A Concept of a Patient-centered Healthcare System Based on the Virtualized Networking and Information Infrastructure

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*Abstract***—In the paper we introduce and discuss the concept of an architecture of a patient-centered eHealth ecosystem. It is composed of three layers which were developed around three autonomic types of platforms of services in eHealth. The first platform is a corporate eHealth network which is based on the concept of the LivingLab system introduced earlier. This level is concerned with specialized reference centers and is a natural place for a broad range of advanced tools and eHealth infrastructures. The next level is developed basing on the concept of regional healthcare networks. Some examples of such networks or projects in Poland are mentioned. Regional Healthcare Networks are the most natural environments which bring together all the actors involved in patients' healthcare. The third level in the proposed architecture is related to the family (or individual) eHealth platforms. The environment of this kind is natural for storing, management of and access to personal health records. The concept of a proposed architecture was used to discuss its three main paradigms and their importance for the future global eHealth ecosystem. The presented approach assumes the evolutionary model which enables the virtualization on every level, new generation communication protocols between corresponding networks, and finally a smart electronic health record.**

Keywords-Regional Healthcare Networks; Virtualization; Electronic Patient Records; eHealth; Resource Management

I. INTRODUCTION

These days, in the first two decades of the new century, we are becoming aware of rapid ICT development and widespread deployment of emergent services and applications across the world. Many barriers in further development of modern societies can be overcome since new services are enabled by ICT in sectors such as e-government, e-education and e-health. On the other hand, we are facing a new problem. The sustainable, dynamic growth of different local markets of new services creates new barriers aggravating the interoperability of systems like healthcare networks, which is crucial to enable users to access their data and services anytime and from any place.

The improvement of the quality in healthcare systems depends on the relation between medical processes and ICT. Such a trend is visible all over the world; it is also particularly noticeable that many initiatives are undertaken in the European Union. A substantial effort has been made in order to define a strategy for founding and development of Regional Healthcare Networks (RHCNs) – eHealth systems on a macro regional scale. The example is the Baltic Sea macro region [1].

This scope of integration between medical systems and ICT is the one of the most popular trends in recent years [2][3]. Due to this fact, Section II shortly presents the European strategy regarding RHCNs, and next we give some examples of those systems which are currently under development in Poland. One of them, the Wielkopolska Center of Telemedicine, is managed by the authors.

However, the analysis of barriers and challenges in eHealth performed in the context of emergent new technologies, such as: Future Internet, grids, cloud computing, and ubiquitous computing [13] provides a basis for thoughts of fundamental manner. The principal sphere of healthcare is related to regional systems, but a very important place in the entire health ecosystem is assigned to other two areas: the domain of highly specialized medical aid as well as the field of at-home-care. The first one concerns specialized reference centers with adequate, knowledgeable human assets and equipped with unique diagnostic devices (which are very often associated with advanced ICT applications supporting medical processes). The second area is related to a patient home monitoring, assistance in chronic illness as well as prophylaxis. Though, these areas of medical treatment together with RHCNs, form a common, global system which the authors have compared to a tree structure in Section III (the Healthcare Tree). Next, through mapping this tree onto processes of integration with ICT we obtain the three-ply structure of networks: Family eHealth Net, Regional eHealth Net, and Corporate eHealth Net. We characterized them briefly in Section III.

When we take a global sight over such a structure of eHealth networks and we consider it as an integrated system, we will notice a problem of an interoperability assurance within the structure. In Section IV and V, the authors concentrate on two areas of interoperability: communication and data layer. In the first case, broader use of network virtualization techniques as well as intelligent management of network resources and connected devices is propounded, , then the concept of Smart Electronic Health Record is introduced in the second case.

II. REGIONAL HEALTHCARE NETWORKS

For more than 10 years it has been regional e-Health systems which have been in close proximity to day-to-day health care, and in many cases have grown from the concept

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of Regional HealthCare Networks [4][5][6]. These types of systems became broadly deployed in Europe as well as many other countries, and allowed to boost the quality of healthcare through integration with ICT, which was noticed by patients.

A. European Strategy

Improvement in healthcare in Europe is induced through setting appropriate priorities on the deployment of ICT means for health market (referenced as eHealth technologies). One of the fundamentals of the global strategy in this area was to build Regional Health Care Networks which aimed at combining three existing techniques into one regional health system:

- Internet and web techniques, making access to advanced communication functionality easy
- Security techniques, making the Internet usable for patient-related information.
- Standardisation techniques, making integration possible with existing IT systems already in use by the professionals in the region [2].

Rapid development of RHCNs was in line with European view on healthcare, which perceives macroregional connections as a way for providing patient-centric services. Such seamless integration can be achieved only when new technical means are deployed in order to ensure the interoperability of existing eHealth systems. An appropriate action has been taken to build a technical platform to implement this policy [1][7].

The strategic direction of the European Commission was also to enable the deployment of Europe-wide computer-supported networks based on broadband infrastructures and Grid technologies. In parallel, a substantial effort has been made in developments of these technologies which are crucial for eHealth as well as for other application areas.

B. Interoperability within common data space - examples

Common diagnosis and information space for patient-centered health services are related to all diagnosis devices which produce digital images that are gathered in electronic health records. These records collect all information about a patient (including the history of his/her medical examinations). It is obvious that all data must be organized in a completely secure environment and should be available for any kind of process related to patient treatment. Moreover, at the same time, all these data should serve as a basis for research related to early detection of diseases as well as prophylaxis. In particular, a patient who is treated outside the hospital or needs continuous medical surveillance should be remotely connected to his/her information space and parameters within this space should be monitored by his/her medical support.

1) Wielkopolska Center of Telemedicine

The Wielkopolska Center of Telemedicine project (WCT) aiming at establishing a telemedical infrastructure in the area of trauma in Wielkopolska started in May 2009 [8]. The objective of the project is to build a regional platform for remote medical teleconsultations allowing to introduce standardized communication in trauma. This platform will connect 26 hospitals from Wielkopolska with 7 clinical departments. In addition to the deployment of the platform for medical teleconsultations, the project also constructs the Medical Digital Library which collects anonymous medical data and provides this information through accompanying telemedical services of educational nature [9][10]. Both subsystems are closely coupled with each other to enable the sharing of data between them and allow users to seamlessly utilize services provided by both of these subsystems. WCT is also the field for prototype implementation of the concepts discussed thereinafter.

2) Pomerania

A telemedical network connecting 32 hospitals is under development in the Euroregion ‘Pomerania’. The network is to link 11 hospitals in the Zachodniopomorskie region (Poland) and 21 hospitals in Meklemburg-Vorpommern and Brandeburg (Germany). It is aimed at increasing the quality of medical services and increasing the diagnosis success rate in the region facing the decline in the number of available medical specialists. The project develops a system which will allow to order medical expertise through submitting a request containing a full set of medical information related to a given patient. The information will be centered around radiological images and additional documents containing useful information concerning the requested expert opinion. The project tackles challenges in such medical domains as teleradiology, telepathology, telestroke, teleophthalmology, telecardiology and teleurology.

3) Regional System of Medical Information in Łódź

The Regional System of Medical Information in Łódź aims at supporting management of the regional healthcare system. Its main goal is to improve the efficiency and quality of medical services. The system will bring real benefits for patients, namely better management and planning of medical services, which should facilitate easier access to specialists and shorter waiting time for visits.

The new solution which involves 18 healthcare centers will have an influence on efficient administration of supplies. Additionally, through data aggregation, the system will facilitate the evaluation of regional public health.

4) Medical Information System in Podkarpackie

The Medical Information System in the Podkarpackie region will help in data exchange in the scope of:

- electronic transfer of medical documentation, routine access to electronic documents which are relevant to continued treatment and finally an admission of service provider with regard to information about medical history of the patient;
- access to electronic medical records enabled for patients and providing an information regarding planned and delivered healthcare services.

The main priorities of the System are related to interoperability of IT systems in the scope of access to electronic medical records, organization of medical processes, healthcare management as well as standardization.

C. Further development of RHCNs

Over the last ten years we could observe a process of intensive development of ICT as well as substantial

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advancement in medical research. It also influenced the development of RHCNs. We are currently facing a new digital revolution. Its boundaries are set by way of expected fast networks/Internet, in which the user access interface is expected to be delivered at the level of 1 Gb/s (including mobile users) and backbone networks are headed towards terabit bandwidth. The most powerful computers will get to petaflops performance, and will be using advanced techniques of distributed processing in grids [11] and clouds [12] broadly. Technologies of Future Internet such as human (i.e. patient) digital surrounding, context- and semantics-based services, knowledge sharing and, last but not least, user-friendly, human-to-machine natural interfaces.

We have already set the concept of the integrated Health LivingLab platform against the above-mentioned trends in [13]. In this context a broader question about the significance of this development for eHealth global attitude and the role of future regional systems has to be raised.

III. eHealth Ecosystem

A. The concept of eHealth ecosystem

To some extent the healthcare system should be a reflection of some reality. Patients live in smaller or larger families within a particular area (i.e. regions). Consequently, it is natural that they look for help and care in their proximate surroundings. However, in difficult cases both patients and regional healthcare 'actors' look for any kind of support in collective competences and experience. More often than not and at the same shared level, the scientific research is carried out, and the unique diagnostic laboratories can be accessed together with other resources which might be helpful and promising in solving complex problems. Such healthcare ecosystem can be visualized as 'the healthcare tree' (Fig.1).

After its integration with broadly understood advanced ICT tools, the healthcare tree makes up a three-layered architecture of the patient-centered e-Health ecosystem containing corporate eHealth platforms, regional eHealth platforms and family (or individual) eHealth platforms (Fig.2).

B. Corporate Networks

The first level of connectivity within the eHealth ecosystem is provided through the dedicated network. Parties which are usually connected to the Internet via different ISPs can join this backbone network through Virtual Private Network (VPN) connections provided for them by particular telecom operators or ISPs.

This level can be associated with the range of university hospitals and main (national) specialistic medical centers. They are usually equipped with rare, complex diagnostic instruments, specialized ICT applications, which support medical processes. They are very often related with research on understanding and eradicating diseases or drug discovery. Therefore, we define this level as a corporate networks level. The authors declare in [13] that this type of a network can be effectively developed and deployed using scientific IT infrastructure (e.g. eInfrastructure in Europe, Cyberinfrastructure in USA). Such a trend has become a leading force for new strategies, e.g. ICT Infrastructures for e-Science in Europe [14] and US UCAN project with Internet2 in USA [15].

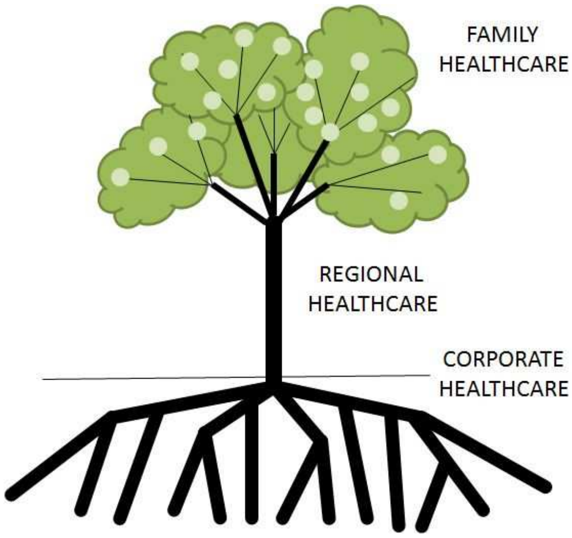

Figure 1. The Healthcare Tree

The corporate network level can connect and provide other components which are essential for applications delivery. They may include applications for disease research and treatment organization, teleconsultations, medical teleeducation, virtual laboratory for medical imaging studies and diagnosis, as well as diagnosis support.

C. Regional Networks

Regional Healthcare Networks have been established in Europe in many different regions. They are generally one of the most important outcomes of EC strategies in the development of infrastructure for healthcare. The region is the most natural environment which brings together all the actors involved in patients' healthcare. Some projects introduce collaboration as the most important feature of these networks at this moment [4].

D. Private Family Networks

The patient groups in private family networks will be,

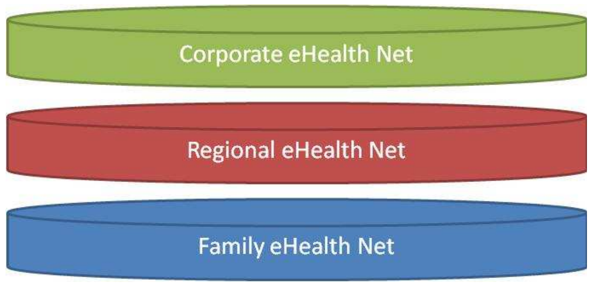

Figure 2. Patient centered eHealth ecosystem

first of all, families: it seems that due to the inheritance of certain diseases, or inheritance of susceptibility to diseases, enabling an integrated analysis of medical data concerning ancestors will potentially allow to diagnose diseases quicker or implement better prevention. As a new concept it requires more attention.

The patient environment includes various biosensory equipment allowing to measure vital health signals or otherwise (semi-)automatically control diagnostic or therapeutic processes. Some examples of such equipment are: pulse oximeters, blood pressure monitors, glucose meters, ECG meters, weight scales or insulin pumps. These devices are usually connected to mobile phones, PDAs or PC computers to allow receiving of data from the sensors and transmitting the data for further processing. Due to their personal character such devices are a permanent part of the Private Family eHealth Network of the given patient. On the other hand, the patient may also be temporarily exposed to the activity of other equipment, or find him/herself in an environment where a specific condition is also monitored in addition to the patient's vital signals. Such equipment includes various imaging modalities (e.g. USG or Computer Tomography) and public space environment sensors (e.g. measuring air temperature or pollution). Such devices will get connected to the Private Family eHealth Network for the time required to acquire the patient's data and transfer them to his/her PDL. Finally, the backbone eHealth network will include, in addition to all networking devices allowing to maintain an active link between all systems in question, systems that either contain some vital information concerning the patient or should receive the data stored in PDL. These systems are, among others, hospital information systems (and information systems installed at other healthcare institutions) that store parts of patient's Electronic Health Record (EHR) and serve as an entry point for the medical personnel supporting the patient. The concept of such network and application scenarios was introduced in [16].

E. The new concept for eHealth infrastructure

In corporate networks interesting medical data which are broadly used in research are gathered. However, when looking from the research perspective, those medical data which are gathered in network from other layers, i.e. RHCNs and Family Networks, are of great importance. Thus, the problem of using these data is the main reason for building global or federated repositories of medical data. Such a scenario can be realized through mechanisms of the Medical Digital Library [9][10]. However, modern medicine is currently facing the problem of searching and processing within mass data space. To reduce this problem we propose to apply in the medical data layer a solution of Smart EHR, which was originally designed in [40].

To illustrate the potency of integration with ICT and to show how fragmented and interregional communication between platforms could be changed, gaining from technological achievements we concentrate on two areas of the interoperability: communication and data layer.

IV. MECHANISMS FOR GLOBAL INTEROPERABILITY IN THE EHEALTH ECOSYSTEM

A. Communication interoperability conditionning in the global eHealth system

The internetworking communication is the first paradigm which is critical to guarantee the interoperability in the global eHealth system. This paradigm concerns both the communication between systems in the scope of the same architecture layer (i.e. within the corporate platforms or regional platforms or family platforms) and the communication between systems from separate layers.

Private, family healthcare networks form an environment for communication of digital medical devices, which can be located in the patient surroundings: in their house or in their private space. Moreover, an environment of this kind is natural for storing, management of and access to Personal Health Records (PHRs). According to concepts introduced and realized by our team within two projects [17] and [18], these records are to be stored in the so-called Patient Digital Library [19]. We will continue the discussion further on, but evade issues which are related to standards for data acquisition from medical devices, standards for storage and representation of medical data as well as standards for communication in telemedicine.

We will face the problem of communication between family eHealth networks with their neighborhood, mainly regional eHealth networks. This connection hereupon has to guarantee appropriate parameters in terms of bandwidth, robustness and security. Many authors (e.g.[20][21]) point out problems with sustenance and attainment of these parameters at the level required by eHealth applications. One should also remember that the communication with RHCN has the dynamic characteristics of the Internet (excluding specialized constant monitoring) in the extranet alike structures as well as that the patient exploits the Internet also (or even mainly) for the purpose of other services.

The crucial role in a substantial revolution in communication means will be played by widespread new networking technologies such as: fiber to the home (FTTH) in the structure of wired NGN [22] and LTE in wireless networks [23].

Target bandwidth, which is for instance expected to be offered within European home networks, is at a minimum level starting from 30 Mb/s, through 100 Mb/s and up to 1 Gb/s [24], and a wireless networks from 150 Mb/s to 1 Gb/s. Making such a breakthrough is expected to come not only in the stationary communication but also in the mobile one, which will influence patient availability anytime and anywhere.

This advancement will also enforce a comparative change in eHealth networks at the higher layers, i.e. regional and corporate ones, in which the necessity will occur to handle the aggregated traffic as well as the accessibility of networking and information resources with respect to economic factors, i.e. costs of network connections and other essential resources. This change has, among others, an effect on the necessity of building dynamic links but with predictable parameters.

In the authors' opinion, this problem can be solved by applying technologies and mechanisms of the Future Internet: virtualization of networks and protocols for integrated information and network resources management.

Virtualization can be applied to any resource which has a feature (possibility) of managing a part of a given hardware, software or information resource which can then make up a logical functional entirety. As an example we can quote wired and wireless networks appliances (e.g. switches, routers, access devices, base stations, controllers), computers, external storage, archive systems, operating systems, applications as well as content. Then, it is possible to create (also dynamically) virtual slices of physical resources which are dedicated for particular tasks, services, user groups in an economic manner (sharing of costs related to the usage of resource), with regard to security (dedicated resources) and reliable (easy options for resource multiplication and replacement of broken parts). The concept of virtualization is not new (compare [25]); however, nowadays it becomes a ruling paradigm for building emergent systems.

From the perspective of the main (common) communication medium the above mentioned concept enables the opportunity for building parallel (e.g domain or service specific) Internets (e.g. MANA project [26]), parallel interfaces between user and internet and, moreover, information driven networks (e.g. 4WARD project [27]). As an example of such parallel internets an eHealth Internet can be considered.

Through virtualization the process of eHealth networks assembling will become easier. In networks of local operators and ISPs, users (Family Healthcare Networks - FHCNs) will obtain access to the eHealth Internet (see below), and thus to services provided by family doctors or specialists as well as to other healthcare services, realized in typical RHCNs. The system (cloud) of networks connected this way simplifies the development and deployment of new eHealth services, and facilitates the transfer of services available up to now in former systems of RHCNs towards a new, more efficient and secure platform (Fig.3).

The RHCNs cloud, understood as an eHealth Internet, allows any user of this system (i.e. patient) to choose best possible medical services, advice, consultancies, etc. with regard to individual requirements and priorities. This way, the competitiveness and quality of available services will grow. Particular RHCNs can also create eHealth federations which handle more complex services taking into account narrow specializations, consultations, respite care, etc. It is also natural that an opportunity for creating and management of virtual professional communities in RHCNs (e.g. oncologists, urologists, surgeons) is their important feature.

At the top level of knowledge and competence, very advanced eHealth services are generated, and research often related to grand challenges in medicine is carried out. Among such advanced services we can name processing and simulations of models of diseases, parameterized with individual patient data, searching for similar cases, clinical decision support, an access to medical archives, usage of virtual laboratories, immersive work, teleconsultations,

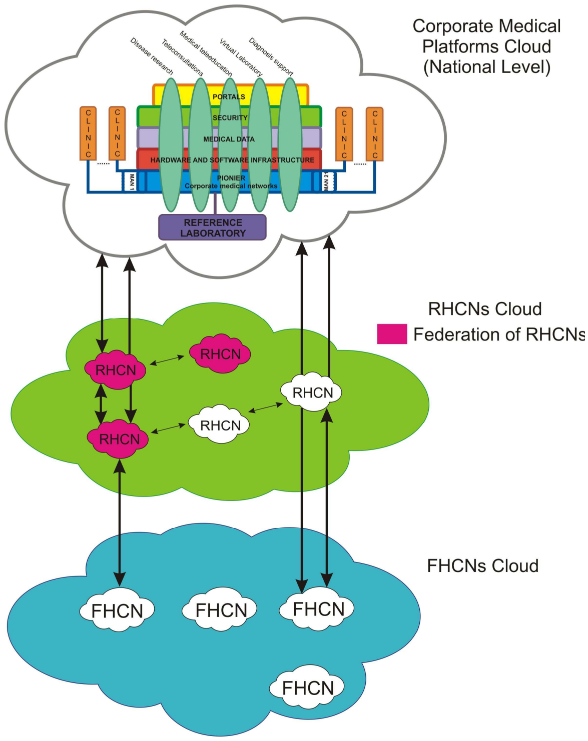

Figure 3. Family, regional and national levels of eHealth virtualized infrastructure

remote surgery transmission, teleeducation and telementoring. For this reason, in the last 10 years some successful approaches have been applied in the area of grid processing structures to build these types of systems [28][29][30]. Recently, this approach is referenced as cloud processing.

One of the main problems to be handled is the configuration of such resource virtual infrastructures to realize particular, dynamic tasks offered by RHCNs. It is a complicated and difficult process. Whenever any part of the requested infrastructure, at any level of the assumed architecture (e.g. eHealth corporate platform) is not available in the traditional system, then after allocated resources in lower layers (e.g. network) become available, the process has to be reiterated. The number of such iterations can be large and also economic calculation is not meaningless here.

In order to avoid aforementioned situations and make the process of building virtual infrastructures which are temporarily dedicated to handling of eHealth services faster, we propose to apply the specialized protocol for integrated control of networks and resource, namely G^2MPLS. In particular, this protocol can be broadly used in communication between the eHealth corporate platforms cloud and RHCNs.

The protocol G^2MPLS is an extension of ASON/GMPLS standard architecture. It facilitates one step allocation and provisioning of network and grid/cloud processing resources.

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The protocol has been developed by the international team involved in the Phosphorus project, which was coordinated by our team [31].

G^{2}MPLS Control Plane, its architecture, services and interfaces are precisely explained in [32][33][34]. The outlook for the model architecture is presented in Fig. 4.

The left part presented in Fig. 4 comes from [33] and illustrates the place in which the G^{2}MPLS protocol is placed in the architecture of advanced systems of distributed processing (grid/cloud). Then, on the right side the corresponding layers of the corporate eHealth platform introduced in [13] are presented. It is important to remember that advanced applications which make use of grid/cloud processing in this platform own the resources that for efficient cooperation require very fast connections which can be obtained in optical networks.

In order to present the usage of this protocol for the purpose of eHealth tasks control, we can imagine several scenarios of communication between corporate networks and RHCNs which require allocation and provision of particular resources able to provide the requested functionality (Fig. 5).

B. *Smart EHR*

The EHR allows to provide health professionals with a better knowledge of the patient's history and of previous interventions by other colleagues. For many years different concepts of integrating patient medical records have been introduced, starting from [35]. Various concepts can be seen for example in [36][37][38].

The communication model defined for a Smart EHR is to be supported by particular services enabled in all layers of an eHealth ecosystem. The key difference between this concept and traditional PHR is that in our opinion most interactions between a patient and a doctor will happen at the regional level close to the patient's permanent location, whereas patient appointments with other doctors may happen spontaneously due to increased patient mobility. In this case, the patient will contact a doctor assigned to another hospital often located in a different region or country. However, patient's virtual health records should always be accessible on-line via the established Network of Trust connecting legal Trusted Third parties which protect and maintain patient records. The patient has full control over his or her data and can provide limited access to any doctor during a certain diagnosis or accident. However, even then the data transfer and all updates should be monitored and audited by a Center for Data Protection responsible for on-line transactions on health records. Thanks to innovative and powerful data integration and exploitation tools as well as multi-scale modeling and large-scale simulations that have been demonstrated in the ACGT project [39][40], we may also envision innovative healthcare services considering and integrating data from the molecular and basic organs to the living organism level that will also be part of the virtual health records. Thus, not only basic historical data will be collected in the trusted networks, but also more sophisticated data structures integrated with personalized computing models for better prediction and treatment of diseases will be available. Depending on regional health problems, local

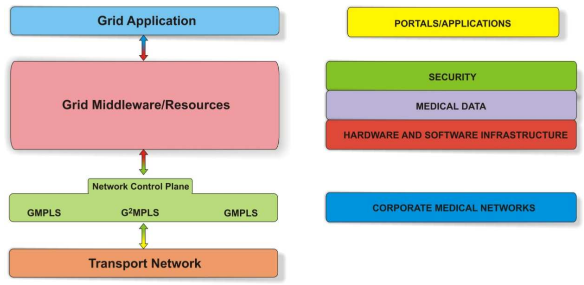

Figure 4. An outlook for G2MPLS architecture

epidemic warnings or key medical challenges (e.g. malaria and cancer treatment) patients will still be encouraged to grant access to their virtual health records to external researchers and medicine experts in a way they fully control and agree upon (e.g. only anonimized data access).

V. IMPLEMENTATION CONDITIONS

A. *G2MPLS*

For the aforementioned scenarios we can provide a simplified communication schema which is based on the G^{2}MPLS Integrated Model (Fig.5).

In this model, G^{2}MPLS is responsible for scheduling and configuring all the job parts, those related to the Grid sites and those related to the network. It seems that at the network level the knowledge has to be available, regarding grid/cloud resources. Regardless of this, to coordinate workflow services, the separate grid/cloud scheduler is required.

The major part of research and development work has to be done in the range of discussed technologies and mechanisms, however one can undoubtedly declare, that problems seem to be solvable within next 5 years and it is possible to provide the basis for the building of a New Generation eHealth System.

It is also worth mentioning that both the resource virtualization functionality and the new protocol for control of resource availability assume that previous communication standards in telemedicine (e.g. HL7RIM, HL7CCOW, HL7v2.x 3.0, DICOM) are applied in this architecture, the above described functionality of the Future Internet.

B. *Smart EHR*

The most important role in data integration is played by a Master Ontology developed for ACGT. It is used for

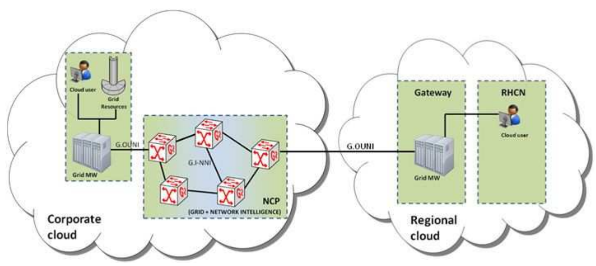

Figure 5. G2MPLS based simplified communication

describing (annotating) the information in the heterogeneous data sources integrated within ACGT environment (Fig.6).

The model chosen for data integration is Query Translation, therefore data stays in their physical location and a virtual view represents the integration. It is realized by

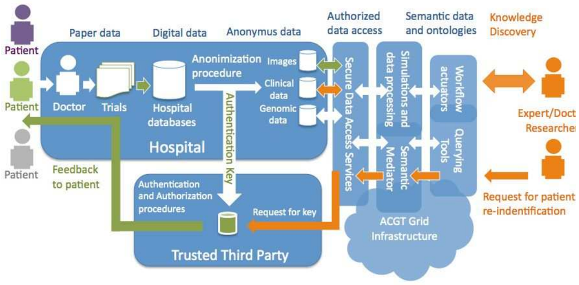

Figure 6. The example of logical data integration in Smart Electronic Health Record

introducing a Semantic Mediator. It requires the creation of a view for every single data source using terms and relationships from the Master Ontology. These views are created through a Mapping process. During the Mapping process, correspondences between elements in the data sources and terms and relations in the Master Ontology are created. These correspondences are used to carry out the query translation. Once a query is performed, the mediator splits it into the necessary queries dedicated to the underlying data sources. Each of these queries passes through the mapping filter which converts the terms and relationships from the Master Ontology to the original database vocabulary, generating the final queries in SPARQL to be sent to the database wrappers.

The results are obtained in the database wrappers result set format. The mediator annotates them using the Master Ontology and finally retrieves an integrated set of results in OWL.

VI. CONCLUSIONS

Recently, people have become more mobile and therefore more often than earlier require help, advice or even medical treatment provided outside their natural regional surroundings. Medical tourism becomes more and more popular, especially in Europe. Patients who need help, either occasionally or intentionally, may decide to be provided with medical services in any place and any time. To receive valuable service they will require access to their complete medical data records. Such patient-centered approach requires new apporaches in the organization of the global eHealth system.

The proposed concept of communication between corporate eHealth platforms, regional healthcare networks and private family networks introduced in this paper builds upon the concept of an integrated eHealth LivingLab platform. The global eHealth ecosystem defined in the proposed architecture is related to three very important paradigms: virtualization on every level, new generation communication protocols between these systems and finally smart electronic health records.

Previous achievements and the level of solutions available up to now set particular conditions for evolution in the process of migration from the existing architecture towards a global new generation eHealth system.

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