Wireless Sensor Networks for In-Home Healthcare: Potential and Challenges

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1. Medical Applications of the Future

Advances in wireless sensor networking have opened up new opportunities in healthcare systems. The future will see the integration of the abundance of existing specialized medical technology with pervasive, wireless networks. They will co-exist with the installed infrastructure, augmenting data collection and real-time response. Examples of areas in which future medical systems can benefit the most from wireless sensor networks are in-home assistance, smart nursing homes, and clinical trial and research augmentation.

As the world's population ages [3], those suffering from diseases of the elderly will increase. In-home pervasive networks may assist residents by providing memory enhancement, control of home appliances, medical data lookup, and emergency communication.

Unobtrusive, wearable sensors will allow vast amounts of data to be collected and mined for next-generation clinical trials. Data will be collected and reported automatically, reducing the cost and inconvenience of regular visits to the physician. Therefore, many more study participants may be enrolled, benefiting biological, pharmaceutical, and medical-applications research.

2. Critical Development Areas

2.1 Enabling Technologies for Future Medical Devices:

- *Interoperability*: As a result of the heterogeneity present in the system, communication between devices may occupy multiple bands and use different protocols. For example, motes use unlicensed bands for general telemetry or ISM equipment. Implanted medical devices may use a licensed band allocated for that purpose by the FCC. In order to avoid interference in the increasingly crowded unlicensed ISM band, biomedical devices may use the WMTS band (wireless medical telemetry services, at 608 MHz). [1] The homecare network must provide middleware interoperability between disparate devices, and support unique relationships among devices, such as implants and their outside controllers.
- *Real-time data acquisition and analysis*: The rate of collection of data is higher in this type of network than in many environmental studies. Efficient communication and processing will be essential. Event ordering, time-stamping, synchronization, and quick response in emergency situations will all be required.
- *Reliability and robustness*: Sensors and other devices must operate with enough reliability to yield high-confidence data suitable for medical diagnosis and treatment. Since the network will not be maintained in a controlled environment, devices must be robust.
- *New node architectures*: The integration of different types of sensors, RFID tags, and back-channel long-haul networks may necessitate new and modular node architectures.

2.2 Embedded, Real-Time, Networked System Infrastructures for MDSS:

- *Patient and object tracking:* Tracking can be considered at three levels: symbolic (e.g., Room 136 or X-Ray Lab); geographical (GPS coordinates of a patient on an assisted living campus);

relational/associational ("Dr. Marvin is currently with Patient Bob"). It is complicated by the presence of multiple patients, non-patient family members, and leaving the range of the home network.
- *Communication amid obstructions and interference*: In-building operation has more multi-path interference due to walls and other obstructions, breaking down the correlation between distance and connectivity even further. Unwanted emissions and glitching are likely to be rigorously restricted and even monitored due to safety concerns, particularly around traditional life-critical medical equipment.
- *Multi-modal collaboration and energy conservation*: Limited computational and radio communication capabilities require collaborative algorithms with energy-aware communication. Richly varied data will need to be correlated, mined, and altered. Heterogeneous devices will be on very different duty-cycles, from always-on wired-power units to tiny, stealthy, wearable units, making rendezvous for communication more difficult.
- *Multi-tiered data management:* Data may be aggregated and mined at multiple levels, from simple on-body filtering to cross-correlation and history compression in network storage nodes. Embedded real-time databases store data of interest and allow providers to query them.

2.3 Medical Practice-Driven Models and Requirements:
- *Records and data privacy and security*: Data collected by the network is sensitive, and ownership issues are not always clear. It is likely that the healthcare provider owns the sensor and network devices, yet the data pertain to the patient. Data must be available during emergencies, but access should leave a non-repudiable “trail," so abuses can be detected. Any priority-override mechanisms must be carefully designed. One may want to filter out “privacy-contaminated” data, for example, a patient walks into the wrong room. The system should not “leak” this information through sensors being monitored in the room.
- *Role-based access control and delegation in real-time*: Doctors may delegate access privileges to other doctors and nurses; family members may monitor quality-of-care for nursing home residents. The system may have DRM-like issues: “read but not copy,” “view but not save," etc. Also, patients may have read but not write privileges for the collected sensor data, in order to avoid fraud.
- *Unobtrusive operation:* Stealthiness is desirable, particularly for in-home and nursing home applications, where intrusive technology may not be tolerated. “Invisible” sensors are both socially more acceptable (draw less attention, more dignified) and more dangerous (unwanted tagging and surveillance).

3. Roadmap: Next Generation Smart Homecare

We propose a wireless sensor network architecture for smart homecare that possesses the essential elements of each of the future medical applications, namely:

- Integration with existing medical practices and technology,
- Real-time, long-term, remote monitoring,
- Miniature, wearable sensors, and
- Assistance to the elderly and chronic patients.

It extends healthcare from the traditional clinic or hospital setting to the patient's home, enabling telecare without the prohibitive costs of retrofitting existing dwellings. Currently, patients visit doctors at regular intervals, self-reporting experienced symptoms, problems, and conditions. Doctors conduct various tests to arrive at a diagnosis and then must monitor patient progress throughout treatment. In smart homecare, the WSN collects data according to a physician's specifications, removing some of the cognitive burden from the patient (who may suffer age-related memory decline) and providing a continuous record to assist diagnosis. In-home tasks are also made easier, for example, remote device control, medicine reminders, object location, and emergency communication. The architecture is multi-tiered, with both lightweight mobile components and more powerful stationary devices. Sensors are heterogeneous, and all integrate into the home network. Multiple patients and their resident family members are differentiated for sensing tasks and access privileges.

Smart homecare benefits both the healthcare providers and their patients. For the providers, an automatic monitoring system is valuable for many reasons. Firstly, it frees human labor from 24/7 physical monitoring, reducing labor cost and increasing efficiency. Secondly, wearable sensor devices can sense even small changes in vital signals that humans might overlook, for example, heart rate and blood oxygen levels. Quickly notifying doctors of these changes may save human lives. Thirdly, the data collected from the wireless sensor network can be stored and integrated into a comprehensive health record of each patient, which helps physicians make more informed diagnoses. Eventually, the analyzing, diagnosis, treatment process may also be semi-automated, so a human physician can be assisted by an “electronic physician."

Healthcare patients benefit from improved health as a result of faster diagnosis and treatment of diseases. Other quality-of-life issues, such as privacy, dignity, and convenience, are supported and enhanced by the ability to provide services in the patient's own home. Family members and the smart homecare network itself become part of the healthcare team. Finally, memory aids and other patient-assistance services can restore some lost independence, while preserving safety.

Examples of envisioned missions where the WSNs can quickly make an impact are the following:

- *Sleep apnea*. Every night, monitor blood oxygenation, breathing, heart rate, EEG, and EOG using on-body sensors to assess severity and pattern of obstructive sleep apnea. Home network monitors agitation (movement) and stores and reports sensor data. Network alerts provider and patient if oxygenation falls below a threshold. Monitoring can continue while treatment efficacy is assessed.
- *Journaling support*. Journaling is a technique recommended for patients to help their physicians diagnose ailments like rheumatic diseases. Patients record changes in body functions (range of motion, pain, fatigue, sleep, headache, irritability, etc), and attempt to correlate them with environmental, behavioral, or pharmaceutical changes. The homecare network can aid patients by: providing a time-synchronized channel for recording and transmitting the journal (PC, PDA, “dizziness" button); recording environmental data or external stimuli (temperature, barometric pressure, sunlight exposure, medication schedule); and quantitatively measuring changes in symptoms (pain, heart-rate, sleep disruption).
- *Cardiac health*. Cardiac arrhythmia is any change from the normal beating of the heart. Abnormal heart rhythms can cause the heart to be less efficient, and can cause symptoms such as dizziness, fainting, or fatigue. Since they are sometimes very brief, it can be difficult to properly characterize them. Cardiac stress tests attempt to induce the event while the patient is wearing sensors in a laboratory. In a homecare setting, wearable EKG sensors can monitor for the condition continuously, over days or weeks, until the event occurs. The recorded data is promptly sent to the physician for analysis. If the event is serious enough, the emergency communication channel may be used to call for help, or it may be dispatched automatically. Other sensors in the home may be able to record environmental data to help identify the cause (side-effect of medicine, little sleep, etc.).

4. References

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Author Biography

Professor John A. Stankovic is the BP America Professor in the Computer Science Department at the University of Virginia. He recently served as Chair of the department, completing two terms. He is a Fellow of both the IEEE and the ACM. He also won the IEEE Real-Time Systems Technical Committee's Award for Outstanding Technical Contributions and Leadership. Professor Stankovic also serves on the Board of Directors of the Computer Research Association. Before joining the University of Virginia, Professor Stankovic taught at the University of Massachusetts where he won an outstanding scholar award. He has also held visiting positions in the Computer Science Department at Carnegie-Mellon University, at INRIA in France, and Scuola Superiore S. Anna in Pisa, Italy. He was the Editor-in-Chief for the IEEE Transactions on Distributed and Parallel Systems and is a co-editor-in-chief for the Real-Time Systems Journal. His research interests are in distributed computing, real-time systems, operating systems, and wireless sensor networks. Prof. Stankovic received his PhD from Brown University.