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Multi-Attribute Decision Making Handover Algorithm for Wireless Body Area Networks

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ABSTRACT

In this paper, we tackle the Wireless Body area Network (WBAN) handover issue where a mobile patient has to select at any time the best access technology according to multiple criteria. We particularly focus on the decision schemes and investigate the Multi-Attribute Decision Making (MADM) methods. The fundamental objective of the MADM methods is to determine among a finite set of alternatives the optimal one. Therefore, we propose a Multi-Attribute Decision Making Handover Algorithm (MADMHA) which helps patient's mobile terminal to dynamically select the best network by providing a ranking order between the list of available candidates. It is a seamless handover approach that guarantees continuous connectivity with respect to the QoS requirements of the WBAN generated traffic types, network history and user preference. Simulation results prove the efficiency of our proposed approach versus the Received Signal Strength Indicator (RSSI) and Data Rate (DR) based handover approaches. Indeed, compared to these latters, MADMHA significantly reduces the packet overhead and the number of handover, while limiting the packet loss ratio.

1. Introduction

WBANs are an effective means to provide many promising applications in different domains [1–3]. In fact, WBANs are applied in a variety of areas such as healthcare, medicine, patient monitoring, sport and multimedia, to cite a few. In the healthcare domain, a WBAN consists of a set of medical sensors (ECG: Electrocardiogram, EEG: Electroencephalogram, etc.) implanted in or on the user's body, and a coordinator for data transmission, which can be a Personal Digital Assistant (PDA) or a smartphone. These devices collect, store and process patient's physiological parameters (heartbeat, blood pressure, body temperature, etc.) and provide ubiquitous healthcare services.

Indeed, remote healthcare monitoring technology is expected to reduce unnecessary hospitalizations and shorten length of stay when admission is necessary. It improves the level of patients engagement and care, regardless of their location around the globe, and enables more timely intervention from caregivers and clinicians through real-time data monitoring and alerts. For clarification purposes, let us take the example of a patient, suffering from coronary heart disease, who wants to go home safe knowing that he is taken care of. So, he leaves the hospital and is sure that a medical team will be promptly dispatched to his location when needed. To achieve this, the remote healthcare ECG application used by the patient must send its ECG pattern and location to the healthcare professionals whenever an irregular ECG pattern is detected. Another interesting example of timely interventions is an application used for trauma situation. In this case, the surgeon may take a decision about the surgery on a trauma patient based on the continuously received bio-signals at the hospital back end healthcare server, while the on-site trauma team is transporting the patient to the hospital [4].

However, the effectiveness of these real-life trials of remote healthcare applications can be affected by *user mobility*, wireless networks availability, required healthcare QoS, network density and the battery limitations of mobile devices. Hence, there is the need for a seamless handover approach that ensures patient mobility management while keeping the patient always best connected.

Furthermore, since recent PDA and smartphones are equipped with several radio interfaces for Bluetooth, WiFi, Universal Mobile Telecommunication System (UMTS), Long Term Evolution (LTE) (among others) the main issue is how to take profit from this multihoming opportunity in order to develop improved WBAN handover practices to maintain healthcare service continuity and cope with mobility and ubiquitous coverage issues [5].

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Even though each technology has its own characteristics (WiFi: high-data-rate, short range, low mobility; 3G: low-data-rate, high mobility, and LTE: low latency, high throughput, high speed and Limited coverage outside urban areas) the majority of WiFi coverage areas overlap with 3G and LTE ones. Furthermore, there exist wide differences in data generation rate and delay/loss-tolerances amongst the data packets generated by heterogeneous WBAN devices. For example, some low-data-rate medical sensors like heartbeat, blood pressure, electroencephalogram sensors may generate very time-critical data packets, which must be communicated to the medical staff within a guaranteed end-to-end delay deadline. In contrast, some high-data-rate sensors (e.g., streaming of ECG signals) may allow a certain percentage of packet losses. Hence, an efficient decision-making algorithm is needed in order to choose the best network among the available list according to the application's requirements, and seamlessly perform the *handover* process.

In the literature, several mechanisms (reviewed in Section 2) have been proposed to mitigate the handover problem. However, to the best of our knowledge, no effective solution has yet been proposed so far particularly for WBANs.

The main innovative contribution of this paper is the proposition and analysis of a handover protocol that well adapts to the remote healthcare domain and takes accurate account of the constant evolution of patient's QoS requirements. In fact, it is important to underline that many changes can happen in terms of QoS requirements of WBAN sensors over time. In other terms, the sampling rate, the required latency, and the importance of sensed data, which are key metrics for network selection, can indeed change according to the patient's condition. For this reason, in MADMHA, the handover triggering process depends on the patient conditions. Furthermore, the proposed handover algorithm allows the patient to remain connected to the current network that still guarantees the required QoS of the running healthcare application even though a new network is discovered. It is also based on a soft handover approach, which is referred to as "make-before-break", thus ensuring that the mobile patient's new connection is created at the target PoA before the old PoA connection is released.

In summary, our paper makes the following key contributions:

- We conduct a technical and numerical comparison between different wireless technologies (i.e., IEEE 802.11x, UMTS, LTE).
- We define a set of healthcare monitoring applications (or traffic categories) to represent general monitoring traffic data, high priority and emergency data.
- We determine for the considered applications their corresponding QoS metrics, which are used by our handover approach to perform an optimal network selection.
- We propose a novel and effective multi-attribute-decision-making handover approach which guarantees the required quality of service level while taking accurate account of network history and user preference issues.
- We perform a thorough performance comparison between our proposed approach and existing ones. Numerical results show that MADMHA is indeed effective; it significantly reduces the packet overhead and handover frequency, while limiting the packet loss ratio.

The paper is structured as follows: Section 2 discusses related work. Section 3 highlights the main characteristics of LTE, UMTS and WiFi technologies. Section 4 introduces our WBAN network model and traffic categories. In Section 5 we present our MADMHA algorithm, while we illustrate and discuss numerical results that show the efficiency of our proposal in Section 6.

Finally, Section 7 concludes this paper and presents some future works.

2. Related work

Since in our previous works [6–8] we already addressed the intra-body communication level, we focus here on the extra-body one.

Specifically, we consider a mobile WBAN-based environment and tackle the handover issue, which is very challenging [5,9–12]. Therefore, in this section we survey several recent works dealing with the handover phenomenon that are tightly related to our work.

Even though in all these works the target is the same (i.e., keeping mobile devices always connected), handover decision parameters vary from one proposal to another. The handover decision may depend on one or a combination of static parameters (power consumption, monetary cost, security) and/or dynamic ones (data rate, available bandwidth, RSSI, Signal-to-Interference-and-Noise Ratio (SINR), latency, velocity, user preference and so on.) [13]. The most widely used parameters in *single metric* handover approaches [14] are the RSSI and the Data Rate (DR). The RSS-VHD approach (RSS-based Vertical Handover Decision) proposed in [14] is based on a comparison between the measured RSS value by different mobile terminals and the defined RSS thresholds. Therefore, when the RSS of WLAN drops below defined thresholds, the registration procedures are initiated for Mobile terminal's handover to the 3G network. On the other hand, the DR-VHD approach proposed by the same authors is based on the evaluation of the offered data rate in the current serving network with respect to available, candidate networks. A DR-VHD takes place whenever a transition to a candidate network can ensure a data rate gain. Although single metric handover approaches are easy to implement, they can suffer from lack of effectiveness. Therefore, unnecessary handover may occur, and this can lead to high energy consumption and huge packet loss due to ping pong effect. Authors in [15] have combined several parameters, such as security, energy consumption, bandwidth and link quality in a normalized weighted cost function to select the best available network. However, evaluating the security level of a network via a simple parameter in a cost function is a difficult task. Network history and traffic differentiation are also overlooked in this latter work. Khan et al. [16] use a cost function to perform the handover decision between WiMAX and WiFi. In a double coverage area, users switch to the network having the smallest cost. However, the cost function adopted in this work is the sum of heterogeneous and non-additive parameters.

Authors in [17] make use of Game Theory to address the handover problem. Indeed, the best target network is modeled through a Bayesian Nash-equilibrium point that trades off between quality of service maximization and cost minimization. Even though the proposal ensures low handover delay and communication prices, it completely overlooks traffic differentiation.

Other works have considered a cross-layer approach [18,19]. In [18], a cross-layer handover management framework is proposed and handover triggers are launched according to an information database gathered from different layers. Then, two types of handover are defined: imperative and alternative handover. A handover is considered as imperative if there is a signal strength loss. On the other hand, it is considered an alternative one when there is a need for QoS enhancement due to a change in application requirements and/or user's preferences.

Similarly, Rehan et al. [19] in their approach gather information from the Medium Access Control (MAC), transport, and application layers for handover triggering, considering user's preferences.

According to their requirements, users may choose a cost effective network or the best performing one even if it is costly.