CLAP: Cross-Layer Protocols for Phealth

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ABSTRACT

In recent years, personalised health is rapidly gaining momentum as a result of advances in various technological areas, prevailing amongst them the ICT domain. However, the new applications are still mostly a dream for the majority of the world population due to cost and infrastructure constraints. We present here initial findings of a low cost, low power, backbone free pHealth solution, suitable for rural areas of developing countries. This work constitutes the technology core of a wider initiative, CLAP, that we envision as a turnaround approach on the way health and quality of life in these areas of the world are being addressed.

KEY WORDS

Rural health, Wireless Sensor Networks (WSNs), Personalised Health (pHealth), ad-hoc networks, energy constrained networks

1. Introduction

Wireless Sensor Networks (WSN) have recently emerged as a new networking environment that provides end users with intelligence and a better understanding and interaction with the environment. For instance, a network of wearable wireless vital sign sensors (including electrocardiogram, blood pressure, etc.) and mobile wireless display devices can be employed to monitor patient health in an outpatient environment (e.g. home or care center).This is one application of the research discipline known as phealth.

Personalised Healthcare (phealth) is a collective term aiming to reflect all modes of patient-centric healthcare delivery via advanced technology means. Personalized health involves the utilization of micro and nanotechnology advances, molecular biology, implantable sensors, textile innovations and information & communication technology (ICT) to create individualized monitoring and treatment plans. pHealth proactively endorses the sense of "one-to-one" communication to elevate healthcare delivery, optimize patient services and ensure seamless from the patient point of view information exchange.

Recent developments in ICT technologies have enabled the creation of electronic communities of educated users in technologically poor or even virgin environments. Such examples may be found in initiatives like OLPC [1] or Moca [2]. , The two major challenges for those parts of the developing world that have found (even partial) solutions on uninterrupted sypply of drinking water and nutrition are health status together with education. An interconnected community (even with limited or low-quality access to a backbone network) has the means to support activities aiming at facilitating disease management and health status control within a larger than the community's population (e.g. adjacent villages). Such activities may include the implementation of pHealth scenarios in which a WSN-like infrastructure supports monitoring, processing and transmitting of personal, ambient and environmental parameters.

A number of research challenges lay ahead in reaching such a vision. CLAP is an ambitious research initiative, whose primary results are presented in this paper.

Today's pHealth systems assume a technology advanced environment. Mitigating it to the developing world reality should take into account power consumption, network bandwidth and processing limitations. On top of that the community oriented health monitoring is a novel concept, that, to the best of our knowledge, we introduce it here for the first time.

pHealth and community health respect the modern view on health, as promoted by WHO, i.e. not the absence of illness, but rather the well-being of the individual, which is primarily affected (controlled) by her environment of living and her lifestyle.Thus, integration challenges are foreseen as well.

This paper is organised as follows. The research challenges and objectives are next presented (Section 2). The conceptualised implementation framework for CLAP is explained in Section 3. In Section 4 the proposed network protocol is described. Relevance to previous work is discussed in Section 5. Case studies proving the pHealth concept in the developed world are presented in Section 6. These results are used for the elaboration of CLAP developed world pilots. Section 7 addresses the important and challenging issue of interoperability and 8 that of security and privacy. The paper concludes with a summary of the results and a discussion on future work.

2. Research Methodology

Some of the key research challenges in WSN deal with the design of simple and efficient protocols for different network operations, design of energy conserving protocols, scalability of network protocols to large number of nodes, design of data handling techniques, data fusion and dissemination, localization and most important of all the development of exciting new applications exploiting to the maximum WSN's potential. This work contributes to the solution of some of the aforementioned problems, by proposing energy efficient techniques and resource allocation schemes based on cross-layer and cooperative transmission in self-organised WSN based on the 802.15.4 legacy.

It is well known that **cross-layer** (CL) approaches, aimed at introducing some degree of knowledge between functionalities in different layers while preserving consolidated protocol stack architecture, might result in more efficient implementations of WSN. The interactions between Physical (PHY) and Media Access Control (MAC) layers are the most important, but they can also affect upper layers and, for example, they can be used to influence the routes through the network in a multi-hop communications layout. If session routes are not provided, then route links need to be carefully selected, since path proximity affects interference and hence energy efficiency. Therefore, in order to enhance their efficiency in terms of energy consumption and Quality of Service (QoS) requirements, advanced cross-layer techniques taking into account the particularities of the WSN are of great interest and pave the way for further research.

It is important to develop and propose novel algorithms and mechanisms that allow a set of free nodes to get somehow self-organized taking decisions in a distributed manner. Some recent proposals for ad hoc networks are based on clustering. **Clustering** offers mainly three advantages; first, it reduces the amount of network topology update information, second, it reduces the routing control information, and finally it facilitates the channel reuse, therefore, increasing the capacity of the network. Due to the particular characteristics of WSN the previous proposals for ad hoc networks cannot be directly applied, so new proposals need to be studied within the context of this project.

Channel variability is one of the main obstacles for reliable communication in WSN; multipath propagation results in signal fading. Interference between simultaneous transmissions is also time varying. The traditional approach consists of countering these effects using power control which is not appropriate for sensor networks, since it is not energy efficient.

An alternative approach consists of generating diversity and using it at the receiver to decrease outage probability. In addition, in sensor networks communication is usually of a multi-hop nature, which makes it vulnerable to the worst link of the end-to-end communication. In this work the new approach proposed is about exploiting the high density of communication nodes of a WSN in order to improve the network performance. This is possible through the **cooperation** of wireless sensors, which has the following advantages:

• Increased robustness of the received signal when the transmitted signal is relayed by one or more neighbouring network nodes

• Reduced energy consumption: the signal reaches the destination through several independent paths, resulting in channel diversity, which reduces the necessary transmitted power.

• More efficient multi-hop propagation.

The key idea is to form virtual antenna arrays where each node acts as a single antenna and cooperates with the other nodes to help out in the communication links. Cooperative transmission is mainly motivated by the broadcast nature of the radio channel. Whenever a station transmits a message, all stations in its neighbourhood can overhear it and help out in reaching the intended destination, therefore, acting as relays. Such mechanisms require research on the coding schemes used for data combining, on Automatic Repeat reQuest algorithms, multiple access protocols, and routing methods.

Energy efficient and low power consumption devices are of a significant importance in healthcare applications. Since all these devices are battery powered the use of advanced techniques to improve their lifetime is a critical issue. Taking into account that the majority of these devices measures vital signs, techniques to increase their lifetime are of high importance for the healthcare domain. In addition, QoS requirements, such as latency and reliability, for the transmission of the measured signs pose another critical issue for WSN in the healthcare domain.

Therefore the use of CL techniques and cooperative transmission can enhance the efficiency of such kind of networks. Moreover, in healthcare the privacy and safety of patients is of paramount importance. However, the WSN vulnerabilities pose a significant risk when used in medical applications. Consider, for instance, the effect of somebody wirelessly modifying an electrocardiogram from a normal to a flat signal during an operation, or the effect of an intruder wirelessly switching a respirator off. Therefore, medical WSNs must be provided with the most effective security means. These issues however, will be dealt in future work of CLAP.

Thus, in a nutshell, our main research short-term objectives include:

1. Definitions of a protocol stack architecture able to accommodate a rich variety of sensor devices and applications.
2. Propose Cross-Layer techniques that can be used in order to enhance the efficiency of WSN for pHealth.
3. Propose new efficient cooperative protocols network coding schemes for health related applications in rural settings WSNs.

4. Define the requirements for providing isolated (not only in the narrow sense of geographical isolation, but in the wider sense of societal , economic even race based isolation) communities with modules for personal and environmental monitoring to facilitate improvement of quality of living and support for patients and local carers through the provision of ICT services.

On-going research work in CLAP will further expand our objectives to include:
5. Adapt the proposed protocols and algorithms to the requirements of the applications defined here.
6. Develop a prototype for demonstration purposes and validate the feasibility of the proposed approaches.

3. Application Framework

Our conceptualized framework consists of four interacting clouds. Wireless sensor networks collect data from monitoring a wide variety of quality of life (QoL) parameters, such as environmental characteristics (water, soil, air, volcanic residues etc), vital signs, health related human receptors, behavioral patterns. This is referred as cloud A. In this cloud, sensors are deployed in crucial parts of the rural areas, that could range from river banks, geographically challenging parts (for example; hilly areas), schools, gathering places, homes, down to individuals. The sensor networks could collect various critical data (e.g., level of water in the rivers which could help for flood warning, earthquakes etc.) and send them to gateways (sinks is a term widely used in WSN literature as well) referred as cloud B.

Usually each of the villages or rural areas has at least one cloud B installation. A cloud B acts as a store & forward facility for the acquired data. In addition to the data collected by the wireless sensor networks, a cloud B may support the collection of other useful data like demographic data, health care information (for example, swine flu reported cases in the rural areas of Mexico), agricultural information, etc. that could be manually or semi-automatically entered. Different solutions have been proposed in the literature to implement cloud B functionality, ranging from kiosk/truck [3], to satellite stations [1], to mobile phones [4]. **In our framework a cloud B is implemented by networked communities that pre-exist for some other reason or are formed for this particular case.** Examples of such network communities may be found in a OLPC equipped village, a mobile phones carrying community or a hospital on wheels, a vehicle mounted medical facility with wireless access functionality. A cloud B may move around the rural areas and serve numerous clouds A implementations or may be attached to only one and collect data only from it. As conceptualized here **cloud B is a distributed self-organized collect, store & forward facility.** One implementation approach to materialize a cloud B is to form wireless ad hoc networks based on PCs (or laptops as a matter of fact). Another approach is to form a Near Field Communication(NFC) network based on mobile phones. A third one would be a tagging network based on RFID and spinners [5]. Independent of the implementation approach any cloud B is able to:

a) Collect data from cloud A installations
b) Store this data and (optionally) additional one
c) (optionally) process all sdata
d) Communicate data to the outer world

Data communication from a cloud B to the outer world is performed by facilities referred as cloud C. The major task of a cloud C implementation is to ensure reliable acquisition and delivery of data from the rural areas to a centrally located center referred as cloud D. A cloud C facility is capable of (wirelessly) communicating data acting as a repeater or router. It may additionally have capabilities for incoming data to be stored temporarily and/or processed. Examples of cloud C implementations may range from very simple solutions of one single PDA carried by a mailman or a drinking water distributor, to more complex facilities of satellite-linked equipment or vehicle mounted communication amenities. Note also that depending on the country and application specifics some implementations may optimally decide to combine cloud B and C to one facility or (less likely) cloud A and B to one installation.

A cloud D collects (processed or raw) data from cloud B installations communicated through the corresponding cloud C facilities. A cloud D would combine this with data from other cloud A implementations and past records for a particular rural area or a number of selected areas and supply it to a referral center (which could also combine decision and action government powers). In this way, the government gets the timely and processed data from the rural areas and accordingly decides on the necessary actions. This data not only help the government to provide various services to rural areas and make educative strategic decisions and planning (as for example by monitoring behavioral patterns and socio-economic indicators), but could also help in combating emergency situations as well as for their prevention (among the many examples one could think, the most self evident are epidemic/pandemic outbreaks and natural disasters).

4. Network Formation Algorithm

We describe a sensor network formation algorithm to exploit the application environment in the framework presented previously. The sensing nodes (we will refer to them as motes in this paper) form Cloud A. The network is formed in four phases with the aid of an existing peer-to-peer Wireless Mesh Network (WMN) (Cloud B). The four phases are summarized in Table I.

4.1 Phase 1: Assumptions: IEEE 802.15.4 parameters

Motes self-organize themselves according to IEEE 802.15.4; self-organization implies that all motes have the status of an FFD [6].

In our application scenario an ad-hoc clustered-tree multi-hop topology is supported (figure 1). Cluster heads and network coordination is assumed by Cloud B nodes. This results in higher energy efficiency and longer lifetime for Cloud A. A beacon mode with a superframe is used.

Phase 1: <kick-off> Figure 1	Motes self-organized or pre-programmed. Sinks are preselected depending on geography (i.e. likelihood of node appearance), sensing parameters, storage capacity or arbitrarily.
Phase 2: <one node phase> Figure 2	A node in proximity advertises its presence; being the only node it serves also as the network coordinator and the gateway; if no B-C link exists information is stored in this node temporarily.
Phase 3: <structuring> Figure 3	As other nodes enter, motes reorganize themselves depending on the identity information advertised by the node; nodes self-organize to decide on clusters, gateways and storage
Phase 4: <steady state>	As more nodes appear the conditions for the motes become more favorable. Multi-hop link distances are reduced. The network reaches maturity conditions. Preselected mote sinks are relaxed to accommodate power usage and extend life time.

Table 1: The four different formation phases of the network

Parent and child roles are interchangeable. A child to mote X at some instance may become a parent to mote X. This is the result of changes in network topology as nodes of Cloud B enter, leave or move in respect to Cloud A. The phase 1 route formation of Cloud A (IEEE 802.15.4

Cluster - tree) is stored as the default status in every mote. Information regarding children and the parent is stored on the motes to be utilized by "upper layers".

4.2 Phases 2-4: Operation Phases

Once Phase 1 is completed and Cloud A is set to normal operation, Cloud B nodes will associate themselves with that network as sinks. In phases 2-4 of operation, where at least one node is associated with the network we witness the following types of motes at a given instance:

- Hop 0 motes: motes with a neighbor node
- Childless motes: motes without any children; all phase 1 sink motes and all phase 1 childless motes that are not hop 0 motes and only these fall in this category
- Parent/ child motes: motes that have both a parent mote and one or more child motes.

Each mote maintains a look up table of available nodes (nodes in range). As nodes advertise their presence (or leave) the lookup table is updated. The node that serves as a parent to a mote is not part of the table. Whenever more than one nodes are available the look up table contains the Presence Entry information of all of them except the parent node.

4.3 Physical layer

We assume a set of motes forming an IEEE 802.15.4 tree topology Wireless Ad-Hoc Sensor Network (Cloud A) [7]. Additional to the motes we assume a set of nodes forming a mesh network using the OLPC PDM algorithm (Cloud B) [1].

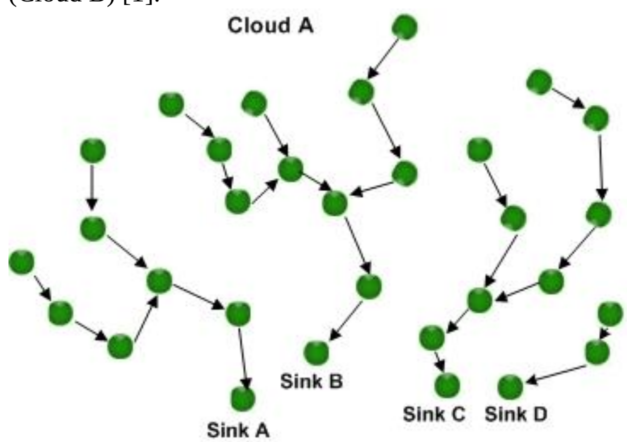

Figure 1: Phase 1; typical IEEE 802.15.4 clustered peer-to-peer ad-hoc formation

Considerations at the PHY layer include band selection (e.g. 2.4 GHz is an unlicensed Industrial Scientific and Medical (ISM) band, thus costs are reduced, but interference is a serious consideration to be studied), antenna design and System on Chip (SoC) specifications. These issues are not addressed in this paper.

4.4 Presence Information

Each node advertises itself as a sink to Cloud A. This is achieved by having each node broadcast a Presence Entry. All motes that receive the Entry and do not have a one-hop relation to another node set the advertising node as their sink. Motes that already have a one-hop relation with a node ignore the invitation In this case the network topology does not change in the child tree branches of these motes.

The motes that decide to accept the node as a cluster head, become hop 0 motes for this cluster. The first node that arrives in the proximity of Cloud A assumes the role of the coordinator of Cloud A (figure 2). All subsequent nodes will form independent clusters. The coordinator could act as a Cloud C gateway as well; The coordinator role may be transferred between nodes.

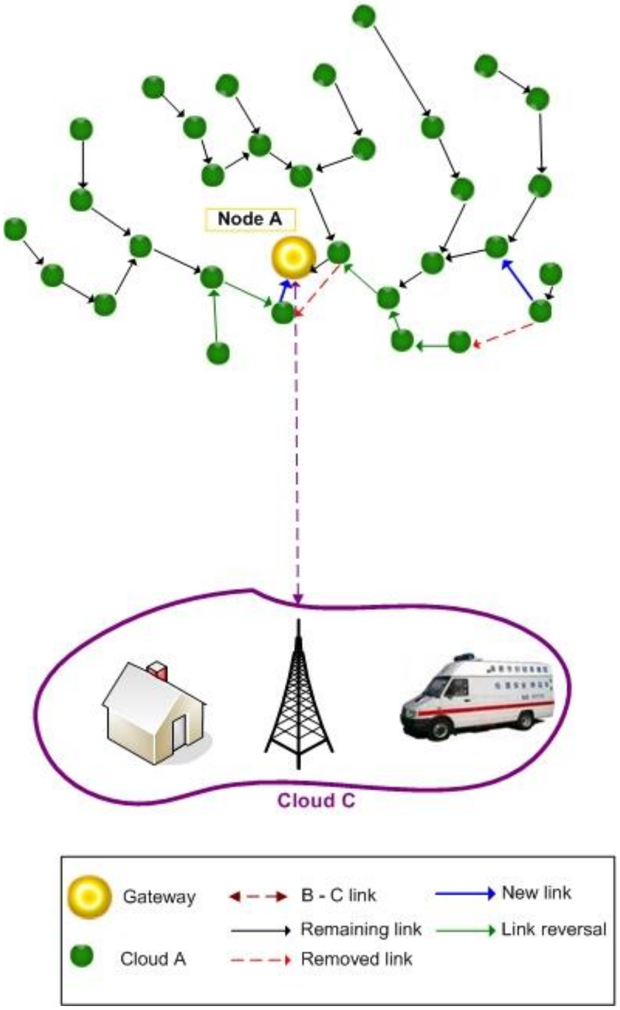

Figure 2: Phase 2; Network in its infancy

4.5 Clustering

Nodes broadcast Presence Entries as they move. When a mote establishes a direct connection with a node, it informs its neighbors; for this purpose it transmits a Presence Entry. In case any of these motes has a 2 or higher hop distance, the other motes transverse their traffic to the mote in question. It may be that the parent of this mote will now become its child (figure 3). In general, whenever a node sends a Presence Entry the following changes in the routing path may occur (in all cases motes disassociate from their past parent node and associate with the new one):

a. Cloud A links broke for the motes that connect directly to the node.
b. Cloud A links reverse for the parent motes that decide to use a (new) route to case a motes.
c. New cloud A links are formed; for each link formed one link disappears.

Motes propagate backwards the new routing status. When any of the above changes occur a new clustered tree network topology is formed.

5. Discussion

Various routing algorithms have been proposed for WSNs [8]. Among them the Minimum Energy Routing and the Minimum Hop Routing suffer from different inefficiencies, the main ones are that they deplete energy in certain frequently used routes and create congestion. Our assumption is that in our application scenarios all motes are equally important and share the same (energy and storage) characteristics.

Homogeneous approaches are closer to our needs. These mostly work by applying a probabilistic choice of the route to use (or the mote to send the next packet) over a set of routes or motes calculated or determined as of least power consumption or over minimizing a metric like residual battery life. All such approaches consider the network as a general purpose network. WSNs however usually do not fit into that rule; they tend to be application dependent, (almost) unidirectional and of predictable rate and thus data flow. In other words, WSNs tend to be (almost) deterministic, as opposed to general purpose (wireless) nets. This is particularly true for medical WSN application, where each measurement is usually equally (critically) important, but information regarding data type and flow is predictable to a high degree.

Application - based protocol design has been studied mostly for the case of cooperation schemes where measurements are inter-correlated and thus redundancy exist [9]. Our scenarios focus on independent measurements. The uncertainty in our case is “controlled” by the (moving) nodes of Cloud B. So at every transmission instance the mote (of Cloud A) has to find the shortest path to Cloud B, i.e. to its “closest” node.

We define presence as a new way of routing. This approach has recently been demonstrated successfully in a mobile peer-to-peer network setting [10]. Presence information identifies a node or a mote in terms of its participation in a route (tree) in a sensor network. However, our problem is different from the aforementioned one for various reasons:

- Only (cloud B) nodes are mobile
- Only (cloud A) nodes transmit genuine information (nodes only retransmit)
- Broadcasting is not required (at least for data transmission)
- State information about a node or a mote does not contain application or user information; rather the status and it contains type.

Thus, our solution focuses on exploiting the collaboration of the two networks, achieving lower network formation traffic.

Another routing algorithm that resembles ours is Low-energy adaptive clustering hierarchy (LEACH) [11]. LEACH adopts a hierarchical approach to organize the network into a set of clusters. Each cluster is managed by a selected cluster head. Simulation results show that LEACH achieves significant energy savings. However, this is only achieved if certain assumptions are valid; these assumptions may evolve to become shortcomings.

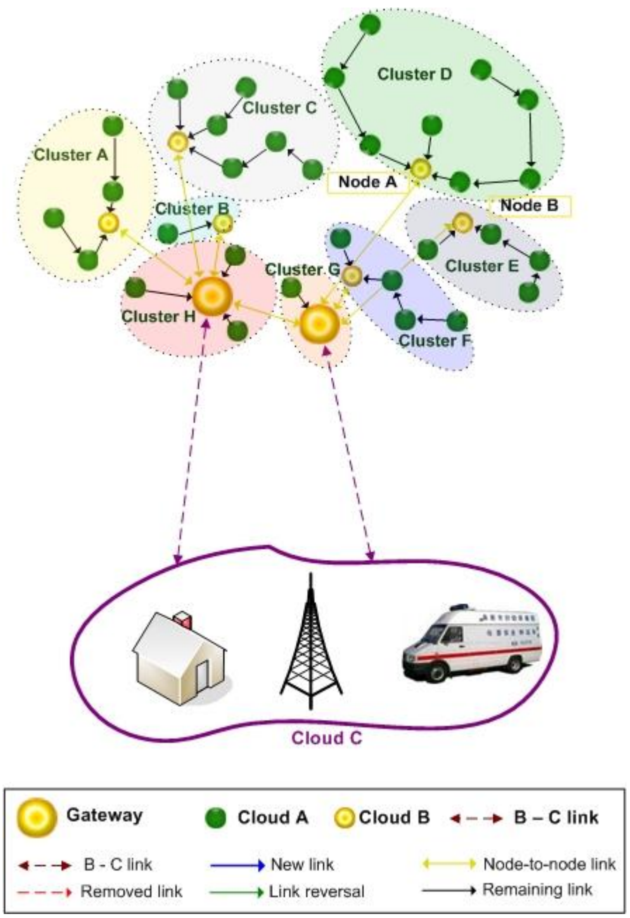

Figure 3: Phases 3&4; Structured Network and maturity

For example, the assumption that all nodes can reach the base station in one hop may not be realistic, and the length of the steady-state period which is critical to achieving the energy savings may not be suitable for particular applications. Our protocol overcomes these shortcomings by introducing application layer information in the decisions. For example, the rotation of cluster heads appearing in LEACH in order not to exhaust specific motes is irrelevant to us, as the Cloud B nodes are exploited. Furthermore, the steady state period is irrelevant of the protocol and is only dependent on the application features. Finally the cluster tree topology adopted is a direct expansion of the LEACH protocol. Note, that in a simplified case, where enough nodes exist to fully cover the network area of Cloud A, i.e. so as all motes become hop 0 motes, then our protocol operates as a static LEACH network, which is known to have superior energy savings compared to other existing WSN MAC approaches [12].

The network formation protocol described here resembles also the design and performance issues of cluster interconnection for beacon-enabled 802.15.4 clusters. Our approach, in which the cluster coordinator is used to bridge clusters, is known to be superior in terms of traffic and efficiency and have the drawback that it becomes a single point of failure and a target for security attacks [13]. However, we overcome this drawback by introducing the Cloud B cluster heading, instead of a single Cloud A mote. To the best of our knowledge, this is an improvement appearing here for the first time in literature.

6. Case Studies

Existing case studies in developed countries help us design our application pilots for CLAP. We present in this Section two such case studies, whose results we use as a guide.

6.1 RHA - telemonitoring pilot

The Regional Health Authority - telemonitoring pilot has been designed with the aim to facilitate General Practitioners in completing every-day tasks and providing quality primary healthcare services to citizens. It is being implemented by the health units operating under the 3rd Regional Healthcare Authority in Greece, covering the Region of Central Macedonia so as to enhance access to specialized healthcare services in remote areas.

The pilot network implementation for the effective health monitoring in remote areas aims at the:

- Provision of advanced healthcare services, regardless of geographical limitations
- Preventive medicine
- Efficient human resources management (for the healthcare providers)
- Scientific personnel facilitation in everyday's activities and diffusion of specialized knowledge

The project generates significant social benefits and enables healthcare professionals to allocate their time in an efficient and effective manner, as they are able to manage more patients, since telemonitoring allows the simultaneous monitoring of multiple patients health status. Patient management and also, data management for each patient is improved, facilitating medication management and the completion of administrative tasks for the healthcare professionals.

The RHA - telemonitoring pilot concerns interaction between GPs and experts. The 3rd RHA is responsible for the coordination and implementation of health care policies and services in the corresponding geographical region. In the frame of the project implementation, the health-centers of five remote areas were equipped with sets of telemonitoring devices for the provision of health telematics services.

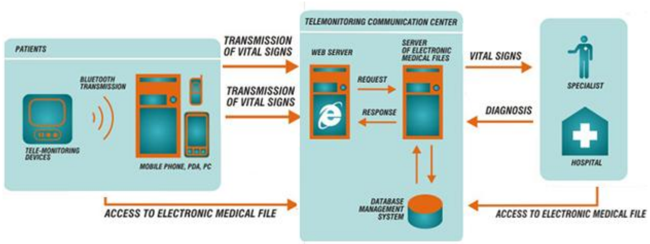

Figure 4: Rural Health Information Flow

Early in the project's lifecycle at design and planning phase, several health units expressed interest in participating to the provision of the telemonitoring services in rural areas. However, these health units operate under different regional healthcare authorities that due to legal and organization complications restricted their participation to the project. As a result the project implementation team faced the selected participants reluctance to change and dealt with it by trying to provide motives for participation, such as the provision of anonymous medical data from the project database to the participants, so that the later will be able to present papers in scientific conferences and journals.

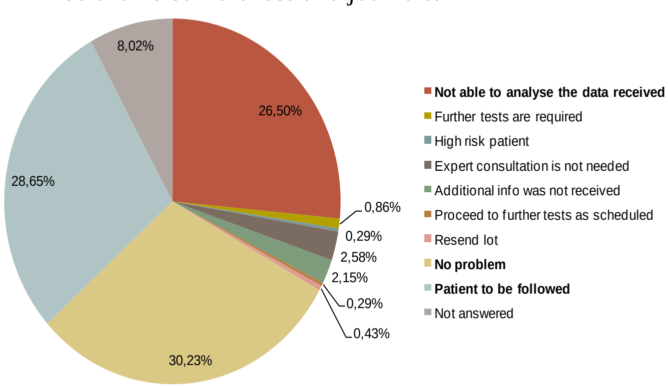

Figure 5: Types of consultations feedback

6.2 Rural Healthcare

A pilot study to assess the performance of the development of a new telecare service for rural areas of Greece featuring a pilot telemetry network has recently reached its mid-life. The network was established in 2008 in 25 remote and isolated rural municipalities of Greece, 10 of them located in islands. The local primary health services were equipped with vital signs telemonitoring devices. At these points the family physicians record the vital signs of the patients suffering from chronic diseases (cardiovascular and respiratory diseases). The data collected by various vital signs sensor devices (Cloud A), are transferred through IEEE 802.15.2 (Cloud B) and are finally transmitted over GPRS (Cloud C) to a central webserver (figure 4). Specialized physicians in Athens consult the recorded measurements and provide advisory diagnosis to the local physicians, nurses or paramedics (figure 5).

A retrospective evaluation study was designed to evaluate the initial 6 months of the network being fully operational. Evaluation criteria measuring the adoption and the outcomes of the implementation of the specific telecare service were based on the recommendations of the WONCA on ICT to Improve Rural Health Care [14].

In total 777 different tele-consultations, evaluating vital signs transferred (figure 6), took place and 2206 logins in the online patients' health records database, with the level of adoption of the telecare services by the local health professionals in everyday practice to vary significantly (figure 7).

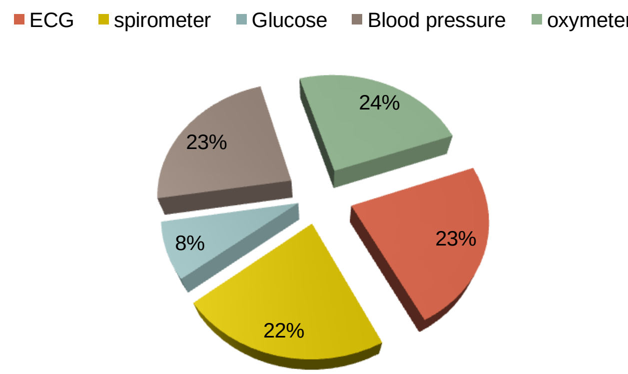

Figure 6: Vital signs measured

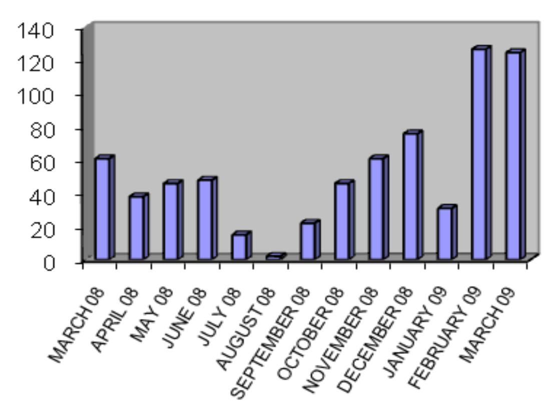

Figure 7: Consultations

So far the study's conclusions can be summarized to that the introduction of telecare services for remote communities cannot automatically be a benefit for rural health workers and the communities that they serve.

Ongoing support and commitment from all engaged partners is crucial in order to maximise the potential for successful and sustainable telecare services to rural communities.

7. Interoperability

pHealth interoperability brings a new challenge to healthcare. This challenge is of a new dimension and in a market environment where unfortunately the management of such processes among stakeholders is not yet in place. The aim of the effort is focusing on “what” needs to be done to deliver systems that will “plug and play” according to the specifications, following the examples of the IT industry in other domains.

Recently a number of coordinated efforts are attempting to overcome this barrier, i.e. lack of interoperability. On the one end the industry has formed international open consortia and alliances, such as the IHE, COCIR and Continua, to create interoperability profiles for specific use cases based on international standards. On the other end the European Commission and the Obama Administration have taken particular steps to encourage cross-border (cross-state) interoperability, the most prominent being the Mandate 403/2007 to CEN/CENELEC/ETSI [15] in Europe and the Healthcare Pact for the Electronic Health Record in the US [16].

A Quality Assurance process reinforcing interoperability may need to include some form of specification or labelling to allow for the easy identification by external parties of the implementation on which the quality assurance was effectively and satisfactorily performed. Many such schemes involving or not third party testers have been used in the medical industry.

The most prominent labelling initiative in pHealth is the Continua Health Alliance [17], a group of technology, medical device, health and fitness industry players, committed to empowering consumers and patients worldwide, to play an active role in taking care of themselves through the use of technology. They have recently unveiled their first set of guidelines, based on proven connectivity standards (i.e. IEEE 11073 and HL7) that will hopefully help to increase assurance of interoperability between devices, enabling consumers to share more easily information with care givers and service providers.

8. Security and Privacy issues

WSNs are particularly vulnerable to security attacks and pose challenging security requirements. Being inexpensive and, thus, no tamper-proof, limited in their energy, computation, and communication capabilities. Deployed in inaccessible areas, with data gathered from the environment, represent ideal targets for attacks not found in other types of wireless networks.

Therefore, security functionalities need to be distributed among (a set of) the WSN nodes. A security architecture for WSN must provide services of data and node authentication, access control, confidentiality and integrity.

We plan to employ a number of innovative approaches to build a comprehensive power-efficient effective CL-based WSN security architecture. Firstly, we will develop a key pre-distribution approach that allows for direct key establishment and exhibits limited resiliency and scalability [18]. Another problem we want to deal with is the updating of pre-distributed keys once nodes are deployed.

Secondly, we will develop security solutions for the proposed cooperative-based MAC approaches based on node reputation [19]. For instance, motes will overhear and control transmissions from other cluster motes. Malicious and misbehaving motes will be detected and rejected from the WSN. For this, we will exploit also the physical characteristics of the environment as allowed by the CL nature of our protocols.

Privacy aspects with regards to the sensitive data of health monitoring will also be taken into account while designing this architecture.

9. Conclusion

Costs and effort required for deploying and maintaining a medical sensor network in a rural undeveloped area, have to be justified. There must be a demonstrable and quantified benefit for all participants involved. Quantification examples range from minimizing the required personnel to operate a system, or the required (technological) literacy, to improving the accuracy of an information retrieval service, not to mention realizing a function that would not be feasible using other available technology. A wireless sensor network can only be helpful if there is a substantial need.

Therefore, many of successful developed countries applications (e.g. smart aeration and lighting control in apartments, extensive traffic monitoring in large urban areas, or supply-chain monitoring) are ruled out because they lack a broad need in developing countries. A requirements analysis is necessary, albeit a localized one as what is in need in an area may not be the case in another one.

Nonetheless, wireless sensor devices turn out to have a well-suited potential for many application areas in less developed countries. Because of their self-organising characteristics and robustness, wireless sensor networks can be deployed in less benign environments and inaccessible places as well as in places where employing humans is difficult or costly. Although back-end communication infrastructures are needed to interface wireless sensor networks with the Internet or a local area network, they can also function in the absence of any communication infrastructures. This makes them particularly attractive for developing countries where the presence of stable communication infrastructures as a prerequisite for deploying computing systems may not be feasible.

Today, a wireless sensor network is almost the only ICT means we have that can operate independent of any external communication infrastructure or/and electricity network. The CLAP initial results show promising potential in this area. In the near future we are planning a pilot roll-out of the system in a developing country to test it in an actual setting. Different possible candidates are currently being reviewed, many of which are OLPC villages.

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