Wireless Sensor Networks with QoS for e-Health and e-Emergency Applications

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Abstract. Most body sensor networks (BSN) only offer best-effort service delivery, which may compromise the successful operation of emergency healthcare (e-emergency) applications. Due to its real-time nature, e-emergency systems must provide quality of service (QoS) support, in order to provide a pervasive, valuable and fully reliable assistance to patients with risk abnormalities. But what is the real meaning of QoS support within the e-emergency context? What benefits can QoS mechanisms bring to e-emergency systems, and how are they being deployed? In order to answer these questions, this paper firstly discusses the need of QoS in personal wireless healthcare systems, and then presents an overview of such systems with QoS. A case-study requiring QoS support, intended to be deployed in a healthcare unit, is presented, as well as an asynchronous medium access TDMA-based model.

1 Introduction

An e-health system consists of a group of sensors attached non-invasively to a patient in order to sense the physiological parameters. It has been used in hospitals during the last decades using conventional wired equipment, hence not allowing the patient to move around freely. However, recent advances in wireless sensors technology are changing this scenario by permitting mobile and permanent monitoring of patients, even during their normal daily activities [1].

An e-health system should be able to accomplish at least one crucial aim: to monitor a patient and, when an emergency occurs, to trigger immediately an event to alert the patient and/or to warn a remote caregiver. In this way, both the patient and the caregiver can take timely the right procedure in accordance with the clinical episode. The system should also be able to trigger an alert anticipating the case where the patient is unaware of his/her health gravity. When a patient´s clinical state turns from a non-critical situation into a critical one, a context change occurs and consequently the healthcare network should adapt its performance requirements to the new situation. For instance, higher monitoring activity and lower delay transmission of the vital signals might be required when the patient´s clinical situation changes from non-critical to critical. Hence, healthcare networks should provide QoS facilities for e-

emergency services, since these clearly demand for high reliability, guaranteed bandwidth, and short delays.

2 Vital Signal Monitoring

e-Emergency requires monitoring of several vital signals simultaneously. For example, a patient in an ambulance is monitored for blood pressure, heart and respiration rates, and temperature. Besides these primary signals, other information may be captured to help diagnosis and medical decision, such as electrocardiogram (ECG), blood glucose level, blood oxygen saturation (SpO_2), heart and breathing sounds, or even an image in cases of trauma. Table 1 presents the electrical characteristics of the vital signals usually used in emergency medical care [2] [3]. If some signal exceeds the defined threshold, the local supervisor node should trigger an alarm to inform a caregiver or the patient himself.

At non-emergency medical situations, ECG and SpO_2 signals are usually transmitted in bursts, while signals such as body temperature and blood glucose are transmitted in single packets to the BS [4]. In fact, to reduce the traffic load and the power consumption of a BSN, the current trend in telemedicine systems is to enhance sensor node intelligence, available memory, processing power, and enabling on-line solicited requests only for results. In this way, continuous and bulk data transfer is sporadic, occurring only in intermittent occasions [4]. However in emergency cases, this should not be the rule, since patient´s life is priceless and above any other consideration. Continuous and bulky data transfer in real-time might be prevalent here.

Table 1. Vital Signal Electrical Characteristics.

Vital signal (Hz)	Freq. range (Hz)	Sampling rate (Hz)	Resolution (bit)
ECG (per lead)	0.01…60-250	120-500	16
Temperature	0…0.1-1	0.2-2	12
Oximetry	0 … 30	60	12
Blood pressure (BP)	0 … 60	120	12
Respiration rate	0.1 … 10	20	12
Heart rate (HR)	0.4 … 5	10	12

3 QoS Needs in e-Health

Some authors argue that differentiation based on data priority is inherent to wireless sensor networks (WSN), since it is normal to have sensors to monitor distinct physical parameters simultaneously, just as in BSNs. Here, the importance of the collected information is necessarily distinct, and so the network must prioritize the transmission of critical data when occurs a sudden clinical change in the patient. For example, in patients with cardiac diseases, heart activity information is more important than body temperature data. Also, depending on the patient´s clinical condition, the priority assigned to a vital signal can change dynamically. For instance, glucose data might be

assigned a low priority when readings are in the normal range, but a higher priority might be reassigned to it when readings indicate hypo or hyper-glycemia.

Most current BSNs only offer best-effort service [5], which is limitative for e-emergency support. In these networks, the QoS provision is required to assist critical cases conveniently. This will enable, for instance, guaranteed bandwidth to higher priority streams for an efficient data delivery, even in case of interference or fading.

QoS mechanisms are usually deployed in networks to guarantee consistent service levels concerning certain parameters, such as packet loss ratio, transmission delay, jitter, and available bandwidth. These are traditional end-to-end QoS parameters used to characterize the performance of communication infrastructures, including BSNs. For instance, the total delay of an ECG signal being displayed in the monitor should be less than 3 s for useful real time analysis by the cardiologists [6]; ECG signals require a minimum sampling rate of 250 Hz to guarantee that jitter does not affect the estimation of the R-wave fiducial point, which modifies considerably the spectrum [7]. No significant difference between ECG traces are detected by sampling the signal at rates between 250 and 500 Hz, but significant reduction in peak amplitude values and inaccurate interval measurements are obtained at 125 samples/s [4].

However, QoS in BSNs may not be fully described using only those parameters, because of its context-aware nature. For example, at application level, QoS may be regarded as guaranteeing the right number of sensors for monitoring the vital signals in accordance with the patients´ emergency state.

The available energy in the BSN is another very important parameter to take into account. In fact, if energy is carelessly consumed, the BSN may rapidly become completely useless due to lack of power. To prevent such failure, energy should be carefully saved using different approaches. For example, if the patient is in normal state then the sampling rate of sensors can be reduced to save power, or if the battery charge becomes low then its energy should be reserved to the more vital tasks of the patient. That is to say, the monitoring activity should adapt in accordance with the patient clinical state for energy saving. To save further energy, communication protocols should be simple, and data should be aggregated, eventually compressed, and transmitted in full-loaded packets, since computing demands much less energy than transmission. Attention must also be paid to delay, as it tends to increase linearly with the packet length.

Additionally, prioritizations may be used to provide QoS. For example, for efficiency reasons a large packet length may be chosen for non-critical situations. But as soon as an emergency occurs, the packet size can be reduced to meet the low delay QoS requirement, and signals considered irrelevant to this emergency episode are sampled at a lower rate, or not sampled at all.

Moreover, the computation power may be lowered to a minimum as all data must be forwarded, in opposition to the regular operation where, to save energy, the cardio-respiratory rhythm can be computed on-board before sending it. Or else, an ECG signal can be processed in the sensor itself to extract its relevant features. In this way, only information about an event is transmitted (e.g., QRS features and the corresponding timestamp of R-peak), hence reducing the traffic load and saving energy.

A BSN does not transmit only measurement data packets. Other packets may be present, such as those carrying control or alerting data. In this way, it is suggested that a high-priority level should be assigned to data packets carrying alarming notifi-

cation and measurements, and acknowledgement of correctly received packets; a medium priority level should be assigned to scheduled transmissions of data packets, and primary control packets (e.g. sensor configuration); and a low priority level should be given to periodic polling of nodes for network integrity check, and secondary control packets (e.g. link) [4].

The vital signals captured from the patient body must be delivered to a remote diagnosis and decision centre, through some available communication infrastructure such as the Internet or a 3G mobile communication network. As a result, the delivered QoS depends necessarily on the network infrastructure chosen for the delivery of mobile health services. Therefore, to meet the required QoS, the mobile health services platform needs to be able to acquire and use contextual information about the QoS offered by communication network infrastructures available at the patient's current location and time [5]. High availability and reliability are the most desirable characteristics that these network infrastructures should offer, as well as QoS guarantees for bandwidth, end-to-end delay, jitter and loss.

4 e-Health Wireless Systems with QoS

Despite the number of e-health systems already developed [1], only a few encompass QoS support. In order to assess how QoS support is being deployed in e-health WSNs, some representative projects were analyzed, as well as the QoS requirements that the respective authors have considered important to incorporate in their implementations. Based on the related literature, QoS projects for e-health can be grouped according to the following topics: frameworks with QoS; QoS through reconfiguration; and algorithms for QoS enhancement.

Frameworks with QoS. She *et al*. [8] propose an infrastructure for remote medical applications using ZigBee and commercial 3G networks. In order to improve the delay and the transmission time of critical vital signals (so improving the overall QoS in terms of latency, bandwidth, and power consumption), a differentiated service based on priority scheduling and data compression is presented. In this model, a patient server receives instructions from a remote hospital server and configures the patient´s BSN accordingly. The wireless sensors transmit the signals to the patient server. Here, each type of vital signal receives a priority level and then is transmitted to the hospital server according to their priorities. By example, for a cardiac disease patient, a higher priority level is assigned to ECG signals than to body temperature. Thus ECG signals will be processed and sent earlier than body temperature if both arrive at the personal server at the same time. High data rate and delay tolerant signals will be compressed and stored in local memory for later transmission. The physician analyses the incoming data and will act accordingly to the clinical episode.

Vergados *et al*. [9] propose a wireless DiffServ infrastructure for mobile telemedicine. Formed by several e-health DiffServ domains, the network can reliably handle both normal and life-critical medical applications under extreme traffic conditions. Assigning different priority levels according to the specific medical application

needs, and according to the urgency of the medical incident, causes the network to intelligently drop and/or delay the packets, in order to achieve a high service level.

QoS through Reconfiguration. Usually a WSN is reconfigured based on common parameters, such as traffic load, node failures, channel utilization, energy drainage, etc. Gondal *et al*. [10] suggest that the reconfiguration also takes into account the physician's recommendations for patient monitoring schedule, the condition of the physiological parameters being sensed by the network, and the disease diagnosis outcome from an automated or manual system. This information will be fed back into the body area network so that it can self-reconfigure to monitor the patient with the required intensity, while concomitantly tries to maximize the network reliability, throughput and lifetime. This operation of translating the clinical operations into network sensing schedules and reconfiguration decision, providing in this way a service with the required monitoring quality, is the key focus of this framework.

MiLAN [11] is a middleware system targeted for reconfiguring centralized networks with few sensors and no mobility, particularly body area networks. It assumes that a vital signal may be read from different sensors with different reliabilities. For instance, ECG sensors and SpO_2 sensors can provide heart rate with reliability of 1 and 0.7, respectively. In this way, MiLAN uses graphs provided by the application, together with information about the current application state, to decide how to configure and manage both the network and sensors in order to meet the QoS application requirements, for instance, the reading of a vital signal with a defined reliability. At the same time, it tries to maximize the application lifetime, instead of the sensors lifetime. However this kind of approach seems unsuitable for e-emergency systems, as full reliability is required.

Algorithms for QoS Enhancement. The common way to recover the lost or corrupted data in connectionless transmissions is through retransmission processes. However common automatic requests mechanisms are unable to guarantee data recovering in a bounded transmission delay, as required in e-emergency systems. To tackle this problem, Henrion *et al*. [12] use restoration algorithms to recover the ECG missing packets that do not arrive to the monitoring equipment within an acceptable delay. Simulations results showed that, even for 8% of packet loss in transmission of ECG data during 30 s, the restoration scheme allow reconstructing a more functional signal for a medical expertise.

Coelho Jr. *et al*. [13] apply the concept of QoS to power management in a real-time remote physiological monitoring system. The authors present a power management model so that an application can adapt dynamically to particular situations, generating less requests from the devices, and therefore saving energy. The model is based on an extended power state machine whose transitions are associated with application events, beyond the energy model of the resource being allocated. In the case of ECG monitoring, examples of possible states can be a patient with a normal ECG, a patient with low risk abnormalities, and a patient with high risk abnormalities; examples of events can be loss of communication channel, ECG abnormal for the last five minutes, or patient signaling that is not feeling well.

According to the e-health projects herein surveyed, QoS support provided in each approach is varied. Despite all this variety, e-health systems should always support QoS in order to provide a pervasive, valuable and totally reliable assistance to any patient. This is the main goal of the case-study presented in the following section.

5 Case-Study

Aware of the different QoS approaches presented above, we are implementing an experimental testbed to deploy QoS solutions based on a real clinical scenario. The scenario under study is based on a hospital room containing six beds with one patient per bed. Each patient is monitored by a personal BSN, and one base-station (BS) collects the vital signals of all patients. The signals being monitored are temperature (T), oximetry (OXI), arterial pressure (ART), respiration rate (RR), and ECG data, as shown in Figure 1. Each signal is collected by a dedicated wireless sensor. Patient´s vital signals are analyzed and/or correlated at BS. Our goal is to develop a solution which guarantees that every signal is delivered to the BS with the appropriated QoS, as specified next.
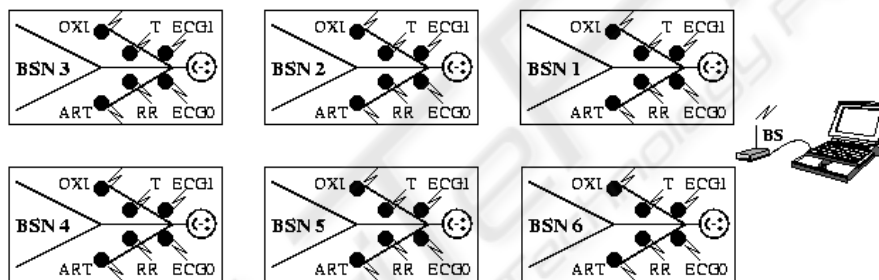

Fig. 1. Hospital room with a patient being monitored in each bed.

According to IEEE 1073 group, a wireless ECG electrode should generate 4 kbps of data, and the latency introduced by framing the data samples and the transmission delay should be below 500 ms. Since ECG signals are the most demanding in terms of QoS, we take this value as the maximum delay that any vital signal should have. Continuous healthcare monitoring normally uses a three leads ECG device, composed of two active electrodes plus one of reference. Since research is being done to eliminate the reference electrode, we assume that each active electrode is implemented by a wireless sensor (ECG0, ECG1). So, according to Table 1, each BSN produces a maximum aggregated rate of 10.424 kbps, hence resulting that the maximum total traffic inside the hospital room is 62.544 kbps. Besides guaranteeing this minimum goodput and latency below 500 ms, the e-health system must also guarantee low packet loss to every vital signal, low energy consumption and balanced energy drainage in every BSN.

In the present case-study we have initially considered Bluetooth and ZigBee technologies. As Bluetooth specifications allow a maximum of seven active slaves (i.e.

sensors) to be controlled by one master (i.e. BS), it was not considered an acceptable option.

ZigBee is a short range, low power, and low data rate standard for WSNs that supports a maximum rate of 250 kbps in the 2.4 GHz band. Therefore, a ZigBee WSN is able to handle the whole traffic generated inside the hospital room without congesting. Nevertheless, other factors which may affect QoS significantly have to be considered, such as the wireless channel access and transmissions errors. It is shown next why ZigBee is unsuitable for this case-study.

If traffic is to be sent within the same ZigBee PAN and short addresses are used, then a payload of 928 bits per packet is available to the applications. Ideally, all packets should be sent full-loaded in order to minimize the overhead, and so saving energy. Thus, to achieve the minimum required rate of 4 kbps, one packet carrying ECG data must be generated every 0.232 s. In addition, according to Table 1, each BSN should generate one full-loaded packet of temperature data every 38.66 s, of oximetry data every 1.28 s, of arterial pressure data every 0.64 s, and of respiration data every 3.86 s. Since delivery delay must be below 500 ms, it is clear that only ECG data packets may be transmitted full-loaded.

Simulation results have shown that ZigBee is not adequate for several sensors to transmit ECG signals to a BS with full efficiency [14]. Either in acknowledged or in unacknowledged mode, the efficiency starts to drop when three or more ECG devices operate in the same RF channel. This is because ZigBee relies on CSMA-CA, a contention-based MAC protocol that is vulnerable to collisions. In acknowledged mode, lost packets may be retransmitted, but there is a maximum number (5) of retries allowed by ZigBee before declaring channel access failure. ZigBee seems to be more adequate for BSNs that do not have large amounts of data to transfer, only several small data packets per hour, like implanted medical sensors [15].

Another approach is using the beacon-enabled PAN mode described at IEEE 802.15.4 standard. The BS sends regularly beacons which bound the superframes. These structures are divided into 16 identical slots. Any device wishing to communicate during the contention access period (CAP) shall compete with other devices using the slotted CSMA-CA. For low-latency applications or applications requiring specific bandwidth, the coordinator may dedicate portions of the active superframe to that application. These portions are called guaranteed time slots (GTSs). The GTSs form the contention-free period (CFP). The PAN coordinator may allocate up to seven of these GTSs, and a GTS may occupy more than one slot period. No transmissions within the CFP shall use a CSMA-CA mechanism to access the channel. The GTSs should be allocated dynamically to sensors accordingly with the QoS needs of the BSN. This TDMA-based transmission technique using slots is presently not available within any ZigBee profile.

Each full-loaded packet transmitted at 250 kbps needs 4.256 ms to be completely transmitted. Assuming that every packet is transmitted in individual slots, the beacon transmission interval must be above 4.256*16=68.096 ms. This means that the beacon order (BO) should be 3, implying a beacon interval (BI) of 122.88 ms (BI=3840*2^{BO} bits, 0≤BO≤14). Note that the next BO (4) implies a BI of 245.76 ms, hence making impossible to transmit a packet every 232 ms. There is a significant waste of bandwidth because the packet never occupies the whole slot duration. With BO=3, only 55.4% of the slot period is used to send a full-loaded packet.

Since twelve ECG sensors are in the hospital room, and ignoring the maximum number (7) of GTSs imposed by the standard, only 4 slots would be available for the other sensors to send data. A CAP having four slots and 55.4% of slot period utilization may transmit at most 34625 bps. Comparing this value with 2424*6=14544 bps of data sent by all the remaining sensors in the room, it is expected a large number of collisions during the CAP, hence degrading seriously the QoS of the system.

5.1 An Hybrid Beacon-based Protocol

Considering the case-study described above, we propose a beacon-based protocol in order to meet QoS requirements. In this protocol, beacons are transmitted at irregular time intervals in order to guarantee the delivery of the patient´s physiological data with the required QoS in presence of bandwidth constraints.
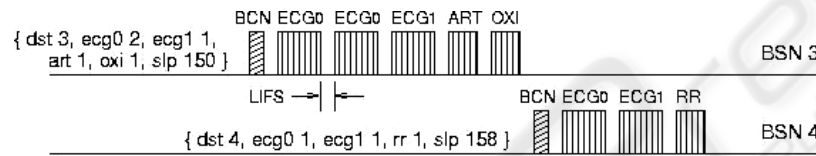

Fig. 2. Illustration of the asynchronous beacon-based protocol (variable mode).

The BS sends beacons to each WSN following a round-robin pattern, specifying which data should be received from its sensors. For example, suppose a BS send one beacon carrying this information: {dst 3, ecg0 2, ecg1 2, art 1, oxi 1, slp 150}. All sensors belonging to BSN 3 receive the beacon and read that information. Then, ECG0 sends immediately two consecutive packets, next ECG1 sensor sends two packets, ART sensor sends one packet and, finally, the oximetry sensor sends one more packet. All these packets are sent consecutively. After transmitting, each sensor may sleep for 150 ms. The BS can estimate this time, because it can preview the data it is going to request from the other BSNs before returning again to BSN 3. After receiving all packets, the BS sends a beacon with a new set of requirements to the next BSN to get the data of its sensors, as shown in Fig. 2. With this scheme, the channel is guaranteed to be free whenever a sensor is about to transmit. For this reason, a CSMA-CA mechanism to access the channel is not required and the hidden node problem is absent. If there are in the surroundings other similar e-health WSNs causing interferences over each other, then distinct operating channels should be selected for each WSN (16 channels are available at 2.4 GHz band). The packet transmission should respect the long inter-frame spacing period specified at IEEE 802.15.4 (0.64 ms) to guarantee that the MAC sub-layer of the BS is able to process all incoming packets. The BS may send periodically a special beacon to allow the association of a BSN newly arrived at the room. The association should be allowed by the BS only if the allocation of resources to the new BSN does not compromise the overall QoS of the system already established. Beacons may eventually carry the clock time of the BS for synchronizing the network for timing measurements. Note that the BS only polls the BSN, and not each one of its sensors. In this protocol, the slots may be efficient and dynamically used, unlike the slotted IEEE 802.15.4, where

the fixed duration of the slots in each superframe leads necessarily to poor bandwidth efficiency. The maximum time a sensor can wait for sending data again is about 176 ms, which verifies the condition of ECG sensors sending at least a packet every 232 ms. A BS may ask for two packets from a sensor (e.g. ecg0 2). This need occurs if the BS did not receive a packet from a sensor in a BSN. Then, in the next polling to that BSN, it requests that sensor for sending the present data as well as the packet lost in the previous transmission. In order to respect the maximum delay, only one retransmission attempt is scheduled in case of transmission failure. This simple ARQ mechanism is able to control the transmission errors.

Two modes of operation are available in the proposed protocol: variable and constant. In **variable mode**, data packets are sent in contiguous variable time-slots. In this asynchronous operating mode, each sensor knows the right time to send data by counting the number of transmitted packets after the beacon reception. A default slot period needs to be defined to prevent the system from hanging, due to a transmission failure in a sensor. As soon as a beacon addressed to its BSN is received, a sensor must always be in listening state until it is scheduled to transmit. In order to balance the energy drainage of the BSN, the vital signal requiring the highest sampling rate should be the transmitted firstly, while that one requiring the lowest sampling rate should be transmitted lastly. In **constant mode**, data packets are sent in contiguous fixed time-slots. The slot duration should be long enough to hold a full-loaded packet and a guard period to avoid adjacent transmissions overlapping. So, after receiving a beacon, each sensor is able to calculate the time it may sleep before transmitting. Because sensors are not required to stay in listening state before transmitting, a WSN is more efficient energetically using constant mode than variable mode, at the cost of a less efficient bandwidth utilization of the channel.

We have been considering that all sensors are monitoring the patients at the highest sampling rates. However, such scenario should only occur in critical clinical episodes. In non-critical clinical situations, the sensors should monitor the patient at lower sampling rates in order to save battery energy and channel bandwidth. Such policy would also improve the scalability of the system. Therefore, self-reconfiguring each BSN in accordance with the patients´ clinical state is an important paradigm to follow. We believe that the proposed protocol associated with the self-reconfiguration of the BSNs may produce very interesting results in terms of QoS and scalability.

6 Conclusions

Since patient´s life is priceless, emergency healthcare networks should be totally reliable and efficient. These networks must support QoS as they clearly demand for reliability, guaranteed bandwidth, and low delays due to their real-time nature. Energy consumption should also be optimized to extend the lifetime of the BSN.

According to representative e-Health projects herein surveyed, it was observed that QoS support provided in each approach is varied and targets different QoS levels. In this context, (i) differentiated service provision based on priority scheduling and data compression; (ii) wireless DiffServ infrastructure for mobile telemedicine; (iii) sending feedback information into a BSN so that this can be self-reconfigured to monitor

properly the patient; (iv) restoration algorithms to recover the ECG missing packets, or (v) extended power management models to save energy, all are illustrative examples of specific QoS deployments in e-health and e-emergency systems. Notwithstanding all this variety, healthcare systems need to support QoS at multiple protocol levels in order to meet a common and final goal: to provide a pervasive, valuable and totally reliable assistance to any patient with risk abnormalities.

We have concluded that neither Bluetooth nor IEEE 802.15.4/ZigBee standards are able to satisfy the QoS requirements demanded by the case-study herein presented. To tackle this limitation, a hybrid medium access beacon-based model has been proposed to fulfill such QoS requirements. Currently, we are testing and improving this model in an experimental testbed.

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