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Vertical Handover Algorithm for WBANs in Ubiquitous Healthcare with Quality of Service Guarantees

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Abstract: Recently, Wireless Body Area Networks (WBANs) have become an emerging technology in healthcare, where patients are equipped withwearable and implantable body sensor nodes to gather sensory information for remote monitoring. The increasing development of coordinator devices on patients enables the internetworking of WBANs in heterogeneous wireless networks to deliver physiological information that is collected at remote terminals in a timely fashion. However, in this type of network, providing a seamless handover with a guaranteed Quality of Service (QoS), especially emergency services, is a challenging task. In this paper, we proposed an effective Multi-Attribute Decision-Making (MADM) handover algorithm that guarantees seamless connectivity. A patient's mobile devices automatically connect to the best network that fulfills the QoS requirements of different types of applications. Additionally, we integrated a Content-Centric Networking (CCN) processing module into different wireless networks to reduce packet loss, enhance QoS and avoid unnecessary handovers by leveraging in-network caching to achieve efficient content dissemination for ubiquitous healthcare. Simulation results proved that our proposed approach forthe model with CCN outperforms the model without CCN and Received Signal Strength Vertical Handoff (RSS-VHD) in terms of the number of handovers, enhancing QoS, packet loss, and energy efficiency.

Keywords: wireless body area network; multi-attribute decision-making; content-centric networking

1. Introduction

Over the past decade, Wireless Sensor Networks (WSNs) have attracted a large amount of attention from both a theoretical and applied point of view. Real-life applications of these networks have been widely used in many areas, including environmental monitoring, emergency response, agriculture, industrial automation, and aeronautics. Based on the profits in the field of portable medical sensors, WSNs have been applied and adopted in ubiquitous healthcare, interactive gaming and entertainment applications (called WBAN) [1]. In a WBAN, various sensor nodes are equipped on the patient that continuously send patient information (such as electrocardiogram (ECG), electroencephalogram (EEG), electromyography (EMG), heartbeat, blood pressure, body temperature, etc.) to a remote server or physician via a PDA (Personal Digital Assistant), laptop or Smartphone.

With their ubiquitous functions in healthcare, WBANs help to monitor the status of patients over the long term without restricting daily activities. WBANs can be used to diagnose chronic conditions, supervise rehabilitation from a surgical procedure and monitor in physiotherapy [2]. In addition, WBANs can aid in promptly handling emergency events through remote instruments. Therefore, this technology provides benefits by reducing unnecessary hospitalizations, reducing the number of doctors required and decreasing the time required for fast analysis and diagnosis. WBANs improve the level of patient care and allow for timely intervention from physicians and emergency medical technician staff through data monitoring and storage. Nevertheless, the effectiveness of remote healthcare applications can be significantly impacted by the existing wireless network, the power of mobile equipment and user requirements on the quality of experience (QoE) in terms of user mobility, required quality of service (QoS) of healthcare and personalized interaction.

To minimize these influences and improve the transmission efficiency of heterogeneous networks, many wireless access technologies are proposed to integrate with WBANs [3–5]. In these networks, multi-interface terminals play an important role in ensuring seamless connectivity with high performance. Multi-interface terminals (namely, coordinator devices) known as PDAs, laptops and Smartphone are supported and have different interfaces to interact with wireless technologies. Each access technology has specific characteristics that complement each other. For example, a WiFi network provides high received signal strength and a high data rate at a low cost. Moreover, Universal Mobile Telecommunications System (UMTS) can supply full mobility and a low data rate. At the same time, Long Term Evolution (LTE) provides a low latency, high throughput, and high speed at a high cost [6]. Furthermore, each WBAN application will have different data packet requirements that are generated by the coordinator devices, such as the data generation rate, delay, and packet loss. These data can change in the QoS requirement over time. For these reasons, there is a need to select the best connection for each application in order to satisfy QoS requirements. Hence, a network selection algorithm can play an important role in choosing the best network to meet the application requirements and guarantee seamless connectivity.

To achieve the above aim, this paper effectively implemented both a handover algorithm and heterogeneous network architecture. The main contributions of the paper are summarized as follows:

- We propose the effectiveness of a Multi-Attribute Decision Making (MADM) handover algorithm that is based on the types of applications and patient conditions to perform a handover when necessary. Thus, the proposed algorithm allows sustaining the best connection for WBAN users that satisfies application requirements and guarantees seamless internet working.
- We integrate a Content-Centric Networking processing module into the edge network devices of all the networks, such as the WiFi access point, UMTS base station, LTE eNodeB and the edge routers. This approach can support the WBAN architecture in terms of caching efficiency, reducing packet loss, and improving QoS and network quality. Thus, the proposed integration allows the patient to maintain the current connection that guarantees QoS requirements, avoids unnecessary handover and has energy efficiency.

The remainder of this paper is structured as follows. Section 2 highlights some of the related studies that pertain to this paper. Section 3 describes our WBAN network architecture model. Section 4 shows our MADM handover algorithm, and we evaluate and discuss the results in Section 5. Finally, the paper is concluded in Section 6.

2. Related Work

WBAN architectures are typically composed of three tiers, such as intra-body (tier-1), extra-body (tier-3) and inter-Body Sensor Network (BSN) communications (tier-2) [7]. These WBAN communication tiers must efficiently deliver the data to the decision makers at the application side with QoS guarantees and must minimize energy consumption. Hence, many solutions have been proposed to support three-tier body sensor network communications; in this paper, we focus on the tier-3 aspect.

In extra-body communications, many wireless technologies have recently been investigated in WBAN applications for the purpose of ubiquitous healthcare. Internet/WiFi/Cellular networks are used in CareNet [8], WiMoCA [9], and MIMOSA [10]. In more detail, CareNet effectively addresses reliability as well as privacy-preserving patient data transmission. With its flexibility, WiMoCA can fulfill diverse application requirements in an accurate and timely manner, whereas MIMOSA is a smart architecture for mobile terminals and is optimized for flexibility and low-power short-range radios. Furthermore, the authors in [11] have proposed two novel network models by the integration of Zigbee with WiMAX and an LTE network. A network model with LTE achieved a lower delay transmission in comparison with WiMAX; however, they both can effectively support a high burst of data and are suitable for real-time data transmission. Similarly, an integration of WBAN and LTE has also been investigated to support high user mobility and reduce content delivery delay [12]. In addition, an efficient content distribution scheme was presented to reduce costs and packet loss as well as the increase bandwidth efficiency by leveraging the benefits of Name Data Networking technology [12,13].

As mentioned previously, a solution that involves integration can help users to transmit/receive content at any time and from anywhere depending on the wireless network coverage in that place. However, these solutions of integration and interoperability will face great challenges in terms of their technological diversity, and one challenge is the handover problem [14,15]. Therefore, to clarify this problem, we also present some recent studies that pertained to our work.

For seamless and secure handoffs in wireless environments, handover decision making can be decided by a single metric or a combination of attributes from a network (bandwidth, Received Signal Strength Indicator (RSSI), security, data rate, latency and reliability) to user preferences and devices (monetary cost, user profile preference velocity and battery power) [16]. A single metric is known as a horizontal handoff decision (HHD), which chooses the best network based on one attribute (e.g., the Received Signal Strength, RSS). The RSS approach proposed in [17] is used in a comparison of the RSS thresholds that are measured by different mobile terminals. When the measured RSS of a wireless network falls below the defined thresholds, the handover procedures to 3G will be activated immediately afterward. Although HHD approaches are simple and easy to implement, they suffer many restrictions, such as unnecessary handovers, high-energy consumption and the ping-pong effect. A combination of attributes is known as vertical handoff (VHD), in which the decision parameters for handover not only consider poor RSS but also the availability of other networks that have better services. Many potential VHD schemes have been conducted in different categories to compare each algorithm to others in terms of complexity, flexibility and reliability, including User-Centric [18], Markov [19], Fuzzy Logic [20], MADM [21] and Game Theory [22]. Among the existing VHD strategies, MADM is one of the schemes that based on strong multi-attributes to select the best from a list of available networks that have medium complexity and high flexibility. In this paper, we just focus on the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) approach that is selected to implement in our proposed algorithm [23], with theaim ofselecting the best network in the available list based on multiple attributes with high accuracy in identifying the ranking. This approach deems that the best alternative should have the shortest Euclidean distance to the ideal solution and the farthest distance from the negative ideal solution.

Based on the studies mentioned above, this paper proposes an improvement of the MADM approach by leveraging the strengths to overcome the weaknesses of the existing TOPSIS methods and optimize the attributes before handovers by integrating the CCN module into the edge network elements [24,25].

3. Network Architecture Model

To tackle the issues mentioned above, we present our network architecture model and the WBAN traffic categories, which are detailed below.

3.1. Network Architecture Model

In this section, we propose a solution by seamlessly integrating the Institute of Electrical and Electronics Engineers standard (IEEE 802.15.6) with other wireless networks. This standard is specially designed for WBAN to gain the benefits of low power, a short range and high reliability while supporting a wide range of data rates for various applications [26].

All the sensor nodes that were mentioned previously (ECG, EEG, EMG, heartbeat, blood pressure and body temperature) are placed on the patient to collect sensory data and are then ubiquitously disseminated to the healthcare staff via WBAN coordinator devices such as PDAs, laptops, Smartphone or robot-assisted devices. These devices will be equipped not only for IEEE 802.16 interfaces (for intra-body communication) but also for other wireless interfaces such as WiFi, UMTS, and LTE. Normally, a coordinator device always connects to the best available network, mainly in overlap coverage due to the popularity, flexibility or cost effectiveness. Nevertheless, in this paper, the QoS application requirements will be accounted to select the best connection for normal traffic, especially for emergency traffic types that are strictly required for accurate and timely transmission.

Furthermore, to evaluate the performance of the proposed solution, we have also integrated CCN processing modules into all the network elements in extra-body communications, such as WiFi-access points, UMTS base stations, LTE eNodeB and edge routers. Figure 1 illustrates our network model architecture.

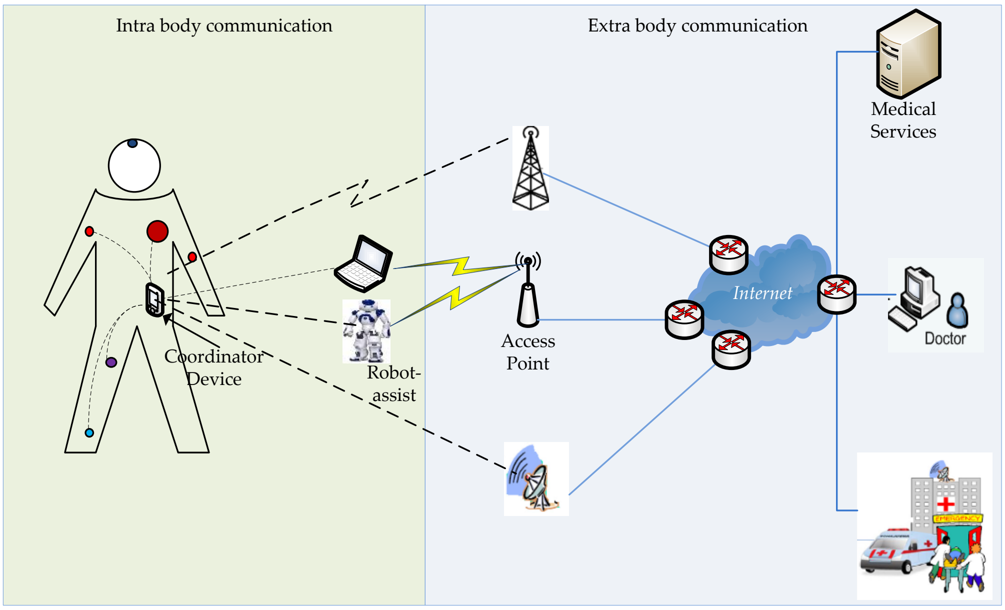


Figure 1. A conceptual view of wireless body area networks (WBAN).

3.2. WBAN Traffic Categories

In WBANs, sensory data have their own characteristics due to different requirements in terms of delay, priority, packet loss, and other factors [27]. Thus, from the viewpoint of remote healthcare monitoring and important levels, we classify the WBAN traffic into emergency and normal traffic, which are defined as follows:

- *Emergency traffic* includes not only the critical data packets (e.g., ECG, EEG) but also the data that are initiated by nodes when they exceed a normal threshold (e.g., blood pressure (BP) $\geq$ 140 mmHg or body temperature $\geq$ 40 °C). They are strictly required in terms of reliability and immediate response. Hence, QoS attributes, such as bandwidth, RSSI, security, data rate, latency, and reliability, are placed at a higher priority level than user preference aspects, such as the monetary cost, in the network selection.
- *Normal traffic* is the data traffic that is used to monitor normal patient conditions without any criticality (e.g., EMD, SpO2, Non-invasive cuff). In contrast to emergency traffic, the monetary cost in normal traffic is an important attribute for network selection. In other words, normal traffic can be easily satisfied by all the candidate networks, and anetwork with a low cost could be considered the best network onthe available list.

To gain a deeper understanding of the purpose of the above classifications, the next section proposes an efficient handover algorithm according to the QoS requirements of the application types.

4. MADM Handover Algorithm

Having described the operation of the network architecture model as well as the WBAN traffic categories, we now present the proposed MADM approach, including the following steps. In the first step, the algorithm will monitor and collect the information that is related to the QoS of the running application requirements, and the QoS attributes are presented in detail. Then, we discuss the handover decision making that accounts for the QoS application requirements to choose the most efficient network connection. The algorithm also considers the weight vectors for the classified WBAN applications that are computed by using a pairwise comparison of the attributes.

4.1. Quality of Service Attributes and User Preferences

Handover decision-making chooses the best network depending on a set of attributes that include the network conditions, user preferences, devices, applications and traffic. In this paper, we focus on several QoS attributes (such as the received signal strength indicator-RSSI, delay, utilization and packet loss) and user preferences (cost per byte) that are suitable for the WBAN traffic categories in Section 3.2. These parameters are calculated according to the expression detailed hereafter.

In radio propagation environments, the RSSI can be calculated as follows [28]:

$$RSSI(\text{dBm}) = P_t - 10\eta \log \frac{d}{d_0} - X \tag{1}$$

$$f_x(x) = \delta_x^{-1} \times e^{\frac{x+\delta_x}{\delta_x}} \times e^{-e\left(\frac{x+\delta_x}{\delta_x}\right)} \tag{2}$$

where P_t denotes the transmission power of the sender (dBm). Here, η is the path loss exponent (e.g., η = 2 in a free-space environment); and d and d_0 are the distance from the sender to the receiver and the reference distance, respectively. Additionally, X is a Gaussian random variable with zero mean and deviation δ_x in Equation (2), shown in Figure 2.

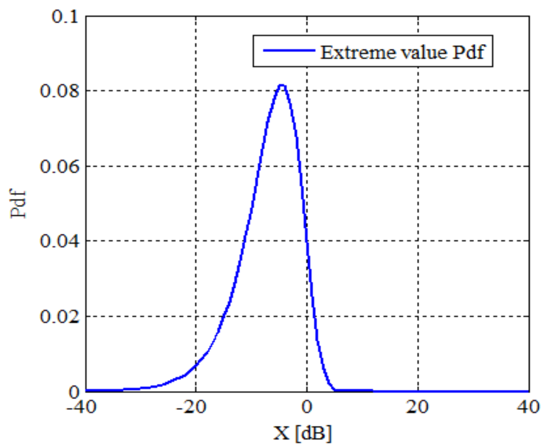


Figure 2. Distribution of the probability density function (Pdf) of X.

The utilization is given by Equation (3)

$$U_{utilization}\ (\%) = \frac{data\ (\text{bit})}{Bandwidth\ (\text{Hz}) \times Interval\ (\text{s})} \times 100 \tag{3}$$

The delays in the WiFi, UMTS and LTE are shown in Equations (4)–(6), respectively, as follows [29]:

$$D_{WiFi} = T_{difs} + T_{sifs} + T_{boff} + T_{data} + T_{ack} \quad (4)$$

The data transmission time T_{data}, back-off slots time T_{boff}, and acknowledgement time T_{ack} are given by the following equations [27]:

$$T_{data} = \frac{L_{phy}+L_{machdr}+payload+L_{macfrt}}{R_{data}} + \frac{d}{s}$$

$$T_{boff} = bo_{slots} \times T_{boslots}$$

$$T_{ack} = \frac{L_{phy}+L_{machdr}+L_{macfrt}}{R_{data}}$$

$$D_{UMTS} = 5\text{ ms} + X \times 10\text{ ms} + \frac{l}{\alpha} \times 10\text{ ms} \quad (5)$$

$$D_{LTE} = T_{up} + T_{Buff} + T_{re} + T_{U\_sch\_r} + T_{U\_sch\_g} + T_{UE} + T_{eNodeB} + T_{core} \quad (6)$$

The remaining parameters used in this paper are listed in Table 1.

Table 1. Definition of parameters.

Parameters	Definition	Unit
L_{phy}	Length of Physical header	kbit
L_{machdr}	Number of MAC headers	kbit
L_{macfrt}	Size of MAC footer	kbit
R_{data}	Data rate of the network	kbit
d	Distance from the sender to the receiver	meter
S	Speed of light	m/s
l	Payload length of the data packet	kbit
a	Length Factor	-
bo_{slots}	Number of back-off slots	-
T_{difs}	Distributed inter-frame space time	ms
T_{sifs}	Short inter-frame space time	ms
$T_{boslots}$	Time for a back-off slot	ms
T_{up}	LTE uplinks transmission time	ms
T_{buff}	LTE buffering time	ms
T_{re}	LTE retransmission delay	ms
$T_{U\_sch\_r}$	LTE uplink scheduling request	ms
$T_{U\_sch\text{-}g}$	LTE uplink scheduling grant	ms
T_{UE}	UE delay estimated time	ms
T_{e_NodeB}	e_NodeB delay estimated time	ms
T_{core}	Core network delay time	ms

MAC: Media Access Control; LTE: Long Term Evolution; UE: User Equipment.

4.2. Handover Decision-Making

The main objective of our MADM handover algorithm is to choose the best network in n available networks (integrated with the CCN processing module) for each application, with the QoS requirements based on the m attributes (including QoS attributes and user preferences) and two WBAN traffic categories.

The following are the steps that are followed in our algorithm (detailed in Sections 4.2.1–4.2.3).

4.2.1. Evaluation of the Current Network

Before the handover execution, our algorithm makes an assessment as to whether the current network meets the QoS of the running application. This evaluation is based on the QoS parameter threshold of the different applications as shown in Table 2, and these values are defined in accordance with the real application requirements [27,30]. If any QoS parameter value exceeds its required threshold, the handover process will trigger; otherwise, the current connection is sustained.

Table 2. The quality of service (QoS) parameter threshold of different application types.

	RSSI (dBm)	Delay (s)	Utilization (%)	Packet Loss (%)
Emergency Traffic	−50	10	100	3
Normal Traffic	−87	100	100	30

4.2.2. The Attribute Weight Calculations

The methods for performing the weight calculations of the attributes are the main challenges in the MADM approaches. With an increasing heterogeneous complexity of the nature of the attributes, the attribute weight calculation is increasingly challenging, which in turn affects the handover execution. Furthermore, depending on each WBAN application, each attribute will have a different level of importance in meeting the requirements of the application. For example, some of the signals (e.g., heartbeat, BP, EEG) are strictly required for timely transmission, and thus, the QoS parameters (end-to-end delay and packet loss) are very critical in guaranteeing the transmission deadline. In contrast, there are some normal applications in which the cost is more important than any of the QoS parameters.

Therefore, to determine attribute weights effectively for each of the application requirements, we calculated the weights of the attributes based on the Analytical Hierarchy Process (AHP) approach [31] and divided them into two weight vectors according to the WBAN traffic categories.

The following are the main steps for the weight calculation of the m attributes.

Step 1: Deriving the reciprocal matrix A with the perceived one-dimensional vector L_m:

$$\mathbf{A} = \mathbf{a}_{\text{qp}} = \begin{bmatrix} 1, & if\ L_p = L_q \\ L_p - L_q + 1, & if\ L_p > L_p \\ \frac{1}{L_p - L_q + 1}, & if\ L_p < L_q \end{bmatrix} \tag{7}$$

where the attributes p and q are mapped to any one of the linguistic values $\in \{1, 3, 5, 7, 9\}$ to denote the scale of importance, as shown in Table 3. The pairwise comparison $a_{qp} \in \{1/9, 1/7, 1/5, 1/3, 1, 3, 5, 7, 9\}$ depends on L_m as defined by the decision maker.

Step 2: Computation of weights as follows:

$$w_j = \frac{1}{m} \sum_{p=1}^{m} \frac{a_{jp}}{\sum_{q=1}^{m} a_{qp}} \tag{8}$$

where $j = 1, 2, 3, \ldots, m$ with $\sum_{1}^{m} w_j = 1$.

Step 3: Verification of the weight.

This step aims to check the consistency and reliability of the calculated attribute weights W_j in step 1 and is evaluated using the consistency ratio (CR), which is given by Equation (9).

$$CR = \frac{\text{Consistency Index } (CI)}{\text{Random Consistency Index } (RI)} \tag{9}$$

where

$$CI = \frac{\lambda_{\max} - m}{m - 1} \tag{10}$$

$$\lambda_{\max} = \sum_{j=1}^{m} \left(w_j \times \sum_{p=1}^{m} a_{pj} \right) \tag{11}$$

where *RI* is the index of the matrix coherence. The value of *RI* is 0.52, 0.89, 1.11, 1.25, 1.35, 1.40, 1.45, 1.49, 1.51, 1.54 and 1.56, with the different sizes of the matrices (or number of attributes) being 3, 4, 5, . . . , 12 and 13, respectively [32].

According to the main steps of the Simplified and Improved Analytical Hierarchy Process (SI-AHP) approach above, we calculated two weight vectors for the WBAN traffic categories (W_1, W_2) with the consistency ratios CR_1 = 0.02, CR_2 = 0.03, respectively. The values of the consistency ratios are very low and are fulfilled by the condition ($CR \leq 0.1$). Therefore, the calculated weight attributes W_1, W_2 are accepted, which ensures a high consistency and reliability of these values, as detailed in Table 4.

Table 3. Scale of relative importance.

AHP Scale of Importance for Comparison Pair (a_{qp})	Linguistic Value
Very High	9
High	7
Medium	5
Low	3
Very Low	1
Intermediate values between the two adjacent judgments	2; 4; 6; 8

AHP: Analytical Hierarchy Process.

Table 4. The attribute weights for the WBAN traffic categories.

Attributes	Emergency Linguistic	Emergency Value	W_1	Normal Linguistic	Normal Value	W_2
RSSI	High	7	0.174	Medium	5	0.130
Delay	Very High	9	0.456	Medium	5	0.130
Utilization	High	7	0.174	Low	3	0.053
Packet Loss	High	7	0.174	Medium	5	0.130
Cost/Byte	Low	1	0.031	Very High	9	0.557

RSSI: Received Signal Strength Indicator.

4.2.3. The Normalized Attributes and Handover Decision-Making

All the attribute values are normalized by the Euclidean normalization method (r_{ij}) to construct the normalized decision matrix, which provides the highest-ranking consistency [33]. Each element r_{ij} is calculated as follows.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} {x^2}_{ij}}} \tag{12}$$

where the values x_{ij} concern the ith network (i = 1, 2, . . . , n) and jth attribute (j = 1, 2, . . . , m). The ranking of the networks is executed according to the TOPSIS approach [34], which is based on the attribute weights in Section 4.2.1 and the normalized values above. The network with the highest ranking is the best network that satisfies the QoS application requirements. The proposed handover procedure is summarized in Figure 3.

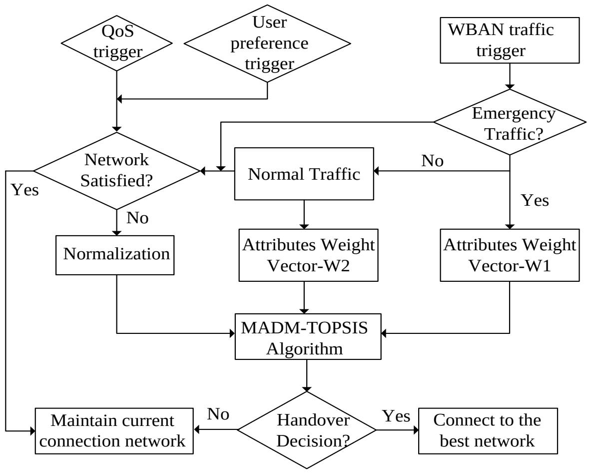


Figure 3. The handover process flowchart.

5. Evaluation and Discussion of the Results

Having described the model architecture and the proposed approach, to illustrate its effectiveness, we first describe the WBAN scenario as well as the simulation setup; we then analyze and evaluate the results that are achieved.

5.1. Simulation Scenario

The proposed model is implemented by using OPNET Modeler 16.0 (OPNET Technologies, Bethesda, MD, USA). In our simulation, we use a network topology that considered in Figure 1, however, the deployed network consists of eight access points (AP), four base stations (BS), and four eNodeBs; this topology is deployed in coverage of 1000 $\times$ 1000 m^2. A patient can be in the coverage of any AP, BS, and eNodeB with a CCN processing module. Each AP covers a circular area that has a radius of 100 m and employs an IEEE 802.11b standard protocol, whereas each BS and eNodeB covers an area that has a radius of 600 m and 1000 m, respectively.

Table 5. Simulation parameters.

CCN-Packet Types	Interest Packet (IntPk) Data Packet (DataPk)	32 B 1 KB
WBAN user	Buffer size Start time–Stop time	1000 Pks 50 + Uniform(0,10) s–300 s
Other links	Gateway-Gateway Other links	OC-24 1000 BaseX
Content	Data size	400 DataPk/s
Content Store (CS)	Replacement policy	FIFO
Max receive-signal threshold	WiFi (802.11b) UMTS LTE	−89 dBm −121 dBm −123.4 dBm
Power transmission	WiFi (802.11b) UMTS LTE	27 dBm 43 dBm 46 dBm

UMTS: Universal Mobile Telecommunications System.

We assumed that mobile WBANs have an initial connection to AP and move in the area with 0.5 m/s speed. The ability to make a handover from the current network to another network absolutely depends on the network characteristics, which consist of the RSSI, delay, utilization, packet loss and user preferences such as monetary cost (namely, the cost per byte). Thus, the physician (doctor or nurse) can receive data on the patient anywhere where they are connected to these networks. We also considered two different applications (emergency traffic and normal traffic) in the case of changing priorities and, in addition, increasing the number of WBAN users. Table 5 lists the rest of the simulation parameters.

5.2. Simulation Results

According to the simulation scenario above, this section describes the performance evaluation results. Actually, almost the research papers and real deployment are focused on single metric like RSS-VHD because this information is measured in almost all mobile devices when this approach apply to implement in handover aspect due to the cost and simple. Therefore, to investigate the effectiveness of our proposed approach (MADM with CCN) as well as to underline its advantages, the simulations are conducted in comparison with those without CCN and RSS-VHD in terms of the number of handovers, enhancing the QoS, the packet loss, and the energy efficiency.

5.2.1. Changing the Priority of WBAN Applications

Selecting the best network based on the QoS application requirements helps to enhance the effectiveness of our algorithm in WBAN, especially for emergency traffic.

Therefore, to evaluate this aspect, we assumed that the initial application running on patients is a normal traffic type, and the default is to connect to WiFi AP with the 802.11b standard. These patients move (0.5 m/s speed) far away from their default AP. Moreover, this normal traffic type will exceed a normal threshold after the simulation period (e.g., blood pressure $\geq$ 140 mmHg), thus moving to an emergency traffic type. To keep the best connection for the patient, the device will switch to other networks that satisfy the QoS of the running application. In this case, the best network is the highest-ranking network (LTE) in the ranking list, as shown in Table 6. This result demonstrates the effectiveness of our approach in the selection of the best network for each application type, even when the QoS requirements change over time.

Table 6. Network ranking order with respect to the ranking values.

Normal Traffic		**Emergency Traffic**	
Network	Ranking Value C_2	Network	Ranking Value C_1
WiFi (802.11b)	0.93114	LTE	0.9614
4G (LTE)	0.14878	WiFi (802.11b)	0.1257
UMTS	0.06263	UMTS	0.0660

5.2.2. The Number of Handovers

In wireless communications, the ping-pong effect is one of the crucial problems that leads to packet loss and high computation cost. This effect is clearly expressed through the number of handovers. Therefore, to perform an evaluation of our proposed algorithm in this respect in comparison with the approach without CCN and RSS-VHD, we considered a scenario simulation as given in Section 5.2.1; however, the running application is always a normal traffic type during the simulation time.

Figure 4 shows the number of handovers that were experienced with our proposed approach with and without CCN, as well as the RSS-VHD during a patient movement. The figure demonstrates that the MADM with CCN (10% handover) significantly outperforms the MADM without CCN (22% handover) and the RSS-VHD approach (40% handover) and strongly reduces the ping-pong effect. This circumstance is caused by the fact that MADM is based on a combination of attributes, unlike RSS-VHD, which depends on a single metric. The current network will be maintained if it still satisfies the QoS of the running application, even if better networks co-exist. Moreover, MADM with the CCN approach helps to reduce end-to-end delay, packet loss and utilization of the network by leveraging the benefits of CCN caching and therefore helps to increase QoS and avoid unnecessary handover.

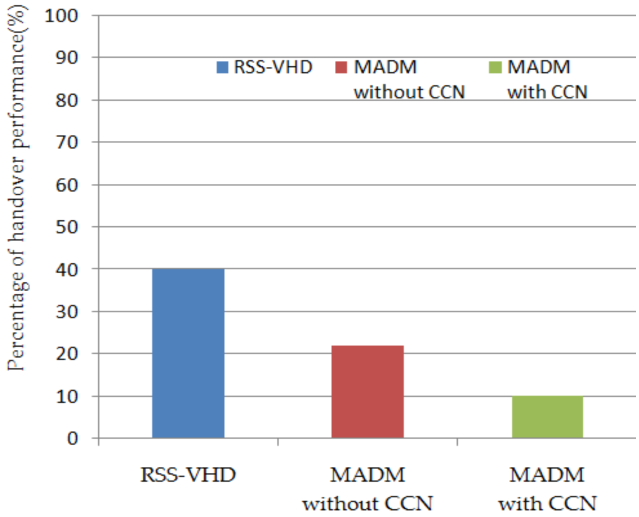


Figure 4. Percentage of handover performance.

5.2.3. The Number of WBAN User Evaluations

To ensure the QoS for each application when the number of users increases is a challenging task for MADM. Therefore, to perform this evaluation, we assumed that the available networks were WiFi and LTE. Additionally, we assumed that the number of patients increases at the same time and that each patient application has a 400 Kbps up/download speed.

Figure 5 illustrates that the percentage of LTE use increases in a linear fashion with the number of WBAN users. However, the percentage increases of the three methods (RSS-VHD, MADM without and with CCN) are substantially different from one another. The percentage of LTE use in the RSS-VHD approach significantly increased in comparison with that of MADM without and with CCN. This finding is caused by increasing the number of patients per access point and leads to a decrease in network quality and resource degradation. Thus, although the LTE network is more expensive than WiFi, it is still selected in the case of increasing the number of connections per WiFi-AP when it exceeds the maximum number of allowed connections.

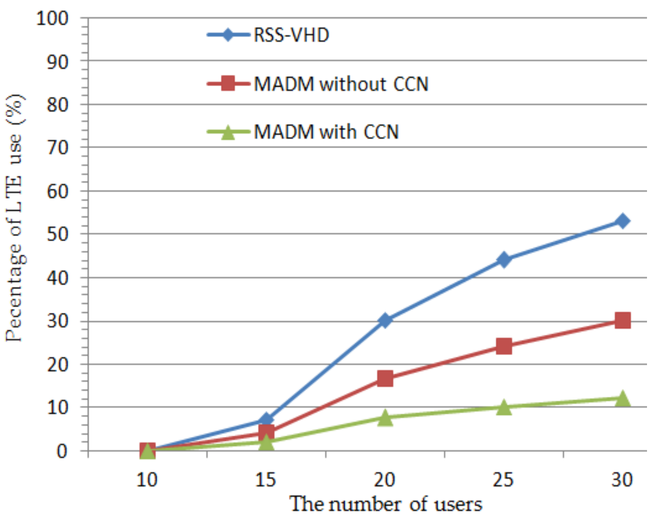


Figure 5. LTE use percentage with the number of users.

5.2.4. Energy Consumption Efficiency

To evaluate the effectiveness of our proposed approach in term of the energy aspect, we first calculate and analyze the additional energy consumption of a handover execution in the total energy consumption of each application. We then compare the energy consumption efficiency of three handover approaches.

The total energy consumption of wireless networks $E_{WiFi,UMTS,LTE}$ (mJ) can be computed as follows:

$$E_{WiFi,UMTS,LTE}(\text{mJ}) = \sum\left(E_{pro} + E_{transfer} + E_{tail} + E_{idle}\right)_{WiFi,UMTS,LTE} + E_{handover} \quad (13)$$

Furthermore, the additional energy consumption of a handover execution $E_{handover}$ can be calculated as follows:

$$E_{handover} = E_{turn-on} + E_{associating} + E_{promotion\ state} + E_{turn-of} \quad (14)$$

where $E_{turn\text{-}on}$, $E_{associating}$, $E_{promotionstate}$ and $E_{turn\text{-}off}$ and are the energy consumptions of the states: turn-on the new network interface, discovering, associating to the new network, promotion state to establish a new connection and turn-off the current network interface, respectively [35]. Moreover, the promotion energy consumption (E_{pro}), tail energy consumption (E_{tail}) and idle energy consumption (E_{idle}) are measured as shown in Table 7 [35].

Table 7. Network ranking order with respect to the ranking values.

Parameters	WiFi		UMTS		LTE	
	Power (mJ/s)	Duration (s)	Power (mJ/s)	Duration (s)	Power (mJ/s)	Duration (s)
WiFi turn on	24	-	24	-	24	-
WiFi turn off	29	-	29	-	29	-
Associating	120	2	250	1	250	1
Promotion	124.4	0.08	659.4	0.058	1210.7	0.026
Tail	119.3	0.24	601.3	0.824	1060	0.1
Idle on	77.2	0.0076	374.2	0.055	594.3	0.0432
Idle off	0	-	0	-	0	-
Idle cycle	-	0.308	-	5.112	-	1.2802

Usually, the transfer energy occupies a large part of the total energy consumption. It depends mainly on the transmission time t (seconds) and the up/downlink throughput (Mbps). The transfer energy $E_{transfer}$ for WiFi, UMTS and LTE is computed as follows [36]:

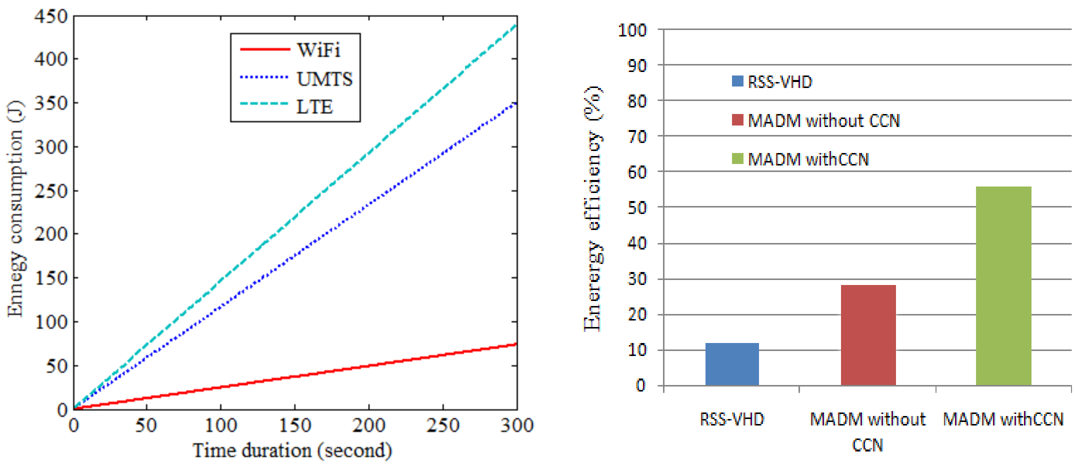
$$\begin{cases} E_{Transfer,WiFi}(\text{mJ}) = \{283 \times throughput\ (\text{Mbps}) + 132\} \times t \\ E_{Transfer,UMTS}(\text{mJ}) = \{869 \times throughput\ (\text{Mbps}) + 818\} \times t \\ E_{Transfer,LTE}(\text{mJ}) = \{438 \times throughput\ (\text{Mbps}) + 1288\} \times t \end{cases} \quad (15)$$

From Equations (13)–(15), we can easily calculate the total energy consumption for each application. The energy consumption efficiency is calculated as follows:

$$E(\%) = \frac{E_{\max} - \sum(E_{WiFi,UMTS,LTE} + E_{handover})}{E_{\max}} \times 100 \quad (16)$$

where $E_{\max}$ is the maximum energy consumption. For example, in the scenario simulation in Section 5.2.2, we assume that the handover to the LTE is executed immediately after the default connection to the WiFi network. Therefore, the total energy consumption of the LTE is the maximum consumption in this case.

We assume that the simulation scenario is similar to Section 5.2.2 (mobile WBANs have an initial connection to AP and move in the area with 0.5 m/s speed; however, the running application is always a normal traffic type during the simulation time). The average upload throughput is required for the setup, which is equal to 400 Kbps. As analyzed above, the two facts that mainly effect the total energy consumption of each application are the selected network to transmit data and the number of handovers. Figure 6a proves that the energy consumption of the WiFi, UMTS, and LTE networks are significantly different. Moreover, the popular applications in the WBANs are of the normal traffic type, which can easily satisfy the QoS through the WiFi network with low energy transmission in comparison to UMTS/LTE. The default connection to the WiFi, MADM with CCN approach helps to maintain the current WiFi connection and minimize the number of handovers by integrating CCN and a combination of different QoS and user preferences. These are the reasons that lead to the energy consumption efficiency of our proposed approach (which reaches 56.09%) in comparison with MADM without CCN (28.33%) and RSS-VHD (11.68%), as shown in Figure 6b.



(a) (b)

Figure 6. (**a**) Comparison of the energy consumption; (**b**) Comparison of the energy efficiency for different approaches.

5.2.5. Packet Loss

Each network has an average packet loss. Of course, we also know that the packet loss ratio falls in the descending order of WiFi-LTE-UMTS, which can be estimated by using Erlang models [37]. This difference is explained by the fact that WiFi uses the same carrier for multiple users simultaneously, whereas it is divided by time slots in the UMTS and LTE networks.

Handover in wireless networks normally produces packet loss, delay, and jitter, thereby significantly degrading network performance and service quality. The effect of handover in packet loss is shown in Equation (17).

$$P_{packetloss} = N_{handover} \times L_{handover}(\mathrm{s}) \times X(\mathrm{pps}) \tag{17}$$

where $P_{packetloss}$, $N_{handover}$, $L_{handover}(\mathrm{s})$, and $X(\mathrm{pps})$ are the number of packet losses, the number of handovers, the delay time per handover made and the packet arrival rate (packets per second), respectively. Equation (17) reveals that the number of packet losses is linear with the number of handovers. As a result, minimizing the number of handovers of MADM with CCN leads to a significant decrease in dropped packets and the packet loss ratio.

6. Conclusions

In this paper, we proposed a handover approach for WBAN in heterogeneous wireless networks by integrating a CCN processing module into WiFi, UMTS, and LTE access networks. In particular, we proposed the effectiveness of an MADM handover approach throughan improvement of the TOPSIS algorithm to guarantee seamless connectivity for WBAN users. Based on WBAN traffic categories, our proposed approach helps to select the best connection according to the QoS requirements of the application type and user preferences. Furthermore, the integration with CCN allows WBAN users to maintain the current connection, which guarantees the QoS requirements of each application and avoids unnecessary handover. The obtained results illustrate the significant effectiveness of our proposed approach in terms of the number of handovers, enhancing the QoS, improving the packet loss and increasing the energy efficiency. As for future work, we plan to consider more attributes that are related to networks, users and devices (e.g., the velocity, security, reliability, user profile) for a more accurate selection of the candidate network method. Additionally, we plan to precisely investigate the relative importance of attribute weights and expand the calculation of the weight vectors for each popular WBAN application.

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