Wireless Sensor Network (WSN) in Space Applications

Driss Benhaddou, Xiaojing Yuan, and Manikanden Balakrishnan

University of Houston, Houston, TX, USA

dbenhaddou@uh.edu

ABSTRACT

The application of Wireless Sensor Network (WSN) in time-sensitive applications, such as remote healthcare, fire tracking, integrated system health monitoring (ISHM) and industrial automation, demands support for emergency services with guaranteed Quality of Service (QoS) bounds. In particular, the continuous monitoring of physiological condition of crew members and spaceflight equipments during long space missions is of paramount importance to NASA as it mitigates mission performance risks. Continual performance tracking and local response advisory capabilities, within space environments, are crucial to ensure overall mission success. This paper will present challenges and opportunities of wireless sensor network in space applications, and the investigation of Quality of Service (QoS) capabilities to meet the stringent requirements of space applications. The paper will also present current evaluation of a new QoS wireless medium access technique as well as a prototype implementation of WSN for remote performance monitoring.

Keywords: wireless sensor networks, quality of service (QoS), remote monitoring, space applications.

1 INTRODUCTION

With the advances of wireless and mobile communication technologies, sensor devices, and wearable medical devices, wireless sensor network (WSN) is becoming ubiquitous. WSNs recently find applications in remote healthcare, fire tracking, integrated system health monitoring (ISHM) and industrial automation. In particular, space applications are using wireless sensor networks to ensure the overall missions success. For instance, space crew health performance can be tracked down using telemedicine without the assistance of a doctor by taking advantage of sensor local processing and tele-communications capabilities. On the other hand sensors can be deployed within the spacecraft to implement integrated system health monitoring system (ISHM).

The implementation of sensor-based systems involves challenges and innovative opportunities at different levels of overall system implementation and integration. A WSN system involves components at different levels from sensor devices, sensor processing and communication interfacing, to reliable communications that support quality of service (QoS). The system should be scalable and support modularity and interoperability. Modularity is the ability to automatically plug a sensor in the network without the need to manually configure and set up the system, i.e plug and play. Interoperability is very important in this aspect, since a scalable system should not rely on one technology or one vendor. Sensor standards, such as IEEE 1451, are being developed to standardize such interfaces that will enable the implementation of smart sensor networks with plug and play capability. Scalability is another important characteristic, since we need to be able to deal with large number of sensors (e.g. thousands or millions) and dynamically add or discard a sensor without the need for reconfiguring the whole system.

This paper presents the challenges and opportunities of wireless sensor network in space applications and the investigation of wireless access technique supporting Quality of Service capabilities to meet the stringent requirements of space applications. The paper describes an architecture that utilizes sensor network along with wireless smart phones to implement multiple functionalities. In this architecture a medium access control (MAC) protocol design is discussed that will meet the quality of service (QoS) requirements of time-sensitive applications.

This paper is organized as follows; the second section presents the general architecture of wireless sensor network in space applications. Different challenges and research opportunities are described in sections 3 and 4. Section 3 focuses more on system integration point of view while section 4 focuses on networking protocols development. Section 5 points to future directions and conclusions.

2 WSN IN SPACE APPLICATIONS: CONCEPTUAL ARCHITECTURE

Sensor network architecture in space environments should be hierarchical and highly flexible for allowing integrated operation of diverse applications. The medical sensors, system and environment monitoring sensors need to operate under a unified communication platform, and so interoperability between multiple wireless platforms and sensor plug-and-play capabilities would be crucial. A hierarchy can be at the crew monitoring level, which communicates with upper level hierarchy to convey information for more processing. Another hierarchy can be at the space habit level and at the extravehicular activities (EVA) stage. Note that hierarchies may operate independently and may communicate with upper hierarchies to further process the information (see Figure 1).

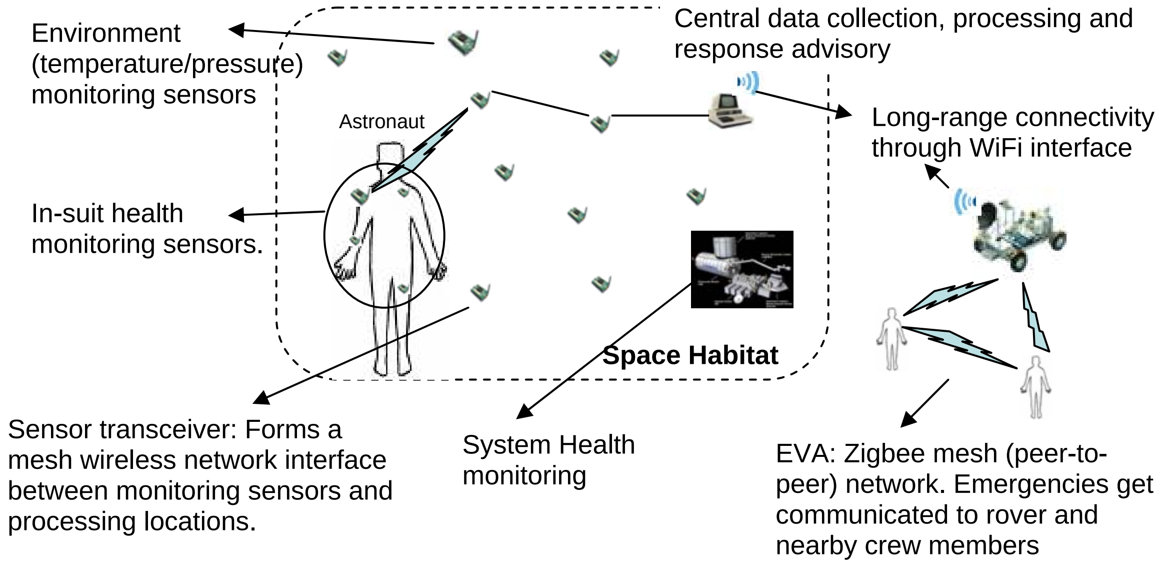

Figure 1: Conceptual architecture of sensor network in space applications

3 SENSOR DEVICE COMMUNICATION INTERFACE

Autonomous sensor systems need to be interfaced with a communication platform for large-scale operations. For example, spacecrafts typically comprise hundreds of equipments and it would be impossible to monitor system health from individual locations. Single-point information collection and processing through networked sensor systems would be extremely efficient. The sensor devices need to be interfaced with a communication module, which will allow information to be telecommunicated to central locations for collaborative processing (correlated information estimation from multiple sensor readings tends to provide more useful inferences). The following components are crucial for developing a unified communication platform for sensor systems within space habitats.

3.1 Sensor Devices

The sensor device is the end point of a wireless sensor network. The information sourced by the sensor devices will be reliably communicated by the WSN to its destination. It is this information that will be used to make a decision and the corresponding action should be taken by the system as a whole. For instance in system health monitoring, the information may indicate that there is something wrong with a combustion system and therefore action needs to be taken. Sensors that will be deployed in space devices should present the following features:

- Miniaturization and integration, which will have effect on the mass and cost of space exploration as well as reliability since a miniaturize system can be easily integrated with processor based systems [1].
- Efficiency, safety, and reliability from the system integration point of view to end performance

There has been a fast growth in the sensor manufacturing area that utilize nanotechnology and Microelectro-Mechanical Systems (MEMS) technologies to make sensor devices that are smaller, faster, and smarter, with storage, processing and wireless communication capabilities.

3.2 Wireless Communication Standards

Implementation of the best communication strategy for seamless data flow across the distributed sensor devices used in spaceflights is still an open challenge. 802.15.4/Zigbee [2], 802.11x [3], WirelessHART [4] and ISA100.11a [5] are some of the standardized wireless communication strategies, and we need to evaluate the capacity of these standards for applicability in space habitats.

NSTI-Nanotech 2009, www.nsti.org, ISBN 978-1-4398-1782-7 Vol. 1, 2009

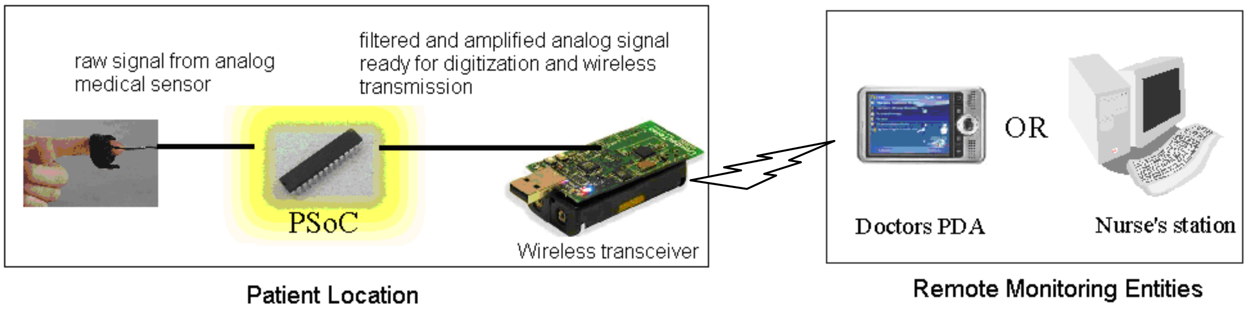

Figure 2: Medical signal conditioning using PSoC.

3.3 Signal processing interface between sensor and communication module

The voltage measure of human/environment/system condition from sensors is typically very small (in the order of milliVolts) and has to be signal conditioned for wireless transmission. The signal processing interface between sensors and wireless transceiver is one of the crucial components for faithful waveform generation at the receiving end. Signal conditioning interface using Programmable System on Chip (PSoC) will allow for rapid changes to component design through software programming. PSoC will allow for rapid experimentations with filter design and other signal conditioning process (such as FFT) and can prove to be extremely time-efficient for identifying and separating the signal and noise components. Figure 2 shows the conceptual architecture of medical signal conditioning interface developed in our labs

3.4 Interoperability among multiple wireless platforms

Interoperability implies the ability to disseminate information seamlessly across different wireless standards. Space applications are diverse and may require specific wireless standards for satisfying application-specific needs. Physiological condition monitoring medical-sensors may require low-range, low-power, and low-data rate WPAN technologies similar to 802.15.4 standards. 802.11 (WiFi) standards are well suited for network back-haul (central data collection, storage and wide-area distribution) due to their high data rates. A mobile network component may be needed for anywhere anytime alarming about emergency situations. Space habitat can be viewed as a collection of local sensor networks (health, system, and environment) integrated by high-speed back-haul wireless networks. Software-interface development becomes an essential component for data dissemination across such heterogeneous wireless platforms.

3.5 Device Interoperability and Plug-n-play

To support interoperability and plug-and-play functions of multiple sensor systems over a unified platform, a standard needs to be adopted. The sensor community is ratifying the IEEE 1451 smart sensor standard that defines the interfaces and the data structures to be implemented. For instance, a Transducer Electronic Data Sheet (TEDS) pertaining to each sensor should follow certain format so that a sensor from company A can be easily interfaced with an electronic board developed by company B. The standard also deals with plug-n-play capabilities and its implementation. The plug-n-play interoperability of space data systems is also being developed within international space agencies, CCSDS (the Consultative Committee for Space Data System) [6]. CCSDS is adopting IEEE 1451 among other networking technologies and define the following three steps to accomplish plug-n-play [7]:

- **Device discovery** – discover when a device is plugged to the networks and what network technology is utilized;
- **Service discovery** – discover the capabilities of the devices added;
- **Device adaptation** – adapt the device to generic classes and functions.

4 PROTOCOL-LEVEL OPTIMIZATIONS

4.1 Energy Efficiency

Sensor devices are typically energy constrained (battery powered) and the efficiency of network operation depends on the effectiveness in using the limited energy supply. The power consumption ratio of latest sensor devices [8] is approximately 0.1:1:2:4 for the sleep, idle, reception and transmission states respectively. Thus, increasing the time the sensor nodes in sleep state in stead of idle state (a state where the device is ON, but not involved in any data exchange) would be significant for extending the overall operational time of the mesh sensor network. Sleep-coordination, ultra-low power operation, radio transmission reduction, data-aggregation are some of the crucial energy conservation schemes that can be implemented at the protocol level.

4.2 Sensor Network Quality-of-Service (QoS)

Maintaining link connectivity in harsh wireless environments is essential for network reliability.

Electromagnetic (EM) propagation study is crucial to understand the wireless channel behavior within space habitats. EM modeling will identify the optimal sensor transceiver placements that will guarantee radio signal link quality anywhere within the space environment without connection voids. The EM modeling will also quantify important physical layer parameters that will be utilized by upper layer protocols for robustness against link errors.

Wireless Sensor Networks (WSNs) find most of the applications in data-centric network environments, where the deployed sensors collaboratively work towards accomplishing a common application task. In such cases, preferential traffic services (QoS) were not perceived important, since every data was considered equal for satisfying the application task. However, the exploration of sensor technology use in health and system monitoring during space missions has created the need to support traffic priorities and differentiated resource allocation methods. The network needs to be configured to dynamically adapt to emergency situations in time-sensitive applications.

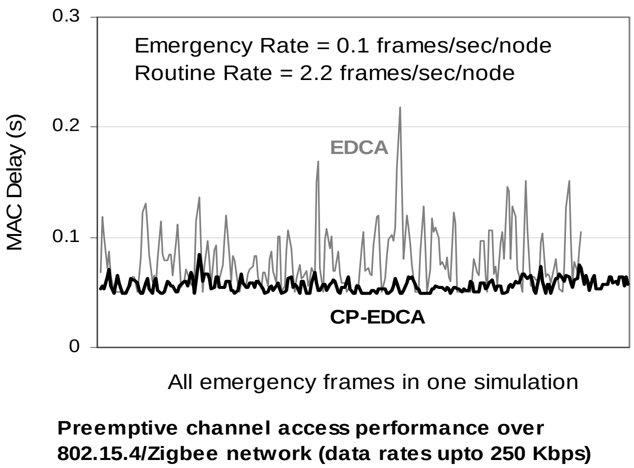

Figure 3. Emergency Performance

The popular IEEE 802.11e standard [9] is an attractive option for QoS support in distributed communication platforms, but needs crucial enhancements for time-sensitive applications. Our group is already working on an important QoS enhancement, **In-channel Service Preemptions**, which will widen the applicability of 802.11e standards to emergency networking. The smart algorithm will identify pending emergencies and will invoke preemption privileges to interrupt the services of other routine traffic in the network for rapid dissemination of emergency traffic (similar to ambulance on road). Analytical and simulation validations [10], of our Channel Preemptive Enhanced Distributed Channel Access (CP-EDCA), depicted up to 50% uniform reduction in emergency access delays, deterministic delay bounds and insensitivity to routine traffic competition (see figure 3).

5 FUTURE DIRECTIONS AND CONCLUSIONS

Wireless sensor networks (WSN) are used in many applications that range from smart home, to telemedicine, to transportation, to space explorations. Because of the local processing capabilities added to the sensors a lot of decisions can be made locally reducing the communication time between the sensor/actuator and the decision making entity. Because of this improved feedback time and improved intelligence associated with modern sensor devices, wireless sensor network are proliferating in control systems and space exploration systems. Given that there are networking technologies that can be used with some deterministic delay bounds, along with sensors that utilize miniaturized technologies; the weight factor is significantly reduced along with improved reliability. They will further find applications in control systems with stringent requirements. These advantages bring certain challenges that need to be addressed, including

- Wireless channel is prone to interference and therefore the number of devices that can be connected should be designed to satisfy the signal to noise ratio requirements
- Reliability: studies need to be conducted on fault tolerance and QoS reliability in space environments
- Optimum placement of sensor transceivers within the space habitat for consistent radio link connectivity.

REFERENCES

[1] T. Bohnke, L. Stenmark, “Development of a MOEMS sun sensor for space applications,” *The 13th International Conference on Solid-State Sensors, Actuators and Microsystems*, Volume 1, Page(s):589 – 592, 5-9 June 2005.

[2] http://www.zigbee.org

[3] IEEE 802.11 Standards for Wireless Local Area Networking, 2007, http://standards.ieee.org/getieee802/802.11.html

[4] http://www.hartcomm2.org/index.html

[5] www.isa.org/isa100wireless

[6] http://www.CCSDS.org

[7] Q.A. Shams, et al., “Applying MEMS technology to field, flight and space deployable systems,” 19th International Congress on Instrumentation in Aerospace Simulation Facilities, Page(s):246 – 255, Aug. 2001.

[8] http://www.xbow.com

[9] http://standards.ieee.org/getieee802/download/802.11e-2005.pdf

[10] M. Balakrishnan et al., “In-channel Service Preemptions for Emergency Medium Access in Healthcare Sensor Networks” *MILCOM 2008*, IEEE, San Diego, November 2008

NSTI-Nanotech 2009, www.nsti.org, ISBN 978-1-4398-1782-7 Vol. 1, 2009