A Flexible Vital Sign Representation Framework for Mobile Healthcare

Hailiang Mei, Ing Widya, Aart van Halteren, Bayu Erfianto

Abstract—This paper proposes a framework for patient's vital sign representations. This framework offers the flexibility to extend or to augment represented vital signs, e.g. with trend signs or professional's annotations. It further enables multi standard representations of vital signs and meta-level information for processing of represented vital signs. Vital signs represented in accordance with this framework are therefore suitable for forwarding, processing and rendering within a heterogeneous mobile environment which applies different formatting standards or use a diversity of wireless communication technologies of different quality.

We analyze the needs of three mobile healthcare stakeholders to capture the requirements of vital sign representations and manipulations that have to be accommodated by the framework. The derived stakeholders' requirements are closely examined during the XML-based development of the framework. Several scenarios are presented to illustrate the benefits of the framework.

Index Terms—Vital sign, representation, flexibility, M-health

I. INTRODUCTION

Mobile healthcare (M-health) applications have been receiving more and more attentions due to its ability to reshape healthcare delivery satisfying today's society demands, like patient self-management, continuous and anywhere tele-monitoring and tele-treatment [1]. Several distributed vital sign monitoring applications have been developed for mobile network environments [2-5].

One issue which affects the usability of these M-health applications is the resource capacity fluctuations within the mobile environment [5, 6]. For example, in an epilepsy detection M-health application [7], ECG data indicating a possible seizure may arrive late at the remote doctor's location due to bandwidth limitation of the access network. The remaining time to seizure therefore can be insufficient

for this doctor to validate the forecasted seizure and to guide the patient to react appropriately. In such cases, it might be necessary to distinguish between the more important vital signs from the less important ones during transmission. Augmenting meta-data to vital sign representations (e.g. priority indicators or other kinds of information about the represented vital signs) allows automatic processing to better cope with capability changes of the infrastructural resources, for example deferring or dropping signs considered less important for the concerned medical activity.

Another issue raised by mobility is that healthcare applications more often operate in a heterogeneous environment which applies different vital sign standardized formats [6]. For example, when a patient is traveling abroad, the new care center responsible for the tele-monitoring may employ a different standard of vial sign format. The vital sign representation is ought to deal with such heterogeneity and support cross-platform technologies.

The aforementioned problems illustrate the needs for representing vital signs in a flexible manner. A challenge in M-health is therefore how to facilitate such kinds of flexibility.

This paper proposes a framework for vital sign representations to tackle the problems. This framework is a structuring and coordinating architecture which gives guidance on constructing vital sign representations. It can cope flexibly with the constraints and requirement raised by different M-health stakeholders. Although examples of how to format vital signs is presented in this paper, it is not our intention to propose a new vital sign format for medical IT systems since there are already so many standardizing activities on this issue. These examples merely illustrate how the framework facilitates the incorporation of proprietary or standardized vital sign formats.

Our work originates on one hand from the needs identified in our M-health projects [5, 8] and is on the other hand inspired by the MIME [9] standard. MIME specifies the way to represent and to encode multimedia information in email services for use across different platforms. With the help of MIME types and subtypes, information of known and unknown format can be specified and (partially) processed by MIME compliant mail agents. For example, "multipart/alternative" denotes that the enclosed parts are alternatives encoded using different formats but representing the same information; the recipient mail agent selects the alternative one preferred by the user, e.g. as stored in the

user's profile. "Multipart/parallel" indicates that the enclosed parts should be processed concurrently and the "-x"-type is a placeholder for non-standardized formats which require experimental or proprietary encoders and decoders to compose and to visualize received mails. Due to its flexibility, MIME is often adopted as a presentation layer data formatting standard for non-email services as well. For example, in HL7 standard [10] , the CDA documents [11] are embedded in MIME packages for exchange.

This paper is organized as follows: in Section 2, relevant M-health stakeholders are identified and their requirements on the vital sign representations are captured; in Section 3, the design of the framework is illustrated and analogies with the MIME approach are highlighted; in Section 4, examples of the generated data document based on the scenarios and their applications are explained; the conclusion is given in Section 5.

II. STAKEHOLDERS AND THEIR REQUIREMENTS ON VITAL SIGN REPRESENTATION IN M-HEALTH

In this section, the stakeholders of vital sign representations in M-health are identified first and then the requirements are derived from each stakeholder's viewpoint. In a summary, the obtained main requirements are expressiveness, manipulativeness, openness, extensibility and privacy-friendly.

A. M-health Stakeholders

A stakeholder can be defined as "any person or organization that has an opinion, a responsibility for, or who may be influenced or affected by the proposed system" [12]. Based on this definition, we may distinguish three M-health stakeholders whose requirements on the use of vital signs or the constraints on vital signs provisioning typically influence the vital sign representations. The identified stakeholders are: 1) End-users that includes both patients and the healthcare professionals, such as the medical specialists, nurses, physiotherapists, etc.; 2) M-health system providers, in a general perspective, who are involved in the design life-cycle of M-health infrastructures, applications and vital sign representations, i.e. the formats and encoding rules. These providers are assumed to be aware of the applied information and communication technology; 3) Care centers, such as the primary care centers (centers of several physicians), healthcare call centers (also called healthcare portals), and the secondary care center's (e.g. corporate hospitals with their departments of a diversity of specialties).

B. Requirements from end users

From the healthcare professional's point of view, the vital sign representation should support adequate expressiveness such that the healthcare professionals can access and medically interpret segments of the patient's vital sign data in accordance with their way of working: 1) Healthcare professionals like to access units of interpretable segments of vital signs in a quality appropriate for the task purpose, e.g.

patient's ECG plots in high resolution necessary to inspect ventricular contraction; 2) Healthcare professionals may want to access a group of coherent (i.e. inter-related) vital signs, e.g. patient's oxygen saturation, heart beat, blood pressure, and respiration that together form an indicator of the oxygenation of the patient's brain in trauma care; 3) Healthcare professionals may have priorities regarding the importance of vital signs, e.g. doctors may prefer to see trend signs and only in case of abnormalities, they need the underlying vital signs; 4) Healthcare professionals may need to know how vital sign data was measured and processed.
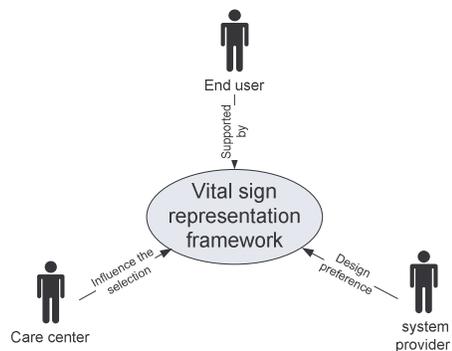

Figure 1: Stakeholders of vital sign representation framework

On the other hand, medical and sensor technologies are evolving and new vital signs or sensors may be developed for measuring patient's health condition in mobile environments. Therefore, vital sign representations should be extensible to enable the introduction of new vital signs or the integration with new data like professional annotations.

In some M-health applications, patients generate vital sign by attaching sensors on their body and initializing the vital sign acquisition devices. These patients, especially mobile patients, may need to check and calibrate the sensors' readings regularly. For example, patients may need to re-attach (surface) sensors in case of bad skin contacts. Patients therefore have their own demands for visualizing vital signs: they may require vital signs to be displayed in an easily understandable form.

Personal medical record (including vital sign data) is highly private information. Patients do care about how well their vital sign data are protected. The vital sign representation framework should enable the inclusion of this privacy need. If appropriate, it should support anonymous medical records and should enable the decoupling of securely stored patient's identity information from the vital sign records transferred or processed in the mobile networked environment.

C. Requirements from system providers

System providers know the infrastructural properties of M-health systems and care about how the vital sign representation can support the operations. As an example of

2

the processing and distribution flows of vital signs in M-health, we present the network configuration used in the healthcare related projects Awareness [8] and MobiHealth [13] in Figure 2. We analyze the system provider's requirements on the vital sign representations based on the network configuration shown in the figure.

Some connections in Figure 2 are wireless and are potential performance bottlenecks. For example, in the tele-treatment healthcare scenario, lack of bandwidth capacity at Link 2 (UMTS/GPRS connection) could slow down the transfer of vital sign data, thus also delay the doctor's feedback to the patient. Some adaptation strategy may be applied to control the vital sign data transmission, e.g. down-sampling, prioritizing or discarding some of the packets to improve the transfer utility of vital signs considered relevant to the medical task. Therefore, the framework should enable this kind of vital sign manipulations, namely prioritized transfer of important signs and deferred transmission of the remaining data. Consequently, the framework should further support aggregation and resynchronization to reconstruct the original set of vital signs. We illustrate this case of vital signs splitting and recombination in the following.
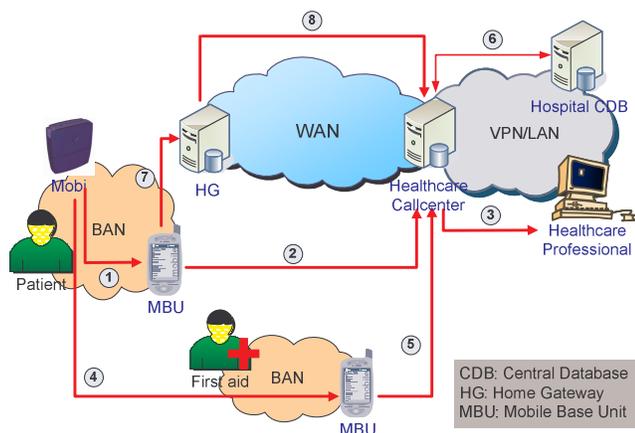

Figure 2: Vital signs transmission across multiple networks in MobiHealth system.

In normal cases, for example outdoor, the Mobi collects all the sensor data and forwards them to the MBU which acts as a gateway of the BAN (Body Area Network of sensors) to the Internet (cf. Link 2 in Figure 2). In an indoor scenario, however, the patient's BAN which exists inside the home network may alternatively use the MBU as a gateway to reach the HG (Home Gateway) via Link 7. Further relaying the vital signs to the call center via Link 8 instead of using Link 2 typically saves communication costs. The vital sign data may also be processed in a computing system co-located with the HG and non-critical vital sign data may even be temporally stored in a storage system co-located with the HG and pushed into the call center during cheaper service hours. Thus, manipulative vital sign representations are required to enable

data splitting, routing, aggregation and synchronization in an easy way.

D. Requirements from care centers

Care centers, especially the corporate hospitals, operate diversity of specialized systems, each of which typically applies specific vital sign formats. Thus, vital sign representations used in M-health that incorporate the requirements of this stakeholder has to be "open" to facilitate multiple formats of vital sign representations. The existing formats include CEN VITAL format [14], HL7 [10], FDA XML data format for representing waveform signals (e.g. ECG) [15], DICOM [16], etc.

III. SPECIFICATION OF THE FRAMEWORK

After the requirement analysis, appropriate design decisions can be made on the vital sign representation framework. In this paper, we use XML schema to define the vital sign representation framework and we specify several vital sign representations in XML in a way aligned with the framework.

A. Design notations

Instead of showing raw XML schema files, we use XML Schema Diagrams in this paper. The generation of these diagrams is supported by XMLSpy1, which is a commercial tool for editing XML documents and XML schema specifications. This tool also provides automatic generation of XML schema specification from the XML document, and vice versa (the skeleton XML file can be created.). The XML schema diagram can visualize the hierarchical structure of the schema document. One benefit of defining XML schema through XML schema diagram is that XML schema specifications can be conveniently and more accurately modified by means of a graphical interface instead of a text-based editor. The XML schema diagram notation used in this paper is summarized in Figure 3.
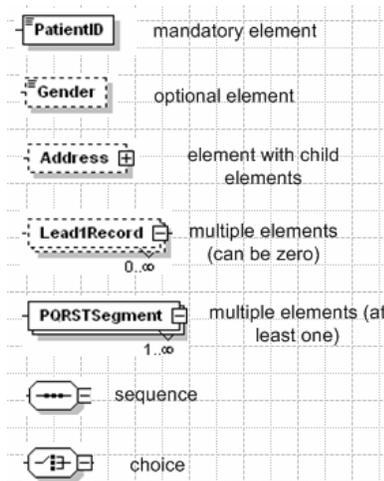

Figure 3: XMLSpy legends

3

B. Overview

Unlike the conventional record-centric approach to represent vital sign information (e.g. HL7, CEN), we take a patient-centric approach to design the framework. This is to make the framework be able to support diverse vital sign representations for a particular patient in the mobile environment.

The overview structure of the framework is shown in Figure 4. It consists of two parts: Patient Demographics Records (PDR) and Vital Sign Records (VSR). The PDR part is not in the focus of this paper, it is presented here only for illustrations. Among all the child-items of PDR, patient's ID is the only mandatory element in our context. This is to fulfill the privacy requirement of the end-user stakeholder because vital sign records can be specified anonymously. For a more complete study on demographic data, readers are referred to the PID (patient identification) segment defined in the HL7 standard [10].

The VSR part consists of vital sign records categorized in an extensible way, optionally in different formats, for example Awareness, FDA, CEN, HL7 and X-Unknown. The advantage of such a structure is that it can support M-health applications in an environment containing various equipments and programs from different vendors to satisfy the openness requirement. The five identified sections can be classified into three groups and are explained in more details in the coming sections:

- The Awareness section contains the vital sign format specification for Awareness M-health applications [8].
- The three sections (i.e. FDA, CEN, or HL7), each of which corresponds to a standardized format, are denoted as "foreign" XML records in our paper and are discussed as one category. These foreign records will be treated as a "black box", because we do not specify these formats although these format specifications can be accessed. In this way, we allow the use of existing vital sign processing tools complaint with these formats without the necessity to specify these formats.
- Inspired by MIME, X-Unknown section is introduced to support vital sign representation with unknown format. This section is similar to the foreign sections but it enables extensions with new (experimental and unregistered) formats during the deployment of the framework. Another difference is that the "X-" format specification is not easily accessible as the "foreign" format. Most of time, it has to be obtained from the format owner based mutual agreement.
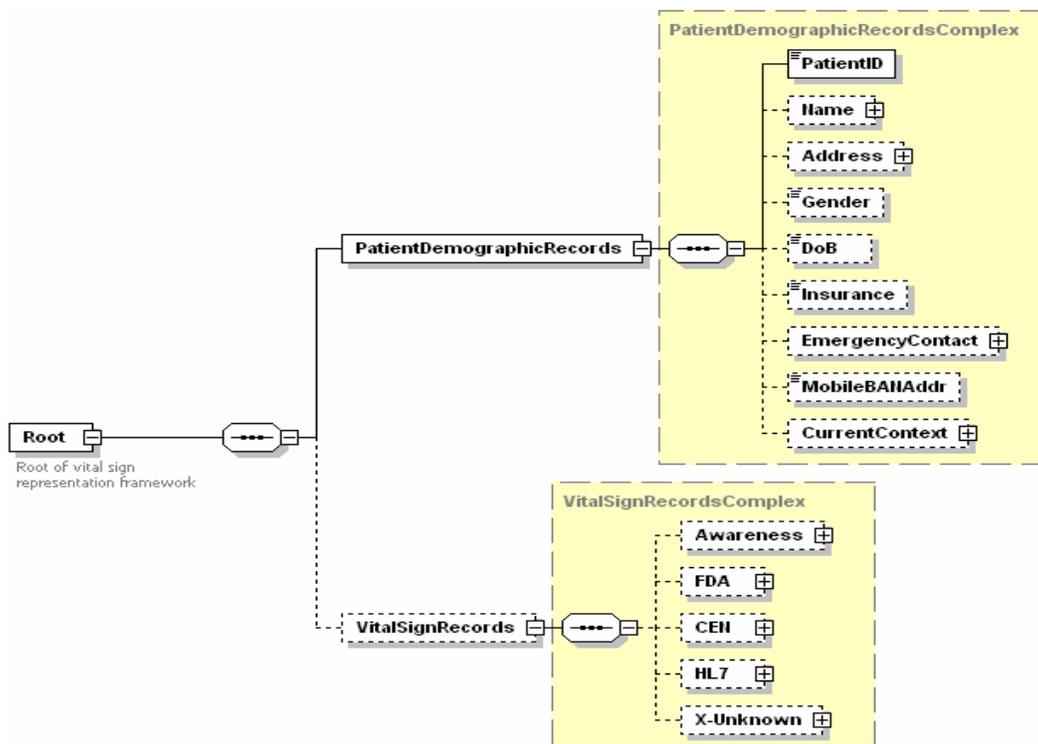
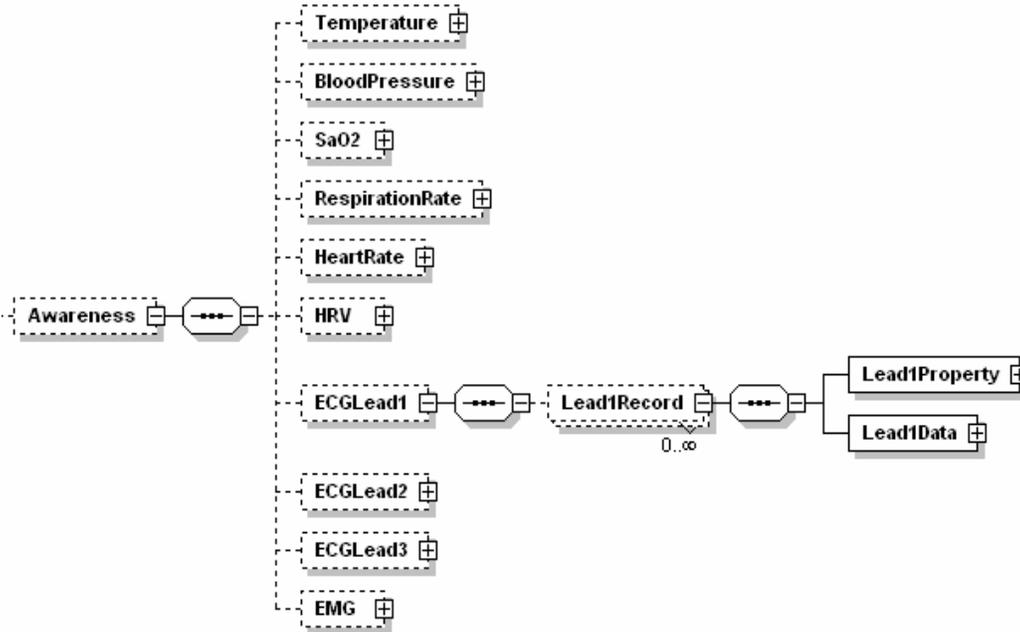

Figure 4: Overview of the framework

Figure 5: Awareness vital signs

C   Awareness record section

Awareness [8] is a Dutch project, which develops a context-aware service platform and applications, including M-health. The healthcare applications support tele-treatment of patients with chronic pain and tele-monitoring of epileptic seizures and uncontrolled movements in spasticity. These applications are context aware, e.g., in case of an epileptic seizure the system can use location and availability information to notify an available close-by caregiver.

Based on the medical scenarios defined in Awareness, a few vital sign types are supported (Figure 5). These types could be divided into the following categories:

- The still-media or numerical-tuple vital sign type: e.g. temperature, SaO2 and blood pressure.
- The continuous-media or continuous-time vital sign type: e.g. ECG, EMG, respiration.

If the Awareness project requires the extension of other vital signs, the "Awareness" XML complex type could be extended with new child elements.

As presented in Figure 5, each Awareness vital sign record has a data section and a property section, which is meta-data. The property section is specified as a complex type called VSRecordPropertyComplex as shown in Figure 6. It provides the necessary information for processing the vital sign data correctly and efficiently. In particular, the manipulativeness requirement introduces the property elements to support the following purposes:

- *Prioritizing*: Priority is a required property element to indicate the level of importance of this vital sign in the healthcare delivery process.
- *Splitting and aggregation*: Besides the support for splitting and aggregation of vital signs per type, the Awareness record can also support the splitting of

vital signs per quality by data down-sampling or per duration by data cutting. Record ID, measurement start time, sampling rate, resolution and duration (Figure 5) are defined to enable data segment identification which is necessary for the splitting and aggregation operations.

- *Synchronization*: the start time, sampling rate and duration elements can support the synchronization between the displays of several vital signs. It is because that based on these three elements, the synchronization points can be calculated and then be ticked to the vital sign data.
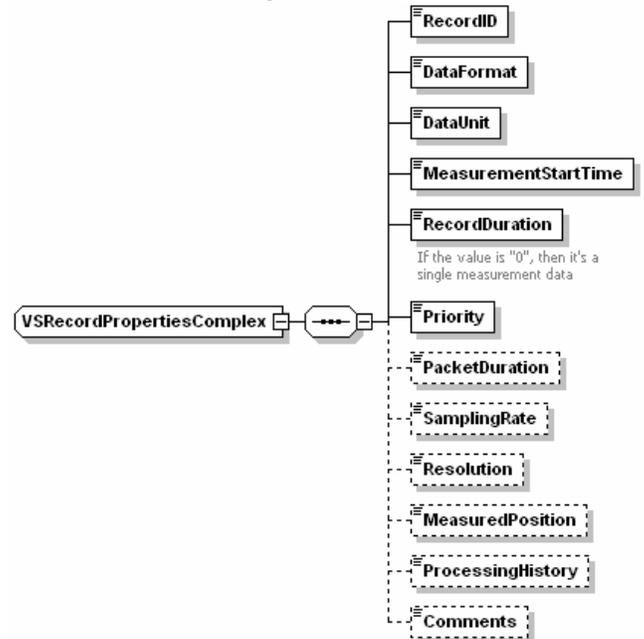

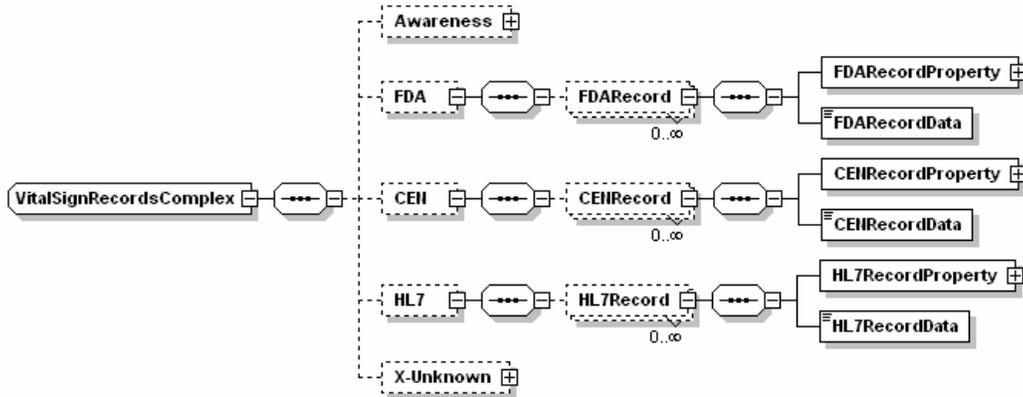Figure 6: Awareness vital sign record properties complex type

5

Figure 7: Three groups of "foreign" vital sign records in standard format

Some other selected elements, e.g. data format, packet duration, measured position and processing history are for supporting better expressiveness of the vital sign data.

D   Foreign record sections

Three popular standards for vital sign representations are enabled in the Awareness vital sign framework as "foreign sections:

- FDA standard denotes the vital signs in the format specified by the FDA in the United States.
- CEN standard specifies the vital sign format that should be adopted in Europe. IEEE teamed up with ISO to push the CEN standard [17].
- HL7 [10] standard defines and integrates the format of electronic healthcare information and it gains the most widely support internationally.

The structure of the foreign record sections is shown in Figure 7.

Similar to the Awareness vital sign record, each foreign record also consists of two sections: the property part and the data part. The decision we take during the design of the framework is to treat the foreign record as a "black box". For example, the CENRecordData element is the place to store the entire vital sign record in CEN format without any modification to it. However, in order to support the M-health application to maneuver the record appropriately, some "black box" features are placed in the property section for the foreign record (Figure 8):

- *Record ID*: the unique identifier of the foreign record in the scope of this system.
- *Obtained time*: it indicates the time when the application receives this piece of vital sign data. It gives certain information about how "fresh" this record is.
- *Priority*: this parameter tells the acknowledged importance of the corresponding "foreign" record. If nothing is known about the importance, a neutral value can be given to this field.
- *Record size*: The size of the record in number of bytes.
- *Processing history*: this property specifies the

processing history of the vital sign. It specifies the relation between the processed vital sign and another vital sign record which is referred in this property. The property may further specify the applied vital sign processing tool, the applied parameters and values of the tool, the professional responsible for the processing and the time and day of the processing.

Besides vital sign processing tools like filtering tools, format conversion tools may be specified, for example to relate vital sign records of different formats (e.g. ECG in the FDA format which is equivalent to the converted ECG in CEN format due to the FDA-CEN ECG format conversion tool as referred in the history property (Figure 9)). These ECG records of different formats may be processed independently or transferred via different network routes. Similar to e-mail structures with the MIME "multipart/alternative" construct, these vital sign records also may be transferred together to a recipient agent which then may choose which of them to render on the professional's terminal.
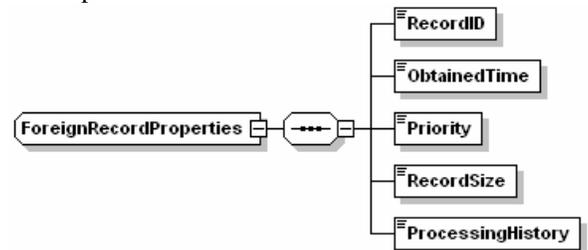

Figure 8: Foreign record prosperities complex type

The item of "processing history" also appears in the type of vital sign record properties (c.f. Figure 6). It is the place storing the relations between multiple vital sign documents or between multiple vital sign records within the same document. Such relations can be used by M-health application to detect the equivalence for multiple vital sign records as shown in Figure 9. This is a bit different than the MIME framework that shows such equivalence information using explicit types.
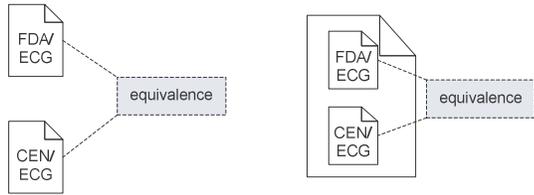
6

Figure 9: Equivalence within and between vital sign document

E   X-unknown

Inspired by the MIME [9] scheme, we introduce "X-unknown" section into the framework. This allows non-standard vital sign record being used, which must be given record names starting with "X-". The applications involved in the processing of certain "X-" records should be configured by mutual agreement prior to the start. The non-participated application to this agreement will just simply ignore or discard the "X-" record if it receives one.

The proposed framework merely offers the place holder for "X-" records. Therefore, similar to the foreign record, "X-" record is treated as a black-box as well by the framework (Figure 10). The property section of "X-" record is identical to the one of foreign record as shown in Figure 8. As discussed previously, the items in the property section can support certain maneuverability of the "X-" records, e.g. prioritizing and discarding.
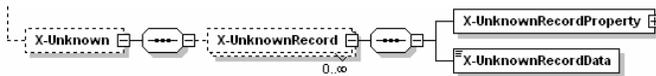

Figure 10: "X-" records supported by the vital sign representation framework

IV.   EXAMPLE OF SUPPORTED APPLICATIONS

Two applications are presented in order to explain the use of previously proposed vital sign representation framework.

A.   Vital sign stream degradation and handover

In this section, based on one context-aware scenario used in Awareness [8], we study the M-health application which can deal with vital sign degradation and handover. Our purpose is to show how the vital sign representation framework can support the required transfer documents. Due to the black-box nature of foreign records and "X-" records, the flexibility feature presented in this section is only available for Awareness vital sign records. However, once the inside information becomes available, the same kind of flexibility can be applied to the "black-box" records as well.

1)   Scenario

A patient is at home and his MBU is sending the measured ECG lead1 data continuously to the call centre in a high quality (e.g. 24bits/sample, 1024samples/second, packetized ECG with packet duration of 1s) via a home gateway. The measurement starts at 9:30 and supposed to continue for 30 minutes. At a certain moment (9:50), the patient is leaving his house (a context change) and GPRS becomes the only available network connection on his MBU. Thus the quality

of the lead1 data needs to be down-graded to a lower quality (e.g. 16bits/sample and 256samples/second, packetized ECG with packet duration of 1s) to fit the lower bandwidth.
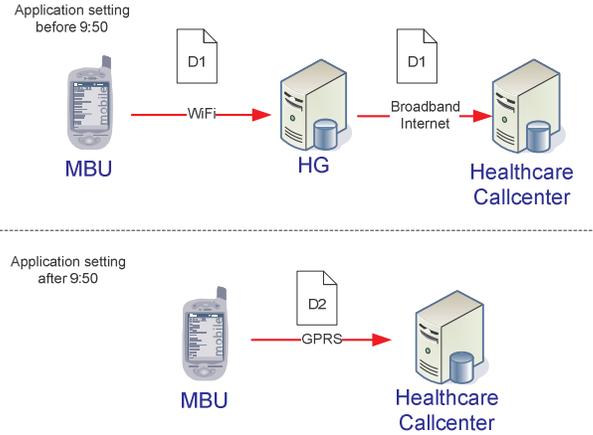

Figure 11: M-health application with degradation and handover support

2)   Application setting

As illustrated in the scenario, two settings are involved in this M-health application based on the identified vital sign streams shown in Figure 2:

- In the first setting, vital sign data (i.e. D1 in Figure 11) is relayed to the call center via a HG.
- After a handover, the application switches to the second setting where the vital sign data (i.e. D2) is transferred to the call center directly via GPRS link.

3)   Transfer documents conform to the framework

As shown in Figure 11, the transfer documents of the two settings are different and contain ECG data in different quality. Based on our proposed representation framework, these documents can be created. For example, the transfer document created right before the switch of application setting and the one right after are shown in Figure 12 and Figure 13 respectively.

```
...
<PatientDemographicRecords>
    <PatientID>1119443</PatientID>
</PatientDemographicRecords>
<VitalSignRecords>
    <Awareness>
        <ECGLead1>
            <Lead1Record>
                <Lead1Property>
                    <RecordID>100</RecordID>
                    <DataFormat>PacketizedECG</DataFormat>
                    <DataUnit>mV</DataUnit>
                    <MeasurementStartTime>
                        2005-10-17T09:30:00-01:00
                    </MeasurementStartTime>
                    <RecordDuration>PT30M</RecordDuration>
                    <Priority>20</Priority>
                    <PacketDuration>PT1S</PacketDuration>
                    <SamplingRate>1024</SamplingRate>
                    <Resolution>24</Resolution>
                </Lead1Property>
                <Lead1Data>
                    <PacketID>1200</PacketID>
```

```
                    <!-- 1200 = (50-30)*60 -->
                    <PacketPayload>
                            <!-- lead1 wave signal -->
                    </PacketPayload>
                </Lead1Data>
            </Lead1Record>
        </ECGLead1>
    </Awareness>
</VitalSignRecords>
```

Figure 12: The vital sign document containing high quality ECG (1024/24).

Since the transfer document right before the switching is created at 9:50, therefore the ECG packetID is (9:50-9:30)*60/1 = 1200. Where 9:50-9:30 = 20 (minutes) is the duration between the starting time of the whole monitoring and the starting time of this particular ECG packet; 60 is the ratio between 1 minute and 1 second; 1 second is the ECG packet duration.

The transfer document (Figure 13) created at 9:50:01 is the first document created after the switching, therefore it contains a new ECG record and packet ID restarts from 1.

```
…
<PatientDemographicRecords>
    <PatientID>1119443</PatientID>
</PatientDemographicRecords>
<VitalSignRecords>
    <Awareness>
        <ECGLead1>
            <Lead1Record>
                <Lead1Property>
                    <RecordID>101</RecordID>
                    <DataFormat>PacketizedECG</DataFormat>
                    <DataUnit>mV</DataUnit>
                    <MeasurementStartTime>
                       2005-10-17T09:50:00-01:00
                    </MeasurementStartTime>
                    <RecordDuration>PT10M</RecordDuration>
                    <Priority>20</Priority>
                    <PacketDuration>PT1S</PacketDuration>
                    <SamplingRate>256</SamplingRate>
                    <Resolution>16</Resolution>
                </Lead1Property>
                <Lead1Data>
                    <PacketID>1</PacketID>
                    <PacketPayload>
                            <!-- lead1 wave signal -->
                    </PacketPayload>
                </Lead1Data>
            </Lead1Record>
        </ECGLead1>
    </Awareness>
</VitalSignRecords>
```

Figure 13: The vital sign document containing lower quality ECG (256/16)

B. Vital sign data flow transformation

As argued in the beginning of this paper, one particular challenge faced by M-health application is the interoperability and standards issue.

1) Scenario

One cause of facing environmental heterogeneity is the mobility of patient. For example, in case an American patient travels to Europe, this heterogeneity problem may arise. In United States, the common vital sign format is FDA. Therefore, we could have the following valid assumptions:

- The medical sensors wearing by the patient can only produce vital sign data in FDA format and;
- Patient's MBU can create transfer document contains FDA formatted records.

While the patient is in United States, he could receive the tele-monitoring services from the local call center with the assistance of healthcare software. They can understand FDA formatted records perfectly. However, after the patient arrives in Europe, the tele-monitoring responsibility might be taken over by the counterparts in Europe. The European call center and healthcare software may only interpret the vital sign in CEN format. Therefore, in order to support seamless M-health applications to patients, some kind of translations is required. The proposed vital sign representation framework in this paper can provide a general guideline to solve this problem.

2) Application setting

The representation framework presented in Section III can facilitate several vital sign format standards. Based on this feature, we present a solution that can solve the transformation problem illustrated in the previous scenario. In this solution, we assume patient's MBU, HG (could also be the hotel gateway in this case) and the call center all support the framework. The MBU has the ability to interpret FDA formatted vital signs while the call center can only read the CEN formatted documents. A 3rd party FDA to CEN document converter can be loaded physically into the HG or even remotely invoked at its original site. HG can just feed the "black-box" FDA data from the received transfer document into the converter and put the result, again as a "black-box" record, in the place holder of CEN records of the outgoing transfer document. The element of "processing history" is set to denote the equivalence relation between the CEN record and the FDA record. Both of the incoming and outgoing transfer documents conform to the framework. Thus, when the transfer document arrives at the call center, the call center can comfortably read the CEN records and perform its assigned medical task. This design is illustrated in Figure 14.
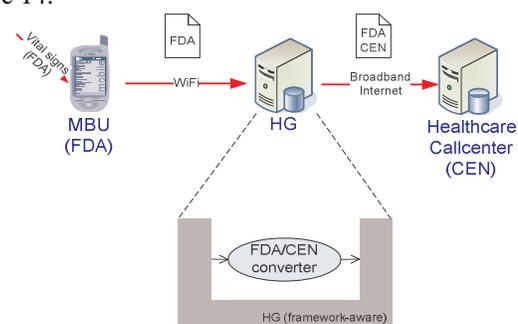

Figure 14: M-health application with vital sign data flow transformation support

It is worth noting that this conversion task can be performed by the call center in case HG is not available. The

vital sign representation framework still applies.

V. CONCLUSION AND FUTURE WORK

In this paper, we argued the necessity of providing flexibility on representing vital signs in M-health services and applications to achieve pervasive healthcare. This flexibility is essential for adaptive or context-aware systems to overcome infrastructural changes due to patient's mobility.

Based on the stakeholder's requirement analysis, we discussed five aspects of this flexibility, i.e. expressiveness, manipulativeness, openness, extensibility and privacy-friendly and proposed a framework for vital sign representations which incorporate these flexibility aspects. The design of framework itself is presented in terms of XML schema diagrams. This framework for creating flexible vital sign data documents can support various adaptations, e.g. downgrading the quality of vital signs due to limited bandwidth or automatic conversion of vital sign documents in multiple standardized formats. For a better explanation of the use of this proposed framework, two examples correspond to adaptation are presented with the scenario description and application setting.

The next research step will be applying this framework into the design and implementation of more concrete M-health applications within our Awareness project. This can further validate and improve the current framework.

REFERENCES

[1]   TelemedicineAlliance, "Telemedicine 2010: Visions for a Personal Medical Network," 2004.
[2]   K. Hung and Z. Yuan-Ting, "Implementation of a WAP-based telemedicine system for patient monitoring," *Information Technology in Biomedicine, IEEE Transactions on*, vol. 7, pp. 101, 2003.
[3]   L. Yuan-Hsiang, I. C. Jan, P. C. I. Ko, C. Yen-Yu, W. Jau-Min, and J. Gwo-Jen, "A wireless PDA-based physiological monitoring system for patient transport," *Information Technology in Biomedicine, IEEE Transactions on*, vol. 8, pp. 439, 2004.
[4]   M. F. A. Rasid and B. Woodward, "Bluetooth telemedicine Processor for multichannel biomedical signal transmission via mobile cellular networks," *Information Technology in Biomedicine, IEEE Transactions on*, vol. 9, pp. 35, 2005.
[5]   A. v. Halteren, R. Bults, K. Wac, D. Konstantas, and I. Widya, "Mobile Patient Monitoring: The MobiHealth System," *The Journal of Information Technology in Healthcare*, vol. 2, 2004.
[6]   V. Jones, F. Incardona, C. Tristram, S. Virtuoso, and A. Lymberis, "Future challenges and recommendations," in *M-health Emerging Mobile Health Systems*, R. S. H. Istepanian, S. Laxminarayan, and C. S. Pattichis, Eds.: Springer, 2006, pp. 267-270.
[7]   T. Broens, A. v. Halteren, M. v. Sinderen, and K. Wac, "Towards an application framework for context-aware m-health applications," presented at Proceedings of EUNICE 2005 "Networked Applications". 11th open European Summer School, Colmenarejo, Spain, 2005.
[8]   AWARENESS, "Freeband AWARENESS project webpage," http://www.freeband.nl/project.cfm?id=494&language=en, 2005.
[9]   N. Freed and N. Borenstein, "Multipurpose Internet Mail Extensions (MIME) Part One: Format of Internet Message Bodies," IETF, 1996.
[10]   HL7, "Health Level Seven Standards version 3." www.hl7.org, 2005.
[11]   R. H. Dolin, L. Alschuler, S. Boyer, and C. Beebe, "HL7 Clinical Document Architecture, Release 2.0," 2004.
[12]   E. Hull, K. Jackson, and J. Dick, *Requirements engineering*: Springer, 2002.
[13]   MobiHealth, "MobiHealth project webpage," 2003.
[14]   CEN, "Health Informatics - Vital signs representation," EUROPEAN COMMITTEE FOR STANDARDIZATION 1999.
[15]   B. Brown, M. Kohls, and N. Stockbridge, "FDA XML Data Format Design Specification," Food and Drug Administration 2002.
[16]   DICOM, "DICOM Part 5: Data Structures and Encoding," Digital Imaging and Communications in Medicine 2004.
[17]   "IEEE 1073, Point of Care Medical Device Communication Standards - Overview & Status Update." http://www.ieee1073.org/standards/standards-at-a-glance/CEN-IEEE-ISOStandardsEditorialPlan_rev%2021_.pdf.