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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.

Table 1
Properties of WiFi, UMTS and LTE [28].

	IEEE 802.11a	IEEE 802.11b	IEEE 802.11g	IEEE 802.11n	UMTS	LTE
Radio technology	OFDM MIMO	OFDM MIMO	OFDM MIMO	OFDM MIMO	CDMA FDD	OFDM SCFDMA
Frequency	5 GHz UNII	2.4 GHz	900 MHz	2.4, 5 GHz	450, 850 MHz, 1.9, 2, 2.5, 3.5 GHz	800, 1800 MHz
Range	~30 m	~30 m	~30 m	~50 m	~26 km	30–50 km
Peak downlink (Mb)	54	11	54	600	14.4	326.4
Peak Uplink (Mb)	54	11	54	600	0.3840	86.4
Typical downlink throughput (Mb)	20	5	20	–	2	–
Access protocol	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA	WCDMA	OFDMA
Network topology	Infrastructure	Infrast.	Infrast.	Infrast.	RAN	RAN
Main disadvantages	Short range	Short range	Short range	Short range	Handover problems	Expensive

However, even though a variety of parameters from different layers are used to perform the handover, the decision-making process described in such a work is not well-defined and somehow ambiguous.

MADM is a process for making preference decision over the available alternatives. Simple Additive Weighting (SAW), Weighting Product (WP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are existing MADM methods that deal with the issue of selecting the best one from a set of alternatives, according to multiple attributes. These different methods are adopted by researchers to treat the handover problem [20–22]. The authors in [20] combine SAW and WP to rank the list of visited networks and select the best one. TOPSIS has been used in [21] to ensure a seamless handover. In [21], the authors point out the worst and best network, and define the target network as the closest to the ideal solution and the farthest from the worst one.

Although these MADM methods have many strengths, they suffer from some limitations. Indeed, according to [22] both SAW and WP suffer from the lack of accuracy in identifying the rank of alternatives, while TOPSIS suffers from the ranking abnormality problem. Such problem occurs when a low ranking alternative is removed from the list of candidates (e.g., one network is suddenly disconnected), so that the order of higher ranking alternatives will change abnormally. Thereby, to improve MADM for seamless handover, we propose in this work an hybrid approach, called MADMHA, that leverages the strengths and overcomes the weaknesses of existing MADM methods.

3. Comparison of wireless technologies

A wide variety of different wireless technologies exist (i.e., WiFi, WiMAX, UMTS, LTE, LTE Advanced), some in direct competition with each other, others designed for specific applications [10,23–27]. In this section, however, we focus on WiFi, LTE and UMTS for providing extra-body communication since nowadays commercialized personal devices are equipped with radio interfaces using these wireless technologies, in addition to Bluetooth for intra-body communications. For an exhaustive review of different wireless technologies, with their advantages and disadvantages, for promoting mobile e-health applications please refer to [10,27]

WLANs, often known by their commercial product name WiFi, have a variety of standards, each represented with a letter suffix. Of these, the standards that are most widely known are IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, and IEEE 802.11n. Besides, 4G WAN technologies (e.g., LTE) provide even higher bitrates and many architectural improvements than 3G ones (UMTS). These technologies can be evaluated by a variety of different metrics of which some are described in this section. Therefore, Table 1 illustrates a rough comparison between different WiFi standards, UMTS, and LTE technologies.

The complementary of these technologies in terms of coverage area, technical characteristics and commercial opportunities for the operators fostered the development of smartphones and PDA integrating multiple radio interfaces. The emergence of such mobile terminals equipped with various interfaces provides many interesting benefits, such as permanent and ubiquitous access. However, it raises vertical handover issues which is the process of handover that occurs by the movement of a mobile node among the heterogeneous technologies [16].

4. Network model and traffic categories

Despite the fact that WBANs have many promising application domains, this work focuses on the remote healthcare monitoring one. Therefore, in this section we present our healthcare network model as well as the proposed traffic categorization in this latter domain.

4.1. Network model

In our network model, we consider a set $\mathcal{N}$ of WBANs (e-health users) and a set $\mathcal{M}$ of heterogeneous wireless networks. We focus in this work on remote healthcare monitoring applications, and we define three categories of traffic (GM, DS, and EM) which are described in detail in the next section. Let us denote the set of applications (or traffic categories) by $\mathcal{K} = \{GM, DS, EM\}$.

As mentioned before, a WBAN's collected data is transmitted to its final destination via a Personal Device (PD). We assume that the PD is equipped with an IEEE 802.15.6 interface for intra-body communication (communication between the PD and the sensors of the same WBAN) and other radio interfaces (like WiFi, 3G, 4G, etc.) to ensure extra-body communication (communications between the PD and the medical staff).

A WBAN (or a patient) may move in different places, like a mobile system, and wants to ubiquitously disseminate its collected data to the e-health staff (doctor, nurse, emergency car, and so on). Hence, an efficient e-health system should get a WBAN connected anywhere he goes taking into account QoS e-health application requirements. Otherwise, it should allow the PD to be always

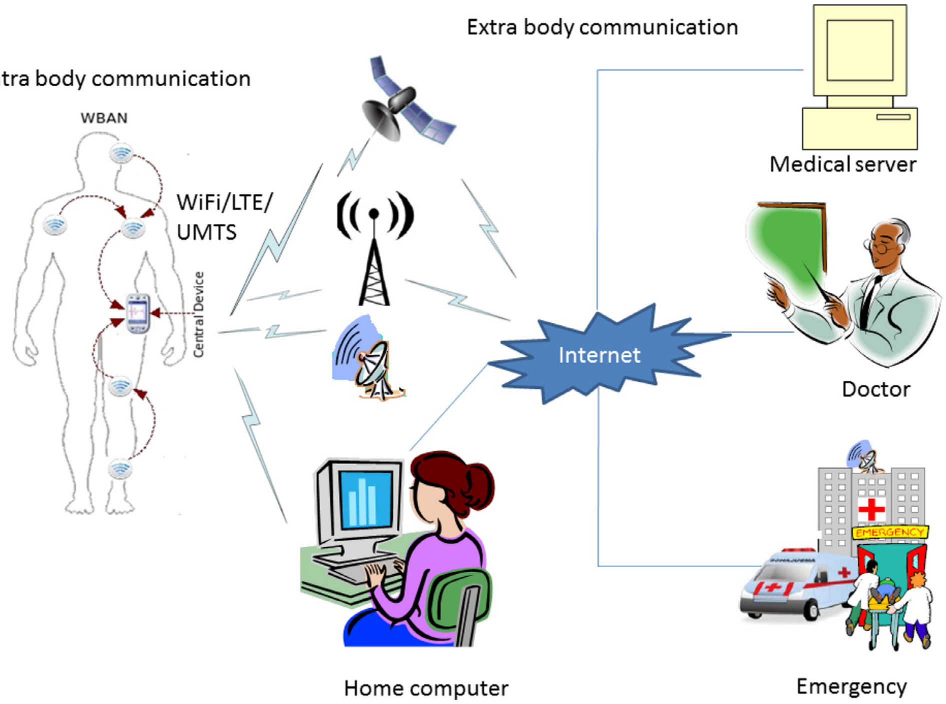

Fig. 1. Network model architecture.

Table 2
Delay and bit rate requirements of healthcare data [28].

Data source	Bit rate [bps]	Delay [s]	Sampling rate [Hz]
Electrocardiogram (ECG)	10–100k	<10	63–500
Blood pressure [mmHg]	10–30	>120	63
Non-invasive cuff	0.05	30–120	0.025
Cardiac output [L/min]	1k	<10	63
CO_2 concentration	1k	30–120	63
Temperature (°C)	0.3	>120	0.02

connected to the best available network mainly in multi covered zones.

Fig. 1 illustrates our network model architecture.

4.2. Traffic categories

Unlike conventional Wireless Sensor Networks (WSNs), each sensor node in a WBAN has its own requirements in terms of delay, priority level and data rate. For instance, in most real life trials, ECG sensor readings are considered with higher priority than SpO2 (percutaneous oxygen saturation) and body temperature data. ECG needs a high sampling rate while a few samples per day are sufficient for SpO2 and body temperature sensors. However, it is important to underline that many changes can happen in terms of QoS requirements of WBAN sensors over time. The sampling rate, the required latency, and the importance of sensed data change according to the patient's condition. For instance, in post-surgery conditions, patients require continuous 24-h monitoring. However, for injured and stable patients, the test frequency may be set to every hour or even less. Furthermore, when readings coming from a low priority sensor (SpO2, pulse rate, temperature, etc.) exceed normal thresholds (e.g., body temperature $\geq 40°C$) the sensor's priority is increased. Table 2 shows in detail the heterogeneous characteristics of some commonly used medical sensors.

Thereby, to guarantee healthcare service efficiency, it is necessary to design WBAN protocols that can handle such heterogeneity and the variation of QoS requirements over time.

Accordingly, the IEEE 802.15.6 standard [29] has specified a user priority field in the WBAN's frame structure.

Furthermore, a packet subtype field allows users to define other data subtypes. Therefore, in view of that, in our solution we suggest the following mapping between traffic designation and the packet subtype field:

- General Monitoring (GM) packets for ordinary medical data;
- Delay Sensitive (DS) packets for high-priority medical data;
- The Mandatory Emergency (EM) data subtype.

More details on data packet type classification and field encoding are presented in Table 3. Accordingly, to give meaning to this classification made, in the next section, we propose a handover approach aware of the heterogeneous and time varying QoS requirements of each application type.

5. Seamless Multi-Attribute Decision Making Handover (MADMH) approach

Having presented the network model and traffic categories, in this section we introduce our MADMH approach. The most challenging issues that our approach will encounter are:

- how to ensure a seamless switching from one network to another (better) one;
- how to satisfy QoS requirements for different WBAN applications;
- how to reduce the number of handover.

Our handover process can be divided into two main phases: (i) network monitoring and information gathering phase, and (ii) decision-making and handover execution phase.

Before describing in detail these two phases, let us first present the QoS attributes, corresponding to the previously introduced applications, used by our approach to choose the most efficient network (or technology) amongst the available ones.

Table 3
Data packets type classification and field encoding.

User priority	Traffic designation	Packet type	Packet subtype	Description
7	Emergency or event report	Data	EM	They are the most critical data packets. They should be forwarded in brief time and reliable way. They are used to report data from important sensors, like ECG, EEG, and all sensor readings that exceed normal thresholds
6	Medical data	Data	DS	The video traffic type defined by the standard is designed for non-medical applications, e.g., video gaming. Moreover, some medical sensors like EMG and motion sensors generate delay sensitive data. For this reason, we defined the DS type as the medical data that must be delivered within a stringent deadline and tolerates a reasonable packet loss
3	Controlled load	Data	GM	The lowest priority is given to GM packets. They correspond to regular measurements of patient physiological parameters that typically indicate normal values received from lower priority sensors (SpO2, Non-invasive cuff, etc.)

5.1. Quality of Service attributes

QoS attributes are chosen according to traffic categories presented in Section 4.2 and consist of the Data Rate (DR), the Packet Delivery Ratio (PDR), the Received Signal Strength Indicator (RSSI) and the Point to Point packet Delay (PPD) which represents the total transmission time that is needed to send a data packet from the PD to the Point of Attachment (PoA). In this work and the performance evaluation section, these QoS metrics are computed based on the expressions detailed hereafter, in line with existing literature.

In particular, the RSSI in dBm can be expressed as follows:

$$RSSI_{dBm} = P_t - 10\eta \log \frac{d}{d_0} - X, \tag{1}$$

where P_t represents the transmission power of the sender, η is the path loss coefficient, d is the distance between the sender and the receiver, d_0 is a reference distance to be in a far field condition, and X is a random variable that takes into account fading effects.

The basic notations used in this paper are summarized in Table 4.

The PDR is given by:

$$PDR = \frac{\text{Number of received packets}}{\text{Number of sent packets}} \tag{2}$$

We assume that, in a WiFi network scenario, the PD accesses the medium using the CSMA/CA MAC protocol, the access in UMTS is based on Wideband Code Division Multiple Access (W-CDMA), while it is based on SC-FDMA/OFDMA in LTE. Therefore, the PPD in WiFi, UMTS and LTE scenarios are given, respectively, by expressions (3), (4) and (5) [30]:

$$PPD_{WiFi} = T_{difs} + T_{sifs} + T_{boff} + T_{data} + T_{ack}, \tag{3}$$

where the data packet transmission time T_{data} is equal to the sum of transmission delay and propagation delay:

$$T_{data} = \frac{\mathcal{T}}{\mathcal{R}} + \frac{d}{\mathcal{S}}$$

and the global size $\mathcal{T}$ of a transmitted packet is:

$$\mathcal{T} = PHY_{hl} + MAC_{hl} + MAC_{ft} + P_{load}$$

$$PPD_{UMTS} = 5\,\text{ms} + X \cdot 10\,\text{ms} + \lceil \frac{l}{\alpha} \rceil \cdot 10\,\text{ms}, \tag{4}$$

$$\begin{aligned} PPD_{LTE} &= T\_up + Buf\_t + R\_d + U\_sch\_R + U\_sh\_g \\ &\quad + UE\_d + eNodeB\_d, \end{aligned} \tag{5}$$

5.2. Network monitoring and information gathering

As a first step, *information gathering* may significantly influence the success of the overall handover process. In fact, the network must be well monitored and the handover decision must be made at the right time to establish a right new connection before the service disruption of the current one. Hence, information gathering process must be invoked in compliance with the application requirements, network conditions and user preference variations. Therefore, our information gathering triggers can be of two types: user-preference triggers and QoS triggers. The information gathering user-preference trigger refers to a change set by the user in his network preference list. On the other hand, information gathering QoS triggers are in their role two-folds: application layer and link layer triggers. The first type refers to a change in the application's QoS requirements due to a change in its type; for example, due to an aggravation of the patient's situation, the application type may change from a general monitoring application to an emergency one and vice versa.

The information gathering link layer triggers are driven by links going down or up. In particular, they depend on monitored RSSI values variations. We make use of RSSI, due to the fact that it is hard to estimate other metrics like Signal to Interference (SIR) and

Table 4
Notations and definitions.

P_t	Transmission power of the sender
d	Distance between the sender and the receiver
d_0	Reference distance to be in far field condition
X	A random variable that takes into account fading effects
η	Path loss coefficient (for the free space case $\eta = 2$)
T_{difs}	Distributed interframe space time
T_{sifs}	Short interframe space time
l	Payload length of the transmitted packet
α	Length-factor
T_{ack}	Time to receive an acknowledgement
T_{boff}	Backoff time
T_{data}	Data packet transmission time
$\mathcal{R}$	Network data rate
$\mathcal{S}$	Speed of light
PHY_{hl}	Physical header's length
MAC_{hl}	MAC header's length
MAC_{ft}	MAC's footer
P_{load}	Packet payload
$\mathcal{T}$	Global size of the transmitted packet
T_up	LTE uplink transmission time
U_sh_R	LTE uplink scheduling request delay
U_sh_G	LTE uplink scheduling grant delay
R_d	LTE retransmission delay
$eNodeB\_d$	LTE eNodeB processing delay
Buf_t	LTE buffering time
UE_d	LTE user equipment processing delay

Signal to Interference and Noise (SINR). Furthermore, the interference issue will be considered in a future work.

In fact, a link going down trigger is fired whenever the PD detects that the RSSI is not appropriate for the current application type. For the link up trigger, it is fired whenever the PD detects a new network with a high RSSI value. Therefore, adaptive thresholds to control the RSSI (and similarly the other metrics) are defined and set according to applications types. Indeed, in our approach, for each application type $\in \{GM, DS, EM\}$ and each QoS evaluation metric $\in \{RSSI, PDR, DR, PPD\}$ we define a min and a max threshold. For example, the min and max RSSI thresholds that we use for GM applications are respectively −87 dBm and −65 dBm. All used adaptive QoS metric thresholds are presented below in Table 6.

To summarize, four scenarios may prompt the PD to trigger the information gathering process and after the decision making:

- Scenario 1: The user selects another network since he favors this latter with respect to the current one.
- Scenario 2: An important change in the captured data values occurs, which leads to a change of the application type either from GM to EM or from EM to GM.
- Scenario 3: A link deterioration is detected via the controlled RSSI values (due to WBAN's distance to a PoA, an obstacle and/or congestion).
- Scenario 4: A new network is discovered during WBAN's movement (capturing a signal with a high RSSI value).

Hence, whenever a trigger among those just mentioned is launched, the information gathering process of the current network starts. If the current network still meet the current running application requirements, the PD keeps connecting to it. Otherwise, it begins collecting information about the list of available networks. The gathered information related to the user preferences, current running application and its QoS requirements as well as the list of available networks and their corresponding QoS parameters (RSSI, PPD, DR, PDR) will be communicated to MADMHA to make the right handover decision. The decision process is well detailed in the following section.

5.3. Multi-Attribute Decision Making Handover Algorithm (MADMHA)

The fundamental objective of MADMHA is to determine, among a finite set $\mathcal{M}$ of available wireless networks, the optimal one for an application $k \in \mathcal{K}$; the selected network must provide the best available QoS and network stability according to application k's priority. MADMHA decision attributes may be grouped in two main categories: QoS related and user related.

The MADMHA algorithm consists of the following five main steps (detailed in Sections 5.3.1–5.3.5):

5.3.1. Construction of the QoS matrix

The main target here is to choose among the several available networks $\mathcal{M}$, having m different QoS parameters, the one that meets the best an application $k \in \mathcal{K}$'s QoS requirements. Hence, for each application k, we model this selection problem with a QoS decision matrix called U^k_{QoS}, defined as follows:

$$U^k_{QoS} = \begin{pmatrix} U^k_{11} & U^k_{12} & \cdots & U^k_{1m} \\ U^k_{21} & \cdots & \cdots & U^k_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ U^k_{|\mathcal{M}|1} & \cdots & \cdots & U^k_{|\mathcal{M}|m} \end{pmatrix}$$

where m is the number of QoS attributes (in our case $m\tilde{} = 4$) and U^k_{ij} represents the utility of the PD when choosing the alternative wireless network i with respect to the QoS attribute j for $i \in \{1, \ldots, \mathcal{M}\}$ and $j \in \{1, \ldots, m\}$. The utility function U^k_{ij} can be expressed as below:

$$U^k_{ij} = \begin{cases} -1, & V^k_{ij} < V^k_{min} \\ C\frac{V^k_{ij} - V^k_{min}}{V^k_{max} - V^k_{min}}, & V^k_{min} \leq V^k_{ij} < V^k_{max} \\ 1, & V^k_{ij} \geq V^k_{max} \end{cases} \quad (6)$$

where V^k_{ij} is the current value of the QoS attribute j in the alternative network i. V^k_{max} denotes the ideal upper threshold of the QoS attribute j for an application k. V^k_{min} is the minimal requirement value of j QoS attribute that the $k-th$ application requires. C is a coefficient that reflects the relative change of the j attribute over time, and is used to promote alternative improving networks. This latter is computed as follows:

$$C = \begin{cases} 1, & t = 0 \\ 1 + \dfrac{V^k_{ij,t} - V^k_{ij,t-1}}{V^k_{ij,t}}, & t \geq 0 \end{cases} \quad (7)$$

with t representing time, $V^k_{ij,t}$ the current value of the QoS attribute j in the alternative network i and $V^k_{ij,t-1}$ the last measured value (at time $t-1$) of this latter.

5.3.2. Construction of the global QoS vector V

After modeling the QoS parameters in a QoS Matrix U^k_{QoS}, the second step consists in multiplying the columns of each row of this latter matrix to obtain a global QoS vector VG^k. VG^k may be expressed as follows:

$$VG^k = \begin{pmatrix} VG^k_1 \\ \cdots \\ \cdots \\ VG^k_{|\mathcal{M}|} \end{pmatrix}$$

where

$$VG^k_i = \delta * \prod_{j=1}^{m} |U^k_{ij}| \quad (8)$$

$$\delta = (-1)^{\lfloor \frac{N_b+2}{N_b+1} \rfloor} \quad (9)$$

Note that, it is quite possible that one network i has more than one QoS parameter j not meeting the QoS requirements of an application k ($U^k_{ij} = -1$) (see Eq. (6)). We note by N_b the number of that QoS parameters values that are lower than the required thresholds in the alternative network i ($U^k_{ij} = -1$). If N_b is an even-numbered integer, the resulting VG^k_i value will be positive, even if network i does not meet all the QoS requirements of the current running application. To cope with this problem, we make use of the δ coefficient, which guarantees that:

$\forall\ network_i\ i \in \{1, \mathcal{M}\}; VG_i < 0 \Leftrightarrow N_b \geq 1$

Proof. For $N_b = 0$: $\lfloor \frac{N_b+2}{N_b+1} \rfloor = \lfloor \frac{2}{1} \rfloor = 2$. So, $\delta = (-1)^2 = 1$.

For $N_b \geq 1$: $\lfloor \frac{N_b+2}{N_b+1} \rfloor = \lfloor (1 + \frac{1}{N_b+1}) \rfloor = 1$. So, $\delta = (-1)^1 = -1$.

Therefore, $\forall\ network_i\ i \in \{1, \mathcal{M}\}; VG_i < 0 \Leftrightarrow N_b \geq 1$. □

5.3.3. Construction of the filtered QoS vector V_f

In order to keep in the list of candidate networks only those having sufficient QoS services, we filter the VG vector as explained below. First, we compute the global minimal QoS requirement value VG^k_{min}, where

$$VG^k_{min} = \prod_{j=1}^{m} \frac{U^k_{ij,min}}{U^k_{ij,max}} \quad (10)$$

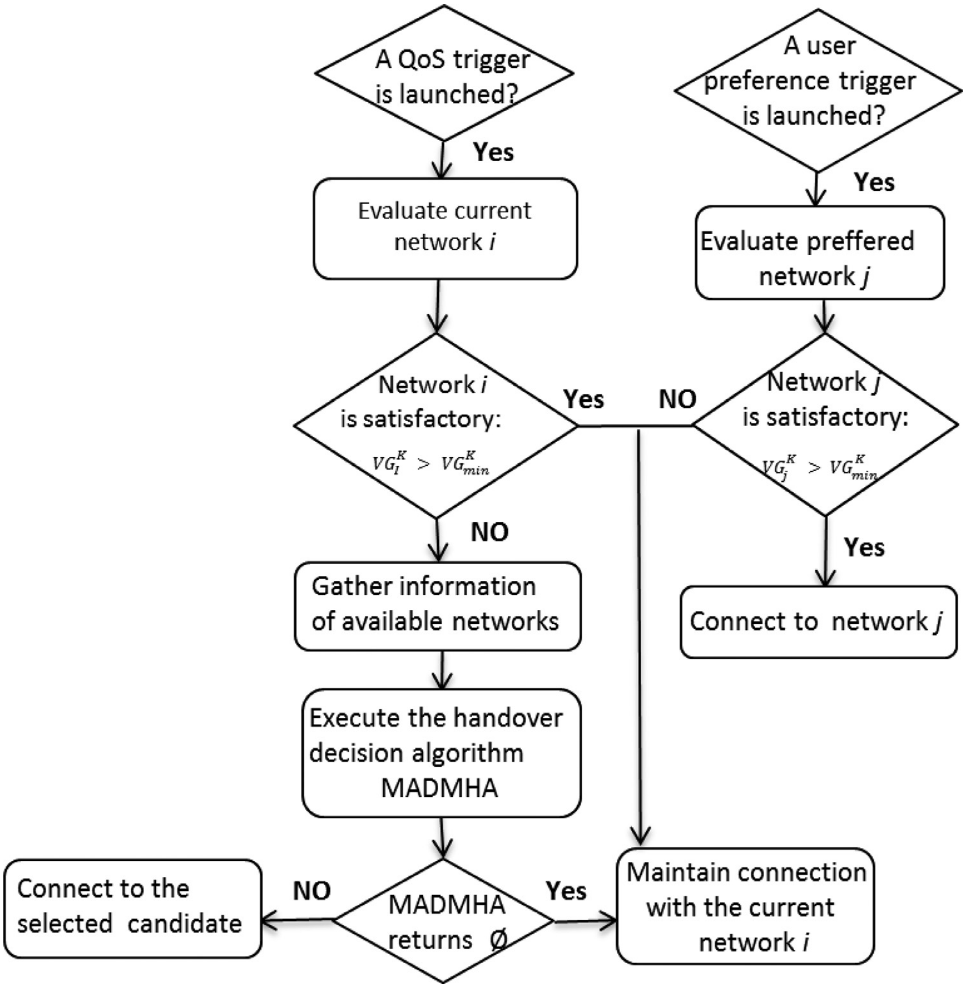

Fig. 2. The handover process flowchart.

Second, we discard networks having a global QoS value smaller than the minimal requirement VG_{min}^k from the VG vector to obtain the filtered QoS vector V_f. Hence:

$$VG_i^k \in V_f \Leftrightarrow VG_i^k > VG_{min}^k$$

5.3.4. Construction of the normalized weighted vector V_N

In our proposed mechanism, we consider the user's preference, which may be related, for example, to the notion of familiarity and confidence in a given network, or its monetary cost. Therefore, in order to get a realistic evaluation of different networks, we combine in our evaluation QoS-related parameters with user-related ones. As the QoS parameters are taken into account in the V_f vector, we model the user preferences with respect to candidate networks with a vector named *UP*. Finally, we sum the two vectors to obtain a *normalized weighted one*, called V_N.

$$V_N = \alpha \begin{pmatrix} VG_1^k \\ \cdots \\ \cdots \\ VG_{|\mathcal{M}'|}^k \end{pmatrix} + \beta \begin{pmatrix} UP_1 \\ \cdots \\ \cdots \\ UP_{|\mathcal{M}'|} \end{pmatrix} \tag{11}$$

Here, α and β are the weighting coefficients assigned respectively to the QoS and user preference vectors, while $|\mathcal{M}'|$ is the number of candidate networks.

5.3.5. Selection of the best solution

The final task is to select the optimal solution which is the network *i* having the greatest $V_{N,\,i}$.

5.4. Handover execution

Once the decision is made and a new target network is chosen, the handover execution will be carried out. According to [31], the handover execution techniques can be of two types:

- *Hard handover*: The current network is released and only after this operation the target one is engaged. With such technique, the handover is done in a break-before-make way.
- *Soft handover*: In this case, the connection to the target network is established before the connection to the source is broken, hence this latter technique is called make-before-break.

As mentioned before, in a e-health monitoring application, treated data is indeed crucial, and the slightest mistake can seriously affect patients safety. This requires service continuity during the handover execution process, which is our main goal. In the case of a hard handover, a service disruption period can be experienced due to the time needed for disconnection from the current cell and connection to the target one. However, this risk is avoided in a soft handover case. In our approach, we hence adopt the soft handover technique.

To summarize, the proposed seamless Handover approach can be outlined in the flowchart depicted in Fig. 2. In fact, as mentioned before, the handover process may be fired either with a user or a QoS trigger. In the first case, the target network is evaluated by computing its *VG* value. If the obtained *VG* is greater or equal to the average required QoS value, VG_{min}, the user connects

Table 5
Simulation parameters.

Wireless technology	Max Tx power (dBm)	Cell radius (m)	Data rate (M)	Recv_signal threshold (dBm)
UMTS	43	600	2	−121
IEEE 802.11b/g	20	100	4	−91
IEEE 802.11b	27	100	11	−89
IEEE 802.11a	17	75	6	−89
IEEE 802.11g	26	75	6	−92
IEEE 802.11n	18	125	24	−72
LTE	46	1000	13	−123.4

Table 6
QoS parameters of different application types.

	EM	DS	GM
Min delay threshold (s)	8	10	80
Max delay threshold (s)	10	30	100
Min PDR threshold (%)	97	80	70
Max PDR threshold (%)	100	100	100
Min RSSI threshold (dB)	(−50)	(−65)	(−87)
Max RSSI threshold (dB)	(−40)	(−55)	(−65)
Min data rate thresholds (kbps)	290	330	30
Max data rate thresholds (kbps)	400	600	100
α coefficient	3	2	1
β coefficient	1	2	3

to this latter network, otherwise he remains connected to the current one, hence limiting the ping-pong effect. In the second case, the user looks for a QoS enhancement. Thus, the system gathers information of all available networks, executes the MADMHA algorithm, and if a better network exists, then connects to the selected one.

6. Performance evaluation

This section presents numerical results that illustrate the validity of the proposed MADMHA algorithm for network selection by mobile WBANs. More specifically, we test the sensitivity of the proposed algorithm to different parameters like the number of WBANs and their traffic types (EM, DS, and GM).

Hereafter, we first describe the simulation setup and then we analyze and discuss the performance achieved by the proposed approach.

6.1. Simulation setup

The proposed approach and algorithms are implemented using the OMNeT++ simulator [32]. The deployed network is composed of 10 mobile WBANs in a simulation area of 1000 × 1000 m^2. This area is covered by eight WiFi access points (APs), four 3G base stations and four LTE eNodeBs. Access network selection related information for each of the considered networks is reported in Table 5.

Mobile WBANs move in a pedestrian environment (i.e., at a 0.5 m/s speed) according to the random waypoint model [33]. Moreover, the AP, eNodeB and BS positions are unknown a priori. Consequently, the probability to perform a handover from one network to another, is strictly dependent on the network characteristics. In our simulations we consider three different healthcare applications: EM, DS, and GM. In particular, EM packets correspond to ECG and EEG readings, while DS traffic is generated by Motion sensing and EMG sensors. Glucose and Body temperature sensors' readings are considered as general monitoring traffics. However, as said before, we note here that traffic priorities may vary depending upon the values generated by the sensors. For instance, body temperature readings may produce EM traffic flows if their values exceed certain thresholds. QoS parameters, as well as α and β coefficients used in our simulations, are reported in Table 6, and they are defined in compliance with the real sensors requirements previously reported in Table 2.

For user preference parameters, we consider two parameters which are the monetary cost and the patient's confidence in candidate networks.

6.2. Simulation results

Simulations are performed in order to validate the effectiveness of the MADMHA algorithm, in comparison with that of existing (reviewed in Section 2), RSS-VHD and DR-VHD approaches [14].

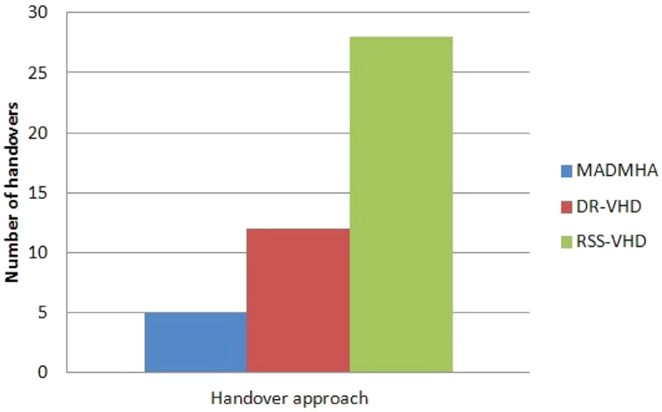

Fig. 3. Handover frequency per hour for different handover approaches.

6.2.1. Number of handover evaluation

Since the limitation of ping-pong effect is a mandatory task, we consider the number of handover as an important metric to prove the effectiveness of our MADMHA algorithm.

Therefore, to evaluate this metric, we assume that each mobile WBAN is by default associated to a WiFi AP, and this AP belongs to the cheapest and most secure network (user preferred network). Additionally, at the beginning, we assume that all WBANs are running a GM application (controlling the body temperature of the patient). However, throughout one simulated hour, the body temperature of some WBAN (patient) rises to reach 40 °C, hence, the running application is no longer considered as GM but as EM. After a quarter of an hour, the temperature drops to a normal level, which leads to a novel change of the application type from EM to GM. While patients are doing their routine activities, they move and may be far away from their default AP (i.e., go somewhere in the corridors, media room, or in the playground, for example) as well as they may discover new WiFi APs with high RSSI value, depending on their location. In these cases, to keep the patient best connected, he will have to switch to another network (WiFi, UMTS or LTE) that satisfies the QoS of the running application taking into consideration the user preference. In other terms, the four handover triggers described in Section 5.2 are used in this scenario.

Therefore, Fig. 3 shows the average number of handover per hour experienced with MADMHA, RSS-VHD, and DR-VHD during a WBAN's movement. Numerical results prove that MADMHA performs well compared to RSS-VHD and DR-VHD, and strongly limits ping pong effects. This is due to the fact that, unlike RSS-VHD and DR-VHD, MADMHA is based on a combination of different QoS, user preference and network history parameters. Moreover, the handover is executed only if needed. Indeed, if the current network still meets the current running application requirements, the handover doesn't take a place, even if a better network exists.

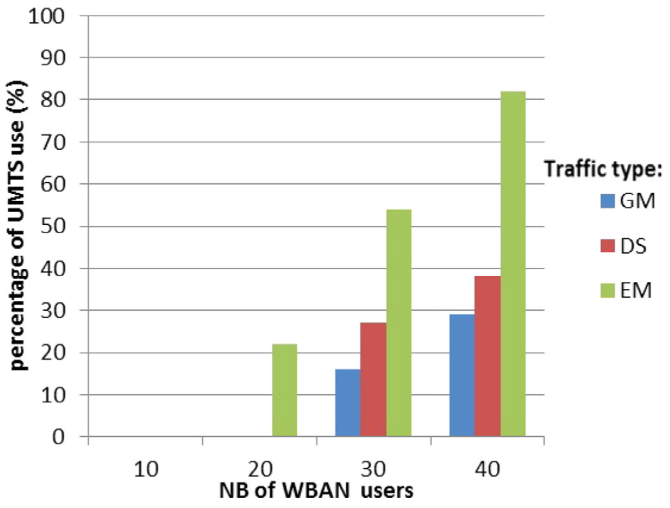

Fig. 4. UMTS use percentage in a WiFi covered open space versus the number of users and traffic types.

6.2.2. Percentage use of wireless technologies

Selecting the best network is a mandatory task for WBANs, especially for critical traffic. Therefore, in the next simulation scenarios, we assume that WBAN users are located in a dedicated open space covered by WiFi, and we increase the number of connected users per AP. This open space may be a waiting room in a hospital, a seminar or conference room, where patients can attend a health-awareness conference. Therein, the number of patients is not fixed: they can move around, enter one by one or in groups, thus increasing the channel contention.

Scenario 1. In this scenario, we assume that the available networks are IEEE 802.11b/g and UMTS.

We measure the frequency use of UMTS for the three considered traffic types versus the number of WBAN users located in the open space covered by WiFi. Obtained results are illustrated in Fig. 4.

We observe in Fig. 4 that, for all traffic types, the percentage of UMTS connections linearly increases while increasing the number of WBAN users in the room. We also note that such an increase is strongly related to the traffic type. More specifically:

- for 10 users, all patients use WiFi;
- for 20 users, all patients generating DS and GM traffic keep using WiFi, while 16% of EM users migrate to UMTS;
- when the number of indoor users reaches 40, the percentage of migration to UMTS for GM, DS and EM peak, respectively, to 29%, 38% and 82%.

These results can be explained by the fact that, increasing the number of WBAN users per AP leads to network quality and resources degradation. On the other hand, EM traffic requires a higher network performance than DS and GM traffics. So, even though the UMTS network is expensive compared to WiFi, it is selected when the number of connections per AP exceeds 10. However, the UMTS network is selected only when the number of connected WBANs per AP exceeds 20 for DS and GM traffics.

Scenario 2. In this scenario, the available networks are WiFi and LTE. In order to compare the different WiFi standards (IEEE 802.11a, IEEE 802.11b, IEEE 802.11g and IEEE 802.11n), we change the AP type in each simulation run. Therefore, we measure the frequency use of LTE for the three considered traffic types versus the number of WBAN users and WiFi AP type. Obtained results are illustrated in Table 7.

Table 7
LTE use percentage in a WiFi covered open space versus the number of users, used WiFi technology and traffic types.

WiFi AP				
Nb users	IEEE 802.11a	IEEE 802.11b	IEEE 802.11n	IEEE 802.11g
10	0	0	0	0
20	17% (EM) 4% (GM)	10% (EM) 0% (GM)	0 0% (GM)	19% (EM) 6% (GM)
40	29 % (DS) 71 % (EM) 16% (GM)	19% (DS) 39% (EM) 3% (GM)	2% (DS) 5% (EM) 0% (GM)	31% (DS) 74% (EM) 18% (GM)
60	29% (DS) 71% (EM)	27% (DS) 70% (EM)	9% (DS) 11% (EM)	49% (DS) 83% (EM)

We can observe that the results obtained with LTE are in line with those of scenario 1, for all used WiFi technologies. The higher the number of connected users per AP, the lower is the percentage of WiFi connections. We further note that such behavior highly depends on traffic and AP types. For the three WiFi technologies (IEEE 802.11a, IEEE 802.11b and IEEE 802.11g), the migration of users generating EM traffics to LTE network begins when the number of connected users per AP reaches 20. However, the degree of migration differs from one technology to another. Indeed, IEEE 802.11n performs better than IEEE 802.11a and IEEE 802.11g. For example, for 60 users per AP and a DS application, the degree of migration to LTE is as follows:

- 49% for IEEE 802.11g;
- 45% for IEEE 802.11a;
- 27 % for IEEE 802.11b;
- 9% for IEEE 802.11n.

Furthermore, for a GM application and IEEE 802.11n any migration to LTE is noted. These results can be explained by the fact that (i) IEEE 802.11n and IEEE 802.11b offer greater available bandwidth and coverage area than IEEE 802.11g and IEEE 802.11a, and (ii) GM applications require less resources than DS and EM.

6.2.3. Packet Overhead evaluation

The Packet Overhead (PO) is defined as the total number of control packets as well as data packets, including retransmitted packets due to collisions. PO is a source of energy wasting and packet loss. Hence, the handover process has to be performed in a seamless way while keeping the PO low.

In this scenario, we suppose that 10 patients are going for a healthy walk/run in the hospital's green garden to promote their physical activity. We assume that 4 patients are running EM applications (ECG for monitoring heart beat), 3 are running DS applications (EMG), and the other 3 are running GM (monitoring the body temperature) applications. The considered packet rates for GM, DS and EM are set respectively to 30 Kbps, 340 Kbps and 400 Kbps. In fact, we compute the amount of the extra paging messages, WiFi management frames and retransmitted data packets caused by the handover operation during a simulation time of 500 s for the walk scenario with a speed of 5 km/h. More specifically, we compute the additional overhead caused by the network gathering information, interface switching, handover execution/failure and interferences. We note that, due to patient mobility, the measured average number of effective handover executed respectively by MADMHA, DR-VHD and RSS-VHD during 500 s is equal to 1, 2 and 5.

Fig. 5 shows the obtained PO values for the three handover approaches.

As proven before, RSS-VHD and DR-VHD suffer from ping pong effect, which induces a high signaling cost (total number of control messages to perform the handover procedure) and disruption time. In other terms, the high handover frequency in RSS-VHD and DR-VHD increases the interference of radio waves, thus increasing the possibility of losing data packets. Moreover, it causes data

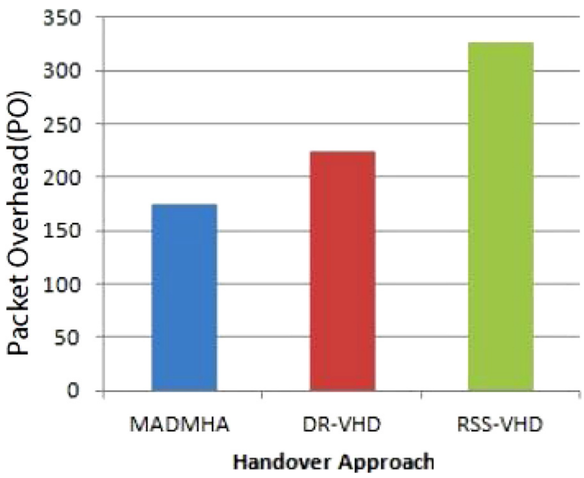

Fig. 5. Packet overhead for different handover approaches.

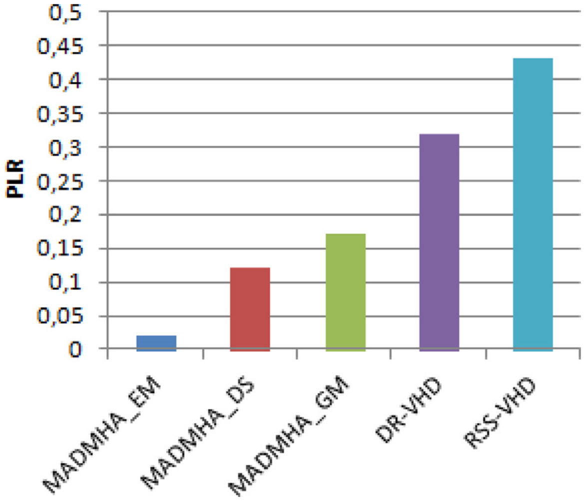

Fig. 6. Packet loss ratio versus traffic type for different handover approaches.

packet retransmissions and leads to exchange more control packets to restore the connection between senders and receivers. Consequently, these latter approaches suffer from a significant overhead. In fact, Fig. 5 shows that RSS_VH has the highest overhead, while MADMHA has the smallest PO value.

6.2.4. Packet loss ratio evaluation

The packet loss ratio (PLR) is used to evaluate the network reliability, and is defined as the total number of lost data packets divided by the total number of transmitted data packets. Using the same parameters as in the previous PO simulation, we compute here the PLR of the three considered applications for MADMHA, RSS-VHD and DR-VHD. Fig. 6 illustrates the obtained results.

Fig. 6 shows that MADMHA has the smallest PLR value, even for EM traffics. We further note that the PLR is the same for all traffic types for the two other approaches. This behavior is justified by the fact that such approaches do not perform traffic differentiation. Furthermore, MADMHA ensures the best PLR since it provides the smallest PO and handover frequency values, which are tightly related to the PLR metric.

6.2.5. Probability of handover failure

A handover failure may occur in the following cases:

- If the travelling time inside the serving PoA coverage is shorter than the handover latency.
- When the handover is initiated but the target network does not have sufficient resources to complete it.
- When the handover is initiated and disrupted before the process is finalized handing over to another target network.

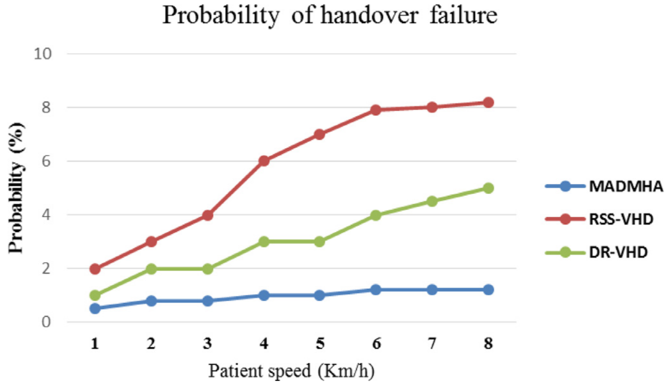

Fig. 7. Probability of handover failure versus patient speed.

From that, it can be seen that the handover failure depends on the mobile patient's location and speed. In fact, the time required by the mobile patient to remain connected to the serving PoA with a speed V may be computed as follows:

$$T\_c = \frac{D\_i}{V} * (1 - pf) \tag{12}$$

where

D_i is the distance to travel inside the serving PoA coverage.

pf is the probability to initiate a handover while remaining inside the coverage of the serving PoA.

Consequently, if the speed V is low, the remaining connection time T_c is longer as it foresees that the mobile patient takes longer time to move to the edge of the coverage and discover new PoA. However, if the speed is high, the delay is shorter and the probability of handover failure is higher. Hence, in this scenario the number of handover failures is evaluated as a function of the WBAN (patient)'s speed. Therefore, we consider the previous scenario and only vary the speed from 1 km/h to 8 km/h during one hour of simulation. Fig. 7 shows that in all cases the probability of handover failure increases when increasing the patient speed. Furthermore, it can be observed that RSS-VHD has the highest probability of failure. This can be explained by the fact that under RSS-VHD all WBANs (or their corresponding PDs) perform handover decisions based on RSSI measurements, meaning that, if a WBAN with a high speed enters the coverage area of a new AP whose RSSI is above the one of the AP to which it is currently connected, such WBAN will initiate the handover procedure. However, as explained in Eq. (12), the time spent within the AP's coverage T_c will be limited with high speed V. Consequently, the handover procedure will not be successfully completed promoting a call drop or decreasing the overall QoS. Finally, by using the proposed MADMHA algorithm, which is based on multiple QoS parameters, network history and user preference, the patient's PD remains connected to the current network that still guarantees the required QoS of the running healthcare application even though a new network is discovered. Moreover, we recall that MADMHA is based on soft handover approach which is referred to "make-before-break". In other terms, the mobile patient's new connection is created at the target PoA before the old PoA connection is released.

6.2.6. Additional Energy consumption

In this scenario, we compare the additional energy consumed by the three handover approaches. We set the average energy consumption per transmitted bit for WiFi, UMTS and LTE, equal to $1\mu J$,

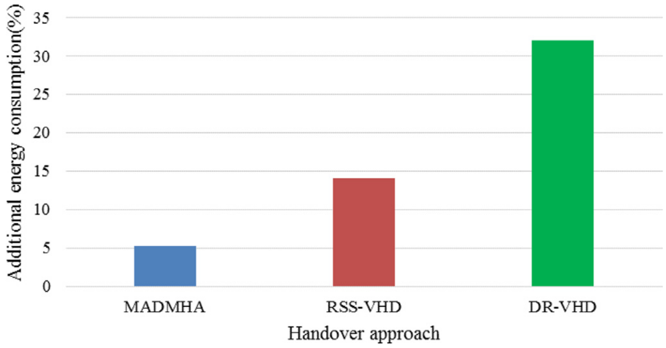

Fig. 8. Percentage of additional energy consumed by the handover approach.

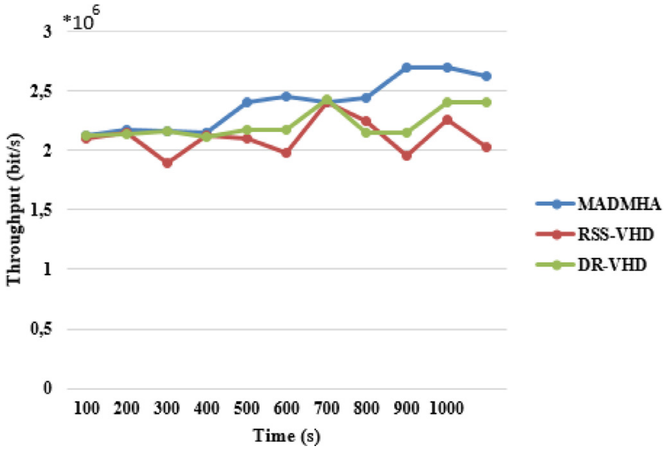

Fig. 9. Average throughput for different handover approaches.

15μJ and 20μJ, respectively, while the cost due to switching network interface is equal to 1μJ [29]. In fact, the additional energy consumed by the handover processes during a period of time t may be computed as follows:

$$AEng\_t = EE\_ov + EE\_switch \tag{13}$$

where

EE_ov presents the additional energy consumed by the total packet overhead generated by the handover operations during a period of time t.

EE_switch is the additional energy consumed by the switching interface operations during the period t.

Fig. 8 shows the average additional percentage of energy consumed by a PD to conduct the handover operation during one hour of simulation. We can observe that when the RSS-VHD and DR-VHD handover schemes are adopted, the PD consumes much more energy than with MADMHA. This is in line with our previous simulation results, proving that MADMHA reduces the packet loss, packet overhead and ping pong effect.

6.2.7. Throughput

An efficient Handover approach is that which ensures high throughput despite terminals mobility. Thereby, using the same parameters as in the previous PO simulation, we compute here the throughput for the three handover approaches with respect to the simulation time. Fig. 9 shows that the MADMHA obtained throughput (bits per second) is higher than that of RSS-VHD and DR-VHR. This may be explained by the fact that MADMHA is able to remain connected to the same network as long as possible, since its network selection is tuned according to various QoS and user preference parameters. Therefore, as proven in previous simulations, MADMHA limits the number of handover compared with the two other approaches. Moreover, MADMHA is based on soft handover concept which means that buffered data are sent over both old and new connections when a handover occurs. In this way, packet loss and retransmission are avoided. Furthermore, we can see that for the three handover approaches the throughput drops in some time points. This is due to the occurrence of handover process at this time. However, compared to RSS-VHD, DR-VHD and MADMHA appear to have a moderately downward trend line.

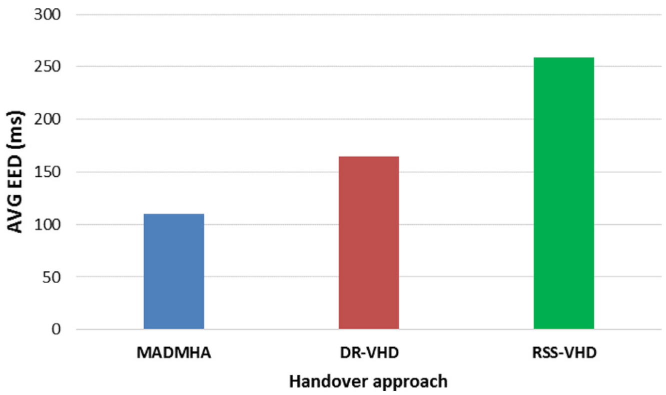

Fig. 10. Average End to End Delay for different handover approaches.

6.2.8. Average End to End Delay

For sensitive application like healthcare the shortest the End to End Delay (EED), the better the application performance. Therefore, in this scenario we measure the average (AVG) EED for the three handover approaches. Obtained results are presented in Fig. 10.

It can be seen in Fig. 10 that MADMHA performs the smallest EED. This because, the experienced packet delay depends on the number of handover and networks reliability and as proven before our protocol outperforms RSS-VHD and DR-VHD in handover frequency and PO. In fact, frequently oscillating between different networks deteriorate the network performance leading collisions, interference and packet retransmissions.

7. Conclusion and future works

In this paper we addressed the handover issue in Wireless Body Area Networks, focusing our attention on three radio technologies (namely WiFi, 3G and 4G access networks). In particular, we proposed a hybrid Decision Making Handover Algorithm, named MADMHA, which ensures ubiquitous connectivity for mobile WBAN users throughout their roaming. Furthermore, MADMHA classifies the generated healthcare traffic into three classes having heterogeneous QoS requirements (General Monitoring, Delay Sensitive and Mandatory Emergency). Based on such classification, MADMHA performs an intelligent network selection according to QoS requirements of each application type, while further taking into account the network history. We performed a thorough numerical analysis of the proposed algorithm, showing that our approach achieves very good results in terms of number of handover experienced by users, energy consumption, packet overhead and reliability.

Three interesting areas for future work can be identified in the context of the presented work. MADMHA solution that we develop allows us to consider additional attributes and to define various relative importance between such attributes. Indeed, other network attributes (e.g., security of the candidate network) can be added to consider more selection objectives. Another issue concerns the setting of weighting parameters. How can we define exactly the relative importance of attributes? In our context, the weights are estimated by human judgement. However, the scale of relative importance between attributes can be chosen by using an auto-learning algorithm. Besides, the network performance in terms of algorithm complexity and convergence speed may be addressed in our future works and validated through real test scenarios.

References

[1] N. Bradai, L. Chaari, L. Kamoun, A comprehensive overview of wireless body area networks (WBAN), Int. J. E-Health Med. Commun. 2 (3) (2011) 1–30.

[2] M. Patel, J. Wang, Applications, challenges, and prospective in emerging body area networking technologies, IEEE Wirel. Commun. 17 (1) (2010) 80–88.

[3] J. Bernhard, P. Nagel, J. Hupp, W. Strauss, T. von der Grün, BAN-Body area network for wearable computing, in: Proceedings of the 9th Wireless World Research Forum Meeting, Zürich, July, 2003.

[4] P. Pawar, Context-aware vertical handover mechanisms for mobile patient monitoring (2011).

[5] T.D. Wallace, A. Shami, A review of multihoming issues using the stream control transmission protocol, IEEE Commun. Surv. Tutor. 14 (2) (2012) 565–578.

[6] H. Ben Elhadj, S. Boudjit, L. Chaari, A cross-layer based data dissemination algorithm For IEEE 802.15.6 WBANs, in: Proceedings of the International Conference on Smart Communications in Network Technologies (SaCoNeT), Paris, France, June, 2013.

[7] J. Elias, A. Mehaoua, Energy-aware topology design for wireless body area networks, in: Proceedings of IEEE International Conference on Communications, ICC 2012, Ottawa, Canada, June 2012, pp. 3409–3413.

[8] J. Elias, Optimal design of energy-efficient and cost-effective wireless body area networks, Ad Hoc Netw. 13 (2014) 560–574.

[9] S. Fernandes, A. Karmouch, Vertical mobility management architectures in wireless networks: a comprehensive survey and future directions, IEEE Commun. Surv. Tutor. 14 (1) (2012) 45–63.

[10] M.A. Algaet, Z.A.B.M. Noh, A.S. Shibghatullah, A.A. Milad, A. Mustapha, Provisioning quality of service of wireless telemedicine for e-health services: a review, Wirel. Person. Commun. 78 (1) (2014) 375–406.

[11] Y. Zhou, B. Ai, Handover schemes and algorithms of high-speed mobile environment: a survey, Comput. Commun. 47 (2014) 1–15.

[12] A. Ahmed, L.M. Boulahia, D. Gaiti, Enabling vertical handover decisions in heterogeneous wireless networks: a state-of-the-art and a classification, IEEE Commun. Surv. Tutor. 16 (2) (2014) 776–811.

[13] M. Gondara1, S. Kadam, Requirements of vertical handoff mechanism in 4G wireless networks, Int. J. Wirel. Mob. Netw. 3 (2) (2011).

[14] A.M. Vegni, G. Tamea, T. Inzerilli, R. Cusani, A combined vertical handover decision metric for QoS enhancement in next generation networks, in: Proceedings of IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, WIMOB, October, 2009, pp. 233–238.

[15] N. Nasser, A. Hasswa, H. Hassanein, Handoffs in fourth generation heterogeneous networks, IEEE Commun. Mag. 44 (10) (2006) 96–103.

[16] P. Khan, N. Ullah, S. Ullah, K. Sup Kwak, Seamless interworking architecture for WBAN in heterogeneous wireless networks with QoS guarantees, J. Med. Syst. 35 (5) (2011).

[17] K. Radhika, V. Reddy, Vertical handoff decision using game theory approach for multi-mode mobile terminals in next generation wireless networks, Int. J. Comput. Appl. 36 (11) (2011).

[18] A. Bhuvaneswari, E. George Dharma Prakash Raj, A cross layer based vertical handoff decision making framework, Int. J. Comput. Appl. 50 (19) (2012) 28–32.

[19] M. Rehan, M. yousaf, A. Qayyum, S. Malik, J. Wozniak, Cross-layer user centric vertical handover decision approach based on MIH local triggers, in: Proceedings of WMNC, IFIP AICT 308, 2009, pp. 359–369.

[20] K. Savitha, C. Chandrasekar, Vertical handover decision schemes using SAW and WPM for network selection in heterogeneous wireless networks, Glob. J. Comput. Sci. Technol. 11 (9) (2011).

[21] L. Sheng-mei, P. su, X. Ming-hai, An improved TOPSIS vertical handoff algorithm for heterogeneous wireless networks, in: Proceeding of the 12th IEEE International Conference on Communication Technology (ICCT), 2010, pp. 750–754.

[22] P.N. Tran, N. Boukhatem, Comparison of MADM Decision Algorithms for Interface Selection in Heterogeneous Wireless Networks, in: Proceeding of the IEEE International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, Coratia, September, 2008.

[23] S. Sesia, I. Toufik, M. Baker, LTE: The UMTS Long Term Evolution, Wiley Online Library, 2009.

[24] L. Luo, J. Yang, K. Chen, et al., System-level performance evaluation of UMTs with multi-service, Comput. Commun. 29 (9) (2006) 1470–1479.

[25] H. Zhao, E. Garcia-Palacios, J. Wei, Y. Xi, Accurate available bandwidth estimation in IEEE 802.11-based ad hoc networks, Comput. Commun. 32 (6) (2009) 1050–1057.

[26] M. Rinne, O. Tirkkonen, LTE, the radio technology path towards 4G, Comput. Commun. 33 (16) (2010) 1894–1906.

[27] P. Keikhosrokiani, N. Zakaria, N. Mustaffa, T.-C. Wan, M.I. Sarwar, K. Azimi, Wireless networks in mobile healthcare, in: Mobile Health, Springer, 2015, pp. 687–726.

[28] IEEE Engineering in Medicine and Biology Society, ISO/IEEE Standard 11073: Health Informatics – POC Medical Device Communication – Part 00101: Guidelines for the Use of RF Wireless Technology, 2012.

[29] IEEE, 802.15.6-2012: IEEE Standards for Local and Metropolitan Area Networks. Part 15.6: Wireless Body Area Networks, 2012. http://standards.ieee.org/findstds/standard/802.15.6-2012.html (accessed 2014).

[30] M. Laner, P. Svoboda, E. Hasenleithner, M. Rupp, Dissecting 3G uplink delay by measuring in an operational HSPA network vol. 6579 (2011) 52–61, doi:10.1007/978-3-642-19260-9_6.

[31] Cho.J.P. HyangDuck, K.O. Wadin, L. Keumsang, K. Wooshik, Study on the MCHO method in Hard handover and Soft handover between WLAN and CDMA, in: Proceedings of International Conference on Consumer Electronics, ICCE, 2005, pp. 391–392.

[32] OMNeT++. http://www.omnetpp.org/ (accessed 2014).

[33] F. Bai, A. Helmy, A Survey of Mobility Models in Wireless Adhoc Networks, vol. 206, University of Southern California, USA, 2004.