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Katarzyna Wac[1, 2], Aart van Halteren[2], Tom Broens[2]

[1] University of Geneva, CUI/OSG, 24 rue General Dufour, 1211 Geneva 4, Switzerland
[2] University of Twente, EWI/INF, P.O.Box 217, 7500 AE Enschede, The Netherlands
{k.e.wac, a.t.vanhalteren, t.h.f.broens}@utwente.nl

***Abstract*— Inevitably, healthcare goes mobile. Recently developed mobile healthcare (i.e. m-health) services allow healthcare professionals to monitor a mobile patient's vital signs and provide feedback to this patient anywhere and any time. Due to the nature of current supporting mobile services platforms, m-health services are delivered with a best-effort, i.e., there are no guarantees on the delivered quality of service (QoS). In this paper, we argue that the use of contextual information in an m-health services platform improves the delivered QoS. We give a first attempt to merge contextual information with a QoS-aware mobile services platform in the m-health services domain. We illustrate this with an epilepsy tele-monitoring scenario.**

***Index Terms*— m-health, tele-monitoring, QoS, QoS-awareness, context-awareness, 3G**

I. Introduction

The introduction of third generation (3G) public wireless network infrastructures, such as the Universal Mobile Telecommunications System (UMTS), gives rise to new mobile services in all kinds of areas of our daily life. Application of these services in the healthcare domain i.e., introduction of mobile healthcare (m-health[1]) services, is a relatively new idea. As mentioned in [1], tele-monitoring of patients may be a solution to reduce healthcare costs and increase productivity and the quality of life of working patients, or patients with chronic diseases. The number of current attempts for realization of patients' tele-monitoring systems given in literature [2, 3] indicates an urgent increasing need for the development of m-health services.

In frame of the European MobiHealth project, we designed, implemented, deployed and made operational a generic m-health services platform for patients and healthcare professionals. In particular, our goal in this project was to explore the capabilities of 2.5G and 3G broadband wireless communication networks to support delivery of m-health services. One of the offered services is a patient tele-monitoring service that compromises remote collecting of the patient's vital signs from a healthcare centre, with use of 2.5G and 3G communication networks. Towards this end, we developed a Body Area Network (BAN) consisting of sensors and actuators worn by a patient. Details of the MobiHealth system and its services can be found in [4, 5]. The system was evaluated in nine trials; with different healthcare cases and different patient groups in four different European countries (the Netherlands, Spain, Sweden, and Germany) [6].

Presently, as part of the Freeband Awareness Dutch national project [7, 8], we are extending the existing MobiHealth m-health services platform with context-awareness. Context is knowledge on a service users' actual situation (e.g. the patient's location and time, current patient's health state, some preferences and BAN capabilities), which may be relevant for service delivery [9, 10]. One of the research questions addressed by our project is the type of contextual information that may be used in the m-health services platforms to improve (the quality of) delivery of tele-monitoring services.

The MobiHealth project indicated that healthcare professionals find it difficult to specify the user requirements for m-health based services (e.g. tele-monitoring service) in terms of possibilities of new technologies [11]. A plausible cause may be the unfamiliarity with ICT enhanced healthcare services and therefore lack of understanding services' possibilities and shortcomings. Hence, no strict MobiHealth tele-monitoring service requirements (i.e. *required* quality of service QoS) were specified. Therefore, the MobiHealth tele-monitoring service was implemented as a best-effort service, (i.e. without the specification of a *delivered* QoS). However, we anticipate that the users' QoS requirements will play a significant role in development of forthcoming m-health services. Healthcare professionals will dictate requirements (i.e. required QoS) concerning for example performance of this service (e.g. delay, jitter), expected security level, acceptable price, etc. The QoS delivered by the m-health services platform needs to match the required QoS. We anticipate that the required QoS will be defined to guarantee that in case of an emergency situation, the healthcare center can react in time and bring medical assistance to a patient. It is possible that the required QoS for an emergency situation will differ from a non-emergency situation. Therefore, the m-health

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

services platform should be able to have knowledge on the actual situation (i.e. health state) of the patient. This knowledge is application-level contextual information, and it is presently possible to acquire and provide it for an epilepsy tele-monitoring scenario in the Freeband Awareness project.

In this paper, we argue that use of contextual information in a QoS-aware m-health services platform plays a significant role in the definition of required QoS and it improves the delivered QoS. Our idea is that a QoS-aware m-health services platform may benefit from contextual information, such that the required QoS are always met (or at least there is always an attempt to meet the required QoS). Contextual information may serve as an implicit input to a QoS-aware m-health services platform, which is not explicitly provided by the service user. Moreover, context may help to capture the user's goals, and therefore the user's required QoS. Our argument is applicable for an arbitrary mobile services platform.

Following our argument, we present two complementary ideas on merging context-awareness with a QoS-aware m-health services platform. Firstly, we show that the m-health services platform needs to be able to acquire and use contextual information relevant for the *definition of the required QoS*. This contextual information, amongst the others, concerns the actual situation (i.e. health state) of the patient. We anticipate that the required QoS is more demanding in case of an emergency situation.

Our second idea focuses on the delivered QoS, which needs to meet (or at least should attempt to meet) the required QoS. The complication is that the delivered QoS depends on a chosen communication network infrastructure; i.e., on a QoS *offered* by the networks supporting delivery of m-health services. Therefore, to meet the required QoS, the m-health services platform needs to be able to acquire and use contextual information about the QoS offered by communication network infrastructures (WLAN/2.5G/3G) available at the patient's current location and time. Furthermore, to meet the required QoS, the m-health services platform needs to utilize this contextual information. This may mean adapting service delivery to the offered QoS of the actually used communication network infrastructure (see section 4.A for details) or conducting a seamless handover to the communication network offering better QoS than the actually used one (see section 4.B for details).

The reminder of this paper is structured as follows. In section 2, we provide an example tele-monitoring service scenario that we use to illustrate our research ideas. In section 3, we provide requirements for a context- and QoS-aware m-health services platform. Section 4 presents two examples of incorporating context into our m-health services platform. In section 5, we restate our argument and give particular research objectives along the proposed research trajectory. Section 6 provides conclusion.

II. Tele-monitoring Scenario

The following future application scenario illustrates how an epileptic patient [10] can benefit from m-health services. We present the scenario in boxed paragraphs followed by explainations what technology we propose to support this scenario.

> Sophie is a 28 years old epileptic patient living in a small village in the suburbs of Paris. The neurological disorder affects her nervous system already for four years. Although the occurrence of a seizure (i.e. an epilepsy attack) is often sudden and unexpected, she does not feel limited in her daily life and insecure when she is alone. It is because Sophie is being treated under a continuum healthcare program; the Epilepsy Safety System (ESS) tele-monitors her health condition. She is not confined to a healthcare center without loosing her feeling of safety. She has learnt to live with such a condition and generally, it does not disturb her too much in her active life.

The ESS (Figure 1) is responsible for predicting, detecting and handling the occurrence of epileptic seizures. The ESS

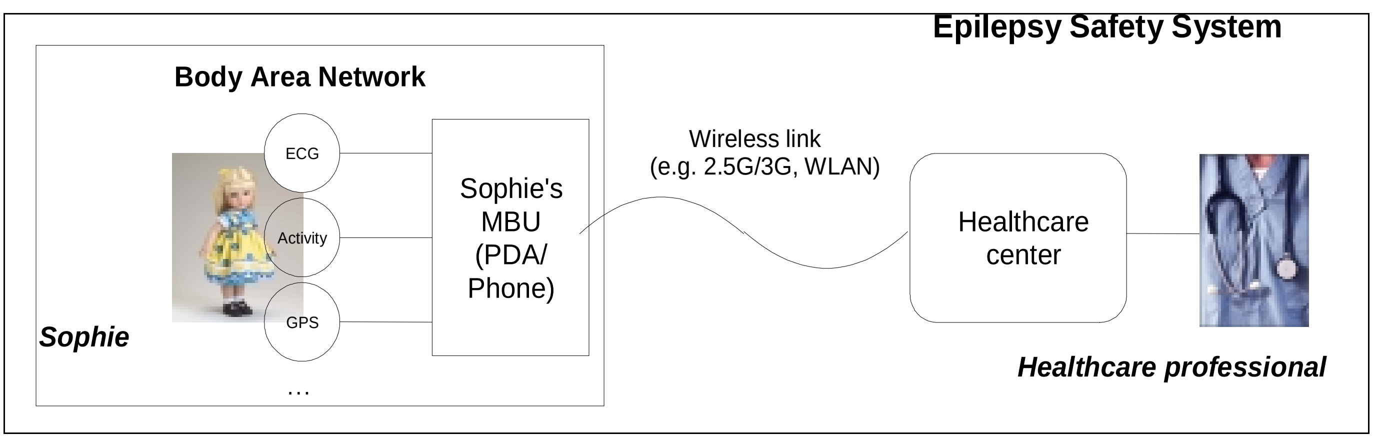

Figure 1. Epilepsy Safety System architecture

predicts if an epileptic seizure is likely to happen, based on Sophie's vital signs[2]. Therefore, she wears a Body Area Network (BAN), responsible for a collection of her vital signs data. The BAN consists of sensors (to measure ECG and activity), a GPS module (to determine Sophie's location information) and a Mobile Base Unit (MBU). A local ad-hoc communication network (e.g. Bluetooth) connects the sensors, GPS module and the MBU. The MBU is a gateway between the intra-BAN network and external (2.5G/3G/WLAN) communication networks and can be used to (locally) process the sensor data. The MBU could be implemented as a Personal Digital Assistant (PDA) or a mobile phone. The BAN continuously monitors Sophie's vital signs, which are made available to the healthcare centre. This constitutes an m-health tele-monitoring service.

To make Sophie's data available to her healthcare professional, the MBU connects to one of the external communication networks (e.g., WLAN, 2.5G or 3G) as available at Sophie's current location and time. To support Sophie's mobility, the MBU supports seamless handover between these networks.

Sophie's doctor may always tele-monitor her vital sign's data at the healthcare centre. This data has a delay defined according to Sophie's current health condition. The delay should be a maximum of 5 seconds for a non-seizure condition and a maximum of 1 second in case of an epileptic seizure (i.e. emergency). This delay is a time elapsed from the moment the data is gathered from Sophie's body to the moment it is displayed to her doctor in the healthcare centre. The doctor defined this delay requirement; such that in a case of an emergency, the healthcare center can react in time and provide Sophie medical assistance.

Besides the delay, the doctor defined which basic data (e.g. seizure alarm and location information in case of an epileptic seizure) must always be made available to him. He also defined which data is redundant (e.g. the full ECG signal). These definitions constitute very important requirements for the tele-monitoring service, since the kind and volume of data transported to the healthcare centre depends on the capabilities of communication networks available at Sophie's current location and time.

Sophie works in a bank located in Paris city centre. In her workplace, there is WLAN available and whenever she leaves her job, there are 2.5G/3G communication networks available in the city and its suburbs. At home, she also has a WLAN communication network.

The ESS system has one more, very important feature. In case of a seizure, depending on its severity, the ESS alarms Sophie and her healthcare centre (i.e. her doctor) and eventually Sophie's mother (in case of a strong seizure). These activities constitute an m-health alarm service.

It is Saturday and Sophie is enjoying her day; she does not go to work. In the morning, she went to the gym and did some shopping in a local shopping mall. Now she wants to go to the library and she chooses a route to the library via the city centre. She is biking. Although Sophie feels good, her ESS warns her of a possible seizure and triggers a seizure alarm at the healthcare centre. She stops riding the bike and sits on a bench near-by. Before she can ask somebody for help, a seizure starts. ESS activates the m-health alarm service.

This time the seizure is very strong and ESS notifies her doctor and her mother. Sophie is in the city centre of her village, and a 3G network is an available communication network. All Sophie's sensor data together with her location information is continuously send to the healthcare centre. Sophie's doctor decides to intervene based on the ECG signals he sees on his screen. He sends an ambulance to the scene of the seizure.

Minutes later the ambulance reaches Sophie and medical professionals give her medical assistance and decide to take her to the hospital.

Sophie's doctor continues to monitor her while she is being transported. During the ride to the hospital, the ambulance moves out of the range of the 3G network and the MBU transparently switches to a 2.5G network. Once Sophie arrives at the hospital, the MBU connects to the available WLAN and her full ECG signals are automatically displayed in the emergency room.

After a final check-up and some rest, Sophie's mother meets her daughter in the hospital and takes her home.

When the MBU switches between different communication networks, the ESS adapts the signals it sends to Sophie's doctor. As result, the doctor will not see the ECG signals when the ambulance moves out of the 3G network coverage and the 2.5G network is used.

III. REQUIREMENTS FOR A CONTEXT- AND QOS-AWARE M-HEALTH SERVICES PLATFORM

The above scenario is one of the possible scenarios for an m-health service. There are many other possible healthcare applications for other health conditions, and there are many variation points in both: the presented scenario and the presented structure of the ESS. To support various m-health services' scenarios, the Freeband Awareness project [7, 8] defines a high-level architecture for context-aware mobile services (see Figure 2).

AWARENESS defines a three-layered architecture. The bottom layer of the architecture is the *communication network infrastructure* layer, offering seamless mobile connectivity (e.g. 2.5G/3G and WLAN). The middle layer is the *service infrastructure* layer that provides an execution environment for mobile services. It provides generic functionality like service discovery and security mechanisms. The top layer is the *application* layer which offers *generic application services* like context management and *domain specific services* like in

[2] According to the clinical research, an epilepsy seizure can be predicted at best 30 seconds before the seizure, based on ECG signals and an increasing heart rate of a patient. A prediction succeeds in 80% of the cases.

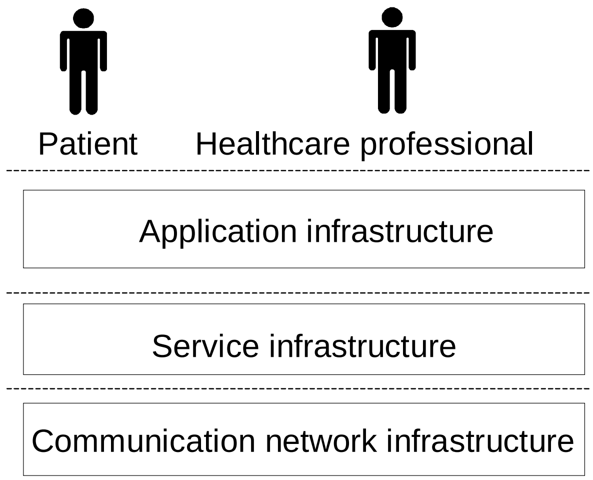

Figure 2. High-level AWARENESS architecture

the case of the ESS: tele-monitoring services (e.g. seizure detection) [16].

If we consider the QoS aspects of the AWARENESS m-health services platform, we can conclude that there are recurring problems to solve and issues to address:

- QoS specification – The scenario shows that a doctor is able to specify what health data must be always tele-monitored at the healthcare centre. In addition, the doctor also specifies the delay of data transport. The m-health services platform must be able to handle these QoS specifications.

- QoS mapping – The QoS specifications must be mapped to QoS requirements on the underlying communication network infrastructure.

- QoS adaptation – In case a communication network handover occurs, the QoS offered by the communication network infrastructure's changes and the service infrastructure should adapt (i.e. reduce data by only sending the basic data or adapt application protocol (see section 4 for details))

- Context adaptation – In case of an emergency, a context change takes place and results in a change in QoS requirements. The service infrastructure could incorporate contextual information when mapping QoS and adapting to QoS changes.

IV. Incorporating Context

Following the QoS concerns mentioned above, we claim that the use of contextual information in an m-health services platform improves the delivered QoS. To support this claim section 4.A shows how application protocol adaptation can benefit from contextual information about the QoS offered when transporting patient data with use of the 3G network. Section 4.B shows how location-specific information about QoS offered can further improve QoS adaptation and delivered QoS.

A. Application protocol adaptation

To meet the required QoS, the m-health services platform needs to be able to acquire and use contextual information about the QoS offered by communication network infrastructures (WLAN/2.5G/3G) available at the patient's current location and time. One way of utilizing this information is adaptation of service delivery to the offered QoS by the actually used communication network infrastructure.

To illustrate it we use our knowledge about QoS offered by 3G communication network infrastructures. This comprises results of the performance evaluation of 3G communication networks as presented in [12, 13, 14]. Figure 3 shows the goodput[3] and delay characteristics of a 3G network as a function of the application protocol's packet size sent in an uplink (i.e., from a terminal of a mobile patient to a system in the healthcare centre). As can be expected a higher packet size results in a higher goodput, but is also accompanied with higher delays.

In a context-unaware situation, the application protocol designer maps service user's QoS requirements to some fixed application protocol packet size. For example, if the application dictates a low delay, a small packet size could be chosen. However, if the application dictates an efficient (and cost-effective) use of the 3G network a larger packet size could be chosen. The choice for a packet size is a design-time choice.

If we incorporate contextual information in the application protocol, the packet-size could be adapted according to the context-dependent service user's QoS requirements. For Sophie's case that would mean that a large packet would be chosen in a non-critical situation and as soon as an emergency occurs (i.e., a seizure is predicted) the packet-size is reduced to the level that meets with the low delay QoS requirement.

B. Location-based QoS adaptation

To meet the required QoS, the m-health services platform needs to be able to acquire and use contextual information about the QoS offered by communication network infrastructures (WLAN/2.5G/3G) available at the service user's current location and time. As presented in section 4.A, one possible way of utilizing this information is adaptation of service delivery to the offered QoS to the currently used communication network infrastructure. In this section, we present another possible way of utilizing this information. This comprises conducting a seamless handover to the communication network offering better QoS than the network that is currently in use.

[3] Goodput is a throughput of a communication network infrastructure as observed at the application layer

Because the service user is mobile, the underlying communication networks, and the QoS offered by these networks, change as the mobile user moves. The QoS offered by these networks depends, amongst others, on the user's actual location and time, i.e., which communication networks are available at a certain location and time and the performance characteristics of these networks. The offered QoS of a wireless communication network fluctuates over time because of changing number of mobile users at a given location and their changing demands. Therefore, we denote this information as location-based offered QoS. The location-based offered QoS should be incorporated as contextual information into the QoS-aware service infrastructure in real-time. This will guarantee that the m-health services platform recognizes a context change resulting in a change of the offered QoS. Our idea is that the platform would always choose the communication network infrastructure offering QoS, which the best matches the services user's required QoS. To meet the required QoS may imply that the services platform conducts a seamless handover to the communication network offering better QoS than the actually used one.

In a context-unaware situation, the system designer maps service user's QoS requirements to QoS offered by some default communication network. The choice for used communication network is a design-time choice.

If we incorporate location-based offered QoS context ual information in the m-health services platform, the choice of the actually used network could be adapted according to the context-dependent service user's QoS requirements. For Sophie's case that would mean that a low-bandwidth network (e.g. 2.5G) would be chosen in a non-critical situation and as soon as an emergency occurs (i.e., a seizure is predicted), the handover to the high-bandwidth low-delay network (e.g. 3G) would occur that meets with the low delay (emergency case) QoS requirement.

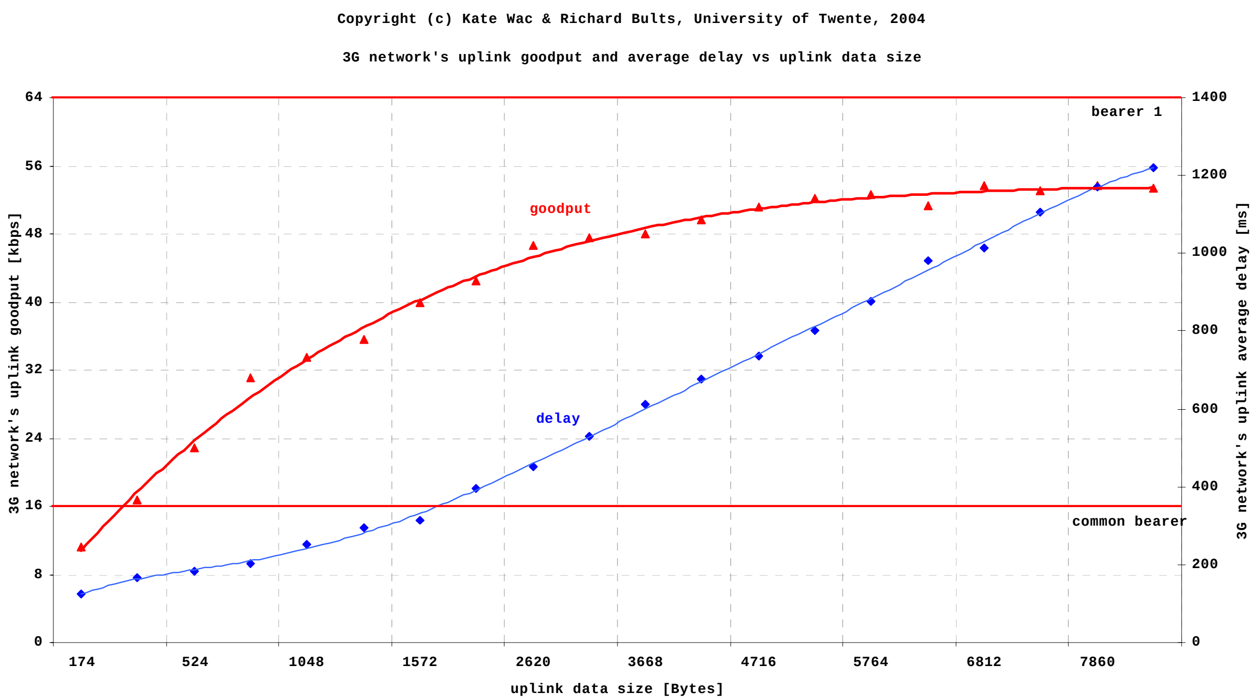

Figure 3. Performance characteristics of 3G communication network infrastructures

Furthermore, we anticipate that the location-based offered QoS contextual information changes in time. For example, it may occur that if the Sophie's seizure happens at 9.00 am in the morning, her company WLAN network offers a low QoS (due to people arriving at the office and logging into the server, downloading emails etc). Given this time-based contextual information, the system would decide to use the 3G network, instead of the WLAN network, to transmit Sophie's health signals to the healthcare center and fulfill the tele-monitoring service's QoS requirements for an emergency case.

V. Research Trajectory

In this paper, we argue that use of contextual information in QoS-aware m-health services platform plays a significant role in the definition of the required QoS and it improves the delivered QoS. Our argument is an innovative idea and we did not find previous work on this topic or counterclaims. However, background research is needed separately on a QoS-aware m-health services platform and on context-awareness, before we may merge these ideas. Consequently, there are the following objectives structuring the trajectory of our research.

Firstly, we need to define a suitable QoS-aware services platform to be used by the AWARENESS m-health services platform. The QoS-aware services platform needs to support QoS specification, mapping and adaptation requirements. We will start our research in this direction based on the existing QoS-aware services platforms for mobile services platforms. The outcome of this step is QoS-awareness of the AWARENESS m-health services platform.

Our following research step constitutes incorporation of contextual information into the QoS-aware AWARENESS services platform. It will be important to decide what context is relevant and how to acquire it and then incorporate into the service infrastructure. Due to an unreliability of contextual information sources [9, 10], the services platform should deliver a best-effort QoS when context is not available.

For our QoS-aware AWARENESS services platform, we need to define a precise mapping of service user QoS requirements into the platform requirements and furthermore into the QoS requirements for the underlying communication network infrastructures. The contextual information will be used to support this mapping. The contextual information may serve as an implicit input to the platform, which is not explicitly provided by the service user. Moreover, the context may helps to better capture the user's goals, and therefore the user's required QoS. It may be also used to handle conflicting QoS requirements.

We consider the location-based offered QoS as contextual information that the QoS-aware AWARENESS services platform is able to acquire and use. The question is how to get this contextual information in a reliable, real-time manner, such that the services platform may fully support the mobility of a service user. The basis to answer this question is a methodology for an end-to-end performance evaluation of hybrid communication network infrastructures (i.e. consisting of wireless and wired communication networks). This methodology we presented comprehensively in [12]. We already applied this methodology to evaluate the performance of 3G communication networks [12, 13, and 14]. We use selected evaluation results to illustrate the example of application protocol adaptation as presented in section 4.A.

This methodology will be a basis for development of an evaluation system for a real-time performance evaluation of hybrid communication network infrastructures. The evaluation system will provide contextual information about the real-time location-based offered QoS.

In [15] we presented the current implementation of the application protocol supporting the tele-monitoring service in the MobiHealth system. This protocol was originally adapted to the QoS offered by 2.5G communication network infrastructures ("default" network). In [12] we presented how this protocol may be optimized to the QoS offered by 3G communication network infrastructures. Moreover, currently we are working on the application framework for context-aware applications. This work includes protocol adaptation as reported in [16].

The final objective of our research is to prototypically validate that QoS improvements can be achieved using contextual information in the AWARENESS m-health services platform. We expect that the results of our research will be applicable in any mobile services platform.

VI. Conclusion

In this paper, we discuss our ongoing research on the use of contextual information in a context- and QoS-aware platform for a mobile service delivery, and in particular for m-health tele-monitoring service delivery. We present our research trajectory aiming to prove that the use of contextual information plays a significant role in required QoS specification and it improves the delivered QoS.

This work is a part of ongoing research in frame of the Freeband AWARENESS project. The Dutch government sponsors Freeband under contract BSIK 03025 [8].

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