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Wireless Sensor Network Architectures for Different Systems

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Abstract

Recent technological advances enabled the design and proliferation of wireless sensor networks capable of autonomously monitoring and controlling environments. One of the most promising applications of sensor networks is for human health monitoring. The wireless body area networks promise to revolutionize health monitoring. Within a smart building many sensors and actuators are interconnected to form a control system. Here a web services-based approach to integrate resource constrained sensor and actuator nodes into IP-based networks. A key feature of this approach is its capability for automatic service discovery. Intelligent Vehicular Systems (IVSs) emerged as a potential candidate for benefiting from the unique features and capabilities of WSNs. In IVSs, transportation infrastructure is supported with the ingenious achievements of computer and information technology to resolve severe situations like traffic congestion and cope with emergency conditions like major accidents.

Keywords: *Sensor Networks, Wireless Sensors, Body Area Networks, Intelligent Vehicular System, Network Architecture*

1. Introduction

Recent advances in wireless networking, microelectronics integration and miniaturization, sensors, and the Internet allow us to fundamentally modernize and change the way health care services are deployed and delivered. Focus on prevention and early detection of disease or optimal maintenance of chronic conditions promise to augment existing health care systems that are mostly structured and optimized for reacting to crisis and managing illness rather than wellness . One of the most promising approaches in building wearable health monitoring systems utilizes emerging wireless body area networks (WBANs) . A WBAN consists of multiple sensor nodes, each capable of sampling, processing, and communicating one or more vital signs (heart rate, blood pressure, oxygen saturation, activity) or environmental parameters (location, temperature, humidity, light). Typically, these sensors are placed strategically on the human body as tiny patches or hidden in users' clothes allowing ubiquitous health monitoring in their native environment for extended periods of time. In this paper we describe a general WBAN architecture and how it can be integrated into a broader telemedical system. To explore feasibility of the proposed system and address open issues we have designed a prototype WBAN that consists of a personal server, implemented on a personal digital assistant (PDA) or personal computer (PC), and physiological sensors, implemented using off-the-shelf sensor platforms and custom-built sensor boards. The WBAN includes several motion sensors that monitor the user's overall activity and an ECG sensor for monitoring heart activity.

Recent advances in the field of material science led to an improved energy efficiency of the building envelope, a lot of energy is consumed by different equipment such as HVAC (heating, ventilating, and air-conditioning), lightning, home and office appliances. In a first step, decentralized sensor nodes of different types are required to report the current energy usage or environmental conditions to a centralized monitoring system. A smart power outlet will report the current energy usage of the attached device to a central server. Temperature sensors are used to react upon variations in room temperature. Actuator nodes are responsible to control small subsystems within the building. A presence sensor can automatically switch off the ceiling lightning when an employee has left its office. However, even more energy can be saved when different subsystems cooperate with each other. For example, the central control system can switch off the office lights, lower the heating and send an employee's PC to standby mode when the door system reports that the employee has left the building. In this paper, we present an approach to integrate tiny wireless sensor or actuator nodes into an IP-based network. Sensors and actuators are represented as resources of the corresponding node and are made accessible using a RESTful web service.

An interesting field where the use of WSNs proves effectiveness is the field of Intelligent Vehicular Systems. An Intelligent Vehicular System uses technological advances in computers and information technology to improve the efficiency of both new and existing vehicular systems. By providing surveillance and tracking services, traffic conditions, in both urban and rural areas, can be monitored continuously. A direct consequence of that is resolving the congestion problem by properly directing the traffic away from the highly crowded and congested roads. Moreover, IVSs can be used to manage parking lots, report emergency situations, navigate destinations, propagate traffic conditions on highways, provide traveler information, avoid vehicle collisions, and enhance driver's safety. Various governmentally-funded IVS projects have been launched in many countries like Canada, USA, Europe, Japan, Australia and others. Furthermore, various projects have been funded by educational institutions, regional organizations, and the industry to research IVS.

2. WSN System Architectures

2.1 Health Monitoring System

The proposed wireless body area sensor network for health monitoring integrated into a broader multitier telemedicine system is illustrated in Figure 1. The telemedical system spans a network comprised of individual health monitoring systems that connect through the Internet to a medical server tier that resides at the top of this hierarchy. The top tier, centered on a medical server, is optimized to service hundreds or thousands of individual users, and encompasses a complex network of interconnected services, medical personnel, and healthcare professionals. Each user wears a number of sensor nodes that are strategically placed on her body. The primary functions of these sensor nodes are to unobtrusively sample vital signs and transfer the relevant data to a personal server through wireless personal network implemented using ZigBee (802.15.4) or Bluetooth (802.15.1). The personal server, implemented on a personal digital assistant (PDA), cell phone, or home personal computer, sets up and controls the WBAN. provides graphical or audio interface to the user, and transfers the information about health status to the medical server through the Internet or mobile telephone networks (e.g..GPRS. 3G).

The medical server keeps electronic medical records of registered users and provides various services to the users, medical personnel, and informal caregivers. It is the responsibility of the medical server to authenticate users, accept health monitoring session uploads, format and insert this session data into corresponding medical records, analyze the data patterns, recognize serious health anomalies in order to contact emergency care givers, and forward new instructions to the users, such as physician prescribed exercises. The patient's physician can access the data from his/her office via the Internet and examine it to ensure the patient is within expected health metrics (heart rate, blood pressure, activity), ensure that the patient is responding to a given treatment or that a patient has been performing the given exercises. A server agent may inspect the uploaded data and create an alert in the case of a potential medical condition. The large amount of data collected through these services can also be utilized for knowledge discovery through data mining. Integration of the collected data into research databases and quantitative analysis of conditions and patterns could prove invaluable to researchers trying to link symptoms and diagnoses with historical changes in health status, physiological data, or other parameters (e.g.. gender, age. weight). In a similar way this infrastructure could significantly contribute to monitoring and studying of drug therapy effects.

The second tier is the personal server that interfaces WBAN sensor nodes, provides the graphical user interface, and communicates with services at the top tier. The personal server is typically implemented on a PDA or a cell phone, but alternatively can run on a home personal computer. This is particularly convenient for in-home monitoring of elderly patients. The personal server interfaces the WBAN nodes through a network coordinator (nc) that implements ZigBee or Bluetooth connectivity. To communicate to the medical server, the personal server employs mobile telephone networks (2G. GPRS. 3G) or WLANs to reach an Internet access point. The interface to the WBAN includes the network configuration and management. The network configuration encompasses the following tasks: sensor node registration (type and number of sensors), initialization (e.g.. specify sampling frequency and mode of operation), customization (e.g.. run user specific calibration or user-specific signal processing procedure upload), and setup of a secure communication (key exchange). Once the WBAN network is configured, the personal server manages the network, taking care of channel sharing, time synchronization, data retrieval and processing, and fusion of the data. Based on synergy of information from multiple medical sensors the PS application should determine the user's state and his or her health status and provide feedback through a user friendly and intuitive graphical or audio user interface. The personal server holds patient authentication information and is configured with the medical server IP address in order to interface the medical services. If the communication channel to the medical server is available, the PS establishes a secure communication to the medical server and sends reports that can be integrated into the user's medical record. However, if a link between the PS and the medical server is not available, the PS should be able to store the data locally and initiate data uploads when a link becomes available. This organization allows foil mobility of users with secure and near real time health information uploads. A pivotal part of the telemedical system is tier 1 - wireless body area sensor network. It comprises a number of intelligent nodes, each capable of sensing, sampling, processing, and communicating of physiological signals. For example, an ECG sensor can be used for monitoring heart activity, an EMG sensor for monitoring muscle activity, an EEG sensor for monitoring brain electrical activity, a blood pressure sensor for monitoring blood pressure, a tilt sensor for monitoring trunk position, and a breathing sensor for monitoring respiration, while the motion sensors can be used to discriminate the user's status and estimate her or his level of activity.

Each sensor node receives initialization commands and responds to queries from the personal server. WBAN nodes must satisfy requirements for minimal weight, miniature form-factor, low power consumption to permit prolonged ubiquitous monitoring, seamless integration into a WBAN. standards based interface protocols, and patient-specific calibration, tuning, and customization. The wireless network nodes can be implemented as tiny patches or incorporated into clothes or shoes. The network nodes continuously collect and process raw information, store them locally, and send processed event notifications to the personal server. The type and nature of a healthcare application will determine the frequency of relevant events (sampling, processing, storing, and communicating). Ideally, sensors periodically transmit their status and events, therefore significantly reducing power consumption and extending battery life. When local analysis of data is inconclusive or indicates an emergency situation, the upper level in the hierarchy can issue a request to transfer raw signals to the next tier of the network.

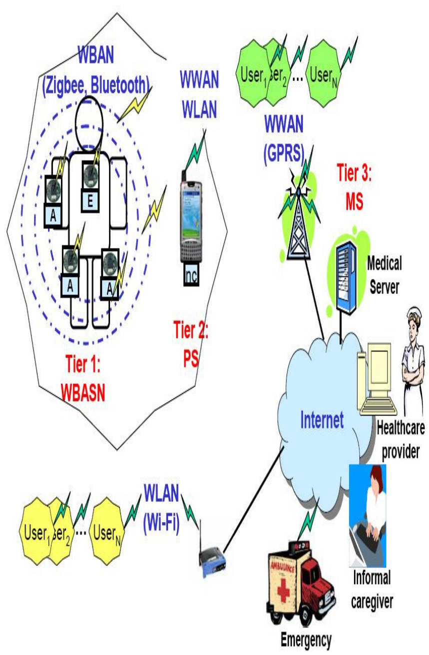

Figure-1 Health Monitoring System Network Architecture

2.2 For Smart Buildings

Building automation and control systems rely on many sensors and actuators placed at different locations throughout a building. Reducing the power consumption of a modern building requires continuous monitoring of various environmental parameters inside and outside the building. The key requirement for an efficient monitoring and controlling is that all sensors and actuators are addressable over the network. Different proprietary protocols and industry standards for building automation have been proposed over the years, e.g., CEBus, EIB, BACnet or Local Control Network (LCN). However, integration of different services based on the Internet protocol (IP) suite has become an important trend during recent years. While standard IP-based protocols introduce some overhead compared to a customized protocol, the increased possibilities to connect different devices certainly pay off. Although we are using tiny devices, we still want to use the standard protocols which made the Web so powerful. It is even possible to run proprietary protocols in certain parts of the network. A smart gateway at the network boundary is then used to provide access for IP-based protocols. As a large number of devices may be placed at different locations throughout the building, connecting them using wires, e.g.by Ethernet, is often not practical. The IEEE 802.11 wireless LAN standard solves the problem of laying wires, but the energy consumption of the radio transceiver makes it infeasible to operate devices on batteries. We address this problem by employing a wireless sensor network based on the IEEE 802.15.4 physical layer standard which is optimized for energy efficient communication with low data rates. The 6L0WPAN header compression scheme allows to efficiently send IPv6 packets over IEEE 802.15.4-based networks. The overall architecture of the system presented in this work is outlined in Figure 2.

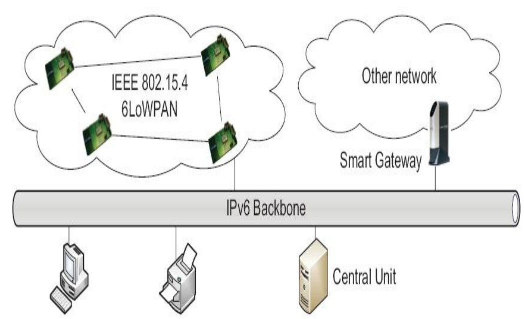

Figure 2 Architecture of a monitoring and control system for smart buildings. 6LoPAN-enabled wireless sensor nodes are directly integrated into the IPv6 network (left). Access to non IP-enabled devices is provided through a smart gateway at the network boundary (right). Sensors and actuators are accessible by a central unit.

Web Services for Wireless Sensor Nodes--Web services allow the interaction between different devices over the network in order to exchange data or to trigger certain actions. Data is exchanged between peers using the Hypertext Transfer Protocol (HTTP). Traditional enterprise solutions tend to use the Simple Object Access Protocol (SOAP) together with XML for the data representation. Recently, a more lightweight solution called Representational State Transfer (REST) has been proposed which is built on top of the GET, POST, PUT and DELETE methods of HTTP . Web services following these principles are denoted as RESTful web services .

Data Access Schema--Sensor nodes are responsible to provide information about their sensors and actuators to the central monitoring server. One possibility to guarantee that the server has up-to-date information is that the sensor node periodically sends status messages to the monitoring server. An alternative approach would be that the server polls the state of the sensors according to demand. While the first approach is preferable if no actuators are connected to the sensor node, the second variant offers more flexibility since the same interface can be used to read out the state of a sensor as well as to modify the state of actuators. The requirements of our Web-based API are similar to the second option, which is preferable for the implementation.

RESTful API for Sensor Nodes--Our approach implements a RESTful Application Programming Interface (API) on sensor nodes to provide access to sensors and actuators through the Web. As each sensor node may connect with different sensors and actuators, manual configuration of a central monitoring system is infeasible if a large number of sensor nodes are used. Based on the RESTful API, we introduce a plug-and-play approach. which enables the automatic discovery of sensor nodes in a wireless network, but also of the functionality they provide. The Representational State Transfer (REST) protocol can be outlined as a collection of network architecture principles and is nowadays used by various Web 2.0 applications to offer their functionality over an API. Unlike other web services, such as SOAP, which rely on other application layer protocols, REST uses the HTTP protocol as application platform. The functionality of a system is implemented as a set of resources that can be identified using the corresponding URI; thus both the sensor node and the temperature sensor get an own URL. A RESTful web service is a collection of resources. By using the four basic operations provided by the HTTP protocol (GET, PUT, POST and DELETE), clients can interact with the resources. Each operation executes a corresponding action like updating a resource or creating a new entry in a collection. Its lightweight stack simplifies the integration of REST in devices with limited resources such as sensor nodes. Not only the device is a resource, but all sensors itself provide a resource that can be accessed over the network. As web services are not limited to sensor nodes, they can be used in any devices integrated in the monitoring and controlling system of a smart building.

Resource Discovery and Access--As an individual sensor node potentially offers many different resources, the device has to provide functionality for automatic discovery of resources.

2.3 Intelligent Vehicular System

WSN Architectures for IVSs--In our study of the WSN-based architectures for IVSs. we identify two main architecture categories under which various contributions have been reported:

1.Planar (flat) architectures: in this category, a single-tiered WSN architecture is used to support an IVS. Infrastructure less (i.e.. peer-to-peer ad hoc wireless networks) communication paradigm is utilized to support inter-vehicle (V2V), communication while infrastructure-based communication paradigm supports vehicle-to-infrastructure (V2I) communication.

2.Multi-tiered architectures: in this category, two or more tiers constitute the WSN architecture in its support of an IVS. In their support of V2V and V2I communications, these tiers maybe homogeneous (i.e.. using a single technology alone), or heterogeneous (i.e.. incorporating different technologies in the different tiers to achieve enhanced performance).

In the following two subsections we elaborate on these architecture categories.

Planar Architectures-- The planar architectures is similar to the basic WSN architectures. The only main difference is that a planar architecture for an IVS includes mobile sensors (installed on vehicles). The advantage of this architecture is that it resembles the one already in use for the "object or target tracking" application. This means that some of the challenges encountered in such architectures are known, in spite of that IVSs are dealing with larger number of objects (i.e.. vehicles) to track and monitor. On the other hand, the main drawback of this architecture is that the IVS has major constraints in terms of processing capability of the nodes. Thus, the ability of the WSN to support QoS is limited. The planar architecture is used in [20] [21] [22] and we describe these contributions in the following.

(i)If WSN-based Navigation System in WiMAX networks--This architecture (we refer to it as WNSW in the rest of the paper) is proposed in [40]. The architecture is intended to support a navigation system that determines the optimal route (that is. the route that is most economic in gasoline exhausting while achieving least travel time) to a targeted destination. This architecture is infrastructure-less and the communication paradigm of use is inter-vehicle. (V2V). The vehicles communicate on a peer-to-peer basis to exchange the required data. Therefore, the mobile stations can form a mobile ad-hoc wireless network (MANET) to exchange data. Different types of sensors are installed on each vehicle to sense the speed and direction of neighboring vehicles. Furthermore, vehicles are equipped with the IEEE 802.16 (WiMAX) network interface to exchange the traffic information with the neighboring vehicles. The usage of the latter interface is motivated by the wide range (3-5 km) of communication it provides, which enables each vehicle to collect more accurate data about the intended destination. Also, a data rate of 30 Mbps is achievable with that interface, and this eliminates any restrictions on the volume of data exchanged. Finally. GPS devices are used on each vehicle to get the longitude and latitude of its position.

(ii) Wireless Sensor Network for Intelligent Vehicular Systems--The Wireless Sensor Network for Intelligent Vehicular System (WIVS) collects and communicates information to organize the traffic at intersections [21]. This architecture depends on a fixed infrastructure composed of roadside units (that is, Sensors installed on both roadsides) and intersection units. The communication paradigm supports both V2I and I2V. Vehicle units (that is, vehicles equipped with sensors) send vehicle parameters (speed, direction, location, etc.) to roadside units. Roadside units work on aggregating the received data before transferring them to the intersection unit, which relays them to the final strategy sub-system. Roadside units are installed on both sides of a road in order to achieve a redundancy in sensor nodes. Furthermore , the flow of data among the roadside units (on each single side) is either upstream or downstream. Thus, with the help of the information about the position of the passing vehicles, localization of the roadside units becomes simple. We note that physical and MAC layers in this architecture support the IEEE 802.15.4 (ZigBee) standard.

(iii)Clustered WSN for IVS--The Clustered WSN for IVS architecture is intended to support road traffic monitoring [42]. This is a clustered architecture where each cluster is constituted of a BS (the cluster head) installed on the roadside and one or more passing by vehicles (the cluster members). Several BSs are installed on the roadside to monitor the passing traffic. Data are transferred from vehicles to the BSs (that is. V2I). from BSs to vehicles (that is. I2V) and among the BSs themselves . Vehicles are equipped with sensors while the BSs comprise mass storage memories to store a large volume of information. The existence of multiple BSs enables the WSN to tolerate faults. The failure of a certain BS should not degrade the performance of the network as several other BSs are available. Usually. BSs are separated by a 100m distance and each BS can alone monitor up to 200 vehicles. An interesting point about this architecture is the support of security. A key refreshment algorithm is applied periodically between neighboring BSs as well as between a BS and a vehicle. The BSs and the vehicle sensors perform DES-based encryption in their data communications.

Multi-Tiered Architectures--The multi-tiered architectures use hierarchical designs in order to improve the performance of the WSN in terms of delay and routing. As mentioned earlier, multi-tiered architectures may either be homogeneous, like in [26]. or heterogeneous, like in [27]. The heterogeneous architectures couple a WSN with other technologies (like WLAN) such that higher performance can be achieved. The main target is to move the burden of handling complex processing and computations to another layer where other technologies can be more efficient than WSN. As a result, more attention can be given to support intelligent applications where QoS is a high concern. A drawback of the heterogeneous architectures is that dealing with more technologies adds to the complexity of the design. Interfacing among different technologies should be handled with extreme caution. In the following we describe the available multi-tiered architectures contributions.

(i)Sensor Network with Mobile Station--The Sensor Network with Mobile Station (SNMS) architecture is proposed in [23]. The architecture is intended to support road traffic monitoring. Two tiers are used: the lower tier, which is a single-hop network constituted by sensor units and a single vehicle, and an upper tier, which is constituted by a P2P network of vehicles. The lower tier supports I2V communications while the upper tier supports a V2V communications. Sensor units, which are installed along road sides, sense various parameters like humidity, temperature and traffic situation. Vehicles are equipped with sensors that collect and aggregate the data sent by the roadside units. In other words, vehicles appear as mobile sinks in the lower tier of the architecture. Bluetooth technology is used in the lower tier to achieve short-range communications over 2.4 GHz with a bandwidth of 1 Mb/s. In the upper tier, vehicles use two modes of communication: 1) WLAN mode, in which the vehicles form a netted structure for communication, and 2) Multihop ad hoc network mode, in which vehicles exchange the data and route them through other vehicles.

(ii)Two-tiered WSN for Real-Time Communications--The Two-tiered WSN for Real-Time Communications (TTW-RTC) architecture is intended to support road traffic monitoring [24]. There are two tiers: 1) A lower tier that is a WSN constituted by vehicles equipped with sensors, and 2) An upper tier that is an overlay WLAN constituted by resourceful Access Points (APs). This overlay network serves as a backbone for the WSN. V2V is the paradigm of communication used in the lower tier while V2I communication is used in between the two tiers. The IEEE 802.15.4 (ZigBee) standard is implemented in the WSN while the IEEE 802.11 (WiFi) with the IEEE 802.1 le extension is implemented in the backbone WLAN. The main advantage of this architecture is that it removes the burden of complex computations from the WSN and migrate it to the resourceful (in terms of available memory and power resources) upper tier. The latter can support a range of coverage up to 300m and a data rate of 11 Mbps (compared to < 150 m and 128 kbps. respectively- in the case of the lower tier). Also, the routing functionality that provides connectivity among all the sensors of the large WSN is handled by the APs. Furthermore, localization is highly simplified with the availability of the fixed infrastructure (APs). While the lower tier is capable of covering a range of 150m. the upper tier can go as far as 300m. The disadvantage of this architecture is that, while an AP provides critical services to the part of the WSN it covers, a failure of that AP may lead that part to lose its connectivity to the other parts of the WSN.

(iii)Sensor Network-Based Traffic Information Service System--The Sensor Network-based Traffic Information Service System (SNTISS) is intended for traffic information collection [25]. It has a three-tiered clustered architecture composed of: 1) A lower-tier, which is constituted by clusters of sensors responsible for the sensing and data fusion functionality. 2) A middle-tier, which is constituted by cluster-heads (or leaders) that handle management functionality beside transmission of data to terminals in the upper-tier, and 3) An upper-tier, which is the decision making tier that is constituted by a mass data storage terminal that handles practical traffic control and service strategies based on the data collected from the other two tiers. An important aspect about this architecture is that it is a pure infrastructure-based architecture that assumes no sensors installed on the travelling vehicles. The sensor nodes (forming the clusters) are installed on both sides of each road to monitor the traffic of vehicles (the cluster-head is elected within each cluster). The data terminal node at the upper tier, given its complicated computations, is a resourceful node. As the cluster-heads consume more power than other cluster members, they are supported with a backup battery or direct wired power supply to avoid shortage of energy.

3. Conclusions

We believe that WBAN systems will allow a dramatic shift in the way people think about and manage their health in the same fashion the Internet has changed the way people communicate to each other and search for information. This shift toward more proactive preventive healthcare will not only improve the quality of life, but will also reduce healthcare costs. we presented an approach to interconnect different sensor and actuator nodes in building control and monitoring systems. Even though we are targeting tiny sensor nodes with limited memory and processing power, we propose the use of lightweight web services based on Representational State Transfer (REST). Sensor nodes run a small web server on top of a TCP/IP stack to provide access to sensor data and actuators using HTTP requests. Using a simple browsing mechanism, clients can fetch a list of services offered by a device. Service discovery based on multicast DNS messages enables the system to integrate new devices without additional configuration effort. Using established and widely spread technologies which are not limited to WSNs, enables the connection of various types of devices, which is a must for smart buildings. we provided a general overview of the opportunities provided by WSNs to support an efficient IVS. We discussed the important parameters that drive the design of any WSN architecture and showed how these parameters can be relaxed or simplified in the case of IVSs. We have also reviewed some major contributions available in the literature towards building effective WSN-base IVS. By categorizing these architectures into planar and multi-tiered ones we could see the diverse strengths and weaknesses that are associated with the different architectures. The main conclusion we draw from this is that multi-tiered architecture can show promising performance, over the planar architectures, since they can alleviate the problems associated with constraints in the WSNs, in terms of power and complexity of processing, by incorporating more tiers and different technologies, with different capabilities, at each tier.

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