Analysis of Mobility Management Solutions for Mobile Medical Multimedia Transmission in HetNet Environments

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Abstract. By 2020 the number of mobile-connected devices will reach 11.6 billion, including smartphones, tablets, wearable devices, sensors among others, which will exceed the world's projected population at that time. Wirelessly connected devices by their nature imply that users are able to be part of a network, giving space for new-generation, novel fields such as mobile healthcare applications. Such pervasive and ubiquitous services rely advanced network architectures designed to provide reliable communication and high quality data transmission in any mobility scenario. Increasingly growing heterogeneous network (HetNet) technologies hold the potential to address longstanding challenges in healthcare domain, to ensure advanced communication solutions for critical mHealth services and to support patient-centric, 'care anywhere' concept. The focus of this article is to present and evaluate the effects of an optimized HetNet-aware mobility management proposal on mHealth applications with intense multimedia transmission.

Keywords: Mobile healthcare (mHealth) · Mobility management · Heterogeneous networks (HetNet) · Mobile medical multimedia · Quality assessment · Performance evaluation

1 Introduction

Ever growing penetration of connected-devices, data-hungry, real-time and pervasive applications like social media, M2M (machine-to-machine), mobile healthcare services create serious challenges for the traditional network infrastructures, which cannot offer reliable connection with an acceptable quality for both emergent traffic growth and ubiquitous applications. To enable the highest quality experience for demanding mobile device users, HetNet technologies have been recognized as a key-important solution [1,2]. HetNet covers the combination of several wireless technologies such as cellular architectures (2G/3G/4G), WLANs, pico- and femtocells to provide efficient network resource usage and enhance the user experience of real-time, pervasive applications, furthermore improves the

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coverage of access networks and increases the network capacity. A large part of mobile Health (mHealth) use-cases requires advanced and reliable mobile communication solutions to provide efficient multimedia transmission with strict medical level Quality of Service (QoS) and Quality of Experience (QoE) provision [3,4]. HetNet can be a promising technique to fulfill the requirements of such mHealth services [5,6]. Critical mHealth applications, on which a life may depend, are going to require the 'always available,' high capacity capabilities of HetNet systems.

Aiming to solve the above challenges of real-time mHealth service provision in our previous works [7–9] we designed and implemented a Mobile IPv6-based, cross-layer optimized flow mobility framework. The goal of this article is to analyse our scheme in the light of existing mobility management standards and to present the evaluation of medical multimedia transmission quality in various mobility scenarios.

The rest of the paper is organized as follows. In Sect. 2 we present the related work on advanced mobility management schemes already applied for real-time mHealth services. Section 3 recaps our advanced flow mobility architecture, the signalling framework, and the integrated multi-criteria decision engine. Section 4 presents the comparison of our proposal with standard mobility management schemes performed in scenarios focusing on simultaneous transmission of multiple medical multimedia streams over HetNet. In Sect. 5 we conclude the paper and describe our future work.

2 Backgorund and Related Work

The deployment of HetNet covers the aggregation of various wireless access schemes, hereby integrates traditional mobile solutions such as 3G/4G cell with WLAN technologies for pervasive, and seamless communication techniques in any mobility event without connection drops and access network failures. Benefits of such heterogeneous environments can only be exploited if mobility between the different wireless accesses is efficiently handled. The Mobile IPv6 protocol (MIPv6) family aims to provide reliable communication and solves the session continuity for mobile nodes on the move. MIPv6 [10] allows that each mobile node always can be identified by its home address, regardless of its current point of attachment to the Internet (e.g., in case of moving between different Wi-Fi access points). A mobile node is also associated with a care-of address (CoA) provided by the foreign network. IPv6 packets addressed to a mobile node's home address are transparently routed to its CoA thanks to the Home Agent (HA) entity of the MIPv6 concept. The protocol enables IPv6 nodes for mobile nodes to create bindings between the home address and the CoA, thus any packets destined for the mobile node can directly sent to its CoA. Recently mobile devices are equipped more network interfaces like Wi-Fi, 3G/4G, Bluetooth among others. For matters of cost, bandwidth, delay it is useful for the mobile node to get Internet access through multiple accesses simultaneously, in which case the mobile node would be configured with multiple active IPv6 CoA. However MIPv6 cannot be applied in multi-access environments, since it enables only one care-of address binding at a time with its home address, so mobile nodes cannot use multiple interfaces to send and receive packets while taking advantage of session continuity provided by MIPv6. In order to exploit the advantages of such heterogeneous solutions Multiple-care of Address extension of MIPv6 [11] (MCoA) was designed in the IPv6 domain. MCoA enables a mobile node to register multiple CoAs for a home address and create multiple binding cache entries. If HA receives Binding Update (BU) message, creates a separate bindings. MCoA exploits the network resources provided by heterogeneous networks. A possible MCoA handover mechanism was introduced in [12]. The solution relies on overlapping radio access networks (RANs), and in case of an appearing new access network on an unused interface, moves every traffic to this new RAN by activating symmetric policy rules for all the MR transmissions (e.g., between LTE and Wi-Fi). Due to the limitations of MCoA, further optimization is required with the help of Flow Bindings extension of MIPv6 [13] (FB). FB enables to bind a particular flow to a particular CoA directly with correspondent nodes/mobility agents (i.e., home agents and mobility anchor points), such creates a fine grained mobility management and offloading tool for HetNets. However, neither MCoA nor FB handover execution schemes are able to work efficiently without proper handover decision and control, which requires a complex mobility architecture to implement for real life mHealth use-cases [8].

3 A Review of Our Proposed Mobility Architecture

In this section we briefly introduce our mobile device driven, flow-aware mobility architecture designed for real-time mobile medical multimedia transmission. Only a high-level overview of the main components are discussed in this section, while a detailed description can be found in our previous works [7,8]. In our proposed framework a highly customized Android-based mobile device plays the role of the central entity responsible for the client-based flow-aware mobility management and provide reliable communication in various mobility event in heterogeneous access environment. Our solution relies on MIP6D-NG [14], which is a novel Mobile IPv6 [10] implementation extended with multi-access, flow mobility, and advanced cross-layer communication support among others. A key part of the architecture is the network discovery and selection module, which collects static and dynamic information (e.g., throughput in the uplink/downlink, rate of erroneously received and discarded packets, number of discarded packets and number of users) of Wi-Fi APs or cellular. We consider both built-in Android APIs (e.g., WiFiManager, Telephony, NeighboringCellInfo etc.), external tools running on the router (e.g., OpenWrt Bandwidth Monitoring tool[1] and network-assistance mechanisms [15,16] for the comprehensive network discovery process. The network selection module relies on a widely-used multi-criteria decision technique, namely Analytical Hierarchy Process [17]. Our proposed AHP-based decision engine decides about the optimal network(s) for the selected med-

[1] OpenWrt bmon tool: https://wiki.openwrt.org/doc/howto/bwmon.

ical multimedia flow(s) based on the collected information and directs the network management module to connect the mobile to the selected network(s). The proposed solution adaptively follows the changes in the network environment and dynamically modifies assignments of flows and networks/interfaces. Another important part of our architecture from the healthcare point of view is the Sensor Data Aggregator module collecting data from connected diagnostic devices and medical sensors, device-integrated sensors, etc., and sends the multimedia data towards a correspondent node, which is typically a hospital or an emergency centre.

4 Testbed and Measurement Results

4.1 Testbed Environment

A multi-flow mHealth streaming application was used to test and compare different mobility management techniques and mobility scenarios in a heterogeneous testbed environment depicted in Fig. 1.

The measurement story-line focuses on a real-time, continuous medical multimedia transmission from a diagnostic clinic's ultrasound and ECG device to a medical specialist on the move. Our IPv6-based HetNet environment combines traditional 3G/4G mobile network and Wi-Fi access points located in the campus of Budapest University of Technology and Economics (BME). In the presented setup these networks are covered by two Wi-Fi access points belonged to the campus of BME and by a commercial 3G/LTE mobile network. Wi-Fi APs ensure native IPv6, contrarily Android devices do not support native IPv6 through 3G/4G interface. To enable IPv6 communication on the cellular interface we applied a TAP-based OpenVPN tunnel. The detailed description of our testbed setups is presented in our previous work [7,9].

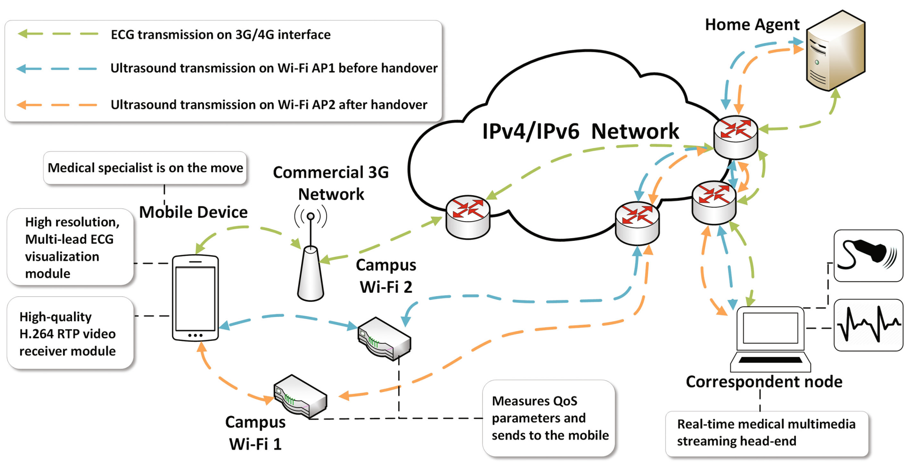

Fig. 1. HetNet testbed for multi-flow mobile medical multimedia transmission

4.2 Measurement Results

For the analysis we transferred two different medical multimedia flows (an ECG flow and an ultrasound video stream) from the correspondent node (playing the role of the mobile medical multimedia streaming head-end) to a medical experts' smartphone device. The used ECG flow is pre-recorded data provided by PhysioNet [18]. The chosen signal records contain 12 standard leads records from patients undergoing tests for coronary artery disease with 257 Hz sampling rate [19]. These digital ECG signals were transmitted and received using a custom packetizer with a simple UDP socket-based implementation at 950 kbps. The transmitted video was a colour ultrasound stream of a fetal heart with HD resolution (720 × 1280 pixel), 30 fps frame rate and 880 kbps UDP/RTP encoded with H.264 and provided by the Mátyásföldi Klinika diagnostic clinic. For the real-time ultrasound transmission and objective evaluation we used the software components of the Evalvid framework [20]. We have also initiated TCP background traffic (BT) generated with iperf3[2] toolset. In this section ten different mobility scenarios are described as Table 1 shows.

Table 1. The defined mobility scenarios

ID	Available network(s)	Used network(s)	BT (Mbit/s)	Applied MM technologies
#1	3G	3G	no	None
#2	3G	3G	5	None
#3	LTE	LTE	no	None
#4	LTE	LTE	5	None
#5	Wi-Fi	Wi-Fi	no	None
#6	Wi-Fi	Wi-Fi	5	None
#7	Multiple WiFi APs, 3G	Multiple WiFi APs	5 (WiFi)	MIPv6
#8	WiFi, 3G	WiFi, 3G	5 (WiFi)	MIPv6+MCoA
#9	Wi-Fi, 3G	Wi-Fi, 3G	5 (WiFi)	MIPv6+MCoA+FlowB
#10	Wi-Fi, LTE	Wi-Fi, LTE	5 (WiFi)	MIPv6+MCoA+FlowB

To perform the analysis by evaluating the quality of the transmitted medical multimedia flows we applied the cumulative distribution and probability density functions (CDF and PDF) of end-to-end delay for the ultrasound video, and the packet loss rates for both the ultrasound and the ECG streams. The measurement scenarios have been categorized based on the available/used network interfaces and IPv6 protocol family extensions applied to the mobility management mechanism (MM).

In scenario 1–6 only one interface was used for transmission of both medical flows and the additional background traffic without any mobility mechanisms. In these scenarios both medical flows suffer significant packet loss due to the

[2] iperf3 tool: https://iperf.fr/.

limited throughput capacity of 3G, LTE or even of Wi-Fi, which cannot guarantee the suitable bandwidth for both ultrasound and ECG flows in case of higher background traffic volumes.

Scenario 7–10 depict a mobility event, where the mobile device is moving and changing its Internet point of attachment through accesses belonging to different IP domains, thus IP level handover is required. In scenario 7 the mobile device executes a handover between two Wi-Fi APs using MIPv6 causing extra packet loss in the transmitted data. Scenario 8 shows a condition, where two Wi-Fi APs, and a 3G network are available, however, due to the lack of flow mobility, the device cannot separate medical flows between the available interfaces, thus both medical flows are moved from 3G to Wi-Fi using a simple MCoA handover.

Thanks to our solution integrated with multi-access and flow binding support, we can provide flow-aware decision and proper handover execution in scenarios 9 and 10. It means that the mobile device transfers mobile medical multimedia flows bound to appropriate interfaces based on fine grained coupling of applications and available access networks. Scenario 9 still includes small degradation on both flows due to the limited capability of 3G, however the proposed solution provide optimal mobility management in LTE and Wi-Fi environments as shown in scenario 10. Our multi-access, flow-level architecture and decision intelligence eventuate medical quality simultaneous ECG and ultrasound transmission even in mobile environments and other active background TCP sessions. As an important performance indicator, Fig. 2 summarizes the above and shows the packet loss rate of both ECG and ultrasound flows in before-described mobility conditions.

The application policies of the incoming ECG flow prefer the 3G/4G interface of the mobile device in order to benefit from the enhanced QoS provisioning and security capabilities of a 3GPP operator. Policies of the ultrasound transmission favour Wi-Fi for more bandwidth and lower delays, as well as of any TCP-based (background) traffic.

As another important performance indicator we examined end-to-end delay of transmitted ultrasound video.

Figure 3 shows the empirical cumulative distribution and estimated probability density function of end-to-end delay of video frames. We can observe that 3G cause significant end-to-end delay on the multimedia video, approximately

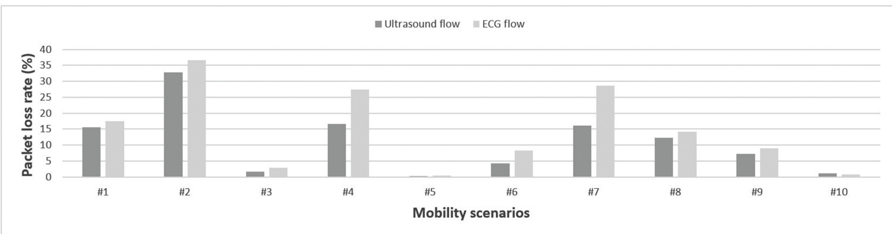

Fig. 2. Packet loss rate of ECG and ultrasound flows in different mobility scenarios

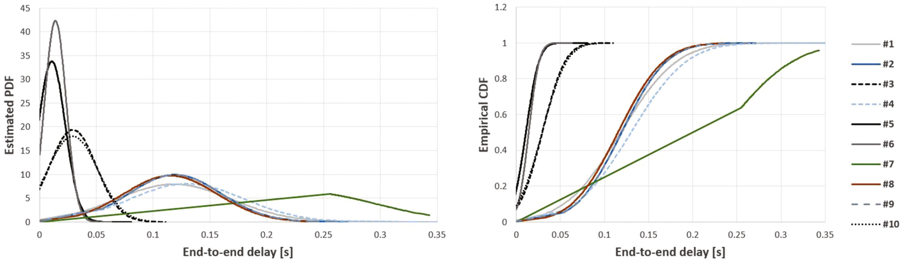

Fig. 3. Estimated PDF (left) and empirical CDF (right) of ultrasound video's end-to-end delay in different mobility scenarios

around 120 ms, while the transmission over LTE implies in average 25 ms. Using our intelligent flow-based Wi-Fi offloading for the ultrasound transmission the average end-to-end delay of the real-time stream closes the pure Wi-Fi case which is under 10 ms.

5 Conclusion

Increasingly spreading heterogeneous network (HetNet) concepts offer the possibility to provide reliable, advanced and pervasive communication solutions for critical mHealth services and to support patient-centric scenarios. The goal of this article is to analyse our cross-layer optimized, multi-access, flow mobility framework designed and developed in our previous works in the light of existing mobility management standards and to present the evaluation of medical multimedia transmission quality in various mobility scenarios. Results of the introduced evaluation show that our framework gives an efficient and fine-grained mobility solution for quality-sensitive real-time and pervasive mHealth services.

As a part of our future work we are planning to provide a comprehensive mapping between QoS (e.g., Packet Loss), objective QoE (e.g., PSNR), and subjective QoE (i.e., diagnostically relevant quality) metrics for different mobile medical multimedia applications with the help of medical experts.

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