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Cognitive radio system for interference reduction in BANETs focused on epilepsy diagnosis

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ABSTRACT

Epilepsy is considered a disorder in which a person has episodes of disturbed brain activity characterized by increased and abnormal synchronization of electrical neuronal activity and this electrical behavior is manifested with physical changes in the overall behavior of the body. As such, epilepsy can be diagnosed analyzing the electroencephalographic changes and their effects monitoring the other body signals. There are different clinical tools that allow monitoring physiological signals associated with a possible epileptic episode. However, they require wired connections and therefore monitoring is restricted to factors such as limited physical movements and loss of information when sensors are disconnected.

This work proposes and designs a body area network (BANET) for continuous monitoring and event detection and we study the system behavior for different parameters associated with the transmission of information. The continuous monitoring signals are form the electroencephalogram (*EEG*) and electrocardiogram (*ECG*) sensors since these signals provide the most important data for the epilepsy detection while the event detection system is composed mainly by the electrogastrogram (*EGG*) sensors but other sensors are also considered. Also, we propose a system to reduce interference and energy consumption by making a more efficient use of the channels using a cognitive radio system. This system is mathematically studied.

1. Introduction

Epilepsy is one of the most common serious brain diseases. It is a chronic disease with complex side effects on professional, occupational, psychological, social and economical implications [1]. This brain disorder is characterized by an enduring predisposition to generate epileptic seizures causing neurobiological, psychological and social consequences of patients suffering this condition [2,4,5]. It can be detected, according to International League Against Epilepsy [3], by the presence of abnormalities in the electroencephalogram with manifestation in the behavior and/or epileptic seizures. Currently there are many devices and tools to monitor biological signals of human beings in a wired manner for the analysis of biological signals. These signals may determine certain patterns that provide information for the prevention or control of this disease. Among the most commonly performed studies is the electroencephalogram (EEG, neurophysiological examination based on the registration of electrical brain activity under different conditions) with at least 19 electrodes [5], electrocardiography (EKG / ECG, representing the electrical heart activity) with at least 5 electrodes and electrogastrography (EGG, recording technique of gastric electrical activity) with at least 3 electrodes, among others. Such studies normally require the patient to attend a hospital or medical cabin in order to be monitored using a wired system. As such, patients are greatly restricted during the medical analyses.

Building on this, a Body Area Network (BANET) that is composed of many nodes performing the different studies, e.g. EEG, ECG and EGG, can be used as an ambulatory system eliminating any restrictions on medical instrumentation wiring and allowing patients to perform their normal activities in everyday life while the medical staff receives and studies the different medical data related to the patient. In this way, it is possible to perform long duration analysis (of many hours or even days) in a non-restricted environments. Note that in order to have an ambulatory system,

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nodes have to transmit wirelessly in order to allow patient's movement.

To this end, this work proposes, studies and analyses the design of a hybrid wireless sensor network for continuously monitoring signals of *EEG* and *ECG*, and that is capable of gathering information only when a specific event occurs, such as the *EGG* signals. Such hybrid approach (both continuous monitoring and event driven detection), is very challenging since the system has to adapt to different traffic conditions while assuring an efficiency operation in terms of channel occupancy and packet loss. Additionally, considering the high number of nodes in a small area, a collision-less protocol, such as Time Division Multiple Access (TDMA) has to be used.

In order to verify the operability of such demanding system, a mathematical model and discrete event simulations are used to provide some insights on the expected behavior of the BANET for the study of epilepsy. Then, considering that the interference level introduced by the continuous transmission of dozens of nodes may cause some interoperability issues among electronic equipment in the patient's surroundings, we propose the use of a Cognitive Radio Network (CRN), where nodes can efficiently use the radio-electric spectrum, to reduce the amount of transmissions of continuous monitoring nodes and taking advantage of empty spaces for event driven data transmission. CRN is the approach considered in this work. However, other alternative methods can be used in this particular scenario, such as the use of MIMO (Multiple Input Multiple Output) systems where antenna arrays allow the transmission and reception of multiple signals without interfering among them or multiple coding techniques. Such techniques can be used in addition to the proposed CRN system and can be studied in future works in the area.

The concept of CRN was proposed by Mitola and Maguire [15] where nodes have to have some knowledge of radio etiquette, devices, software modules, propagation, networks, user needs, and application scenarios in a way that supports automated reasoning about the needs of the user. As an additional benefit of using this technique, the lifetime of the system is increased by allowing continuous monitoring nodes to turn off their radios in order to allow event nodes to transmit their information. As such, the proposed system is also energy-efficient. Two different Cognitive Radio Systems are proposed:

- In the first one, event reporting has priority over continuous monitoring data. Indeed, certain events can be relevant for the epilepsy study (such as heart activity or muscle movement, etc.) and the system should provide the most accurate data possible regarding such events. As such, whenever the event occurs, nodes that detect it, can use time slots previously assigned to continuous monitoring data, effectively preempting them to be used by event reporting nodes. However, we are also interested on studying the system when continuous monitoring packets are not discarded to profit event reporting.
- As such we also propose a second cognitive radio based system where continuous monitoring data is not affected by the occurrence of events.

We believe that a mathematical model that describes the behavior of this system is of major importance before the actual implementation of the BANET in order to accurately select the operational parameters that entails an adequate operation. From this, the first scheme is the one based on the original concept proposed by Mitola while the second scheme is not respecting the original concept of cognitive radio. However, it is important to note that the secondary network only interferes with the primary network when no resources are available. As such, in the normal operation conditions, the secondary network does not interfere nor degrades the performance of the primary network. Only when an event occurs and multiple event sensors are reporting when primary packets can be dropped to allow the event packets to be transmitted.

It is important to remark that in a CRN, the Primary System (PS) legally owns the frequencies and the Secondary System (SS) has to operate transparently without degrading in any way the performance of the PS. However in this case, both the PS and SS are wireless sensor networks and both part of the same system. As such, we only use the concept of Cognitive Radio where the PS is using the resources in a continuous manner while the SS is using the resources sporadically, i.e., the event reporting nodes. As mentioned above, in one of the proposed CRNs the SS has priority over the PS, which is typically not allowed in CRNs (in the other proposed CRN, the continuous monitoring packets are not affected by the secondary network). The rationale behind this is that whenever a biological signal is detected to have values above or below a certain threshold, it is important to relay this information as fast as possible. As such, the proposed system works differently than a typical CRN, but we use the concept of being aware of empty spaces in order to better use the radio resources in the system based on a dynamical channel access. Building on this, the proposed system is a preemptive system in the sense that priority packets (event reporting packets) are allowed to preempt continuous monitoring packets when no empty slots are available.

In the literature, there are different *WSN*s deployed for BANETs. However, most studies are focused on other types of measurements. For example, in [8–11] where the monitoring of bioelectrical signals are mainly for e-health applications.[1] Nowadays on the market there are non-invasive sensors, aimed at monitoring bioelectric signal and recording anomalies indicating bearer studies and monitoring. These commercial systems, as well as the proposed in this work, are conceived in order to monitor in a simple and transparent manner for the user, monitoring their respective body functions in different parts. Brand new sensors like *Medtronic* or *IntraMed* have this kind of functionality. Martinez et al. [12] describes a wireless sensor network focused on the study of epilepsy but, the paper does not consider a cognitive ratio system. However, none of these studies propose the use of a CR system to efficiently perform the required tasks. Also, the present study evaluates the behavior of the network under different environments and analyses the energy consumption and successful event probability in order to allow a practical implementation in a future work.

In the rest of the paper, first we present the bioelectrical signals considered to be monitored for the study of epilepsy. Then, we present the basic communication scheme where no Cognitive Radio capabilities are considered. This basic system is studied in terms of energy consumption and average occupancy. Then, the system with Cognitive Radio capabilities enabled is presented and mathematically studied. We finish the paper presenting relevant numerical results and conclusions.

2. Bioelectrical signals

In this section, we present the main bioelectrical signals that are considered to be the most relevant for the study of epilepsy. As such, the following studies are considered for the BAN design, i.e., nodes transmitting in a wireless fashion are placed for these particular studies.

[1] According to the final usage of the bioelectrical monitor system, the recording of the biological signals could be for diagnosis (the priority is to recover morphology and dynamics of the signals), control such as Brain-computer interface, and haptic application for games where the power density or changes of mean response are enough to take decisions. Research in diseases and physiology of the biological system where its complexity entail several levels of control interrelated are considered for the use of sensor networks of several types of biological signals for long periods [16–18].