Cooperative Mobile High-Speed and Personal Area Networks for the Provision of Pervasive E-Health Services

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Abstract— **The present paper studies the performance of a joint network comprised of a high-speed third-generation (3.5G) networking technology, HSPA (High Speed Packet Access), wireless sensors, and satellite network for delivering crisis management and emergency e-health applications under urgent situations via satellite backhauling. We propose an emergency system architecture for performance assessment based on the joint transmission of voice, real-time video, vital data (such us electrocardiogram, vital signals and heart sounds) and healthcare records file transfer between the disaster-site and the safe-site. Three scenarios were concerned in terms of real-time, non-real-time and emergency applications in random locations, where no other system but 3.5G is available in case of crisis or disaster. The accomplishment of quality of service (QoS) was explored through a step-by-step improvement of the HSPA and satellite system's parameters, attributing the network system for best performance in the context of the desired emergency services.**

Keywords- Satellite, HSPA, backhaul, CF/DAMA, S-ALOHA, ZigBee, e-health

I. INTRODUCTION

Crisis and disaster management issues have lately become of paramount importance [1],[2]. Civilians are especially sensitive and demanding about security and safety. This is evidenced by the fact that their presence in crowded places and/or concentrating events depends on the security level provided and the ability of the organizers to effectively handle crisis situations. Local and national authorities are obliged to adopt all necessary measures in order to provide a safe and secure hosting for people and workers within such premises, including their capability to prevent and effectively manage crisis situations. High technology solutions including state of the art communication systems are essential for such purposes.

In this context, the present paper attempts to evaluate the ability of communication infrastructure, based on satellite and wireless heterogeneous networks, for managing emergency services (like accidents) or crisis situations (major accidents, terror attacks, war etc) by providing a realistic scenario during a mass emergency/crisis event. HSPA [3] for uplink (a.k.a. Enhanced Uplink) and downlink (a.k.a. HSDPA), together with 3G, 4G and wireless sensor networks and the satellite systems are expected to enforce the emergency and crisis applications and overcome the communication boundaries between time and space. High usability, support for multimedia services with good reliability and low transmission cost, personalization of the services, more capacity and spectrum efficiency are some of the key features of the evolving mobile technologies. Guaranteed availability of "on-demand short term" service for Emergency Management purposes remains a problem, but at medium bandwidths, with rapidly expanding capacity, this is not currently a critical issue.

The scope of this study is to design and evaluate via simulation an integrated high-speed uplink and downlink mobile applications system along with the use of wireless sensor and satellite networks for crisis management and emergency conditions. The simulation trials were selected to represent a range of services and to include both near-real-time and real-time requirements in data transmission, in conjunction with asynchronous data transfers. The overall goal was to test the ability of 3G infrastructures to support value-added crisis management services via satellite. The trials are evaluated in terms of admission control and Quality of Service (QoS) provisioning, the number of the system's users, the data rate, the congestion of the 3G network, and the available satellite bandwidth planned for both uplink and downlink circumstances. Additionally, various simulation scenarios were implemented in order to incorporate the typical types of communication for high-speed data transfer.

The remainder of the paper is organized as follows; In Section 2, the evolving technology of satellite backhauling is described in relation to the general overview of the architecture and requirements of the proposed system, while in Section 3 the specific operational crisis management and e-health scenarios under study are presented. Section 4 includes the description of the developed simulation model along with the parameters of the involved technologies, whereas in Section 5, simulation results regarding emergency conditions, making use of crisis management and e-health services sessions dedicated to video application, VoIP, medical and file data transfer are presented. The main objective of these simulations is the validation of the system throughput for the aforementioned scenarios, in terms of end-to-end delay per number of users (congestion of the cells), as this metric is widely considered to be amongst the optimum indicators in order to evaluate a network's performance, influencing directly or indirectly most of the other performance metrics. Finally, Section 6 discusses the findings and concludes the paper.

II. Satellite Backhauling and the Proposed System Overview

A. WPAN's

With many small devices such as simple sensors and actuators, continuous communication with high data rate is not usually necessary. Occasional wireless communication through interconnections with the maximum data rate of a few tens or a few hundreds of kilobits per second, and the maximum communication range of a few tens of meters, can facilitate the portability or installation of this kind of devices. Power management, security, coexistence with Bluetooth and WLAN, and Quality of Service (QoS) capabilities have been incorporated to support high-quality multimedia transport, portable devices and ad hoc networking. Since 2000, IEEE 802.15 task group 4 (TG4) [4] has worked to standardize a physical and a MAC-layer applicable in very low-power wireless application systems, which should be able to operate at least several months on a battery without replacement. In parallel with IEEE 802.15 TG4, the ZigBee alliance has been founded, aimed at establishing open industry specifications for unlicensed, untethered peripheral, control and entertainment devices requiring the lowest cost and lowest power consumption communications between compliant devices anywhere in and around the home.

B. Enhanced Uplink Technology

HSPA is a packet based cellular system deployed on top of the current WCDMA networks and is an evolution of WCDMA-UMTS technology, achieving greater bit rates and reduced delays. Responsible for the standardization of HSPA is the 3GPP organization [5],[6]. HSPA incorporates a significant number of innovative features, such as Adaptive Modulation and Coding, short Transmission Time Interval (2 msec), fast Hybrid Automatic Repeat Request (HARQ), customized schedulers for the proper manipulation and routing of the data, as well as the possibility for a Multiple Input Multiple Output (MIMO) add-on. Evolved High-Speed Packet Access (HSPA+) can offer multiple data rates, achieving great performance theoretically up to 56 Mbps for the downlink and 22 Mbps for the uplink per base station (Node-B), utilizing single carrier operation, 64-QAM and MIMO techniques and having ideal signal conditions.

III. Pervasive Healthcare Applications and E-health Scenarios

Wireless sensors are being used to monitor vital signs of patients in home and hospital environment [7]. Compared to conventional approaches, solutions based on wireless sensors are intended to improve monitoring accuracy while also being more convenient for patients. Seven types of vital signals are presented henceforward. Each provides different and complementary information on the well being of the subject and for each specific examinee the anticipated range of signal parameters is different. For example, heart rate may vary between 25 and 300 beats/min for normal people in different circumstances; likewise, breathing rate could be between 5 and 50 breaths/min. EEG, ECG, and EMG are considerably more complex signals with spectra spanning up to 10 kHz. Voltage levels of the recorded signals vary from less than 1 μV to tens of millivolts. Not all the signals are required for each examinee.

The presented pervasive e-health scenarios deal with follow-up services, patient telemonitoring and homecare services. Follow-up service is provided to high risk or post surgical patients for monitoring their biosignal data periodically so that if any unusual condition is detected a corresponding alarm rises. Patients recently discharged from hospital after some form of intervention, for instance, after a cardiac incident, cardiac surgery or a diabetic comma are less secure and require enhanced care. The most common forms of patient monitoring are ECG arrhythmia monitoring, post surgical monitoring, respiratory and blood oxygen levels monitoring and sleep apnea monitoring. In addition, homecare is generally used for rehabilitation of the elder patients to minimize the number of visits for therapists, and thereby, the risk involved in moving the patients. The elder mainly requires monitoring of his vital signals (i.e., ECG, blood pressure, heart rate, breath rate, oxygen saturation and perspiration). Facilities for medical practice at home are limited by the availability of medical devices suitable for producing biosignals and other medical data. These new systems provide automated connection with remote access and seamless transmission of biological and other data upon request.

In this research, we will examine 3 scenarios with scalable increasing requirements in terms of patient monitoring capabilities and bandwidth resources. The data exchanged in the examined scenarios are specified in Table I.

TABLE I. Examined Scenarios and their Attributes

Scenario	Biomedical Data	Environmental Data
Simple Patient Monitoring	ECG, Heart Rate, Respiratory rate, Pulse Oxymetry, Temperature of body, Patient movement (with 3 sensors), On –body sound (On body Zigbee, Bluetooth)	Environmental sound (1 channel compressed), Compressed and full motion video (WLAN)
Moderate Patient Monitoring	ECG, Heart sound, Heart Rate, EEG, Respiratory rate, Pulse Oxymetry, Temperature of body, Patient movement (with 6 sensors), On –body sound (On body Zigbee, Bluetooth)	Environmental sound (2 channels compressed), Compressed and full motion video (WLAN)
Advanced High Capabilities Patient Monitoring	ECG, Heart sound, Heart Rate, EEG, Respiratory rate, Pulse Oxymetry, Temperature of body, Patient movement (with 10 sensors), On –body sound with 2 sensors (On body Zigbee, Bluetooth)	Environmental sound (2 channels compressed), 2 channels of compressed and full motion high quality video (WLAN)

Information regarding the patient movement and status is frequently acquired through visual tracking of the patient's position and processing of environmental sound. A different approach for collecting patient activity information is the use of sensors that integrate devices like accelerometers, gyroscopes, contact sensors and microphones attached on the patient body. The decrease of sensors size and weight, in conjunction with the introduction of embedded wireless transceivers allows their pervasive placement on patients and the transmission of the collected movement and audio information to monitoring units wirelessly. Collected data from the accelerometers (i.e., usually rotation angle or acceleration in the X, Y and Z axis) is used in order to verify the placement of the patient and time occupation in rooms and detect abrupt movement that could be associated with an urgent situation i.e. a patient fall [8].

IV. Description of the Simulation Model

In order to evaluate the performance of telemonitoring services over a Personal Area Network (PAN) in conjunction with a 802.11 and a 3.5G system (specifically High Speed Enhanced Uplink) a simulation campaign is among the optimum solutions [9]. In this case, a simulation was developed using OPNET. The Zigbee and 802.11b models that OPNET incorporates were used as platforms for respective systems under examination and the interested reader may refer to the equivalent specifications for these models. A contributed model, which is accessible via OPNET's official site accounted for Bluetooth PAN, while a detailed description of the Bluetooth simulator's functionality is available in [10]. As far as HSPA is concerned, functional versions of both forward and reverse link have been implemented from the very beginning in the simulator, though our attention will be focused on the reverse link hereafter. The main parameters of the reverse link of the 3.5G system are summarized in Table II. For reasonable conditions and for simulation purposes, the common peak bit rates provided by mobile providers for uplink are around 1.5 Mbps using 16-QAM modulation (Category 6).

TABLE II. PARAMETERS OF ENHANCED UPLINK

Parameter	Value
Carrier frequency	2.1 GHz
Channel bandwidth	5 MHz
TTI duration	2 msec
Cell radius	1000 m
Path loss model	$L = 128.1 + 37.6 * \log_{10}R$
Slow fading model	Log-normal distribution
Deviation of slow fading	8.0 dB
Thermal noise density	-174 dBm/Hz
Other-to-own-cell interference	0.2
Rise over Thermal (RoT)	6 dB
Scheduler UL	M-LWDF [11]

All the attributes of the separate cooperating networks were adjustable; from this point of view, a rather large set of aspects was available for investigation. In order to fulfill the objectives of our simulation campaign, the sessions were statically created at the beginning of each simulation run. We considered nearly fixed Zigbee and Bluetooth users and fixed terminals equipped with suitable interfaces to collect the biosignals, so as simulating exactly the conditions of telemonitoring service provision. All the typical characteristics of a Zigbee network (ACKs, retransmissions after failed packet deliveries etc.) were enabled, while this statement holds also for the Bluetooth and 802.11b networks. All the fundamental entities of Enhanced Uplink (RNC, Node B, air interface, UE etc.) were implemented to such an extent, that an insight to the system's performance would be feasible and precise. The propagation model of the 3.5G network calculates path loss and shadowing, adapted to a dense urban environment. Shadowing is both spatially and angularly correlated. Finally, the power allocation for the cellular network is calculated per Transmission Time Interval (TTI).

Zigbee, Bluetooth and 802.11b models allow the generation of packets according to a variety of possible distributions for the interarrival time between the packets, as well as for the packet's length. This feature of the models enabled the generation of biosignals in a plausible manner. Complementary, a traffic generator process, which accounted for the environmental signals (sound and video), was implemented, for real-time approach using constant bit rate (CBR) for biosignals and adaptive multi-rate (AMR) for audio signals. Especially for the compressed video, trace files from real networks were used (compressed video based on H.264/AVC standard). The proposed traffic generator is carefully designed and customized to receive as input raw data files containing information about the time that a packet has been generated in another network, the length of the packet, the already sustained delay etc. Afterwards the packet is treated like any other packet, but the derivation of statistics takes into account the information contained in the initial raw data file.

Miscellaneous inevitable simplifications have to be taken into account, usually leading to a slight overestimation of the overall system's performance. A single cell Enhanced Uplink network was used throughout the paper (it should be noted that the first layer of six identical adjacent cells has been virtually deployed around the cell of interest, in order to accurately incorporate interference effects, which play important role in Enhanced Uplink). Moreover, no erroneous packet reception was considered in the cellular network and no packet discard was allowed. Finally, we assumed that a sufficient number of Zigbee or Bluetooth sensors might co-exist in a small area without significant QoS deterioration due to interference issues. All results were averaged over five simulation runs per scenario, in order to exclude any random effect.

V. Simulation Results and Evaluation

As discussed in Section IV, three primary scenarios were taken into consideration and a step-by-step performance evaluation was accomplished. We kicked off by examining the threshold of a fixed point-to-point Zigbee link in terms of throughput. Afterwards we tackle with the performance of a joint network when Zigbee serves as the PAN for the simple patient monitoring case, followed by studying the moderate patient monitoring case keeping the same network technologies. Finally, patient monitoring with advanced capabilities is examined, for both Zigbee and Bluetooth technologies. Results are mainly presented in terms of end-to-end delay, as this metric is widely considered to be amongst the optimum indicators in order to evaluate a network's performance, influencing directly or indirectly most of the other performance metrics.

Before moving on to the results of the scenarios, it would be useful to reach to a rough estimation of the Zigbee capacity capabilities. At each simulation run the offered load is incremented by 10 kbps and the results are depicted in [8]. At the time that offered load exceeds 200 kbps, Zigbee seems to be incapable of serving the traffic adequately. At 210 kbps the gap between offered load and achieved throughput is yet nearly negligible, but beyond this point the degradation of link's performance is abrupt. This is a finding of crucial importance, as all point-to-point links (for transmission of biosignals in our case) consisted of Zigbee sensors, are hereafter constrained to a maximum bit rate of 200 kbps.

A. Simple patient monitoring

Each of the patient's sessions comprise of sensors for ECG, heart rate, respiratory rate, pulse oxymetry, temperature of body [8], 3 sensors for patient's movement and on-body sound. The biosignals are generated within the PAN and routed via the 802.11b and the Enhanced Uplink towards the final destination. A 32 kbps compressed sound channel and a compressed full motion video (high quality, H.264/AVC encoded, 152 kbps bit rate with Peak Signal to Noise Ratio of 41.3 dB) are also captured and transmitted by the WLAN towards the 3.5G system, as environmental signals. Starting from inserting a single session into the network and incrementing by one for each subsequent simulation run until the number of five, the results for average delay and jitter are given in Fig.1.

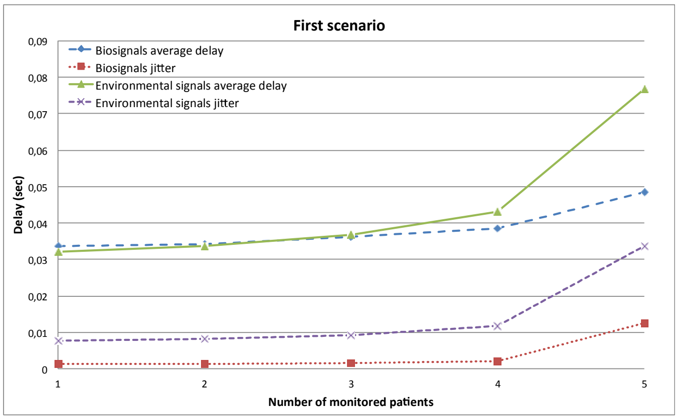

Figure 1. Signals delay and jitter vs. number of monitored patients for simple patient monitoring case.

Under these circumstances, the joint network manages to serve up to 5 users, while achieving to preserve the desired QoS. Observing Fig.1, it is noticeable that the delay curves of biosignals and environmental signals cross at the point where a third session is admitted into the system. The factor that accounts for this mischievous behavior is that biosignals experience an added delay, as they originate from the PAN. Within the cellular system, they are prioritized and eventually at high load conditions biosignals delay is considerably lower than their environmental signals counterpart. According to Fig.1, it may be concluded that the overall system is operating smoothly under this load, as the delay's jitter is kept within acceptable levels. The trend of the curves shows nevertheless that the admission of an extra user could lead to a serious degradation of the provided QoS, especially for the non-prioritized environmental signals.

B. Moderate patient monitoring

Moving forward, the performance of moderate patient monitoring is evaluated. Heart sound, EEG, 6 sensors for patient's movement are inserted into the bio-measurements, while a second environmental sound channel is also added. This way, a more precise tracking of the patient's condition may be attained, when the circumstances require more drastic actions to be undertaken. The results of these simulation runs are depicted in Fig.2.

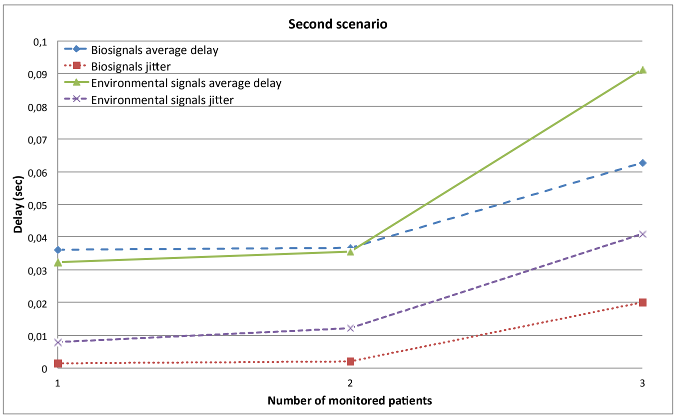

Figure 2. Signals delay and jitter vs. number of monitored patients for moderate patient monitoring case.

According to Fig.2, the combined network is able to handle the offered load and sufficiently serves this scenario. The delay for each separate application running within the primary sessions is surely acceptable, within the thresholds for each Class of Service (CoS). Moreover, served throughput equals the nominal bit rate of each application and is quite steady. It is evident though that the insertion of a fourth session within the network would cause a serious QoS degradation. Actually, each monitored patient generates an approximate load of 500 kbps. Keeping in mind that the bottleneck for the considered topology is the 3.5G system, an admission of an extra session into the system would lead to a total offered load of 2 Mbps, which clearly surpasses Enhanced Uplink's capacity capabilities.

C. Advanced high capabilities patient monitoring

In this scenario, the performance of advanced patient monitoring is evaluated. EMG and 10 sensors for patient's movement are inserted into the bio-measurements, while on-body sound is collected through 2 sensors. In this subsection, discrimination has been made between two system setups. In the first one, Zigbee technology serves as the PAN, while at the second one Bluetooth plays this role. Due to the fact that EMG is a resource demanding application and surpasses Zigbee's capabilities, only the latter setup includes it. A second compressed video stream for the enhancement of patient's visual monitoring is also added in the environmental signals. This scenario is in fact the ultimate resort when an extremely thorough monitoring of a patient is regarded absolutely necessary. Fig.3 and Fig.4 depict the results of the two different setups.

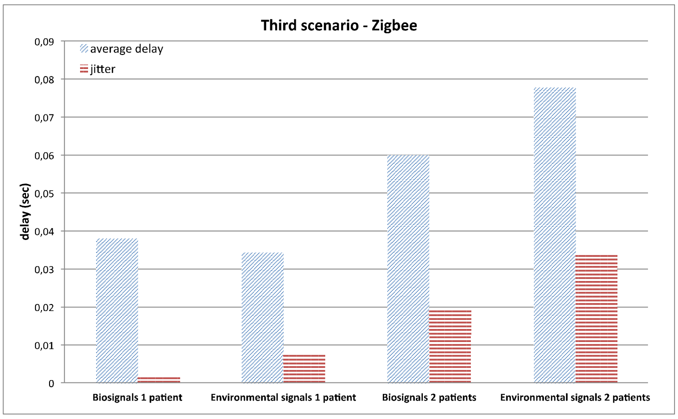

Figure 3. Signals delay and jitter vs. number of monitored patients for advanced high capabilities patient monitoring case – Zigbee serving as PAN.

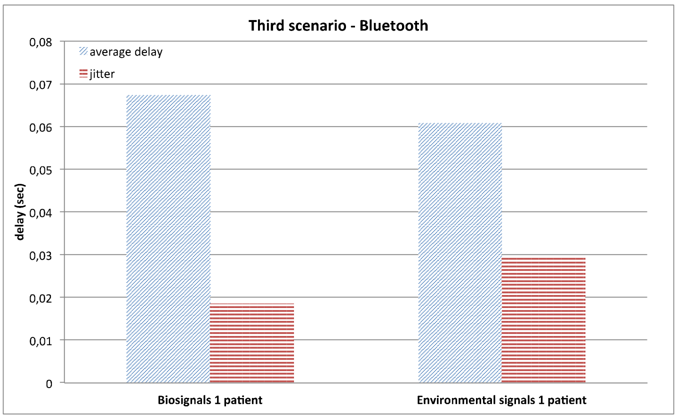

Figure 4. Signals delay and jitter vs. number of monitored patients for advanced high capabilities patient monitoring case – Bluetooth serving as PAN.

In Fig. 3, where Zigbee acts as PAN, each monitored patient requires a net bit rate of 750 kbps. According to this calculation, the Enhanced Uplink cell may serve up to two patients, while managing to preserve the desired QoS. On the other hand, when Bluetooth acts as PAN (Fig.4), the offered load deriving from both biosignals and environmental signals comes up to approximately 1.35 Mbps (due to the fact that EMG is also measured), while the amount of patients that the joint network is able to handle is restricted to one. Though these numbers seem to be rather prohibitive considering that a network should be able to serve an adequate number of users, it should be noted at this point that this is an extreme case where a patient must be fully monitored at all costs. Conclusively, advanced monitoring should be the last resort of providing telemonitoring services and may be utilized only in cases where such treatment is absolutely necessary, due to its inherent resource wasteful nature.

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VI. CONCLUSIONS

In this paper a combined network comprising of a PAN (Zigbee or Bluetooth), a 802.11b WLAN and an Enhanced Uplink cellular network for serving e-health applications has been studied and simulated. The study demonstrated the feasibility of utilizing a realistic joint network for such applications, utilizing the PANs for biosignal measurements collection, the WLAN for environmental measurements collection and for forwarding the data to the cellular system, while the Enhanced Uplink network provides a means of transferring the patients' data to their destination acting as the backbone network. The performance of the proposed scheme has been evaluated mainly in terms of delay under different load and service requirements, proving that it may serve as a new generation technology and trustworthy solution for telemonitoring health systems.

Future work will incorporate advanced wireless technologies, such us WiMAX instead of WLAN and LTE/LTE-Advanced in place of HSPA acting as the backbone network, so as to meet the requirements for the new architecture of the telemedicine network.

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