
Context-aware QoS provisioning in an m-health service platform

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Abstract: Inevitably, healthcare goes mobile. Recently developed mobile healthcare (i.e., m-health) services allow healthcare professionals to monitor mobile patient's vital signs and provide feedback to this patient anywhere at any time. Due to the nature of current supporting mobile service 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 context information in an m-health service platform improves the delivered QoS. We give a first attempt to merge context information with a QoS-aware mobile service platform in the m-health services domain. We illustrate this with an epilepsy tele-monitoring scenario.

Keywords: m-health; tele-monitoring; Quality of Service (QoS); QoS-awareness; context-awareness; 3G.

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1 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. The introduction of mobile healthcare (m-health)¹ services slowly catches some momentum. Tele-monitoring of patients may be a solution to reduce healthcare costs, increase a working patient's productivity and the quality of

life of patients with chronic diseases (Air2Web, 2002). The number of current attempts for realisation of patients' tele-monitoring systems given in literature (Tachkara et al., 2003; van Halteren et al., 2004a), indicates an increasing need for the development of m-health services.

Within the framework of the European MobiHealth project, we designed, implemented, deployed and made operational a generic m-health service platform for patients and healthcare professionals (MobiHealth, 2004; van Halteren et al., 2004b). In particular, our focus in this project was to explore the capabilities of 2.5G and 3G wireless communication networks to support m-health services delivery. One of the offered services is the patient tele-monitoring service that enables remote collection of patient's vital signs initiated from a healthcare centre, using 2.5G/3G wireless communication networks. We developed a Body Area Network (BAN) consisting of sensors and actuators worn by a patient and Back-End services to implement the tele-monitoring services. 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) (Alonso et al., 2003).

Within the framework of the (on-going) Freeband AWARENESS Dutch national project (Wegdam et al., 2004; Freeband AWARENESS, 2004) we extend the existing MobiHealth m-health service platform with 'context-awareness'. Context-awareness refers to knowledge of 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 (Dey, 2000; Dockhorn Costa, 2004). One of the research questions addressed by our project is the type of context information that may be used in m-health service platforms to improve (the quality of) delivery of tele-monitoring services.

The MobiHealth project indicated that healthcare professionals find it difficult to specify their 'end-user' requirements for m-health services (e.g., tele-monitoring service) in relation to applicability and possibilities of new technologies (Herzog, 2002). A plausible cause may be the unfamiliarity with ICT enhanced healthcare services and therefore lack of understanding these services, their advantages 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; without the specification of a *delivered* QoS. However, we anticipate that the end-users' QoS requirements will play a significant role in development of forthcoming m-health services. Healthcare professionals will provide end-user service requirements, from which service platform requirements (i.e., *required* QoS) will be derived, concerning service performance (e.g., delay, jitter), expected security level, acceptable price, etc. The goal is that QoS delivered by the m-health service platform needs to match the required end-user QoS. We anticipate that the

required end-user QoS will be defined to guarantee, that in case of an emergency situation, the healthcare centre can react in time and bring medical assistance to a patient. It is possible that the required end-user QoS for an emergency situation will differ from a non-emergency situation. Therefore, the m-health service platform should have knowledge on the actual situation (i.e., health state) of the patient. This knowledge is application-level context information, and it is presently possible to acquire and provide it for an epilepsy tele-monitoring scenario in the Freeband AWARENESS project (Dockhorn Costa, 2004).

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

Following our argument, we present two complementary ideas on merging context-awareness with a QoS-aware m-health service platform. Firstly, we show that the m-health service platform needs to be able to acquire and use context information relevant for deriving the required QoS. This context information, amongst others, includes 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 QoS delivered by the m-health service platform depends on a chosen communication network infrastructure at a particular geographical location and particular instance of time; i.e., the location-specific QoS offered by the underlying communication network infrastructure. Therefore, to meet the required end-user QoS, the m-health service platform needs to acquire and utilise QoS related context information obtained from communication network infrastructures (e.g., WLAN/2.5G/3G) available at the patient's current location and time. This may result in adaptation of service delivery to the offered QoS of the currently used communication network infrastructure (see Section 4.1 for details). Alternatively, a seamless handover may be conducted to a communication network infrastructure offering a closer matched QoS than the one currently used (see Section 4.2 for details).

The remainder 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. Section 3 provides requirements for a context-aware and QoS-aware m-health service platform. Section 4 presents two examples of context information incorporation into

our m-health service platform. In Section 5, we restate our argument and give particular research objectives along the proposed research trajectory. Section 6 provides the conclusion.

2 Tele-monitoring scenario

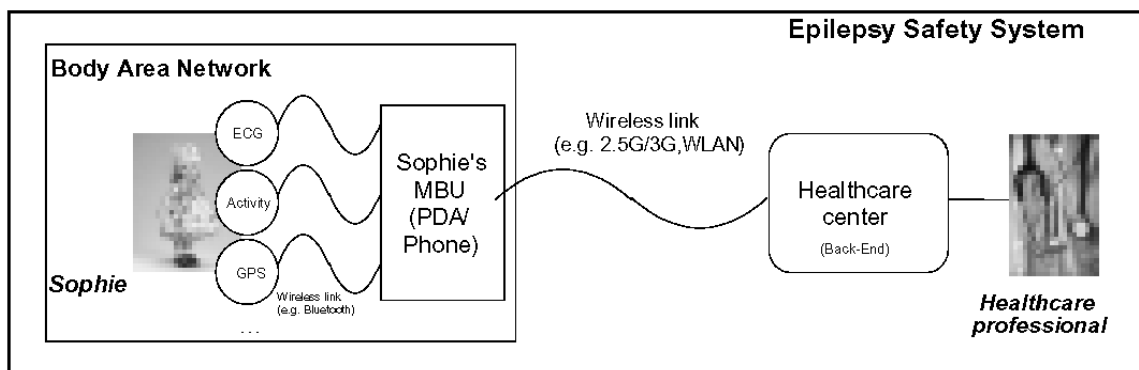
The following future application scenario illustrates how an epileptic patient can benefit from context- and QoS-aware m-health services. We present a scenario in boxed paragraphs followed by explanations of the technology we propose to support this scenario. This scenario we use further to derive m-health service platform requirements.

Sophie is a 28 years old epileptic patient living in a small village in the suburbs of Paris. Epilepsy is a neurological disorder, in which, from time to time, nerve cells of the brain release abnormal electrical impulses, so-called seizures.

This neurological disorder has affected Sophie's nervous system already for four years. Although the occurrence of a seizure is often sudden and unexpected, she does not feel limited in her daily life or insecure when she is alone. This is because Sophie is treated under a continuous healthcare program; the Epilepsy Safety System (ESS) remotely monitors her health condition. She is not confined to a healthcare centre without losing her feeling of safety. She has learnt to live with her 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 predicts if an epileptic seizure is likely to happen, based on

Figure 1 ESS overview



Besides the transport 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 are redundant (e.g., the full ECG signal). These definitions constitute important requirements for the tele-monitoring service, since the type 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's vital signs.² Therefore, she wears a BAN, responsible for measuring her vital signs data. The BAN consists of a sensor-system (containing sensors to measure, for example, ECG and Sophie's activity), a GPS module (to obtain Sophie's location information) and a Mobile Base Unit (MBU). A local ad-hoc communication network (e.g., Bluetooth) connects the sensor-system, GPS module and the MBU. The MBU is a gateway between the intra-BAN network and external (e.g., WLAN/2.5G/3G) 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 smart phone. The BAN continuously monitors Sophie's vital signs, which are made available (via a Back-End service) to be viewed in 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 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 monitor her vital sign's data at the healthcare centre. This data has a required 'transport' 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 the time elapsed from the moment the data is gathered from Sophie's body to the moment it is visible to her doctor in the healthcare centre. The doctor defined this transport delay requirement; such that in a case of an emergency, the healthcare centre can react in time and provide Sophie medical assistance.

Sophie works in a bank located in the city centre of Paris. In her workplace, there is a WLAN communication network 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 network.

The ESS system has one more, very important feature: the alarm service. In case of a seizure, depending on its severity, the ESS alarms Sophie, 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 free day; she did 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 chooses a route 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. The 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 communication network is available. Sophie's sensor data together with her location information are continuously sent to the healthcare centre. Sophie's doctor decides to take action 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 an available 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.

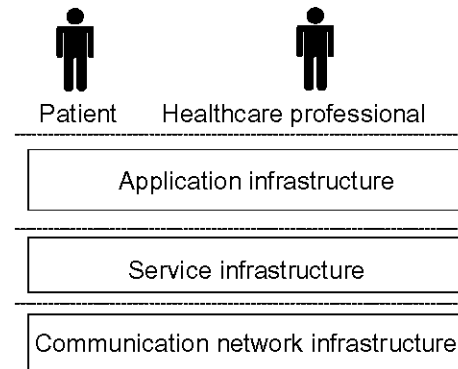
After a final check-up and some rest, Sophie's mother meets her daughter in the hospital and takes her home.

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. He will see again Sophie's full ECG signals displayed in the healthcare centre where WLAN is used.

3 Requirements for a context- and QoS-aware m-health service platform

The above scenario is one of the possible scenarios for the use of m-health services. 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 (Wegdam et al., 2004), (Freeband AWARENESS, 2004) defines a high-level architecture for context-aware mobile services (Figure 2).

Figure 2 High-level AWARENESS architecture



AWARENESS defines a three-layered architecture. The bottom layer of the architecture is the *communication network infrastructure* layer, offering seamless mobile connectivity (e.g., WLAN/2.5G/3G). 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 the case of the ESS: tele-monitoring services (e.g., seizure detection) (Broens et al., 2005).

If we consider the QoS aspects of the AWARENESS m-health service platform, we can conclude that there are recurring problems to solve and requirements to be addressed.

- *QoS specification.* The scenario shows that a doctor (m-health service end-user) is able to specify what health data must be always be transported to the healthcare centre. In addition, the doctor also specifies the delay of vital sign data transport. The m-health service platform is responsible for supporting these end-user QoS requirements as closely as possible.
- *QoS mapping.* The end-user QoS specifications must be mapped to m-health service platform's QoS requirements, which in turn maps to QoS requirements of the underlying communication network infrastructure.
- *QoS adaptation.* In case if a communication network handover occurs, the QoS offered by the communication network infrastructure's is likely to change and the m-health service platform must respond (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, the patient context changes and triggers a QoS requirements change. The m-health service platform should incorporate patient context information when mapping end-user QoS to communication network QoS.

4 Incorporating context

Following the QoS concerns mentioned above, we claim that the use of context information in an m-health service platform improves its delivered QoS. To support this claim, Section 4.1 shows how an application protocol adaptation can utilise context information about the QoS offered when transporting patient data with use of the 3G network. Section 4.2 shows how location-specific information about QoS offered by different networks can further improve application protocol adaptation and in a consequence improve the delivered QoS.

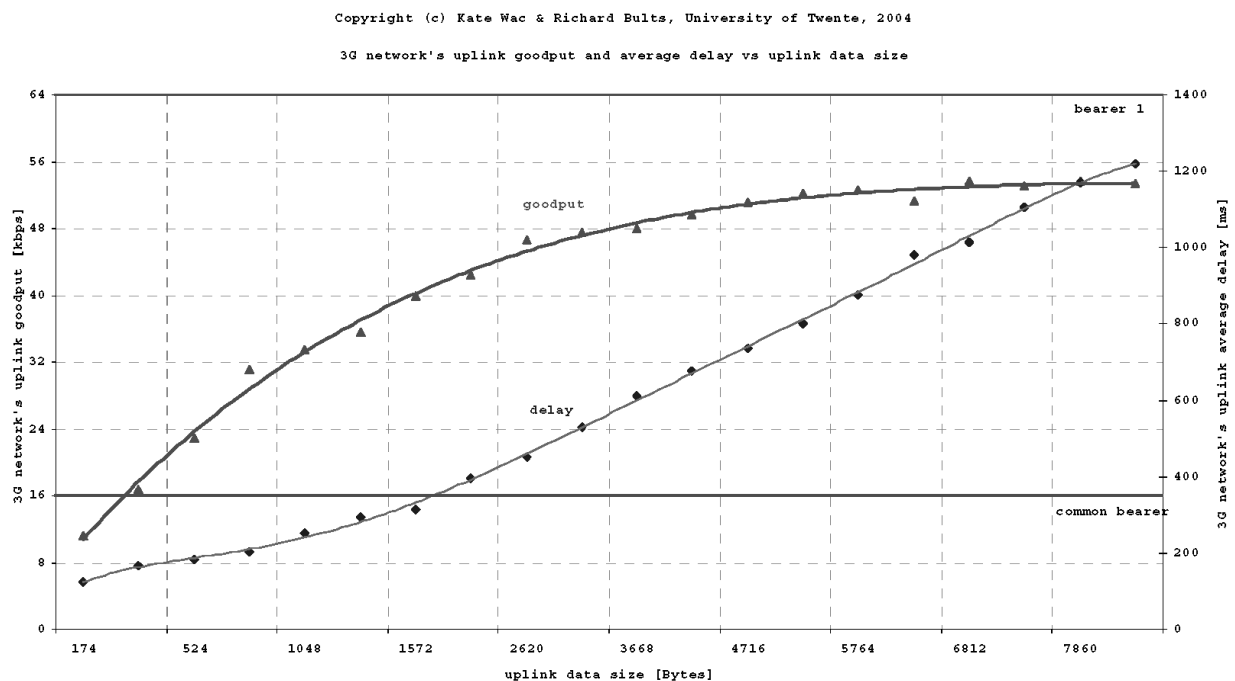
4.1 Application protocol adaptation

To meet the required end-user QoS, the m-health service platform needs to be able to acquire and utilise context information related to the QoS that is

offered by communication network infrastructures (e.g., WLAN/2.5G/3G) available at the patient's current location and time. Using context information may result in adaptation of m-health services delivery to the offered QoS by the currently used communication network infrastructure.

To illustrate this idea, we use our knowledge about QoS offered by 3G communication network infrastructures. This knowledge comprises results of the performance evaluation of 3G communication networks (Wac and Bults 2004; Wac et al., 2005; Bults et al., 2005). Figure 3 shows the goodput³ and delay characteristics of a 3G network as a function of the application protocol's packet size sent in the uplink direction (i.e., from a mobile patient's BAN to a Back-End system in the healthcare centre). As expected, larger packet sizes result in higher goodput, but they also yield higher packet-transmission delays.

Figure 3 Performance characteristics of 3G communication network



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

If we incorporate context information in the application protocol, the packet size could be adapted according to the context-dependent service end-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 the low delay QoS requirement.

4.2 Location-based QoS adaptation

As presented in the previous section, one possible way of using context information is adaptation of service delivery to the offered QoS of the currently used communication network infrastructure. In this section, we present another possible way of context information usage. This comprises conducting a seamless handover to the communication network that offers better QoS (i.e., closer matching the end-user required QoS) than the network that is currently used.

Because the service user is mobile, the underlying communication networks, and the QoS offered by these networks, can 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 can fluctuate over time because, for example, of a changing number of mobile users at a given location in combination with their changing demands. Therefore, we denote this information as location-based offered QoS. The location-based offered QoS should be incorporated as run-time context information into the QoS-aware m-health service platform. This will guarantee that the platform recognises a context change resulting in a change of the delivered end-user QoS. Our idea is that the platform would always select a communication network infrastructure that offers the QoS best-matching the end-user required QoS. To meet the required end-user QoS, the m-health service platform may initiate a seamless handover to the communication network offering a better QoS than the one currently used.

In a context-unaware situation, an application protocol designer maps end-user QoS requirements to QoS offered by some default communication network. Therefore, the choice for a communication network is a design-time choice.

If we incorporate location-based offered QoS as context information in the m-health service platform, the selection of a communication network could be adapted according to the context-dependent service end-user's QoS requirements. For Sophie's case, it would mean that a low-bandwidth network (e.g., 2.5G) is selected in a non-critical situation. However, in an emergency situation (i.e., a seizure is predicted) a handover to a high-bandwidth low-delay network (e.g., 3G) that meets the low-delay QoS requirement, should be initiated.

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

5 Incorporating context

In this paper, we argue that using context information in a QoS-aware m-health service 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, more background research is needed on QoS-aware m-health service platforms and on context-awareness, before we may merge these ideas. Consequently, the following objectives structure the trajectory of our research.

Firstly, we need to define a suitable QoS-aware services platform to be used as the AWARENESS context aware

mobile service platform. The QoS-aware (m-health) services platform needs to support end-user QoS specification, 'cross-layer' QoS mapping and adaptation of service delivery to context and offered QoS information. We start our research in this direction based on existing QoS-aware services platforms for mobile service platforms. The outcome of this step is a QoS-aware mobile service platform, used and validated within the AWARENESS project.

Our following research step constitutes incorporation of context information into this QoS-aware mobile service platform. It will be important to decide what context information is relevant and how to acquire it and then incorporate into the platform. Due to unreliability of context information sources (Dey, 2000; Dockhorn Costa, 2004), the mobile service platform should hold assumptions on a default context when context information is not available.

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

We consider the location-based offered QoS as context information that the QoS-aware mobile service platform is able to acquire and utilise. The question is how to get this context information in a reliable, real-time manner, such that the services platform may fully support the mobility of a service user. Crucial in answering this question is the availability of a methodology for the end-to-end performance evaluation of hybrid communication network infrastructures (i.e., consisting of wireless and wired communication networks) (Wac and Bults, 2004). We already applied this methodology to evaluate the performance of 3G communication networks (Wac and Bults, 2004; Wac et al., 2005; Bults et al., 2005) and we used selected evaluation results to illustrate the example of application protocol adaptation as presented in Section 4.1.

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 context information regarding real-time location-based offered QoS by underlying communication network infrastructures.

The current implementation of the application protocol supporting the tele-monitoring service in the MobiHealth system was originally adapted to the QoS offered by 2.5G communication network infrastructures ('default' network) (Dokovsky et al., 2003). We already researched on how this protocol may be optimised to the QoS offered by 3G communication network infrastructures (Wac and Bults 2004). Moreover, currently we are working on the application framework for context-aware applications

(Broens et al., 2005). This work includes application protocol adaptation.

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

6 Conclusion

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

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Notes

¹m-health services are a sub class of the e-health service class, which deploy wireless mobile telecommunication technology to realise mobile-based health (care) services.

²According 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 (Dockhorn Costa, 2004).

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