Challenges in Sensor Networks for Intelligent Systems

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Abstract- Recent advances in low power semiconductor technology, MEMS (micro electro mechanical systems) and wireless technology have made it possible to have a large-scale, low power, inexpensive, smart sensor network. Intelligent systems are critical not only for military/security, but also for many consumer applications. To make expert decisions in intelligent systems, the sensor network provides necessary information in real time.

Technical challenges in sensor network include network discovery/ architecture, control, communication protocol and routing of information in real time, accurate measurement of signal and information processing at low cost, and operation with low power consumption. This presentation covers some of the challenges in sensor network's node architecture, wireless sensor network issues, software issues and emerging applications.

Key Words: Sensor network, sensor node, wireless communication, low power processing.

1. Introduction

Miniaturization of Sensors, combining them with low-power Processors, communication devices, software, internet and others makes it possible to measure, and process any physical phenomena in real time. Sensor networks can be wired or wireless. Wired Sensor Network can be found in: Automotive application, Home monitoring applications, Industrial Applications, Distributed control, Real Time alert, Health monitoring and others. Wireless Network can be found in: Weather monitoring in remote locations, Military surveillance, Remote Bridge monitoring, Electricity Power pole structural health monitoring, environmental monitoring, industrial sensing and diagnostics, military and many others.

The development of silicon micro-machined sensors enables physical transducers to be integrated with control and signal processing electronics in a single, compact package.

This type of "smart" sensor will revolutionize the design of sensor systems. It will become easier, cheaper, and faster to design a sensor system and the resulting systems will be more reliable, more scalable, and provide higher performance than traditional systems.

Smart devices with multiple sensors, networked through wire or wireless links and deployed in large numbers, provide many ways to control homes, cities and the environment. They have many applications in defense for reconnaissance, early detection of threats, and for security. Smart sensors have embedded processor to process information and take intelligent decisions, communicate to neighboring nodes/sensors, route the messages to other nodes. In addition, the smart sensor has enough storage capability and may use a GPS (global positioning system) to locate its position. Intelligent Systems are capable of observing necessary information/data, learn, adapt and provide correct solutions/control. A network of smart sensors plays a big role in intelligent systems. Intelligent systems' applications include: military, physical security, traffic control, automotive applications, industrial automation, robotics, environment monitoring in buildings and structural (e.g. Bridge) monitoring. We present briefly two intelligent system type applications for automotive and home in section 2. In section 3 we present hardware and software challenges in sensor networks.

2. AUTOMOTIVE SENSOR NETWORK

Present day vehicles have a network of sensors like multiple radars and camera in automobile to help in lane sensing, object, and hazard identification. Safety applications include adaptive cruise control, pre-crash prediction, active head-rest, tire pressure monitoring, rain sensors to adjust braking, and multiple airbag. Inside the advanced automobile we have a fusion of multiple sensors. The development of silicon micro-machined sensors enables physical transducers to be integrated with control and signal processing electronics in a single, compact package. For example, one may be interested to know whether the temperature at a location has exceeded a certain threshold or not. A smart sensor node would send just one message when the temperature criteria are met. It dramatically decreases the communication bandwidth required to support each node, thus allowing more nodes to reside on a single network. Figure 1 compares sensors in a typical car with sensors in a typical building.

Typical New Cars	**Typical New Building**
40-50 Sensors per car • Temperature sensors e Pressure sensors • Accelerometers • Oxygen sensor • Fluid level sensor • Proximity sensor • Speed sensor • Front impact sensor • Throttle position sensor • Seat belt sensor •	Less than 15 type of sensors • Thermostat with Temp sensors • Electric meter with energy consumption sensor • Gas meter with gas flow sensor • Water meter with sensor • Smoke sensors • CO sensor • Occupancy sensor to turn light off/on • Sunlight sensor to turn lights • Sensors embedded in equipments

Figure 1: Sensors in Cars and Buildings

The number of sensors used in a typical home is far less compared to a car. The sensors in a car are linked by wire/wireless link. More connected-sensors in buildings to improve comfort and energy efficiency are being demonstrated/developed in various countries.

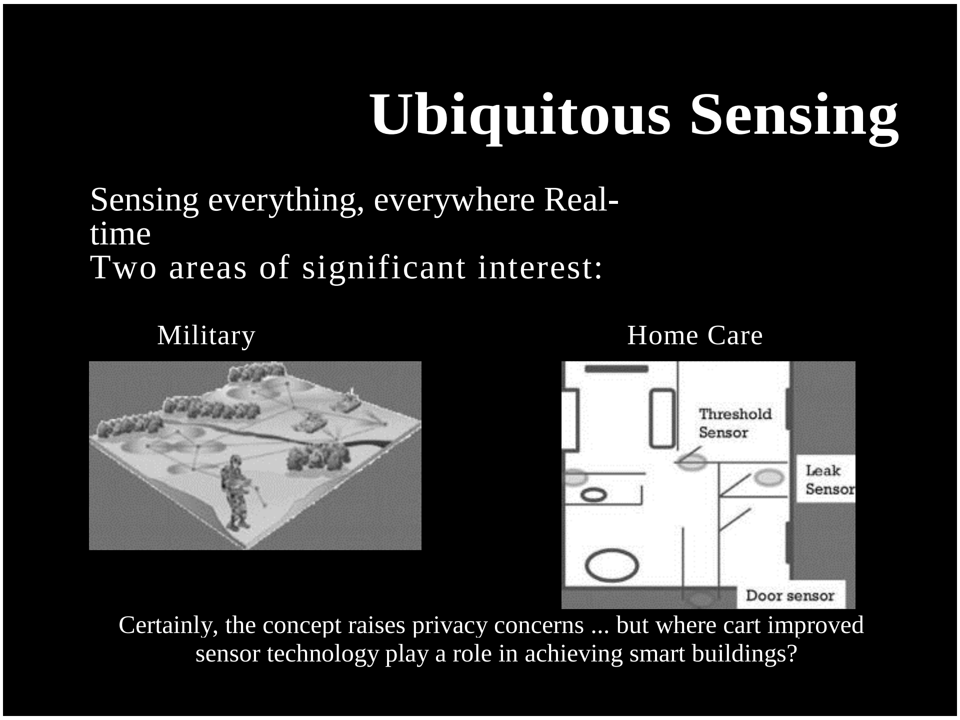

Figure 2: Application of Sensors in real time [Ref. William Healy, NIST, April 2010].

Real time monitoring is one of the applications for sensor network. Figure 2 shows two applications i.e. Military surveillance and Home health or security.

One of the intelligent applications for the sensor network in a vehicle or home is condition based maintenance. Continuously monitoring the operation of the vehicle with intelligent system can help in predicting failure of say coolant system and warn the driver for maintenance. The sensor system can also be used to diagnose the cause after the failure of say coolant system. Condition based maintenance and predictive maintenance application for vehicle needs development of intelligent algorithms, indirect prediction if direct sensor is not available etc. This requires collection of a huge amount of data from sensors and performing data mining to develop the necessary algorithms and intelligence.

Mote Node designed by Berkeley, operates un-tethered, wirelessly using a microprocessor with limited memory for local data storage/repository, on-board transducer, MEMS sensor, CMOS radio, and wireless modem. Nodes could cluster together to form a low-power wireless network application.

Future Sensor Node applications areas are: Smart paint, Smart homes and ubiquitous computing, Wearable computing, Ingestible device networks, Computationally-augmented environments, etc. Some of the Sensor Node research projects are: MIT — Oxygen, Amorphous computing, Berkeley — Smart Dust, UCLA, Xerox — Sensor Networks, and AT&T— Smart environments. A Macro Mote sensor node contains RF transmitter/receivers, accelerometer, Atmel MCU with 4K Flash, local memory, temperature sensor, pressure sensor, light sensor, humidity sensor, and magnetic field sensor. Mass manufacturing and miniaturization of this node architecture will be economical and will cost less. Depending on the application, some of the sensors may or may not be used. Using power management module in each node, unwanted sensor circuits can be switched off.

Tiny OS is an operating system with small code footprint with minimal memory requirements. It is open source, developed by Intel and the UC Berkley, is distributed algorithm based and designed for WSNs. Software limitations are simple task model, minimal device and networking abstractions, parts of the OS are compiled with the application and application is built into the OS and only a static memory allocation is possible. TinyOS Manages strict resource constraints, high reliability requirements of embedded designs, maintains common functionality across many leading platforms, supports simple driver framework to incorporate new sensors and actuator drivers, supports embedded mesh networking stacks etc.

There are over 10 simulators for sensor networks. Some of them are TOSSIM, Omnet++ and ns-2. Ns-2 is popularized by academia, has open source, online documentation, simulates routing and multicast networks, used in ad-hoc research, supports many wired & wireless protocols, built using C++ and provides object oriented interface (OTc1). TOSSIM is a TinyOS mote simulator, eases the development of sensor network applications on Berkley Motes, can be scaled to thousands of nodes, and compiles directly from TinyOS code. Developers can test algorithms, implementations and use actual software code in the simulation. Popular WSN Standards are 802.11, 802.15.4 radio protocols, Bluetooth, Zigbee, and Zwave.

3. Challenges

Sensor network requires rethinking of the fundamentals: Hardware miniaturization, software with new programming abstractions, communication with new protocols and theory for scalable behavior **[1,** 2].

The first few Challenges in Sensor network are:

- Development of new types of smart-sensors for different applications
- Development of low cost sensors with more functionality, small size, and low power consumption.

- Integration of sensors in the application or system
- Sensor Maintenance: Self diagnosing, Self healing, Self calibrating, Self correcting

Hardware Challenges include manufacturing in large numbers and economically miniature hardware devices. But, the current microprocessor manufacturing technology will soon reach its lithographic size limits. Other possible alternative future technology may be biological cells.

Software Challenges include: support for large numbers of unattended device, adaptive behavior in an unpredictable environment and data centric communication. Programming sensor network as Massively Distributed Systems means that individual devices are not important, program must tolerate device failures and irregularity, program does not know exact device locations, and program must provide the desired overall behavior.

Active Bat Sensor System implemented by AT@T is as a smart-office system. "Bats" are attached to tracked objects and people, they emit ultrasonic signals, and an array of sensors in the building locates the bats by ranging. Physical entities in the environment are represented as software CORBA objects. Applications for Bat include spatial monitoring, browsing the physical environment, follow-me systems, etc. Low Power Communication is necessary for sensor nodes. Radio communication consumes too much power and requires a large antenna.

Wireless Sensor Network (WSN) supports information processing across multiple nodes in a resource aware manner Collections of tiny networked computers monitor almost anything and are networked by forming wireless meshes, uses low-power radio, wireless networking protocols, middleware, microprocessor, limited memory, and web services. Rapidly emerging requirement is for networks with capability for self-organizing and self-healing.

Real time requirements, communicating sensor data within a dead line to a central node is a challenge for distributed large sensor network. Real time routing is a challenge. For example the RAP protocol proposes a new policy called velocity monotonic scheduling. But this protocol does not provide guarantees. It is important not only to develop real time protocols, but also we need to meet the challenges of simulation, modeling, creating a test bed and analyzing the real time issues in WSN.

We may employ to avoid false alarms, multiple sensors to monitor the same parameter. This will provide high confidence in monitoring, but increase power consumption and cost.

Sensor networks interact with physical environment and people and this can pose security problem. Various security attacks on the data/sensor by unauthorized persons are possible. This leads to research challenges in security algorithms, authentication, privacy, prevention of denial-of-service attacks, secure routing etc. Security hardware and software should become part of the sensor node architecture. Encryption need to be used in WSN to prevent eaves dropping and tampering data.

WSN Challenges include, sensor tasking and control, data management, software design, real-time-communication subsystem, mesh network discovery, service establishment and data routing and aggregation. WSN Research Issues include, finding more efficient routing protocols, MAC layers to application layers to meet needs of WSN, shrink mote footprint to better enable "smart dust" capabilities, adding increasing mobility capabilities to the nodes, programming methodologies and tools for sensor networks, and need better performance in localization, tracking and routing schemes.

4. Conclusion

There is an explosive growth of the need for high performance sensor networks for intelligent systems. Integration of sensor network for novel applications in military, automotive, home and health monitoring and many others are presenting new challenges. In this presentation we listed for sensor networks a few key challenges like hardware challenges, software challenges, communication, routing, low power consumption, size and ever increasing sensor functional requirements challenges. Sensor networks have great potential to be part of the future intelligent systems. The impact of the sensor network with intelligent systems will be high on the future world and it will be increasing with new technologies.

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