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BAN-BASED M-HEALTH SERVICES: EXPERIENCES AND PROSPECTS
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ABSTRACT
The University of Twente and partners are developing and prototyping Body Area networks (BANs) for healthcare. We define a BAN as a network of devices worn on or around the body which communicate amongst themselves and perform a set of services for the user. Our work began with the European MobiHealth project whose objective was to investigate the potential of 2.5 and 3G wireless communication technologies to support useful services and applications. In this article we discuss the main aims and results of the MobiHealth project. On the basis of these results we further discuss a particular methodology which we believe gives leverage on the problem of managing the complex of objectives and expectations of the different parties involved in the process of design, development and implementation of ICT systems for healthcare. This methodology aims at articulation and translation of the visions and expectations of both designers and prospective users in future development scenarios. These scenarios may be used to specify potential uses of health BAN technology in particular contexts, to anticipate and evaluate possible outcomes and effects, and to feed back insights obtained from this anticipatory technology assessment into the ongoing process of design, development and deployment.

Keywords: wireless, communication, technologies, healthcare, scenarios

1. AIMS OF THE MOBIHEALTH PROJECT

The concept behind the MobiHealth project [1-9] was to bring together the technologies of Body Area Networks (BANs), wireless broadband communications and wearable devices to provide mobile healthcare services for patients and health professionals. The MobiHealth concept arose out of earlier work conducted at the University of Twente and within the Wireless World Research Forum (WWRF) on mobile applications for
healthcare [10-15]. The MobiHealth consortium involving 14 European partners was brought together during 2001. The project began on May 1st 2002 and was funded by the European Commission under IST.

For patients, the combination MobiHealth technology enables remote patient care services such as telemonitoring and teletreatment. These ICT enabled services can form part of the care package for many conditions and can be used both in management of chronic conditions and in detection of health emergencies. For health professionals the MobiHealth technology offers access to information and communication services from a mobile device, thus enabling mobility for the individual professional and supporting the operation of distributed ‘virtual’ healthcare teams.

The overall goal of MobiHealth was to evaluate the ability of 2.5 and 3G communication technologies to support innovative mobile health services. The main output of the project therefore was an assessment of the suitability of GPRS and UMTS to support such services. During the MobiHealth project a generic BAN for healthcare and a generic m-health service platform were developed, trialled and evaluated. The MobiHealth BAN consists of a body-worn network of devices where the nodes of the BAN include a PDA and a set of devices such as medical sensors, positioning devices, activity sensors and multimedia devices. The set of devices used varies with the clinical application. The PDA acts as the gateway for external communication and as a computation platform for local processing. Biosignals measured by sensors connected to the BAN were transmitted to a remote healthcare location over 2.5/3G public wireless networks, using commercial GPRS and UMTS services.

The MobiHealth BAN and service platform were trialled in Spain, The Netherlands, Sweden and Germany from May 2003 onwards. The trials in Germany involved monitoring of patients with cardiac arrhythmias. In Sweden other variants of the BAN were used for telemonitoring of patients in residential care, for patients with rheumatoid arthritis and patients with respiratory insufficiency. In another trial Bans were used for monitoring patients recently discharged from hospital into a remote rural environment. In the Spanish trials the BANs were used in home-based care for elderly chronically ill patients suffering from co-morbidities including COPD, and to monitor patients with COPD during remotely supervised outdoors training programmes.

In this paper we focus on the gynaecology application which was represented in one of the two Dutch trials (the other Dutch trial involved trauma care administered by ambulance paramedics). Figure 1 shows a gynaecologist fitting a pregnancy monitoring BAN to a patient. On the left of the picture the elements of one BAN configuration are shown, consisting of a PDA, a sensor front end (the blue box) and a set of devices (here electrodes for measuring ECG and an activity sensor.) The purpose of the Pregnancy BAN is to replace hospital monitoring of at risk pregnancies with home monitoring. For the MobiHealth trials only healthy (not at risk) patients participated. The Pregnancy BAN includes a 5-lead ECG (positioned as shown in Figure 1) and an alarm button. Maternal and foetal signals are monitored with the objective of detecting conditions of concern including premature labour and foetal distress.
2. DISCUSSION OF THE MAIN RESULTS OF THE PROJECT

Twelve pregnant women were monitored between August 2003 and February 2004. The patients could move freely at home or outside the home whilst the BAN was transmitting data. Two members of staff of the Gynaecology Department at Medisch Spectrum Twente in Enschede, the Netherlands, were involved. Tests were conducted transmitting over GPRS (3 patients) and UMTS (9 patients). Blood pressure was measured manually and blood pressure and type of activity were input to the BAN by the patient. These data were transmitted along with the ECG output. The equipment at the hospital was capable of displaying patient’s BAN data in real time or offline. However due to strict hospital security policies the staff in the Gynaecology Department did not observe the patients’ data in real-time.

The technical evaluation showed that UMTS proved more stable than GPRS, however with more limited geographical coverage due to the limited coverage of the UMTS service at the time of the trial. The limiting factor on patient mobility was battery power of mobile devices. The received biosignal data was valid [16].

Results of the user evaluation showed the main findings as follows (over all trials) [17].

- The need for, and advantages of, the system were clear to all users
- All users agreed that a stable commercial MobiHealth system would be very useful
- The system needs further improvements and validation to fully meet market requirements, as well as users’ wants and needs in order to be accepted
- The MobiHealth system meets a huge market potential and is able to demonstrate and set up convincing business cases for all players involved
• Demand for m-health services was demonstrated by requests from hospitals and health care funds all over the world to participate on the further development and validation of the MobiHealth system.

However there were a number of criticisms of the details of the implementation. Here we focus on the feedback from the gynaecology trial. The staff involved in this trial gave positive feedback regarding the effectiveness of the BAN in general. In relation to the viewer application, they considered that it provided relevant information but that it did not make work more effective. As well as not completely meeting the user requirements the viewer application also needed improvements in user interface and especially in improving ease of use [17].

3. **Conclusion reflecting on perspectives of different stakeholders**

The participants in all the trials recognized the usefulness of the technology; the pregnancy trial participants were particularly enthusiastic users and keen to continue the work. But the difference in expectations between the clinical users and the technology developers was sometimes evident in some of the trials. Users involved in clinical applications are naturally eager to have specific applications ready for use in patient care, and are sometimes impatient with a prototype which falls short of the high standards of user interface and ease of use, for example, which would be expected in a fully fledged commercial product, whilst at the same time recognising the utility of the functionality being prototyped.

MobiHealth was funded under the call entitled “2.5-3G Mobile Applications and Services (IST 7bis)”, and therefore the specific aims of the project were concerned with evaluation of the technological potential of telecommunications infrastructures and supporting services. The MobiHealth team demonstrated this potential by developing a BAN and BAN platform and by conducting trials involving the measurement and transmission of vital signs and other bio-signals. The principle outcome was the investigation of, and comparisons between, the technical characteristics of GPRS and UMTS affecting their ability to support m-health services. Development of mature BAN applications was never an objective.

The project should be regarded as an investigation of enabling technologies for m-health, and as a first step in the development trajectory leading towards possible future roll-out of m-health services. In other words the MobiHealth project was never expected to end the development, but to begin it. The development work continues, and problems and research issues raised by MobiHealth are pursued in a number of other projects and initiatives.

We said that development of mature BAN applications was never an objective of MobiHealth. It is however one of the objectives of the Freeband Awareness project [18]. In Awareness the MobiHealth BAN is developed further and the applications which use the transmitted data are targeted. Smart, context aware applications are developed which perform clinical interpretation of biosignals and combine context factors such as knowledge about the patient and their location with the biosignals data in order to make inferences and trigger intervention. An example is applying detection algorithms to
analyse combinations of ECG and activity sensor data transmitted from the BAN in order to detect and even predict epileptic seizures and to dispatch appropriate assistance.

In contrast the HealthServices24 [19] project addresses the organisational and business context of m-health and works with all the involved stakeholder groups to develop business models for mobile healthcare and to develop the MobiHealth technology into a commercial product suitable for large scale roll-out. Sustainable market deployment and commercial success depend on all aspects of the healthcare value chain being addressed. For successful deployment of m-health services the broader context into which the technology is launched must be taken into account. The context includes social and economic factors, business models, working practices, drivers, incentives and disincentives, stakeholders’ involvement and costs/benefits to involved groups. HealthServices24 includes development of the pregnancy monitoring application, thus continuing the successful collaboration with former MobiHealth partners.

In the work of the MOSAIC project [20] and of the AmI@Work Wellbeing Services community [21] a more futuristic vision of the evolution of the MobiHealth BAN and its embedding in future ambient intelligent environments (AmIEs) is envisioned. In the Major Incident Scenario the MobiHealth Trauma setting is extended to include not only one ambulance team but many ambulance teams, cooperating with the other emergency services in the context of a Major Incident such as a large scale accident, natural disaster or terrorist attack. Here we project into a future where police, firefighters and paramedics are equipped with Ami-BANs integrated into their uniforms. The AmI-BANs measure internal and external parameters and interconnect with other AmI-BANs and the AmIE using ad hoc networking in order to provide smart services to the wearer and to the community.

4. A SCENARIO APPROACH

As we noted in the foregoing, the MobiHealth project has aroused great interest among health professionals and prospective patient users, but as a project focussing on the investigation, development and integration of enabling technologies, it did not and could not fully address the hopes and perspectives of its various stakeholders. This observation is used in this paper as a starting point for a presentation of a particular scenario methodology, in which we consider the design, development and implementation of new technologies as a complex process of learning, which involves the many different aspects and actors involved. From this broader perspective, the work of technology developers not only involves the design of a particular technology, but also implies the design of a future ‘world’ in which technology will become part of a new socio-technical configuration, for example a new health care practice. Even in the early stages of design, developers of a new technology will have to deal with considerations and choices which may, sometimes irreversibly, affect key features of this future world [22]. However, in the early stages of development, the features of this new world will only be partly articulated in the activities, promises and expectations of designers, and learning will be focussed on specific – and mostly technological – aspects of this world. Trials which primarily evaluate the technological potential of a new system or device will thus offer only limited opportunities to involve other stakeholders in learning processes exploring its various applications. This raises the question of how to anticipate and make explicit...
the future worlds implicated in the development of new (enabling) technologies in such a way that, already in the early stages of design, learning could become more inclusive and reflexive, in terms of both aspects and actors involved.

In the literature Constructive Technology Assessment has been introduced as an approach which should facilitate more inclusive (societal) learning in the process of design by involving users and other impacted communities in activities which aim at articulation of desirable outcomes and potential impacts of technological development [23]. On the basis of this approach we are applying in this paper a particular methodology which may help us to articulate and translate the visions and expectations of both designers and prospective users of health BAN technology in socio-technical scenarios, and thus may help us to explore future worlds in which this technology is embedded in the professional practice of hospital pregnancy care. In this way we want to create more room and opportunities for a variety of stakeholders to learn about and reflect on various configurations, uses and implications of BAN technology. What we expect from this anticipatory technology assessment is a constructive and valuable contribution to the ongoing process of design, development and deployment of this new technology. In the following we present an outline of our scenario methodology and we discuss some preliminary results from the first steps that we have taken in exploring the future world of mobile health care in the context of hospital pregnancy care.

5. **LOOKING FOR A ‘SCRIPT’**

Although a world in which MobiHealth has become part of everyday hospital pregnancy care does not (yet) exist, we do have promises and expectations and also descriptions of working prototypes to tell us what this future world might look like. Promises and expectations we find for example in the documents which describe the aims and programme of the MobiHealth project, referring to new remote care services for patients and new forms of access to information for health professionals. Likewise, we may get an impression of what the future MobiHealth system will be like from the configuration of the prototype and the first experiences in trials involving health professionals and patients in pregnancy care. As we have seen in section 2 above, patients are considered to move freely at home or outside the home whilst a BAN is transmitting data. In addition the patient is supposed to feed data into the system about blood pressure and types of activity. For security reasons BAN data are only made available to medical staff in the Gynaecology Department by storing and displaying these data offline.

Promises, expectations, prototypes and experiences we may see as elements containing a ‘script’ in which various activities, roles and responsibilities are ascribed or ‘delegated’ to both human actors and technical devices which together constitute a socio-technical network. As a first step in the construction of scenarios we may draw out this script [24, 25]. That is, we may further articulate the expected configuration of a future socio-technical network in hospital pregnancy care and make clear what actions and competencies are expected from users for the technology to function, and what is expected of the technology to make things work in practice. In this way, a script analysis can show how roles, competencies and responsibilities may be redistributed as a result of new developments towards a BAN-based socio-technical network.
For example, in current pregnancy care women with a high risk pregnancy will be hospitalized in order to be regularly monitored and measured biosignals will be examined by staff from the Gynaecology Department. Recently a pilot has been started in Twente whereby patients may be monitored at home by a nurse who visits every day and who, in this role also has to take responsibility for the examination of the measurements taken [26]. The introduction of continuous BAN-based pregnancy monitoring at home will bring about further shifts in the distribution of tasks and responsibilities. In this case part of the assessment of the signals is delegated to software, that is, to an application which is designed to generate an alarm, should the measurement patterns indicate a problem. Of course, in case of an alarm, some (human) agent should have the responsibility to act on it, perhaps by calling the patient to ask what is happening, or by sending an ambulance right away. Moreover, a MobiHealth system also requires a new set of ICT services such as those needed to keeping the BAN server online and functioning, so that clinicians in the hospital have access to the vital signs of the mother and child whenever they need it.

What we are attempting here is to articulate a script that is implied in the promises and expectations of those who are developing BAN-based systems and that to some extent has already materialized in the configuration of a MobiHealth pregnancy monitoring system. What we are also doing is to formalize the de facto scenarios proposed by the developers of the technology [24]. The results obtained from this analysis may serve as input in a creative process in which we further explore and construct scenarios by adding perspectives from other stakeholders and more contextual information.

6. CONSTRUCTION OF SCENARIOS

On the basis of the information obtained from our script analysis we will proceed to construct different scenarios of future developments. The following steps are to be taken in the construction of scenarios:

- Identify elements for which ‘there is no alternative’ (TINA)
- Identify uncertainties and possibilities for choice
- Translate the information into scenarios
- Evaluate the scenarios

6.1 IDENTIFY TINAS

As a first step, we can identify from the de facto scenarios that we have articulated in our script analysis characteristic elements that will be shared by any future MobiHealth development scenario we may think of. For these elements ‘there is no alternative’ because they are considered fundamental for the purposes of the mobile health care service. This “TINA” concept covers the idea of “core requirements” from the user and technical perspectives; it also covers essential elements in the treatment protocol, for example. Such elements have indeed been formulated by the project developers as requirements that should be satisfied in trials of potential applications of BAN technology. We have listed the following TINAs.

- GPRS/UMTS: One of the project requirements, as we have noted, was to use wireless services, preferably UMTS.
• Extramural application: Patients being at home and still being monitored, is an often repeated promise in many of the MobiHealth documents.

• Mobility: Patients should be able to move around freely with the MobiHealth BAN.

• Continuous monitoring: Patients should be monitored 24/7 (if needed) instead of only for short time intervals, independently of availability of health professionals.

With regard to the promises and expectations of the MobiHealth pregnancy BAN in particular, the TINAs mentioned above apply, and specific pregnancy BAN related TINAs may be added to the list. For example:

• Measurement of foetal activity is normally conducted using ultrasound. The MobiHealth pregnancy BAN however has to use a sensor set that measures electric signals to allow for continuous monitoring.

6.2 IDENTITY UNCERTAINTIES AND POSSIBILITIES FOR CHOICE

The TINAs we have identified do not of course completely determine the socio-technical configuration of a future world of MobiHealth. There are also various uncertainties and choices to be made, both with regard to the technological potential of the system and with regard to the needs, wishes and abilities of its potential users. Interviews with stakeholders who are not involved in the design process but who will be affected by a future MobiHealth system may be used as an important source of information about uncertainties and possibilities for choice. On the basis of this information we can construct more diverse and rich scenarios of possible future developments.

Interviews we held with nurses at the Gynaecology Department revealed for example uncertainty about the target users of a pregnancy BAN. In these interviews doubts were raised about the idea of women with (high) risk pregnancies not being seen any more by nurses every day. Certain conditions will not appear in routine measurements, but will be spotted by clinical personnel when seeing the patient (eg. kidney problems). When asked about the possible use of a MobiHealth system, respondents wondered whether this group of patients should be considered for wearing a pregnancy BAN.

Moreover, women with high risk pregnancies who participate in the home monitoring pilot mentioned in section 5 above must stay at home and rest and are allowed only limited activities, such as taking a shower or making themselves a sandwich. In such cases, the mobility advantage of wearing a BAN will not be much utilised. As a consequence, only very low risk pregnancies might be considered for BAN monitoring and those women would be sent home anyway under conventional treatment. In this case, the actual target group meeting the MobiHealth eligibility criteria might be very small. In one of the interviews a nurse considered the MobiHealth system not as a replacement, but as a good addition to home monitoring, when a nurse attends the patient at home. In her view, nurses could visit patients three or four days a week while the patient might be continuously monitored at a distance in between.

Obviously, there is also the possibility of alternative technological configurations of the system in response to the preferences and experiences of users. For example, patients who participated in the gynaecology trial have made complaints about the number of
different devices in the prototype BAN: sensors worn on the body, the blue box that can be attached to the belt, the PDA, and a mobile phone to make the wireless connection to the server. Sometimes people forgot to take all the devices with them. Furthermore batteries had to be charged regularly for each mobile device. Of course future technological developments will involve miniaturisation and integration of separate devices into one unit.

6.3 TRANSLATE THE INFORMATION INTO SCENARIOS

The identification of TINAs, in combination with knowledge of the perspectives and experiences of different stakeholders and contextual information about current practices in hospital pregnancy care, are needed to help us to construct more articulate scenarios of future developments in mobile health. In table 1 below we have included a brief sketch of two scenarios just to show how some of the information we have referred to above may be translated into different scenarios.

<table>
<thead>
<tr>
<th>Scenario A</th>
<th>Scenario B</th>
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<tbody>
<tr>
<td>A pregnant woman with symptoms calls the receptionist of the Gynaecology Department to make an appointment. The patient meets the gynaecologist (or assistant gynaecologist) who examines her and concludes she has a high risk pregnancy. Normally she would have to stay in the hospital for monitoring, but that is not necessary anymore. He tells her a pregnancy BAN will be assigned to her, and she can stay home and be monitored from a distance. The gynaecologist explains how the BAN works and shows the patient and the relative accompanying her how to put on the sensors. On the screen of his computer he shows her that the measurements have started already. At home she wears the system day in day out. Once a week she has to come back to the hospital to have the lab take some blood for tests. The hospital also gave her a blood pressure monitor; she measures her BP every day and enters the results manually into the system. One time there is an alarm and she gets a call from a nurse to check whether she is OK, or if an ambulance is needed. She feels OK, but takes an extra blood pressure measurement just in case. In the hospital the assistant gynaecologist has taken a look at the readings and concluded that probably the mother made some movements which disrupted the signal.</td>
<td>A pregnant woman with symptoms calls the receptionist of the Gynaecology Department to make an appointment. The patient meets the gynaecologist (or assistant gynaecologist) who examines her and concludes she has a high risk pregnancy. He tells her she has the choice of remaining in the hospital, or to have a pregnancy BAN assigned to her which will allow her to stay at home and to be monitored from a distance. Once every three days she will be visited by a nurse. During every visit the nurse will measure her blood pressure, and once a week one of the nurses will take some blood for examination. If the patient chooses to wear the BAN instead of staying in the hospital, she can make an appointment with the nurses of the Gynaecology Department who will explain how the system works. They will also show her how to put on the sensors, although she probably won’t have to put them on herself, for if needed the visiting nurse will replace them. In the hospital the assistant gynaecologists uses some spare time between appointments to check the measurements that are being displayed at that moment. On a list with names of patients he puts his signature beside the names of the patients whose measurements he has checked and approved.</td>
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Table 1. Two different scenarios of MobiHealth in pregnancy care

The scenarios in table 1 present of course only two examples of the many (and more complex) stories to be told. In full versions of these scenarios more elements will be taken into account, including for example the technologies that constitute the working MobiHealth system (eg. sensors, UMTS, Bluetooth, Internet), the situation of the patient at home, and the role of insurance companies paying for MobiHealth services (or not).
6.4 Evaluate the Scenarios

As soon as we have more fully articulated scenarios available we may return to the various actors involved in order to discuss and evaluate these scenarios. The evaluation may be carried out on the basis of interviews or workshops, including representatives of all the different actors who have been assigned a particular role in the scenarios and thus will be affected by the introduction of the MobiHealth pregnancy BAN. This activity is expected to have two kinds of outcomes:

- The actors may give their opinions about the credibility of the scenarios, the likelihood of them occurring. This will be a test to see if we adequately developed scenarios, missed some elements, or misinterpreted them.
- The actors may judge whether they see the situation described in the scenarios as a desirable outcome, and also indicate their preferences in regard to different scenarios.

In addition to this interactive evaluation including various actor perspectives, we would like to evaluate our scenarios from a more general normative point of view, thus addressing the broader debate going on in the Netherlands about the ethical implications of emerging home care technologies [27-29].

7. Conclusion

As we have discussed in the foregoing, the European MobiHealth project can be viewed from a technology point of view as an investigation of enabling technologies for m-health, and as a first step in a possible development trajectory leading towards roll-out of m-health services. However, given the complex of perspectives which is typical of multidisciplinary collaboration in health care technology development, we regard the explicit addressing of the perspectives of all different stakeholders as a prerequisite for successful implementation. In this context we have discussed a scenario methodology which may used as a tool in stimulating anticipatory learning and reflection about prospective MobiHealth development trajectories. We see this methodology as a form of controlled speculation. It is controlled speculation because we start from an analysis of emerging technological options and expectations about these options among different stakeholders. It is controlled speculation because the developments we envision on the basis of this analysis are open-ended and will stimulate us to identify a variety of possible futures and implications. By raising in this way particular important issues and choices we hope to contribute to the ongoing process of design, development and deployment of MobiHealth technology in the context of current projects like the Freeband Awareness project and the HealthServices24 project.

Here we have begun to investigate how to fuse approaches from the domains of computer science and social science. In future work we will investigate how Constructive Technology Assessment can enrich design approaches such as UML and MDA and how the approach described here can help in assessing the societal impact of health technology innovation and aid in the business process re-engineering of European healthcare processes and health care delivery to take best advantage of ICT innovation.
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