Wireless Sensor Network for Aircraft Health Monitoring

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Abstract

Wireless Sensor networks is an emerging paradigm of computing and networking where a node may be self-powered, and have sensing, computing, and communication capabilities. They have been proposed for use in a wide variety of applications. The objective of this paper is to describe a wireless sensor network for monitoring of the health of aircraft engines. We describe the architecture of the wireless sensor network along with how it fits into the general area of wireless sensor networks.

I. INTRODUCTION

Wireless sensor networks is an emerging area of research which attempts to change the way data is generated in the Internet. Wireless sensor networks consist of a large number of small nodes which have built in computing power, sensors to acquire data from the environment, and wireless transmission and reception capability. Because of the low cost of such nodes, they can be deployed in huge quantities. They have limited battery life, and are considered dead when they run out of battery power. Consequently, minimizing power consumption is fundamental in designing the nodes, network protocols, and algorithms for a wireless sensor network.

Wireless sensor networks are being investigated for use in a variety of applications [1], such as military (battlefield surveillance, reconnaissance of enemy forces, nuclear, biological and chemical attacks), environmental applications (forest fire and flood detection, monitoring of drinking water and level of air pollution), health applications (telemonitoring of human physiological data, tracking and monitoring of doctors and patients), home applications (intrusion detection, home automation), commercial applications (material fatigue, monitoring of product quality, transportation, climate control in large buildings) and habitat monitoring [2]. List of applications of wireless sensor networks can be found in [3], survey papers on wireless sensor networks have been published by a number of researchers [4], and various types of wireless sensors are given in [5].

The objective of this paper is to describe the architecture of a wireless sensor network that has been designed for monitoring of the health of aircraft engines. We provide the design criteria of the network, and show how it can be used to monitor aircraft engines.

We also describe the general characteristics of wireless sensor networks and subsequently show how our wireless sensor network addresses those characteristics.

The rest of the paper is organized as follows. In Sec. II, we describe the characteristics of wireless sensor networks and nodes. Differences between wireless sensor networks, network of sensors and ad hoc networks are highlighted in Sec. III. We describe in detail the architecture of a wireless sensor network for monitoring of aircraft engine health in Sec. IV. Finally, concluding remarks are given in Sec. V.

II. CHARACTERISTICS OF WIRELESS SENSOR NODES AND NETWORKS

We describe below the general characteristics of wireless sensor networks and the nodes used in a wireless sensor network [6].

- Nodes are small with limited power, computing and communication capability. A node consists of CPU, memory, transmitter and receiver, sensing devices 2 (for example, video, audio, temp, pressure, vibration (seismic senor), smell, speed), and possibly movement capability.
- Nodes may not have IP address, but may have their own identifiers. They should be able to reorganize themselves. They may know their geographical location using GPS technology.
- Computing should be preferred over communications because of power requirements [7]. Message transmission costs typically dominate energy consumption of sensor nodes. For example, the energy required to transmit one bit is equivalent to energy consumed in 800 instructions [8]. As an example, instead of each sensor transmitting their temperatures to a querying node, the individual temperatures could be averaged as the information moves up the chain to the querying node. As a second example of reducing the energy consumption, querying the nodes of a wireless sensor network could be like "Who are the nodes whose temperature is above 200F?", rather than saying "Can you all send me your temperature readings?" Addressing of nodes will, therefore, be "attribute based" rather then individual nodes [8].
- Nodes can have temporary failures (go up or down due to environmental conditions) or permanent failures due to running out of power or being destroyed beyond repair.
- Nodes are unattended and may not be serviceable; they may die at the end of their life. Nodes may sometimes be used in hostile environment (for example, battlefield, chemical, fire, under the ocean, rough terrain) and should be self organizing [7].

The fact that nodes are unattended and can develop temporary or permanent failures gives rise to challenges in the design of algorithms. The algorithm designer can no longer assume that all the nodes will be functional. In fact, it may be able to communicate with only its neighbor. Because of energy limitations in the nodes and the power consumed for transmitting data, the algorithm should not require too much communication between nodes.

"Networks of sensors" have been used in various applications for quite some time. A typical example of network of sensors would be the the meteorological project at the University of Oklahoma which uses a network of radars (used as sensors) to collect and send data on atmospheric conditions to a central site where it is processed and used for weather forecasting. These radars have continuous power supply, are expensive, and are accessible and serviceable. They do not have the limitations described above and hence can be called a "network of sensors". A number of other characteristics of wireless sensor networks are given in Sec. III. In this paper, we refer to "sensor networks" as those networks which posses the characteristics mentioned above, and should not be confused with a "network of sensors".

III. DIFFERENCES BETWEEN WIRELESS SENSOR NETWORKS AND AD-HOC NETWORKS

Although there are some similarities between wireless sensor and adhoc networks, a number of features distinguish wireless sensor networks from adhoc networks as given below.

- The number of sensors in a wireless sensor network may be several orders of magnitude and much more densely deployed than an adhoc networks.
- Nodes are prone to failures in both networks: however, they can probably be serviced in an ad hoc network.
- Topology may change very frequently in a ad hoc network.
- Broadcast communication may be used.
- In contrast to ad hoc networks, wireless sensor networks have limited power, computation, memory.
- Nodes in a wireless sensor network may lack global identification.
- Batteries in an ad hod network can be recharged, while they are not replaceable in wireless sensor networks.

The goal of a wireless sensor network is to prolong battery life at the expense of QoS and bandwidth utilization [7], whereas the objective of an ad hoc network is to provide QoS.

IV. HONEYWELL AIRCRAFT ENGINE HEALTH MONITORING WIRELESS SENSOR NETWORK 1

Modern physical systems, such as those used in aircrafts, are becoming more and more complex. This increase in system complexity has led to an increased desire for automated prognostic and health monitoring systems. One particular aircraft system in which prognosis and health monitoring capability becoming increasingly desirable is aircraft engine system. To provide such capabilities, however, a number of sensors of varying types may be mounted on the engine, or inside the engine, to sense various physical parameters (such as, operation temperature, oil temperature, vibration, pressure, etc.) associated with engine operation. Using a network of sensors, these physical parameters can be transmitted to a central processing unit using wiring and multiple wiring harnesses for further prognostic analysis, or engine health prediction. These wiring and wiring harnesses can increase overall system weight and cost, and can reduce overall system reliability. Therefore, there is a need for a system and a method of providing various aircraft engine parameters without using wiring and multiple wiring harnesses.

[1] The concept and the design described here are patent pending.

As a design example of wireless sensor networks, in the rest of this section, we describe how the concept invented at Honeywell Labs has addressed one or more of these needs of engine health monitoring applications. In Table I, we describe the relationship between the characteristics of our wireless sensor network for engine monitoring to those mentioned for a general wireless sensor network which was described earlier in Section II.

A. System Integration

An aircraft engine wireless sensor network includes a number of wireless sensor communication nodes and a central engine control unit (i.e., engine controller) in operable communication with each other. Each wireless sensor communication node can communicate directly with the engine controller, or through one or more other wireless sensor communication nodes in the network. A detailed description of each subsystem and the integration of subsystems are presented below.

The functional block diagram of a wireless sensor communication node is shown in Figure 1, where a wireless sensor communication node includes three main sections, a sensor section, a communication control section, and a power supply section.

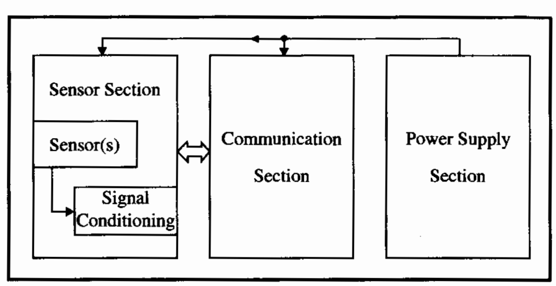

Fig. 1. The functional diagram of a wireless sensor communication node.

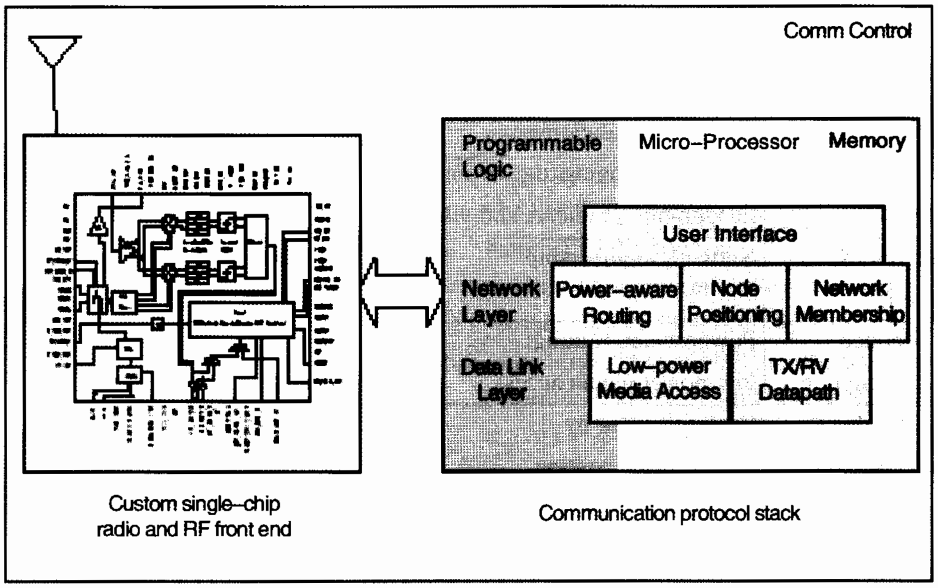

Fig. 2. The functional diagram of communication control.

1) Sensor and Data Collection: The sensor section includes one or more sensors (e.g., temperature sensors, pressure sensors, vibration sensors, proximity sensors, and position sensors, etc.), and appropriate signal conditioning circuitry. The sensor senses physical parameters of the engine, and generates a sensor signal representative of the sensed physical parameters. The signal conditioning circuitry receives the sensor signal from the sensor and conditions the sensor signal, as appropriate, for

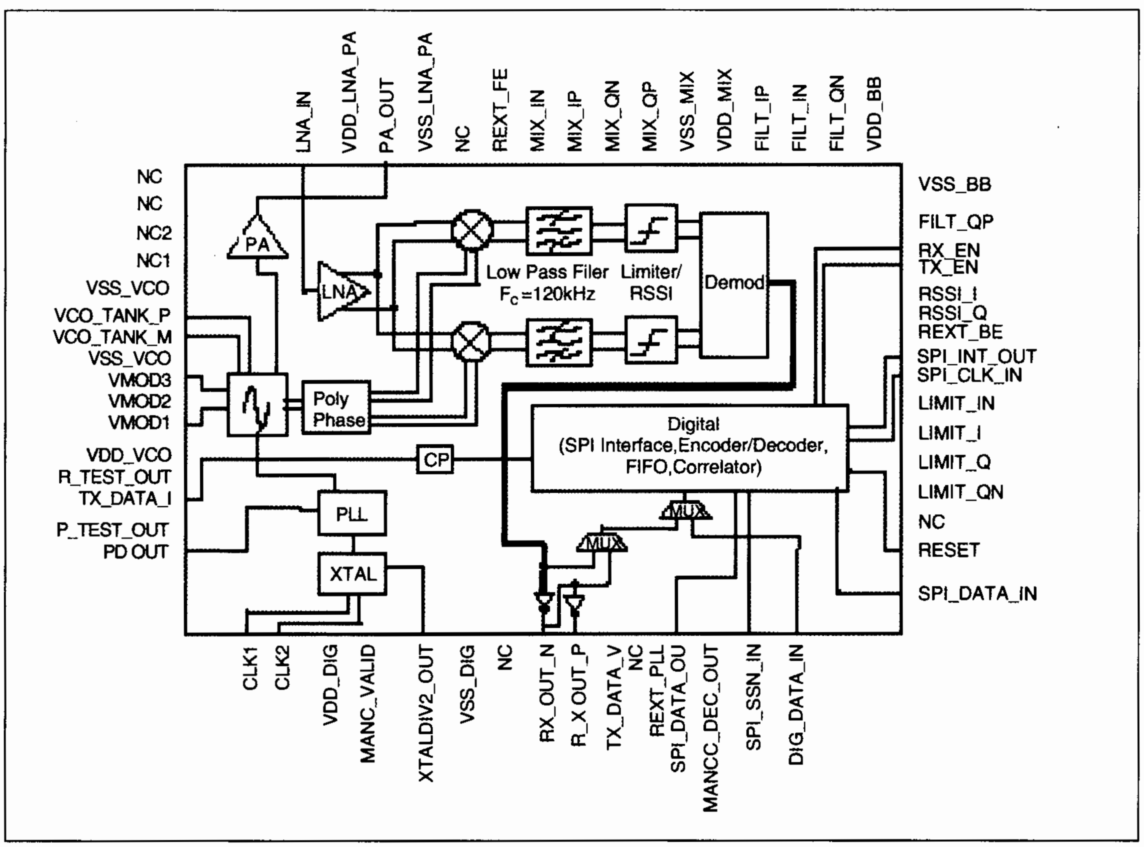

Fig. 3. The block diagram of Honeywell single-chip radio transceiver.

TABLE IHONEYWELL'S SOLUTION TO SENSOR NETWORK ISSUES.

Issues	*Honeywell Solutions*	*Comments*
Limited power supply	Power scavenging, e.g., from temperature gradients and vibration	Other ways of generating power
No IP addresses; need node ID	Network membership	In addition to identification, also provides network authentication capability
Need to Reduce power consumption	Power-aware routing; low-power media access	Focusing on computing, rather than communication
Node failure due to power down	Fault tolerance by power-aware routing	Route data through nodes with maximum power capacities
Node failures	Node positioning	Knowing the location of failed sensors; useful info for engine maintenance personnel
Reliability issues caused by wiring	Wireless sensor data transmission	Also reduce installation costs and the wiring weight
High-temperature engine environment	SOI single-chip node	Up to 250C

further processing in the communication section. The signal conditioning circuitry may or may not be used in the system. The appropriate signal conditioning may also be implemented in the communication section.

2) Communication and Control: Figure 2 shows a block diagram of the communication control section, which includes a communication controller and a singlechip radio transceiver. The single-chip radio transceiver, designed and manufactured by Honeywell International, is implemented using the BFSK (Binary Phase Shift Key) modulation, and Frequency Hopping Spread Spectrum (FHSS) multiple access. As shown in Figure 3, the single-chip radio transceiver consists of a digital data interface, a frequency synthesizer, a transmitter (Tx) and a receiver (Rx). The digital and frequency synthesizers both interface the Tx and Rx. To complete the transceiver function, several off chip components are required. They include a crystal (which can be shared with the application's microprocessor), transmitter and receiver LC impedance matching and filtering components, regulated DC power source, antenna(s), etc.

The microprocessor and programmable logic in the communication protocol stack implement various communication control functions, which are represented as protocol modules in Figure 2 and stored in memory. These communication protocol modules include a power aware routing module, a node positioning module, a network membership module, and a low-power media access module as described below.

Power aware routing module: The functionality of the power aware routing module is illustrated in Figure 4 , which depicts a sensor communication network having eight nodes that include seven wireless sensor nodes 200 (i.e., 200-1 through 200-7), and the engine central control unit 100. As Figure 4 illustrates, each wireless sensor node transmits its own power capability data to, and receives power capability data from, one or more other sensor nodes. Based on the power capability data each wireless sensor node receives, it determines the optimum data transmission route through the wireless sensor communication network. In particular, the power aware routing module determines a data transmission route that preferably routes the data to its intended destination via other wireless sensor nodes that have the greatest power capability. In the example shown in Figure 4, it was determined that sensor data from wireless sensor node 200-1 should be routed to the

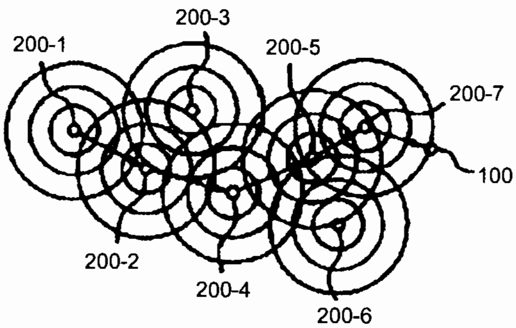

Fig. 4. The illustration of a power-aware routing example.

engine central control unit 100 via wireless sensor nodes 200- 2, 200-4, 200-5, and 200-7. The power aware routing module may be implemented with, for example, Ad-hoc On-demand Distance Vector routing (AODV), Dynamic Source Routing (DSR), and Global State Routing (GSR). The power aware routing module, when used with these other schemes, provides an added level of enhancement to these other routing schemes.

Node positioning module: It is desirable that each wireless sensor node, in addition to transmitting sensor data and power capability data, also transmits data representative of its position. This position data could be the physical location of the region or device where the parameter being sensed. If the sensor is located in a fixed position, then this position data will likely be a constant. If, however, the wireless sensor is located such that its position may change, then the position data will also change. In this latter case, a sensor with positioning capability (e.g., positioning by variation of magnetic strength) should be used to generate and update the position data that it transmits. Similar to the power capability data, each wireless sensor node in the network transmits its position data to, and receives position data from, some or all of the other wireless sensor nodes. Moreover, the position data is preferably transmitted simultaneously with the sensor data and the power capability data. The position data allows a receiving node, be it a sensor node or the engine central control unit, to determine where the sensor data came from.

Network membership module: The network membership module provides identification and authentication functionalities for each wireless sensor node. The network membership module supplies identification data that uniquely identifies each wireless sensor node in the network. The network membership module uses the received identification data to determine if the wireless sensor node that transmitted the identification data is a member of the network. The network membership module also determines the number of wireless sensor nodes that are presently active in the network. In addition, the network membership module also determines when a wireless sensor node joins and leaves the network. Moreover, the network membership module also performs an authentication function. Specifically, when a wireless sensor node receives data from another wireless sensor node, the network membership module can parse the data received to determine whether the received data was transmitted from a node that is presently a member of the network, or can be allowed membership within the network.

Media access module: The low-power media access module may implement a media access schedule that is similar to Time Division Multiple Access (TDMA), rather than the conventional random access. In other words, each wireless sensor node is assigned a given access time to the network. During its access time, a wireless sensor node may attempt to gain access to the transmission medium either one or multiple times as needed. If access fails after a predetermined number of times, the node may place itself in sleep mode. By providing access to the transmission medium in accordance with an access schedule, the wireless sensor node will likely use less power as compared to a configuration in which random access to the transmission medium is attempted. The low-power media access module is also configured such that the wireless sensor node will place itself in sleep mode whenever it is neither sending nor receiving data. This functionality can provide significant power savings.

3) Power Supply: The power supply section is to supply electrical power to the sensor section and the communication control section. The power supply may be any one of numerous types of stand-alone electrical power supplies. For example, the power supply may include one or more batteries and

appropriate signal conditioning circuitry, or it may be a thermoelectric power supply that is driven by temperature gradients on the engine. It also could be a vibration-powered generator that is driven by engine vibration and converts mechanical power to electrical power. These power scavenging mechanisms can be implemented using Micro Electro Mechanical System (MEMS) technology to make the size of a node as small as possible.

B. Single Chip Solution

The communication control section of a wireless sensor node, depicted in Figure 2, is implemented as two physically separate parts. However, the communication controller and transceiver can be implemented in a single integrated circuit chip. Particularly, such an integrated circuit chip is implemented with Honeywell state-of-art Silicon On Insulator (SOI) technology, which will allow the integrated circuit chip to operate in an environment (such as aircraft engine) with up to 250C temperature. SOI is a semiconductor fabrication technique developed by IBM that uses pure crystal silicon and silicon oxide for integrated circuits (ICs) and microchips. A schematic of the SOI-based single chip solution is shown in Figure 5.

V. CONCLUSIONS

Wireless sensor networks is an emerging research area with application in many fields. In this paper, we have described in detail the architecture of a

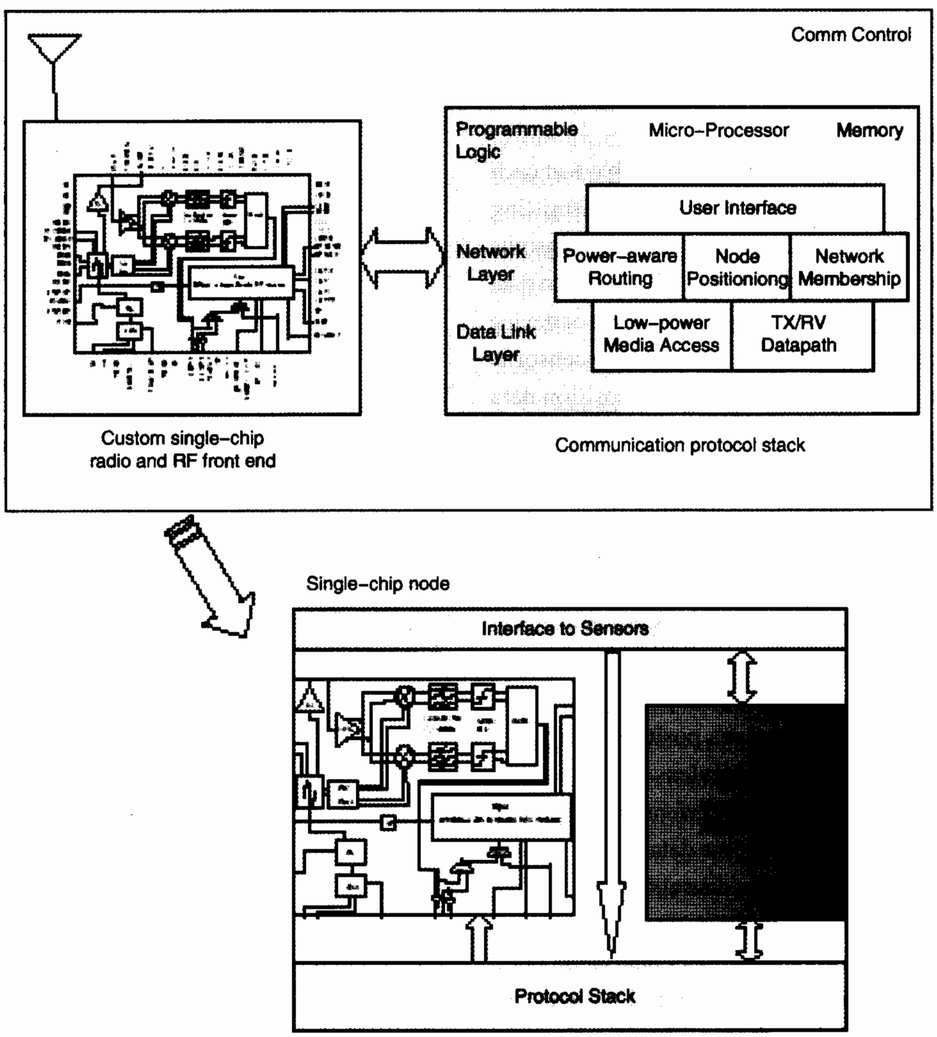

Fig. 5. The single chip solution.

wireless sensor network which can be used to monitor the health of aircraft engines. The wireless sensor network is being fabricated for real world testing. Future extension of this work consists of performance evaluation of the wireless sensor network and field tests for monitoring of engine health.

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