Context-aware Mobility Management with WiFi/3G Offloading for eHealth WBANs

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***Abstract*—Wireless Body Area Network (WBAN) relays on IEEE802.15.6 communication standard optimized for low power and short range communication between wireless medical sensors installed on the patient body that gathers health data (e.g. Heartbeat, SPO2, etc.). In addition, every WBAN has a specific component called gateway that permits to send the measured health datas to remote servers. For long range communications, the gateway is equipped with a 3G/WiFi interfaces. 3G interface allows high Quality transmission of health data during mobility. However, the large amount of 3G data traffic transmitting through this network is expected to grow rapidly with the popularity of mobile applications and therefore degrade the overall service. The aim of this paper is a contribution to improve the Quality of Service (QoS) of ehealth applications to assure an efficient and continuous remote monitoring of patients and elderly. For that, we propose a design of a new context-aware mobility management system that is able to take benefit from multiple available access wireless networks (3G and WiFi) to offload smartly specific traffics and maintain the QoS of critical services such as ehealth services.**

***Index Terms*—WBAN, Heterogeneous networks, Traffic offloading, Energy efficiency, WBAN, ZigBee, 3G, WiFi**

I. Introduction

During the last few years there has been a significant increase in the number and variety of wearable health monitoring devices, ranging from simple pulse monitors, activity monitors to sophisticated and expensive implantable sensors. Traditionally, personal medical monitoring systems have been used only to collect data. Data processing and analysis were performed off-line, making such devices impractical for continual monitoring and early detection of medical disorders. Systems with multiple sensors for physical rehabilitation often feature inconvenient wires between the sensors and the monitoring system. These wires may limit the patient's activity and level of comfort and thus negatively influence the measured results [1].

One of the most promising approaches to improve remote health monitoring is the one build on emerging Wireless Body Area Networks (WBANs) [2] associated with Cloud Computing technology [3] [4]. A WBAN consists on multiple interconnected wireless sensor nodes, each capable of sampling, processing, and communicating one or several vital signs (heart rate, blood pressure, oxygen saturation, activity) or environmental data (location, temperature, humidity, light). Patients are also equipped with a PDA (Personal Digital Assistance) that plays the role of gateway for the WBAN. It gathers the health data sensed by the WBAN sensors and transmits it to remote health provider(s) server(s) for diagnosis using any available long range communication network (3G, WLAN, GPRS or LTE).With Cloud Computing technology, these applications could also run in the Cloud. Indeed Cloud Computing allows the delivery of computing resources as a service. Shared resources, software, and information are typically provided to computers and other devices as a Utility over the Internet network.

WBAN usually relays on IEEE802.15.6 communication standard that is optimized for low power and short range communications. However, these wireless communication are expected to relay on integrating heterogeneous networks consisting of cellular and backbone networks. Several technical issues and challenges are associated with the integration of WBANs an Cloud Infrastructure in the context heterogeneous wireless access networks. The main issues of this heterogeneous inter-connectivity are the interworking of the different network including seamless Vertical Handover (VHO) mechanisms to guarantee the reliability of critical healthcare data transmission. Solutions based on WiFi offloading are generally used to avoid transporting unnecessary traffic and to maintain a high QoS for users while saving energy consumption. The aim of this paper is to design a context-aware mobility management system that can support high mobility in the WBAN/WLAN/3G inter-working environment based on WiFi offloading, while minimizing power consumption for healthcare applications.

This paper is organized as follows: in Section II, we present first some related works on wireless Access Network Selection (ANS) and traffic offloading in heterogeneous networks. We highlight also the problem statement when using WBANs. In Section III, we formulate the problem and present the considered scenario. In Section IV, we introduce the proposed architecture for Context-Aware Mobility Management System for WBAN (CAMMSW), including the inter-working architecture between WBAN, WLAN, and 3GPP technologies. Section V presents an implementation and evaluation of the proposed architecture in a simulator and discuss the obtained results. Finally, conclusions are presented in the last section.

II. Related Works

A. Access Network Selection

The problem of wireless Access Network Selection (ANS) and VHO (Vertical HandOver) have been previously addressed

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in several application domains. The common goal of all approaches was to maintain the Mobile Terminal (MT) connection during the mobility of the user across heterogeneous access networks (e.g., walking, using a car, traveling in a train). In [5], the authors proposed a Terminal Control Handover (TCH) policy-based approach to identify the appropriate time to initiate the VHO and to select the most appropriate interface. In [6], the authors proposed a VHO decision algorithm that takes into account not only network parameters but also energy consumption to maximize the collective battery lifetime of MT. Finally in [7], authors proposed an analytical model to capture the preferences of end-users and ANS mechanism that takes into account all aspects of the trade-off between the quality of the connections, the preferences of the end users and the cost. In parallel to these contributions addressing VHO mechanisms, other works have focused on the architectures to support these mechanisms. In the work presented in [8], [9], an Media Independent Handover (MIH) mechanism proposed by the National Institute of Science and Technology (NIST) IEEE 802.21 standard is presented and implemented. It is based on the results of the joint work between IEEE 802.21 and Internet Engineering Task Force (IETF). Actually, in order to facilitate the handover and interoperability between IEEE802 (WBAN, WLANs) and non- IEEE802 technologies (e.g. 3GPP standard), seamless convergence architecture based on MIH IEEE802.21 standard could be used to provide transparent service continuity across heterogeneous networks. However, none of these works has considered to offload part of the traffic based on the location of Access Points (APs) and the mobility behavior of the subscribers.

B. LIPA, SIPTO & IFOM

From the core network side, operators are today seeking for cost effective solutions to overcome the limitation of bandwidth in access and core networks. However, an increased capacity is also needed at the core network to cope with the increased traffic and ensure guaranteed QoS. Solutions such as Local IP Access (LIPA) , (SIPTO) and (IFOM) have been designed to solve this problem and avoid a bottleneck at the core network by reducing both data on the backhaul. LIPA is primarily for end users to access their local network or Intranet through a local 3GPP access point (e.g., indoor Femtocell/Picocell). This can be used by patients to quickly upload/downloaded their daily Electronic Health Record (EHR). With LIPA, a patient equipped with PDA can access its home services directly using Mobile Packet Core Network (MPCN). Its PDA could connect directly to a Local GW (L-GW) located in the Femtocell level [10]. SIPTO is another solution that allows handling Internet traffic in an efficient way. It actually works with both Femtocell and Macrocell. It enables routing of selected IP traffic through the most optimal path in an operator's core network or bypassing it completely. The type of traffic to offload can be determined by the operator (an operator can decide to allow only priority traffics to use its core network such ehealth traffic). Another solution to offload traffic at the RAN network is the IP Flow Mobility (IFOM). IFOM allows a MT to simultaneously connect to 3GPP access and WLAN. Thus, a MT can balance different IP flows belonging to the same session [11]. IFOM solution allows the operator to specify an offload policy indicating how IP flows are routed through the available access systems and to selectively offload some traffic (e.g. best effort traffic) to WLAN while using 3G or LTE for other traffic (e.g. traffic with specific QoS requirements such as ehealth traffic) [12].

From these perspectives, we have targeted the following research questions:

- How to identify the QoS requirements of ehealth applications: delay tolerant or real time profile, data accurate profile, energy saving profile ?.
- Based on the mobility profile of patients, why and when triggering WiFi/3G offloading?.
- How to design an efficient NSA based on MIH standard and apply to WiFi/3G offloading?.

We focus in this work mainly on the network part and not the cloud computing part even if we mention. In order to answer these questions, we need to perform the following tasks:

- Capture the QoS requirements of ehealth application's in term of data traffic, delay etc.
- Design of Context-Aware Mobility Management System for WBAN (CAMMSW) that uses an opportunistic WiFi/3G offloading.
- Highlight using simulations how the WiFi/3G offloading can be efficiently integrated in the CAMMSW architecture.

III. Problem Formulation

We consider a scenario where an ehealth service provider (e.g., hospital) associate with a network provider to provide continuous remote monitoring of the health status of subscribed patients. For that, patients will be equipped with medical sensors and a PDA forming a ehealth WBAN. To ensure a continuous connection of the WBAN to the Cloud where the ehealth applications are running (virtual ehealth servers), the network provider Operating Support System (OSS) will propose to the WBAN the best available networks forcing them sometimes to offload their traffic to different networks depending on the patient profile and the ehealth application priority.

To highlight the problem, we consider an area where several wireless networks technologies are deployed. We consider also that following technologies IEEE802.11 (WLAN), IEEE802.15.6 (WBAN) and 3G are available. The considered area is fully covered by 3G network (3G Cell coverage) while the deployed WiFi APs only cover a limited part. Within this area, we initially assume N_{max} patients (to continuously monitor and assist) are equipped with PDA embedding several ehealth mobile applications (client parts). The patient can move randomly moving within the whole area with a random velocity and path. These patients can be walking in the street (i.e. almost static) or in a hospital area at low velocity. They can also move fast in case there are in a car or in a public transportation vehicular. We assume that patients have subscribed to a 3G operator and their PDA running ehealth

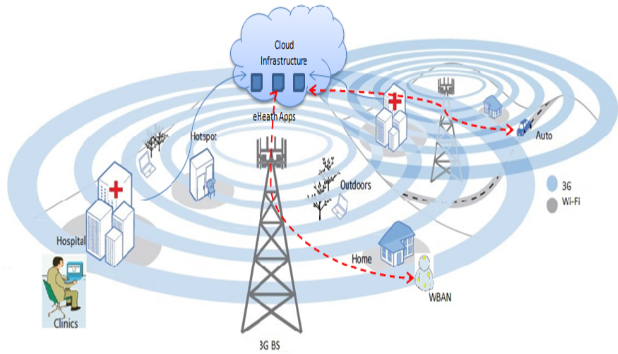

Figure 1. WLAN and 3G cellular networks for healthcare applications

application connected to virtualized ehealth servers deployed by a health provider and running the back-end logic of the eheath applications. The patient is equipped with a set of medical sensors forming a WBAN. We also assume that the ehealth mobile application embedded in the PDA can start or end a transfer session with back-end servers at anytime and therefore the number of active PDA can randomly change during time. When the patient moves around, its PDA can be covered by differed wireless access networks technologies. Fig.1 highlights the main elements of this scenario. The objective of this work is to design a system that will allow the patient to be always under control i.e. the ehealth mobile applications in the PDA get the best QoS at anytime, anyplace.

A. WiFi/3G Offloading

Since one technology is not capable to support the traffic of all MTs, the objective is (i) to seamlessly hand off some PDAs between WiFi and 3G and (ii) to smartly offload data from the 3G network to the WiFi network to maintain the service as long as possible and to extend the battery lifetime. However, the challenges for WiFi are the limited range of the technology and the high scanning overhead. For this aim, we propose to offload some sessions from 3G to WiFi when necessary to either save energy or reduce the load on the cellular network. However, to reduce the energy overhead of WiFi interface, it is necessary to switch it off whenever it is not necessary. Therefore, we propose to solve this problem by identifying when to switch off or on the WiFi interface of a MT (i.e. gateway of the WBAN) depending on mobility prediction model provided by the operator.

B. Optimization Problem

We consider that one-day analysis is divided into T time slots since the traffic and the mobility of subscribers (patients and other users) may change from one time slot to another. In addition, we suppose that each subscriber has a probability p_c^t to be in an area covered by a WiFi AP at any time slot $t \in T$ and a mobility profile (based on daily statistics recorded by the operator OSS). Also, we consider that 3 patient profiles are defined as follows: High-risk-patients (5% of the population), Rising-risk-patients (20%) and Low-risk-patients. All other subscribers (75%) will belong to the default profile. In addition, we define two classes of traffic (Best Effort and QoS). The total traffic demand of the subscriber u is represented by the vector $X_u(t)$ at time slot $t \in T$. The traffic volume of the subscriber u via the 3G interface only is represented by the vector $Y_u(t)$ at time t. Whereas, the traffic volume offloaded through the WiFi interface is represented by $Z_u(t)$ and is given by the following equation:

$$X_u(t) = Y_u(t) + Z_u(t) \tag{1}$$

Let T_{BW} be the volume capacity provided by the operator (which is the sum of the NodeB capacities in the network). The traffic demand $X_u(t)$ of all subscribers should not exceed the capacity of the cellular network.

$$\sum_{u=1}^{Nmax} X_u(t) \leq T_{BW} \tag{2}$$

We suppose that the operator OSS implements a mechanism that allows to determine the available WiFi Bases Stations at any location. First, the OSS identifies mobility profiles of subscribers at a given time $t \in T$ (GPS information, speed and direction). Using these profiles, the operator OSS updates the list of cells available around each MTs and broadcasts this information to each subscriber's MT. Let's denote by $NB_c(t)$ the number of subscribers in cell c at time t. The objective of the operator is to satisfy as much as possible all its customers' demands. This means that possibly, it needs to offload some MTs to existing WiFi accesses to allow other to still benefit from good QoS on the cellular network. To reach this goal, first, the network operator estimates the acceptance probability of each user based on the maximum number of users that can be served, the available WiFi connection and the total available bandwidth as described in equation 3. Then, the operator selects among the set of users of each profile (High, Rising, Low and Others) the ones that are generating the highest traffics possibly exceeding the capacity of the operator. Once this set of users identified, the network will decide to offload or not these traffics WiFi accesses if any.

Users' profiles are therefore integrated in the acceptance probability estimation as formulated in the following equation

$$A(X(t)_k, c_k) = [F_v(X(t)_k)]^{w_v}[F_c(c_k)]^{w_c} \tag{3}$$

, where $F_v(X(t)_k)$ and $F_c(c_k)$ are the cost functions of the traffic demands and the coverage AP respectively. We assume that the operator has good information about its subscribers' preferences (w_v and w_c) as well as their sensitivities to the QoS (i.e. Best Effort or QoS). Using these parameters, the ehealth application estimates the minimum acceptance probability λ of each patient u's PDA located at in the cell c and executes the Algorithm 1 every δt time.

IV. The Proposed Architecture

In this section we present the architecture called Context-Aware Mobility Management System for WBAN (CAMMSW), the inter-working architecture between WBAN, WLAN, and 3GPP technologies and the offloading mechanism in the NSA process. CAMMSW is a cross-layer interactive

Algorithm 1 Network Selection Algorithm

Require: $patient_u$ mobility profile, $patient_u$ λ, c, $NB_c(t)$, $X_u(t)$, $Y_u(t)$, $Z_u(t)$, T_{BW}, $Req_u(t)$

if $Req_u(t) \neq \emptyset \wedge X_u(t) \leq T_{BW} \wedge p_c^t > p_{threshold}$ **then**

  Evaluate $A(X(t)_k, c_k) = [F_v(X(t)_k)]^{w_v}[F_c(c_k)]^{w_c}$;

  if $A(X(t)_k, c_k) \geq \lambda$ **then**

    Turn on WiFi interface and hand off to WiFi (offload);

    Serve $Req_i(t)$ in cell c , $\forall i < NB_c(t)$ patients;

    $Z_u(t) := Z_u(t) + Req_i(t)$, $\forall i < NB_c(t)$ patients;

  else

    Turn off WiFi interface and hand off to 3G;

    $Y_u(t) := Y_u(t) + Req_i(t)$, $\forall i < NB_c(t)$ patients;

  end if

else

  Do nothing;

end if

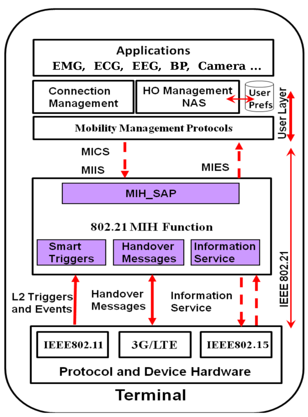

Figure 2. MIH Framework at the Terminal Side (PDA)

architecture that allows WBAN seamless handover between different access networks. It is a distributed solution based on MIH implemented at both core/access network and the WBAN gateway node. It takes into account factors such as: type of ehealth mobile applications (e.g., normal traffic, on-demand traffic and emergency traffic), coverage cell, link quality and power level battery. The CAMMSW architecture is composed of several components responsible for context information collection, smart handover decision-making, handover triggering, traffic offloading and post-handover management. CAMMSW introduces a MIHF client located in the protocol stack of the WBAN gateway node. MIHF consists of a signaling framework and triggers that make information available from lower layers (MAC and PHY) to higher layers of the protocol stack (network to application layers). Fig. 2 depicts the main component of the MIH framework. The IEEE802.21 local or remote L2 interfaces deliver events and triggers to the MIH Function (MIHF) layer called link events. These MIH events are made available to upper layers through the MIH SAP (Service Access Point). The handover management module that includes the NSA uses these MIH events to discover available networks and to select the best access network.

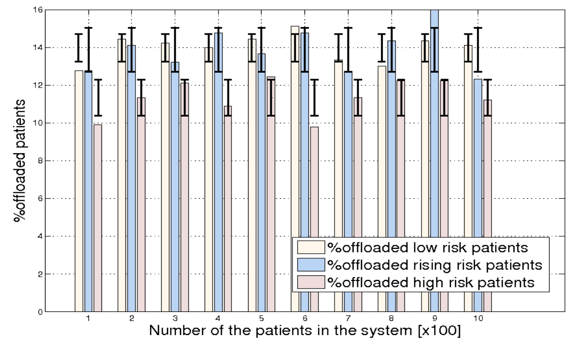

Figure 3. The impact of NSA offloading on the number of patients located in the city

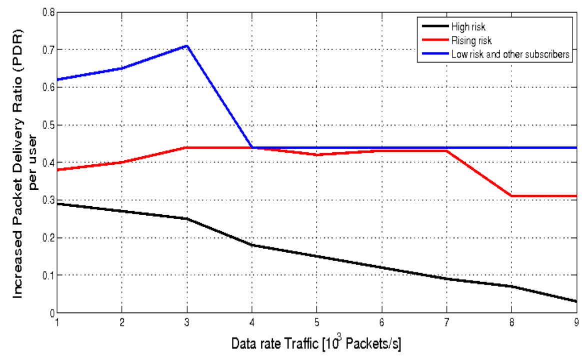

Figure 4. Packet Delivery Ratio (PDR) vs. Data Rate Traffic for each categorie of user (high risk, rising risk and low risk/others)

V. Performance Evaluation

To evaluate the benefit of this solution, we have defined a scenario where we consider a set of patients equipped with PDA and WBAN. We supposed that each embedded ehealth applications in patients' PDA have specific traffic profiles (i.e, emergency traffic, video traffic or data traffic (ECG)) and a delivery delay constraint (real time or non-real time). Table I summarizes the simulation parameters. To investigate the effectiveness of the proposed solution, we have implemented the CAMMSW including the implementation of the proposed NSA, and run several simulations in an appropriate simulation environment based on NS2. We have evaluated through simulations the performance of NSA in terms of number of patients which are offloaded in the system and their categories. We have also evaluated the energy consumption of PDA handled by patients and highlight our proposed solution. We provide results showing the benefit that the patient can achieve from our proposed NSA solution in the CAMMSW platform.

A. Simulation results

We ran several simulations varying the number of patients/users, the mobility profile of each patient/user (static patients located at home or at the hospital or mobile, walking or using transportation). We started from evaluating the impact of offloading part of the traffic on WiFi network while patients, randomly deployed in the city, try to maintain their

Table I
SIMULATION PARAMETERS

	3G (HSPA+)	IEEE802.11g	IEEE802.15.6
Coverage area	1000m	25-75m	$1-3$m
PHY Spec. Propagation model	Two-Ray Ground Model	Two-Ray Ground Model	UWB
Frequency Range	2.4Ghz	2.4Ghz	$402-405$ Mhz
RXThresh	5.25089e-10w	4.4613e-10 w	ND
Antenna Type	OmniAntenna	OmniAntenna	No
Peak Data rate	21Mb	54Mb	10Mb
License cost	Expensive	Free	Free

connectivity with the server located at the hospitals. Fig.3 depicts the distribution of the patients according to their profile (low, rising and high risk) while In Fig.4, we highlighted the benefit to offload some subscribers when their data rate application increase in order to maintain their session with the operator. The first observation is that traffic originated from High risk patients is the least affected by the offloading technique described in Algorithm1 since the traffic priority of this category of patients should always be satisfied. However, it's not recommended for the operator to offload eventually whenever WiFi hotspots are available. In the other hand, patients that belong to lower profile categories are very sensitive to offloading their traffics and maintaining their connectivity.

VI. CONCLUSIONS

Long range communications usually are required to provide high Quality of Service (QoS) and a sustainable connectivity during mobility of patients in healthcare systems. However, the large amount of 3G data traffic transmitting trough these networks is expected to grow rapidly because of the popularity of such portable healthcare devices and applications (e.g., PDA, Smart-phone with medical sensors, etc). In addition, the energy consumption of the different networking interfaces in a PDA can be significant due to multiple factors such as: distance, interference, signal strength or device model. Therefore the aim of this paper is to permit the coexistence of heterogeneous network including seamless vertical handover mechanisms in order to maintain the Quality of Experience (QoE) of patients and ensure them reliable data transmission between their WBAN and remote health servers possibly deployed in the Cloud. We propose a mechanism for the management of mobility based on the context of a subscriber. We highlighted the benefit using WiFi offloading to maintain communication sessions QoS which can be critical for ehealth applications. The achieved simulations showed that the approach works and permits to improve the performance of the system.

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REFERENCES

[1] J. E and all., "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation." *J Neuroeng Rehabil.*, vol. 1, no. 6, 2005.

[2] C. Otto, A. Milenković, C. Sanders, and E. Jovanov, "System architecture of a wireless body area sensor network for ubiquitous health monitoring," *J. Mob. Multimed.*, vol. 1, no. 4, pp. 307–326, 2005.

[3] P. Mell and T. Grance, "The NIST Definition of Cloud Computing," *NIST Special Publication 800-145*, September 2011. [Online]. Available: http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf

[4] E. C. Project. Extensible Architecture and Service Infrastructure for Cloud-aware Software. [Online]. Available: http://www.easi-clouds.eu/

[5] H. J. Wang, R. H. Katz, and J. Giese, "Policy-enabled handoffs across heterogeneous wireless networks," in *Proc. of the Second IEEE Workshop on Mobile Computer Systems and Applications*, Washington, DC, USA, 1999, pp. 51–60.

[6] S. Lee, K. Sriram, K. Kim, Y. H. Kim, and N. Golmie, "Vertical handoff decision algorithms for providing optimized performance in heterogeneous wireless networks," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 2, pp. 865 –881, 2009.

[7] Q.-T. Nguyen-Vuong, N. Agoulmine, E. H. Cherkaoui, and L. Toni, "Multicriteria optimization of access selection to improve the quality of experience in heterogeneous wireless access networks," *IEEE Transactions on Vehicular Technology*, vol. 62, no. 4, pp. 1785–1800, 2013.

[8] H. Marques, J. Ribeiro, P. Marques, and J. Rodriguez, "Simulation of 802.21 handovers using ns-2," *J. Comp. Systems Networks Communications*, vol. 2010, pp. 1–7, 2010.

[9] S.-J. Wu and C.-Y. Yang, "Hip-based handover mechanism under MIH architecture in heterogeneous wireless networks," in *7th International Conference on Networked Computing and Advanced Information Management (NCM)*, Gyeongju, Korea, 2011, pp. 329 –334.

[10] H. Claussen, L. T. W. Ho, and L. G. Samuel, "An overview of the femtocell concept," *Bell Labs Technical Journal*, vol. 13, no. 1, pp. 221–245, 2008.

[11] T. G. P. 3GPP, "3gpp ts 23.261 "ip flow mobility and seamless wireless local area network (wlan) offload; stage 2," *Release 10*, Mars, 2012.

[12] A. D. L. Oliva, C. Bernardos, M. Calderon, T. Melia, and J. Zuniga, "Ip flow mobility: smart traffic offload for future wireless networks," *IEEE Communications Magazine*, vol. 49, no. 10, pp. 124–132, 2011.