Ad Hoc Networks 42 (2016) 1–18

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

A Priority based Cross Layer Routing Protocol for healthcare applications

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ARTICLE INFO

Article history:
Received 28 February 2015
Revised 9 October 2015
Accepted 20 October 2015
Available online 2 November 2015

Keywords:
Wireless Body Area Networks
Healthcare
QoS
MAC
Cross layer
Routing

ABSTRACT

Wireless body area networks (WBANs) represent one of the most promising approaches for improving the quality of life, allowing remote patient monitoring and other healthcare applications. Data dissemination and medium access in a WBAN are critical issues that impact the network reliability, the efficiency and the total energy consumed by the network. In this paper, we propose a Priority-based Cross Layer Routing Protocol (PCLRP) along with a Priority Cross Layer Medium Access Channel protocol (PCLMAC) for healthcare applications.

PCLRP combined with PCLMAC ensures reliable traffic dissemination and customized channel access for intra- and inter-body communications. Simulation results show that the proposed protocol achieves customized quality of services and outperforms state of the art existing protocols in terms of power consumption, packet delivery ratio and delay.

1. Introduction

The increase in average lifespan and health costs along with the advances in miniaturization of electronic devices, sensing, battery and wireless communication technologies have led to the development of wireless body area networks (WBANs). In the health field, a WBAN consists of a set of medical sensors (i.e., ECG, EEG) and a coordinator (personal digital assistant (PDA) or a smart phone) implanted in or on the user's body [1–4]. These devices aim to collect, store and process patient's physiological parameters and provide him ubiquitous healthcare services. Due to their specific properties such as small size, data rate, reliability, security, mobility, power constraint, QoS requirements, and heterogeneous traffic, WBANs require special protocols design to meet their particular needs. In other words, although WBANs derive somehow from WSNs, there are intrinsic differences between these two networks (which are summarized in Table 1).

Ever since WBANs have emerged, different optimization schemes have been proposed to overcome the above challenging issues.

Cross-layer approaches have proven to provide better WBAN optimization results than their layered counterparts [7]. Indeed, layer cooperation in cross-layer based schemes well enhances the overall WBAN performance. For instance, in a cross-layer scheme, the QoS requirements at the application layer can be communicated to the MAC layer in order to achieve better resource allocation for the running healthcare application. Furthermore, the channel state information and battery level can be fed to the network layer to avoid paths including channels in a bad state or depleted nodes.

The great number of proposed WBAN cross-layer approaches (reviewed in Section 2) proves that there is still a need for further optimization of such networks, and that cross-layering is efficient to accomplish that. From this point of view, this paper presents a Priority based Cross Layer Routing Protocol for healthcare applications, named PCLRP. PCLRP is an adaptive protocol in the sense of slot assignment

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http://dx.doi.org/10.1016/j.adhoc.2015.10.007
1570-8705/

Table 1
Comparison between WSNs and WBANs [5,6].

Challenges	WSN	WBAN
Scale	Monitored environment (m/km)	Human body (cm/m)
Node number	Many redundant nodes for wide area coverage	Fewer, limited in space
Node tasks	A node performs a dedicated task	A node performs multiple tasks
Node size	Preferred small, but not important	To be small is essential
Network topology	Very likely to be fixed and static	More variable due to body movement
Data rates	Homogeneous	Heterogeneous
Node replacement	Performed easily, nodes may be even disposable	Difficult (implanted nodes)
Node lifetime	Several months/years	Several months/years
Path loss	medium (free space)	important
Energy scavenging source	Most likely solar and wind power	Most likely motion (vibration) and thermal (body heat)
Biocompatibility	Not a consideration in most applications	A must for implants and on-body sensors
Security level	Lower	Higher, to protect data of patient
Impact of data loss	May be compensated by redundant nodes	More significant, may require additional measures to ensure QoS and real-time data delivery
Wireless technology	Bluetooth, Zigbee, GPRS, WLAN, ...	Low power technology (i.e., Bluetooth low energy)

techniques, sleep and wakeup mechanisms in face of topology changes. Moreover, it combines TDMA and priority guaranteed CSMA/CA approaches to access the channel and well defines a synchronization scheme to avoid collisions, data loss and idle listening. Furthermore, PCLRP handles WBAN traffic heterogeneity by defining three traffic classes:

- General Monitoring packets for ordinary Medical data;
- Delay Sensitive packets for High-priority medical data;
- Emergency packets for critical medical data.

PCLRP further ensures resource allocation and route selection in compliance with the heterogeneous QoS requirements of such traffic classes. In fact, as a key innovative feature, in this work we investigate the channel access issue both for intra and inter body communications with a clear differentiation between multiple traffic types with respect to their QoS requirements. This paper is a significant extension of existing WBAN MAC protocols in which the TDMA slots allocation is restricted to intra body nodes. More specifically, to ensure more reliability and collision avoidance, the PCLMAC superframe contains a Contention Free Period (CFP) customized for inter WBAN cooperation.

In summary, our paper makes the following key contributions:

- We define a set of healthcare monitoring applications (or traffic categories) to represent general monitoring traffic data, high priority and emergency data.
- To give meaning to the traffic classification, we propose a Priority Cross Layer Medium Access Channel protocol, PCLMAC, which operates in compliance with the defined traffic categories.
- We further propose an intra-body and extra-body routing protocols that operate in cooperation with the defined PCLMAC protocol.
- We perform a thorough performance comparison between our proposed approach and the Wireless Autonomous Spanning tree Protocol (WASP) for multi-hop wireless body area networks [8] and Data centric Multi objective QoS-aware routing protocol (DMQoS) for body sensor networks [9]. Numerical results show that PCLRP is indeed effective, since it significantly saves energy and ensures high reliability.

The paper is structured as follows: Section 2 discusses related work. Section 3 introduces our WBAN network model and traffic categories. In Section 4 we present our PCLRP approach, while we illustrate and discuss numerical results that show the efficiency of our proposal in Section 5. Finally, Section 6 concludes this paper and presents some future works.

2. Related work

Several works have appeared in the literature with the purpose of ensuring efficient routing and enhancing the QoS of WSNs [10,11]. Nevertheless, as mentioned in Table 1 the specificity of the operating environment and treated data make WBANs unique and require specific protocol design. In brief, WSNs protocols will not work as efficiently as the protocols specifically designed for WBANs. In this section, we survey some relevant ones that are tightly related to our work.

WBAN cross-layer protocol design is an emergent research area that aims to deliver greater efficiencies than single layer adaptation schemes [7]. We highlight the proposed cross-layer routing protocols for integration in WBAN systems.

Generally, cross-layer schemes may be either loosely coupled or tightly coupled designed. Loosely coupled protocol designs focus on communicating the lower layers available parameters to upper layers and/or coupling the functionalities of some adjacent layers in order to ensure overall network performance. Accordingly, in the loosely coupled approach the individual layers within the protocol