Health Care Sensor Networks
– Architecture and Protocols

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Wireless sensor networks consist of a large number of tiny devices capable of executing sensing, data processing and communication tasks and as such can be applied in numerous user scenarios. Various military, security and environment monitoring applications are the most frequent examples. Another area that can also significantly benefit from advanced features of this technology is health-care monitoring. In contrast to the conventional, face-to-face oriented health-care systems organized around health-care centers, the new health-care paradigm presented in this paper relies on personal mobile health-care solutions that utilize ad-hoc networking principles and wireless communication technologies to provide continuous and unobtrusive health monitoring regardless of patient’s or caregiver’s location and activity. Health-care sensors worn by patients are controlled by user’s communication device (for example mobile phone) that automatically recognizes the sensors’ functions and establishes required communication links. In this paper, architecture of such systems is proposed and discussed. A flexible XML based communication protocol that supports various types of sensors is also presented. The concept of distributed, peer-to-peer, health care systems is also discussed.

1. INTRODUCTION

Wireless sensor networks research is primarily focused on large networks of tiny devices with sensing capabilities, able to perform simple data
processing tasks and to communicate wirelessly between themselves to exchange data. Once devices are deployed, networks are established automatically using self-organization protocols. Data is forwarded to appropriate sensor nodes using multi-hop routing protocols. The deployment itself is executed in an ad-hoc manner: dropping from a plane, firing from a cannon or scattering manually across an area. Small device size and wireless communication capability enable placement of sensors closer to the observed phenomenon than what is possible using conventional sensors, but result in a poorer sensor accuracy and sensibility. In order to circumvent that drawback, a redundant number of wireless sensors are used to monitor the same phenomena. Their observations are combined and aggregated before delivering final result to users.

Sensors communicate wirelessly using short-range communication technology like Bluetooth, ZigBee, UWB (Ultra Wide Band) and simple RF communication etc. Available data throughput, quality of service support, power consumption and ubiquity of the technology in end-user devices are the main features that differentiate these technologies and are used in the process of evaluation of their suitability for a specific application.

Users and sensors communicate via one or more dedicated nodes that serve as sensor network gateways. Depending on the application scenario users and gateways communicate over a short-range wireless communication technology or a wide-area mobile network. The primary role of a gateway node is to inject user requests for specific sensor data into a sensor network and to gather sensor responses and deliver them to users. In contrast to the classic communication paradigm where communication is established between two specific nodes determined by their unique network addresses, sensor networks use a different paradigm. Users request data from sensors using data queries. As a redundant number of sensors monitor the same phenomena from different angles, only their combined and aggregated responses provide accurate and reliable results. Hence, user queries have to be addressed to all relevant sensors. For that purpose, instead of using broadcast techniques to reach all nodes, sensor networks use attribute based routing protocols. Each query uses attributes to describe data user is interested in. Based on that description routing protocols forward data to all nodes capable of providing requested information.

How do wireless sensor networks relate to health-care and medicine?

World population is getting older and the number of people over age 65 is steadily increasing since the last century. It is expected that the number of people in this age group will more than double from 357 million in 1990 to
761 million by 2025 [1]. This has given rise to various age-related disabilities and diseases, like Alzheimer’s. At the same time, the number of heart diseases and other chronic diseases are also on the rise, which combined with the aging population puts a heavy burden on the existing health-care systems and requires significant financial means to maintain the system. It also puts a significant burden on adults as, according to [2], almost one third of US adults are serving as informal caregivers.

Health care systems around the world are already suffering from a great pressure and have significant problems serving all patients properly and timely. Modern health care systems in its current, centralized, form will not be able to cope with the increased number of elderly and chronic patients, and a major shift in their organization is required.

Mobile technologies combined with wireless sensor networks principles, enable development of decentralized and distributed mobile health-care systems that present a possible solution for many of the issues mentioned above. This concept envisages continuous health monitoring enabled by sensors worn by patients or embedded into the patients’ environment. Sensors’ information is gathered by user communication devices like mobile phone or PDA, presented to patients and forwarded to health caregivers’ desktop PC or mobile communication device. Usability and flexibility of the system are the main prerequisites for successful deployment of mobile health-care sensor networks and this is where ad hoc networking principles and attribute based addressing of wireless sensor networks add significant value.

In this paper, architecture of a health-care system based on personal mobile health-care sensor networks is proposed and described. The abstraction layer that contains the complete information of all aspects of a sensor network is the central layer of the architecture. In combination with the XML based XMLSens protocol, designed to support communication with various types of sensors and able to transfer various data types in different formats, it makes a flexible platform that can support a broad range of user requirements. The concept of the fully distributed peer-to-peer health-care system that enables people, patients and caregivers, to interact and organize based on their current health status and needs is also presented in this paper.

The rest of the paper is organized as follows. In Section 2, principles and benefits of mobile telemedicine systems are given. Section 3, describes related work. In Section 4, proposed architecture, protocols and concepts are explained. Section 5 concludes the paper.
2. MOBILE TELEMEDICINE SYSTEMS

Telemedicine is considered as one of the most important steps in cutting costs and increasing service quality in health care [3]. The traditional telemedicine systems are generally designed for two purposes: to enable communication between health professionals in order to give doctors situated in remote locations access to the expert knowledge base available in large health care centers and to enable remote monitoring of patients for home care or emergency applications. Due to the limitations of the fixed communication networks and bulky medical equipment that are primarily used in traditional telemedicine systems, remote monitoring was feasible in confined environments with the appropriate infrastructure only.

Although conventional telemedicine systems add significant value in certain scenarios, they didn’t change the mainstream health-care systems organization that is still based on health-care centers and extensive face-to-face meetings. Long waiting lists in hospitals, shortage of beds, lack of qualified medical personnel and financial problems in general, are factors that indicate deficiencies of the current health-care systems. Other trends that indicate the necessity for changes in the way health-care services are provided are as follows:

• Active lifestyle and increased life expectations – people generally want to enjoy their free time as much as possible and hence strive to reduce, make simpler and more efficient all other activities that prevent them from doing it. Traveling to and from hospitals, waiting in queues for medical check-ups etc. are some of the activities people would like to avoid;
• Elderly people expect to live an active and autonomous life, but at the same time require significant care especially in case of diseases like Alzheimer’s;
• Sense of necessity to lead a healthy life style is increasing – more and more people are engaging in regular physical exercises, taking care of their diet, wishing to maintain good health and hence need advices from medical personnel;
• There is an increasing number of patients suffering from chronic illnesses – heart problems, diabetes and asthma are among the most frequent diseases. These health problems require constant monitoring that is today ensured through periodic health checks at health-care centers.
To successfully face these challenges the organization of the health systems, including patient and doctor roles and the way they interact have to be radically changed. Mobile telemedicine systems enable paradigm shift from the traditional centralized system, where health care services are provided in hospitals and clinics, towards distributed, personalized and interactive health care services that are seemingly provided with a minimum amount of effort, disturbance and cost to all involved parties. With the tiny health-care sensors attached to their bodies and a number of sensors embedded into everyday environment (chairs, tables, cups, doors, etc.) that can wirelessly communicate with remote caregivers it is possible to monitor and learn about users’ health, activities and behavior. Patients are able to roam freely and to lead an active life while still maintaining a continuous connection with their caregivers. The caregivers can remotely control functionality of their patients’ sensor networks to adapt them to the current patients’ needs (for example more or less frequent data readings). Sensors can be easily added or removed from the system to further ensure that optimal set of measurements is available based on the patient’s current health status. Such continuous measurements provide a health footprint for each patient that helps in the medical treatment personalization and detection of health problems in the early stages of illnesses. In other words, instead of prescribing medicaments and tracking their impact based on patient’s periodical visits to a hospital, health caregivers can continuously follow patients’ recovery and finely tune medication types, dosage and the treatment in general. The existence of various sensor types and ability to automatically detect new sensors and reconfigure a system, make modifications of health-care sensor network easily achievable. This functionality enables personalization of the system possible, i.e. sensors can be added to or removed from a system to adapt to the patient’s current health status, similarly to adding or removing certain medications from a patient’s therapy.

With such technology in place, requirements for “on-site” caregivers will be significantly reduced. Both elderly persons and their caregivers will be able to live more autonomous lives, while still keeping in constant touch. Persons in need of care will have “peace of mind”, certain that if something should happen to them medical personnel will be promptly notified and will be able to provide timely help. Instead of taking periodic health status snapshots during hospital visits, patients’ health will be continuously communicated to their doctors. Such approach will enhance and simplify patients’ lives and at the same time will provide more valuable medical information that can be used for fine-tuning and personalization of medical treatment.

As potential users are diverse, of different ages, with different education
background and technical awareness, high usability and maintainability of the system is of primary importance for its wide acceptance. Easy configuration and reconfiguration that require very little or no manual intervention, ability to seamlessly support various sensor types, high level of control over the sensors’ functionality and the ability to forward data to mobile and fixed caregivers are the main functions that have to be supported, if mobile telemedicine systems are to be successfully deployed and used. Leveraging on the characteristics and features of ad-hoc networking, i.e. automatic discovery of available sensors in the environment and self-organization of networks, combined with the attribute based addressing that facilitates easy querying, most of these issues can be efficiently resolved.

3. RELATED WORK

Since the inception of telemedicine various telemedicine systems have been proposed in literature. Until recently all proposals were based on fixed telephone networks and were providing health-care at fixed locations only [4], [5], [6]. The new generation of telemedicine systems, based on wireless communications enables health care monitoring regardless of a patient’s location [7], [8], [9].

In [7], a ring with several sensors and a built-in wireless interface is used for constant monitoring of patients. Retrieved data is wirelessly transmitted to a desktop computer in the patient’s vicinity and then forwarded to a physician using a fixed network.

An integrated mobile telemedicine system is presented in [8]. Sensors are connected to a processor responsible for storage, compression, multiplexing and encryption of retrieved data. It is connected to a mobile phone via a standard infrared interface. Data is transmitted over a GSM network to a remote server.

A concept of wireless distributed sensor networks for patient monitoring and care is presented in [9].

In [10], the wireless distributed data acquisition system for a prolonged, health/stress monitoring of patients is presented. It is based on mobile client devices and gateways that communicate using 900MHz wireless links. The mobile gateway, implemented on a Personal Digital Assistant (PDA), is responsible for collecting data from sensors during periodical visits to test sites. Retrieved data is processed and synchronized with the existing records on the telemedicine server.

The goal of the Mobiealth project [11] is to develop mobile health services using GPRS and UMTS for connection of patient’s body area
network and hospital servers. A body area network comprises various health-care sensors wirelessly connected to a mobile phone or a PDA. A mobile phone or a PDA acts as a gateway towards wide area networks, thus providing access to remote databases and doctors in charge.

In [18], advantages of P2P networking in e-medicine are advocated. Today, patient data from different health professionals are generally not linked together. It is extremely hard, if not impossible, to always have access to and maintain a complete data set with results from different tests, medications other physicians have prescribed, information from laboratories, hospitals, pharmacies, etc.

Utilizing P2P protocols, health professionals could form one or more groups to share relevant data between themselves. Some of the possible applications of peer-to-peer networking in hospitals are one to one communication between physicians, data sharing during visitations of sick people and data transfer from the clinical data processing units to a physician’s PDA.

4. SYSTEM ARCHITECTURE

The general architecture of the mobile telemedicine systems is shown in Figure 1. Patients wear a number of health care sensors depending on the application requirements at a given time. At the same time they also interact with various sensors embedded in the environment that track patient’s location, behavior, movements, etc. All sensors have a built-in short-range wireless interface for communication with user control device (mobile phone or PDA). Each sensor is attached to a microprocessor to enable execution of various data processing and aggregation algorithms and communication protocols.

FIGURE 1
General architecture of mobile telemedicine systems
The control unit (CU) is responsible for organization and maintenance of a patient’s sensor network. Automatic discovery of sensors, establishment of communication links with sensors, sensor control and analysis of the obtained data are some of the main tasks performed by this unit. Provision of access to sensors for remote users (doctors and caregivers in general) is another important responsibility of this unit. The CU checks, grants or denies access to sensors and forwards commands and responses between sensors and remote users. Remote users communicate with a CU over a mobile network using IP based links or mobile services like SMS (Short Messaging Service) and MMS (Multimedia Messaging Service).

Sensor data is sent to a CU where is temporarily stored in the CU’s memory. Periodically, it is sent (over a mobile network connection) to a relational database where is stored permanently along with the patient’s personal data and history of illnesses. Simultaneously, based on the user-defined rules and application requirements, sensor data can be forwarded to mobile caregivers as well. In urgent situations or on specific doctor’s request, forwarding is done in real time. In other situations data is forwarded periodically. Mobile caregivers will use their mobile terminals (mobile phones or PDAs) to quickly assess patients’ health. Desktop PCs will be used when complex examinations are required.

If patient’s specific circumstances change after the initial system configuration (health improves or deteriorates), patients themselves or their remote caregivers can modify data forwarding rules and settings of all sensors in order to adapt the overall system functionality to the patient’s current health condition and requirements (similar to prescribing new medications due to a changed health condition).

The proposed protocol stack of a mobile telemedicine system is given in Figure 2. Roles and descriptions of each layer are given in the following sections.

![Figure 2: Protocol stack](image_url)
4.1 Wireless sensor architecture

Wireless sensors are intelligent, tiny devices that monitor one or more physical phenomena, process gathered data and communicate with other sensors and user control units. In principle, these devices consist of one or more sensors, a short-range wireless interface, a microprocessor and a memory unit (Figure 3).

![Architecture of an intelligent sensor](image)

Data gathered by attached sensors is digitalized, processed by the microprocessor and stored temporarily in the wireless sensor’s memory. It is forwarded to a CU according to the defined rules: periodically, triggered by an event (for example, measured value is over a defined threshold) or on-request. The microprocessor runs a user-defined application that sits on top of the core system software. This application is downloadable “over-the-air” to enable modifications of data processing algorithms and addition of user-specific functionality. The system software implements communication protocol used for interaction with CUs and controls physical interfaces towards attached sensors.

The purpose of the memory unit is twofold: to provide temporary storage space for sensor data and to permanently store profiles of all sensors belonging to this unit. Sensor profiles describe characteristics and functionality of each sensor and have a crucial role in the system. The role, format, structure and other details of sensor profiles are described in the following section.

In an ECG (Electro Cardio Gram) system based on the described architecture, each ECG lead can be implemented as a separate wireless sensor. Similarly, blood pressure, temperature, pulse oximetry, EEG (Electro Encephalon Graph) and other medical measurements can be implemented as individual wireless sensors. Depending on user
requirements and chosen radio technology, it might be beneficial to combine several physical sensors into one wireless sensor (for example one wireless sensor containing 3 or all 12 ECG leads). “One sensor – one wireless interface” approach gives the maximum flexibility to users and requires the minimum amount of wiring (or no wiring at all) which is, from the user point of view, a preferable solution. However, having one wireless interface, a microprocessor and a memory unit for each sensor, increases the overall price of the system. Also, as the amount of data generated by “health-care” sensors is generally rather small, wireless interface would be mostly underutilized and from that point of view it would be more efficient to have several physical sensors integrated into one wireless sensor. The main drawback of this approach is that it requires wired connections between physical sensors and the main body of the wireless sensor, which is annoying to patients. Depending on the actual application, approaches can be combined to give the optimum solution.

4.1.1 Sensor profile

A sensor profile is associated to each sensor in a system. It defines sensor’s characteristics and its role in the system. The proposed sensor profile is a flexible XML structure adaptable to the specific user and application requirements. It consists of two parts: attributeProfile and dataProfile.

The attributeProfile describes basic sensor characteristics like sensor type, location, manufacturer, accuracy, measurement range, calibration date, etc. The second part of the profile, the dataProfile, describes format of data the sensor is generating, i.e. is it an integer or float value, a single number or sequence of numbers, how many bytes are used to represent one sample, etc.

Static sensor attributes like sensor type, accuracy and manufacturer are set by the sensor manufacturer. Users have full control over dynamic

```xml
<?xml version="1.0" encoding="UTF-8"?>
<sensor>
  <attributeProfile>
    <attribute name = "type">
      ECG
    </attribute>
    <attribute name="position">
      <attribute name="chest">
        left side
      </attribute>
    </attribute>
  </attributeProfile>
  <dataProfile>
    <dataAttribute>
      <adResolution>
```
parameters that define the sensor’s role in a system and can modify existing parameters or add completely new parameters to suit their specific needs. An example of a sensor profile describing an ECG sensor follows. When a CU discovers a new wireless sensor, it collects profiles of all the attached physical sensors first. Based on the information provided in obtained profiles, CU creates and configures software objects and parameters required for efficient access to sensors and data they generate.

4.2 Control Unit

Control units are used by patients and their caregivers to communicate with sensors to obtain and visualize sensor data. A patients’ CU (PCU) communicates directly with sensors over a short-range wireless interface, while caregivers’ CU (CCU) devices communicate with sensors via patients’ CU over a wide area network interface. In order not to obstruct users in their regular activities, CUs have to be small, portable and energy efficient devices. Size, functionality and ubiquity of mobile phones and PDAs make them the most natural platform for implementation of this functionality.

The PCU presents a gateway between sensors and remote caregivers. It hides the internal structure of the local sensor network it controls and provides a high-level description of sensor network abilities and characteristics required for a successful sensor querying and data collection to the outside world. The XMLSens is a flexible XML based communication protocol used for communication between sensors and a PCU. The PCU user interface enables patients to view gathered data, control sensors and set access rights for remote users.

PCUs and CCUs communicate on the sensor network abstraction level using the XMLSensAPI methods over a mobile network connection. Once remote users gain access to sensors, i.e. when a PCU grants access to a local sensor network, they have the same level of control over sensors as their patients and can change and modify sensor settings to adapt system
functionality to suit current circumstances. The proposed architecture of a PCU is shown in Figure 4. It is a flexible architecture that supports various communication technologies, sensor types and user applications with no or minimal modifications. Architecture of a CCU slightly differs and does not contain the short-range interface and the XMLSens protocol.

The lowest layer in the architecture is the communication layer. Usually, two communication technologies are supported in a system: one short-range and one wide range. Figure 4 shows Bluetooth and 3G as selected interfaces, but depending on the implementation various other interfaces like ZigBee, IEEE 802.16, 802.11, proprietary RF, GPRS etc. can be supported as well. The responsibility of this layer is to:

- Discover available wireless sensors;
- Establish reliable communication links with all sensors in a network;
- Execute a routing protocol if such is required for forwarding information to and from sensors;
- Establish and maintain access to a mobile network using the most appropriate available service (SMS, MMS, audio/video streaming, TCP connection, etc.) for a given application.

The sensor network abstraction layer with its API represents the core functional entity of the proposed architecture. This layer splits communication between sensors and caregivers and encapsulates the internal organization of a sensor network. It provides attribute-based access to sensors in a network and their information and takes care of communication with sensors using the underlying XMLSens protocol.
4.2.1 Bluetooth interface implementation

As previously stated, the role of the short-range communication layer is to establish and maintain communication links with available wireless sensors. The Bluetooth wireless interface is being increasingly integrated into various electronic devices including mobile phones and PDAs. Wide availability of this interface and its features (most notably possibility of ad-hoc connection establishment and significant data throughput) make this interface an interesting option for implementation in the mobile health-care systems.

Discovery of wireless sensors, in this case, is performed in the same manner as discovery of any other Bluetooth devices, i.e. using the Inquiry procedure. During the Inquiry procedure, along with a Bluetooth address and clock that are required for connection establishment, devices exchange two parameters that on a high level define device’s type. These two parameters are Major Device Class and Minor Device Class. In order to shorten the time required to establish connection with sensors and to avoid waste of resources on establishment of unnecessary links, each wireless sensor sets the value of Major Device Class to the “wireless sensor” value. After a wireless sensor is discovered, the CU establishes Bluetooth communication link with it and proceeds to the Bluetooth service discovery procedure to get the necessary parameters for establishment of higher-level communication links.

The Bluetooth specification defines several so-called profiles that are used to ensure compatibility between different devices. For the purposes of mobile telemedicine systems the most appropriate profile is the serial port profile that uses the RFCOMM protocol to ensure reliable communication. After communication on the RFCOMM level is established, the abstraction layer takes over control.

4.2.2 3G network interface

The wide area network interface provides access to mobile network services and enables communication between a PCU and therefore sensors on one side and remote users (doctors, caregivers, database) on the other side. The most widely available mobile network technology is GSM. The main limitation of this technology from mobile telemedicine systems point of view, is poor support for data oriented communication. The improvements brought into the GSM by introduction of the GPRS significantly enhance usability of such networks for remote health monitoring applications. The latest generation of mobile technologies, 3G, will provide the most versatile and convenient platform for health care applications. A significant throughput, data oriented communication and
quality of service, are some of the most important features that make 3G suitable for remote health care monitoring.

The role of the 3G-communication layer is to provide access to transport channels of a mobile network. Standard access procedures executed by a mobile phone when accessing a mobile network like cell selection, radio measurements, establishment of radio bearers, allocation of an IP address, etc. are tasks performed by this layer. Based on the types and numbers of sensors in a network, the 3G network interface requests and reserves appropriate radio transport bearers that can support required quality of service. After a successful execution of the basic connectivity procedures, the telemedicine service layer initiates required service level procedures.

4.2.3 Telemedicine service layer

Today, various value-added services offered by mobile service providers are part of the service layer that is overlaid on top of the mobile network transport channels. Similarly, mobile telemedicine services will be part of the same service layer. There are two options how remote health care services can be organized within this layer: using the traditional service model approach, where a service provider is the central point for service provision to which service users subscribe, or using a new peer-to-peer approach where a mobile network facilitates service discovery only while peer nodes are service users and providers (Section 5).

If the centralized approach is adopted, mobile telemedicine service providers shall provide the following services:

- Establishment of connections between patients, physicians and health care institutions based on users’ subscription;
- Permanent and safe storage of patient’s health data;
- Provision of access to stored data for purposes of medical diagnostics and examination from mobile or fixed locations;
- Notification of the most appropriate emergency services in urgent situations, provision of a patient’s location and a real-time access to the patient’s health data to enable a fast and efficient health care service.

It is the responsibility of the PCU’s telemedicine service layer to attach a patient’s sensor network to the service, i.e. to execute login procedure and get access to a remote database and other information provided by the operator. Due to the wide availability and coverage of mobile networks, maintaining connectivity regardless of patients’ or caregivers’ locations at a
given time is not a problem. However, certain aspects of the mobile health care services, like location and contact numbers of emergency service centers or availability of health care centers close to the patient’s current location (if urgent face-to-face examination is required), are dependent on the facilities in the local area and required information won’t be readily available to operators that do not have local presence. In other words, if a mobile subscriber were roaming in a foreign network it wouldn’t be possible for its telemedicine service provider to provide access to local facilities without specific agreements with telemedicine service providers in that area.

Another possible drawback of the centralized solution is the number and versatility of services that an operator is providing. For example, some of them can provide a limited or no access to medical experts for certain health problems, or price plans might not suit user’s requirements and possibilities.

As already stated, the centralized solution assumes that data processing is mainly performed in telemedicine centers, while personal sensor networks that patients are wearing are used for data collection only. However, similarly to the computer world where intelligence and data processing were pushed from the mainframe computers towards the edge of the network, i.e. desktop PCs, laptops and PDAs, sensor data analysis can be pushed towards personal health care sensor networks. Increased intelligence of the end nodes and the need for a flexible environment that can easily support both local and global user requirements will spark development of the distributed health care systems described in Section 5.

4.2.4 Sensor network abstraction layer and XMLSens protocol

The abstraction layer encloses the core functionality of mobile telemedicine systems. The complete knowledge of a sensor network, i.e. its characteristics, structure, organization etc. is contained in this layer. The information is compiled and provided to users in XML format. The main responsibilities of this layer are as follows:

• Establishment of communication links with available sensors using the underlying XMLSens protocol;
• Gathering sensor profiles and compilation of that information into a form suitable for usage by remote users;
• Provision of the attribute-based addressing scheme for sensors in a network, i.e. allowing users to describe data they need instead of requesting them to define which exact sensors they need data from;
• Mapping sensor network API methods to communication protocol messages and vice versa to enable sensor control.
The *XMLSens* is an XML based communication protocol designed for communication with wireless sensors. It has a flexible structure that enables ad-hoc interaction with sensors of various types and transmission of various data formats. The main messages of the protocol are described in the following paragraphs.

After establishment of the underlying short-range wireless link, the abstraction layer generates *getSensorList* message and forwards it to all discovered wireless sensors. Wireless sensors reply with the *getSensorListResponse* message that contains profiles of all sensors attached to it. The structure of these messages is as follows:

– GetSensorList

```xml
<?xml version="1.0" encoding="UTF-8"?>
<XMLSensCommand>
  <name>
    GetSensorList
  </name>
</XMLSensCommand>
```

– GetSensorListResponse

```xml
<?xml version="1.0" encoding="UTF-8"?>
<XMLSensCommand>
  <name>
    GetSensorListResponse
  </name>
  <sensor>
    <attributeProfile>
      ...
    </attributeProfile>
    <dataProfile>
      <dataAttribute>
        ...
      </dataAttribute>
    </dataProfile>
  </sensor>
  ...
</XMLSensCommand>
```

An example of a GetSensorListResponse message is given below.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<XMLSensCommand>
  <name>
    GetSensorListResponse
  </name>
  <sensor>
    <attributeProfile>
      <attribute name="sensorID">
        sensor1
      </attribute>
      <attribute name="type">
        ...
      </attribute>
    </attributeProfile>
  </sensor>
</XMLSensCommand>
```
It is obvious that the previously described wireless sensor contains two sensors: ECG and temperature. The identity of the ECG sensor is “sensor1” and it has 3 ECG leads. Data obtained from this sensor is digitalized using 10bit A/D converter. The minimum and maximum sampling rates of 100 and 300 samples per second respectively are available. Each sample is of 16-bit size. The temperature sensor, “sensor2”, has a measurement range between 20 and 42 degrees Celsius. Each measurement is represented as a 16-bit value.
After obtaining this information, the abstraction layer creates one object per each sensor. These objects are “sensor replicas” with attributes that store sensor profile information and gathered data. Each object provides methods that applications use to communicate with respective sensors. These methods use services of the underlying communication layer for data transmission. Users do not have to take care of the actual transmission methods or routing protocols – all they need is access to the sensor object.

This approach would cause creation of a huge number of objects in large networks and that, obviously, is not very efficient. However, health-care networks will most frequently contain only a handful of sensors and in such scenario creating one object per sensor is not an issue.

The process of getting measurement data from sensors is initiated by sending the \textit{GetData} message to relevant sensors. Its structure is given below:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<XMLSensCommand>
  <name>
    GetData
  </name>
  <sensor>
    <sensorID>2</sensorID>
  </sensor>
  <transmitMode>
    <attribute name="periodical">
      <attribute name="period">5min</attribute>
    </attribute>
  </transmitMode>
  <dataFormat>
    <attribute name="type">byte</attribute>
    <attribute name="totalNumber">10000</attribute>
    <attribute name="sampleRate">200</attribute>
  </dataFormat>
</XMLSensCommand>
```

The \textit{GetData} command consists of two distinctive parts. The first defines data forwarding rule: periodically, on-request, triggered by an event or streaming. The second part defines required data and its format: the sampling frequency, sample size, number of samples etc.

Wireless sensors reply with one or more \textit{GetDataResponse} messages that
contain requested data. The message is sent in requested moments of time or when triggered by a defined event. After the message header, it contains a sequence of bits representing the sensor data. At the far end, the PCU reconstructs data based on the data format defined in the previously sent `GetData` message.

Using this approach, adding new sensors that use previously unknown data format does not cause any problem nor requires any modifications of the existing messages. The abstraction layer forwards data to applications either as a standalone XML file that contains the complete data description along with the data itself or in the same manner as in the `GetDataResponse` message.

Some of the other XMLSens protocol messages are the `SetEvent` and `CancelEvent` used to define or cancel events that trigger forwarding of data, the `SetSensorSettings` used to set various sensor features in a sensor profile, the `UploadSensorProfile` used to define a sensor profile and upload it to a wireless sensor etc.

4.3 Sensor network API

The abstraction layer provides sensor network API that is a set of generic methods required for an efficient control of a mobile telemedicine system. The methods are designed to be independent of the number and type of sensors contained in a network, communication technology and network organization in order to enable easy porting of applications across different mobile platforms. Sensors querying is the main functionality provided by the API. Other methods include those for sensor discovery, setting data forwarding rules, events, etc.

Descriptions of available sensors in a network can be obtained using the `GetAttributes` method. From the user’s point of view, this method works as a service discovery method that returns description of available services, i.e. a list of characteristics of available sensors. The abstraction layer compiles this list based on the previously gathered sensor profiles. The list is delivered as an XML structure to the application.

```xml
<query>
  <constraint attrName="type">
    <equals>ECG</equals>
  </constraint>
  <transmitMode>
    streaming
  </transmitMode>
</query>
```
Based on the provided list, the user defines data he/she is interested in and requests delivery using the *QuerySensor* method. An example of a query used in this method is presented below.

Effectively, users describe required data instead of the traditional approach where node’s unique network address is used based on the previously acquired knowledge about the services the node provides.

The abstraction layer compares data descriptions with available sensor profiles and generates and forwards appropriate messages (*GetData*) to relevant sensors. This approach can be easily applied not only in one-hop networks with direct communication links between sensors and a PCU, but also in multi-hop hierarchical networks. In such networks, each cluster head maintains a list of attributes of sensors belonging to its cluster. On the next hierarchical level, the cluster head maintains a list of available sensor characteristics based on lists maintained by the cluster heads on the lower levels.

When a user requests data of a certain type, the abstraction layer compares description of the requested data with the information available in its characteristics list and forwards the *GetData* messages to those cluster heads that have relevant information. The cluster heads then forward data to relevant sensors in their clusters and collects data from them.

Bluetooth *piconets* and *scatternets* are suitable for such hierarchical organization and can be used in health care networks that involve a number of sensors deployed in the environment in combination with wearable sensors. Definition of data forwarding rules from a PCU to remote users (CCUs and databases) is performed using the *sendDataToRemoteUser* method. Each user can define data recipient, data format and the preferred mobile network transport service.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<XMLSensaCommand>
  <name>
    sendDataToRemoteUser
  </name>
  <attribute name="user">Database</attribute>
  <database>
    <attribute name="IP address">101.101.101.101</attribute>
    <attribute name="connection type">HTTP</attribute>
  </database>
  <transmitMode>
    <attribute name="periodical">
      <attribute name="period">5</attribute>
    </attribute>
    <attribute name="unit">
```
Today, health and health problems are topics that frequently connect otherwise not connected people through sharing experiences, exchanging advices, providing help, etc. The initial contacts, or “network establishment procedure” in telecommunication terminology, is done through informal contacts made ad-hoc during hospital visits or by “word of mouth”, i.e. using peers – family, relatives and friends. Assuming that in the coming years a significant number of people will wear health-care sensors with access to mobile networks, there is a potential for health-related peer networking on a much larger scale than today, based on the type of used sensors and data they generate, i.e. based on the health status, problems and help each user has or needs.

In recent years, the P2P networking and applications available on the Internet have proved to be an efficient and popular way of searching for different types of information and collaboration with people that share common interests [15], [16]. Based on that experience, we envisage development of mobile peer-to-peer health care networks that will organize all health related entities (patients, physicians, hospitals, health insurance companies, practitioners of alternative medicine, pharmacies, recovered patients, etc.) into one distributed system capable of connecting them based on specific health problems and expertise they have or need.

Each entity, including personal health-care sensor networks represented by a PCU will act as peer nodes. Each peer node will offer or search for services, while the role of the underlying P2P protocols layer (Figure 5) will be to ensure efficient service discovery, service provision and establishment of communication paths between peers. Description of health problems and
corresponding expertise will be the main parameters used for the establishment of the service provider-user relationship. For example, health data generated by individual health care sensor networks will be automatically compared with descriptions of available expertise of other peers. Based on the results of this comparison, connection between adequate peers will be established. In other words, output from an ECG sensor network will be forwarded to an ECG expert for analysis, EEG data to EEG expert and so on. In case that several measurements were done simultaneously, several experts will be organized into a peer expert group and will be able to collectively analyze obtained data. Hence, instead of having centralized health-care services, organized around several multi functional health-care centers, this novel approach adopts distributed oriented organization and utilizes the wide availability of mobile networks to interconnect numerous independent health-care service providers and their potential users into an efficient health-care system.

The same platform will be used not only for provision of formal health services, but also for various informal services like exchange of health related advices, experiences, ideas etc. between the patients based on their current needs, requirements and abilities or for alternative health services.

Architecture of a patient’s peer node is shown in Figure 5. Peer nodes that do not have personal health-care sensor network do not need Bluetooth and XMLSens protocol layers in their protocol stacks.

Publishing of and searching for services in a mobile and distributed environment like this, is a challenging task. Broadcasting description of the required services to all peers is one obvious solution. However, this approach would generate a lot of unnecessary traffic and would in many

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**FIGURE 5**
Architecture of a CU node in P2P network
cases cause network congestions. Another option is, as mentioned above, based on the P2P protocols and procedures.

We have investigated usability of the JXTA middleware [14] as a P2P networking platform in this context [17]. The JXTA is a set of simple, open peer-to-peer protocols that enable any device on a network to communicate, collaborate, and share resources. JXTA peers create a virtual, ad hoc network on top of the existing networks, hiding their underlying complexity. It is designed to enable interconnected peers to easily locate and communicate with each other and offer services to each other seamlessly across different platforms and networks. So-called “rendezvous” peers provide service discovery mechanism to other peers. As the discovery mechanism rely on the use of the IP multicast which is not supported by mobile networks, we have implemented a dedicated rendezvous peer within the service layer of a mobile network to which all other peers were registered. Since mobile networks are completely controlled by their operators, providing rendezvous peer services as part of a mobile operator service portfolio as an anchor point for all P2P mobile subscribers seems to be a good approach that can guarantee uninterrupted rendezvous service which can be easily replicated across various mobile networks to ensure worldwide availability and connectivity (similar to roaming agreements today).

All JXTA resources are described by XML structures called advertisements. In our proposed architecture, characteristics and features of sensor networks are described by the XML based sensor profiles, which practically enables direct mapping between these two structures. After a personal sensor network obtains access to a mobile network, the CU forwards a description of a user’s sensor network compiled by its abstraction layer to a rendezvous peer. Similarly, physicians, hospitals, emergency centers and other peers register their services (continuous monitoring of health data, emergency response, expert for a specific area) with the rendezvous peer.

Service discovery in the JXTA is performed using the XML queries. Similarly to describing sensor profiles, a user describes required service: continuous monitoring, emergency help, ECG or EEG examination, regular check up or ad-hoc examination due to acute problems, etc. These queries are compared to the available service description and if a match is found, connection between peers is established. Then, peers can use the sensor network API methods to access sensor data and perform agreed services.

The initial JXTA implementation that we used in our experiments was rather “heavyweight” and not easily deployable on mobile communication
devices like those intended for the CU implementation. It proved to be pretty cumbersome and slow to use JXTA in mobile networks. However, recent JXTA revisions are improved and are more suitable for the constrained mobile environment and as such present a promising P2P platform.

6. CONCLUSION

The current health care system organization is hierarchically organized around a number of health care centers and is based on extensive face-to-face meetings and examinations. As such, it is not very well positioned to support modern lifestyle and its requirements for provision of continuous and complex health care services in a seamless and flexible manner in patient’s regular working and living environment.

Ad hoc networking, wireless sensor networks and mobile communications are the basis for implementation of a new approach to health care services provision. Architecture and protocols proposed in this paper utilize advance features of these technologies to provide support for various sensor types, high-level of automatic configuration and maintenance as well as easy adaptation to different transmission technologies. The proposed concept of peer-to-peer organization of health care systems connects everyone needing or providing health care services, including individual personal health-care sensor networks into a powerful health-care system that can provide a variety of easily accessible health services based on users’ own requirements.

Security and privacy issues have not been dealt with specifically in this paper. Proper resolutions of these issues are of great importance for success of mobile health-care solutions and further work is required in this area. Also, evaluation of the proposed systems in a real world environment, both from a technical and end-user point of view, is necessary. The effect of numerous health-care sensor networks attached to mobile networks has to be evaluated from the mobile networks point of view, to ensure their proper dimensioning (both radio and transport network resources) and if required to propose suitable modifications of the current mobile network architecture.

The need for an improvement of the health-care systems is obvious and various efforts are under way. Solutions proposed in this paper build on advanced features of wireless technologies to provide mobile health-care solutions that can be easily personalized to suit the specific needs of each user and thus to provide the level of health care services not possible today.
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7. REFERENCES