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Real-time query processing optimization for cloud-based wireless body area networks

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ABSTRACT

Wireless body area networks (WBANs) have received a lot of attention from both academia and industry due to the increasing need of ubiquitous computing for eHealth applications, the continuous advances in miniaturization of electronic devices, and the ultra-low-power wireless technologies. In these networks, various sensors are attached either on clothes, on human body or even implanted under the skin for real-time health monitoring of patients in order to improve their independent daily lives. The energy constraints of sensors, the vital and large amount of data collected by WBAN nodes require powerful and secure storage, and a query processing mechanism that takes into account both real-time and energy constraints. This paper addresses these challenges and proposes a new architecture that combines a cloud-based WBANs with statistical modeling techniques in order to provide a secure storage infrastructure and optimize the real-time user query processing in terms of energy minimization and query latency. Such statistical model provides good approximate answers to queries with a given probabilistic confidence. Furthermore, the combination of the model with the cloud-based WBAN allows performing a query processing algorithm that uses the error tolerance and the probabilistic confidence interval as query execution criterions. The performance analysis and the experiments based on both real and synthetic data sets demonstrate that the new architecture and its underlying proposed algorithm optimize the real-time query processing to achieve minimal energy consumption and query latency, and provide secure and powerful storage infrastructure.

1. Introduction

The observed aging of population in many developed countries and the rising costs of health care, has been receiving a considerable interest from researchers, system designers, and application developers on a new type of network generally known as wireless body area networks (WBANs) [1,5,15,27]. A wireless body area network is composed by small and intelligent devices, generally called body sensors, attached either on clothes, on body, or even implanted under the human skin. These devices are able to sense, sample, process, and wirelessly communicate continuous user's physiological state monitoring [11,39]. The sensed data is sent to a nearby personal server (PS) device, e.g., a Personal Digital Assistant (PDA)

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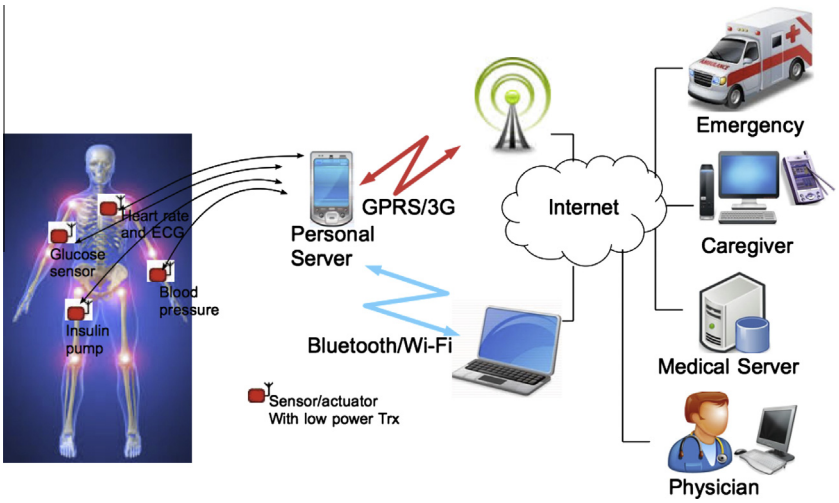

Fig. 1. Illustration of a WBAN architecture.

or a Smartphone, which acts as a sink. Then, through a Bluetooth/WLAN connection, this data is streamed remotely either to a medical personnel's site for real-time diagnosis, or to a medical database for storage, or even to the corresponding equipment that issues an emergency alert [6,15,47]. Fig. 1 illustrates a WBAN and exemplifies the above-mentioned connection scenarios.

Generally, a wireless body area network uses two main types of devices, sensors and actuators. Sensors are used to measure certain parameters of the human body such as heartbeat, blood pressure, body temperature, and recording prolonged electrocardiogram (ECG). Actuators perform some specific actions according to the data they receive from the sensors or through interaction with users. For example, an actuator equipped with a built-in reservoir and pump administers the correct dose of insulin to diabetics based on the glucose level measurements from body sensors [27]. However, these tiny sensors are severely energy-constrained since they run either off a small battery or use energy scavenging techniques [34]. Therefore, optimizing energy consumption is an essential focus point in WBANs research [33,44,49].

Energy-efficient solutions for WBANs can be obtained at different levels [30], such as low power RF transceiver design [4], network architecture [35], energy scavenging [37], energy-efficient communication protocols [46], and node level [14,2]. Since wireless communication activities are more expensive in energy consumption than the sensing and processing activities [20,32,33], saving energy by minimizing the data communication activities is one of the main research topics on this area and the main driver of this work.

Systems based on body sensor networks are getting increasingly used in many areas of application including vaginal temperature monitoring [10,40], healthcare, athletic training, workplace safety, consumer electronics secure authentication, and safeguarding of uniformed personnel [12]. However, the processing time becomes increasingly critical for such applications. These applications must query and analyze the data in limited time periods in order to take real-time decisions and to react efficiently [19].

The data collected from a WBAN must closely reflect the current physiological state of the targeted patient. However, the patient's physiological state changes constantly and the data is collected in discreet moments of time. Then, the collected data has a temporal validity and as time advances it becomes less accurate until it does not reflect the physiological state of the patient any longer [23,24]. It is then fundamental that responses of queries from medical applications ensure that returned data complies with logical and temporal constraints. Moreover, the energy constraints of sensors, the vital and large amount of data collected from WBAN nodes requires powerful and secure storage, and a query processing mechanism that minimizes the energy consumption and latency. In this context, the design of a secure and powerful storage infrastructure, and a query processing mechanism that takes into account both time-constraints of data and energy consumption is fundamentally important due to the real-time requirements of medical data and the resource limitations of WBAN nodes. To reach these goals, this work proposes a new architecture that combines a WBAN, which uses cloud services [9,29,48,50] with statistical modeling techniques in order to optimize real-time user queries to achieve minimal energy consumption and latency, and provide a secure storage infrastructure. The main contributions of this paper are the following:

1. Proposal of a new architecture that combines a WBAN that uses cloud services with statistical modeling techniques in order to efficiently extract and store patient data, and provide to nearby or remote user/medical personnel a real-time diagnosis.
2. Proposal of a query processing algorithm, which is based on the new architecture and optimizes the real-time user query processing for minimizing the energy consumption and the query latency. The query processing algorithm uses a statistical model to compute the error and the confidence interval on the patient data stored in the medical database server