Computers in Industry 69 (2015) 92–104

Contents lists available at ScienceDirect

Computers in Industry

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

Impact of sensor nodes scaling and velocity on handover mechanisms for healthcare wireless sensor networks with mobility support

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ARTICLE INFO

Article history:
Received 2 February 2014
Received in revised form 28 June 2014
Accepted 25 September 2014
Available online 11 November 2014

Keywords:
Body sensor networks
Healthcare applications
Healthcare wireless sensor networks
Mobile health
e-Health
Mobility

ABSTRACT

Health promotion in hospital environments can be improved using the most recent information and communication technologies. The Internet connectivity to small sensor nodes carried by patients allows remote access to their bio-signals. To promote these features the healthcare wireless sensor networks (HWSN) are used. In these networks mobility support is a key issue in order to keep patients under real-time monitoring even when they move around. To keep sensors connected to the network, they should change their access points of attachment when patients move to a new coverage area along an infirmary. This process, called handover, is responsible for continuous network connectivity to the sensors. This paper presents a detailed performance evaluation study considering three handover mechanisms for healthcare scenarios (Hand4MAC, RSSI-based, and Backbone-based). The study was performed by simulation using several scenarios with different number of sensors and different moving velocities of sensor nodes. The results show that Hand4MAC is the best solution to guarantee almost continuous connectivity to sensor nodes with less energy consumption.

1. Introduction

Wireless sensor networks (WSNs) are increasing their interest and applicability in network domain applications. Following the vision of Internet of Things (IoT) paradigm and, even, the Internet of everything, WSNs become one of the most promising technologies able to potentiate that vision. Recently, special focus has been devoted to WSNs application in healthcare facilities [1]. This new application emerged at the top of WSNs' research topics [2,3]. The use of WSNs in healthcare domains try to optimize operations related to patients' monitoring tasks. Traditionally, medical staff close to patients performs these tasks at regular time intervals. These traditional methods do not allow continuous control of certain health parameters. Moreover, if abnormal situations occur between these time intervals, then the time needed to detect these issues could be too long. WSNs applied in healthcare scenarios (known as healthcare WSNs–HWSNs) can help medical staff to perform effective continuous and real-time monitoring of patients over all health conditions [4]. HWSNs can ensure a tight control of the patients' health parameters [5]. The monitoring tasks of patients' health parameters can be autonomous and automated using small sensor nodes attached to their bodies. Besides, these sensor nodes can be wireless, connected to a network infrastructure and so make them accessible anywhere, at any time over the Internet [6]. To promote the patients' comfort, the sensor nodes have to be tiny and light. These features limit the resources available in these devices. A sensor node is comprised of four main modules, namely, processing module, sensing module, communication module, and power module [7]. The processing module includes the microcontroller which is responsible for executing the software algorithms that operate the device; the sensing module which provides the sensor node with the ability to collect certain parameters; the communication module that allows the sensor node to send data wirelessly to a network typically compliant with the standard IEEE 802.15.4; the power module includes the power

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http://dx.doi.org/10.1016/j.compind.2014.09.002
0166-3615/

source (typically batteries) that keeps the sensor node alive [7]. Due to the sensor nodes' constraints, especially available energy, the operations performed by these devices should be optimized.

Using this technology in scenarios where sensor nodes tend to be mobile, like healthcare scenarios, brings new challenges to the WSNs research area [8–10]. Due to the limitations of the wireless signal propagation in situations like these [11], the creation of wireless networks for indoor environments should have several network access points (APs). Thus to cover the entire area of an infirmary, for example, several APs should be used. One of the main challenges in these scenarios is how to keep sensor nodes accessible to the network if they travel between different APs' coverage areas [12]. To keep sensor nodes always accessible they should not lose their connection to the network [13]. This means that the sensor nodes should be aware of the right moment to change their network attachment between two APs. This change should be performed within the overlapped coverage areas of two APs by evaluating the best solution to keep the sensor nodes connected to the network. This process of evaluating and changing the network point of attachment is called handover [14]. Deciding if it is better to perform a handover or not, the sensor node should be aware of certain network parameters. For handover decisions one of the most common parameters is the received signal strength indicator (RSSI). After receiving a message the RSSI value for that message can be obtained. Analyzing this value can estimate if handover is needed or not. Variations in RSSI values are related to the distance between the sender and the receiver. So, if the RSSI value becomes too small, it means that the sensor node is too far from the sender. This process is widely used to decide node handovers in WSNs. Several approaches were recently proposed to estimate the best moment to perform handover of sensor nodes [15–18]. As above-mentioned, it is important to keep the patients' bio-parameters constantly under control [19]. Thus, all the handover approaches should attempt to maximize the connectivity of sensor nodes to the network. In this quest, one of the main concerns is to reduce the energy consumption used along handover processes and thus increase the battery life of sensor nodes [20].

This paper presents a comprehensive study of the most significant proposals for handover in WSNs. It demonstrates, by simulation, the application of these proposals in a HWSN scenario. Several situations were evaluated and the results for each proposal were compared and analyzed in detail. Then, the main contributions of this paper are the following:

- Performance assessment of the most significant handover mechanisms in comparison with the perviously proposed. Hand4MAC mechanism, considering different healthcare scenarios;
- Influence analysis of the number of sensor nodes and their velocity on the network connectivity and energy consumption.

The rest of the paper is organized as follows. Section 2 presents the most significant handover approaches presented in the literature. Section 3 describes the network model under study while Section 4 focuses on the performance evaluation of the handover mechanisms considered on this study. Finally, Section 5 concludes this paper highlighting the main conclusions of the study.

2. Handover mechanisms for intra-mobility support

This section provides an overview of the most recent and more relevant WSNs handover mechanisms available in the literature for mobility scenarios. These solutions allow communication to sensor nodes even when traveling across several APs coverage areas. This study devotes special attention to the application of these solutions in HWSNs scenarios [21]. Based on a comprehensive review of handover approaches it was concluded that they could be clustered into two main groups. These two groups are mentioned in this study as RSSI-based group and Backbone-based group. Next, a detailed description of each group is presented.

The RSSI-based group combines solutions based on continuous monitoring of RSSI values. The comparison of these values with a predefined threshold is used to decide whether a handover should be performed or not. On these solutions the sensor nodes and the associated APs exchange messages at short intervals in order to evaluate the RSSI value in comparison to the predefined threshold. If the received RSSI value is under the threshold then the sensor node proceeds to handover and starts searching for a new AP to associate with it. Relevant available solutions that use this approach are presented in [16–18,22].

Zinon et al. [16] and Jara et al. [17] proposed an intra-mobility support system named GinMAC. This proposal works as follows. The APs send a KEEP-ALIVE message to the registered sensor nodes at periodic time intervals. This behavior helps the sensor nodes to know the exact moment to expect for these messages. If a sensor node does not receive this message from its registered AP, then, it sends a NODE-ALIVE message to that AP and waits for the response. If the AP does not answer to that message, afterwards, the sensor node starts searching for a new AP. This proposal defines a critical zone bounded by a predefined RSSI threshold and a rupture point. If the RSSI value of the received KEEP-ALIVE message is within this critical zone, then, the sensor node immediately starts searching for a new AP. In the other hand, if the KEEP-ALIVE message is not received within the critical zone it means that the sensor node is already out of AP's coverage area and, therefore, without connection to the network.

Valenzuela et al. [20] presented a mobility support system for wearable sensors in controlled environments like home. One of the sensor nodes carried by the patients act as a coordinator, which is responsible for the communication with the network APs. To start the process of mobility support the coordinator broadcast a PING_MSG. All the APs that receive this message respond to the coordinator. The coordinator then analyzes the RSSI value of all the received messages and chooses to register to the AP with better RSSI value. After the registration all the data messages exchanged by the sensor node and the registered AP are used to monitor the RSSI value. If this value drops bellow a predefined threshold it is evaluated the possibility of any other sensor node controlled by this coordinator assume temporarily the coordination. This evaluation is based on the RSSI values of these sensor nodes and the registered AP. If the RSSI value drops below a predefined threshold for all the sensor nodes under control of that coordinator, then, it means that is time to search for a new AP as described at the beginning of this description.

The Backbone-based group combines solutions that use a shared Backbone to interconnect all the APs. This Backbone is used to exchange information between adjacent APs to guarantee the communication to sensor nodes. In these solutions the handover process is performed through the Backbone by predicting the next AP in the route of the sensor node. Under this approach each sensor node has a corresponding AP. This AP is responsible for the handover handling of all the sensor nodes that it is corresponding. The choice of corresponding AP for a certain sensor node is based on the best available RSSI value. The link quality between sensor nodes and their APs are always under monitoring using short interval exchange messages. If a deterioration of the RSSI value is detected, then, the corresponding AP informs the adjacent APs to start searching for this sensor node. This communication is performed through the Backbone. When a new AP detects the sensor node this AP becomes the new corresponding AP for that sensor node. Then, this new AP informs the previous AP of this