A Reliable Sensor Data Collection Network for Health Monitoring

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Abstract In this paper we propose system architecture for smart healthcare based on an advanced wireless sensor network (WSN). This paper presents a method for reliably collecting data events from sensors and forwarding the data via a mobile ad hoc network (MANET) to sensor monitoring stations located on an external network. At the core is a MANET concept that consists of ground and unmanned aircraft (UA) nodes. UA enable a model whereby widely spaced sensors are intermittently connected to the network and data are sent in stages as connections become available along each stage. This paper describes our efforts to build such a network for a real application. The paper describes the sensor data collection model, the reliable multicast data delivery mechanism, and our experiences so far in this project. In particular, it describes our existing network test bed and the control of an UA through a MANET. It specifically targets assisted living residents and others who may benefit from continuous, remote health monitoring. We present the advantages, objectives, and status of the design.

Keywords Ad hoc networks · Unmanned aircraft · Sensor data collection

Introduction

This paper considers the role of a mobile ad hoc network (MANET) to support sensor data collection [1]. In this model an area has intelligence, surveillance, and reconnaissance (ISR), environmental monitoring, or other sensors that can range

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V. Kumar and M. Bhatele (eds.), *Proceedings of All India Seminar on Biomedical Engineering 2012 (AISOBE 2012)*, Lecture Notes in Bioengineering,
DOI: 10.1007/978-81-322-0970-6_19,

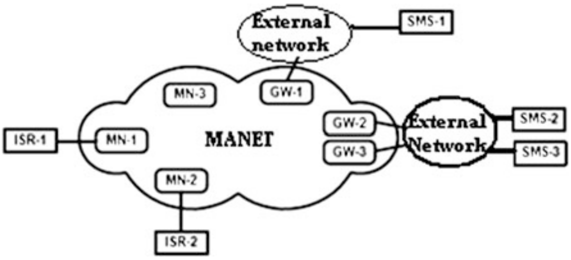

Fig. 1 Sensor data collection concept showing ISR sensors delivering data through a MANET to multiple gateways and sensor monitoring stations

from small and simple thermometers to large and highly functional RF scanners. Sensors need to report results in near real-time to one or more sensor monitoring stations (SMS) located at remote locations. A sensor reports events either periodically or upon some triggering condition. The sensor interfaces with a MANET node (MN) which in turn delivers the sensor event to a gateway node (GW) which connects to an external backhaul network to the SMS. The MANET can have stationary ground nodes to support this communication. A ground node typically has short-range and cannot support sensors over a wide area. Therefore, in order to provide a node capable of long-range communication and also having wide ranging coverage, unmanned aircraft (UA) are out with radio interfaces. The concept diagram is shown in Fig. 1. As the world's population ages, those suffering from diseases of the elderly will increase. In homes and nursing homes 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. Researchers in computer, networking, and medical fields are working to make the broad vision of smart health care possible.

This concept has several issues to be resolved in routing, addressing, and the interaction between the UA mobility and communication. Each sensor event is considered valuable and requires a reliable delivery mechanism through the dynamic network to multiple SMS [5]. Mobility in the MANET may lead to a temporary lack of routes to the GW. The gateways may connect to external networks via satellite or cellular links which have occasional link outages. The distribution of the sensors and available MANET resources may be such that there is never an end to end route from the sensor and all the SMSs. The sensor is assumed to be simple and should be isolated from network specifics such as the number and network location of the SMS. The addresses of the sensors, MN, and external network nodes must be managed not only to enable the multicast delivery of sensor data to each SMS, but also to enable an individual SMS to make queries to specific sensors. The MN, in turn, should be isolated from the specifics of the GW to SMS backhaul network.

Major Goals

We are developing network architecture for smart health care that will open up new opportunities for continuous monitoring of assisted and independent living residents while preserving resident comfort and privacy. The network manages a

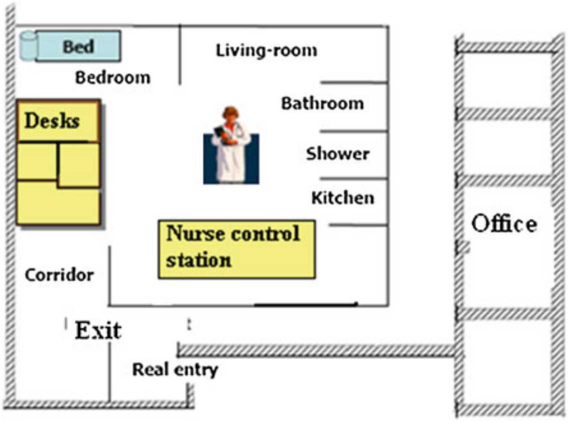

Fig. 2 Layout of the experimental smart health home at UVA

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 resident's 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 [2, 3]. Based on the fundamental elements of future medical applications (integration with existing medical practice and technology, real-time and long-term monitoring, wearable sensors and assistance to chronic patients, elders or handicapped people), our wireless system will extend health care from the traditional clinical hospital setting to nursing and retirement homes, enabling telecare without the prohibitive costs of retrofitting existing structures. Figure 2 shows the layout of the experimental laboratory. The architecture is multitiered, with heterogeneous devices ranging from lightweight sensors, to mobile components, and more powerful stationary devices.

The advantages of a WSN are numerous for smart health care, as it provides the following important properties:

1. **Portability and unobtrusiveness**: 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.
2. **Ease of deployment and scalability**: Devices can be deployed in potentially large quantities with dramatically less complexity and cost compared to wired networks. Existing structures, particularly dilapidated ones, can be easily augmented with a WSN network, whereas wired installations would be expensive and impractical. Devices are placed in the living space and turned on, self-organizing and calibrating automatically.

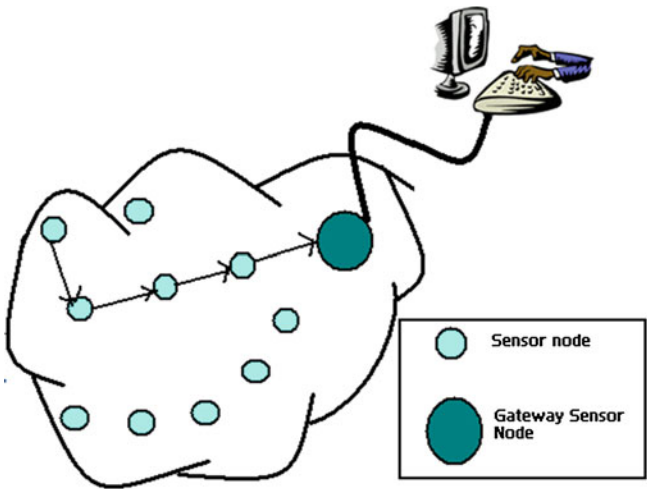

Fig. 3 Typical multihop wireless sensor network architecture

3. **Real-time and always on**: Physiological and environmental data can be monitored continuously, allowing real-time response by emergency or health care workers. The data collected form a health journal, and are valuable for filling in gaps in the traditional patient history. Although the network as a whole is always on, individual sensors still must conserve energy through smart power management and on-demand activation.
4. **Reconfiguration and self-organization**: Since there is no fixed installation, adding and removing sensors instantly reconfigures the network. Doctors may retarget the mission of the network as medical needs change. Sensors self-organize to form routing paths, collaborate on data processing, and establish hierarchies (Fig. 3).

The WSN is built of "nodes"—from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors, and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed, and communications bandwidth. The topology of the WSNs can vary from a simple star network to an advanced multihop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding.

Communication Architecture

This section develops the detailed architecture and describes the protocols and addressing schemes that are used. It further explains how the network meets the design criteria and how it deals with network anomalies to guarantee packet delivery.

System Overview and Elements

The overall system architecture is shown in Fig. 3. An ISR sensor [6, 7] produces events that are sent to a nearby MN via a wired Ethernet connection to mitigate interference. This MN manages communication for the ISR and is designated the terminus. The terminus uses the MANET to connect to GW nodes which forward the data to the external networks and on to the SMSs. This ISR initiated event multicast is designated as Event communication. Conversely, an SMS can send commands on the reverse path to a specific sensor. This SMS initiated Command and Query Exchanges are designated as Command communication. Event communication sends sensor readings from one ISR to all active SMSs. Command communication enables a single SMS to control and query one ISR. Both communication paths are based on the same reliable forwarding protocol [4] as described in the next section.

Reliable Forwarding Approach

The design criteria dictate high reliability, but at the same time operation over an intermittently connected network, as well as minimal event message delivery time and overhead. Two primary mechanisms are used to provide reliable delivery: staged delivery and reliable transport. The first mechanism is that the packets are delivered in stages from the ISR to the Terminus, from the Terminus to the GW, and from the GW to the SMS. At each stage, the source node uses a reliable mechanism to deliver the packet to the destination node. Once delivered, the destination node becomes the source node for the next stage and is responsible for advancing the node to the next stage's destination. This breaks down the delivery problem so that the nodes in one stage are isolated from the network-specific issues in other stages. For instance, the ISR is only concerned with delivering its packets to the terminus and does not need to be aware of any of the MANET or satellite link protocols in the networks beyond the terminus. The second mechanism is a reliable delivery protocol, implemented by all communicating entities. As seen in earlier AUGNet experimentation, an ad hoc network with fast moving nodes possess a considerable challenge to existing reliable transport protocols like TCP. Since the goal is purely message transport, compared to data streaming, the UDP protocol was chosen and augmented with functionality to guarantee data delivery. The RUDP protocol provides windowing, congestion control, in order delivery, and over buffering. These are not necessary features in our data collection scenario and we instead chose a simpler UDP mechanism.

Conclusion

This paper describes the design and implementation of a reliable sensor data collection network for sparsely deployed sensors. A meshed ad hoc network of ground nodes and small, fast moving UA is used to gather sensor information and hand them over to SMS. The unique contributions of the conducted research are the control of the UA solely through a meshed ad hoc network, the reliable forwarding of single event packets from sensors to multiple monitoring stations through the intermittently connected network, and the demonstration of autonomous plane operations based on network and environmental parameters. The baseline of the system is implemented. A one-week experiment showed a robust system with some straightforward communications from front to backend of the system. The modularity of this system should enable progressive development of the research areas. We believe this system design will greatly enhance quality of life, health, and security for those in assisted living communities.

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