Developing a Data Infrastructure for Patient-Centered Telemedicine

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Abstract— **Patient-centered care is an emerging healthcare model that is changing how people think about health and about the patients themselves. It emphasizes the coordination and integration of care, and the use of appropriate information, communication, and education technologies in connecting patients, caregivers, physicians, nurses, and others into a healthcare team where the health system supports and encourages cooperation among team members. However, in spite of the widespread adoption of telemedicine, existing telemedicine applications neither support patient centered-care nor the interoperation of relevant e-health tools. In this paper we present a cloud-based telemedicine consultation server, which manages telemedicine consultation request and their allocation to consulting physicians. It also aids physicians to access patients' health documentation either through a Personal Health Record (PHR) or Personal Health Information System (PHIS). Although both ways are suitable for supporting patient centered telemedicine the PHIS is superior in that it integrates the functionalities of a variety of e-health tools, and thus provides a holistic approach for personal healthcare. However, the integration of e-health tools requires the introduction of a shared ontology and the transformation of patients' health records in the format that is compliant with the shared ontology.**

Keywords - telemedicine; patient-centered care; personal health records; CCD standard, cloud computing; ontologies; eHealth ecosystem

I. INTRODUCTION

Telemedicine is the use of telecommunication and information technologies in order to provide clinical health care at a distance [1]. It aims to eliminate distance barriers and can improve access to medical services that would often not be consistently available in distant rural communities [2] [3]. In particular, telemedicine is viewed as a cost-effective alternative to the more traditional face-to-face way of providing medical care [4].

At the same time, the introduction of new emerging healthcare trends, such as patient-centered care [5], pharmaceutical care [6], chronic care model, and personal health records (PHRs) [7], are changing how people think about health and about the patients themselves. In addition, many studies have demonstrated that the provision of these healthcare models can increase compliance with treatment regimens, satisfaction with the health care provider and medical facility, and improve the ultimate health outcome for the individual [8].

It is also true that patients who do not understand their treatment instructions, disease management, or prescription requirements are more likely to mishandle their health, be hospitalized more frequently, and have much higher medical costs than their more involved counterparts [9].

Unfortunately, none of the categories of telemedicine support these emerging healthcare trends: *Store-and-forward telemedicine* involves acquiring medical data and then transmitting this data to the system that is accessible to patient's physician. *Interactive services* provide real-time interactions between patient and physician. It includes phone conversations, online communication and home visits. *Remote monitoring* enables medical professionals to monitor a patient remotely using various technological devices.

In this paper, we describe our work on developing a data infrastructure that supports patient-centered telemedicine. In particular, we describe our work on developing a cloud-based telemedicine system that manages consultation requests by a software module called Consultation Server. It also assists physicians in accessing patients' health information that is stored either in Personal Health Records (PHR) [10] or Personal Health Information System (PHIS) [11, 12].

In our vision PHRs, and especially PHISs, can significantly contribute to the introduction of patient-centered care. Further, they do not only improve the quality of care but also significantly increase the efficiency of consulting physicians as they can be authorized to access patient's health documentation.

Our approach changes the traditional telemedicine paradigm: its main goal is not only to provide a cost-effective alternative to the more traditional face-to-face way of providing medical care but rather to provide a data infrastructure for information sharing among patient's healthcare team.

In the design of the Consultation Server, as well in the design of the PHIS, we have followed the idea of knowledge oriented organizations [13]. Its key idea is to revolve all applications around a shared ontology. The main gain of such architecture is that the applications can interoperate by accessing the shared ontology.

In our introduced ecosystem the participants that agree to work together for practicing telemedicine is called as a *telemedicine affinity domain*. Examples of possible telemedicine affinity domains include nationwide and regional affinity domains, regional federations made up of several local hospitals, healthcare providers, and insurance provider supported communities.

A useful feature of a telemedicine affinity domain is that it is global: its components can locate anywhere in the Internet, and it can be exploited by patients and consulting physicians as far as they have an Internet connection.

The notion of telemedicine affinity domain has similarities with the *clinical affinity domain* of the IHE XDS [14], which studies the problem of patient's scattered clinical documentation. Its key idea is that patient's clinical documents are dynamically retrieved from a clinical affinity domain by exploiting relevant registries. This model assumes that patients' clinical documentation follow them as they move from one clinical affinity domain to another. Another difference between IHE XDS and PHRs is that in the former patient's clinical documentation is managed by healthcare authorities while in the latter they are managed by a patient.

The rest of the paper is organized as follows. First, in Section II, we give a motivating scenario of our ideas of patient-centered telemedicine in practice. Then, in Section III, we give an overview of the emerging healthcare models that have inspired our work. Further, in Section IV, we give an overview of various approaches for storing patients' healthcare documentation. However, as in our case PHRs and PHISs have a key role in storing patients' health documentation, they are considered more detailed in Sections V and VI, respectively. With respect to PHRs we focus on considering the expression power of the HL7 CCD standard while with PHISs we introduce our designed system, which extends traditional PHRs by the functionalities of various e-health tools. The key point here is that these tools interoperate by sharing an ontology, which is an integration of the data sources of these e-health tools.

In Section VII, we consider operational aspects of telemedicine. In particular, we present the Consultation Server that manages telemedicine consultation request and their allocation to consulting physicians. It also aids physicians to access patients' health documentation either through a CCD standard-based PHR or through our designed PHIS. In Section VIII, we consider the Consultation Server as an ecosystem having many interconnected parts. Finally, Section IX concludes the paper by analyzing the potential risks that may jeopardize the deployment of our designed telemedicine system. We also shortly consider our future work on integrating the Consultation Server with other e-health tools used by the consulting physicians.

II. MOTIVATING SCENARIO

Assume that a patient, named Nancy Taylor, has an online Web-based free PHR, where her health data and information related to the care given to her is stored. She can access her PHR from any place having an Internet connection.

One day Nancy discovered a rash on her waist, and so she decided to visit the nearest general practitioner having a contract with a telemedicine affinity domain. The practitioner examines Nancy's rush but the practitioner does not know what kind of treatment or medication should be prescribed for Nancy, and so the practitioner decides to request medical consultation by his Web browser.

To carry out the consultation the practitioner first takes a photo from Nancy's waist. Then the practitioner fills the request document by describing the symptoms of the rash and attaches the photo to the document. The document also provides a hierarchical classification (i.e., a taxonomy) of diseases. The practitioner marks the node "skin disease". In addition, authorized by Nancy the practitioner adds a link to Nancy's PHR and authorization for its use (including required access rights). Finally, the practitioner clicks the submit button, and so the document is delivered to the Consultation Server, which maintains a queue of the pending requests.

Each request includes a set of metadata items such as disease(s), source of request, language and possible priority of the request. The function of the metadata items is to enable automatic matching of the requests and the consulting physicians. So the Consultation Server shows for a consulting physician only the requests that match with his or her profile. Therefore, each consulting physician of the affinity domain also has a profile, which has values for the metadata items and is stored in the Consultation Server.

Assume that a physician, named John Smith, is a specialist in a hospital of a telemedicine affinity domain. In addition his profile matches with the request concerning Nancy, and so the request is in the consultation request queue shown for him.

After a few minutes John Smith picks up the consultation request document and examines the symptoms described in the document as well as the attached photo. Immediately he recognizes Nancy's rash as shingles (herpes zoster), which can be treated by a medicinal product named Aciclovir. Then he checks from Nancy's PHR whether Nancy has some allergies that would prevent the use of the drug or whether she has some ongoing medical treatment that could cause mutual negative effects. As there are no such findings the physician updates Nancy's PHR by the prescribed medication and by the diagnosis he made. Finally John constructs and signs the prescription electronically, which is then electronically delivered to the general practitioner visited by Nancy.

Further, assuming that instead of PHR Nancy is using a PHIS that integrates the functionalities of various e-health tools including information therapy server, then the PHIS would automatically send by e-mail relevant medical information (or their links) dealing with the prescribed medication (i.e., Aciclovir) and the diagnosis (i.e., herpes zoster).

III. EMERGING HEALTHCARE MODELS

Patient-centered care emphasizes the coordination and integration of care, and the use of appropriate information, communication, and education technologies in connecting patients, caregivers, physicians, nurses, and other into a healthcare team where health the system supports and encourages cooperation among team members [15]. It is based on the assumption that physicians, patients and their families have the ability to obtain and understand health information and services, and make appropriate health decisions.

Pharmaceutical care emphasizes the movement of pharmacy practice away from its original role on drug supply towards a more inclusive focus on patient care **[**16**].** It emphasizes the responsible provision of drug therapy for the purpose of achieving definite outcomes that improve patient's quality of life [17].

Chronic care model [18, 19] emphasizes patients' long-term healthcare needs as a counterweight to the attention typically paid to acute short-term, and emergency care. In this sense, the traditional care models are not appropriate as the patients with chronic illness do not receive enough information about their condition, and they are not supported in caring themselves after they leave the doctor's office or hospital.

Information therapy is a type of healthcare information service that has emerged in the past decade. The goal behind information therapy is to prescribe the right information to right people at right time [20]. Information therapy is also described as "the prescription of specific evidence based medical information to specific patients at just the right time to help them make specific health decisions or behavior changes" [21].

Information therapy applies to a wide range of situations and context. For example, information therapy may be a physician-written prescription telling a patient what to read, or it may use to help a patient to make treatment decision such as whether to continue medication.

Information therapy can be compared to similar concepts in medicine such as drug therapy, physiotherapy or bibliotherapy [22]. However, information therapy differs from these in the sense that by exploiting information technology information therapy aims at providing personalization, targeting and documentation.

Personalization means that the content of the delivered information depends on the familiarity of the user. Targeting means that the information prescriptions are targeted according to patient's moment in care, i.e., information is delivered at right time. Documentation means that information prescriptions are documented as part of the provided treatment.

There is a variety of paper-based mediums for delivering information therapy such as handing out information pamphlets or sending them through the post. There are also many electronic infrastructures (such as electronic medical record systems, personal digital assistants, order entry systems and personal health records) that have been proposed for delivering information therapy.

IV. MANAGING PATIENTS' HEALTH DOCUMENTATION

A. *PHRs vs. EHRs*

A PHR is a record of a consumer that includes data gathered from different sources such as from health care providers, pharmacies, insures and the consumer [23]. It includes information about medications, allergies, vaccinations, illnesses, laboratory and other test results, and surgeries and other procedures [24]. PHRs are owned by the patients. They also allow individuals to access and coordinate their lifelong health information and make appropriate parts of it available to those that are authorized by the individual.

In medical consultation, as well as in any medical treatment, a complete and accurate summary of the health and medical history of the patient is of prime importance. A problem here is that as a patient may have lived in various places and a patient may have many healthcare providers, including primary care physician, specialist, therapists and other medical practitioners, patient's health documentation may be distributed over several healthcare providers.

PHRs provide a simple way for solving the problem of patients' scattered clinical documentation [25]. They differ from EHRs (Electronic Health Record) [26, 27] in that they are owned by the patients and they can only be accessed by the patient and those that are authorized by the patient while EHRs assume that the health records are designed only for use by health care providers and are owned by medical authorities.

Managing fragmented healthcare documentation by EHRs has been successful only in a very few industrialized countries, such as in Singapore and Denmark [28]. Instead successful results from the use of PHRs are reported from many countries and communities. Therefore we have also concluded that the use of PHRs instead of national EHR's in managing patients' health documentation is a more appropriate solution in the context of telemedicine.

B. *Web-Based PHRs*

PHRs can be classified according to the platform by which they are delivered. In web-based PHRs health information is stored at a remote server, and so the information can be shared with health care providers. They also have the capacity to import data from other information sources such as a hospital laboratory and physician office. However, importing data to PHRs from other sources requires the standardization of PHR-formats.

Various standardization efforts on PHRs have been done. In particular, the use of the Continuity of Care Record (CCR standard) of ASTM [24] and HL7's [29] Continuity of Care Document (CCD standard) [30] has been proposed. From technology point of view CCR and CCD-standards represent two different XML schemas designed to store patient clinical summaries [31]. However, both schemas are identical in their scope in the sense that they contain the same data elements.

Web-based PHRs are core components in our proposed ecosystem. However, it does not assume that all patients have a PHR, but it encourages patient to acquire a PHR. Using a PHR does not require patients to own any personal devices for internet connection nor any efforts for managing it. Rather it requires patient to authorize healthcare personnel to maintain and access their PHR.

Acquiring a PHR is a tempting opportunity as there are many freely available web-based PHRs available, and moving personal data between standard-based PHR is supported by the vendors. For example, as the support of the Google Health was retired on January 2012 Microsoft has developed a transfer process for the user of the Google Health for moving their health records into Health Vault.

Similar to Dossia and World Medical Card, it is a web-based system to store, maintain and share health and fitness information. They support a number of exchange formats including industry standards such as the CCR and CCD standards.

V. CCD STANDARD AND PHRS

A. CCD Standard

CCD standard (an XML schema) is nowadays increasingly used for specifying the structure of exchanged clinical documents as well as specifying the structure of the PHR. This feature simplifies the update of the PHR as well as the generation of the clinical documents that will be stored in the PHR.

The CCD standard is a constraint on the HL7 CDA standard. The CCD standard has been endorsed by HIMMS (Healthcare Information and Management Systems Society Though) [32] and HITSP (Healthcare Information Technology Standards Panel) [33] as the recommend standard for exchange of electronic exchange of components of health information.

Although the original purpose of the CCD documents was to deliver clinical summaries between healthcare organizations, nowadays the XML schema of the CDD documents is increasingly used for specifying the structure of the PHRs. The same schema can be used in message as all its parts are optional, and it is practical to mix and match the sections that are needed.

B. HL7 RIM and RMIM

We have given preference to CCD standard (an XML schema), which is based on HL7 RIM (Reference Information Model). The RIM is the cornerstone of the HL7 message development process and development methodology [34]. It expresses the data content needed in a specific clinical or administrative context and provides an explicit representation of the semantic and syntactical connections that exist between the information carried in the fields of HL7 messages [35].

The RIM is based on two key ideas [28]. The first idea is based on the consideration that most healthcare documentation is concerned with “happenings” and things (human or other) that participate in these happenings in various ways.

The second idea is the observation that the same people or things can perform different roles when participating in different types of happening, e.g., a person may be a care provider such a physician or the subject of care such as patient.

As a result of these ideas the RIM is based on a simple backbone structure, involving three main classes, Act, Role, and Entity, linked together using three association classes Act-Relationship, Participation, and Role-Relationship (Fig. 1). Note that HL7 uses its own representation of UML to reflect the use of these six backbone classes. Each class has its own color and shape to represent the stereotypes of these classes, and they only connect in certain ways.

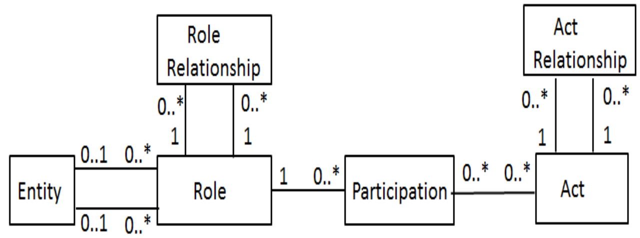

Figure 1. RIM backbone structure.

Each happening is an Act and it may have any number of Participations, which are Roles, played by Entities. An ACT may also be related to other Acts via Act Relationships. Act, Role and Entity classes have a number of specializations (subclasses), e.g., Entity has a specialization LivingSubject, which itself has a specialization Person.

The classes in the RIM have structured attributes which specify what each RIM class means when used in a message (exchanged document). For example, Act has structured attributes classCode and moodCode. The former states what sort of Act this is (e.g., observation, encounter, or administration of a drug). moodCode indicates whether an Act has happened, is request for something to happen, a goal or a criterion. The idea behind structured attributes is to reduce the original RIM from over 100 classes to a simple backbone of six main classes [28].

Note that the RIM is not a model of healthcare, nor is it a model of any message, although it is used in exchanged messages. The structures of exchanged documents are defined by constrained information models [28]. The most commonly used constrained information model is the RMIM (Refined Message Information Model). Each RMIM is a diagram that specifies the structure of an exchanged document.

A RMIM diagram is specified for a specific use case [35]. The diagram is derived from the RIM by limiting its optionality. Such specifications are called CDA Profiles [36].

In developing a RMIM diagram the RIM is constrained by omission and cloning. Omission means that the RIM classes or attributes can be left out. Note that all classes and attributed that are not structural attributes in the RIM are optional, and so the designer can take only the needed classes and attributes. Cloning means that the same RIM class can be used many times in different ways in various RMIMs. The classes selected for a RMIM are called clones.

The multiplicities of associations and attributes in a RMIM are constrained in terms of repeatability and optionality. Further, code binding is used for specifying the allowable values of the used attributes.

Although the semantics of all CDA documents is tractable through a RMIM back to the RIM, we neither can use the RMIM nor the RIM in formulating queries on patient’s health documentation as each RMIM only models one type of documents. Another reason is that there are no query languages specified for the information model used in the RMIM and RIM schemas.

C. HL7 CDA Levels

Each CDA document has one primary purpose (which is the reason for the generation of the document), such as patient admission, transfer, or inpatient discharge. Each Clinical Document Architecture (CDA) document is made up of the header and the body [28].

Depending whether the header and body of the CDA documents are based on the RIM they are classified into three levels:

- CDA Level 1: Only the header is based on the RIM while the body is human readable text or image.
- CDA Level 2: Only the header of the document is based on the RIM while the body is comprised of XML coded sections.
- CDA Level 3: Both the header and the body are based on the RIM.

The CDA header is common to all the three levels of CDA. The header contains basic metadata. These include information about what the documents is, who created it, when, where, and for what purposes. Its primary purpose is to provide unambiguous, structured metadata about the document itself, which can be used in document registers to classify, find and retrieve documents.

In HL7 CDA terminology the header is an instance of an Act called Clinical Document. This means that there is a Refined Message Information Model (RMIM) that models the headers of all HL7 CDA documents. To illustrate this, a simplified RMIM of the Header of CDA documents is presented in Fig. 2. The diagram presents classes of the RMIM but not all their attributes.

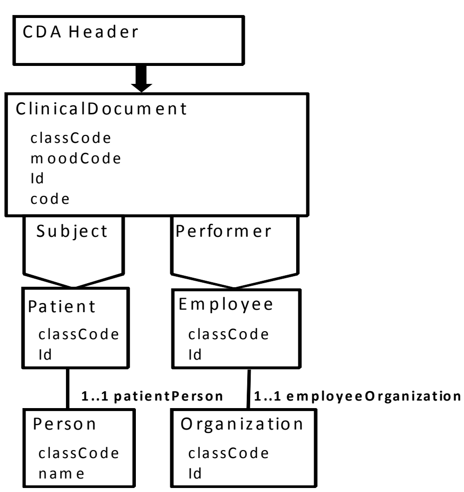

Figure 2. A simplified RMIM of CDA Header.

Note that HL7 uses its own representation of UML in RMIM diagrams: each class has its own color and shape to represent the stereotypes of these classes, and they only connect in certain ways.

The entry point of this diagram (CDA Header) is ClinicalDocument, which is specialization of the RIM class Act. Classes Patient and Employee are specializations (subclasses) of the RIM class Role. Person and Organization are specializations of the RIM class Entity. Subject and Performer are specializations of the association class Participation. Each specialization inherits all of the properties (attributes) of the generalization. For example, the class Patient is a specialization of Role with the addition of the optional attribute veryImportantPersonCode.

D. The Structure of a CCD document

Each CCD document have one primary purpose (which is the reason for the generation of the document), such as patient admission, transfer, or inpatient discharge. Further, each CCD document, as well all HL7 CDA documents, is comprised of the Header and the Body.

The sections that can appear in the Head and in the Body in a CCD document are presented in Fig. 3.

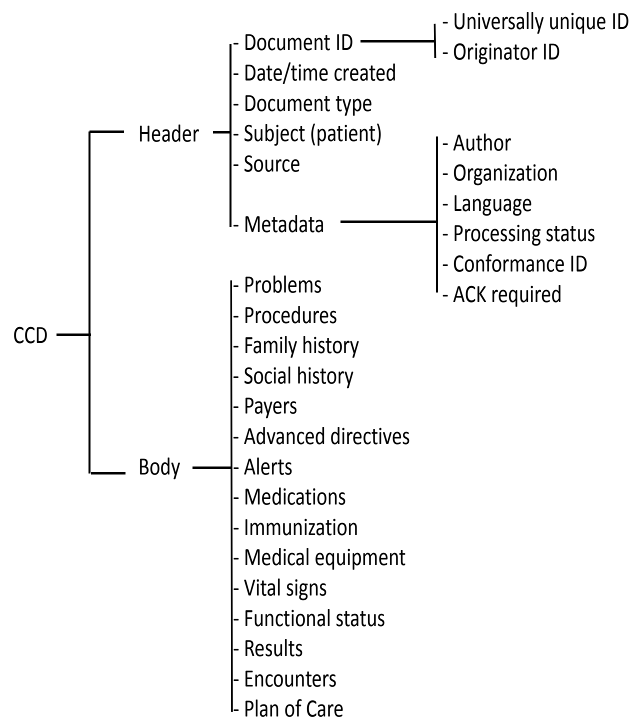

Figure 3. The parts of the CCD document.

A CCD document that includes a header and the Medications section from the Body is presented in Fig. 4. The content of the document is derived from the scenario presented in Section II, i.e., the document would be inserted in Nancy Taylor's PHR, which is based on the CCD-standard.

In a PHR the CCD documents are usually organized into hierarchical structures that simplify the search of documents, e.g., grouping together the documents by episode, clinical specialty or time period. Yet each clinical document is stored as a stand-alone artifact, meaning that each document is complete and whole in itself.

```
<CCDfile>
  <DocumentID>DOC_123</DocumentID>
  <Patient>
    <PatientID>AB-12345></PatientID>
    <PatientName>Nancy Taylor></PatientName>
  </Patient>
  <Medications>
    <Medication>
      <MedicationID>Medication.567</MedicationID>
      <DateTime>
        <ExactDateTime>
             2012-03-01TO12:00
        </ExactDateTime>
      </DateTime>
      <Source>
        <Actor>
          <ActorID>Pharmacy of  Health</ActorID>
          <ActorRole>Pharmacy</ActorRole>
        </Actor>
      </Source>
      <Description>
        <Text>Two tablets twice a day</Text>
      </Description>
      <Product>
        <ProductName>Aciclovir </ProductName>
        <BrandName>Zovirax</BrandName>
      </Product>
      <Strenght>
        <Value>400</Value>
        <Unit>milligram</Unit>
      </Strenght>
      <Quantity>
        <Value>40</Value>
        <Unit>Tabs</Unit>
      </Quantity>
    </Medication>
  </Medications>
</CCDfile>
```

Figure 4. A simplified example of a CCD document.

VI. DESIGNING A PHIS

A. *Personal Health Information System PHIS*

Traditional PHRs fail in supporting information therapy, which is a key component in patient-centered care. Further, our studies have indicated that user-friendly health system should support the functionalities of many traditional e-health tools such as PHRs, remote patient monitors, health-oriented blogs, and health-oriented information servers. Further, by gathering these functionalities into one system we can achieve synergy, i.e., achieve functionalities that would not be obtainable by any of the e-health tools independently.

In gathering functionalities into a PHIS we have adapted the ideas of knowledge centric organizations to i.e., we have revolved the e-health tools around a health oriented knowledge base. So, all the e-heath tools share patient's health data. Further, by exploiting the characteristics provided by cloud computing [37] we can easily ensure the interoperation of patient's healthcare team: accessing the advanced PHR requires only internet connection.

A. *PHIS Ontology*

The architecture of the PHIS and its connections in the cloud are presented in Fig. 5. As the figure illustrates patient and the members of his or her healthcare team access the PHIS-server through the personalized health portal. It is a site on WWW that provides personalized capabilities for its users and links to other relevant servers.

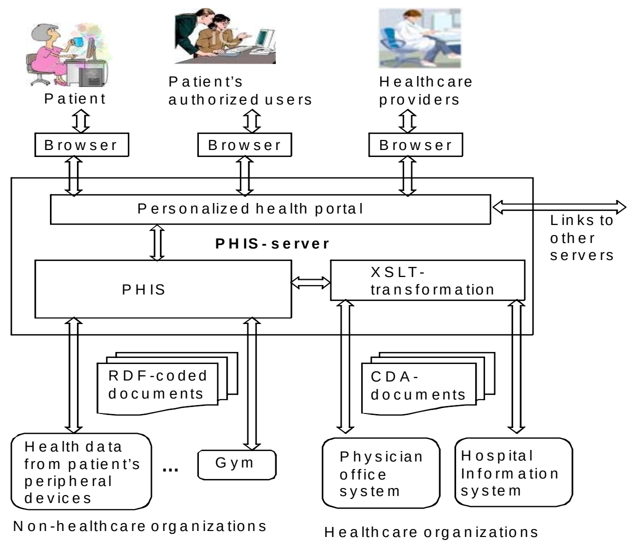

Figure 5. The component of the PHIS-server and its external connections.

In designing the PHIS we have followed the idea of knowledge oriented organizations [13], where the key idea is to revolve all applications around a shared ontology (stored in a knowledge base), which we call *PHIS-ontology*. It is developed by integrating the ontologies of the e-health tools supported by the PHIS. For now we have integrated the ontologies of the Blog manager, Information therapy (Ix) manager, Remote manager, and PHR manager. Such an internal architecture of the PHIS is presented in Fig. 6.

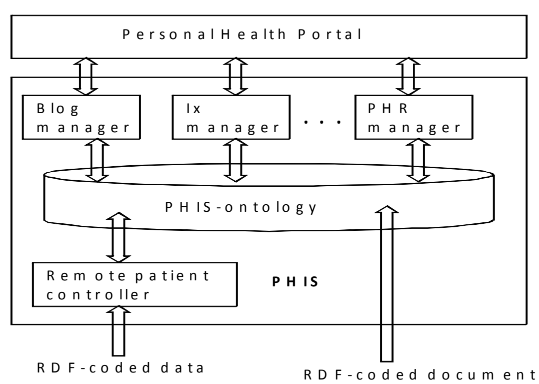

Figure 6. The e-heath tools accessing the PHIS-ontology.

Fig. 7 illustrates the idea of the knowledge base and the case where PHIS-ontology is developed by integrating the Blog-ontology, Ix-ontology, PHR-ontology and RM-ontology (Remote Monitoring ontology). In the figure ellipses represent OWL´s classes, rectangles represent OWL's data properties and the lines between ellipses represent OWL's object properties. Accordingly class A is shared by all the four ontologies.

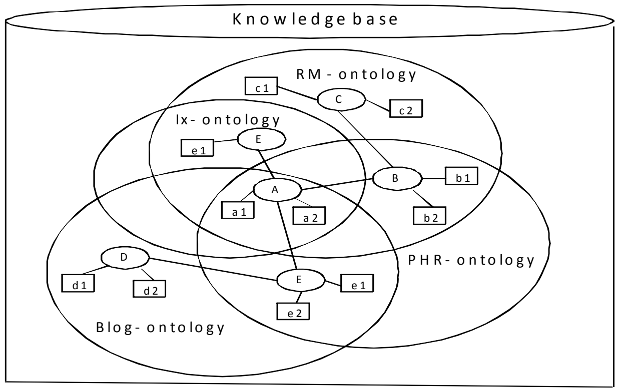

Figure 7. PHIS-ontology.

In order to illustrate shared classes, A could be class Disease, B class Patient, and C class Informal_entity. Further assume that object property A-B is suffer_from, object property A-E is deals, data property b1 is patient_name, and data property e1 is a url. In such as setting we could specify by RDF (Resource Description Framework) that John Smith suffers from diabetes and the educational material dealing diabetes is stored in a specific url.

A portion of the PHIS-ontology is graphically presented in Fig. 8. In this graphical representation ellipses represent classes and subclasses, and rectangles represent data and object properties.

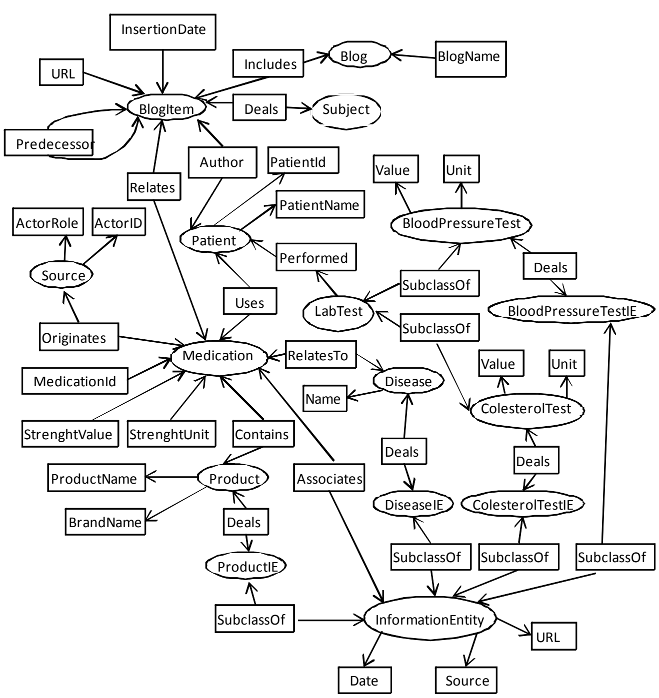

Figure 8. A portion of the PHIS-ontology.

A portion of the graphical ontology of Fig. 8 is presented in OWL in Fig. 9.

```
<rdf:RDF
        xmlns:rdf=http://www.w3.org/1999/02/22-rdf-syntax-nsl#
        xmlns:rdfs=http://www.w3.org/2000/01/rdf-schema#
        xmlns:owl=http://www.w3.org/2002/07/owl#>

        <owl:Ontology rdf:about=“”PHA/>
         <owl:Class rdf:ID=“Blog/”>
         <owl:Class rdf:ID=“BlogItem/”>
        <owl:Class rdf:ID=“Patient/”>
        <owl:Class rdf:ID=“Medication/”>
        <owl:Class rdf:ID=“Source/”>
        <owl:Class rdf:ID=“Product/”>
        <owl:Class rdf:ID=“LabTest/”>
        <owl:Class rdf:ID=“BloodPressureTest”>
                <rdfs:subClassOf rdf:resource=“#LabTest”/>
        </owl:Class>
        <owl:Class rdf:ID=“ColesterolTest”>
                <rdfs:subClassOf rdf:resource=“#LabTest”/>
        </owl:Class>

        <owl:ObjectProperty rdf:ID=“Relates”>
                <rdfs:domain rdf:resource=“#BlogItem”/>
                <rdfs:range rdf:resource=“#Medication”/>
        </owl:ObjectProperty>

        <owl:ObjectProperty rdf:ID=“Uses”>
                <rdfs:domain rdf:resource=“#Patient”/>
                <rdfs:range rdf:resource=“#Medication”/>
        </owl:ObjectProperty>
                .
                .
                .
</rdf:RDF>
```

Figure 9. A portion of the PHIS-ontology in OWL.

In order to understand the relationship of XML, OWL and RDF note that XML (Extensible Mark-up Language) is just a meta language for defining markup languages. By a meta language we refer to a language used to make statements about statements in another language, which is called the object language. Accordingly RDF [38] and OWL [39] are object languages. Instead, XML says nothing about the semantics of the used tags. It just provides a means for structuring documents. Due to the lack of semantics we do not use XML for representing PHIS-ontology but instead we use ontology languages RDF and OWL.

B. *Transforming HL7 CDA into OWL*

Although the semantics of all CDA documents is traceable through a RMIM back to the RIM, we neither can use a RMIM nor the RIM in formulating queries as there are no query languages specified for the information model used in the RMIM and RIM schemas. For this reason we transform the RMIM of the CDA header into OWL.

Transforming a RMIM diagram into OWL is straightforward in the sense that both models are object-oriented although the notation used in RMIM diagrams slightly differs from the traditional UML notation. Yet their basic modeling primitives are the same, namely classes, subclasses, properties and values. The classes are also connected in a similar way through properties.

In order to illustrate the transformation of RMIM diagram into OWL we have presented the RMIM diagram of Figure 4 in OWL in Fig. 10.

Classes, subclasses, data properties and object properties are modeling primitives in OWL [40]. Object properties relate objects to other objects while datatype properties relate objects to datatype values [13]. For example, Performer is an object property. Its domain is clinicalDocument and range is employee. Note that, in Fig. 10 we have omitted most datatype properties. The only datatype property presented in the figure is “code”. Its domain is clinicalDocumernt and its range is xsd:string, i.e., string in “XML-terminology”.

```
<rdf:RDF
 xmlns:rdf=http://www.w3.org/1999/02/22-rdf-syntax-nsl#
 xmlns:rdfs=http://www.w3.org/2000/01/rdf-schema#
 xmlns:owl=http://www.w3.org/2002/07/owl#>
 xmlns:xsd =http://www.w3.org/2001/xml-schemal#>
 <owl:Ontology rdf:about="registryOntology"/>
 <owl:Class rdf:ID="act/">
 <owl:Class rdf:ID="role/">
 <owl:Class rdf:ID="entity/">
<owl:Class rdf:ID="participation/">
 <owl:Class rdf:ID="clinicalDocument">
      <rdfs: subClassOf rdf:: resource "#act"/>
 </owl : class>
 <owl:Class rdf:ID="patient">
      <rdfs: subClassOf rdf:: resource "#role"/>
 </owl : class>
 <owl:Class rdf:ID="employee">
      <rdfs: subClassOf rdf:: resource "#role"/>
 </owl : class>
 <owl:Class rdf:ID="person">
       <rdfs: subClassOf rdf:: resource "#entity"/>
 </owl : class>
 <owl:Class rdf:ID="organization">
       <rdfs: subClassOf rdf:: resource "#entity"/>
 </owl : class>
 <owl:ObjectProperty rdf:ID="subject">
         <rdfs:domain rdf:resource="#clinicalDocument"/>
         <rdfs:range rdf:resource="#patient"/>
 </owl:ObjectProperty>
 <owl:ObjectProperty rdf:ID="patientPerson">
         <rdfs:domain rdf:resource="#patient"/>
         <rdfs:range rdf:resource="#person"/>
 </owl:ObjectProperty>
 <owl:ObjectProperty rdf:ID="performer">
         <rdfs:domain rdf:resource="#clinicalDocument"/>
         <rdfs:range rdf:resource="#employee"/>
 </owl:ObjectProperty>
 <owl:ObjectProperty rdf:ID="employeeOrganization">
         <rdfs:domain rdf:resource="#employee"/>
         <rdfs:range rdf:resource="#organization"/>
 </owl:ObjectProperty>
 <owl:DatatypeProperty rdf:ID="code">
          <rdfs:domain rdf:resource="#lclinicalDocument"/>
          <rdfs:range rdf:resource="&xsd;string"/>
 </owl:DatatypeProperty>
        .
        .
        .
</rdf:RDF>
```

Figure 10. A part of CDA Header in OWL.

VII. CONSULTATION SERVER

A. The Architecture of the Consultation Server

In designing the internal architecture of the Consultation Server we have followed the idea of knowledge oriented organizations, where the key idea is to revolve all applications around a shared ontology. As illustrated in Fig. 11, in our solution all the applications of the Consultation Server are revolved around the Consultation Ontology.

The users access the Consultation Ontology through the Consultation Portal, which provides connections to the relevant cloud applications. The applications are based on the use cases of the various user groups. For example, Submit Consultation Request and Pick-up a Consultation Request are two typical applications developed for physicians. These applications interoperate through accessing the same data items included in the Consultation Ontology.

Note that although the Consultation ontology is specified in QWL and queried by SPARQL [41] (i.e., by a RDF-based query language), it is stored for the efficiency reasons in a relational database [42].

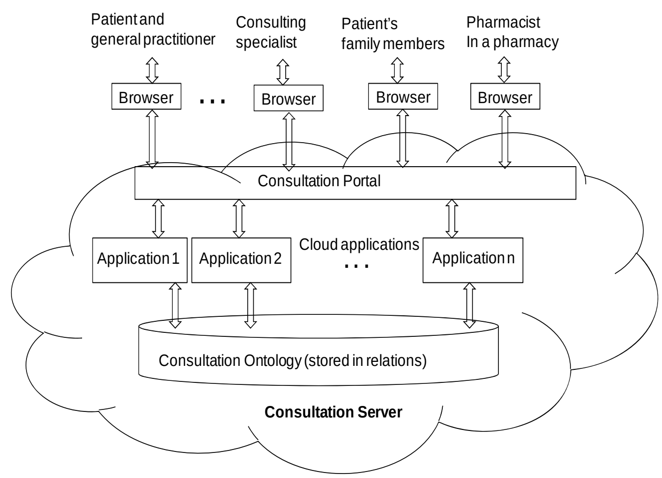

Figure 11. The components of the cloud-based Consultation Server.

B. The Structure of the Consultation Ontology

A portion of the Consultation ontology is graphically presented in Fig. 12. In this graphical representation ellipses represent classes and rectangles represent data type and object properties. *Object properties* relate objects to other objects while *data type properties* relate objects to datatype values. Classes, data type properties and object properties are modelling primitives in OWL.

Note that in Fig. 12 we have presented only a few of objects' datatype properties. For example, in the figure we have omitted most of the datatype properties from the classes Physician and Organization. Instead all the datatype properties of the class Consultation request are presented in the figure. The class Speciality and its datatype property Class represent a taxonomy. That is, except for the root node there is a link from each class instance to its parent.

The idea behind this taxonomy is that the symptoms and the specialities of the physicians are specified by the same vocabulary. This feature simplifies the matching of consultation requests and physicians' specialities.

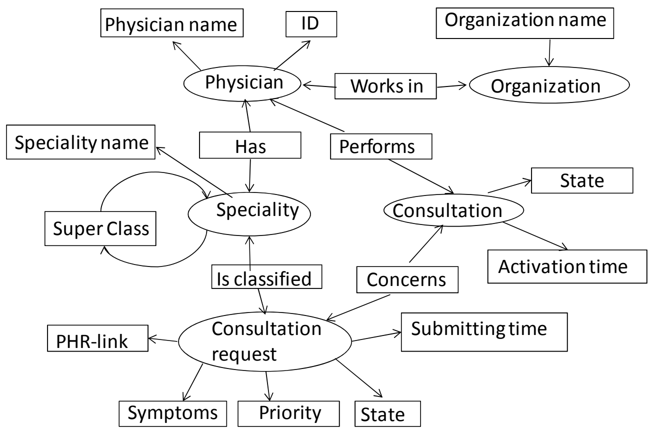

Figure 12. Graphical presentation of a portion of the Consultation Ontology.

The Consultation Ontology enables a variety of useful queries for physicians such as the followings:

- Is there any pending consultation request having classification "Skin diseases"?
- Is there (in the affinity domain) any physicians having speciality in diabetes?
- Is there any consultation request matching with my speciality?
- Is there any pending consultation request that is submitted by a physician of the University Hospital?
- Is there any consultation request that has been pending over ten minutes?
- Give me the names and specialties of the consulting physicians that work in a specific affinity domain.

Note that the Consultation Server can support more than one telemedicine affinity domain. Further, as most OWL ontologies, such as the Consultation Ontology, are usually stored in relational database systems, it is also possible to use the triggering mechanism of the SQL [43] in automating the management of the consultation requests. For example, a request can be automatically allocated to a physician having required speciality and having no ongoing consultation.

C. *Cloud Computing and SaaS*

Cloud computing is an appropriate choice for telemedicine consultation management as it allows organizations to use applications without installation. Moreover, in most cases cloud-based solutions reduces the cost of acquiring, delivering, and maintaining computing power [37]. However, in our vision the main goal behind cloud computing is to achieve synergy through controlled sharing of data.

In particular the Saas (Software as a Service) [44] model of cloud computing is appropriate for the Consultation Server. It is a software delivery model in which applications are hosted by service provider and made available to customers over the Internet. It provides access to software and its functions remotely as a Web-based service.

Further, there are various architectural ways for implementing the SaaS model. For example, in the case where the Consultation Server serves more than one telemedicine affinity domain we could use the following software architectures:

1. Each telemedicine affinity domain has a customized version of the Competence Server that runs as its own instance.
2. Many telemedicine affinity domains use separate instances of the same application code.
3. A single program instance serves all telemedicine affinity domains.

In our designed version the Consultation Server supports only one clinical affinity domain and so only one version and one instance is required.

VIII. TELEMEDICINE ECOSYSTEM

To succeed e-health systems should not be considered just as a technical infrastructure but rather as ecosystems having many interconnected parts [45].

So far we have considered the technical infrastructure and the services of our designed telemedicine oriented cloud-based ecosystem. The other key parts of the ecosystem are ethical aspects, governance regulations, financing and stakeholders. For now, we shortly consider what kind of new alternatives the introduction of cloud-based solutions gives for these parts of the ecosystem.

A. *Ethical Aspects in Telemedicine Resource Alloation*

Resource management is the efficient and effective deployment of an organization's resources when they are needed. Such resources may include financial resources, inventory, human skills, as well consultation resources in telemedicine.

Resource allocation is a part of resource management. It is used to assign the available resources in an economic way. In process management, resource allocation is the scheduling of activities and the resources required by those activities while taking into consideration both the resource availability and the process time.

Although the resource allocation issues in healthcare sector are economic by nature, they inherently raise issues relating to ethics. According to the principles of medical ethics physicians should merit the confidence of the patients entrusted to their care, rendering to each a full measure of service and devotion. However, often scarcity of resources makes it difficult or impossible to provide the full measure of service and devotion.

When the conditions of scarcity occur, we have to decide what considerations should guide decisions for tradeoffs in a fair and compassionate manner. Further, to carry out the decisions the resource needs or requests must be prioritized, and finally the competitive request must be treated according to their priorities.

B. Governance Regulations

E-health application that maintains patients' health documentation must adhere to national legislated policies and regulations, which concerns privacy and security issues. One problem is that in many countries that are just beginning to investigate on e-health application do not yet have enough mature legislation with respect to e-health. Thereby national governments have an important role in promoting the development of appropriate legislation concerning e-health.

In our developed telemedicine ecosystem patient's health documentation is not stored in the national archives but rather on PHR system, where the patient's health documentation is owned by the patient and only used by the physicians, patient's family members and healthcare personnel authored by the patient. As a result, patients' health documentation is not under the control of national healthcare authorities, and thus is not so tightly dependent on whether there is advanced legislation for e-health.

C. Financing Cloud-Based E-Health Ecosystems

In designing an e-health ecosystem it is important to ensure that appropriate funding is in place for its implementation and operation. Financing can come from a variety of sources, such as government or public-private partnerships.

Financing PHRs is not an actual problem as there are many freely available web-based PHRs available. Further there are many freely available PHRs for specific communities, e.g., for employees of specific organization, customers of a specific insurance company or for the customers of a specific healthcare provider.

D. Stakeholders of Global Ecosystem

In designing the implementation of an e-health ecosystem, it is of prime importance to involve in preparation all the key stakeholders, such as governments, public and private healthcare providers, patients, as well as patient advocacy groups [45].

As our proposed ecosystem is not nationwide but rather "internet-wide", the system itself as well as its stakeholders may span over many countries. For example, governments and healthcare providers from a variety of countries may be involved in the ecosystem, and each stakeholder has different objectives and motivations for participating in the ecosystem.

IX. CONCLUSION AND FUTURE WORK

The goal of our work has been to show that cloud-based global telemedicine ecosystems that support patient centered care can be implemented from technology point of view. Yet there are many problems that may jeopardize the success of such ecosystems. In particular, the introduction of new technology requires training: the incorrect usage of a new telemedicine technology, due to lack of proper training, may ruin the whole ecosystem. In addition, a consequence of introducing a new telemedicine practice is that it significantly changes the daily duties of healthcare personnel, and the role of patient and patient's family members. Therefore one challenging aspect is the changing the mind-set of the involved healthcare personnel.

The introduction of a new technology in telemedicine is also an investment. It includes a variety of costs including software, hardware and training costs. Introducing and training the staff on new technology is a notable investment, and hence many organizations like to cut on this cost as much as possible.

In order to minimize the changes that the introduction of the system will cause on healthcare personnel, in our future work we will investigate how telemedicine consultation can be linked into physicians' day-to-day work patterns. In particular, we will consider how the functionalities of the Consultation Portal can be integrated with other e-health tools used by the physicians.

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