Software Defined eHealth Networking Towards a Truly Mobile and Reliable System

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***Abstract*—The eHealth technology will change the way the health system is handled, mainly in developing countries, such as Brazil, where there is a huge shortage of healthcare professionals to assist the patients, especially for those living in rural and remote areas. The Context-Aware Mobile Approach (CAMA) seeks to improve the Brazilian primary healthcare system through context-aware eHealth facilities, such as people mobility, expecting to change the way that healthcare services are applied, managed, and maintained to achieve efficiency and safety for both patients and hospital staffs. Since this type of technology will handle vital parameters of people, it is mandatory that the involved network infrastructure can provide dependability and reliability so it can fulfill their role properly. This paper presents a network infrastructure based on the Software Defined Networking (SDN) paradigm to enable quality-oriented mobility control capabilities in the CAMA approach, to deploy mobility prediction, Point of Attachment (PoA) decision and handover setup meeting both application quality requirements and current wireless quality conditions, then improving the dependability and reliability of the eHealth biofeedback systems.**

***Keywords*— eHealth; body sensor networks; software defined networking; mobility control; quality of service**

I. Introduction

The development of new *Information and Communication Technologies* (ICTs) are constantly changing people's daily lives, providing alternatives for your convenience and quality of life. Among these main initiatives, healthcare systems has been receiving special attention from researchers who are interested to allow the transformation of this traditional system towards the revolutionary eHealth [1].

The eHealth is envisioned to enable solutions to bring many benefits and efficiency for patients, healthcare professionals and institutions in both the private and public sectors. In a very near future, eHealth will provide both affordable and personalized medicine services through cost-effective and secure use of ICTs. Examples of eHealth applications include remote patient/medical devices surveillance/sensing, intelligent real-time diagnosis, sharing of medical information/exams, remote appointments/surgery [2].

The primary care is one of the most deficient areas in the Brazilian healthcare system, where health agents need to visit patient's residence since, for many reasons, they cannot go to a hospital. Hence, the health agent is in charge to monitor patient's health status, by manually collecting body measures. Furthermore, he must fill out paper forms and deliver them to a doctor, when available. This scheme takes too much time in the workday of health agents, and reduces the capacity of them in consulting patients along the day.

This kind of problem has been currently the focus of the biofeedback [3] eHealth field, performed by medical sensors installed on a patient body to enable remote, accurate, and low-cost health monitoring. It allows the capturing and monitoring of physiological parameters any time and everywhere [4], using the most appropriate wireless network technology available. Through this, data are delivered to doctors remotely located via a wireless network (instead of presentially as deployed traditionally), so that they can make real-time diagnosis.

The CAMA (*Context-Aware Mobile Approach*) [2] proposal, a previous work of our research team, is a promising biofeedback inspired approach that aims to improve the Brazilian primary healthcare with eHealth pervasive technology, by means of allowing patients to be monitored remotely and in real-time. It focus in providing infrastructural support to enable the design of value added eHealth applications, while allowing the healthcare services become faster, safer, and much better. For instance, emerging eHealth applications are envisioned with capacities to place real time medical information in the right hands, provide better access to specialist care in remote areas, and trigger a nearby ambulance to attend patients in critical circumstances.

To accomplish this, it makes use of *Body Sensor Networks* (BSNs) [4], which are composed by several small sensors placed along patient's body, with the goal to collect physiological parameters for healthcare monitoring purposes and capable to send them wirelessly to remote eHealth management stations. In order to detect any anomaly in the patient health status, BSNs need to operate every time and everywhere, being necessary that the network infrastructure provide the appropriate dependability, reliability and mobility support, thus keeping patient's continuous monitoring, so it can always be connected to some gateway to the Internet and therefore to back-end health providers.

In CAMA proposal, the *eHealth Smart Device* (eHSD) is a component with multifunctional capabilities to enable mobility, processing, and transmitting support. It is fitted with multihoming capability, which means that it is able to decide the most appropriated network interface for data transmission.

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In other words, a eHSD triggers the mobility process after detecting that the *Received Signal Strength* (RSS) of the current PoA is low, whilst the RSS level of the neighbouring PoAs is higher, and denotes that the eHSD is moving.

Despite its innovative approach, CAMA does not consider reliable communications provisioning in its design, and omits important factors for determining the connection such as the quality requirements of demanding applications, as well as the level of quality of the network nodes. These procedures are insufficient to ensure that the mobility process towards new network connections will improve service performance. For instance, the optimal handover procedure for the eHSD requires it to be triggered in the presence of a degradation of data transmission quality (e.g., excessive packet error/loss rates), which means that it is not necessarily guided by mobility factors, when assigning another PoA with a better level of quality. This drawback will seriously restrict the scope of CAMA in next generations eHealth environments.

In view of this, it is evident that CAMA lacks a infrastructure which enables to accommodate bandwidth-intensive mobile session flows that can guarantee both *Quality of Service* (QoS) and *Quality of Experience* (QoE) over time, in terms of keeping wireless connections with limited delay, error and loss rates experience. It is necessary that the mobility control functions of CAMA must take into consideration alternative parameters to link layer-based ones (e.g., user preferences, eHSD capacities, minimum application and service quality requirements, etc.) to guide quality-oriented seamless mobility. Needless to say that dependability, safety and reliability are requirements that must satisfy the emergency nature of medical applications, so it can justify the need for QoS/QoE in wireless medical networks [5].

The limitations described above justify our work in the sense that there is a need to extend the mobility support of CAMA with quality-oriented mechanisms for both prediction and handover control functions. First of all, we propose a network infrastructure based on the *Software Defined Networking* (SDN) [6] concept to provide new services, mechanisms, features and optimizations for these scenarios in order to achieve quality-oriented mobility control efficiently. The reason for choosing SDN is justified by the attempt to devise a proposal that is not affected by the shortcomings imposed by the current Internet infrastructure [7]. Through this, it is possible to design, test and validate new network architectures with new mechanisms and create testbeds for real-scale experimentation.

Then, we proposed a mobility control architecture to achieve efficient quality-oriented mobility control decisions that can meet the quality demands of mobile eHealth session flows and current wireless conditions of PoA(s) candidate(s).

The remainder of the document is structured as follows: Section 2 presents the background for this work, highlighting the SDN concepts and mobility control basics. Section 3 provides an overview of our proposal. And Section 4 outlines the next stages of this work.

II. Background

The emergence of new technologies such as the Internet of Things and Cloud Computing, in addition to the significant growth of mobile devices with multiple access capabilities, has led to a number of requirements, such as mobility and reliability, which the Internet is currently unable to satisfy effectively. The attempts to enhance the Internet of today and address new emerging demands, has resulted in a sharp increase in its complexity whilst jeopardizing its performance and scalability. In this context, there have been several attempts by researchers to focus on Internet redesigns [7], a.k.a. Future Internet (FI), and to adopt a new approach that is completely re-architected with new services, mechanisms and protocols to deal with new capacities.

Among diverse initiatives to deal with the problems of the current Internet infrastructure, proposing new solutions, most make use of the *clean slate* approach, which does not take into account any compatibility with the current Internet. The architecture being proposed must be designed from scratch to provide better abstraction and performance based on new principles [8]. However, the use of different clean slate solutions focusing on separate aspects is not necessarily a Future Internet architecture. It is necessary a remodeling of the whole architecture that takes into consideration all possible aspects [7]. Under this new approach, with a number of challenges to be overcome, reliability is the key for the success. To reach it, there is a need to meet some basic assumptions: Availability, Quality of Service, Mobility Control, Security, Scalability and Flexibility [8].

The validation of these new proposals is still a challenge, since the results obtained through simulations do not always correspond to those obtained through experimentation in real environments. Furthermore, experimentation in production networks is not always allowed by organizations.

In this context, the Software Defined Networking paradigm is increasingly receiving the attention of the academic community and the computer networking industry, mainly for its flexibility and potential for innovation in developing new technologies for the Future Internet. SDN [9] consists in a structure that allows the network to be controlled by applications [6]. In other words, SDN enables the programming of network behavior by separating the control plane from the data plane, moving part of the decision logic from network devices to an external element, named controller. From this it is possible to manage the equipment in a more flexible manner by inserting and removing applications through an well-defined *Application Programming Interface* (API)

Among the various technological options to manage the control plane, OpenFlow [10] shows itself as a very interesting alternative for presenting a flexible open standard for programming the flow tables in the switches.

The increasing demand for real-time content and services require from the wireless networks management systems, mechanisms that support different traffic characteristics at different levels of quality [11]. Furthermore, the need to be

Always Best Connected (ABC) [12] also requires the existence of mechanisms that enable the migration (*handover*) of users to networks with better access conditions.

The handover process basically involves four different phases of operation: (i) Handover initiation; (ii) System discovery; (iii) Handover decision; and (iv) Handover execution [13]. The process begins in the handover initiation phase, with detecting alterations to pre-defined criteria parameters, such as the RSS, battery lifetime, available bandwidth, among several others. Afterwards, the system discovery phase is invoked, and seeks to gather information about neighbour networks (i.e., PoA candidates) as from the *Mobile Node* (MN) scan.

The information gathered during the system discovery phase is used to support the handover decision phase. The handover decision is applied by means of an appropriate algorithm, which is employed to choose the most suitable PoA at the moment when the MN is under the handover influence. Finally, the handover execution phase is responsible for enforcing the wireless connection setup between the referring MN and the new PoA, as well as to release all connections with and the previous PoA seamlessly (i.e., those deployed by the network infrastructure).

This means that, the handover decision phase is a key factor in keeping the MN best connected, whereas its efficiency depends on the mobility parameters taken into account. In order to enable quality-oriented decisions, a handover algorithm is required to take into account both the minimum quality requirements of the mobile session flow (bitrate, tolerance to packet delay/loss/error, etc.) and the current wireless link conditions of the PoA candidates (available traffic classes, packet delay/loss/error current rates, wireless technology, etc.) [14]. An efficient approach to quality-oriented mobility control must always keep the mobile nodes best connected over time, and guarantee that the whole activated mobile session flow meets their quality requirements even under the handover influence of the handover procedure. The literature provides a number of quality-oriented mobility control solutions, and an analysis of the most significant ones can be found in the following.

The *Multiple Attribute Decision Making* (MADM) techniques are employed in the most important mobility control algorithms to address the handover decision problem [15]. When formulating a mobility control algorithm that follows a MADM [16] approach, the handover decision problem can be expressed in a matrix format, where the j^{th} attribute of the i^{th} alternative is represented as x_{ij}. In the case of a quality-oriented handover decision, the alternatives are the candidate networks and the attributes are the required quality parameters. The networks are ranked by the use of scoring techniques, which attach different importance values (weights) for each parameter [17].

There are several MADM methods which are widely used to deal with the handover decision problem. Here we briefly describe some of them.

A. Analytical Hierarchical Processing

The *Analytical Hierarchical Processing* (AHP) method is mainly used to determine the criteria for weighting the attributes. Its mechanism allows evaluations of intangible qualitative criteria to be incorporated alongside tangible quantitative criteria by making a synthesis of priorities [18].

B. Simple Additive Weighting

The basic operation of *Simple Additive Weighting* (SAW) consists of calculating the weighted sum of all the considered metrics, where the score of each candidate network i is given by the standardized values of each considered metric v_{ij} multiplied by the weight w_j [19].

C. Technique for Order Preference by Similarity to Ideal Solution

The main goal of the *Technique for Order Preference by Similarity to Ideal Solution* (TOPSIS) is to choose the alternative which has the closest similarity to an ideal case solution and is farthest from the worst solution [17][20].

D. Multiplicative Exponential Weighting

The computed score of *Multiplicative Exponential Weighting* (MEW) is calculated by the weighted product of the attributes [19].

E. Grey Relational Analysis

The *Grey Relational Analysis* (GRA) method ranking computing is performed by the data standardization to deal with benefit and cost metrics and a *Grey Relational Coefficient* (GRC) calculation is carried out for each network. The GRC is the score that is used to account for the similarity between each candidate network and an ideal network. The chosen network is the one with the greatest similarity to an ideal network [20].

III. Proposal Overview

The main objective of this work is to provide a network infrastructure to support CAMA with quality-oriented mobility control capabilities so that it can be able to maintain best connectivity over time, and can make mobility decisions that go beyond those that are strictly guided by the motion events of eHSD. Thus, we propose a SDN-based network infrastructure that is able to provide new resources that can improve the mobility process on the network. In our approach, quality requirements of eHealth applications are semantically defined for each session in order to guide the mobility mechanisms.

The proposed framework is presented in Figure 1, depicting the enhancements made over the OpenFlow Controller [10] and the eHSD. It consists in a SDN-based infrastructure composed with the eHealth Controller, that is responsible for both storing information about the existing entities (Topology Manager) and eHealth sessions (Session Manager), as well as for performing routing related tasks, implementing the sessions into the switches. The Mobility Manager is responsible for handling and controlling mobility procedures in the network. And the eHealth Switch consists of an extended OpenFlow switch to support QoS control and mobility, by enhancements inspired by the IEEE 802.21 *Media Independent Handover* (MIH) [21] and the eHSD represents the CAMA eHealth Smart Device. In this way, the communication mechanisms become aware of new network connection points detected by eHSD and use this information to enhance the handover process in the network.

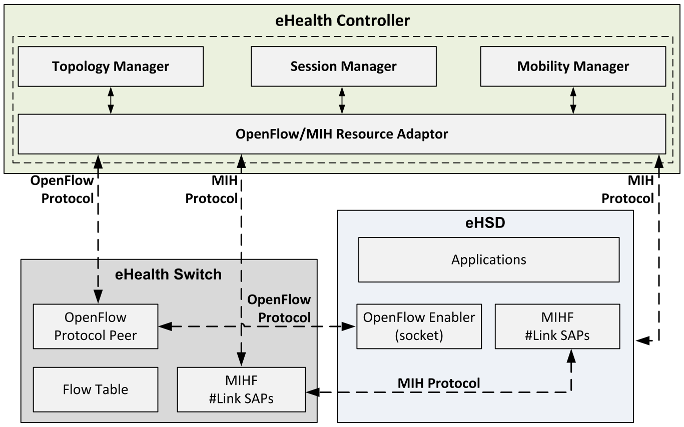

Figure 1: Proposed framework

To achieve quality-oriented mobility capabilities we propose a mobility control architecture to extend the Mobility Manager, named QoDM (*Quality-oriented Decision Manager*) that consists of the following components:

A. QAMC

QAMC (*Quality Attribute Monitoring and Collector*) is responsible for identifying the modification of parameters that indicates the occurrence of mobility or quality degradation of current session and for obtaining the quality parameters of the entities. In case of occurrence of the first event, the QAMC can start the handover process (System Discovery) by asking the eHSD to scan networks in their coverage area. Collected data (with pre-determined frequency) will be sent to FNQE, to enable the handover prediction based on the quality of the active eHealth session.

B. QWCM

The QWCM (*Quality Weight CoS Mapping*) component is responsible to perform the mapping for the CoS to which a particular eHealth session (affected by the events identified in QAMC) belongs, and thus, determine the importance weights of attributes, through the AHP [18] method.

C. Decision Maker

This component works intermediating the different requests for the decision function (E2BS) and quality estimation (FNQE) subcomponents of the architecture.

D. E2BS

E2BS (*Extended Elitism for Best Selection*) is a handover decision method inspired in the Elitist Selection Strategy [22], combined with MADM (*Multiple Attribute Decision Making*) [18] features to enable quality-oriented mobility decisions efficiently. Its main goal is to meet both the quality requirements of active mobile session flows and to match the current quality standards of neighbouring PoA candidates. The elitism strategy employed by E2BS is based on a multi-attribute evaluation of the QoS candidate networks. In our model, the population is represented by a set of PoAs and their attributes. This technique is used to select the PoA which offers the best connection criteria. Assessing the QoS offered by the various PoA to select the best one is carried out by measuring the similarity between the attributes of the elite individual, represented by the reference PoA, and other candidates. The reference PoA is considered to be the one that have the ideal values, (i.e. attributes like delay and jitter should have values close to zero). The following steps are required to perform the calculating of the score of the candidate networks:

1) The QoS attributes of the candidate networks are joined to compose the decision matrix;
2) Since the data value of the attributes is expressed in different formats, there is a need for standardization;
3) Traffic class weight assignment is applied according to the respective traffic classes;
4) The final score is computed by calculating the Euclidean distance between the attributes of the reference PoA and other candidates. The selected network is that which has the highest final score;

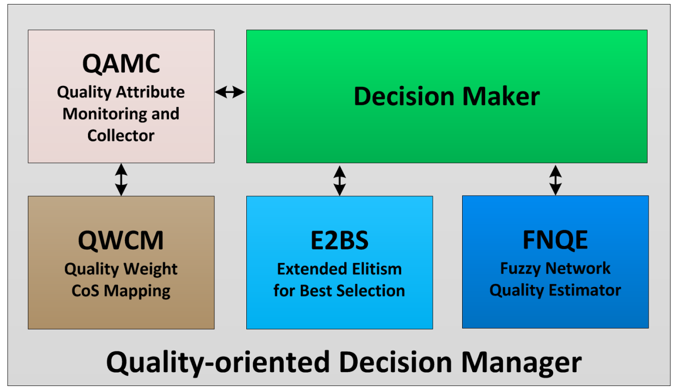

Figure 2: Quality-oriented mobility architecture

E. FNQE

FNQE (*Fuzzy Network Quality Estimator*) is a quality estimator that makes use of fuzzy logic [23] to assess the quality of active eHealth sessions, enabling the handover in situations where there is no explicit mobility. To accomplish this, it will check if the quality level provided by the network meets the needs of the eHealth application.

During the session establishment, the eHSD should inform your communication requirements, and through these data the FNQE will be able to model the fuzzification system by means of the CoS to which the application belongs. Through this process, the crisp input values will be represented by linguistic terms and associated with a given set according to their degree of membership, where delay is rated by three linguistic terms:

low, medium and high. Each term represents the thresholds for certain application in its respective CoS.

The requirements of each attribute will, at first, go through the fuzzification process in order to identify which universe of discourse is associated to your needs. Then, the QAMC will send to FNQE, with certain frequency, the data collected from the network to new fuzzification. Thus, according to the degree of membership, new results will be generated to be correlated in the inference process, where pre-defined rules for the respective CoS will be confronted with the linguistic terms which were derived from the previous step. The result of this process, known as defuzzification, corresponds to the stage where fuzzy values are converted to real numbers and are associated with the universe of discourse of the application preferences, represented by: Desirable, Good, Tolerable, Weak and Poor. In the cases where the conditions offered by the network does not meet the expectations of the applications, the FNQE will trigger the Decision Maker to start the System Discovery process.

IV. Conclusion and Future Works

We believe that the benefits of our proposal will contribute to improve the CAMA approach so it can change the way current healthcare Brazilian system will involve towards the eHealth.

Since the eHealth controller is under development, our team is investigating specific aspects to support the eHealth controller requirements, such as: characterization of normal and life-critical medical applications through their urgency nature; internal and external interfaces for all sub-systems; context processing/reasoning; among others. In order to evaluate the feasibility of our framework, we are working in extending the OpenFlow implementation with the eHealth controller architecture according to the proposals in Section III.

Whereas this work is still in progress, the next steps are to improve the eHealth Controller with advanced over-provisioning centric allocation scheme for QoS resource handling, embedding new mechanisms to support advanced routing, resource reservation, admission control and priority queuing functionalities. In order to fulfill the required end-to-end QoS, we are developing a dynamic QoS routing super-dimensioned provisioning centric strategy to provision automated, systematic and dynamic network resource allocation for multimedia sessions over OpenFlow. The entire framework will be evaluated in a real scenario, built over the Brazilian island of the OFELIA [24] testbed.

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