Goodput Analysis of 3G Wireless Networks Supporting m-health Services

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Abstract— The introduction of third generation (3G) public wireless network infrastructures, such as the Universal Mobile Telecommunications System (UMTS), enable the development of innovative mobile services. For example, deploying m-health services which embed tele-monitoring and tele-treatment services become feasible with the role-out of 3G networks. These services allow healthcare professionals to monitor a mobile patient's vital signs and provide feedback to this patient anywhere and any time. The performance of m-health services perceived by end-users depends on the serviceableness of 3G networks to support these services. Hence, the performance of 3G networks is a critical factor for successful development of m-health services. In this paper, we present a methodology for measurements-based performance assessment of 3G networks that aim to support m-health services. This methodology has been applied to evaluate end-user perceived service performance, in relation to the performance (i.e. serviceableness) of a 3G network. In addition, we analyse the measurements with the purpose to improve the end-to-end delay characteristics of the tele-monitoring service as well as optimize the (derived) goodput behaviour of this 3G network. Our results show that the goodput behaviour is asymmetric and depends on a bearer assignment policy of the network. Based on our results we provide guidelines for the design of application protocols for m-health services and how these protocols deal with the changing performance behaviour of 3G networks.

I. INTRODUCTION

Emerging 'high capacity' mobile operator networks (e.g. 3G networks) enable the deployment of new mobile services in all kinds of areas of our daily life. Application of these services in the healthcare domain, i.e. mobile healthcare (m-health¹) services, is a relatively new idea. Development of m-health services supported by next generation mobile operator networks is a challenging task. Deployment of these services by healthcare providers induces strict service performance requirements on these networks, especially in the case of patients with a chronic disease that need monitoring on a regular basis.

The main goal of MobiHealth² EU project was to assess the serviceableness of 2.5/3G mobile operator networks to

support deployment of m-health services. For this purpose, the project developed the MobiHealth system delivering particular m-health services. One of these services is an ambulatory patient's vital signs³ monitoring service (i.e. a tele-monitoring service). This service uses the BANip application protocol [1], which in turn uses an underlying transport system to convey vital signs data. In general, transport systems are hybrid telecommunication systems consisting of communication protocols on top of wireless (e.g. 2.5/3G) and wired communication technologies.

Successful tele-monitoring service delivery strongly depends on the serviceableness of the transport system to support the service requirements. For example, for healthcare professionals to use the monitoring service on chronic patients successfully, it is very important to disclose and understand the transport system's behaviour. For example, the supported service data type (i.e. vital signs data, text, audio, and video) and data volume strongly depend on the capacity (e.g. bandwidth) of the underlying transport system.

In parallel to the deployment of mobile operator networks, performance of e.g. WLAN [2], 2G and 2.5G [3, 4] networks have been evaluated by means simulation, modelling and measurements. However, the performance of operational 3G networks is relatively unknown. Only the delay characteristics of 3G networks obtained from real-network measurements [5], or extensive simulation-based results [6, 7], are currently available.

This paper addresses selected research objectives of the MobiHealth project. The performance of 3G networks available to the MobiHealth project was unknown. In addition, the performance criteria and characteristics adequate to evaluate the performance of these networks were not known. Therefore, it was unclear if these networks are suitable to support application protocols transporting monitoring data of chronic patients. In addition, another research objective was to investigate if (and how) the performance of these 3G networks influences the design of these application protocols. Following these objectives, we selected the *speed* performance criterion to evaluate one of the 3G networks available to the MobiHealth project. It is important to note that mobile network operators in general, do not disclose any information on the performance of their 3G networks due to e.g. commercial and legal reasons, nor allow public access to their core network. Hence, we evaluate the performance of the selected 3G network from an end-user

¹ M-health services are a sub class of the e-health service class, which are based on the deployment of wireless mobile telecommunication technology to realize mobile-based health (care) services.

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³ Electrocardiogram (ECG), Oxygen saturation (SaO₂), plethysmogram, respiration frequency, etc.

perspective and disclose its performance by execution of a measurements-based performance evaluation methodology developed for this purpose.

We executed all measurements during the 3G network's transition from pre-commercial to the commercial state.

Because we were the only (single) user of this network and executing all the measurements at a stationary geographical location, we obtained *reference* (best-case scenario) measurements results.

This paper focuses on 3G network measurements results for the speed performance criterion. The performance evaluation of this network is applicable as a reference for other 3G networks. Based on these results, we give an assessment of the serviceableness of 3G networks to support m-health services and in particular the current implementation of the MobiHealth monitoring service. In addition, we indicate how the performance of 3G networks influences the design of application protocols (e.g. BANip application protocol) supporting monitoring services.

II. MEASUREMENT METHODOLOGY

This section provides details on the methodology developed and executed to evaluate the performance of 3G networks as transport systems supporting m-health services.

A. Overview

There were (pre)commercial 3G networks available as transport systems in the MobiHealth project. Therefore, we decided to select one and evaluate the performance of this network by means of measurements rather than simulation or modelling. For this purpose, a measurements-based evaluation methodology was developed. We use [8], which provides a methodical approach to measurements-based performance evaluation of telecommunication networks (i.e. transport systems), as a basis for our methodology and extended the original evaluation activity. It is important to note that our methodology is generic and can be used to evaluate the performance of arbitrary hybrid transport systems supporting mobile services.

The methodology consists of three major steps: *preparation*, *execution* and *performance evaluation*. The preparation phase states the goals of the performance measurements activity and provides a conceptual model of a selected transport system and its service description. In addition, it describes the performance criteria and mechanisms to generate measurements data in a controlled way from this transport system. The methodology execution phase comprises the development of distinct measurements experiments, their design, instrumentation and execution. Finally, based on the measurements results we evaluated the performance of the transport system and assessed its serviceableness for m-health services.

Section 2.2 provides details on the measurements preparation phase and section 2.3 focuses on the execution phase. Section 3 describes the analysis of measurements results and the evaluation of the selected transport system.

B. Measurements preparation

We selected the monitoring service from the MobiHealth system set of services. This service enables tele-monitoring of a patient's vital signs (i.e. data) and is

implemented by a Body Area Network (BAN). The data is collected from a personalised sensor system by a Mobile Base Unit (MBU⁴), processed for transmission and transported over a transport system to the MobiHealth Back-End system (BEsys⁵) located in, e.g., a hospital [9]. The hybrid MobiHealth transport system consists of wireless (e.g. 2.5/3G) and wired communication technologies. Figure 1 presents the MobiHealth transport system and its subsystems.

Figure 1. MobiHealth transport system

The mobile operator network, is the selected 3G network available to the MobiHealth project. We denoted this network as the *transport (sub)system of interest*. In [5] we presented a priori knowledge of the transport system of interest. This system offers an asymmetrical IP datagram service to its (service) users, with different *uplink* and *downlink* capacities mapped to different *bearers* (i.e. data carrying channels). We denote the transport direction from the MBU (service user) to BEsys (service user) as the uplink, and in reverse direction the downlink. There are 2 uplink bearers and 4 downlink bearers. Figure 2 indicates the nominal capacities of the available uplink and downlink bearers.

Figure 2. 3G network bearers

The uplink has a capacity of 0-16 kbps (*common bearer*) or 16-64 kbps (*dedicated bearer 1*). The downlink has capacities of 0-16 kbps (*common bearer*), 16-64 kbps, (*dedicated bearer 1*), 64-128 kbps (*dedicated bearer 2*) and 128-384 kbps (*dedicated bearer 3*). This was the only a priori knowledge available of the 3G network used as the mobile operator network.

Our goal was to evaluate the performance of a selected MobiHealth transport system delivering a transport service for monitoring service data between the MBU and BEsys. Recall, that this data is transported between the service user residing at the MBU and BEsys by means of an application protocol (Figure 3). The service users residing at the MBU and BEsys are applications (software modules). We use [10] as the conceptual framework to explain the monitoring service delivery. Service users access the underlying service, provided by an application protocol, at *Service Access Points* (APP_SAP in Figure 3) and exchange at this SAP *Service Data Units* (SDU)

⁴ central controlling unit of a Body Area Network worn by a patient

⁵ security, control, management, and data storage sub-system

containing the vital signs data. The application protocol entities, residing at the MBU and BEsys, access the transport service at its service access points. The transport service is available, dependable and accurate and we have

Figure 3. MobiHealth layered architecture

chosen to implement the transport service's access points as TCP_SAPs. We aimed to evaluate the performance of the transport service offered at the TCP_SAP.

From a 'vertical' service delivery perspective, the application protocol entity constructs a *Protocol Data Unit (PDU)* by concatenating a *Protocol Control Information (PCI)* and SDU. The application protocol entity offers the PDU to the TCP_SAP. Because the application protocol entity is a transport system user, the transport service handles the PDU as a SDU. Hence, the monitoring service data is exchanged between the service users by SDUs. From a 'horizontal' protocol perspective, PDU delivery assumes that the service is delivered at SAPs by means of PDU exchange between the corresponding protocol layers at the MBU and BEsys.

The monitoring service is based on a user-confirmed application protocol providing a user-confirmed service (*UC-service*). SDUs are exchanged between the service users in the following manner. Firstly, the MBU service user interacts with the UC-service at APP_SAP (*request* event), by offering a SDU (containing vital signs data). The MBU application protocol entity constructs a PDU from the SDU, and interacts with the transport service at TCP_SAP. This interaction constitutes a *Service Primitive (SP)* with the application protocol PDU as a parameter, further denoted as SP_{send} . This PDU is transported from the MBU service user to the BEsys service user, resulting in an *indication* event. The BEsys service user interacts with the UC-service at APP_SAP (*response* event) by offering the SDU containing the response data. The BEsys application protocol entity constructs a PDU out of the SDU, and interacts with the transport service at TCP_SAP. This interaction constitutes a SP_{recv} with the application PDU as a parameter. This PDU is transported from the BEsys service user to the MBU service user (*confirmation* event). The execution sequence of two SPs constitutes the basic element upon which the complete monitoring service is provided, further denoted as the monitoring *Service Element (SE)*. The SP_{send} is executed in uplink and SP_{recv} in the downlink direction. We treat SPs as data with a particular size. SP_{send} and SP_{recv} can have different sizes and contents.

The goal was to evaluate the performance of the MobiHealth transport system and in particular, its transport capacity. Therefore, we selected the *speed*⁶

performance criterion and the *service delay*⁷ as the performance measure [11]. *Goodput* is a derived performance measure from the delay and it represents a SE execution between the service users, i.e. throughput at the application layer. The goodput is derived for uplink and downlink separately.

We provide definitions for delay and goodput performance measures with the help of a time sequence diagram presenting SPs exchange between service users residing at the MBU and BEsys (Figure 4).

Figure 4. Time sequence diagram for SE execution

The *uplink delay* is defined as time used for transportation of a SP_{send} . Hence, from Figure 4 we concluded that the uplink delay is the time interval between *request* and *indication* events. Analogously, the *downlink delay* is the time used for transportation of a SP_{recv} ; the time interval between the *response* and *confirmation* events. The (total) time used for the SE execution is:

$$SE\ delay = \text{uplink delay} + \text{downlink delay}$$

$$\text{uplink delay} = (T_{recv, BEsys} - T_{send, MBU})$$

$$\text{downlink delay} = (T_{recv, MBU} - T_{send, BEsys})$$

From these definitions, we derived uplink and downlink goodput:

$$\text{uplink goodput} = SP_{send}\ \text{size} / \text{uplink delay}$$

$$\text{downlink goodput} = SP_{recv}\ \text{size} / \text{downlink delay}$$

All performance measures defined above are statistical random variables.

C. Measurement Execution

After defining the MobiHealth transport system boundaries and the speed performance criterion of interest in the methodology preparation phase, we designed 11 different measurements experiments. One experiment was used as a *benchmark* for all other experiments. The remaining experiments aimed to evaluate the influence of system parameters (e.g. 3G terminal) and multiple users (5 and 10) on the performance of the transport system of interest. In addition, some experiments aimed to evaluate the influence of the Internet and the Enterprise network on the MobiHealth transport system performance.

We designed a Java-based distributed *evaluation system* implementing a *workload generator* and a *measurement*

⁶ Time needed to transport data from a source to a destination

⁷ The service delay excludes queuing of a SE at the service users end-points

function [12] to execute the experiments. Both evaluation systems were deployed on computer systems taking part in measurements. Evaluation systems had their internal functions timely synchronized by means of an out-of-band synchronization method (NTP-based).

We executed experiments between July 2003 and 1 April 2004 at the University of Twente (UT), in the Netherlands. Therefore, the Enterprise network was the campus network of the University of Twente. In total more than 3 GB of data has been transported during measurements under different conditions and hours. Figure 5 presents the measurement setup of the benchmark experiment. To be as realistic as possible, the

Figure 5. Benchmark measurements setup

data transported during the measurements was copied from MobiHealth monitoring service data (i.e. patient's vital signs data). The transported data consisted of 20 different SP sizes for uplink (SP_{send} range: 174 to 8122 Bytes) and 20 sizes for downlink (SP_{recv} range: 174 to 48208 Bytes). Therefore, in total 400 different combinations of SP_{send} and SP_{recv} sizes (i.e. SE's) were examined. We believe that this (relatively high) number of possible combinations of SPs, with the (adequate) SP sizes granularity⁸, was suitable to disclose the behaviour of the transport (sub)system of interest.

We define an *SE measurement*⁹ as a measurement of SE delay, constituting of an uplink and downlink delay. To get statistically sound data, each SE measurement was repeated 500 times, representing 500 *observations*. These observations constituted one *sample*, which was individually recorded and statistically analysed. We obtained the statistical mean (average) of uplink, downlink and SE delays, their standard deviation (jitter) and accuracy for a 95% confidence interval. From this data set, the uplink and downlink goodput values were derived.

All measurements were executed during the 3G network's (i.e. transport system of interest) transition from a pre-commercial to commercial state. Because we were the only (single) user of this network and executing all the measurements at a stationary geographical location, the measurements results are considered as a *reference* (best-case scenario).

III. MEASUREMENTS RESULTS ANALYSIS

From the experiments, we have concluded that the Internet and Enterprise network have no significant influence on the overall MobiHealth transport system performance (i.e. they are no performance bottlenecks). Hence, our performance measurements reflect the

performance of the 3G network – transport (sub)system of interest.

Our first finding was the capacity switching behaviour of the 3G network. The network capacity correlates to an assigned 3G network bearer, which in turn depends on the data volume (i.e. size and rate) offered to the network. Therefore, we denoted the capacity switching behaviour as *bearer assignment* behaviour. For any standalone transport request, the 3G network assigns the common bearer by default to both uplink and downlink. For additional data transport requests, it assigns an adequate dedicated bearer (with a higher capacity) that “matches” the offered data volume. The bearer assignment behaviour is always gradual; i.e., the 3G network assigns a contiguous bearer (to the current one) for the uplink and/or downlink. The bearer assignment behaviour may result in a transport system with an asymmetric capacity.

The exact conditions, under which bearer assignment behaviour takes place is not clear to us. However, we considered this behaviour as ‘normal’ if it *converges* to an adequate bearer and this bearer is used for the remaining time of data transport. Figure 6 presents one sample of (raw) data illustrating the downlink converging behaviour. The sample (raw) data is for a SE SP_{send} 1048 Bytes and SP_{recv} 9432 Bytes, and shows the uplink delay (red), downlink delay (green) and SE delay (blue) for a sequence of 500 observations (this sample). Delays are provided in milliseconds. The observations are displayed in the order they were made. In addition, the figure provides sample information data: measurements timeframe (*start*, *stop* labels) and delay statistics. We conclude from the figure that both uplink and downlink have been assigned dedicated bearer 1 after a first few (approximately 10) observations. The uplink uses dedicated bearer 1 for the remaining time of data transport. The downlink bearer assignment starts at dedicated bearer 1 (observations 10 to approximately 80), then dedicated bearer 2 (observations approximately 80 to approximately 360) and it converges to dedicated bearer 3 (observations approximately 360 to 500). This bearer is used for the remaining time of the data transport.

Figure 6. 3G network downlink's converging behaviour

⁸ SPs were uniformly distributed in a given SP range

⁹ The SE measurement excludes queuing delays of SE at the service users ends-points

During the measurements execution, we collected raw data for all SEs in the format presented in Figure 6. For each individual SE, we calculated uplink and downlink goodput values from the average delay values. The following sections present goodput graphs calculated on all SEs. Section 3.A provides the 3G network's uplink goodput analysis and section 3.B the downlink goodput analysis.

A. 3G network's uplink goodput behaviour

Figure 7 presents the 3G network's uplink goodput and delay as a function of SP_{send} , i.e., SP size offered to the uplink. We derived this function based on selected SEs: with changing SP_{send} sizes and a fixed SP_{recv} size of 524 Bytes.

Figure 7. 3G network's uplink goodput and delay behaviour versus SP_{send} size

The horizontal axis in the figure gives values of the SP_{send} size in Bytes. The left vertical axis presents the corresponding uplink goodput in kilobits per second (kbps). Two red horizontal lines indicate the nominal capacities for the four downlink bearers of the 3G network, respectively, the common bearer (16 kbps) and dedicated bearer 1 (64 kbps). The right vertical axis presents the corresponding delay in milliseconds.

We conclude from this figure that the goodput and average delay increase with the SP_{send} size. The 3G network assigns a common bearer for a SP_{send} size of 174 Bytes, and for sizes larger than 174 Bytes, the dedicated bearer 1. The value of corresponding delay increases linearly when the goodput stabilize (for SP_{send} larger than 6812 Bytes). The maximum achievable goodput is approximately 53 kbps (efficiency 83%) which indicates that the 3G network's uplink is a goodput bottleneck.

B. 3G network's downlink goodput behaviour

Figures 8 and 9¹⁰ present respectively, the average delay and goodput of the 3G network's downlink as a function of SP_{recv} , i.e., SP size offered in the downlink. We derived the function presented in Figure 8 from one group of SEs with a fixed SP_{send} size of 2096 Bytes and changing SP_{recv} sizes. The function presented in Figure 9, is derived from groups of SEs each with a fixed SP_{send} size and changing SP_{recv} sizes, resulting in 20 groups of SEs. Hence, there are 20 curves in Figure 9 and they represent 'tendency' in 3G network's downlink behaviour observed for different SP_{send} sizes.

In both figures, the horizontal axis gives the values of the SP_{recv} size in Bytes. The left vertical axis presents the

corresponding downlink goodput in kilobytes per second (kbps). Four red horizontal lines indicate the nominal capacities for the four downlink bearers of the 3G network, respectively, the common bearer (16 kbps) and dedicated bearers 1 to 3 (64, 128 and 384 kbps). In addition, the right vertical axis in Figure 8 presents the corresponding average delay in milliseconds.

From both figures, we conclude that the 3G network's goodput behaviour correlates with the offered data volume. As we know, the goodput correlates to the capacity of assigned bearer in the 3G network. Therefore, we put forward the following hypothesis: the goodput behaviour can be characterized by four *goodput behaviour regions* depending on SP_{recv} size. We associate each region with one or more assigned bearers.

¹⁰ In the figures, the measurement points are connected, however the presented behaviour should *not* be interpreted as a continuous function

Region 1 relates to small SPs up to and including SP_{recv} size of 2096 Bytes. In this region, the goodput increases with the SP size and its value is predictable for all functions; e.g., for a SP_{recv} equal 2096 Bytes it is approximately 45 kbps. In this region, the 3G network assigns either the common bearer or dedicated bearer 1. *Region 2* relates to SP_{recv} sizes bigger than 2096 Bytes but smaller than 10480 Bytes. In this region, the goodput is highly variable. For a SP_{recv} equal 10480 Bytes, its value is predictable for all functions and equals approximately 100 kbps. In this region, the 3G network assigns either

dynamic, depending on the offered data volume and depending on the bearer assigned in by the network. Moreover, the 3G network is a goodput bottleneck with an uplink maximum goodput of 53 kbps and a downlink goodput of approximately 300 kbps. We collected (best-case scenario) *reference* measurement results, which may be used as reference data for performance evaluation activities conducted on other 3G networks. The MobiHealth system provides a monitoring service, an example of an m-health service. The monitoring service data comprises of vital signs data only (i.e. neither audio

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Figure 8. 3G network's downlink goodput and delay behaviour versus SP_{recv} size (SP_{send} 2096 Bytes)

dedicated bearer 1 or dedicated bearer 2. *Region 3* relates to a SP_{recv} size bigger than 10480 Bytes but smaller than 23056 Bytes. In this region, the goodput is highly variable. For a SP_{recv} equal to 23056 Bytes, its value is predictable for all functions and equals approximately 300 kbps. In this region, the 3G network assigns either dedicated bearer 2 or dedicated bearer 3. *Region 4* relates to SP_{recv} sizes bigger than 23056 Bytes. In this region, the goodput stabilizes and its value is predictable for all functions. The 3G network assigns dedicated bearer 3 and the maximum achievable goodput is approximately 300 kbps. Hence, indicating that the 3G network's downlink is a goodput bottleneck.

IV. CONCLUSIONS AND DISCUSSION

By executing the measurements-based methodology, we were able to evaluate the performance of one of the 3G networks available for the MobiHealth project. We evaluated its capacity from a network user's perspective, according to the speed performance criterion and a goodput performance measure. We discovered that the goodput behaviour of the 3G network is asymmetric and

no video data), and is collected from the patient at a fixed intervals. In the current implementation of the system, the service data rate offered to the underlying transport system (i.e. the 3G network) is constant and approximately 20 kbps. It needs to be emphasized, that there were no MobiHealth service's performance requirements defined; in the project; the aim of the project was a feasibility study and the MobiHealth system delivers a best-effort service. Therefore, based on our findings of the 3G network capacity, we conclude that this network is suitable to support provision of the current MobiHealth tele-monitoring service. However, due to goodput bottlenecks, this network may not be suitable to support future implementations of a monitoring service that will require fast, high-capacity networks. An example is trauma tele-monitoring service [13], where service data comprises patient vital signs data, audio and video data. This kind of services may be hindered by the restrictions imposed by the 3G network's goodput bottleneck and/or the asymmetric transmission capacity. The downlink link capacity in 3G networks is (much) higher than the uplink, while the reverse would be beneficial to monitoring services. Current 3G networks support the standard

producer-consumer paradigm; i.e., a wireless service user (mobile client) is the information consumer receiving more data from a wired server (e.g. Web server on the Internet) than it generates. However, in the m-health service domain the consumer-producer roles are inverted. The mobile end-user (i.e. patient) is a producer of information, transmitting high quantities of data to the hospital. Mobile network operators and manufactures of 3G terminals should consider this fact in order to allow for a better support of forthcoming monitoring services, and in general for a better support of m-health services.

Within the MobiHealth system, the volume and rate of service data (i.e. vital signs data), offered by the mobile system (i.e. BAN) part of the monitoring service to the underlying transport system, is configurable. Our aim is that the MobiHealth system benefits from the performance

the underlying 3G network acting as a transport system. To deal with the dynamic performance behaviour of 3G networks (consequence of bearer assignments), the application protocol designer needs to ensure buffering capacity (at the application level) at the mobile part of the system.

In this paper, we presented the (selected) results of a 3G network speed-related performance study. The importance of our findings is the dynamic performance behaviour of this 3G network due to bearer assignments. Furthermore, we observed that the capacity perceived by user is significantly less (-14%) from the nominal capacity that mobile network operators promise. We obtained (best-case scenario) reference results that can be used to compare speed-related performance studies of other 3G networks.

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Figure 9. 3G network's downlink goodput behaviour versus SP_{send} size

characteristics of underlying wireless networks, and in particular 3G networks. We suggest to decrease the data volume and increase the data rate offered by the mobile system part to the 3G network. This yields a more efficient use of 3G networks. In the current situation, the MobiHealth system offers a high data volume and a low data rate. Decreasing the volume and increasing the rate, will also have an effect on the delay between two consecutive samples perceived by the end-user; the delay between two samples decreases.

In the context of re-configurable service delivery, we conclude that the performance of 3G networks influences the application protocols (e.g. MobiHealth BANip) design. The goal of application protocol design for monitoring services is to benefit from the performance of

We consider two complementary future work areas. First area comprises a detailed study of performance requirements for m-health services' as defined by its end-users and translation of these requirements into the system requirements. The MobiHealth project indicated that healthcare professionals find it difficult to specify the user requirements for mobile healthcare services, e.g., for a tele-monitoring service. A plausible cause may be the unfamiliarity with ICT enhanced healthcare services and therefore lack of understanding their possibilities and shortcomings. Hence, no strict MobiHealth system requirements were specified. However, we anticipate that forthcoming m-health services will have strict service performance requirements translated into the specific system requirements.

The second future work area comprises a 3G networks accuracy- and dependability-related performance study. We obtained reference results from a 3G network without background traffic (only user scenario) and suggest repeating measurements in commercially exploited networks with background traffic (multiple users scenario). The influence of background traffic on the observed performance may thus be determined. Finally, we recommend an unreliable transport service study in contrast to our reliable service study to observe any changes in end-user perceived m-health service performance.

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