A Pattern for Web-based WSN Monitoring

(Invited Paper)

Anthony Marcus, Mihaela Cardei, Ionut Cardei, Eduardo B. Fernandez
Department of Computer and Electrical Engineering and Computer Science
Florida Atlantic University
Boca Raton, FL 33431, USA
Email: {amarcu10@, mihaela@cse., icardei@cse., ed@cse.}fau.edu

Fulvio Frati and Ernesto Damiani
Department of Information Technology
University of Milan
Email: {fulvio.frati@, damiani@dti.}unimi.it

***Abstract*— This paper describes a pattern for the architecture of web-based wireless sensor network monitoring. Sensor nodes are used to measure characteristics of the physical environment and sensed data is stored on the Internet using web-based technologies. Users can access data remotely as long as they have Internet connectivity. Many wireless sensor network applications developed today use smartphones as a gateway between the sensor network or the user, and the Internet. This allows the sensor network and/or the users to be mobile. Implementation of a web-based wireless sensor network architecture, that uses smartphones, provides a scalable solution with applicability in many areas such as healthcare, environmental monitoring, border security, structural health monitoring, and many more.**

Index Terms: Wireless sensor networks, web-based architecture, architectural pattern, remote monitoring, mobile users.

I. INTRODUCTION

A wireless sensor network (WSN) is a deployment of wireless devices that can sense, compute, and communicate with other devices for the purpose of gathering local information, which is then used to make global decisions about a physical environment.

Research on sensor networks was originally motivated by military applications, such as acoustic surveillance and target detection. However, WSNs have many practical applications such as healthcare, weather monitoring, infrastructure security, environmental and habitat monitoring, traffic control, and gaming.

Dependent on the application, a WSN is scalable and can range from several sensors (e.g. monitor traffic lights or the condition of a machine in a factory) to a huge population of sensors (e.g. trillions of sensors in the Central Nervous System for the Earth [17] project). For applications requiring a large number of sensor nodes, the protocols designed must be scalable and localized.

The main components of a sensor node and a pattern for a sensor node is presented in [16]. Sensor nodes have typically limited resources: finite energy resources, low power CPU, limited memory, and small transmission range. For example, the Crossbow MICAz mote [6] operates on the 2.4GHz ISM band, uses two AA batteries, and has an ATmega 128L processor at 8 MHz, 4 Kbytes RAM, and a transmission range up to 30 m (indoor) /100 m (outdoor). An important issue in WSNs is network lifetime. Sometimes it is impossible or infeasible to recharge or replace the sensors. Therefore the algorithms and protocols designed must be energy-efficient to prolong network lifetime.

Some of the sensor nodes (e.g. medical sensors) are mainly concerned with measuring certain parameters and reporting those measurements using direct communication. Some other sensor nodes (e.g. environmental Crossbow sensor nodes) are involved both in data sensing and in data forwarding on behalf of other sensor nodes. Data transfer is done using either direct transmission or multihop communication. Sensor nodes may also act as routers and forward data using a certain routing protocol (e.g. Directed Diffusion [10]). A pattern for a sensor network architecture is presented in [3], where the main architecture components, class diagram, and the main use cases are presented.

In general, WSNs have a dynamic topology. This is due to the fact that some of the sensors will die in time from physical damage or energy depletion, and some of the sensors may cycle into a sleep mode to save energy. Quality of service requirements are different than those of the traditional networks. They may include concepts such as reliable detection of events, and amount and quality of information that can be extracted from given sinks about monitored objects or areas [13].

Once the sensed data is collected (e.g. data acquisition step), it is processed and analyzed, and made available to the user. A general architecture [3] involves remote access to the sensed data, where the user is not in direct communication with the sensed data. As smartphone and web-based technologies are ubiquitous nowadays, they are being used extensively in current WSN applications. Many WSN solutions use a smartphone as a gateway

Manuscript received February 15, 2011; revised May 15, 2011; accepted June 15, 2011.

This work was supported in part by NSF grants CCF-0545488 and OISE-0730065.

doi:10.4304/jcm.6.5.393-399

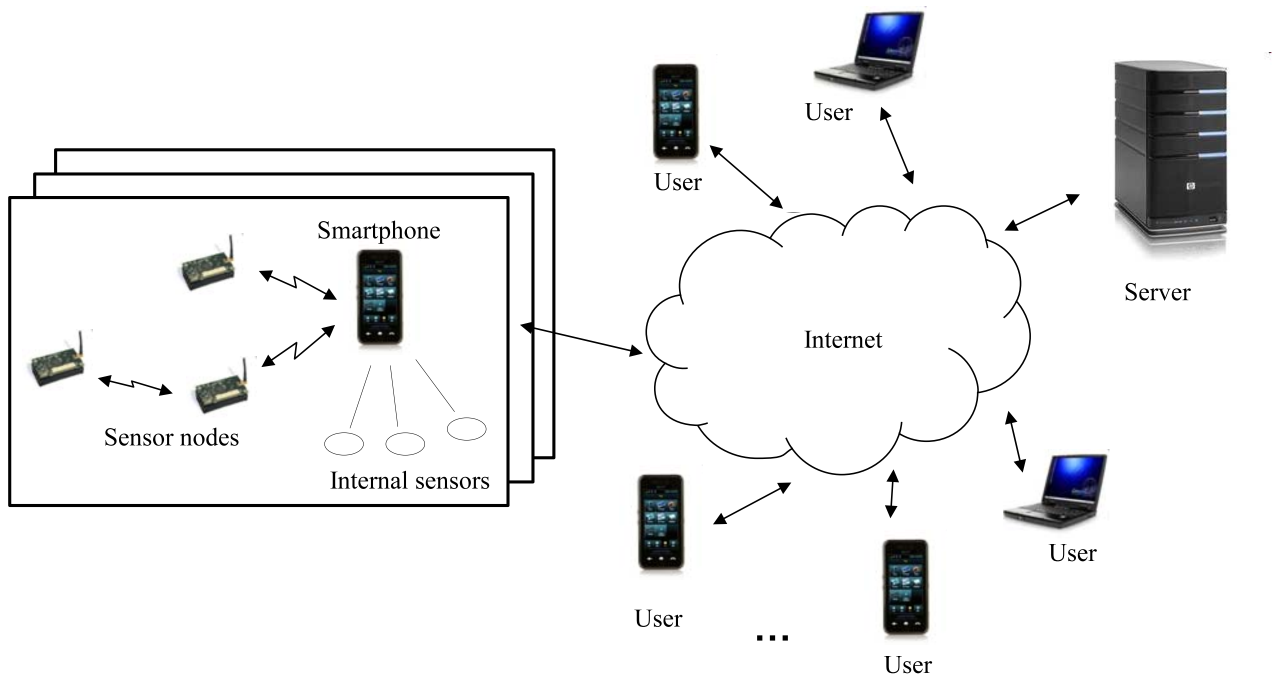

Figure 1. Components of a web-based monitoring system

between the collected data and the Internet, being used both in data acquisition and data consumption (e.g. accessing the data). Web-based technologies and services represent fundamental mechanisms in remote data storage and access.

The contribution of this paper is to formalize the main features of the web-based wireless sensor network monitoring architecture into a pattern that describes the general structure including the components involved in sensing, data acquisition, storage, and consumption using UML class diagrams and the main interactions and communication between these components using UML sequence diagrams. A pattern is an encapsulated solution to a problem in a given context. The pattern description includes information on the context – when to apply the pattern, and on the general solution – how to apply it. Based on this architectural pattern, an application designer can adapt it to the specifics of their application needs. Strictly, our pattern is more a reference architecture [18], a generic domain architecture, but because it is relatively specialized we prefer to consider it a pattern. Our work uses the POSA template for patterns [5]. We detail our pattern in section II and conclude the paper in section III.

II. Pattern of an Architecture for Web-based Wireless Sensor Network Monitoring

A. Intent

Many applications use sensors to monitor various parameters. The web-based WSN monitoring system allows users to access the sensor data remotely.

B. Example

Determining how much a patient walks provides an important tool for evaluating the health of the patients suffering from mobility-affecting chronic diseases such as Muscular Dystrophy and Parkinson's. Continuously monitoring of such patients is difficult due to the high cost of medical services and lack of medical personnel to continuously observe such a patient. Short clinical visits do not provide ample time to assess trends in their mobility, to measure variations over time, and reactions to varying treatments.

C. Context

This pattern is applicable for applications where:

1) typically many wireless sensor networks must monitor each an environment as part of the same application
2) the physical environment to be monitored may be inside a building or external surroundings, and it may also be mobile
3) WSNs can be fixed or mobile
4) each WSN has a gateway (sink) with a connection to the Internet
5) sensor data must be available to users connected to the Internet
6) users can be remote or local, fixed or mobile
7) sensor data can be stored distributively in a cloud environment

D. Problem

If users do not have access to the monitored data, they cannot monitor the physical environment, which may

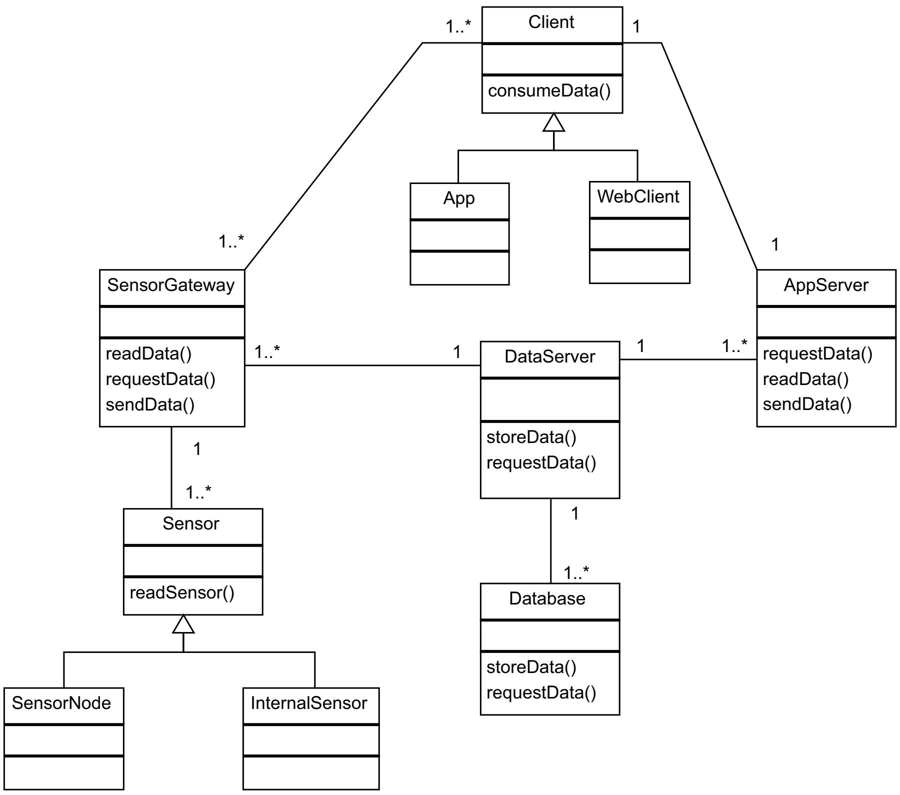

Figure 2. Class diagram for web-based WSN monitoring architecture

prevent them from taking proper decisions and actions. Sometimes the monitored environment and/or the user are mobile and remote from each other. This prevents users from being physically located near the sensed environment. In addition, sometimes the physical environment being monitored is a dangerous or vast area (e.g. monitoring a fire forest or volcanic activities). Another problem is when a set of users have to monitor a larger number of physical environments.

The possible solution is constrained by the following forces:

- The physical environment to be monitored may be inside a building or external surroundings, and it can be fixed or mobile. It can involve measuring the parameters of living beings, environmental attributes, and attributes of machines and equipment.
- The monitored data must be made available to the users.
- The users can be local or remote, fixed or mobile.
- Sometimes the same individuals which are monitored must be able to access data.
- The system must be scalable with respect to the number of sensor nodes and the number of users.
- The system must use the available technology.
- The cost of the system must be relatively small, otherwise the system may become too expensive to implement and operate.
- It should be easy to add security and reliability measures.

E. Solution

The solution consists of a web-based WSN monitoring system that implements two main functions: data acquisition and data consumption, see Figure 1. Sensor nodes or other sensors (e.g. a smartphone's internal sensors) monitor the physical environment. The environment to be monitored can be a living being, environment, machine/device, or a combination of them. The sensors perform readings of various attributes and transmit data to the sensor gateway (e.g. a smartphone). Some of the data processing can take place locally and then data is transmitted over the Internet to a server. From here, the data are stored in a database for future use.

Since the system must support remotely located environments, the solution uses multi-hop communication to transmit data to the storage location. Some applications may use direct transmission to the sensor gateway, while others (e.g. involving vast areas) may use multi-hop transmission to the sensor gateway.

The sensor gateway has Internet connectivity, which allows the servers and the database to be located remotely, accessible by any sensor gateway with authorization and Internet connectivity. The sensor gateway can be a smartphone (e.g. Iphone, Android, etc), laptop, or PDA, which constitutes ubiquitous technology nowadays.

From the gateway, sensed data is transmitted over the Internet and stored in a database, where it can be accessed by the authorized users.

In the data consumption process, remote users access data by connecting to the Internet throughout a gateway.

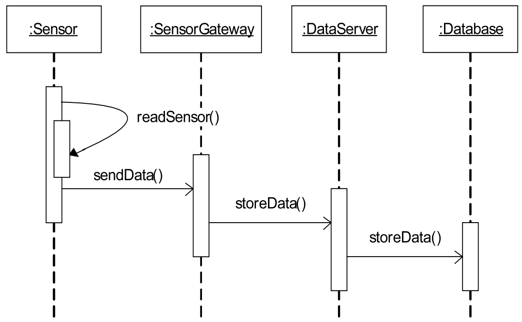

Figure 3. Sequence diagram for data acquisition and storage

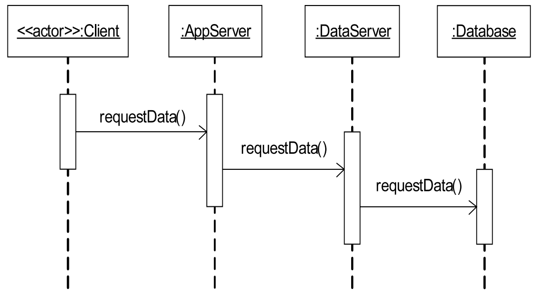

Figure 4. Sequence diagram for data consumption. Data is available in the Database.

The gateway can be a smartphone or router. Data is accessed by querying the database where the data are stored.

Sometimes, the same gateway can be used both in data acquisition and data consumption. For example, a user equipped with body sensors uses his smartphone for acquiring the data, and uses the cell infrastructure to store data remotely. In addition, the user can use his smartphone to remotely access some other sensed data of interest.

Structure: Figure 2 shows the class diagram for the web-based WSN monitoring architecture. For data acquisition, **Sensors** use a **SensorGateway** (e.g. smartphone, router) to transmit data over the Internet to a **DataServer**, where the data are stored in a **Database** where they can be accessed at any time remotely. **Sensors** that produce data can be **SensorNodes** (e.g. environmental sensors, see the Sensor Node pattern [16]) or they can be **Internal Sensors** (e.g. smartphone internal sensors).

For data consumption, the **Client** is running a custom application (**App**) or a web application (e.g. **WebClient**) that allows him to connect over the Internet to the **DataServer** storing the data. The **DataServer** is running a server application (e.g. **AppServer**) and it serves client requests by querying the **Database**.

The **Client** can be, for example, a smartphone using a web browser application to connect remotely to the **DataServer** using the cell-phone infrastructure. The **DataServer** uses an **AppServer** to interface with the **WebClient** application.

Dynamics: We describe the dynamic aspects of the Web-based WSN Monitoring Architecture using sequence diagrams for the use cases Data Acquisition and Storage (see Figure 3) and Data Consumption (see Figures 4, 5, and 6).

Figure 3 shows the sequence of events for the use case Data Acquisition and Storage. The description is as follows:

1) The Sensor reads the information from the sensing components based on the onboard timer.
2) The Sensor sends the data to the SensorGateway.
3) The SensorGateway may process data and sends the data to the DataServer.
4) The DataServer stores the data in the Database.

Figure 4 shows the flow of events for the use case Data Consumption, when the data is available on the Database. The description is as follows:

1) The Client queries the AppServer requesting data.
2) The AppServer requests the data from the DataServer.
3) The DataServer requests the data from the Database successfully. The data are returned in a call parameter.

Figure 5 shows the flow of events for the use case Data Consumption when the data is not available in the Database. In this case, the DataServer gives the Sensor the command to read the new data via the SensorGateway. As the new data is read, it will be sent to the Client and stored in the Database as well. The description is as follows:

1) The Client queries the AppServer requesting data.
2) The AppServer requests the data from the DataServer.
3) The DataServer requests the data from the Database and fails.
4) The DataServer sends a read data message to the AppServer.
5) The AppServer sends a read data message to the SensorGateway.
6) The SensorGateway sends read data message to the Sensor.
7) The Sensor reads the sensing components locally.
8) The Sensor sends the data to the SensorGateway.
9) The SensorGateway may process data locally and sends the data to the AppServer.
10) The AppServer sends the data to the Client.
11) The AppServer sends the data to the DataServer.
12) The DataServer sends the data to the Database for storage.

Some applications may allow the Client to request data directly from the SensorGateway when the Client and the SensorGateway are within transmission range of each other. In this use case, the Internet is not used for data retrieval. Consider, for example, the case when a patient is equipped with body sensors and a nurse visits

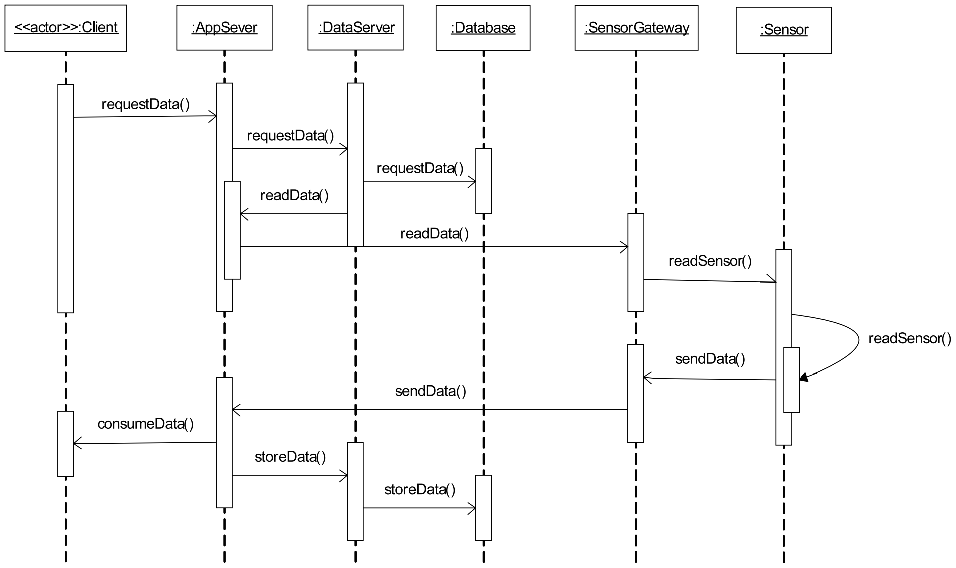

Figure 5. Sequence diagram for data consumption. Data is not available in the Database.

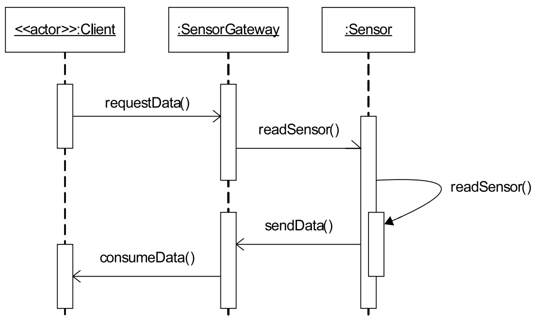

Figure 6. Sequence diagram for data consumption. The Client requests data directly from the SensorGateway.

the patient. The nurse's PDA/smartphone must be able to directly retrieve the sensor data. In this way data retrieval is faster and more reliable. This use case is presented in Figure 6. In addition, the sensed data may be stored in the Database, but this variation is not shown in the figure. The description of this use case (see Figure 6) is as follows:

1) The Client queries the SensorGateway requesting data.
2) The SensorGateway sends read data message to the Sensor.
3) The Sensor reads the sensing components locally.
4) The Sensor sends the data to the SensorGateway.
5) The SensorGateway sends the data to the Client.

F. Known Uses

CodeBlue [14] is a project developed at Harvard University, designed for deployment in emergency and medical care scenarios. The CodeBlue system was designed to provide coordination by routing, naming, discovery, and security for wireless medical sensors. The system uses ad hoc networking which allows mesh connectivity within the network and facilitates reliable connectivity regardless of the topology. CodeBlue is based on the publish/subscribe model for remote data delivery, allowing sensing nodes to publish streams of vital signs, locations, and identities, to which PDAs or PCs accessed by physicians and nurses can subscribe. To avoid network congestion and information overload, CodeBlue supports filtration and aggregation of events as they flow through the network. In addition, the stream of vital signs can be integrate with an electronic patient care record.

The Berkeley Tricorder [15] is an ambulatory health monitoring device, able to measure a subject's ECG, EMG, blood oxygenation, respiration and motion. The Tricorder is a complete system for personal use that utilizes remote telemetry to access and transport information over current cellular networks and integrated Bluetooth technology. Using a system such as this is necessary to provide real time monitoring of patients in remote locations and overpopulated areas where health care professionals are lacking in number.

Researchers at Intelesense Technologies have developed InteleNet [12], a global smart wireless sensor network capable of collecting data from a multitude of sensors, sending this information to a database over the Internet, and giving users secure, real-time access to their data integrated with other information sources. The InteleNet combines disparate data sources such as weather, water quality and flow, soil moisture, animal biotelemetry, seismic and earth magnetic field readings, video, audio, GPS-mapped human field observations and field research data, and even human knowledge and historical information to capture the environment on a scale that has never been attempted before.

In [11], by combining wireless sensor network and GSM technology, a low-power consumption remote home security monitoring and alarm system is proposed, that can detect theft, leaking of raw gas, and fire. When an event is detected, the system sends an alarm message to the house owner's mobile phone.

The last example is an application that uses the smartphone's internal sensors to detect car accidents. WreckWatch [19] is a system which uses smartphones in a wireless mobile sensor network that can capture the streams of data provided by their accelerometers, compasses, and GPS sensors. These data are assembled to create a portable "black box" that detects traffic accidents and records data related to these events, such as the G-forces (accelerations) experienced by the driver. WreckWatch is a mobile client/server application developed to automatically detect car accidents. If such an event is detected, the smartphone alerts the emergency responders using the cellular infrastructure.

G. Implementation

A wide variety of commercially available sensors can be purchased and tailored for the application. Such sensors can be Sensor Nodes, which are external sensors such as environmental sensors (e.g. Crossbow Mica motes [6], medical sensors for heart and activity monitoring [1], etc.) or they can be internal sensors. For example, the HTC Android smartphone has internal sensors such as GPS, accelerometer, digital compass, and ambient light [8].

These nodes are either pre-programmed and start collecting information once they are installed or they can be programmed according to the application's characteristics. The access to the sensors is done through a SensorGateway, which can be a smartphone or router. The communication between sensor nodes and the SensorGateway is done either directly (if the SensorGateway is in range) or can be multihop, using well known protocols such as LEACH [9] and Directed Diffusion [10].

The Sensor Node Pattern [16] and the Sensor Network Architecture Pattern [3] show the details of the implementation of a sensor node and sensor network, respectively.

The communication between the Sensors and SensorGateway can be accomplished using various wireless standards, such as Bluetooth [4] or ZigBee [20]. Bluetooth is an industry specification for short-range radio connectivity between portable devices. It operates in the 2.4 GHz ISM band and may support up to 3 Mb/s in the enhanced data rate mode with 10-100 m transmission range. The basic piconet configuration is a star topology network with one master and seven slave devices.

The SensorGateway can be a smartphone using Google's Android operating system, which offers open interfaces, availability of quality tools, documentation, and community-based development support. The smartphone has several internal sensors such as a 3D accelerometer, digital camera, GPS, and a Bluetooth transceiver. The SensorGateway can run an application to process and filter data. Various programming languages can be used, such as Java with Android SDK.

From the SensorGateway, the sensed data and status are transmitted to the DataServer over the Internet, using a cellular network (3G/4G) or a residential/business Internet connection using the phone's WiFi card. The upload data rate for current 3G technology exceeds 100 kbps in most coverage areas. As an example, the EV-DO Rev A 3G standard in use by Verizon and Sprint supports 500-800 kbps data rates. 4G links further increase data upload rates several times over. Data stored in a database is accessed by clients using web-based protocols (HTTP). The type and nature of the application determines the data type and how frequently they are transmitted to the DataServer.

The architecture uses web-based applications, besides the data acquisition service used for moving sensor data from the wireless network to servers for storage and analysis. Technologies such as Javascript/Java/AJAX/Google APIs are used on the client side and Java/XML/PHP on the server side. The Web Services approach is the preferred way to build modern distributed applications over the Internet (Web 2.0) as they simplify the design, integration, and deployment.

Data integration is a key feature, i.e. the ability to pull in data from various sources to build complex web applications with plug-and-play components. The web services can be implemented as Java EE servlets or PHP scripts executed on the web server.

Two important operations are data acquisition and data consumption. Data acquisition web services receive the flow of sensor measurements coming over the Internet from the SensorGateway applications and save them to a database. The sensor data consumption service allows access and queries to sensor data for the clients.

The server (or group of servers for reliability), must be connected to the Internet, protected by a firewall. The server runs a web services framework, such as Apache Tomcat, and it has a relational database, e.g. MySQL database that stores sensor data and executes background programs for analysis on the current sensor data in the database. Access to the database content must be secured with HTTPS and secured authentication. Only authorized users may be given access permission.

H. Example Resolved

Use of the web-based WSN monitoring architecture provides a mechanism for individuals to track how the health status of patients with chronic ambulatory problems changes over time or in response to various treatments and conditions, and can provide information to authorized medical professionals, family, and caretakers to asses patient's progress.

If the patient is using a smartphone, then internal sensors such as acceleration and GPS can be used to monitor patient mobility. The smartphone's SensorGateway component can upload the collected mobility information and location to a server, allowing remote access and monitoring for family and caregivers with an Internet connection.

I. Consequences

The Web-based WSN monitoring architectural pattern has the following advantages:

- Sensed data is available to clients even if they are not within direct transmission of the sensor nodes.
- Allows clients and the environment to be mobile and/or remotely located.
- It allows data to be stored and accessed later by authorized clients.
- The system is scalable, allowing the use of multiple monitoring applications simultaneously.
- The proposed system uses available technology.
- The proposed web-based WSN monitoring architecture has a relatively low cost. Usage of the sensors is application specific.
- We can add security and reliability controls. This would require a threat analysis as shown in [7].

J. Related Patterns

A pattern for a sensor node is presented in [16]. A pattern for sensor network architecture built using the sensor node pattern as a unit is presented in [3]. The sensor node pattern is also used as a component in the SCADA pattern [7].

III. CONCLUSIONS

This paper presents a web-based WSN monitoring architecture that allows users to access sensed data remotely using Internet connectivity. We presented the components of the architecture and showed sequence diagrams for use cases of the main operations: data acquisition and storage and data consumption. An application designer can use this architectural pattern and adapt it to the specifics of his application needs. The proposed architectural pattern has a considerable potential for use in areas such as healthcare, environmental monitoring, and transportations.

REFERENCES

[1] Alive Technologies, http://www.alivetec.com/products.htm, last accessed Nov. 2010.

[2] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, A Survey on Sensor Networks, *IEEE Communications Magazine*, Vol. 40, No. 8, pp. 102-116, Aug. 2002.

[3] M. Cardei, E. B. Fernandez, A. Sahu, and I. Cardei, A Pattern for Sensor Network Architecture, *2nd Asian Conference on Pattern Languages of Programs* AsianPLoP 2011, accepted.

[4] Bluetooth, https://www.bluetooth.org, last accessed Nov. 2010.

[5] F. Buschmann, R. Meunier, H. Rohnert, P. Sommerland, and M. Stal, *Pattern-oriented Software Architecture*, Wiley, 1996.

[6] Crossbow Technology, http://www.xbow.com, last accessed May 2010.

[7] E. B. Fernandez and M. M. Larrondo-Petrie, Designing secure SCADA systems using security patterns, *Procs. of the 43rd Hawaii Conf. on Systems Science*, Honolulu, HI, Jan. 2010.

[8] HTC Droid Technical Specifications, http://www.htc.com/us/products/droid-incredible-verizon#tech-specs, last accessed Nov. 2010.

[9] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, Energy-Efficient Communication Protocols for Wireless Microsensor Networks, *Proc. Hawaaian Int'l Conf. on Systems Science*, Jan. 2000.

[10] C. Intanagonwiwat, R. Govindan, D. Estrin, J. Heidemann, and F. Silva, Directed Diffusion for Wireless Sensor Networking, *ACM/IEEE Transactions on Networking*, Vol. 11, No. 1, pp. 2-16, Feb. 2002.

[11] H. Huang, S. Xiao, X. Meng, Y. Xiong, A Remote Home Security System Based on Wireless Sensor Network and GSM Technology, *Second International Conference on Networks Security, Wireless Communications and Trusted Computing*, 2010.

[12] Intelesense Technology, http://www.intelesense.net/public/downloads/press/intelesense-technical-information.pdf (last access on Dec. 2010).

[13] H. Karl and A. Willig, *Protocols and Architectures for Wireless Sensor Networks*, Willey 2005.

[14] D. Malan, T. Fulford-jones, M. Welsh, S. Moulton, CodeBlue: An ad hoc sensor network infrastructure for emergency medical care, *International Workshop on Wearable and Implantable Body Sensor Networks*, 2004.

[15] R. Naima and J. Canny, The Berkeley Tricorder: Ambulatory Health Monitoring, *Sixth International Workshop on Wearable and Implantable Body Sensor Networks*, 2009.

[16] A. Sahu, E. B. Fernandez, M. Cardei and M. VanHilst, Patterns for Sensor Nodes, *Conference on Pattern Languages of Programs* PLOP 2010.

[17] J. D. Sutter, 'Smart Dust' Aims to Monitor Everything, *CNN Labs*, 2010, http://www.cnn.com/2010/TECH/innovation/05/25/smart.dust.sensors/index.html?iref=allsearch, last accessed on Sep. 24, 2010.

[18] R.N. Taylor, N. Medvidovic, and E.M. Dushofy, *Software architecture: Foundations, theory, and practice*, Wiley 2010.

[19] C. Thompson, J. White, B. Dougherty, A. Albright, and D. C. Schmidt, Using Smartphones to Detect Car Accidents and Provide Situational Awareness to Emergency Responders, *Third International ICST Conference on Mobile Wireless Middleware, Operating Systems, and Applications (Mobilware)*, Jun. 2010.

[20] Zigbee Alliance, www.zigbee.org, last accessed Jun. 2010.