Seamless Interworking Architecture for WBAN in Heterogeneous Wireless Networks with QoS Guarantees

Pervez Khan · Niamat Ullah · Sana Ullah · Kyung Sup Kwak

Abstract The IEEE 802.15.6 standard is a communication standard optimized for low-power and short-range in-body/on-body nodes to serve a variety of medical, consumer electronics and entertainment applications. Providing high mobility with guaranteed Quality of Service (QoS) to a WBAN user in heterogeneous wireless networks is a challenging task. A WBAN uses a Personal Digital Assistant (PDA) to gather data from body sensors and forwards it to a remote server through wide range wireless networks. In this paper, we present a coexistence study of WBAN with Wireless Local Area Networks (WLAN) and Wireless Wide Area Networks (WWANs). The main issue is interworking of WBAN in heterogenous wireless networks including seamless handover, QoS, emergency services, cooperation and security. We propose a Seamless Interworking Architecture (SIA) for WBAN in heterogenous wireless networks based on a cost function. The cost function is based on power consumption and data throughput costs. Our simulation results show that the proposed scheme outperforms typical approaches in terms of throughput, delay and packet loss rate.

Keywords WBAN · WLAN · WiMAX · QoS

Introduction

A wireless sensor network is a collection of cooperative nodes using wireless links to perform a distributed sensing task. These nodes are typically provided with an embedded microprocessor and a very small amount of memory. Wireless sensor networks (WSNs) are being applied in many areas, such as medical monitoring, emergency response, security, industrial automation, environment and agriculture, seismic detection, infrastructure protection and optimization, automotive and aeronautic applications, building automation, and military applications [1]. Wireless sensor networking has opened up new opportunities in healthcare systems by enhancing the quality of life provided for the patients and also the quality of healthcare services [2]. In such networks different kinds of sensors are attached on clothing or on the body or even implanted under the skin. For example, patients need not be physically present at the physician clinic for their routine diagnostic check if they are equipped with Wireless Body Area Network (WBAN). A WBAN has shown to be adequate for emergency cases, where it continuously sends patient’s information to a remote server or physician to maintain optimum health status. When integrated in a telemedicine system, it also allows physician and emergency medical technician staff (Nurses and Technicians) to predict or even treat life-threatening diseases [3, 4]. This technology is expected to reduce the amount of time doctors require to identify the problem, the amount of paper work required and eliminates the duplication of patient records. Figure 1 shows a conceptual view of WBAN.

At the end of 2007, IEEE launched a new task group on WBAN [5] known as IEEE 802.15.6. The purpose of the group is to establish a communication standard optimized for low-power and short-range in-body/on-body nodes to...
serve a variety of medical, consumer electronics and entertainment applications. The standard provides efficient communication solutions to the ubiquitous healthcare and telemedicine systems, interactive gaming, military services and portable audio/video systems. Moreover, a number of technical issues and challenges create problems in the standardization process such as low power consumption, maximum throughput, minimum delay, scalability and interoperability.

Next generation wireless communications are expected to rely on integrated networks consisting of multiple wireless technologies. Heterogeneous networks based on Wireless Local Area Networks (WLANs) and Wireless Wide Area Networks (WWANs) can provide high Quality of Service (QoS) to mobile nodes, especially to a WBAN user by using their respective advantages on available bandwidth, data rates and coverage. In such an environment, multi-interface terminals should seamlessly switch from one network to another in order to maintain a continuous wireless connection and can also obtain better performance. Therefore, a network selection algorithm is important in providing better performance to the multi-interface terminals in the integrated networks. In such networks, a WBAN user will be roaming among different Radio Access Technologies (RATs), which is known as Vertical Handoff/Handover (VHO). Table 1 shows specification comparison of WBAN, WiMAX and WiFi Networks.

The problems associated with handoff can be classified as handoff latency and unnecessary handoff. We make a simple definition and comparison between horizontal handoff [6] and vertical handoff as follow.

(a) Horizontal handoff: It is the process of handoff that occurs by the movement of a mobile node [7] among the homogeneous RATs. Due to the homogeneous network protocols, there is no disconnection in the procedure of handoff. Figure 2 shows a horizontal handoff between Base Stations BS_C and BS_D.

(b) Vertical handoff: It is the process of handoff that occurs by the movement of a mobile node among the heterogeneous RATs. Due to the differences between the communication protocols, there must be a disconnection in the procedure of handoff. Figure 2 shows a vertical handoff between a Base Station BS_B and Access Point AP_A.
The rest of the paper is organized as follows: “Related Works” presents related works. “Interworking Architecture for WBAN” describes the handoff architecture for a WBAN. “Simulation Results” shows the performance evaluation to investigate the effectiveness of the proposed scheme. And finally, “Results and Discussion” concludes our work.

Related works

In wireless networks, the most widely used criteria for handoff evaluation are Received Signal Strength Indication (RSSI) and Bit-Error Rate (BER) [8]. However, considering only the RSSI criterion could lead to unnecessary handoff decisions, particularly in WSN scenarios. For this reason, other parameters such as velocity, direction, distance, Signal to Interference-plus-Noise Ratio (SINR), transmit power and traffic load have to be considered.

A prediction-based adaptive buffering handoff algorithm has been proposed to estimate the future values of handoff criteria, such as RSSI [9]. In [10], the authors used the Grey model in combination with fuzzy logic for predicting the signal strength value and Particle Swarm Optimization (PSO) algorithms to finely tune the weighting function of the handoff decision. In [11], a handover decision for next generation heterogeneous wireless networks is identified as a fuzzy Multiple Attribute Decision Making (MADM) problem where fuzzy logic is applied to deal with the imprecise information of some criteria and user preferences. In [12], the authors proposed a context-aware mobility management scheme that can support high mobility in the WBAN/WLAN interworking environment, while minimizing power consumption. In [13], the authors proposed a VHO algorithm that can support QoS in mobile WiMAX networks by handovering low-speed WiMAX Subscriber Station (SS) to an overlaid WLAN network. The authors of [14] suggested a vertical handoff scheme between WiMAX/WiFi heterogeneous networks that can reduce the unnecessary handoff probability and can also extend the coverage range of WLAN networks. In [15], Dia et al. proposed a new user centric algorithm for vertical handover to continuously maintain the connection and also to maximize user throughput by taking into account the link quality and the current cell load. The vertical handover scheme proposed in [16] can provide a low handover delay to a mobile node and can also reduce handover signaling overhead between WLAN/WiMAX heterogeneous networks. To avoid QoS degradation, this scheme directs a new call request on top of call admission control.

![Horizontal and vertical handoff illustration for a WBAN user](image-url)
Interworking architecture for WBAN

This section is further divided into four subsections. “General Architecture” presents the general architecture for advanced seamless interworking architecture in heterogeneous wireless networks, “QoS Mapping Relation Among WBAN, WiMAX and WiFi” describes the proposed QoS mapping structure, “Mapping Relation Among WBAN, WiMAX and WiFi MAC Frame Format” describes the MAC frame format mapping relation among WBAN,
WiMAX and WiFi, and “Interworking Decision Algorithm” describes the proposed interworking algorithm.

General architecture

Figure 3 shows the proposed advanced seamless interworking architecture in heterogeneous wireless networks. In this architecture, not only guaranteed QoS but also low power consumption and good throughput can be achieved by handovering a WBAN user between heterogeneous wireless networks.

QoS mapping relation among WBAN, WiMAX and WiFi

As shown in Fig. 4, the eight flow classes in WiFi and the QoS flows in WBAN, such as Voice (VO), Video (VI), Background (BK) and Best effort (BE) can be mapped into the four QoS flow classes of WiMAX, i.e. Best Effort (BE),

### Table 2 User priority mapping in heterogeneous networks

<table>
<thead>
<tr>
<th>Priority</th>
<th>WBAN</th>
<th>WiFi (802.11e)</th>
<th>WiMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>Background(BK)</td>
<td>BK</td>
<td>BE</td>
</tr>
<tr>
<td></td>
<td>Best effort (BE)</td>
<td>BE</td>
<td>nrtsp</td>
</tr>
<tr>
<td></td>
<td>Excellent effort (EE)</td>
<td>EE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Controlled lead (CL)</td>
<td>CL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voice(Vo)</td>
<td>VI</td>
<td></td>
</tr>
<tr>
<td>Highest</td>
<td></td>
<td>VO</td>
<td>UGS</td>
</tr>
<tr>
<td></td>
<td>Emergency/medical event report</td>
<td>NC</td>
<td>NC</td>
</tr>
</tbody>
</table>

Figure 5 MAC frame format mapping relation among WBAN, WiMAX and WiFi

![MAC frame format mapping relation among WBAN, WiMAX and WiFi](image)
Non-Real-Time Polling Service (NRTPS), Real-Time Polling Service (RTPS) and Unsolicited Grant Service (UGS), based on the priority. QoS guarantees transparency between WBAN, WiFi and WiMAX Network can be fulfilled by the proposed mapping structures. Table 2 shows the QoS mapping relations among WBAN, WiFi and WiMAX.

Mapping relation among WBAN, WiMAX and WiFi MAC frame format

Figure 5 shows the mapping relation of MAC frame formats between WBAN-WiMAX and WBAN-WiFi. We observe that the WBAN MAC frame control field (32-bit), corresponding to the fields including Header Type (HT), Encryption Control (EC) Type, CRC Indicator (CI), Encryption Key Sequence (ESK) and Header Check Sequence (HCS) of WiMAX and the frame control field (32-bits) of WiFi. Also, the payload field in WiMAX corresponds to the address fields, security sequence number, frame payload and Message Integrity Code (MIC) fields in WBAN MAC format. The address fields represent the recipient ID and sender ID along with the Body Area Network Identification (BAN ID). Moreover, the QoS (16-bits) field in WiFi can be resolved into a CID (16-bit) field in WiMAX whenever there is a VHO between WiFi and WiMAX. The frame body (0–1848 bits) field in WiFi MAC frame format corresponds to the security sequence number (32-bit) field, frame payload and Message Integrity Code (MIC) fields in WBAN MAC frame format.

Fig. 6 Flow chart of the proposed vertical handoff decision algorithm

Fig. 7 File size versus power consumption per hour when TCP traffic is generated

Fig. 8 File size versus throughput when TCP traffic is generated

Fig. 9 Effect of number of WBAN users on the HO performance
Also, BAN ID in WBAN corresponds to the Address-3 and Address-4 fields in WiFi. Moreover, the Recipient ID and Sender ID fields in WBAN MAC frame format correspond to the Address-2 and Address-1 fields in the WiFi MAC frame format respectively.

Interworking decision algorithm

In the Interworking decision phase, a WBAN user determines whether to continue its connection using the existing selected network or to be switched to another network. The decision depends on various parameters including the type of the application (e.g., normal traffic, on-demand traffic, emergency traffic), minimum bandwidth and delay required by the application, current battery status of the WBAN user, access cost, transmit power, and the user’s preferences.

Figure 6 shows the flow chart for the proposed vertical handoff decision algorithm. As shown in Fig. 6, when a WBAN user enters the double-coverage area that is covered by both WiFi and WiMAX, a network selection module collects all the required information for calculating cost from both WiMAX and WiFi networks. The collected information includes data rate, power consumption and monetary cost of each bit for the WiMAX network as well as the expected power consumption and monetary cost of each bit for the target WLAN network. By using the proposed cost function, the network selection module calculates the cost for both networks and then decides whether a WBAN user should perform a VHO or not. That is, if the cost for WiMAX is less than that of WiFi, the WBAN user will switch from WLAN to WiMAX. The result of this decision is delivered to the WBAN user, allowing the WBAN user to connect to the best available network. The cost function for network $I$ can be defined as

$$c(I) = w_t n_t(I) + w_p n_p(I) + w_m n_m(I) \text{ For } I \in \{\text{WLAN, WiMAX}\}$$

Where $n_t(I)$, $n_p(I)$, and $n_m(I)$ denote the normalized variables for throughput, power consumption and monetary cost in network $I$, respectively. While $w_t$, $w_p$, and $w_m$ represent the weights of each factor, being set according to the user preference and their sum is always equal to 1.

Simulation results

In this section, we describe performance evaluation results. To investigate the effectiveness of the proposed scheme in comparison with that of the existing cost-based scheme and typical WLAN First Scheme (WFS), we have developed the simulator using C++. The proposed scheme takes into account the WBAN’s Received Signal Strength (RSS) and Automatic Rate Fallback (ARF) when computing the cost for each network, whereas the traditional cost-based scheme does not. Our simulation model shows good performance in terms of power consumption, throughput, number of VHO and blocking probability.

Simulation setup

In our simulation, we use a network topology consisting of eight APs and being deployed in a single WWAN coverage of $1000 \times 1000 \text{ m}^2$. A WBAN user can be in the coverage of any one of the AP’s of WLAN or Base Station (BS) of WWAN. Each AP in the network topology covers a circular area with a radius of 100 m and employs IEEE 802.11a...
standard protocol, including an adaptive modulation technique. The data rate for WLAN changes adaptively based on an adaptive modulation scheme of five modulation levels of 6 Mb/s, 12 Mb/s, 18 Mb/s, 36 Mb/s and 54 Mb/s, while the WWAN uses the bandwidth of High-Speed Downlink Packet Access (HSDPA), 14 Mb/s.

Results and discussion

Figure 7 shows the power consumption per hour in milli-watts versus the different file sizes when the TCP traffic is generated. We can see from Fig. 7 that the proposed scheme achieves the greatest improvement over the WFS and the typical cost-based scheme for all the values of the file size in terms of power consumption.

Figure 8 shows the throughput evaluation of the three schemes for varying file sizes. We can see that our proposed scheme achieves good performance over the other two schemes for different file sizes. Especially, the throughput improvement using our scheme is increased by 16.8% compared to that of WFS.

Figure 9 plots the evaluation of the Handover (HO) delay as a function of the number of WBAN users. The curves show an increase of the HO execution time (WiMAX to WiFi HOs and WiFi to WiMAX HOs) corresponding to an increase in the number of WBAN users. This parameter exceeds 50 ms until the number of WBAN users exceeds 4. Due to the differences between the communication protocols, there must be a disconnection in the procedure of handoff and due to this disconnection the vertical handoff delay is much higher than that of the horizontal handoff delay.

Figure 10 shows the number of VHOs per hour for different values of the data transmission rates when the User Datagram Protocol (UDP) traffic is generated. As in WFS, a WBAN user performs a Downward Vertical Handover (DVHO) whenever it enters the double-coverage area, therefore showing the greatest number of VHOs. Also the number of VHOs for the cost-based scheme is more than that of our scheme over the whole range of the data transmission rates.

Figure 11 shows the blocking probability versus the number of WBAN users. We observe that the blocking probability in the cost-based scheme and WFS is much higher than that of the proposed scheme, and the advantage is more evident when the number of WBAN users increases.

Conclusion

The coexistence of different wireless access technologies including WLAN and WiMAX has enabled WBAN users to roam freely from one network to another, while being able to maintain their network connection and required QoS. In order to achieve good performance and to maintain a continuous wireless connection in heterogeneous wireless networks, a WBAN user should be handed-over from one network to another. Therefore, in this work we proposed a cost-based vertical handoff decision algorithm based on a cost function for WiMAX/WLAN integrated networks. In the proposed scheme, whenever a WBAN user moves to a double coverage area, VHO is performed only if the cost expected in the WLAN is less than that of WWAN. The cost function is influenced by power consumption and data throughput. Our simulation results showed that the proposed scheme outperforms the typical cost-based scheme and WFS scheme in terms of power consumption, throughput, number of VHO per hour and blocking probability. In the future, people will be capable of using wireless networks to exchange diverse information with great convenience. A new ubiquitous wireless communication world will be truly created.

Acknowledgment

This research was supported by MKE (Ministry of Knowledge and Economy), Korea, Under the ITRC (Information Technology Research Center) support program supervised by the NIPA (National IT Industry Promotion Agency) (NIPA-2010-C1090-1011-0007) and by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST)(No.2010-0018116).

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