WIRELESS COMMUNICATION PROTOCOL BASED ON EDF FOR WIRELESS BODY SENSOR NETWORKS

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ABSTRACT

This paper presents a wireless communication protocol based on the Earliest Deadline First policy for wireless body sensor networks. This work advances a previous effort by proposing using an implicit Earliest Deadline First policy to guarantee real-time communication by optimizing network traffic flow, although this strategy may imply using the totality of bandwidth resources. The proposed protocol uses a slotted time-triggered medium access transmission control that is collision-free, even in the presence of hidden nodes. The protocol has been analytically modeled using Colored Petri Networks and Simulated in OPNET.

KEYWORDS: wireless body sensor networks, wireless communication protocol, Earliest Deadline First, Wireless Ad Hoc Networks.

RESUMEN

Este trabajo presenta un protocolo de comunicación inalámbrica basado en una política de “El más próximo tiempo de expiración primero” para redes de sensores corporales inalámbricas. El presente, mejora un esfuerzo previo proponiendo el uso de una política del más próximo tiempo de expiración primero implícito (Implicit EDF) para garantizar comunicación en tiempo real a través de la optimación del flujo de tráfico en la red, aunque esta estrategia podría implicar usar la totalidad de los recursos de ancho de banda. El protocolo propuesto utiliza un control de transmisión de acceso al medio con ranuras de tiempo, que son libres de colisiones, aún en la presencia de nodos escondidos. El protocolo ha sido analíticamente modelado a través de redes de Petri coloreadas y simulado en OPNET.

1. INTRODUCCTION

Wireless technology, sensor design and energy storage technologies have made significant advances in the area of Wireless Sensor Networks (WSN). Integrated micro-sensors with onboard processing and wireless data transfer capability, the most important components of WSNs, already exist [1, 2]. Present designs have already integrated a range of sensors that can monitor a variety of environmental factors including temperature, humidity, barometric pressure, light intensity, tilt, vibration and magnetic field intensity using short-distances wireless communications.

The enormous cost of providing health care to patients with chronic conditions requires new strategies to more efficiently provide monitoring and support in a remote, distributed, and noninvasive atmosphere. Wireless electromechanical sensors allow the internal biologically-controlled mega-network, governed by the central nervous system, to communicate with an external body sensor network by means of wireless communication technology. This is particularly significant because it permits internal biological functions to be communicated to a monitoring center, where a real-time diagnosis can be made and an intervention plan can be developed. The term "biologically-controlled mega-network" refers to the central nervous system and the proper execution of complex biological systems, which depends on the intricate coordination of a large number of events and their participating components.

Diverse European projects [3, 4] are trying to improve the quality of medical attention by providing remote medical monitoring. These projects are currently developing mobile monitoring systems and integrating remote monitoring into their healthcare protocols in order to provide expanded healthcare services for persons who require monitoring and follow-up but do not require immediate medical intervention or hospitalization.

The importance of monitoring patient health is significant in terms of prevention, particularly if the human and economic costs of early detection can reduce suffering and medical costs. The early diagnosis and treatment of a variety of diseases can radically alter healthcare alternatives or medical treatments. This is particularly true with illnesses such as cardiovascular disease or diabetes. In the case of cardiovascular disease, 4% of the population over 60 and more than 9% of persons over 80 years of age have arrhythmias or abnormal heart rates, which require occasional diminutive electrical shocks applied to the heart. Sensors can identify at-risk patients by monitoring and transmitting their real-time cardiac rhythms to medical professionals who can subsequently determine whether or not they require a pacemaker to assist establish and maintain normal sinus rhythm [5].

Diabetes is an increasingly significant progressive chronic disease that affects several vital organs. The number of people diagnosed in the United States with diabetes has increased dramatically the last 40 years, mainly due to obesity [6]. Presently, approximately 24,000 people become blind and 56,000 people suffer renal failure because of diabetes every year in the United States. Once diagnosed, patients require constant monitoring of their blood glucose levels. Type II diabetes patients often do not require insulin to effectively manage this disease. These patients rely on effective management protocols requiring periodic blood samples at specified intervals as well as dietary restrictions, weight loss in the case of obese patients and exercise. The management of diabetes generally requires motivation and adherence to a new lifestyle that, in large portion, depends on changing habits and behaviors. Body sensor networks used to manage diabetes will one day involve implanted sensors, not only to monitor patient glucose levels, but to administer insulin in a timely fashion. In sum, the abovementioned chronic diseases exemplify the need for biochemical and physiological continuous monitoring. Table I provides further examples of other diseases whose treatment could benefit from continuous monitoring.

Disease Process	Physiological Parameter (BSN Sensor Type)	Biochemical Parameter (BSN Sensor Type)
Hypertension	Blood Pressure (implantable / wearable mechanoreceptor)	Adrenocorticosteroids (implantable biosensor)
Ischemic Heart Disease	Electrocardiogram (EKG), cardiac output (implantable/ wearable EKG sensor)	Troponin, creatine kinase (implantable biosensor)
Cardiac Arrhythmias / Heart Failure	Heart rate, blood pressure, EKG, cardiac output (implantable / wearable mechanoreceptor)	Troponin, creatine kinase (implantable biosensor)
Cancer (Breast, Prostate, Lung, Colon)	Weight loss (body fat sensor) (implantable / wearable mechanoreceptor)	Tumor markers, blood detection (urine, feces, sputum), nutritional albumin (implantable biosensor)

Asthma / COPD	Respiration, peak expiratory flow, oxygen saturation (implantable / wearable mechanoreceptor)	Oxygen partial pressure (implantable/wearable optical sensor, implantable biosensor)
Parkinson's Disease	Gait, tremor, muscle tone, activity (wearable EEG, accelerometer, gyroscope)	Brain dopamine level (implantable biosensor)
Alzheimer's Disease	Activity, memory, orientation, cognition (wearable accelerometer, gyroscope)	Amyloid deposits (brain) (implantable biosensor/ EEG)
Stroke	Gait, muscle tone, activity, impaired speech, memory (wearable EEG, accelerometer, gyroscope)	
Diabetes	Visual impairment, sensory disturbance (wearable accelerometer, gyroscope)	Blood glucose, glycated hemoglobin (HbAlc) (implantable biosensor)
Rheumatoid Arthritis	Joint stiffness, reduced function, temperature (wearable accelerometer, gyroscope, thermistor)	Rheumatoid factor, inflammatory and autoimmune markers (implantable biosensor)
Renal Failure	Urine output (implantable bladder pressure/volume sensor)	Urea, creatinine, potassium (implantable biosensor)
Vascular Disease (Peripheral vascular and Aneurisms)	Peripheral perfusion, blood pressure, aneurism sac pressure (wearable/implantable sensor)	Hemoglobin level (implantable biosensor)
Infectious Disease	Body temperature (wearable thermistor)	Inflammatory markers, white cell count, pathogen metabolites (implantable biosensor)
Post-Operative Monitoring	Heart rate, blood pressure, EKG, oxygen saturation, temperature (implantable/wearable and EKG sensor)	Hemoglobin, blood glucose, monitoring the operative site (implantable biosensor)

Table I. Disease processes and the parameters commonly used to monitor diseases.

The remaining sections of this paper are organized as follows: state of the art in patient health monitoring is presented in Section 2. Related work of the proposed algorithm is discussed in Section 3. Section 4 details our proposed algorithm for wireless body sensor networks. This section also discusses controls for the validation in terms of Colored Networks (PN) and the OPNET simulator. Section 5 shows the results obtained by the colored Petri Net and simulation, and Section 6 discusses conclusions and offers suggestion for future research.

2. MONITORING THE HEALTH IN THE PEOPLE

The continuous monitoring and analysis of vital signs is the key to detecting potential health risks in otherwise healthy-looking patients. There are presently several projects around the world that aim to monitor the health of people [7-15]. The authors in [7] describe the BASUMA project, which focuses on developing a robust and energy efficient platform for human wireless body sensor networks to provide at-home monitoring of chronically ill patients. The initial goals of the BASUMA project are to improve the treatment of obstructive pulmonary disease and provide support for female breast cancer patients undergoing chemotherapy. In [8], the author describes how to implement a personal sensor network to monitor patients and help provide health care. This project combines several intelligent sensors and an integrated control node that functions in conjunction with a Bluetooth network. In [9], the authors present a system based on wireless sensor network technology. This project describes an architecture composed of medical sensors incorporated around the human body using the Zigbee standard. The WHAM-Bios project in [10] proposes telemedicine applications to provide real-time emergency medical services. The WHAM-Bios project is based on a device the authors call “Human Body Gateway” where the sensor nodes provide the information needed to produce instantaneous monitoring results. Real-time monitoring requires algorithms that facilitate contention-free communication in order to reduce the power need to transmit data.

The author in [11] focuses on the safety of body sensor networks and wireless communications in close and constant proximity to humans.

In other studies [12, 13], the objective is to incorporate technologies into clothes or common accessories (for example, watches, bracelets, etc.) to measure, register and transmit different physiological parameters, including: heart rate, body temperature, and movement. The authors in [14] describe a prototype that monitors diabetic patients and the authors in [15] describe another prototype of a retinal prosthesis, based on embedded implanted intelligent sensors.

3. RELATED WORK OF THE PROPOSED ALGORITHM

Continuous monitoring of patients requires not only a technological platform, but algorithms that are time sensitive and avoid packet collisions in wireless environments. For example, sensors that record heart function, oxygen saturation, and pulmonary sounds, that can be placed on the body of patients to wirelessly monitor the human body.

This section presents works related to solving contention problems on wireless sensor/actuator networks and techniques for implementing the Earliest Deadline First (EDF) policy on embedded distributed real-time systems.

Modern sensor network applications suffer from significant real-time constraints including jitter, end-to-end delay, latency, packet collision and packet loss. Consequently, the development of real-time communication protocols should address these factors as well as the optimization of the network bandwidth. However, achieving real-time communication over wireless networks is an open issue and presents the inherent difficulties of interference and attenuation due to multipath signals [16].

A strategy to provide delay and throughput guarantees for real-time messages on wireless sensor networks is presented in [17]. The authors present a network capacity analysis of the Implicit-EDF algorithm used to schedule messages. This algorithm effectively exploits the periodic nature of embedded distributed real-time systems traffic. A strategy based on implicit-EDF that uses a consensus procedure for wireless communication supporting dynamic resource reservation and topology management is proposed in [18]. This work advances previous research carried out by [18] by proposing using implicit EDF to guarantee real-time communication by optimizing network traffic flow, although this strategy may imply using the totality of bandwidth resources. The proposed protocol uses a slotted time-triggered medium access transmission control that is collision-free, even in the presence of hidden nodes.

Providing time guaranteed multi-hop transmission in a real-time robotic sensor application is the focus of [19]. Providing guaranteed multi-hop transmission is extremely important if messages are associated with deadlines and must be transmitted over multiple hops from source to destination. Earliest Deadline Strategies are based on per-hop time constraints and are effective because they effectively exploit spatial reuse of the wireless channel and explicitly avoid collisions, thus significantly reducing missed deadlines.

4. THE PROPOSED ALGORITHM FOR WIRELES BODY SENSOR NETWORKS

Figure 1 presents a typical scenario for wireless body sensor networks. 802.15.4 Technology has been selected for this work because of its popularity, maturity and standardization. 802.15.4 Technology employs Direct Sequence Spread Spectrum (DSSS) and Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) for their physical and Medium Access layers, respectively.

Our design strategy for real-time embedded systems functioning on wireless body sensor networks includes an optimization strategy to improve message scheduling. The proposed algorithm used to access the communication channel is based on the EDF policy for scheduling real-time applications. The primary advantage of the EDF strategy is that it permits optimal exploitation of the communication channel, guaranteeing message delivery within a specified time while avoiding packet collisions. Each message is assigned a deadline and all network nodes execute the EDF strategy in parallel, dispatching messages according to their expiration time. The EDF scheduler thus avoids packet collisions by employing a highly synchronized mechanism. Our protocol has been analytically modeled using Colored Petri Networks and Simulated in OPNET.

Figure 1. Wireless sensor network for monitoring the human body.

The communication model is organized in consecutive slots with a constant duration, T_d shorter than the EDF schedule period. This means that can be more than one consecutive slot during the schedule period. The message model follows a periodic producer-consumer model, where embedded distributed nodes broadcast messages to the network at a given frequency and consumers accept messages addressed to them.

A message is characterized by its identifier m_i, the identifiers of the transmitter node n_i, the transmission period, t_i, the relative deadline, d_i, and the message duration, c_i. Message duration depends on the slot time duration t_d.

$$C_T[i] = m_i(n_i, t_i, d_i, c_i, t_i)$$

where t_i is the starting time of a new message period and the control table C_T is replicated in all nodes.

The following example, consisting of four nodes, is considered in the present work, Node1, Node2, Node3, and Node4. We chose 4 nodes because we intend to compare both analytical, simulation and experimental results.

The messages that must transmit are shown in the Table II.

Message	Period	Deadline	Duration	Node
1	40	35	3	1
2	20	20	4	2
3	20	15	2	3
4	40	30	4	4
5	10	10	3	1

Table II. Values utilized for the scenario.

4.1 The proposed algorithm modeled by Colored Petri Networks

The Colored Petri Networks (CPN) are High Level Petri Networks (HLPN) mark colors, time and hierarchies. It is an appropriate graphical formalism for modeling systems where concurrence, synchronization and communications are the key. The CPN and the Petri Networks have been used in successful form for data network, communication protocols, embedded systems, processes modeled of businesses and systems of manufacture.

The model consists of four main blocks whose scheme is shown in Figure 2.

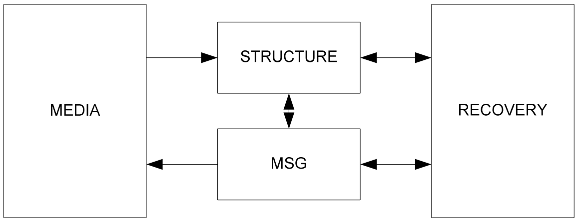

Figure 2. Modeling Scheme.

STRUCTURE BLOCK: This block models the behavior of the table, which is split in two sections:
TAB1: Manages the message sequence. When a node receives a message, the table is updated to determine the next message to be sent.
TAB2: Contains the rest of the table fields, where the information about periods, deadlines, and others important information can be found. When a message is received by a node, it analyzes the table to determine the waiting time of the next message.
***MSG Block*:** This block coordinates the message generation of the nodes and their fields, which include the following:
MSG: The messages in this field are enrolled while waiting to be transmitted.
Nodes: This field models the message generation in the nodes, taking into account their periods.
MEDIA Block: This block models the communication link and contains two sub-divisions:
MSG Out: Represents the exit of the messages.
MSG In: Represents the arrival of the messages.
RECOVERY Block: This block represents the section that is in charge of message sequence recovery. When a node can not send a message, the system has to recover the sequence and send the next message in the list. The most important sections within this block are explained in section S.
S: This section represents the node listening to the medium; the node will remain in this state for the time necessary and is a function of the delays introduced by the transmission medium and the message deadline. If the transmission time is not exceeded before receiving a new message, the message is assigned a new expiration time. If the time between two messages exceeds the assigned transmission time, the recovery process is automatically activated.
Recovery: Validates which node is in charge of transmitting the following message of the list by evaluating the TAB1 and TAB2 sections. If the message has to be transmitted by the high-priority node, it directly transmits its message. If the message is not transmitted within the assigned time limit, the priority node generates and updates the message for the remaining nodes regarding who should transmit the message. The detailed model, making use of CPN Tools is shown in the Figure 3.

4.2 The proposed algorithm modeled in OPNET

The algorithm was simulated in OPNET. We employed the same four nodes as previously described. According to the EDF scheduler, before a node can transmit a packet, it verifies its table and executes the following algorithm (Figure 4).

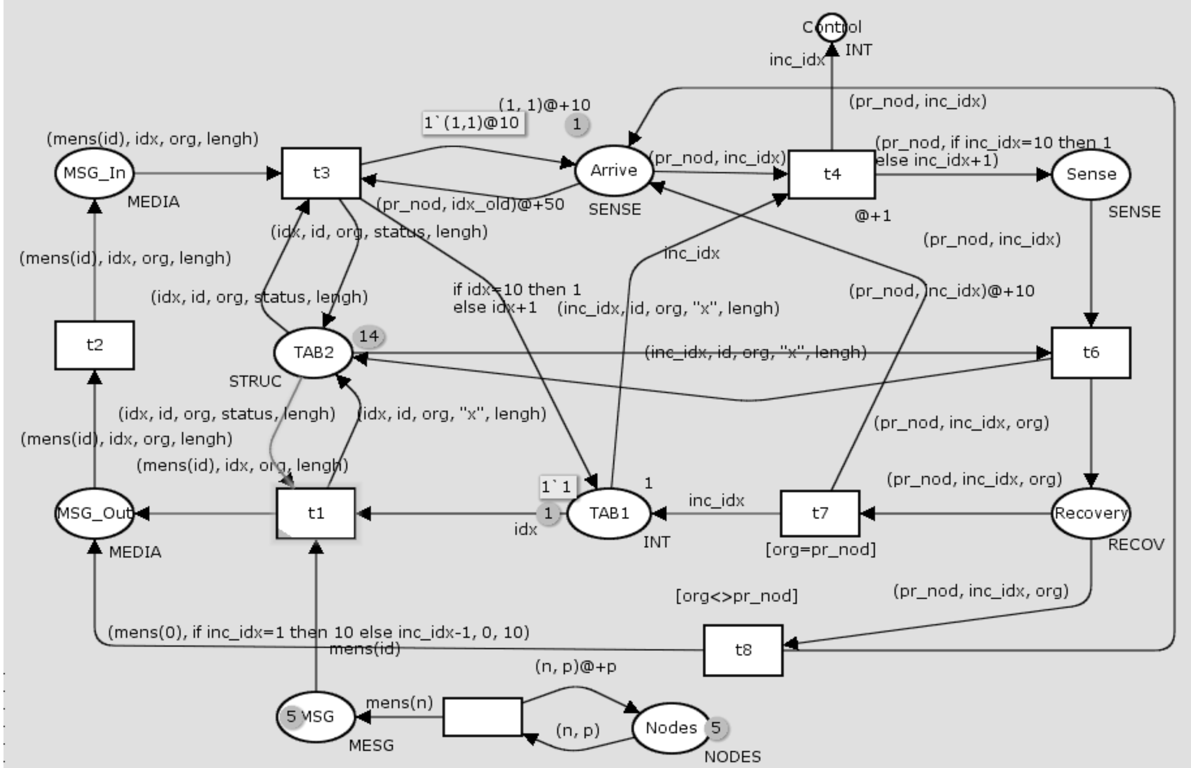

Figure 3. Colored Petri Net for modeling the proposed algorithm.

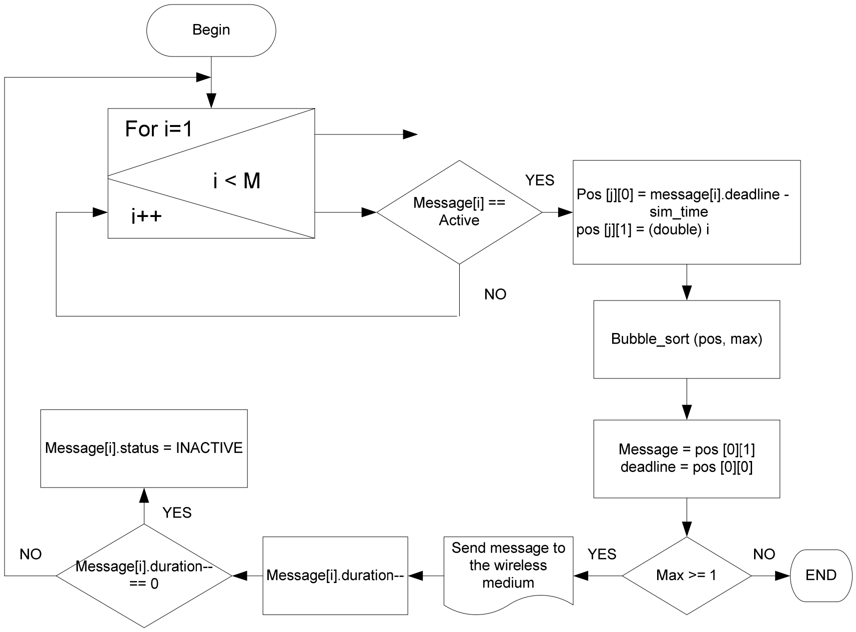

Figure 4. Flow diagram of the proposed algorithm as simulated in OPNET.

5. RESULTS OBTAINED BY CPN AND SIMULATION

Figure 5 shows the message transmission for the simulated scenario. The horizontal axis represents the slot times in seconds and the vertical axis indicates the specific number of message transmitted. Number 5 is the first message transmitted for a period of three seconds. Message Number 3 is the second message transmitted for a total of two seconds. Following this, message Number 2 transmits for four seconds while, simultaneously, message Number 5 activates and retransmits again for three seconds. A different sequence is then initiated for message Number 4 and all of the other subsequent messages.
Figure 6 presents the duration of each message. Here, the horizontal axis indicates the slot time. In figure 6, the duration begins with a value of two, which provides the number of remaining packets to be transmitted. If Figure 5 and Figure 6 are correlated, the number of messages being transmitted and the number of remaining packets of that specific message can be determined. In this real time algorithm, it is possible to have empty slot times because there is no information being transmitted at that specific moment. However, the real time algorithm allows for the deterministic distribution of bandwidth.

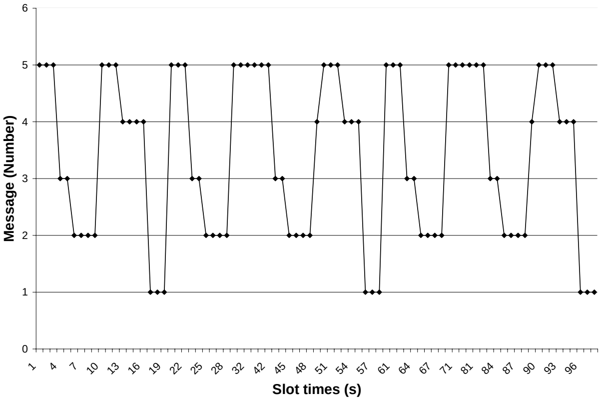

Figure 5: Message transmission

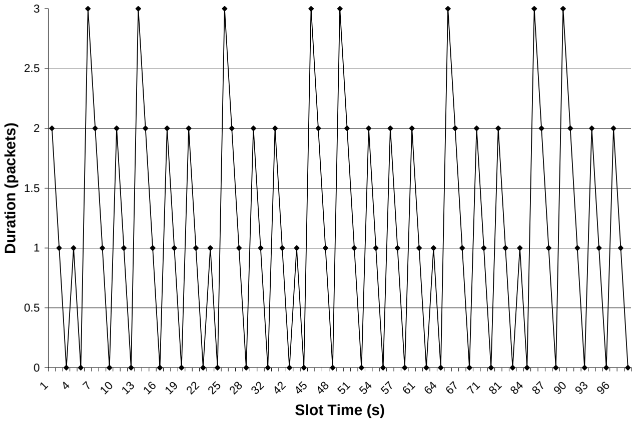

Figure 6: Duration of each message.

6. CONCLUSIONS

This work has validated a novel algorithm that is based on an Earliest Deadline First (EDF) Scheduler for wireless body sensor networks. The proposed algorithm has been analytically modeled using Colored Petri Networks and Simulated in OPNET. Four nodes were distributed and pre-configured off-line with our proposed algorithm, which is currently appropriated for body sensor networks. We propose this real-time algorithm for wireless networks containing few nodes. EDF has the advantage of sharing the bandwidth between all active nodes while prioritizing nodes with the shortest deadline. In future work, we plan to employ a larger test bed and incorporate our proposed algorithm into a set of wireless sensor nodes.

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