Health Condition Observation with High Level Efficiency in an Advanced Sensor Network

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Abstract

This research paper mainly focuses on system architecture for smart healthcare using an advanced Wireless Sensor Network (WSN) and improving the efficiency of sensor to get the data immediately even there is patient in critical condition. It specifically targets assisted-living residents and others who may benefit from continuous, remote health monitoring. It focuses the advantages, objectives, and status of the design and multi-channel cluster clustering algorithm for increasing efficiency. An experimental living space has been constructed at the Lab for evaluation. Early results suggest a strong potential for WSNs to open new research perspectives for low-cost, ad hoc deployment of multimodal sensors for an improved quality of medical care and data retrieval time is very low.

Keywords : Wireless Network, Sensor Network, Remote Monitoring.

1. Introduction

Now a day's people those who are suffering from diseases of the elderly will increase. In-home and nursing-home pervasive networks may assist residents and their caregivers by providing continuous medical monitoring, memory enhancement, control of home appliances, medical data access, and emergency communication.

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For example, some of them are devoted to continuous medical monitoring for degenerative diseases like Alzheimer's, Parkinson's or similar cognitive disorders [6]. Other projects such as "CodeBlue" at Harvard extend WSNs for medical applications in disasters [7]. This network architecture for smart healthcare that will open up new opportunities for continuous monitoring of assisted and independent-living residents [9,10]. While preserving resident comfort and privacy, the network manages a continuous medical history. Unobtrusive area and environmental sensors combine with wearable interactive devices to evaluate the health of spaces and the people who inhabit them. Authorized care providers may monitor residents' health and life habits and watch for chronic pathologies. Multiple patients and their resident family members as well as visitors are differentiated for sensing tasks and access privileges. High costs of installation and retrofit are avoided by using ad hoc, self-managing networks. The proposed wireless system will extend healthcare from the traditional clinical hospital setting to nursing and retirement homes, enabling telecare without the prohibitive costs of retrofitting existing structures.

The architecture is multi-tiered, with heterogeneous devices ranging from lightweight sensors, to mobile components, and more powerful stationary devices. Figure 1 shows a MicaZ device from Crossbow with an environmental sensor board mounted on it. The advantages of a WSN are numerous for smart healthcare, as it provides the following important properties:

a) **Portability :** Small devices collect data and communicate wirelessly, operating with minimal patient input. They may be carried on the body or deeply embedded in the environment. Unobtrusiveness helps with patient acceptance and minimizes confounding measurement effects. Since monitoring is done in the living space, the patient travels less often; this is safer and more convenient.

b) **Comfort to deploy and scalable :** Devices can be deployed in potentially large quantities with dramatically less complexity and cost compared to wired networks. Devices are placed in the living space and turned on, self-organizing and calibrating automatically.

c) **Real-time and always-on :** Physiological and environmental data can be monitored continuously, allowing real-time response by emergency or healthcare workers. The data collected form a health resource, and are valuable for filling in gaps in the traditional patient history. Even though the network as a whole is always-on, individual sensors still must conserve energy through smart power management and on-demand activation.

d) **Reconfiguration and self-organization :** Since there is no fixed installation, adding and removing sensors instantly reconfigures the network. Doctors may re-target the mission of the network as medical needs change. Sensors self-organize to form routing paths, collaborate on data processing, and establish hierarchies.

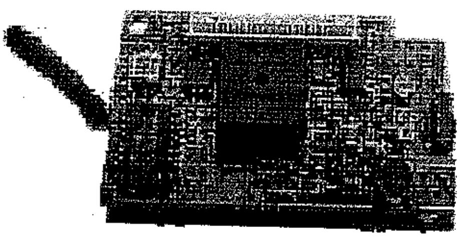

Figure 1 : Mica With MTS 310 Sensor Board

2. High Level System Architecture

A. System Overview

The medical sensor network system integrates heterogeneous devices, some wearable on the patient and some placed inside the living space. Together they inform the healthcare provider about the health status of the resident. Data is collected, aggregated, pre-processed, stored, and acted upon using a variety of sensors and devices in the architecture (pressure sensor, RFID tags, floor sensor, environmental sensor, dust sensor, etc.). Multiple body networks may be present in a single system. Traditional healthcare provider networks may connect to the system by a gateway, or directly to its database. Some elements of the network are mobile, while others are stationary. Some can use line power, but others depend on batteries. If any fixed computing or communications infrastructure is present it can be used, but the system can be deployed into existing structures without retrofitting.

The components of the architecture are shown in Figure 2, dividing devices into any one of several parallel layers based on their roles and physical interconnect. Each tier of the architecture is described below.

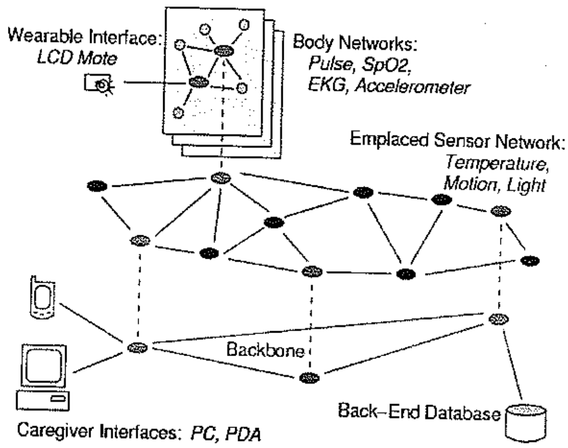

Figure 2 : Multi-Tiered System Architecture, Showing Physical Connectivity

Body Network and Subsystems : This network comprises tiny portable devices equipped with a variety of sensors (such as heart-rate, heart-rhythm, temperature, oximeter, accelerometer), and performs biophysical monitoring, patient identification, location detection, and other desired tasks. These devices are small enough to be worn comfortably for a long time. Their energy consumption should also be optimized so that the battery is not required to be changed regularly. They may use "kinetic" recharging. Actuators notify the wearer of important messages from an external entity. For example, an actuator can remind an early Alzheimer patient to check the oven because sensors detect an abnormally high temperature. Or, a tone may indicate that it is time to take medication. The sensors and actuators in the body network are able to communicate among themselves. A node in the body network is designated as the gateway to the emplaced sensor network. Due to size and energy constraints, nodes in this network have little processing and storage capabilities. More details about the particular body networks we have developed are available [10].

Emplaced Sensor Network : This network includes sensor devices deployed in the environment (rooms, hallways, furniture) to support sensing and monitoring, including: temperature, humidity, motion, acoustic, camera, etc. It also provides a spatial context for data association and analysis. All devices are connected to a more resourceful backbone. Sensors communicate wirelessly using multi-hop routing and may use either wired or battery power. Nodes in this network may vary in their capabilities, but generally do not perform extensive calculation or store much data. The sensor network interfaces to multiple body networks, seamlessly managing handoff of reported data and maintaining patient presence information.

Backbone : A backbone network connects traditional systems, such as PDAs, PCs, and databases, to the emplaced sensor network. It also connects discontiguous sensor nodes by a high-speed relay for efficient routing. The backbone may communicate wirelessly or may overlay onto an existing wired infrastructure. Nodes possess significant storage and computation capability, for query processing and location services. Yet, their number is minimized to reduce cost.

Back-end Databases : One or more nodes connected to the backbone are dedicated databases for long-term archiving and data mining. If unavailable, nodes on the backbone may serve as in-network databases.

Human Interfaces : Patients and caregivers interface with the network using PDAs, PCs, or wearable devices. These are used for data management, querying, object location, memory aids, and configuration, depending on who is accessing the system and for what purpose. Limited interactions are supported with the on-body sensors and control aids. These may provide memory aids, alerts, and an emergency communication channel. PDAs and PCs provide richer interfaces to real-time and historical data. Caregivers use these to specify medical sensing tasks and to view important data.

3. Improving Efficiency

To improve efficiency Multi Channel Cluster Algorithm can use, a typical problem that arises is the hidden node problem of neighboring nodes, which occurs when two nodes maintaining connectivity to a third node, cannot hear each other. In Fig. 3, node D is in communication with node B, where D is currently transmitting. Node C wishes to communicate with node B as well. Following the CSMA-CA protocol, node C listens to the medium, but since C does not detect node's D transmission, it declares the medium free. Consequently, C accesses the medium, causing collisions at B.

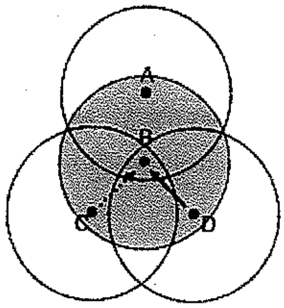

Figure 3 : Hidden Node Problem

The probability of any two nodes having hidden node relationship can go above 40% [5], representing a strong negative impact on the network throughput and packet delay, which for some applications might be critical. In IEEE.802.11 standard, the access technique has been ameliorated, recurring to the Request To Send (RTS) and Clear To Send (CTS) mechanism that reduces hidden node problem. Nevertheless, this mechanism was not introduced in the 802.15.4 standard due simplicity of the protocol. Also, the exchange of these messages results in a strong overhead in the communication, not improving significantly the throughput nor resolving the hidden node problem. As described above, the contention collision problem also rises with this access technique. The use of recursive backoffs of transmission of a node, when a busy channel is sensed, results in dropped packets, when the maximum number of backoffs, NB, is reached. This increases the average packet loss and average packet delay. Herewith is proposed an algorithm to improve performance of 802.15.4 based star topology WSNs. It recurs to a multichannel capability coordinator device, able to operate simultaneously in different radio channels as figure 4. The algorithm implemented by the coordinator is as follows:

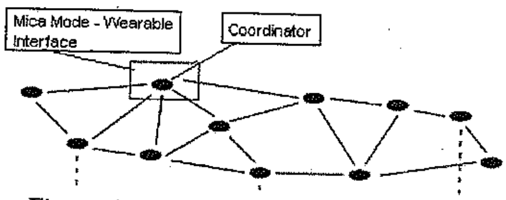

Figure 4 : Sensor Nodes with Coordinator

1. All nodes, including the coordinator, use a default common radio channel for the auto-configuration procedure to establish the network infrastructure.

2. Nodes are grouped into different clusters of nodes following a certain clustering strategy described below. All nodes within each cluster can hear each other.

3. To each cluster of nodes, a specific 802.15.4 radio channel is assigned by the coordinator node to communicate with him, cluster-head of all clusters.

4. Each node is informed of the new radio-channel it shall use to communicate to the coordinator node.

5. In case new nodes appear, or some move, this algorithm may be repeated, updating the communication configuration.

The grouping strategy into clusters is described below:

a) The coordinator sends a date polling frame to each node in turn, requesting an ACK. Nodes that do not hear the ACK from that node, store that node as hidden.

b) At the end of this process, the coordinator sends a request to each node to send the list of hidden nodes. A list of nodes with their associated table of hidden nodes is build by the coordinator, ordered according to the number of hidden nodes. The node with highest Number of Hidden Nodes (NHN) is at the beginning of the list.

c) Based on this information, the coordinator builds the groups:

i. The construction of a cluster is started moving the node with higher NHN from the list to this cluster group. The second higher NHN node is then checked if it sees the first node; if it is seen it is added to the group and removed from the list, if it is hidden, it is left in the list, and the next node is checked.

ii. This process is run through the whole ordered list. For each next proponent node is checked if it is seen by all nodes in the current cluster, being added to the cluster and removed from the list if seen, or left in the list if hidden to any.

iii. When all nodes have been checked, the process restarts at i., until no more nodes are available in the list. The list of nodes and associated NHN tables is continuously updated, being removed a node from it if assigned to a certain cluster

As proven mathematically in [2], 5 clusters are sufficient to cover all nodes around a coordinator node. The implementation of the algorithm confirms these results. As will be demonstrated, this algorithm will remove completely the hidden node problem and reduces drastically delays due to contention collision problems. Also, an increase of capacity is enabled, since 5 radio-channels of equal throughput operate can operate simultaneously without creating interference. Are restrictions of this mechanism that the coordinator is able to operate simultaneously in different channels, needing to have more operation apacity, and be centrally located, to be heard by every node.

4. Simulation

4.1 Data Acquisition

The followings are used when implement this system

Motion sensor: It is a low-cost sensor module that is capable of detecting motion and ambient light levels. The module also has a simple one-button and LED user interface for testing and diagnostics. It is interfaced to a MicaZ wireless sensor node that processes the sensor data and forwards the information through the wireless network. A set of such modules is used to track human presence in every room of the simulated smart health home.

Body network: A wearable WSN service with MicaZ motes embedded in a jacket, which can record human activities and location using a 2-axis accelerometer and GPS. The recorded activity data is subsequently uploaded through an access point for archiving, from which past human activities and locations can be reconstructed.

Indoor temperature and luminosity sensor: These sensors give the environmental conditions of the habitat and are also connected to the backbone via MicaZ.

Bed sensor: The bed sensor, developed by the Medical Automation Research Center (MARC), is based on an air bladder strip located on the bed, which measures the breathing rate, heart rate and agitation of a patient.

Pulse-oximeter and EKG: These sensors were developed by Harvard University [7]. They are wearable, connecting to MicaZ and Telos devices, and collect patient vital signs. Heart rate (HR), heartbeat events, oxygen saturation (SpO2), and electrocardiogram (EKG) are available.

4.2 Backbone Infrastructure

The current backbone is a single Stargate serving as a gateway between the motes deployed in the home environment and the nurse control station. Motes use a Zigbeecompliant (802.15.4) wireless protocol for communication. The Stargate runs Embedded Linux and possesses more power and capabilities than the motes.

4.3 Database Management and Data Mining

A MySQL database serves as a backend data store for the entire system. It is located in a PC connected to the backbone, and stores all the information coming from the infrastructure for longitudinal studies and offline analysis.

4.4 Graphical User Interfaces

Interfaces with residents, healthcare providers, and technicians have different requirements. Each must present an appropriate interface for performing the intended tasks, while conforming to the constraints imposed by form factor and usability. Currently, the system offers four different GUIs.

The first is located on the local nurse control station, and it tracks the motion of the resident using motion activations. A second GUI (see Figure 5), which can run on a PDA, permits a caregiver to request realtime environmental conditions of the living space and the vital signs of the resident. It uses a query management system distributed among the PDA, Stargate and the sensor devices. The interface graphically presents requested data for clear consumption by the user. An LCD interface board was also de-signed for the MicaZ for wearable applications. It presents sensor readings, reminders and queries, and can accept rudimentary input from the wearer.

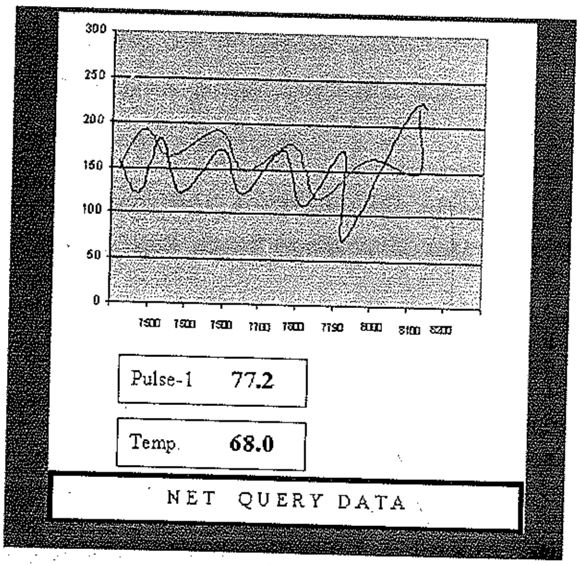

Figure 5 : A GUI Displays Accelerometer Data, Patient pulse-rate and Environmental Temperature.

A final GUI, from a direct medical application based on motion sensors, exists to study the behavioral profile of the user's sleep/wake patterns and life habits, and to detect some pathologies in the early stages.

Simulations were run in different packet sizes. The offered traffic of the totality of the nodes does not exceed the capacity of the sensor network, and in particular of the coordinator node. Results are presented in Figs. 3 and 4 for the average throughput and average packet delay. The average throughput corresponds to the fraction of traffic correctly received by the network analyzer, a device in promiscuous mode hearing all the traffic in the network. The average packet delay is the average delay experienced by a data frame from the start of its generation by the application layer to the end of its reception by the analyzer. The effect of the variation of SO and DO values was not addressed, being a detailed study on the effect of these two values presented in [19]

5. Results

The system is single hop, as the radio range covers all of the facility. A multi-hop protocol will be necessary for access of multiple floors, or if transmission power is reduced. Data communication is bi-directional between the motes and the Stargate. Time-stamping is done by the PC when motion events are received. A first experiment based on seven MicaZ motes, programmed to send motion events over the network containing the location of the user, was performed with no activity in the lab for one week. We observed no false detections in the system under these conditions. However, this experiment showed the necessity of enhancing the power management scheme to prolong the lifetime of the sensors. In another experiment, the supervision program located at the control station correctly displays the location of a mobile resident by polling the MySQL database for motion events.

6. Future Enhancement

1. Multi-modal data association and multiple residents. Data association is a way to know "who is doing what?" in a system without biometric identification and with multiple actors present, such as an assisted-living community. It permits us to recognize the right person among others when he is responsible for a triggered event. This is indispensable for avoiding medical errors in the future and properly attributing diagnostics. Consequently, dedicated sensors and data association algorithms must be developed to increase quality of data.

2. Security and privacy. The system is monitoring and collecting patient data that is subject to privacy policies. For example, the patient may decide not to reveal the monitored data of certain sensors until it is vital to determine a diagnosis and therefore authorized by the patient at the time of a visit to a doctor. Security and privacy mechanisms must be throughout the system.

7. Conclusion

The baseline of the system is implemented. The experiment showed a robust system with some straightforward communications from front to backend of the system with improved efficiency.

Recently, a vast number of wireless applications focusing on the interaction with the environment are emerging, based on Wireless Sensor Networks (WSN). IEEE 802.15.4 standard has been adopted in WSNs to achieve the wireless communication support. Nevertheless, its SMA-CA access technique suffers of the hidden node problem, strongly reducing throughput and delay of the network. An approach was presented to improve performance in star WSNs topologies. It is based on an algorithm used by a multi-channel capabilities cluster coordinator, which creates clusters of nodes that all "hear" each other. Each cluster operates in a different frequency, eliminating completely the hidden node problem, responsible for a 45% throughput decrease in single-channel configurations. From simulation results, the multi-channel strategy presents the aptitude of increasing throughput and decreasing delay by solving the hidden node problem, alleviating contention collisions and improving the global network performance.

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