Study on Medical QoE Evaluation of Wireless Multimedia Transmission in Mobile Healthcare

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***Abstract*—Wirelessly connected portable multimedia devices of our everyday lives are gaining more and more attention in mobile healthcare (mHealth) by providing increasing sensor and communication capabilities to support e.g. home healthcare, real-time remote patient monitoring, and ubiquitous tele-consultation. In the near future such pervasive and ubiquitous services will supposedly rely on heterogeneous network (HetNet) technologies which comprise a combination of different cell types and different access technologies to ensure advanced communication solutions for critical services and patient-centric, customized, 'care anywhere' mHealth applications. This paper presents the initial results of a medical Quality of Experience (m-QoE) evaluation procedure performed to analyse multimedia-intensive mHealth applications over heterogeneous mobile network access technologies.**

Keywords: medical Quality of Experience (m-QoE), mobile healthcare (mHealth), heterogeneous networks (HetNet), mobile medical multimedia, mobility management, quality assessment

I. Introduction

Recently witnessed penetration of connected portable devices, sensor infrastructures, and multimedia-intensive real-time and pervasive high-bitrate applications create serious challenges for currently deployed network architectures, which will not be able to offer anytime-anywhere connection with satisfactory quality for ubiquitous applications when the mobile broadband traffic explosion kicks in [1]. To provide the highest quality of experience for demanding future mobile device users and achieve significant increases in capacity, HetNet technologies have been identified as a key-important solution [2], [3]. HetNet enables seamless switching/handovers between different networks, such as cellular (3G/4G/5G) and Wi-Fi (802.11a/b/g/n/ac/p/etc.) networks, and also uses small cells (pico- and femto cells) to complement existing macro cells, to provide efficient network resource usage, bolster network capacity, extend access coverage, and enhance mobile user experience of pervasive applications. Consequently, the highly enhanced connectivity of HetNet techniques paves the way for innovative use-cases to be supported. Remote patient monitoring/diagnosis, tele-consultation and guided surgical intervention from the mHealth domain are such use-cases: they all require reliable mobile communication with medical level Quality of Service (QoS) and Quality of Experience (QoE) [4], [5]. Thanks to their capabilities of optimally responding to rapid changes in user demands, HetNet solutions have the potential to fullfill the requirements of such advanced scenarios [6], [7]. However, studies focusing on m-QoE evaluation in HetNet scenarios are required for exact performance characterisation. Despite the fact that this topic is really important, only a few efforts were made towards that direction.

Authors of [8] extended existing wireless network QoS architectures with support for differentiating multiple flows and packets of the same service type based on their impact on the QoE. This work focuses on enhancing mobile core network functions and does not compare HetNet access and mobility techniques using m-QoE as a metric. In [9] authors aimed to dilate upon the impact of 4G and beyond small cell HetNets for medical video streaming and propose an m-QoE learning and decision model based on Fuzzy Inference System which takes into account context, content and network related parameters to give estimated m-QoE as an output, but different HetNet access schemes, offloading/coordinating/handover solutions are not considered and compared. I. U. Rehman et al. investigated the impact of deploying 4G and beyond small cell heterogeneous networks for medical video streaming as an example of m-health application, but only considered QoS as a key performance indicator, m-QoE was not studied [10]. According to our best knowledge, none of the available literature deals with m-QoE evaluation of HetNet access and handover schemes. Therefore our main motivation was to analyse m-QoE of wireless medical multimedia transmissions in various possible mobility scenarios of HetNet architectures.

The rest of paper is organized as follows. In Section II we present the implemented testbed, the defined mobility scenarios and the applied m-QoE measurement methodology. Section III shows the measurement details and our results gathered in scenarios where the focus was on simultaneous transmission of multiple medical multimedia streams over different HetNet access techniques and protocols. In Section IV we conclude the paper and describe our future work.

II. Applied Schemes and Methods

A. HetNet testbed for mobile medical multimedia measurements

1) Testbed environment: In this section we give a high-level overview and highlight the key parts of our smartphone driven, flow-aware mobility architecture designed for continuous medical multimedia transmission with medically relevant quality.

The reader is referred to our previous works ([11], [12]) for the detailed introduction of our solution. The proposed framework is controlled by a highly customized Android-based mobile device. Our smartphone is responsible for the advanced flow-aware mobility management and it provides reliable communication in various mobility events in heterogeneous network environments based on MIP6D-NG [13] toolset, which is a novel Mobile IPv6 [14] implementation extended with multi-access, flow mobility, and advanced cross-layer communication support.

Our customized mobile phone includes a network discovery and selection module, which continuously maintain a database about the 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 even cellular networks. The proposed solution adaptively follows the changes in the network environment and dynamically modifies assignments of flows and network interfaces. In our testbed a real-time multi-flow (ECG data and ultrasound video flows) mHealth streaming application was implemented to test and compare different mobility management techniques and mobility scenarios in a heterogeneous testbed environment. The used ECG flow is pre-recorded data provided by PhysioNet [15]. The chosen signal records contain 12 standard leads records from patients undergoing tests for coronary artery disease with 257 Hz sampling rate [16]. Moreover we used a colour ultrasound video of a fetal heart with HD resolution (720x1280 pixel), 30 fps frame rate and 880kbps RTP encoded with H.264 and provided by the Mátyásföldi Klinika diagnostic clinic[1]. Both flows were transmitted and received using UDP socket-based streaming service implementations. These medical multimedia flows were streamed from a diagnostic clinic's ultrasound and ECG device to a medical specialist on the move.

2) Applied mobility scenarios: In our IPv6-based HetNet environment we combine traditional 3G/4G mobile network and Wi-Fi access points. Wi-Fi APs ensure native IPv6, while through the smartphone's 3G/4G interface a tunnel-based IPv6 connection was applied. In addition we have also initiated TCP background traffic (BT) generated with iperf3[2] toolset. For the comprehensive evaluation nine different mobility scenarios have been defined as Table 1. shows.

In scenario 1-6 only one interface is available in the radio coverage of the mobile device, thus only this network (Wi-Fi or 3G or LTE) can be used for transmission of both medical flows and the additional background traffic. In these scenarios advantages of novel mobility mechanisms (MIPv6/MCoA/Flow Bindings) cannot be exploited. Scenario 7-9 depict mobility events, where the mobile device is moving and changing its network attachment point. This condition requires IP level handover mechanism.

[1]http://matyasfoldklinika.hu/

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

TABLE I
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 Wi-Fi APs	Multiple Wi-Fi APs	5 (Wi-Fi)	MIPv6
#8	Wi-Fi, 3G	Wi-Fi, 3G	5 (Wi-Fi)	MIPv6+MCoA+FlowB
#9	Wi-Fi, LTE	Wi-Fi, LTE	5 (Wi-Fi)	MIPv6+MCoA+FlowB

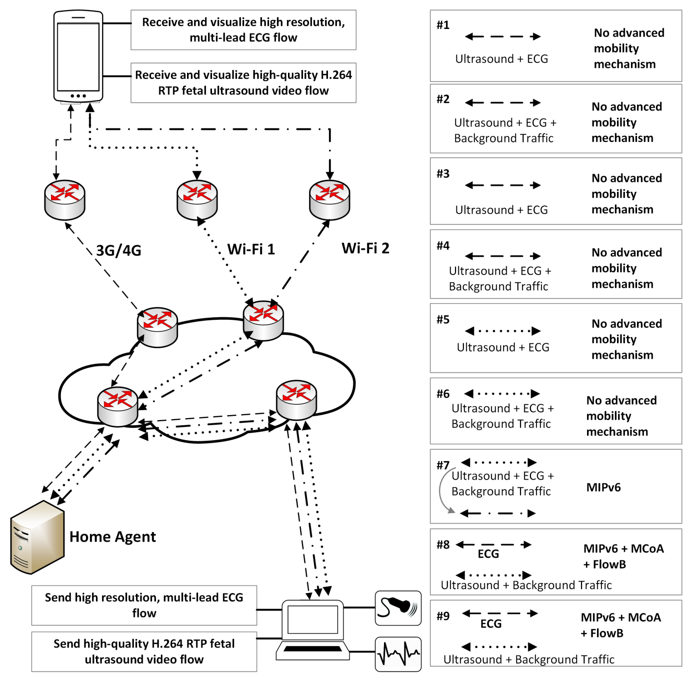

Fig. 1. HetNet testbed for multi-flow mobile medical multimedia transmission

In scenario 7 the mobile device executes a handover between two Wi-Fi APs using MIPv6 protocol. Our solution integrates multi-access mechanism and flow binding support, which allows to provide flow-aware decision and proper handover execution in scenarios 8 and 9. 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. Our testbed setup and the aforementioned mobility scenarios are depicted by Figure 1.

B. Medical QoE measurement methodology

Measuring the diagnostic/usage impact of e.g. data loss, jitter and other undesirable effects in digital medical multimedia transmission is one of the most important procedures in order to provide reliable mHealth services. These so called QoE measurements must be done by involving medical experts.

Mean Opinion Score (MOS) and Multiple Reader Multiple Case (MRMC) metrics are suitable for evaluating the quality perceived by medical professional [17], [18]. In our paper we focus on the (Double-Stimulus Continuous Quality-Scale) DSCQS measurement method that uses MOS metric.

1) DSCQS for system quality evaluation: The DSCQS (ITU BT.500-11, Section 5 [19]) standard method is popular in video quality evaluation as it has almost no sensitivity to context effects, as viewers are shown the sequence twice [20]. In articles [21], [22] and [23] the authors used the second version of DSCQS to verify the efficiency of their own-developed video coding schemes for medical video recordings. In DSCQS the recordings in pairs are presented to the subjects. A pair consists a reference and an impaired video. The subjects view the pairs in random orders and the recordings in a pair are also randomized. The full length of the measurement is approx. 30 minutes and a recording should be 10 seconds according to ITU [19]. Between the pair members there is a 3 second break and after the pair there must be a 5-11 second break. The object of our measurement scenarios was the various degradations caused by mobile transmissions and network switches in children's cardiac digital ultrasound recordings. Since these effects can be examined in recordings that are longer than 10 seconds we set the videos to be 23 seconds length. Thus to fit the 30 minutes maximum measurement duration we investigated 9 different mobility scenarios [11] that are listed in Table 1. The evaluation of the measurements was done by calculating the Differential Opinion Score (DOS) values by subjects:

$$DOS_{i,j} = Ref_{i,j} - Imp_{i,j}, \tag{1}$$

where $Ref_{i,j}$ the MOS score of the reference video j scored by subject i and $Imp_{\,i,j}$ is the MOS score of impaired video j scored by subject i. Averaging these DOS values gives the Differential Mean Opinion Score (DMOS):

$$DMOS_j = \frac{1}{N} \cdot \sum_{i=1}^{N} DOS_{i,j} \tag{2}$$

2) Test subjects: In our measurement procedure 16 medical experts and 9 non-experts were involved. Our aim was to collect subjects that have experience with ultrasound recordings, 12 of them are obstetrician gynecologists and 4 of them are radiologists from Mátyásföldi Klinika diagnostic clinic in Budapest, Hungary.

3) Measurement implementation: For the sake of simplicity we used tablet devices to perform the measurements: Asus Transformer Pad TF300T and Samsung GT-P5100. On these devices a self-developed Android application was running. The application was designed to follow the DSCQS standard regulations: it set the recordings in randomized pairs, it played the pairs in random orders including the prescribed breaks with grey screen.

TABLE II
RECORDINGS ORDERED ASCENDING BY DMOS VALUES

Experts	Non-experts	All
LTE-WiFi (#9)	3G-WiFi (#8)	LTE-WiFi (#9)
WiFi (#5)	LTE-WiFi (#9)	3G-WiFi (#8)
3G-WiFi (#8)	WiFi-5M (#6)	WiFi (#5)
WiFi-5M (#6)	WiFi (#5)	WiFi-5M (#6)
LTE (#3)	LTE (#3)	LTE (#3)
WiFi-WiFi (#7)	WiFi-WiFi (#7)	WiFi-WiFi (#7)
LTE-5M (#4)	LTE-5M (#4)	LTE-5M (#4)
3G-5M (#2)	3G (#1)	3G-5M (#2)
3G (#1)	3G-5M (#2)	3G (#1)

III. Measurement Results

A. Measurement results

In Figure 2 the results are presented that arose after calculating the DOS metric that the single subjects had given. The subjects 3, 16 and 19 perceived that the shown videos have same qualities.

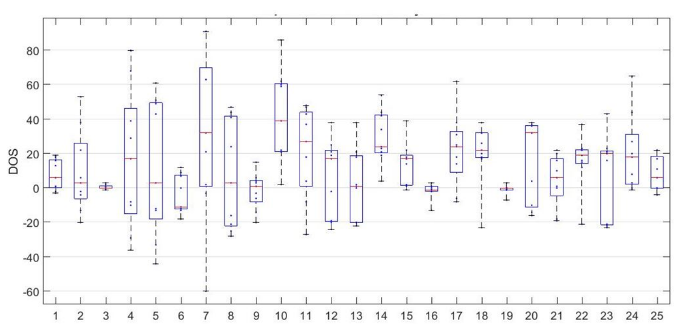

Fig. 2. DOS values in boxplot for each scenarios given by all the subjects

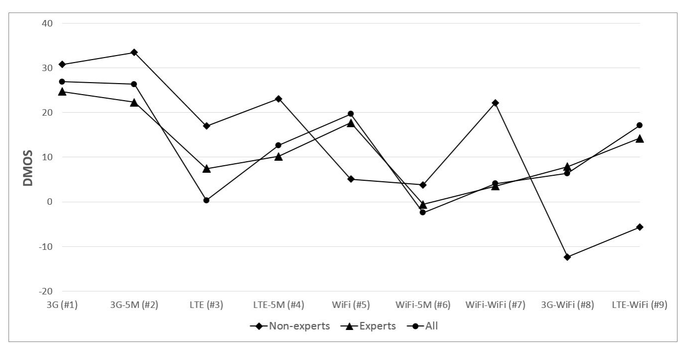

Fig. 3. DMOS values by recordings

After calculating the standard refusal test none of the subjects were rejected.

Figure 3 presents the calculated DMOS values by recordings. From the measurement results a table can be made with the ascending order of the recordings by subject groups (Table 2): the first four recordings were similarly perceived by the experts and non-experts and the order of the rest is exactly the same. The results show that advanced HetNet solutions, such as flow based offloading techniques between overlapping

LTE and WiFi or 3G and WiFi networks, provide similar or even better m-QoE for users as homogeneous 3G/LTE/WiFi alternatives. This finding is really important as it emphasizes the power and justifies the employment of HetNet infrastructures for advanced, multimedia-intensive medical healthcare applications and services. More precisely the underlying emerging control, network switching and handover mechanisms (such as MIPv6/PMIPv6, flow bindings, etc.) have all the capabilities to support high bandwidth and m-QoE demanding pervasive mHealth use-cases.

IV. Conslusion

In our paper we presented a Quality of Experience measurement methodology we applied for multimedia mHealth applications run over different HetNet scenarios. In the beginning of this article the background and related works were given. After that we specified the HetNet test environment and defined the medical QoE measurement method. Finally the test scenarios and results were presented.

As a part of our future work we will try to draw the relation between m-QoE (i.e., diagnostically relevant quality), QoS (e.g., packet loss), and objective QoE (e.g., PSNR) metrics for different mobile medical multimedia applications in the analysed HetNet scenarios.

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