A Survey of Sensor Network Applications

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Abstract

In the past few years, many wireless sensor networks had been deployed, these applications serve to explore the requirements, constraints and guidelines for general sensor network architecture design. In this paper,we present a snapshot of the recent deployed sensor network applications and identify the research challenges associated with such applications.

1 Introduction

The recent advance in Micro-electro-mechanical system(MEMS) and wireless communication technology makes it a pragmatic vision[13, 12] to deploy a large-scale, low power ,inexpensive sensor network. Such an approach promises advantage over the traditional sensing methods in many ways:large- scale, densely deployment not only extends the spatial coverage and achieves higher resolution, but also increases the fault-tolerance and robustness of the system, the ad-hoc nature and ”deploy’em and leave’em” vision make it even more attractive in military applications and other risk-associated applications, such as habitat monitoring and environmental observation. [21, 9, 30, 29, 6, 7, 25]

During the past few years, lots of efforts have been directed to make this vision a reality. Research prototype sensor nodes(UCB motes[15, 16],uAMPS[1],PC104[4],GNOMES[11] etc.) are designed and manufactured, energy effecient MAC[27], topology control protocols [32, 31, 18] and routing schemes[17, 8, 19, 14, 26] are implemented and evaluated, various enabling technologies such as time synchronizations[10], localization and tracking[28] are being studied and invented. In this paper, we intend to take a snapshot of the recent deployed sensor networks, and identify the research challenges these applications brought forward.

Although sensor network research is initially driven by military applications such as battlefield surveillance and enemy tracking,we will survey only civil applications in this paper. Under this civil catagory, the existing applications can be classfied into habitat monitoring, environment observation and forecast system, health and other commerical applications.

The remainder of the paper is organized as follows: section 2 surveys habitat monitoring applications, section 3 surveys EOFS applications, section 4 discusses health applications, section 5 presents other commercial applications, section 6 summaries the field and identifies research challenges.

2 Habitat monitoring applications

Cerpa et al.[9] describe habitat monitoring as a driver application for wireless sensor network: habitat sensing for biocomplexity mapping. In this first cut on habitat monitoring sensor network application, they propose a tiered architecture for such applications and a frisbee model that optimizes energy effeciency when monitoring moving phenomenon.

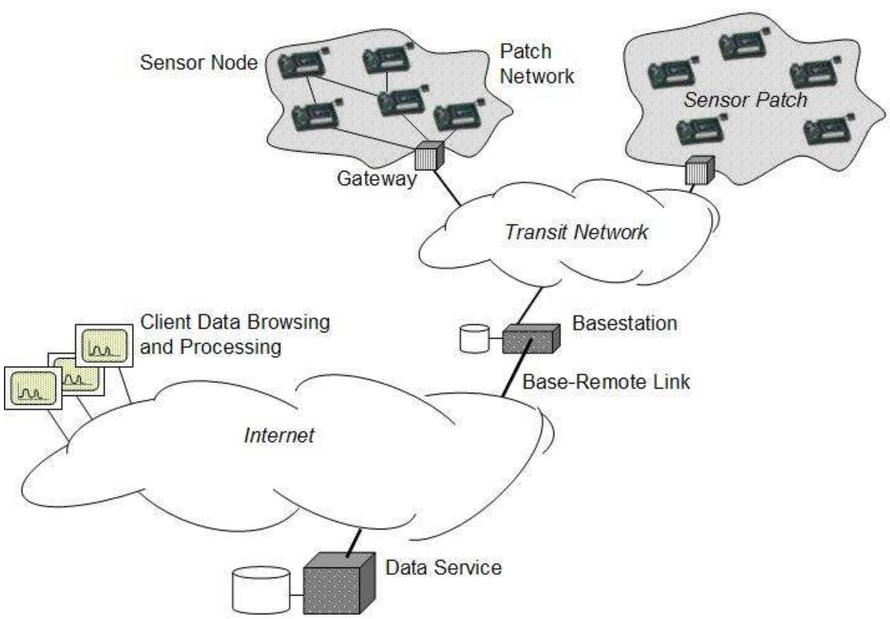
2.1 Great Duck Island(GDI) system

In August 2002, researchers from UCB/Intel Research Laboratory deployed a mote-based tiered sensor network on Great Duck Island, Maine, to monitor the behavior of storm petrel[21].

2.1.1 UCB Mica mote

UC Berkeley Mica mote deployed in this application use an Atmel Atmega 103 microcontroller running at 4MHz, 916MHz radio from RF monolithics to provide bidirectional communication at 40kbps, and a pair of AA batteries to provide energy.The Mica Weather Board, stacked to the processor board via the 51 pin extension connector, includes temperature, photoresistor, barometer, humidity and thermopile sensors. Some new designs to preserve energy on this version include an ADC and an I2C 8x8 power switch on the sensor board,the bypassing of the DC booster etc. To protect from the variable weather condition on GDI,the Mica mote is packaged in acrylic enclosure, which will not obstruct the sensing functionality and radio communication of the motes.

2.1.2 System Architecture



32 motes were placed at area of interest(*e.g.,* inside a burrows). Those motes, grouped into sensor patches, transmit sensor reading to a gateway(CerfCube),which is responsible for forwarding the data from the sensor patch to a remote basestation through a local transmit network. The

basestation then provides data logging and replicates the data every 15 minutes to a Postgress database in Berkeley over satellite link.

Users can interact with the sensor network in 2 ways. Remote users can access the replica database server in Berkeley, a small PDA-size device can be used to perform local interactions such as adjusting the sampling rates, power management parameters etc.

2.1.3 Other works on habitat monitoring applications

Wang et al.[29] discuss methods for habitat monitoring, such as target classification by maximum cross-correlation between measured acoustic signal and reference signal, localization using TDOA-based beamforming, and data reduction using zero-crossing rate technique. A prototype testbed consisting of iPAQs is built to evaluate the performance of those target classification and localization methods.

Energy effeciency shall be one of the design goals at every level:hardware, local processing(compressing, filtering etc.),MAC and topology control, data aggregation,data-centric routing and storage. Wang et al.[30] proposed preprocessing in habitat monitoring applications. They argue that the tiered network in GDI[21] is solely used for communication, they then present a 2-tier network for the purpose of collaborative signal and information processing. The proposed network architecture consists of micronodes and macronodes,the micronodes perform local filtering and data reduction as 2 types of preprocessing that significantly reduce the amount of data transmitted to macronodes. A preliminary experiment shows that data reduction and event filtering using cross-zero rate are effective, especially in the high data volume scenario such as acoustic sampling.

2.2 PODS-A Remote Ecological Micro-Sensor Network

PODS[6] is a research project in University of Hawaii that built wireless network of environmental sensor to investigate why endangered species of plants will grow in one area but not in neighboring areas. They deployed camouflaged sensors node, called Pods, in Hawaii Volcanos National Park. The Pods, consist of a computer, radio transceiver and environmental sensors sometimes including a high resolution digital camera, relay sensor data via wireless link back to the Internet. Bluetooth and 802.11b are chosen as MAC, data are deliveried in IP packets. Energy efficiency is identified as one of the design goals,an ad-hoc routing protocols called Multi-Path On-demand Routing(MOR) was developed. Two types of sensor data are collected,weather data are collected every ten minutes and image data are collected once per hour, users can use Internet to access the data from a server in University of Hawaii at Manoa.

Edoardo[7] further investigates the placement strategy for those sensor nodes. Sampling distance d and communication radius r are identified as key parameters, topologies of 1-dimensional and 2-dimensional regions, such as triangle tile,square tile,hexogon tile,ring,star-m,linear, are discussed. The sensor placement strategy evaluation is based on 3 goals: resilience to single point of failure, area of interest be covered by at lease one sensor,minimum number of nodes. The paper concludes that the choice of placement is depended on d(sampling distance) and r(communication radius).

3 Environment Observation and Forecasting System(EOFS)

EOFS is large distributed system that spans large geographic areas and monitor, model and forecast physical processies, such as environmental pollution, flooding etc. Usually it consists of 3 components: sensor stations,a distribution network,centralized processing farm. Some of the characteristics of EOFS are:

- *Centralized processing* the environment model is very computational intensive,it usually runs on a central server and process data gathered from the sensor network.
- *High data volume* for example,nautical X-band radar can generate megabytes of data per second.
- *QoS sensitivity* it defines the utility of the data,there is an engineering trade-off between QoS and energy constraint.
- *Extensibility*
- *Autonomous operation*

3.1 CORIE

CORIE is a prototype of EOFS for Columbia river. 13 stationary sensor nodes are deployed across the columbia river estuary,1 mobile sensor station drifts off-shore. Those sensor stations are usually fixed on a pier or a buoy. The stationary stations are powered by power grid, while the mobile station uses solar panel to harness solar eneygy. Sensor data are transmitted via wireless link toward onshore master stations, they are then further forwarded to a centralized server and fed into a computationally intensive physical environment model. The ouput of the model is used to guide vessel transportation and forecasting.

Practical difficultes arise from the application. First, the power supply and antenna affixation for the off-shore sensor nodes on buoy need to be addressed. Second, the direct light-of-sight is frequently obscured, because the hight of surface waves frequently exceeds the height of the antenna, this results in a highly dynamic connectivity. Third, since the topology of the network is known in this application, and the direction of data flow is from off-shore toward shore,a topology-informed distribution algorithm is needed.Currently, a next generation of CORIE is being designed to address these challenges.

3.2 ALERT

Automated Local Evaluation in Real-Time (ALERT[2]) is probably the first well-known wireless sensor network being deployed in real world. It was developed by the National Weather Service in the 1970's. ALERT provides important real-time rainfall and water level information to evaluate the possibility of potential flooding. ALERT sensor sites are usually equipped with meteorological/hydrological sensors, such as water level sensors, temperature sensors, and wind sensors, data are transmitted via light-of-sight radio communication from the sensor site to the base station, a Flood Forecast Model is adopted to process those data and issue automatic warning, web-based query is available. Currently ALERT is deployed across most of the western United States, it is heavily used for flood alarming in California and Arizona.

4 Health Applications

Applications in this catagory include telemonitoring of human physiciological data,tracking and monitoring of doctors and patients inside a hospital,drug administrator in hospitals etc.[5].

Loren et al.[23] describe a biomedical application they were working on,the artificial retina. In the Smart Sensors and Integrated Microsystems(SSIM) project,retina prosthesis chip that consisting of 100 microsensors are built and implanted within human eye. This allows patients with no vision or limitted vision to see at an acceptable level.The wireless communication is required to suit the need for feedback control,image identification and validation.The communication pattern is deterministic and periodic, so TDMA fits best in this application to serve the purpose of energy conservation. Two group communication scheme are investigated:a LEACH-like cluster-head based approach and tree-based approach.

Some other similiar applications include Glucose level monitors,Organ monitors,Cancer detectors and General health monitors. The idea of embedding wireless biomedical sensors inside human body is promising, although many additional challenges exist: the system must be ultra-safe and reliable; require minimal maintenance; energy-harnessing from body heat. With more researches and progresses in this field, better quality of life can be achieved and medical cost can be reduced.

5 Other Applications

There are some other applications that have great potential to be commerially successful.

5.1 Structure Health Monitoring(SHM) System

SHM is another important domain for sensor network application. The combined US and Canada Civil infrastructure assets have an estimate value of US$25 trillion[20], SHM applications, serving as precausion measure, can have great social and economical impact. The widely accepted goals of SHM system include detecting damage, localizing damage, estimating the extent of the damage and predicting the residual life of the structure, as proposed in [22]. SHM has been an evolving technology since it was first proposed in 1990's, the latest approach, wireless sensor network based approach, is promissing because it has many advantages: low deployment and maintenance cost, large physical coverage, high spacial resolution etc. One of the barriers is that damage detection is very difficult even for sophisticated sensors, thus breakthrough in damage detection using small MEMS sensors is much needed. So far, a SHM system using wireless sensor network technology is yet to emerge.

5.2 Smart Energy

Societal-scale sensor network can greatly improve the effeciency of energy-provision chain, which consists of 3 components,the energy-generation,distribution, and consumption infrastructure. It is reported that 1 percent load reduction due to demand response can lead to a 10 percent reduction in wholesale prices, while a 5 percent load response can cut the wholesale price in half. In the wake of recent energy regulation in California,[3] proposes a gradual roll-out plan to make energy-supply chain part of an integrated network of monitoring, information processing, controlling, and actuating devices,in a hope to spread the consumption of energy over time reducing peak demand. That would be a complex and long-term project.

5.3 Home Applications, Office Applications

This is a time that we witness more and more electronic appliances enter average household, great commercial opportunities exist in home automation, smart home/office environment. Given the great market potential, breakthrough in this section will surely mark a big milestone in sensor network research.

An example application in this catagory is described in [24], Mani et al. present a ”Smart Kindergarten” that builds a sensor-based wireless network for early childhood education. It is envisioned that this interaction-based instruction method will soon take place of the traditional stimulus-responses based methods.

6 Conclusion

As Deborah Estrin pointed out in a recent talk, there is no real sensor application yet, if short-lived demo does not count. The whole field is analogical to the situation of Internet back in 30 years ago. In our opinion, this is a highly application-specific field, the requirements and constraints of various applications are not yet fully understood, as a result, most of these applications are not ready for real world yet. The deployed applications to date share some common characteristics: raw sensor data transmision over wireless connection, centralized data processing, simple routing scheme, best-effort data transport design. Those applications serve as testbed or prototype to identify research challenges, verify proposed methods etc. With the progress on sensor fabrication technique, sensor network research and increasing multi-disciplinary cooperation, we can expect that real-world sensor network application will come to life in the near future. It is just a matter of time.

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