoS Issues

For satellite communications, one of the most critical requirements is to provide the desired QoS level to the different services. The discussion will focus on IP applications. The QoS issue should be dealt with addressing the diverse network layers and the QoS architecture, and assessing the application and network behaviour. In addition to classic QoS metrics [16], subjective metrics should also be introduced in order to evaluate the IP applications from a user point of view, such as PSNR (Peak Signal to Noise Ratio) and MOS (Mean Opinion Score) [28]. The data to be transmitted is characterized mainly in terms of bit rate, overhead, error rates (BER [Bit Error Rate], or PER [Packet Error Rate]), delay, jitter, average and maximum packet sizes. In the following, two types of services are considered and their salient QoS features will be presented along with a number of constraints from higher layer protocols [20, 21, 22]: real-time applications; data-like loss-sensitive, but not or very little delay-sensitive applications.

QoS Requirements for Basic Applications

a) Real-time applications: A first typical real-time commonly required service is VoIP, which is a delay-sensitive but very little loss-sensitive application. A VoIP call is expected to be intelligible. A strictly minimum bit rate of 5.3 kbps (assuming ITU H.323 G.723.1 ACELP [Algebraic Code Excited Linear Prediction] codec) is required. It has been shown however that optimal bandwidth occupation for VoIP over satellite is around 12 kbps. VoIP bit rate also varies depending on the codec, on whether RTP (Real-Time Protocol) is compressed, and on the redundancy introduced by the headers of the protocol suite (Ethernet, IP, UDP [User Datagram Protocol], RTP). The bit rate can thus be considered to range between 5.3 and 13 kbps. A minimum MOS requirement of 3.5 ensures a good voice quality. Moreover, ITU-T G.114 Recommendation [12] specifies a maximum latency value of 150 ms for one-way VoIP communications. Lastly, in terms of packet corruption and loss, some experiments have shown that the satellite link is quite robust to packet corruption in clear sky or moderately degraded channel environment up to a BER of 10^{-5} (that is, Frame Erasure Rate or FER of 2%) [25].

A second type of real-time services concern video applications. These applications range from real time communications to surveillance, Internet video streaming, as well as collaborative scene visualization, broadcasting and virtual meetings. Although QoS constraints are strongly dependent on the application considered, the following QoS specifications can be used as a baseline for video services [23]: the variable average bit rate allocated to a video application shall not be lower than 256 kbps in the two ways. Critical applications such as telemedicine require a fairly good video quality. The maximum transmission delay should be lower than 400 ms. The video codec which is used (for instance H.323) should be able to provide a good picture quality for telemedicine applications. A video connection should be established in less than 30 s for high priority applications.

c) Data-like loss-sensitive, but not or very little delay-sensitive applications: In this category are for instance SMS (Short Message Service) / MMS (Multimedia Messaging System), email applications, file exchange and Internet browsing. The transmitted mean bit rate must be at least 32 kbps for Web browsing and file exchange, and 200 kbps for email applications [31]. BER values of up to 10^{-6} can be supported [31]. Moreover, the time interval between the sending of an SMS and its reception by the receiver must be between 6 and 8 s in average, given that actually 98% of sent SMSs are successfully delivered by a mobile user to a fixed network within a 5-s time period, according to some telecom operators [4, 5]. Since the integrity of SMS messages is 100%, it is obvious that SMSs are well fitted to telemedicine communications, especially in emergency situations [20, 21, 22], where there is a need to transmit an alarm.

c) Other QoS issues: Another crucial QoS optimization method consists in properly handling and managing data traffic, especially when different services are aggregated. Differentiated services QoS architecture has received much attention these last years as traffic flows are of mixed categories (TCP flows and UDP flows for instance). By assigning each IP packet a specific traffic class, a more optimized management buffer is made possible resulting in improved bandwidth resource utilization. In particular, if excess TCP and excess UDP were both treated equally, TCP flows would reduce their rates on packet drops while UDP flows would not change, and instead monopolize the entire excess bandwidth [2]. All this leads to proper buffer management associated with efficient dropping strategies.

4.3 Issues Related to TCP over the Satellite

TCP is the most widely used Internet transmission protocol located at the OSI transport layer. TCP allows an end-to-end flow control mechanism between a sender and a receiver on the Internet with acknowledgments (ACKs) being sent back by the receiver to the sender, and to vary the transmission packet rate based on the rate at which acknowledgements are received back from the receiver. This mechanism enables to verify the correct delivery of data between a client and a server. TCP supports error or data loss detection, and implements a retransmission technique until the packets sent are correctly and completely received [26]. It also implements a network congestion control. All these TCP features make it a reliable and efficient transport protocol over the Internet stack, independently from the applications above it and the Internet below it. Moreover, the Internet is quite a particular network because it consists of different network topologies, bandwidth, delays and packet sizes. The satellite link possesses inherent characteristics that may have negative impacts on the TCP. Two of them are mentioned here:

- Transmission errors: satellite channels are much more prone to bit errors than typical terrestrial networks. A characterization of the burst errors in satellite links has been given in section §IV.A.2. TCP assumes that all packet drops are caused by network congestion to avoid congestion collapse [27].
- Latency: latency is due to propagation delay, transmission delay, and queuing delay [9]. Of course, the round trip time (RTT) propagation delay of about 275 ms in geostationary links is the prevailing term. The dominant addition to the end-to-end one way latency will be roughly 300 ms of fixed propagation delay [9]. This delay mainly impacts some of the TCP congestion control algorithms. Originally, the TCP protocol suite was designed for a terrestrial environment with short transmission delays that seldom exceed 250 ms [1]. When applied to a geostationary satellite link, TCP performs poorly due to the long latency introduced between a ground Earth station and the satellite. Latency calls for protocol-specific acceleration.

Hence, the use of TCP over the satellite raises important issues to be pondered. Two of them deserve special attention and are tackled in the following [6, 9].

Capacity, Latency and Congestion: TCP is responsible for flow and congestion control, ensuring that data is transmitted at a rate consistent with the capacities of both the receiver and the intermediate links in the network path. Since there may be multiple TCP connections active in a link, TCP is also responsible for ensuring that a link capacity is responsibly shared among the connections using it. As a result, most throughput issues are associated to TCP. Four congestion control mechanisms exist in TCP: slow start, congestion avoidance, fast retransmit before the RTO (Retransmission Time-Out) expires, fast recovery to avoid slow start [26].

The basic principle of the TCP protocol congestion mechanism can be summarized as follows [9]: a congestion window is initialized to a value of one segment upon connection startup. It determines the TCP sending rate. During the slow start phase, the congestion window doubles every round trip time (RTT), until congestion is experienced due to a data packet loss. The congestion avoidance phase is entered upon detection of congestion. Then TCP retransmits the missing segment, and the window is emptied down to its half content. If retransmitted packets happen to be lost again, the TCP sender is forced to retransmit the missing packets, but this is done with an imposed timeout where slow start is resumed and the window is reduced to one segment [26]. Consequently, the throughput becomes very low. Congestion control mechanisms in TCP thus degrade the performance of individual TCP connections over satellite links because the algorithms slowly probe the network for additional capacity, which in turn wastes bandwidth. Indeed, the satellite latency which can easily exceed 2000 ms is seen as evidence of a congested network or packet loss and thus TCP will not increase the rate at which it sends packets, even though there is no actual congestion or packet loss across the satellite link [1].

TCP Acceleration and the Security Issue: Several techniques to accelerate TCP exist. Performance Enhancing Proxies (PEPs) are one of them and basically involve an alteration of the TCP header data before and after the satellite link in order to hide the high latency of the satellite link from the TCP session [1]. Examples of PEP techniques are TCP spoofing and TCP multiplexing (also known as cascading TCP or split TCP). TCP spoofing consists in shortening the delay path and thus bypassing slow start, by adding a spoofing device/software (e.g. a rooter near the satellite link) which is in charge of returning ACKs to the sender, and in the meantime suppressing the ACKs from the receiver [1, 26]. The spoofing device also retransmits any segments lost and contains storage buffers. The TCP multiplexing technique accelerates data transfer rates across the satellite link by converting a single TCP sessions into several parallel TCP sessions. At the receive side, all TCP sessions are recombined into a single session [1].

Problems arise when TCP acceleration is achieved simultaneously with security by means of a VPN (Virtual Private Network) in the tunnel mode. Assuming that the data packets enter the VPN tunnel before TCP is accelerated, one is left with TCP packets entirely encrypted and the header of which cannot be altered anymore, or otherwise the authentication safeguards would be violated [1]. TCP multiplexing technique alone is compatible with VPN, but the processing must not take place inside the satellite modem. In addition, a number of performance degradation factors appear with the technique.

All these performance and security issues associated with TCP acceleration have led to the development of a number of proprietary solutions to optimize the bandwidth resource and utilization for TCP over satellite. Among these, the End II End's patent-pending Broadband Network Optimization (BNO) [1] and UDcast solutions are worth to be mentioned [3].

With the revised, mobile version of the DVB-RCS standard, called DVB-RCS+M [6] as well as with the recent DVB-RCS2 standard, which both use the DVB-S2 waveform and ACM feature for the return channel, other optimization issues over a satellite link would also need to be discussed. In particular, IP encapsulation efficiency depending on the encapsulation technique employed, whether it be MPE, GSE or ULE, should be investigated for the return link as for the forward link [11].

5 Conclusion

In this paper a reflection on some issues related to the use of hybrid wireless / satellite links in the field of telemedicine was conducted. At the starting point of our reflection, was our interest in the analysis of the performance of a combined PG-AR signal reconstruction algorithm we proposed to apply in order to remedy the problem of missing ECG samples at the user-end side. We started from the crude observation that along the transmission chain there were data errors and/or loss that could occur anywhere and anytime, and that was our motivation to investigate more thoroughly the multiple causes of such errors and loss from a pure network and telecommunication point of view.

First, the context was presented with telemedicine projects (U-R-SAFE and OURSES) which enabled us to highlight some issues still open with respect to performance criteria having significant implications in health-care applications, in terms of, for example, packet error rate, energy consumption at the nodes, bandwidth occupation, etc.

Furthermore, due to the multifold impact of the telecommunications and networking issues on biomedical signals, a special emphasis was laid on design constraints in a wireless network architecture, then on the satellite channel itself which can be strongly impaired in high frequency bands, and causes errors of a particular kind. QoS issues such as that of performance requirements as to the transmitted IP-based traffic usable in telemedicine applications, and quite significant issues related to the TCP (Transmission Control Protocol) protocol over the satellite link were also surveyed. Indeed, strong propagation channel impairments requiring efficient adaptive strategies, transmission errors occurring in bursts, and high latency due to the geostationary Round Time Trip (RTT) are the three main drawbacks of the satellite path in high frequency bands. These factors combine together making data errors or packet loss very likely, which we know to be quite critical in telemedicine applications, in that human lives closely depend on high quality biomedical signal reception, and correct diagnoses.

This paper only explored a few well known networking and telecommunication issues from a qualitative point of view for telemedicine applications. The complex connections between the two worlds of telemedicine on one side, and networking and telecommunications on the other side still remain to be investigated in more details from a quantitative perspective. This will be carried out in a forthcoming paper.

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