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Predicting telemedicine system user satisfaction in sub-Saharan Africa☆

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Abstract

During our literature review and on-site research in developing countries, particularly in Sub-Saharan Africa, we could not point out any efforts to measure the Quality of Service (QoS) and Quality of Experience (QoE) provided by telemedicine systems, thus making it impossible to understand their overall levels of user satisfaction in sub-Saharan African countries. Therefore, we conducted a qualitative and quantitative study, with experiments to measure QoS performance and the end-user QoE perception of telemedicine systems. Based on obtained results, we propose a mathematical formula to predict the QoE based on QoS measurement values, since a known relationship exists between QoS and QoE.

Keywords: Telemedicine; Key performance indicators; QoS; QoE; QoX; Predicting QoE

1. Introduction

Telemedicine is the use of electronic information and communications technologies by healthcare professionals to provide clinical services for patients in different locations. Popular telemedicine applications, such as videoconferencing, transmission of diagnostic images, and remote monitoring of vital signs generally use telecommunication and/or networking technologies to provide health care services remotely. These telemedicine applications generate a variety of traffic types, including audio, text, image, and streaming video, the data transmission requirements of which should be fulfilled by the underlying network connection to deliver high quality services to users. The ability of a network to satisfy the stated and implied connection needs of the user is specified in terms of Quality of Service (QoS). The overall acceptability of an application or service, as perceived subjectively by the end user [1] is referred to as Quality of Experience (QoE or QoX) and depends on the QoS provided by underlying communication systems [2]. We refer to QoS as an objective quality measurement, as its evaluation consists of measuring network/system performance. We refer to QoE as a subjective quality measurement; its evaluation consists of interviewing the users of telemedicine systems on their experience and is based on their degree of satisfaction.

Numerous telemedicine applications aim to improve healthcare delivery services in developing countries. However, to the best of our knowledge, there exist no systematic studies conducted in West African countries to assess the QoS and QoE of telemedicine systems, solutions, or applications. Furthermore, literature reviews and on-site interviews reveal the lack of effort put forth to measure the QoE associated with the use of telemedicine systems in sub-Saharan Africa. This void in the telemedicine research presents the opportunity to investigate the overall QoE experienced by users of telemedicine systems in developing countries.

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The main goal of this study is to measure overall levels of user satisfaction (QoE) related to tele-healthcare systems and to determine the correlation between QoS and QoE to better predict user satisfaction with tele-healthcare systems, especially in sub-Saharan African (SSA) nations.

The desired impact of this study is to overcome the lack of regulation in the field of telemedicine in this region of the world. Telemedicine products are considered medical products in the USA and EU, and thus are regulated through directives by bodies such as the FDA (USA) and CE (EU). African countries unfortunately lack these regulatory instruments. Our study outcomes would therefore create awareness in patients and healthcare professionals about the potential uses of telemedicine and therefore could serve as a baseline for generating regulations in this field.

This research uses the case study methodology to investigate telemedicine in two countries, viz., Senegal and Mali. Public healthcare systems, cultural and traditional practices, economic issues, and other lifestyle factors are similar in all SSA countries [3,4]. Based on these facts, we selected these two countries because people there are widely experienced in the use of telemedicine products.

The remainder of this paper is organized as follows: Section 2 presents state of the art of existing scientific literature with a focus on telemedicine and QoS and QoE in telemedicine domains. Material, research methodology, and experimental research work conducted in two West African countries, (1) Mali and (2) Senegal, are discussed in Section 3. Section 4 presents and discusses the results and proposes a formula depicting the relationship between QoS and QoE. The last section outlines the conclusions of this research work and open questions that can be considered in forthcoming work.

2. Definitions and related work

QoS is closely related to network performance, whereas the International Union of Telecommunications (ITU–T) defines QoE as the overall acceptability of an application or service, as perceived subjectively by the end user [5]. Recent research in the field of telemedicine has focused on QoE, which is dependent on QoS. [6] sheds light on the roles of QoS and QoE in the acceptance of eHealth services and concluded that to conduct QoE studies in eHealth appropriately, user involvement and other dimensions of QoE must be considered. Following that framework, [7] evaluated QoE for patient telemonitoring services in which 26 patients used medical sensors and a smartphone application-based service to measure vital signs. These results showed a strong correlation between the QoE and the perceived effectiveness of the mobile interface, perceived ease of conducting a blood pressure measurement task, and motivation for using the service. It is noted that no widely accepted telemedicine QoE parameters or datasets exist that could have been used as a reference (i.e., a "gold standard") [6,8]. [7] also emphasized the relationship between QoS and QoE, identified and analyzed the factors influencing QoE that must be considered for relevant QoE assessment in telemedicine. [6,8,9] all agree on the lack of an established standard for telemedicine QoE measurements and the dependence of QoE on QoS, which measures the technical parameters of network performance.

QoS is closely related to network performance, which has been evaluated by many researchers using a variety of tools. According to James Martin [10], an Ookla speed test [11], complemented by ping test tools [12], broadband reports, and measurement Lab [13] can be considered state of the art of network performance measurement tools. The QoS evaluation approach we had taken consists of measuring technical network parameters, such as delay, jitter, packet loss availability, reliability, and resource sufficiency, all of which influence the QoE of telemedicine services. We use Ookla speed test tools to measure these network parameters in this study.

Our QoE evaluation approach focuses on recording user perception during a telemedicine service session consisting of audio-visual communication with a healthcare expert. We record users' perception of sound and video quality during the communication session within a telemedicine system using the mean opinion score (MOS) parameter. MOS is a popular test used in telephone networks to obtain a human user's view of network quality. The MOS is the arithmetic mean of all the individual scores and ranges from 1 (worst) to 5 (best).

3. Materials and methodology

We introduce the concept of the quality of telemedicine service (QoTS), which combines QoS and QoE for telemedicine products and services. Over the period of one year, we conducted qualitative and empirical research in both urban and rural health centers in Senegal and Mali to measure the QoS and QoE of telemedicine services.

(1) Experimental teleconsultation

Our set of experiments consists of conducting teleconsultation sessions in $M = 5$ different health care centers and clinics (see Table 1) to measure QoS and QoE. To acquire a significant MOS, we simulate a practical telemedicine activity. We utilized Skype installed on a personal computer as communication platform for a teleconsultation application, allowing us to measure the QoS of our pseudo-teleconsultation system. We also varied the test areas to obtain meaningful and/or significant data on the quality of the various networks used.

(2) Survey to determine user satisfaction (QoE)

For better insight into the link between subjective and objective quality measurements, we conducted a quantitative and qualitative paper survey and interviews in person among the 5 health care professionals and 20 patients involved in the study ($N = 25$, see Table 2) about their experiences with the teleconsultation session as well as other telemedicine platforms, specifically iPath [14] and IKON [15]. These telemedicine platforms are in common use in SSA countries, particularly in Mali.

iPath and IKON teleradiology both provide functionalities such as medical expertise and telediagnosis. General physicians (GPs) or nurses particularly in rural areas could

Table 1
Health centers involved in the study.

No.	Denomination	Main medical activities	Geographic location
1	Hôpital Point G	Tele-expertise	Bamako, Mali
2	Hôpital Point G	Teleradiology	Bamako, Mali
3	Hôpital Fan	Tele-expertise	Dakar, Sénégal
4	Keur Siloé	Ophthalmology consulting	Dakar, Sénégal
5	Gaspar Camara	General consulting	Dakar, Sénégal

Table 2
Study participants.

User category	Number of users	Mean duration of involvement (min)	Interview approvals
Patients	20	33	20
Health care professionals	5	172	5

remotely be assisted by expert medical professionals. Unfortunately, the iPath platform does not provide a means of real-time communication; thus, it is not useful in emergencies.

(3) Description of the test system

Our testing system consists of a Skype call interface for telephony over IP (ToIP), videoconferencing, and file transfer. Skype is free of charge and easily accessible from our test site, Senegal. We used Skype to connect patients and medical doctors, stimulating twenty teleconsultation samples using our Skype-based test system and an ADSL network with different data connection rates (1, 2, 4 and 10 Mbps). The 1, 2, and 4 Mbps rates were used on the patients' side and the 10 Mbps on the doctors' side. We performed these steps to confirm the values of technical indicators that have been recommended. Our goal was also to determine a correlation between subjective and objective tests and finally determine the level of performance required for a telemedicine service or system. The overall objective of the study was more focused on determining the correlation between QoS and QoE, though not to evaluate QoE based on factors like age or gender. Therefore, we only focused on roles (patients/health care professionals), as presented in Table 2.

4. Results and application

4.1. QoS measurement results

In this paper, we propose a function called global QoS(x) that enables us to compare network QoS based on data rate and latency values.

$$QoS(x) = D/\log 10(\tau), \quad (1)$$

where D is the down- or uplink data rate perceived by a user in Mbps, τ is latency in ms, which determines the service class, and x is a multiple variable composed of D and τ as $x = (D, \tau)$. We considered data rate and latency to be representative parameters, as high data rates and low latency are related to better user experience and vice versa. Moreover, many publicly available tools (e.g., SpeedTest) exist to measure these parameters.

We used SpeedTest, a tool for measuring Internet connection speed [11,12], to measure network QoS parameters. Parameters such as the download and upload bandwidth, as well as ping (latency) times can be measured using SpeedTest. The average data rate and latency measurements, as well as global QoS(x) values per the type of ADSL connection, are shown in Table 3.

Table 3
Avg. QoS measurement results of ADSL connections.

Speed (Mbps)	Download (Mbps)	Upload (Mbps)	Latency (ms)	QoS(x)
1	0.628	0.25	62.4	0.35
2	1.61	0.376	34.09	1.05
4	3.61	0.28	26.5	2.53
10	6.27	0.36	44.33	3.80

4.2. QoE measurement results

For our study, we randomly chose 20 patients (see Table 2) for face-to-face interviews and paper-based questionnaires. We interviewed these users about system performance and their satisfaction level (QoE) regarding:

(1) *The performance of the network supporting only the system,*
(2) *The performance and/or quality of the provided healthcare services only through the telemedicine system, and*
(3) *The performance of the network together with the quality of the provided care services.*

User satisfaction levels are shown in Table 4. We analyzed the results of the tests and paper-based interviews on QoE by combining the results of these three categories.

Table 4
QoE measurement results.

Question category	% of user satisfaction				
	Excellent	Very good	Good	Fair	Mediocre
Picture quality	5%	25%	61%	7%	2%
Audio quality	20%	25%	53%	1.5%	0.5%
Video quality	2%	25%	63%	8%	2%
Handling of tools and equipment	0%	0%	15%	82%	3%
Quality of care	0%	20%	75%	5%	0%
System benefits	9%	11%	70%	7%	0%

Fig. 1 further shows the overall scores from all test participants, indicating that 15 of the 20 users were satisfied with the QoS provided, while 4 users were very satisfied (with MOS ratings between 3.5 and 4). According to users, the service provided is of good to excellent quality. The average MOS value was 3.065. Therefore, the overall level of satisfaction with the service is middling, which could be attributed to poor network QoS.

4.3. Predicting QoE

Using the previous experiment, we can first investigate whether QoS and QoE are linked, and thus establish a novel

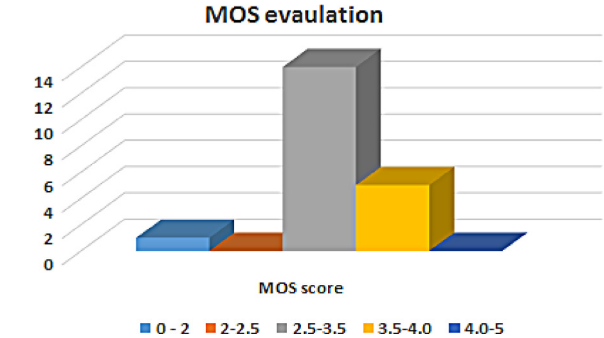

Fig. 1. Telemedicine users' level of satisfaction.

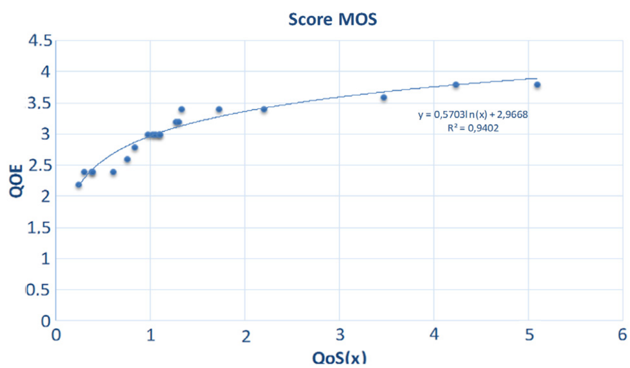

Fig. 2. Patient QoE ratings of network performance as a function of global QoS.

Table 5
Measured QoS and corresponding MOS.

Param.	Excellent	Good	Acceptable	Bad	Poor
QoS(x)	>6	6–2	2–0.4	0.4–0.2	0.2–0
MOS [11]	5–4	4–3.5	3.5–2.5	2.5–2	<2

correlation model for performance evaluation. The global QoS(x) function described in Section 4.1 enables us to calculate QoS and its corresponding QoE. This approach consists of finding an appropriate QoS expression that enables linking the values obtained with corresponding user MOS ratings. We noted through these measures, the following dependency between QoS and QoE:

$$QoE = \alpha \ln(QoS) + \beta, \quad (2)$$

where (α, β) are values of the telemedicine system consisted and are estimated in Fig. 2 based on the collected data.

The higher the QoS value, the higher is a user's satisfaction as measured by MOS. Table 5 contains the values of QoS(x) and MOS for telemedicine services in the specific case of teleconsultation in SSA nations, permitting easy judgment of the performance level of the telemedicine system.

4.4. Application

Telemedicine is increasing in popularity, particularly in African countries, many of which lack regulation in this field. Young entrepreneurs are providing African populations with eHealth applications and systems; however, most of these do not fit the market and thus fail. Major reasons for such failures include low user satisfaction and unquantifiable impacts on population health. The outcomes in our study may help eHealth application and telemedicine developers to predict user satisfaction with an application without conducting a costly survey to evaluate QoE and subsequently fix any issues, to increase QoS and thus, QoE. Evaluating QoS is cheaper and can be accomplished with tools such as SpeedTest. The experiment outcomes and global QoS function can be used as pseudo-regulation directives for increasing the quality of telemedicine and eHealth applications, reducing negative impacts on user health, and increasing user satisfaction in these African countries.

5. Conclusion and future work

In this study, we investigated the QoS and QoE of telemedicine systems deployed in developing countries, with a specific experimental case study of two West African nations. In our experiments, we reported patients' overall appreciation of the service provided. Based on the results we obtained, we noted a positive correlation between QoS and QoE; higher QoS values were linked to greater user satisfaction as measured by MOS. We devised a formula that predicts QoE in terms of MOS based on the global QoS value. Our work is useful for developing regulations for telemedicine use and applications in SSA countries, as well as for entrepreneurs who would like to deploy eHealth services in developing countries.

In future work, we will investigate how the prediction of user satisfaction levels could influence system implementation and the use or launch of tele-healthcare solutions for improving healthcare provision in medically underserved regions.

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