

Wireless Sensor Networks: Technology Roadmap

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Preamble

Wireless Sensor Networks (WSN) has emerged as an important area for research and development. Though WSN is in its early stages, its impact is envisaged to be far reaching, from daily life, to remote monitoring of environment, habitat, agriculture, health care, automobiles, hazardous zones, disaster prone zones, defense applications to probing of planets. Moreover they can be used for monitoring as well as control. In fact, they form the basic constituent of ubiquitous sensing, communication, computing, and control.

Realizing the importance of this area, the Ministry of Communication and Information Technology (MCIT), Department of Information Technology (DIT) decided that it would be prudent to give a cohesive thrust to this very important area and to bring out a white paper which has an Indian as well as an international perspective. With this in mind a [Workshop on Wireless Sensor Networks was held at IITB on April 20, 2007](#). The workshop was attended by over 50 researchers working in this field. It included researchers working on fundamental as well as applied aspects.

Subsequent to this, a [WSN-Survey](#) was sent out to over 200 researchers in India as well overseas. As is with all surveys, about 10% of these responded. We are indeed thankful to researchers who responded to this survey. The white paper incorporates comments received from this survey. The comments were very encouraging and the overwhelming perspective was that, India should give a major thrust to this area, since this is one of the areas which will have a major impact on society. Since the workshop in April 2007, a lot work has taken place in India in WSN. Nevertheless, it needs further impetus – in particular in bringing together communication engineers, computer science researchers and developers and mixed signal design engineers. Another thrust has been on the design of sensors – in fact, communication and computing are at a much more advanced stage than sensing technology. Moreover, the front end of any WSN is a sensor, and consequently a major impetus is needed for sensor design and development.

WSNs are natural progression to ICT systems that have already made a major impact on business productivity and our day to day lives.

Executive Summary

Need for a thorough discussion on Wireless Sensor Networks (WSNs) had been felt considering the rapid progress in the research, development and deployment of WSNs. The present report is an outcome of the one-day workshop on Wireless Sensor Networks held on 20th April 2007 at Indian Institute of Technology Bombay, in which prominent researchers working in the same area actively participated. This workshop was funded by Ministry of Communication and Information Technology (MCIT), Department of Technology (DIT) and organized by Prof. U. B. Desai from Indian Institute of Technology Bombay, Prof. S. N. Merchant from Indian Institute of Technology Bombay and Prof. B. N. Jain from Indian Institute of Technology Delhi, with a primary aim to provide guidelines to further accelerate research and development in Wireless Sensor Networks. The workshops comprised of presentations, demonstrations for various applications, brain storming sessions on technology roadmap, bottlenecks, and most importantly follow up plan for the future of this stirring and evolving technology.

Wireless Sensor Networks has been emerging from the vision of Smartdust project in 1998 that required enabling both communication and sensing capabilities in order of cubic millimeter. The *Sensor Node*, which is a basic element of Wireless Sensor Network, is composed of Sensing, Computation and wireless Communication unit. These sensor nodes are hence capable of observing physical phenomenon, process the observed and received information and communicate the observed or processed information to the nearby sensor nodes to form a network of sensor nodes called Wireless Sensor Networks (WSNs). The wireless networking capability of the sensor enabled nodes, have resulted in various interesting applications ranging from surveillance, smart homes, precision agriculture, disaster detection, underwater, to vehicular and supply chain management applications.

The *Sensor Node*, which is a basic element of Wireless Sensor Network, is composed of Sensing, Computation and wireless Communication unit.

Significant advances in sensing, computing and communication technologies have led to the development of tiny, low power and powerful sensor nodes. This resulted in realization that it can cater to several applications of extreme importance in the present times leading to secure and more luxurious life which requires automation and optimization of various processes based on intelligent sensing of physical phenomenon. This in turn opened up research challenges that were initially appearing to be application oriented and deployment specific but subsequently resulted in some fundamental and theoretical findings. The research challenges with serious practical applicability have attracted prominent researchers to contribute in this field. The key technological contributions seen in the last decade were related to distributed detection and information fusion; Routing and Clustering; Link Scheduling, Coverage,

Localization of sensor nodes, Time synchronization, Multimodal data fusion, Cross layer optimization, Network coding, and Low power electronics design.

The salient features of the present report are:

- Wireless Sensor Network Survey Report: A survey was conducted among researchers working in the field with a questionnaire (Appendix A) and summary to this survey has been presented in Appendix B. This survey helps in identifying various aspects of WSN research such as Potential drivers and applications of WSNs, commercial drivers and potential markets, different perceptions on future of WSN technology, most promising areas of WSNs, efforts for standardization, and moreover potential barriers to the growth of WSNs.
- The report includes more than 100 URLs (websites) on current activities on Research Development and Deployment (RDD) of Wireless Sensor Networks (refer Appendix D). These websites gives strong pointers to the current applications projects, industries working in WSNs and research and development trend of Wireless Sensor Networks.
- Ten recommendations on RDD of WSNs have been incorporated in this report. These recommendations are the result of various brainstorming sessions held during the workshop. The recommendations are very generic in nature and provide simple guidelines on selecting target applications. For example, one of the recommendations suggested is to provide access of *Robots with embedded WSN* to younger generation to envision more applications of WSNs while another recommendation is for government to take a big project to build a *Agricultural Sensor Map* of entire country with having a couple of sensors on every few acres of farming land.
- Summary of Presentations from the prominent researchers in WSNs made in the workshop has also been provided in this report.
- Guidelines for Investment in WSN Research and Development are provided based on the inputs made available during brainstorming sessions.

The present report is hence the consolidation of the intensive thought process of 50 researchers working in the field of Wireless Sensor Networks who participated on the day of the workshop and around 20 researchers from the same field who extended their help by participating in the WSN post-workshop survey. It is hence our belief that the recommendations and guidelines provided in this report should provide new directions and vision to work with Wireless Sensor Networks which has been one of the most promising research areas in the last decade.

We would like to express our deep sense of gratitude to Communication Convergence and Broadband Technology Group, Department of Information Technology, Ministry of Information and Communication Technology. In particular, Mr. B. M. Baveja, who patiently helped with various stages of this study. We would like thank the numerous survey participants and the large number of Indian researchers who participated in the workshop. The authors would like to thank Bhushan Jagyasi, formally a Ph.D.

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1. Introduction

Recent advances in sensing, computing and communication technologies coupled with the need to continuously monitor physical phenomena have led to the development of Wireless Sensor Networks (WSNs). WSN consist of four main components: A radio, a processor, sensors and battery. A WSN is formed by densely deployed sensor nodes in an application area. In most deployments, the sensor nodes have self-organizing capabilities, to form an appropriate structure in order to collaboratively perform a particular task. Wireless Sensor Networks are found suitable for applications such as surveillance, precision agriculture, smart homes, automation, vehicular traffic management, habitat monitoring, and disaster detection.

WSN is great enabling technology that can revolutionize information and communication technology. In fact, it has the potential to significantly change the way we live – just like the Internet and World Wide Web – perhaps more so. Of course, WSN will exploit the Internet and WWW; it will connect the physical world to the Internet at fine granularity. The power of WSN lies in creating a pervasive environment capable of remote sensing, monitoring and control. The positive benefits of this are quite obvious; such a technology will be a will achieve fine granularity tracking of what is going on at far away and generally in inaccessible locations. In the present scenario of global warming, WSN can enable fine grain remote monitoring of components responsible of for global warming.

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The key constraints in the development of WSNs are limited battery power, cost, memory limitation, limited computational capability, and the physical size of the sensor nodes. Research and development in WSN technology has been primarily application-driven. In the last decade, extensive research has been done in: energy efficient hardware and protocol design, identifying alternate power sources, distributed detection techniques, multihop protocols, scheduling, cross-layer optimization, localization, time synchronization and coverage. Most commonly used wireless communications standard in WSNs is based on the IEEE 802.15.4, usually referred to as Zigbee. There are three key areas that has received much less attention are: (i) very low cost and very low power mixed signal design of the WSN radio chip, (ii) enhanced power sources like low cost, small form factor photovoltaics, and (iii) low cost sensors technology for different applications in particular biosensors.

WSN has opened up the challenge for distributed and cooperative computing and communication. Since voluminous unstructured and heterogeneous data is going to be

communicated and collected at the central information processing station, it has brought in a new challenge for distributed data mining.

Another dimension that is being added to WSN is closing the loop. This brings in the convergence of sensing, communicating, computing and control (SC3). Moreover, all these actions could be adaptive. This has given birth to a new field, *Cyber Physical Systems or Internet of Things* --- of course, both these encompass much more than SC3.

The Ministry of Communication and Information Technology (MCIT), Department of Information Technology (DIT) has decided to bring out a white paper related to Wireless Sensor Networks, with an Indian as well as an international perspective. Hence a workshop was held at Indian Institute of Technology Bombay on April 20, 2007. The workshop was attended by over 50 researchers working on fundamental and applied aspects of WSNs. In Appendix A, further details of the one day workshop are presented.

Subsequent to this a [WSN-Survey](#) form (Appendix B) was sent out to researchers in India as well overseas. The suggestions were very encouraging and the overwhelming perspective was that, India should give a major thrust to this area, since this is one of the areas which will have a major impact on society.

2. A Brief History of Wireless Sensor Networks

History of development of sensor nodes dates back to the Cold War. A system of acoustic sensors on the ocean bottom, for sound surveillance was deployed by USA to detect and track Soviet submarines which is now used by the National Oceanographic and Atmospheric Administration (NOAA) for monitoring events in the ocean, e.g., seismic and animal activity. During the same time, United States developed the network of air defense radars to defend its territory, which now is also used for drug interdiction.

Research on sensor networks started around 1980 with the Distributed Sensor Networks (DSN) program at DARPA (Defense Advanced Research Projects Agency) where Arpanet (predecessor of the Internet) approach for communication was extended to sensor networks. The network was assumed to have many spatially distributed low-cost sensing nodes that collaborate with each other but operate autonomously, with information being routed to whichever node can best use the information.

Technology components for a DSN were identified in a Distributed Sensor Nets workshop in 1978. These included sensors (acoustic), communication, processing techniques and algorithms (including self-location algorithms for sensors) and distributed software. Distributed acoustic tracking was chosen as the target problem for demonstration.

The Accent (a network operating system that allows flexible, transparent access to distributed resources needed for DSN) was developed at CMU (Carnegie Mellon University). It then evolved into the Mach operating system, which found considerable commercial acceptance. Other efforts at CMU included protocols for network interprocess communication to support dynamic rebinding of active communicating computations, an interface specification language for building distributed system software and a system for dynamic load balancing and fault reconfiguration of DSN software.

Further, in 1980s, a multiple-hypothesis tracking algorithm based on DSN was developed by Advanced Decision Systems (ADS), Mountain View, CA, which dealt with difficult situations involving high target density, missing detections, and false alarms. MIT Lincoln Laboratory developed the real-time test bed for acoustic tracking of low-flying aircraft for demonstrations. A PDP11/34 computer and an array processor processed the acoustic signals. The nodal computer (for target tracking) consists of three MC68000 processors with 256-kB memory and 512-kB shared memory, and a custom operating system. Communication was by Ethernet and microwave radio.

That was the state of the art in the early 1980s.

This interest rose with the DARPA low-power wireless integrated microsensors (LWIM) project of the mid-1990s and continued with the launch of the SensIT project in 1998, which focuses on wireless, ad hoc networks for large distributed military sensor systems. A total of 29 research projects, from 25 institutions, were funded under this project. A short list of the more prominent development efforts (not all funded through SensIT) follows.

WINS

The University of California at Los Angeles, often working in collaboration with the Rockwell Science Center, has had a Wireless Integrated Network Sensors (WINS) project since 1993. It has now been commercialized with the founding of the Sensoria Corporation (San Diego, California) in 1998. The program covers almost every aspect of wireless sensor network design, from micro-electro-mechanical system (MEMS) sensor and transceiver integration at the circuit level, signal processing architectures, and network protocol design, to the study of fundamental principles of sensing and detection theory. The group envisions that WINS will provide distributed network and Internet access to sensors, controls, and processors deeply embedded in equipment, facilities, and the environment. The WINS communication protocol data link layer is based on a TDMA structure; separate slots are negotiated between each pair of nodes at

PicoRadio

Jan M. Rabaey of the University of California at Berkeley started the PicoRadio program in 1999 to support the assembly of an ad hoc wireless network of self-contained mesoscale, low-cost, low-energy sensor and monitor nodes. The physical layer proposed for the PicoRadio network is also direct sequence spread spectrum; the MAC protocol proposed combines the best of spread spectrum techniques and Carrier Sense Multiple Access (CSMA). A node would randomly select a channel (e.g., a code or time slot) and check for activity. If the channel were active, the node would select another channel from the remaining available channels, until an idle channel was found and the message sent. If an idle channel was not found, the node would back off, setting a random timeout timer for each channel. It would then use the channel with the first expired timer and clear the timers of the other channels. Note that the PicoRadio program at Berkeley is distinct from its perhaps better-known “Smart Dust” program, in which MEMS-based nodes “could be small enough to remain suspended in air, buoyed by air currents, sensing and communicating for hours or days on end. The Smart Dust physical layer would be based on passive optical transmission, employing a MEMS corner reflector to modulate its reflection of an incident optical signal.

Research on sensor networks started around 1980 with the Distributed Sensor Networks program at DARPA where Arpanet approach for communication was extended to sensor networks.

μ AMPS132

The μ AMPS program, led by Principal Investigator Anantha Chandrakasan at the Massachusetts Institute of Technology (Cambridge, Massachusetts), is focused on the development of a complete system for wireless sensor networks, emphasizing the need for low power operation. Their work has led to the development of a sensor network communication protocol called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH features a node-clustering algorithm that randomizes the assignment of the

high-power-consuming cluster head function to multiple nodes in the network. This spreading of the cluster head function to multiple self-elected nodes lengthens the lifetime of the network.

Underwater Acoustic and Deep Space Networks

A wireless sensor network protocol has design features in common with protocols for a wide range of network types, from underwater acoustic networks to deep space radio networks. The need in oceanography for underwater acoustic networks, which share the low power consumption, low data throughput, large physical area network coverage, and high message latency tolerance characteristics of wireless sensor networks, led to the development of several systems by the early 1990s. State-of-the art underwater acoustic networks employ phase shift keying (PSK) in the physical layer, a MACA-derived protocol for medium access control, and multi-hop routing techniques¹⁴²—all features that would be familiar to the designer of a wireless sensor network protocol. Similarly, the strict power consumption constraints, ad hoc network architecture, and tolerance of message latency requirements common in deep space communication networks¹⁴³ also are common with wireless sensor networks.

Conclusion

In the past 85 years, wireless data networks have gone from manually operated transcontinental radiotelegraphic networks to fully automatic local and personal area networks employing spread spectrum techniques. The methods of MAC, and network organization and operation developed for early radiotelegraphic networks were often independently reinvented for use in the computer communication networks that arose from the development of packet-switched systems in the 1960s.

Although public funding of packet-switched systems development (mostly for defense applications) has continued from the 1960s to the present, commercial development of WLANs beginning in 1990 accelerated research in wireless packet data systems for a wide variety of applications, including WPANs and wireless sensor networks. The SensIT DARPA program supported 29 research programs in the field of wireless sensor networks, and the first commercial interest in wireless sensor network systems is now appearing.

3. Current Research and Development Trends

Applications and Deployment

Several applications have been benefited from the advances in wireless sensor networks. These include Agriculture, Health Care, Defense, Wild Life Habitat Monitoring, Under Water monitoring, Disaster Management (Safety) and Industrial (monitoring, control, factory automation) applications. For all these applications, research deployments have been conducted and products incorporating WSNs are appearing. The current research hence focuses on application-driven systems in order to address more concrete issues. Preliminary results obtained from these deployments are encouraging and widespread use is highly likely.

WSNs are capable of enhancing system performance significantly so they hold considerable promise to Industry. WSN technology is slowly graduating from the researcher “market” to the early adopters in industry. Several start-up companies are offering products in the sensor networking domain: Sentilla, Sensicast, Point8, ArchRock, SynapSense, Crossbow, sensorial, and others. Industrial research labs have also funded sensor networking research. In some cases, the technology is showing up in vertical niche markets, e.g., in process control, where it is not even advertised as WSN. The military continues to fund research in this area, now more so in the context of aiding mobile dismounts/units, but is yet to seriously adopt the technology in its operation.

A recent issue of IEEE Spectrum classified WSNs as one of the top 10 emerging technologies. Eventually, it is felt by most of the research community that it will pervade into daily life like the cell phone technology. WSNs may either connect to the rest of the world through the cellular network or through the wired internet. In any case WSN impact on the traditional networks is likely to be transformative, simply by taking into account the amount of data that will enter/leave as machines talk to enterprises and other machines. WSNs have a major role to play in cyber-physical systems, pervasive computing, Body Networks and Internet of Things.

WSN technology is slowly graduating from the researcher “market” to the early adopters in industry.

According to Freedonia Group report on sensors, 2002, Sensor market in 2001 was approximately \$11 Billion while the Wiring installation costs were more than \$100 Billion. With recent advances and availability of wireless sensor device that can be battery powered the cost of wiring would be the major saving. Further over-the-air programming and solar power sensor devices, helps in reducing the deployment and maintenance cost to a large extent.

Activities Spurred due to WSNs

WSN research has spurred activity on several fronts:

- Ad hoc networks
- Distributed computing and decision making. This helps in more on device computation in order to reduce network traffic/communication and hence increase network life.
- Low power electronics/low power modem design.

The current status of WSN technology includes algorithm design as well as hardware design. However, the real challenge is deploying long-lasting systems in the real environments given the issues such as energy efficiency, self-configuration (low management cost) and low cost hardware design.

Contrasting views

Interest in WSNs across industry and academia continues to be very high, although we are now experiencing a bit of a “backlash” due to the large number of academic research groups getting involved and few successes commercially to date. The vast popularity of WSNs as a research field for academia has left some to feel that it is becoming difficult to make fundamental contributions although the field is still very young. There is also a sense of ossification behind the TinyOS and mote platforms which are premature since many application domains involve quite different hardware and software demands than provided by that system. This “second system effect” will likely subside over the next year or so and it will become clearer where the lasting contributions and research directions lie.

Research Issues:

Some of the research issues are:

- **Transducer design:** Developing new sensor transducers that are compact, low power, and cost effective. Bio-degradable / environment-friendly sensor design.
- **Electronic system design:** The system design is one of the promising challenge areas where several new breakthroughs are possible in the near term leading to fundamentally new design directions. Integrating sensors with the appropriate electronic circuitry to extract digital data, using sensor feedback to enhance the data collection within the electronics, and providing low noise outputs using sensor arrays.
- **Node design:** Developing low power sensor nodes with appropriate processing and networking capabilities.
- **System Design:** Developing sensor networks of several nodes and integrating them with application specific information systems.
- **Protocol:** Distributed algorithms, Power Aware Routing, Dissemination, Time Synchronization, Security, Middleware, Localization of sensors, Data aggregation Techniques, Multimodal sensor fusion, Energy-Efficient real-time Scheduling. In the following section we briefly review research in detection and tracking using WSNs.

Distributed Detection and Target Tracking

Here we present summary of some of the recent contributions in Distributed Detection and Target Tracking using Wireless Sensor Networks and Mobile Phone based Sensor Networks.

- **Distributed Detection using Wireless Sensor Networks**

In Ph.D. thesis [42], various data fusion (aggregation) algorithms useful for binary event detection using wireless sensor networks have been proposed. The topologies considered are single-hop (star topology) and multihop (particularly tree topology) of wireless sensor networks. The schemes proposed by Bhushan Jagyasi et al. in [39-42] are capable to aggregate one-bit and multi-bit information from various sensor nodes. The schemes range from that requiring complete knowledge of the a-priori probabilities to the schemes which do not require any such a-priori knowledge. Further, the proposed aggregation schemes are based on different criteria like, Bayesian or likelihood ratio, Minimum Mean Square Error (MMSE) and adaptive Least Mean Square (LMS) criterion. This versatility of the proposed methods makes them usable for many practical scenarios.

- **Tracking a Mobile Target using Energy Constrained Wireless Sensor Network**

The problem of estimating the location of a moving target 'T' in a 2D plane has been considered in [38]. Vaishali Sadaphal et al. in [29-38] have assumed that it is possible for sensors to detect the presence of the target in its vicinity and to (possibly) measure the distance from/to the target. Given that available energy in sensors is at a premium, the protocols are proposed for target detection and route activation that require sensors to conserve energy by switching between 'inactive' and 'active' modes of operations, while waking-up frequently in inactive mode to evaluate the need to become active. Yet another method to save energy is to reduce the number of measurements and, as a result, the number of transmissions. Even though the sensor will have to be in 'wake-up' state (within the 'active' mode), a reduction in the number of messages communicated can significantly reduce power consumption. Given an adequate spread of sensors, and an ability to only detect presence or absence of the target within its vicinity in a timely manner, it is feasible to obtain an approximate trajectory of a mobile target as a function of time. Alternatively, distance measurements from several such sensors may be used to estimate the location of the target T at a point of time. Clearly, the latter approach is expected to track the target more accurately. However, it will necessarily require that there be at least three sensors within the vicinity of the target and, therefore, this approach requires a significantly greater density of sensors. The error in estimating location of the target using distance measurements from multiple sensors is shown to be dependent on two measures viz. proximity of sensors to the target, and colinearity of sensors. In [38], a new measure, ideal direction for selecting a 3rd sensor, given locations of 2 sensors and the location of the target has been proposed. Algorithms to estimate the track of the target by using distance measurements from sensors selected on the basis of the above measures have also been proposed in [38].

- **Multihop Cellular Sensor Networks (MCSN)**

The ubiquitous use of cell phones motivates the idea of using cell phones and other hand-held devices as carriers of sensors which when networked can cater to a large number of urban applications (eg. environmental monitoring, urban planning, natural resource management, tourism, civic hazard information sharing, crime patrolling etc.) [45], [46], [47], [48]. Multihop Cellular Sensor Networks (MCSN), which combines the advantages of mobile Cellular Sensor Networks (CSN) and the Multihop Cellular Network (MCN) infrastructure has been advocated by Deepthi Chander et al. in [43-44]. In addition to an increase in coverage and energy efficiency compared to a static WSN, MCSNs can have the involvement of a human user (for eg. fire detection application) to enhance the application. In [43] [44], Distributed Velocity Dependent (DVD) Waiting Time based aggregation and routing protocol using MCSN for a moving event localization application have been proposed.

The list of important URLs (websites) related to WSN Research, Development and Deployment (RDD) have been included in Appendix D.

4. Survey on WSN Hardware

The fundamental unit of Wireless Sensor Network is a *Sensor Node*, also called as *mote* by UC Berkley. Each sensor node is required to be capable of sensing, processing and communicating the processed data to the neighboring nodes to form a network. Sensor node is hence composed of sensors to sense the physical phenomenon, analog to digital converter, microcontroller for controlling and data processing, memory for algorithms and data storage, radio unit for short range wireless communication and battery unit to power all the units. For many applications, if feasible, solar powered chargeable battery units are used to minimize the failure of sensors and maintenance cost.

Various kinds of motes have been developed and made available by different companies. An exhaustive survey on WSN hardware has been done by Tatiana Bokareva^{*}. The information on various sensors, sensor nodes, processor, radio chipsets, sensor network operating system, protocols is available at Sensor Network Museum[†]. Embedded WiSeNts' *Research Integration: Platform Survey*[‡] compares different WSN platforms, namely ESB/2, Tmote Sky, BTnode, Ambient Platforms (μ Node and SmartTag), and EYES. It further compares Sensor network operating systems: TinyOS 1.x, TinyOS 2.0, Contiki, BTnuts and Ambient RT; Simulation environments: Tossim, Glomosim, Matlab, Avrora, OMNET++ and NS2; and various Testbeds. Here we present list of some of the available motes with specifications and recommendations.

Each sensor node is required to be capable of sensing, processing and communicating the processed data to the neighboring nodes to form a network.

Available Motes

- **MICA2:**

The processor and radio board used is MPR400 which is based on Atmel ATmega128L. The radio uses 868/916 MHz frequency band and supports data rate of 38.4kbps. A variety of sensors and data acquisition boards for the MICA2 mote are available which can be connected to standard 51 pin expansion connector. Apart from its basic function as sensor node, it can also function as a base station when interfaced with MIB 510/MIB 520. The MIB510/MIB520 provides a serial/USB interface for both programming and data communications. Theoretically, it supports 150meter of outdoor range for line of sight communication (1/4 wave dipole antenna).

^{*} Tatiana Bokareva, Mini Hardware Survey,

http://www.cse.unsw.edu.au/~senar/hardware/hardware_survey.html, last access 12th Aug 2009.

[†] The Sensor Network Museum, Home Page, <http://www.snm.ethz.ch/Main/HomePage>, last access 12th Aug 2009.

[‡] Can Basaran et al., Research Integration: Platform Survey Critical evaluation of platforms commonly used in embedded wisents research, Embedded WiSeNts, available at <http://www.embedded-wisents.org/studies/wisents/download/download2.php>, last access 12th Aug 2009.

- **MICAz:**

The processor board used is MPR2400 which is based on Atmel ATmega128L. The MICAz (MPR2400) IEEE 802.15.4 radio (ZigBee compliant) offers both high speed (250 kbps) and hardware security (AES-128). Direct sequence spread spectrum radio provides resistance to RF interference and data security. The 51-pin expansion connector supports Analog Inputs, Digital I/O, I2C, SPI and UART interfaces. It supports 75-100 meter of outdoor range line of sight communication (1/2 wave dipole antenna).

- **Telos B:**

The MICA2 and MICAz motes are found to be more suitable for field deployment purposes. The Telos B motes has programming and data collection facility via USB and is thus suitable for testbed deployment in lab for experimentation. It utilizes IEEE 802.15.4/ZigBee compliant radio (2.4-2.4835 GHz) which enables 250kbps of data transfer. Its other features include 8 MHz TI MSP430 microcontroller with 10kB RAM, Low current consumption, 1MB external flash for data logging, Integrated onboard antenna, Optional sensor suite including integrated light, temperature and humidity sensor (TPR2420).

- **IRIS 2.4GHz:**

It has improved radio range as compared to MICA2, MICAz and TelosB motes. It has outdoor range over 300 meters (1/4 wave line of sight dipole antenna) and indoor range of more than 50 meter (1/4 wave line of sight dipole antenna). The radio used is IEEE 802.15.4 compliant (2.4 to 2.48 GHz) which is a globally compatible ISM band which enables 250kbps of data transfer. Apart from its basic function as sensor node, it can also function as a base station when interfaced with MIB 510/MIB 520. The MIB510/MIB520 provides a serial/USB interface for both programming and data communications. It uses XM2110CA processor board that is based on the Atmel ATmega1281. A single processor board (XM2110) can be configured to run your sensor application/processing and the network/radio communications stack simultaneously. As in Mica2 and MICAz, IRIS also possesses a 51 pin expansion connector that supports analog inputs, digital I/O, I2C, SPI and UART interfaces.

- **IRIS OEM Edition:**

It is specially designed for sensor nodes for Mesh networking. The mote has postage stamp size form factor. The Radio is IEEE 802.15.4 ZigBee complaint (2.4 GHz global compatible ISM band). It hence supports 250kbps data rate. It has 68-pin package designed for easy sensor integration including light, temperature, RH, barometric pressure, acoustic, magnetic, acceleration/seismic, etc. It utilizes XMeshTM software technology, for low power reliable mesh networking.

- **IMote 2.0:**

It uses CC2420 IEEE 802.15.4 radio transceiver from Texas Instruments. CC2420 supports a 250kb/s data rate with 16 channels in the 2.4GHz band. It has a surface mount antenna which supports nominal range of 30 meters. For long range SMA connector can be soldered on board to connect external antenna. It utilizes Intel

PXA271 XScale® Processor at 13 – 416MHz. The PXA271 also includes a wireless MMX DSP coprocessor to accelerate multimedia operations. It has OS support from Microsoft .NET Micro, Linux, TinyOS. It uses 3 AAA size batteries. The Imote2 has a built-in charger for Li-Ion or Li-Poly batteries. It has a 32 MB SRAM and 32MB Flash RAM. It has a camera interface and useful for applications requiring Digital Image Processing and Seismic and Vibration Monitoring.

- **SunSPOT:**

The Sun Small Programmable Object Technology (SunSOPT) is based on Java platform (Squawk J2ME Virtual Machine) developed at Sun Labs. It uses ARM 920T microcontroller. The radio used is IEEE 802.15.4 ZigBee compliant. It possesses 512K RAM for programs and data and 4MB external Flash.

- **CRICKET MCS410:** The MCS410CA, Cricket Mote, is a location aware version of the MICA2. The Cricket Mote includes all of the standard MICA2 hardware and an Ultrasound transmitter and receiver. By using ultrasound transmission, mobile devices can estimate linear range estimates.

- **Epic:** It is an open mote platform for application driven design from UC Berkeley [DTJJ2008]. The approach of modular component or building blocks has been adapted which makes it useful for wider community and large range of applications. It also claims for less expensively quicker deployment of systems.

Gateways

- **Stargate:**

Stargate is based on Intel XScale processor Intel PXA255 with 400MHz operating speed. The complete design, which is developed by joint efforts of several research groups, has been licensed to Crossbow Technologies for commercial production. It works on Embedded Linux platform. It has various connecting options such as RS232 serial, 10/100 Ethernet, USB host and JTAG. It is compatible with Crossbow's MICA2/MICAz family of family of WSN products. It can hence be used as a gateway of WSN to the existing Internet.

Stargate Netbridge is based on Intel IXP420 XScale 266Mhz processor with Debian Linux operating system.

- **Stargate Netbridge:**

Stargate Netbridge is a WSN gateway developed by Crossbow Technologies Inc., which is meant to connect WSN formed by Crossbow sensor nodes to an existing Ethernet network. It is based on Intel IXP420 XScale 266Mhz processor with Debian Linux operating system which is full fledged standard Linux for ARM processors. It features one wired Ethernet and two USB 2.0 ports. It has a program Flash RAM of 8MB, RAM of 32MB and a USB based system disk of 2GB. It displays data when base station is connected onto its USB port using built-in Web server MoteExplore and sensor network management tool XServe.

5. Applications of WSNs

Here we briefly present the role played by wireless sensor network in applications ranging from environmental monitoring, industrial automation, agriculture, disaster control, automotive, structure health monitoring,

1. Security and surveillance

Security and detection are the important applications of wireless sensor networks. Sensor nodes with motion sensing capabilities may be deployed at the borders to detect the intruder crossing the line of control. Hence surveillance of regions, assets, perimeters, borders and cleared areas can be efficiently done by deploying wireless sensor networks.

2. Environmental monitoring

Following are some of the projects and research plans sought in the environment monitoring application of wireless sensor networks.

- **Watershed:** Correctly managing our watersheds is essential to ensure water supply to the increasing human population in the world. Collecting data for understanding the water systems of rivers and lakes including the impact of environmental factors and human activity.
- **Scientific investigation:** Sensor networks are being used for various scientific explorations including ecological and environmental ones.
- **Pollution monitoring:** Growing urban and industrial regions need efficient pollution monitoring technology.
- **Weather study (Singapore example <http://nwsp.ntu.edu.sg/nwsp/>):** Detailed measurements of weather phenomenon at fine granularity help manage weather dependent industries such as agriculture and also help understand other effects such as spread of epidemics.
- **Threat-Identification:** Sensors can be used to identify potential threats such as chemical contamination of water distribution system at various locations, pathogens in the environments, and other subtle changes in critical infrastructure.
- **Coal mine monitoring for poisonous gases**

3. Creative industries

Wireless Sensor Networks has made a significant impact in the automation and control of the industrial processes. The benefits of WSN in industrial applications are to increase production efficiencies, to reduce environmental impact, to form a close loop by both sensing and controlling various equipments at disjoint locations. The sensor nodes can be placed at remote and manually inaccessible locations because of their small size and capability to communicate wirelessly. The WSNs are hence found useful for steel, chemical, oil and gas, pulp and paper, and petroleum industries. Further the sensor nodes capability to sense and control the

atmospheric parameters makes them useful for pharmaceutical, fabrication and cultivation industries.

4. Precision agriculture

Many initial deployments of wireless sensor networks have shown promise to address various issues faced by rural community. With the help of WSNs, many of the farming activities can be precisely done resulting in yield optimization and minimization of the cost incurred in farming. The sensor nodes may be deployed on the field to measure various atmospheric and soil parameters. These can help in making decision on irrigation, fertilizer and pesticide applications. The WSNs may also serve for the applications such as intruder detection, pest detection, plant disease prediction, fire detection, automating irrigation etc. Some of the ongoing and past agriculture projects in India are Agrisens[§] [15], mKRISHI^{**} [14], Agrosense^{††} [13] etc. Other important problems that can be solved using WSNs include mushroom cultivation and cattle tracking.

With the help of WSNs, many of the farming activities can be precisely done resulting in yield optimization and minimization of the cost incurred in farming.

5. Disasters response

Wireless sensor networks are also found useful for detection of various disasters such as Landslide [amrita], [16], Volcanoes [17], [18] and forest fire [19]. When sensor nodes detect occurrence of any such events they communicate that information to their neighboring nodes for in-network data aggregation. A cluster head or sink node makes the decision on the disaster occurrence considering the information received from various sensor nodes. Such collaborative decision making improves the reliability of the decision made by the entire network [39-42].

6. Automotive/Vehicular

The usage of sensor nodes in the vehicles has led to envision of various automotive applications of the wireless sensor networks. The cabling required to be done to connect various sensors in any automobile can be redundant by using wireless sensor nodes. This simplifies placement of the sensors resulting in more accurate measurements. The vehicle to vehicle communication and vehicle to roadside static node communication gives rise to enormous applications such as smart parking, collision avoidance, multimedia data transfer, disaster detection, traffic information communication. Vehicular WSN are also useful to prevent road accidents and prevent vehicles from crashing into each other, prevent speeding streamline traffic management. Some of these applications face the challenges of high speed

[§] AgriSens, Wireless Network for Precision Agriculture, SPANN Lab, E.E. Dept, Indian Institute of Technology Bombay, Mumbai, <http://www.ee.iitb.ac.in/~spann/agrisens.swf>, last access Aug 2009.

^{**} mKRISHI, mobile based agro advisory system, TCS Innovation Labs Mumbai, Tata Consultancy Services, <http://tcsinnovations.com>, last access Aug 2009.

^{††} AGRO-SENSE: Precision Agriculture using sensor-based wireless mesh networks, Indian Institute of Management Calcutta, Kolkata, India.

multihop transmissions, considering high mobility of vehicles. The power constrain of a WSNs may or may not be relevant, depending on the placement of the nodes, in the automotive application.

7. Health (Body Area Networks)

Body area networks are formed by either wearing sensor nodes or implanting them into the human body to measure various parameters. These are capable of communicating wirelessly with each other and with a base station situated at hospital and home in real-time. The sensor nodes are capable of observing critical parameters of a patient to detect the occurrences of disease attacks such as heart attack, diabetes and asthma and communicate the same to the mobile device carried by a family member and a doctor. Physiological sensors worn by patients in their own homes can help doctors deliver healthcare for regions where local healthcare staff is in shortage or hospital beds are scarce. Such systems are also very useful for elder-care.

Body area networks are formed by either wearing sensor nodes or implanting them into the human body to measure various parameters and communicate wirelessly to the base station at hospital.

8. Monitoring health of structures (like bridges)

A vast literature presents the advantages of deploying wireless sensor networks for monitoring health of the bridges as compared to traditional methods. Further, protecting historical monuments by having sensors monitor structural integrity, environmental factors, and usage loads are other applications of wireless sensor networks.

The major issue of power requirement of the sensor nodes has been given due consideration by proposing techniques like energy harvesting [20] and use of solar panels. Park et al. in [21] has compared performance of MEMS accelerometer that come with wireless sensor nodes with the traditional sensing devices. Accelerometer is suggested to be used in [22], [23], [24] to measure vibrations when the trains pass over bridges. They address issues related to time synchronization, routing, data collection, aggregation from sensors and communication to a central device. More research is required to detect health of bridges using other sensors such as temperature, humidity and corrosion etc. Multimodal data fusion (from more than one type of sensors) techniques are hence required to be developed to determine health of bridges.

9. Supply chain management

Wireless sensor networks along with RFID are found useful for managing the temperature of food products as they traverse roads, sea and storage. The integrated WSN with RFID are also envisaged for applications of preserving medicines requiring stringent storage and transportation requirements.

10. Underwater Sensor Networks

Underwater Sensor Networks use acoustic communication due to the low attenuation of acoustic waves in water, especially in thermally stable, deep water settings. In shallow water acoustic communication is confronted with temperature gradients, surface ambient noise and multipath propagation due to reflection and

refraction [26]. Sound has a low propagation velocity in water. The much slower speed of acoustic propagation in water, about 1500 m/s, compared with that of EM and optical waves, lead to large propagation delays which prevents efficient communication and networking. Nevertheless, since the communication technologies like EM waves and optical communication fail under water over large distances, currently, acoustic communication is the preferred technology for underwater communication.

In [25], a specific scenario has been considered where a set of underwater sensor nodes report events to the sink node. A Path Unaware Layered Routing Protocol (PULRP) for dense underwater 3D sensor networks is proposed for an uplink transmission [25]. The proposed algorithm must combat frequent losses of connectivity due to node mobility, energy depletion and must not result in large end-to-end delay. The proposed PURLP algorithm consists of two phases. In the first phase (layering phase), a layering structure is presented which is a set of concentric shells, around a sink node. The radius of the concentric shells is chosen based on probability of successful packet forwarding as well as packet delivery latency. In the second phase (communication phase), we propose a method to choose the intermediate relay nodes and an on the fly routing algorithm for packet delivery from source node to sink node across the chosen relay nodes. The proposed algorithm, PULRP finds the routing path on the fly and hence it does not require any fixed routing table, localization or time synchronization processes. The findings show that the proposed algorithm in [25] has a considerably better successful packet delivery rate compared to the under water diffusion (UWD) algorithm proposed in the paper by Lee et al. (2007) [28]. In addition the delay involved in PULRP is comparable with that of UWD. In [27], the PULRP has been further extended for a 2D UWSN with mobile nodes having a Random waypoint steady state distribution, which is non-uniform. The findings show that for this case of 2D UWSN with non-uniform node distribution, the proposed algorithm, PULRP-2D, has considerably better throughput (successful packet delivery rate) compared to the underwater diffusion (UWD) algorithm for various node densities as well as node velocities. Also, the delay performance of PULRP-2D is better than that of UWD.

11. Future markets

Urban (shopping malls, metro train stations, bus stops^{‡‡}) and residential security is a great opportunity where monitoring services can generate widespread employment. In essence each system has a central controller and several wireless motes (sensors to detect motion, door opening etc). India's leadership in providing services globally can be leveraged to great advantage if we can develop a technology leadership in security surveillance system design. Remote monitoring service for a single home in the US typically costs \$10-\$100 per month and involves mainly responding to alarm phone calls – Indian industry can be more competitive in providing such a service.

^{‡‡} Several commercial products already exist:

<http://www.safemart.com/index.asp?PageAction=VIEWCATS&Category=1018>

6. Investment in WSN Research and Development

We present a summary of the survey on the potential markets and commercial importance of wireless sensor networks in order to provide direction for investment in WSN research and development.

Potential Markets and commercial drivers

1. Military and Security
2. Tele-health and Medical Monitoring.
3. Rural health monitoring
4. Agriculture: Monitoring farms, soil moisture, and environmental factors that impact plant growth and disease propagation.
5. Cold chain: Managing the temperature of food products as they traverse roads, sea and storage.
6. Medicine storage parameters tracking.
7. Watershed monitoring and Water supply management.
8. Ecological and Environmental Scientific investigation
9. Pollution monitoring in urban and industrial area.
10. Protecting historical artifacts.
11. Sea-port water depth and traffic monitoring for efficient management.
12. Threat-Identification or Event Detection.
13. Structural health monitoring
14. Automation
15. Medical Monitoring
16. High Value Asset Tracking
17. Consumer Devices
18. Urban (shopping malls, metro train stations, bus stops) and residential security.
19. Coal mine monitoring for poisonous gases

The collaboration should be tripartite including, **Government Agencies, Academia and Industry**, for complete research-development-deployment cycle

Tripartite Collaboration

The collaboration should be tripartite including, **Government Agencies, Academia and Industry**, for complete research-development-deployment cycle of WSN applications. Equally important roles are there to play for all the three agencies in terms of finance, research and commercializing leading to complete end to end deployment of the WSN for emerging applications. It is indeed very important for all the three to cohesively work to exploit the capabilities of WSN specifically to provide solutions in Indian context.

Role of the **academia** is to solve various research problems relating to design and development of WSNs. Funding is expected to motivate the research and development. Early prototypes can then be commercialized with help of industry partners. Again some seed fund for such commercial efforts would be of great help.

The participating **industry** should have the responsibility of doing market survey, identification of products and their specifications, price structure and must take responsibility of manufacturing and deployment. The industry must be fully committed and must be a stakeholder driving the academia to deliver on time. The **industry** can help academic researchers understand the **practical issues**, interfacing requirements and immediate needs.

The Government must fully finance the theoretical research part of the project and may demand royalties from the industry at a later date. Partnerships with the **government** can focus on **establishing new standards** for application domains that benefit from sensor networks. Structures of public utility, like bridges, dams, roads, railway line etc could be made safe by the use of WSNs. Government should take initiative in taking up defining requirements, disseminate any data at its disposal and take up pilot projects. In this context, academia is required to contribute towards developing innovative sensors and the industry needs to take on the turnkey project execution.

Some partnerships have already been started, for example:

- Indian Institute of Technology Bombay/ Microsoft Research
- Indian Institute of Science Bangalore/ Defense Research Development Organization.

Cross Disciplinary activities in WSN

- a. **Landslide detection** requires interdisciplinary collaborations between departments such as Earth Sciences – Electrical Engineering –Computer Sciences Engineering.
- b. **Precision agriculture application** requires contributions from researchers and scientist from agricultural universities, electrical engineering department and computer science and engineering department
- c. **Structure (like bridges) health monitoring** (Civil Engineering– Electrical Engineering –Computer Sciences Engineering.)
- d. **Vehicular applications** (Automotive Engineering – Electrical Engineering – Computer Sciences Engineering)
- e. **Medical monitoring/ Body network applications** (Medical universities – Biomedical engineering – Electrical engineering and computer science engineering)
- f. **Pharmaceutical application such as drug temperature tracking** (Pharmaceutical department - Engineering –Computer Sciences Engineering)

Bottleneck in WSN RDD (Research Development and Deployment)

- a. **Affordable nodes and Sensors:** The cost of the sensors should be low enough to make WSN solution feasible for real deployments. Further, the deployed WSN is required to be run unattended for years while delivering the minimum required performance for a particular application. Moreover, until now demonstration of WSN capability at an affordable cost to gain market acceptability and penetration is lacking.

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- b. Economy of scales: Design and maintenance at large scale will require new engineering design directions. As opposed to programming single data sources, engineers must think of systems of multiple nodes where they cannot carry out each design step thinking about individual nodes. Rather thinking about ensembles, where high level properties of a group of nodes are used in higher layer design will be needed.
 - c. Not enough attention paid to (a) sensors, (b) packaging, (c) antenna design, and (d) deployment. Until these problems are solved, adopters will not go broad-scale or mainstream.
 - d. Lack of skilled manpower with a combination of expertise in Hardware, Systems Software, and Embedded Software with possibility of also lack of knowledge in Web and Distributed Applications. A huge and critical barrier is the shortage of PhD students in Computer Science and Electrical Engineering discipline.
 - e. Since most of the applications of WSN are interdisciplinary, it is required to integrate IT with Application Domain Expertise.
 - f. Broad deployment cycle: The modeling - theory - prototyping - deployment cycle is very broad for typical WSN applications. Management of complementary expertise to complete an end-to-end system and persistent efforts over several generations of the system may be needed to provide a good solution.
 - g. WSN have to use unlicensed spectrum. Thus spectrum issues need to be resolved. The unlicensed bands are ISM bands like 900 MHz, 2.4 GHz bands and the 3-10.6 GHz band for UWB wireless technology. These bands are already overcrowded and thus spectrum policy allowing the UWB band should also be activated in India, since it's a wider band and can accommodate more devices / mm² and help in reducing interference between devices.
 - h. Need to give an impetus for sensor development. A lot of work has gone into communication and protocol development, but much less into sensor developments. The key component of any and every WSN is a sensor and therefore sensor development does need a major impetus.

7. Funding Policy

There are already various mode of funding available in India. But it was felt that some new avenues of funding could be explored. We enumerate some of these which could have a major impact on research, development, prototyping and incubation of WSN technologies.

- Need to move forward an set up virtual centers
 - Each Center to have collaborations among several disciplines
 - Each virtual center to have participation from at least three academic institutions / organization / industries (i.e. it could be only three academic institutions, or two academic institutions and one industry, etc.)
- Need a long term policy – Should fund for at least 10 years in a phased manner.
- Provide funding for incubating developments that take place form project mode funding. Here a model can be developed wherein a non-profit society driven by DIT holds equity.
- Funding for hosting international collaborations, workshops and conferences on the theme of WSN.
- Special consideration could be given to WSN projects dealing with green growth.
- Specific funding for hosting postdoctoral fellows could be developed. This should include post doctoral fellows from the international arena. Such funding can be a big boost R and D in WSN and application of WSN to Green Growth.
- A fundamental shift in funding has to develop wherein one is looking at long term horizon. It may worth developing a strategy for funding 5 year projects as opposed to the usual mode, wherein 2 to 3 year projects are preferred. Of course, even in long term funding, there has to be periodic reviews and the next phase funding should be based on performance.

8. Recommendations

1. **Virtual centers.** Tree Structure. IITs/IISc should act as nodal points with NITs and Local colleges from neighboring areas (states and cities) as leaf nodes.
2. WSNs should be made available in schools as demos and items to play with. It will be great to have Robots equipped with WSN technology for yet to be imagined applications by young minds. Have open house or take demos to schools etc. Develop a WSN+Robo toy like the LEGO for children to play with.
3. When building new national infrastructure like bridges, roadways, etc., WSN technology should be built into it. This will avoid retrofitting.
4. Agriculture being one of the largest sectors of Indian Business, Government of India should allocate more funds for deploying WSNs for precision agriculture for the coming years. The aim should be to cover every acre of farming land with at least two sensor nodes resulting in a nation wide soil and climate map (sensor map) for entire country.
5. Initially, target applications could be set of applications those are important and challenging, yet do-able.
6. **Tripartite Collaboration** between Academia, Government and Industry.
7. WSN funding must have an interdisciplinary team. This is because most of the applications catered by WSN require application domain knowledge as much as engineering and designing skills.
8. Support sensor development research in industries.
9. Actively support WSN for healthcare / body area networks. This could be one of the biggest driver for adoption of WSN
10. Developing WSN for RFID applications. This can cater to various applications related to storage and transportation of food and drug.

It will be great to have Robots equipped with WSN for yet to be imagined applications by young minds.

9. Conclusions

The area of WSN is thriving and every day new ideas are emerging. A strong testimony to this is the recent report on *Smart Sensor Networks: Technologies and Applications for Green Growth*, by OECD: Organization for Economic Cooperation and Development, Dec. 2009 [49]. This report contributed to the OECD Conference on “ICTs, the environment and climate change”, Helsingør, Denmark, 27-28 May 2009, and is a contribution to the OECD work on Green Growth.

Thus, it is envisaged that WSN could become a major driver for Green Growth. As has been mentioned at various stages of the report and also brought by the survey, WSN has been a bit slow to take off, but once it takes off there will be no stopping it. What is needed is something like the microprocessor and DSP chip revolution where the costs came down by orders of magnitude, processing power went up immensely and energy consumption came down dramatically. This will happen if we develop novel and cost effective mixed signal design technology for WSN chipsets.

Another area which needs a tremendous impetus to make sure that WSN thrives is sensor technology. Perhaps the weakest link in the chain of technologies of WSN is sensor technology. Sensors are very expensive, partly because of niche technology and also because of niche applications. Ubiquitous use of sensors for various day to day applications, as promised by Internet of Things, will indeed help in bringing the cost down for sensors.

Nevertheless, the area of biosensors is wide open. Bio-Wi-sensor networks could turn out to be the biggest applications of WSN. Everything hinges on development of biosensors. Significant financial resources need to be committed to the development of biosensor in India. It is going to be very difficult to buy biosensors from overseas, and thus very imperative that India puts in the requisite resources for development of biosensors.

All in all, when we look at WSN, we need to think of a long haul game. We need to be in the running for a long time and then good things in WSN will indeed emerge for India.

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Appendix A

Survey for Wireless Sensor Network (WSN) Technology (Sponsored by Ministry of Communication and Information Technology, India)

Conducted by Uday B. Desai <ubdesai@ee.iitb.ac.in> B. N. Jain
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Name:
Phone:
E-mail:
Address:

Preamble

It was felt by the Ministry of Communication and Information Technology (MCIT), Department of Information Technology (DIT) that it will be prudent to give a cohesive thrust to this very important area. With this in mind a workshop was held at IITB on April 20, 2007 (http://www.ee.iitb.ac.in/spann/wsn_workshop.html). We felt that in the globalized world it was important to have perspective from a global audience. Thus, we now embark on soliciting opinions from researchers worldwide.

Please do spare a few minutes of your precious time for filling out this survey form. Email the filled out form to ubdesai@ee.iitb.ac.in by **November 15, 2007**

1. Current status and importance of Wireless Sensor Networks (WSN)

2. What is your perception for the future of WSN?

3. Which areas in WSN are most promising?

4. Potential drivers and applications for WSN?

5. How resources should be distributed among:

1. Theoretical Research
2. Practical Research

3. Deployment
6. What are the commercial drivers and potential markets?
7. What efforts for standardization
8. What are the potential barriers to growth
9. What kind of partnerships to evolve between industry, academia, and government for growth in WSN technology for India
10. Any other comments

Appendix B

Survey Results

A survey on Future of Wireless Sensor Network Technology has been conducted by circulating Survey form given in Appendix A to prominent researchers working in the filed of Wireless Sensor Networks. As many as 17 top notch researchers from India and abroad responded to this survey. Following is the list of researchers who have contributed in this survey.

- Aman Kansal
- Anish Arora
- Anurag Kumar
- Bhaskar Raman
- K. R. Sarma
- Mahesh U. Patil
- Matt Welsh
- Nabanita Das
- Onkar Dabeer
- P. R. Kumar
- Pramod K. Varshney
- Rama Murthy, Garimella
- Sanjay Jha
- Vinayak Naik
- Vishal Chandra
- Viswanatha Rao Thumparthy
- Shaheed Khan

Following is the summary of the Survey report:

1. Current status and importance of Wireless Sensor Networks (WSN)

Status:

1. *Research deployments* have been conducted and products are appearing. Research Prototypes and PoC's are seen all across the world including India. However, not many hardware products are manufactured in India for WSN.
2. *Network Protocols:* The simpler problems of network setup, mesh protocols have now been worked on and nearing solution.
3. *Application Driven:* More current research is now focused on application driven systems – so that more concrete issues can be addressed.
4. *Comparison with other technologies of the generation:* A recent issue of IEEE Spectrum classified WSNs as one of the top 10 emerging technologies.
5. *Hardware:* There is also a sense of ossification behind the TinyOS and mote platforms which are premature since many application domains involve quite different hardware and software demands than provided by that system. This “second system effect” will likely subside in some time and it will become clearer where the lasting contributions and research directions lie.

6. *Industry and Academia:* Interest in WSNs across industry and academia continues to be very high, although we are now experiencing a bit of a “backlash” due to the large number of academic research groups getting involved and few successes commercially to date. The vast popularity of WSNs as a research field for academia has left some to feel that it is becoming difficult to make fundamental contributions although the field is still very young.
7. *Challenges:* Several research issues such as energy efficiency, self-configuration (low management cost) and low cost hardware design are some of the important challenges for this technology’s success.

Importance:

- *Funding:* Several applications stand to benefit from sensor networks. WSN’s have received enormous research funding (in US, Europe, and Asia) over the last 10 years. Examples include research centers such as CENS (<http://research.cens.ucla.edu/>) in the US and Swiss Ex http://www.swiss-experiment.ch/SwissEx/index.php/Main_Page, and several other projects. Asian countries including China, Singapore, and Taiwan have several projects in sensor networks as well. Several start-up companies are offering products in the sensor networking domain: Sentilla, Sencicast, Point8, ArchRock, SynapSense, Crossbow, sensorial, and others. Industrial research labs have also funded sensor networking research: http://research.microsoft.com/ur/us/fundingopps/rfps/SensorMap_RFP_Awards_2007.aspx The military continues to fund research in this area, now more so in the context of aiding mobile dismounts/units, but is yet to seriously adopt the technology in its operation. This is historically consistent with it being the visionary for technology but being a slower adopter than the industry.
- *Applications:* WSNs will not have one killer app. They are likely to have many! Most discussions of this topic go into the lengthy (and sometimes identical) list of application domains and a number of these areas over time will pan out. Whether they connect to the rest of the world through the cellular network or the wired internet, WSN impact on the traditional networks is likely to be transformative, simply by taking into account the amount of data that will enter/leave as machines talk to enterprises and other machines. In Indian context, it mainly influences Agriculture, Health Care, Defense, Surveillance, Wild Life Habitat Monitoring, Medical, Under Water WSN and Disaster Management. Thus Potentially WSN can enable a lot of applications for improving the efficiency of industries (industrial monitoring, factory automation), energy saving (home automation, Lighting / HVAC systems), wildlife/agriculture (monitoring animals / soil), safety (fire-detection systems) etc. However WSN are currently not widely deployed or used. Thus despite the promise of WSN, due to the lack of technology at the right performance / price, we do not see WSN entering the mainstream.

Thus it is a unanimous belief that the area of WSN is currently under research and development. Several exploratory deployments have taken place. Preliminary results are encouraging and widespread use is highly likely. WSNs are capable of enhancing system performance significantly so they hold considerable promise. It is also believed that it will pervade into daily life like the cell phone technology.

2. What is your perception for the future of WSN?

WSN technology is the outcome of advances in sensor, transceiver, memory and microcontroller technologies which are all integrated on one board to form a basic element of WSN called sensor node. WSNs are a natural extension to IT systems that have already shown vast potential for improving business productivity. Moreover, this is a direct outgrowth of technological innovations and societal needs.

The future of WSN, as perceived by various researchers, is in its evolution in multiple directions. This has been summarized below:

Integration:

- More and more real time sensor information is expected to get integrated from sensors into business information systems.
- RFID sensor data is now reaching global standardization (Eg. <http://www.epcglobalinc.org/home> and integration of RFID with GPS based mapping systems for tracking).
- Sensors embedded on Mobile phones forming “Cellular Sensor Networks (CSN)” has been considered to be another important research area resulting in another set of novel participatory sensing applications. The involvement of human in maintaining the sensor nodes (mobile phone) solves major issues like deployment and power efficiency in WSNs. However this has another constraint of mobility of nodes which leads to form a more dynamic network.
- Research on incorporating UWB transmission in Wireless sensor networks envisages a shift to cater high data rate applications, unlike low data rate applications which are more often considered in the present scenario.

Future Applications

- The use of sensors in other domains is gaining increased attention, ranging from cold-chain management, security, infrastructure monitoring, to scientific exploration.
- This field has tremendous potential for applications in public domains. With the development of new application specific sensors along with the appropriate networking protocol, data aggregation model, routing and scheduling techniques sensors can invade all spheres of life to assist humans for better life.
- WSNs has a great potential in many application domains, resource monitoring, environmental monitoring, defense applications, traffic systems, health care, precision agriculture, etc. The potential is so great that it is hard to think of what areas may be unaffected by developments in this area.

Hence a widespread use of WSN is expected in the future

Technological Advances

On the technology side, some of the initial design assumptions are giving way to more practical designs learned through experiences in deployments and experiments. For instance, practical systems may not be peer to peer ones with large number of nodes in a mesh network but hierarchically organized with some higher power nodes every few hops. As more and more practical systems are developed, the usefulness of sensor networks will continue to become clearer.

Standardization

Going by the standardization efforts (Zigbee), and the race to build proprietary products (Honeywell, ABB, Hitachi) it appears that the industry has a lot of expectations as well.

Bottlenecks

- No major commercial deployments, as yet.
- Extremely low power consumption and compact high capacity power sources are two of the major bottlenecks.
- Due to the use of unlicensed spectrum, interference by other technologies, especially WLAN could be a challenge.

It is widely believed that the field will continue to grow as the idea of remotely able to retrieve sensory data and then closing the loop by sending control signals is exciting. Hence, despite the challenges there would be demand in the industry to work on WSN products.

3. Which areas in WSN are most promising?

Some of the research issues, as suggested by the researchers working in the area, which holds promise for the future of WSN technology, are summarized here.

Research Issues:

- **Transducer design:** Developing new sensor transducers that are compact, low power, and cost effective. The space of interesting sensors is yet to be seriously explored, and will result in much more serious adoption. Bio-degradable / environment-friendly sensor design is another challenging area with good research potential.
- **Electronic system design:** Integrating sensors with the appropriate electronic circuitry to extract digital data, using sensor feedback to enhance the data collection within the electronics, and providing low noise outputs using sensor arrays.
- **Node design:** Developing low power sensor nodes with appropriate processing and networking capabilities.
- **System Design:** Developing sensor networks of several nodes and integrating them with application specific information systems. System design is one of the most promising challenges where several new breakthroughs are possible in the near term leading to fundamentally new design directions.
- **Distributed Algorithm:** Distributed energy efficient algorithms for data aggregation, routing, scheduling, clustering, time synchronization and localization are some of the extensively researched area for single-hop and multi-hop Wireless Sensor Networks.

4. Potential drivers and applications for WSN?

Potential Drivers:

1. Cost of wiring in retrofitting sensing infrastructure.
2. Cost of sensing in "low visibility" setting. Traditional sensors under perform in many scenarios because of topological constraints.
3. Low power computing technology.
4. Needs for coupling fine grain observation with (largely) automatic monitoring/alerting/control.

Applications:

Design of WSNs to cater novel applications have been the prime focus of the researchers

working in the field of WSNs. Applications envisaged with the development of WSNs technology are:

- Defense and Surveillance,
- Event Detection (Management of natural disaster like Tsunami, Landslide, Cyclone etc.)
- Process industry (chemical plants),
- Structure (road, bridges etc) monitoring,
- Water management,
- Precision Agriculture,
- Vehicular WSN,
- Medical monitoring (health care),
- Wild life habitat Monitoring,
- Data collection in remote hostile environments,
- Under water WSN
- Location Tracking and
- More than sensors, Robotics, Art, Toys and Personal Electronics

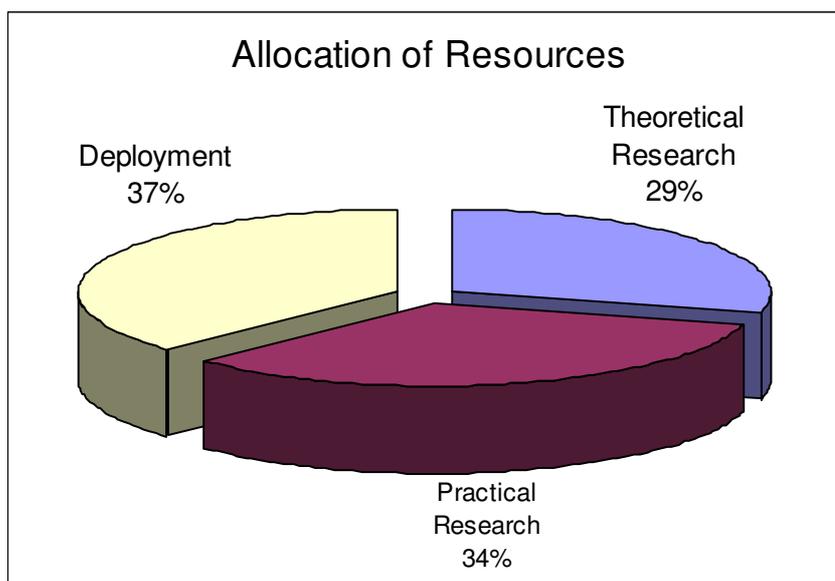
5. How resources should be distributed among:

4. Theoretical Research
5. Practical Research
6. Deployment

According to the feedback of 15 researchers on allocation of resources between Theoretical, Practical and Deployment work in WSNs, following table has been compiled.

Allocation of Resources

Researcher	Theoretical Research	Practical Research	Deployment	Total
1	20.00	40.00	40.00	100.00
2	33.33	33.33	33.33	100.00
3	33.33	33.33	33.33	100.00
4	0.00	0.00	100.00	100.00
5	20.00	40.00	40.00	100.00
6	50.00	25.00	25.00	100.00
7	20.00	50.00	30.00	100.00
8	50.00	25.00	25.00	100.00
9	25.00	25.00	50.00	100.00
10	33.33	33.33	33.33	100.00
11	30.00	40.00	30.00	100.00
12	40.00	30.00	30.00	100.00
13	33.33	33.33	33.33	100.00
14	25.00	50.00	25.00	100.00
15	20.00	50.00	30.00	100.00
Total	433.33	508.33	558.33	1500.00
Percent	28.88888889	33.88888889	37.22222222	



Theoretical Research is about theorem proving/mathematical analysis for relevant models and "Practical Research/Deployment considers design and implementation often based on adhoc methods. Both these are complementary tools with their own advantages/disadvantages.

The first wave of theoretical research seems to be complete. At this stage, a little more attention to practical research (such as interference patterns with WLAN in a home environment etc) and large scale deployment may be required. Practical research takes inputs from Deployments and gives inputs to Theoretical Research. More importance should be given on deployments in the field. Depending on whether or not any significant research issues arise after this, attention can then be focused on theoretical or practical research. This will also result in consideration of Practical assumptions in Theoretical research. More focus on deployment would result in translation of large body of theoretical work into real systems. This in-turn will need revision of theory. Hence resources to theoretical research should also not be ignored completely. This will help the theoretical research efforts to be tied to the real-world problems.

6. What are the commercial drivers and potential markets?

Commercial Drivers and Potential Markets:

- Companies like Crossbow, Meshnetics, Sentilla and Manufacturing sensing related equipments.
- Govt. regulations which push some WSN applications can act as commercial drivers.
- Security space is perhaps the first key driver along with manufacturing.
- Current design may be useful for a wide range of early commercial applications: Agricultural Monitoring, Structural Monitoring, Automation, Medical Monitoring, Military, High Value Asset Tracking, Security, Consumer Devices
- Industrial monitoring, Industrial process control, supply-chain, and medical monitoring are potentially large markets.
- Pipeline management, Rake management in Railways, Sea level monitoring, air traffic management systems are some of the examples which have shown considerable potential of WSN in civilian sector.

- Seismic Networks: Avalanche Monitoring, Ground water management, River water management have also shown potential market for WSN deployment.

Opportunities to build global leadership:

20. Tele-health: Physiological sensors worn by patients in their own homes can help doctors deliver healthcare for regions where local healthcare staff is in shortage or hospital beds are scarce. Such systems are also very useful for elder-care.
21. Agriculture: Monitoring farms, soil moisture, and environmental factors that impact plant growth and disease propagation.
22. Cold chain: Managing the temperature of food products as they traverse roads, sea and storage.
23. Watershed: Correctly managing our watersheds is essential to ensure water supply to the increasing human population in the world. Collecting data for understanding the water systems of rivers and lakes including the impact of environmental factors and human activity.
24. Scientific investigation: Sensor networks are being used for various scientific explorations including ecological and environmental ones.
25. Pollution monitoring: Growing urban and industrial regions need efficient pollution monitoring technology.
26. Weather study (Singapore example <http://nwsp.ntu.edu.sg/nwsp/>): Detailed measurements of weather phenomenon at fine granularity help manage weather dependent industries such as agriculture and also help understand other effects such as spread of epidemics.
27. Protecting historical artifacts and monuments by having sensors monitor structural integrity, environmental factors, and usage loads.
28. Sea-port water depth and traffic monitoring for efficient management
29. Defense: Surveillance of borders and strategic control points in harsh and remote locations.
30. Threat-Identification: Sensors can be used to identify potential threats such as chemical contamination of water distribution system at various locations, pathogens in the environments, and other subtle changes in critical infrastructure.

Opportunities specific to developing countries:

1. Urban (shopping malls, metro train stations, bus stops) and residential security is a great opportunity where monitoring services can generate widespread employment. Several commercial products already exist: see <http://www.safemart.com/index.asp?PageAction=VIEWCATS&Category=1018>. In essence each system has a central controller and several wireless nodes (sensors to detect motion, door opening etc). India's leadership in providing services globally can be leveraged to great advantage if we can develop a technology leadership in security surveillance system design. Remote monitoring service for a single home in the US typically costs \$10-\$100 per month and involves mainly responding to alarm phone calls – Indian industry can be more competitive in providing such a service.
2. Chinese researchers have built systems where they use taxi mounted GPS data streams to monitor urban traffic conditions. Unlike the developed world where road embedded sensors give real time traffic information (<http://trafficmap.cityofbellevue.net/>), developing countries can leverage the high density of taxis in major urban areas to get similar information.
3. Coal mine monitoring for poisonous gases
4. Bangladesh Arsenic contamination: discussed briefly in some of the videos near the

bottom of the page at <http://dms.jamesreserve.edu/>

5. Computing in rural areas: <http://www.cs.washington.edu/htbin-post/mvis/mvis?ID=658>

7. What are efforts for standardization

It is common overall view that high efforts are required for the standardization of WSNs, since it would involve standardization of radio, hardware, software on nodes (middleware as well as EOS along with communication and sensing interfaces), and middleware on the distributed server.

Some of the existing standardization efforts resulted in

- 802.15.4 for low power MAC layer using open spectrum radios
- EPC for RFID sensors
- Electronic datasheets IEEE 1451
- Zigbee for upper layers in the stack such as network layer
- The IPv6 over Low power Wireless Personal Area Networks (IP/6LoWPAN) is IPv6 Network stack for Wireless Sensor Networks in which sensor nodes can communicate using protocols such as ICMP, TCP and UDP. As compared to IEEE 802.15.4, the IP/6LoWPAN provides more convenience for communicating with Internet based devices and web-server and web-browser. Debates are on whether IP-6LowPan with appropriate TCP versions will be a better fit because that is much more inter-operable with the Internet.
- The sensor architecture for various applications could evolve for some standards.
- Standardization should be such that it compliance the large scale deployments, which are almost non-existent. Interoperability issues have not been experienced. This may be one area that would lead to refinement in the standards.

8. What are the potential barriers to growth

Some of the potential barriers to growth as suggested by various researchers working in the area of WSNs are summarized below.

1. **Interdisciplinary collaborations:** Most of the applications catered by WSN require interdisciplinary collaborations. Integrating IT with Application Domain Experts is one of the potential barriers to WSN growth.
2. **Scalability:** Design and maintenance at large scale will probably require new engineering design directions.
3. **Energy efficiency.** The power is still considered as an issue for developing most of the algorithms. The current radio, processors, and software are power hungry. For the nodes to be able to last for long duration (potentially a year or two), would need clever design. The limiting factor could be the state-of-the-art of the battery technology.
4. **Spectrum:** WSN have to use unlicensed spectrum. Thus spectrum issues need to

be resolved. The unlicensed bands are ISM bands like 900 MHz, 2.4 GHz bands and the 3-10.6 GHz band for UWB wireless technology. The ISM bands etc are already overcrowded and thus spectrum policy allowing the UWB band should also be activated in India, since it's a wider band and can accommodate more devices / mm² and help in reducing interference between devices.

5. **Privacy and Security:** Privacy considerations when sensors are used in or on an object being actively used by a human. Privacy and Security is also a critical issue for defense application.
6. **Talent:** A huge and critical barrier is the shortage of PhD students and neglect of adequate research infrastructure, education, capital, development projects. Talent is scarce, especially in terms of expert programmers. Lack of skilled manpower with a combination of expertise in Hardware, Systems Software, and Embedded Software with possibility of also lack of knowledge in Web and Distributed Applications.
7. **Cost:** Cost of the solutions is not regarded as barrier to the growth of WSNs by many researchers in the long run. Whereas, cost per node is still considered to be too high for practical deployment of nodes. It is still unclear that weather these networks can really run unattended for years, while doing something useful. We hence need some experiences with large practical deployments. Moreover, the WSNs will become practicable only when the cost of commercial sensors is brought down significantly from the current value.
8. **Assumptions:** Non-practical, unstated and unjustified assumptions in theoretical research are huge barrier to the actual deployment.
9. **Market Potential:** It should be recognized that fundamentally WSNs are a bit of a niche market and are unlikely to sustain the kind of growth seen in other market segments (servers, Internet, etc.) although it is possible that the market potential is still very large.
10. **Complex Design:** User-friendly devices and systems are required to be developed.
11. **Development Cycle:** The modeling - theory - prototyping - deployment cycle is very broad for typical WSN applications. Management of complementary expertise to complete an end-to-end system and persistent efforts over several generations of the system may be needed to provide a good solution.
12. **Practical Deployments:** Demonstration of WSN capability at an affordable cost to gain market acceptability and penetration.
13. **Others:** Some of the other barriers to growth are hype exceeded delivery, size of the node, interference from other technologies using the same spectrum, packaging, sensors and antenna design.

9. What kind of partnerships to evolve between industry, academia, and government for growth in WSN technology for India

1. Partnerships between industry and academia should *focus on application domains* that can benefit from sensor networks. For instance, food supply industry can leverage sensor networks for maintaining temperature and quality control throughout the farm to fork food pathway. The industry can help academic researchers understand the practical issues, interfacing requirements and immediate needs. Partnerships with the government can focus on establishing new standards for application domains that benefit from sensor networks. Continuing the food supply example, a premium grade food category may be created that is certified to be monitored for temperature and contamination control throughout the production cycle.
2. Process Management: A key ingredient would be a managed process where a government entity assumes a facilitating role in helping academic and industrial contributions transitioning into practice and are responsive to the real user needs.
3. Consortia: The idea of forming consortia to support development of toolsets, IDEs, testbeds, programming environments as well as users can create momentum.
4. Tri-Partite: The project should be tri-partite between academia, government and industry. The bond across the three parties can also help rapid adoption of the technology with academics focusing on Practical Research and Industry focusing on deployments.

The support and involvement of *Government* is needed to make it key to the success of the technology. The govt. also needs to resolve spectrum issues, standardizations issues, make policies which push specific WSN applications and create a reliable market opportunity etc. Structures of public utility, like bridges, dams, roads, railway line etc could be made safe by the use of WSNs. Government should take initiative in taking up defining requirements, disseminate any data at its disposal and take up pilot projects. The Government must fully finance the project and may demand royalties from the industry at a later date.

Academia would need to contribute towards developing innovative sensors and the industry needs to take on the turnkey project execution. Along with theoretical research, the academia should also focus on practical research to be able to bridge the Research & Development gap and help the industry.

The participating *industry* should have the responsibility of doing market survey, identification of products and their specifications, price structure and must take responsibility of manufacturing and deployment. The industry must be fully committed and must be a stakeholder driving the academia to deliver on time. At the stage of development the industry will not be willing to contribute financially. Role of the academia is obvious. The system under development must be modular both in terms of number of nodes, but also in terms of features like secrecy, data rates, power management, frequency band, channel characteristics etc.

5. Government and industry should sponsor efforts to develop SENSOR prototypes and WSN prototypes at educational institutes. Once a working prototype of a sensor for a particular application is developed, the technology could be sponsored to industry and government labs.

-
6. The model of a multi-disciplinary center, such as CENS at UCLA, is a nice way to further research in WSN. It provides a platform for researchers from multiple disciplines to gather and apply their expertise to the different components of a WSN system.

10. Any other comments

Mote design:

Being application driven is good as it leads to more concrete research and helps distinguish the research project from other similar ones. Indian institutions may have an advantage in conducting large scale deployments due to lower cost of manpower, and larger number of graduate students. Building a mote prototype locally should be feasible using schematics shared from Berkeley motes and also having a locally developed design such as through an Electronic Design Project (EDP) at Dept of EE at IITB. Once the core mote is made easily available many researchers can use it to build custom platforms for various apps. This is an important area that allows India to leapfrog the “industrial age” and move into the information driven automated age. This is an important area where India can become a leading player globally. So major effort should go into its development.

At present sensor node exist but they are too expensive to make a WSN deployment cost-effective and attractive. Thus a WSN node (which is a PCB) needs to be converted into an all-integrated SoC to achieve low-costs.

Physical Layer

While a lot of work has been done to improve performance for WSN protocols (already achieved high reliability with high efficiency) the capabilities of PHY layer for robustness, low-power etc., need to be really worked upon.

Communication Capability

A key aspect of wireless sensor networks is that of the communication capabilities of the sensor nodes. Wireless networking adds a new dimension of capabilities to the sensor / actuator / transducer paradigms of the past. As such, new horizons are opened for both research and more ‘practical’ applications, however, the loss of wires (for power & communication) introduce a myriad of new issues:

1. Lack of available RF space in the electromagnetic spectrum. Free bands crowded and any other real-estate prohibitively expensive. Sensor nodes intended to be deployed in large number and from different vendors.
2. Power constraints cannot be ignored.
3. TX power artificially reduced because spectrum must be shared, radio uses a large amount of this limited power.
4. Low-cost parts/radios.

Appendix C

Summary of Workshop Presentations

Program

Monday, 20 th April 2007	
9:00– 9:30	Registration, Coffee and Tea
9:30– 10:00	Welcome Address: Prof. B. N. Jain, Deputy Director, IIT Delhi Inaugural Address: Prof. J. Vasi, Deputy Director, IIT Bombay Address by Mr. B. M. Baveja, Senior Director, MCIT Introductory Remarks: Prof. S. N. Merchant
10:00 -- 10:15	Overview talk Uday Desai / B. N. Jain / S. N. Merchant
Presentations I Chair: S. N. Merchant	
10:15 - 10:30	Venkat Padmanabhan (Microsoft Research India)
10:30 - 10:45	Deepak Bharadwaj (Intel)
10:45- 11:00	Sajid Mubashir (TIFAC-DST)
11:00 – 11:15	Puneet Gupta (Infosys)
11:15 – 11:45	Coffee / Tea / Snacks
Presentations II Chairman: Venkat Padmanabhan	
11:45 – 12:00	Venkat Rangan (Amrita University)
12:00 – 12:15	H. S. Jamadagini (IISc)
12:15 – 12:30	Rajakumar (IIT Kharagpur)
12:30 – 12:45	Dinesh Sharma (IIT Bombay)
12:45 – 13:00	Bharadwaj Amrutur (IISc)
13:00 – 13:15	M. K. Dhaka (DEAL Dehradun)
13:15 – 14:15	Lunch Demo by Airbee Wireless: Rapid WSN Deployment for Commercial Building Automation
14:15– 15:30	Brain Storming Session

	led by Prof. B. N. Jain Prof. U. B. Desai Prof. S. N. Merchant
15:30 – 16:00	Coffee / Tea / Snacks Demo by Airbee Wireless Continued
16:00 – 16:45	Brain Storming Session (<i>continued</i>)
16:45 – 17:00	Follow up Steps: Where do we go from here? and Closing Remarks
17:00 – 18:30	Free Time
18:30 onwards	Banquet Sponsored by Microsoft Research India (MSRI)

Talks Summary

Prof. B. N. Jain

1. How could DIT facilitate R&D in this area.
2. What will it take to realize potential in WSN.
3. Numerous Applications, a variety of sensors and a variety of network technology in WSN
4. Identify those applications that are interesting, important, and challenging and put effort, time and energy in these technologies.
5. Unclear in India: Which few applications and technologies are relevant

Applications:

- mostly in defense,
- now in environment monitoring, and
- detection and prediction of disasters
- Detection of fire in buildings,
- landslide, tsunami detection/early warning,
- exotic body area WSN medical applications,
- Humidity in soil, efficient irrigation,

Today, we must identify:

- Applications, and technology, (global context perhaps?)
- How may we all collaborate on major applications, themes?

Collaborations, a key issue since

- small research group in India,
- WSN network issues as well as sensing issues involved.

Must engage

- Industry in R&D and prototype development, and
- Government for funding.

Prof. J. Vasi:

- Willing to collaborate, Physics, Chemistry
- On-chip circuitry, Nano-electronics

Prof U. B. Desai:

Motivation and issues of WSN

- WSN R&D in US in 1994, India, a decade behind,
- Need to be adventurous, own ideas.
- Invite “ISRO” next time
- Processors are well developed
- Weakest link are sensors, accelerometers are there.
- But not sensors that sense nitrates in the soil, bio chemical substances in soil,
- Sensors are not air-tight
- Sensor technology needs a big push
- Lot of work already done in protocols etc... (slide)
- Attempt to take old algorithms and make them distributed, we must have a new look from collaborative perspective
- Distributed data mining: Tiny DB not much developed
- Java for resource hungry platform: work is in progress
- Zig bee
- Deborah’s group very active
- Shankar Shastry workshop in Taiwan
- Need for a global network
- Almost all major Universities and Research Labs. abroad have R and D in WSN

Biggest deployment: “ex-scale” Ohio University

-IIT Bombay project: Precision Agriculture for Sula vines at Nashik

-Accenture project in Pillsbury

-Landslide detection, Senslide

-WSN in mobile phones: Mobile phone is ON all the time.

-Research in academia (research labs included) however not industry (Virtual Wire, Airbee)

-Roadmap of Crossbow

-Marry RFID and WSN

-We have to ensure that India makes a contribution before 2013 (to catch up with others)

-Funding in comparison with the USA

Challenges:

- Inexpensive sensors

-scalability: large scale

Development of sensors

- Other departments like agriculture, mining, cross disciplinary interaction a must contribute

Issues

- Is USA the key driver

- We in India should have our own drivers

- Need to go out and deploy instead of using simulators like NS2

- Overcome letting ideas die down in the institute, let them be marketed

Enabler technology

- Edited book, invited papers after this workshop

Question: Do we need precision agriculture in India?

UBD: Yes, look at problems associated in making it low cost. Let us not put too many constraints. Attack it. Cost is a major issue.

BNJ: Cost not an issue in Rajasthan, some areas in Rajasthan in are green only because of drip irrigation.

Venkat P (MSR): What is the best application? There is a disconnect between test bed and actual deployment. Deployments are there but not taking up.

UBD: Cost of sensors and battery is an issue; sensors need to be solar powered

Mr. Harish (Airbee): UK Company makes a sensor under 5 dollars.

Prof. Venkat Rangan: RFIDs as WSN? Do we need a breakthrough?

Prof Dinesh: Yes. Earlier, accelometers costed 1000 dollars, now they cost 5-100 dollars. Healthcare: cost of node just right in healthcare.

ICICI looking for software that answers the question: what is health of the crop?

Venkat Padmanabhan (Microsoft Research India)

Title: "Mobility, network and WSN"

Chair: S.N. Merchant	Presenter: Venkat Padmanaban	Microsoft Research
	"Mobility, network and WSN"	

Large scale WSN

MSR has not worked in WSN, worked only for a few weeks

- action is in sensing not in networking eg: thermostat, sensors in the space shuttle
- disposal of sensors (battery poisonous)...big issue

Existing deployment can be:

- piggyback on existing platform (desktops, stick in USB like sensor? each node 5000 dollars)
- mobile phones as sensors, 7 million mobiles in India, advantage: resourceful
- platform: smart phones , mix of radios, blue tooth, cellular, WIFI

Mobile phones in WSN

- incentives, WSN participation in network
- trustworthiness, decentralized control thus some node may give false data
- privacy, location information for example,
- mobility, challenge (need to find mobiles in that location, location as a resource) and opportunity (new applications)
- manage heterogeneity
- include human in loop

Applications:

- Web cam on all mobiles, system may route a query to a mobile, contact a proper mobile to take a required picture.
- Traffic monitoring by noise mapping. By sensing noise level in a city.
- GPS enabled cell phone, tells something about traffic condition, may be my car is broken and is slow. False alarm if information from only one mobile used. Use information from all mobiles and do traffic monitoring

Related work: Nokia Sensor Planet

Complement existing standalone WSN: deployment might be significantly easy since mobile phones are already deployed.

Ques:

Prof Rajkumar, IIT Kharagpur: Security and Billing

- Cost: communication cost, energy cost in participation, combine and find a composite cost
- Privacy: track my mobile device, but system should not know the identity of the person who is moving

Mr. Bharadwaj: platform on mobiles? Windows mobile phones, cost 100\$ mobile, Smart phones?

Summary

Using existing mobile phones and make them into a WSN network, by writing a small application. And move to central query system to get the data from the remote devices.

Billing of added services

CPU usage and network time. Composite cost factored by resource availability.

Privacy issues for anonymous sensor collection. Using smart-phones to create better applications and support the user base which will bring down the price of phones in the hardware end.

Prof. Venkat Rangan

Title: “Disaster recovery management”

Project: WINSOC: self organizing capabilities for critical and emergency applications

Collaboration

11 partners working on this project from Europe and 2 in India. Uses satellite to collect as a sensor clusters from different geographically placed sensors. The project started 6-7 months back. Breaking down the task to sensor activity and distribution of data collection. Application gas leak, forest fire etc.

Sensor networks Criteria

Wireless sensor network with self-organization capabilities for critical and emergency applications

Targeted hardware Platform

-Vibration sensors and rain gauge sensors
-Cell phone size insulin pump
-Highly correlated sensors that senses blood sugar and controls insulin pumps

Research challenges

How to prototype land-slide prediction and deployment where shown as clip. Using heuristic to come up with an early warning system. Using 10-20 sensors covering of 2 kms in land slide areas. Sensors used a rain gauge to start the sensing of other vibration and sliding sensors.

- Sensor Development
- Wireless Mote design

Summary

Early in the deployment stage. Project web site www.winsoc.org

Ques: Dr Venkat (MSR): How much training one had to give to the system, parameters? Does the system learn by itself?

Goal early warning of landslide, detection is also important since it may have moved a train track which we must come to know.

8 different sensors. Columns, area coverage of 2 km,

Is rainfall the only reason for landslide?

Ans: debris flow also a reason

Chair: S.N. Merchant	Presenter: R. K Gargh	DRDO
	“Snow bound areas, climatic conditions and forecasting”	

Sensor networks Criteria

Wireless sensor network for hard to deploy areas
--

Targeted hardware Platform

Avalanche detection and early warning

Research challenges

<p>Using models, first in the form of terrain, weather. Study of hard to deploy areas such as mountain ranges, terrestrial link sending data to one center. Use models to get digital terrain to find out the different faults and defects. Range of sensor is between 2-20 km area of test bed. This data is send to a central processing station e.g. Chandighar. Help the network domain expert to transmit data.</p> <p>Advance forecasting of weather data for the region in Gulmarg, Banihal, Patseo and Dhundi. Difficulty in networking in mountain ranges and wireless reliability and repeater stations. Range is 1.2km. Finding critical route paths and tunnels for expected avalanche activity.</p> <p>Parameters: Location Flow per meter</p> <p>Radio based telemetry system(RRTS) Due to need in specialized hardware and RF requirements it is a good to explore WSN due to its advantages.</p> <p>Parameters in the new system: Avalanche occurrences Pressure, velocity, depth of flow, shear force</p>
--

Static measurements Density profile
--

Collaboration

All weather forecasting stations in India.
--

Summary

Deployed in unique Indian weather conditions:

Sensors need to work in the area in the deployed area. Hence some R&D works to get better understanding of avalanche early detection and the new network and topology requirements. Fault tolerant and how to replace the lost sensors (cost effective).
--

Mr. Dhaka, Defense Electronics application laboratory DEAL:

Chair: S.N. Merchant	Presenter: Manoj Kumar Dhaka	Defense Electronics application laboratory
	“WSN & Ad hoc networking from defense perspective”	

Sensor networks Criteria

Deployment of ad hoc network in hostile environment

- event based system, not monitoring system
- radio silence zone
- bad news gets priority
- move to higher frequency band
- focus on particular satellite
- power is not a constraint, since the sensor is on tanks

Research challenges

Deployment of ad hoc network in hostile environment. Sensors are not rugged for existing war field conditions. To collect data in real-time to extend the active battle field. Issues of mobility in ad hoc network. Power is not an issue due to terrain vehicles like tank.

WSN as the lower layer, upper layer ADHOC network (no power constrain in either case)

Route optimization does not work well with fast moving nodes

NBC monitoring: Nuclear Biological Chemical monitoring
Defense has already developed sensor

Need for performance, different packet lengths

Design goals:

Two fast moving mobile nodes should be able to communicate in an ad-hoc network
Ultra frequency mobility 10 times per second, multihop routing in this scenario
Security in ad hoc networks
To interoperate ad hoc and WSN network

Collaboration

Defense hardware suppliers.

Summary and Recommendations

Applications:

Nuclear radiation sensors, developed by DRDO
Structural defect detection system in war planes

Interface between the sensor and the CPU must be standardized, any sensor must be pluggable

Institutions should come out with proposals, not only on acquaintance based collaborations

Research must be application driven, in some shape in 5 years,
WSN and wireless Adhoc networks should work together.

Mr. Baveja, MCIT:

WSN: communication algorithms, protocols, RFID applications

Chair: S.N. Merchant	Presenter: Mr. Baveja, MCIT	DIT
	“WSN & affordable wireless communications”	

Proposals invited

Design and development of WSN, Real time remote monitoring

Study project on WSN

Outcome in physical terms

Sensor networks Criteria

Next generation communications, WSN and affordable wireless networking

Research challenges

Project:

1. Design and development of wireless sensor networks for real time monitoring
2. Wireless sensor network technology

Collaboration

All the funded DIT projects.

Summary

R&D in IT, R&D Electronics, R&D Communication and broadband and technology and extent to low cost WSN deployment.

Presentations II

Prof. Jamadagni, IISC: CEDT

Application technology for tackling environmental issues:

Chair: S.N. Merchant	Presenter: Jamadagni	IISc
	“The area of sensor network as a research area in environmental applications”	

Modern technology owes ecology an apology: Edison

We spent 200 yrs in conquering the nature now we are beating it to death.

Disaster management:

Plenty of theory, inadequate deployment experience, expensive platform

Use of standard platforms: cell phones

Inexpensive: 150 \$ per piece. Redone (indigenization) in India in Rs. 200

CEDT experience with EPFL, NGO: deploys

Project: Commonsense

Agriculture focused

65% land in India is semi arid

Small farmers: can technology help?

Rainfall 500 mm/year

High annual variation

River floods and then dries up, water flows away

Project vision:

- focus on semi arid region
- resource poor population

WSN for collection of agriculture parameters

Process collected data

Pest disease attack,

Pressed farmers for organic farming

Given that “so much” crop is sowed, and the rainfall is falling, then “how much” yield will I get? So that if the crop is poor, then I can take up another job instead of wasting time in farming.

Rain prediction

Parameters: temperature, humidity, wind velocity, rain fall, soil humidity

Multi-lingual graphical interface, handheld device

Every month change the battery

WIFI node on 11kv pole

Problems:

- Frequent power outages, unreliable power- variable voltage
- Complete dysfunction of sensor nodes
- Sensors buried so signal strength goes down

Node in forest taking pictures

- interesting , will give a lot of info

WSN research going to take a long time, so keep supporting. May take a long time to see the day of light

A man collecting data is not reliable.

Anti poaching people moving around, unreliable

How reliable is the data? Decision?

Soil moisture is generally found out from rainfall, we do direct measurement, which is more reliable.

Groundnut, grapes yield prediction works well

Radio range is large in villages since the interference is low

Self healing ?

Sensor networks Criteria

Technology for environment monitoring.

Research challenges

The area of sensor network as a research area in environmental applications. Technology for environment monitoring. Optimization is very much addressed due to low cost and resource. Use standard platforms, new inexpensive platform. Inexpensive sensors. The e.g. of deployed sensor in Projects

Agriculture

Semi-arid agriculture (various part of India)

Goal: WSN & ICT to achieve the goals

Get agriculture parameters and distribute it to farmers

- water use
- affordable

End user requirements:

Rain prediction

Plant disease

Crop yield

Important measure:

Soil moisture

System Specification:

Real-time data collection, soil moisture using a cluster based networks.

Practical problems:

Battery replacements every one month

Power outage due unreliable lines

Latest Application

WIFI with WSN clustering and aggregation to get remote picture.

Collaboration

Calibrating with Switzerland CISL for sensors. Crop modeling with Australian universities.

Summary

Effective use of timeouts and clustering techniques in WSN for data reliability.

Prof. Raj Kumar IIT Kharagpur: Activities in WSN,

Chair: S.N. Merchant	Presenter: Raj kumar	IIT- KGP
	“WSN algorithm development”	

Umesh Kumar: tracking moving objects using range and bearing information
TMAC

Tracking work: Extended Kalman Filter,
Signal processing algorithm
Underwater acoustic sensors for range measurement

New problem suggestion: find out locations of the mines and thus find out a track
which will avoid mines

Multipath problem

Sensor networks Criteria

Simulation of WSN design and lifetime

Research challenges

WIMAX – Software radio, 4 th generation of mobiles and WSN network Involved faculty from various department working on different WSN areas Tracking of moving object(Association/tracking): Student projects adapted to sensor networks using sonar in underground sensing. (sensors, target passes through the sensors and as the object moves it switches the sensors).
--

Modeling of Lifetime analysis in WSN, how to deploy on nodes Firmware development for WSN sensors Underwater acoustic sensors Power aware in network deployment
--

Created many theses on WSN and a PhD level thesis. Battery replacements every one month Power outage due unreliable lines Latest Application WIFI with WSN clustering and aggregation to get remote picture

Collaboration

ECE, CS and Mechanical depts..

Summary

Prof. Dinesh Kumar Sharma: IIT Bombay Patient monitoring

Chair: S.N. Merchant	Presenter: Dinesh Sharma	IIT-B
	“Wireless sensor networks for health care”	

Environment monitoring

Silicon locket: heart monitoring unit

Rural area : travel to city for a 1 week surgery, but 3 weeks under observation in city is not affordable.

Hospital should monitor remotely.

Worn around in the neck (silicon locket)

Reduce cost

Good processing, reliable – high tech products at low cost

If these produced in small number can never be in low cost.

Solution: platform technology (appropriate for at least one segment) which can be produced in bulk and the cost can be lowered

Low power challenge: can not be switched on always

Local processing since higher communication power

But now local processing means powerful processing, higher energy, tradeoff between the two: keep this mind for platform development

Sleep mode

Human intervention must since one can not apply 110 V to heart just because of noise, thus we need human interface

Silicon locket sends SMS to doctor in case of problem. Doctors logs into a server to check data. Then take a decision to see/not see the patient. Service provider to provide services to doctors to log into the server/web site.

Doctor can also ask for all the data from the silicon locket in case he needs details.

Developed own integrator of analog signals. TI processor for its “low power” property.

Another project:

Monitoring proteins in blood, sensor dip in blood, cantilever type, differential measurement.

Arm based base station (plugged in unit as a base station)
Several silicon lockets on a patient which talk to base station one by one.

Involving the user agencies (domain specific): In this case a hospital involved.

Use of Silicon locket for vibration monitoring of buildings!

Ques: (MSR) Dr. Padmanabhan: In case of critical patients, silicon locket is not good.

Ans: In India rural patients find it difficult to stay in bigger cities for a long time. This is not for critically ill patients.

Another application: Doctor does not go in an ambulance. But the patient can wear the jacket. And the Doctor can monitor from remote: increase oxygen, change in angle of lying down position etc

Armputer: Linux on arm

Can it be used by a pacemaker user? Patients with a pacemaker can not use radio. But card can be taken out from the silicon locket and taken to the doctor.

Removal of motion artifacts necessary

Configurable computing might not work. If you are looking for arrhythmia then you need high computation all the time.

Sensor networks Criteria

To make into a product: wearable WSN applications

Research challenges

Project: Silicon Locket and E Jacket work between IIT-B/TCS

Patient monitoring

Diagnostic

Low power, low cost and reliability

Challenges:

Heart monitoring unit, rural people cannot afford the overheads to go to a city health care provider.

Develop platform technology to address low cost porting to many target devices.

Design of heart sensor for patient diagnostic.
--

Lower deployment using local processing and sending processed data as opposed to raw data.
--

Sensors developed for heart beat detection. Miniaturizing the CMOS made the analog performance suffer.
--

Future Development

Merge analog chip with a low power micro controller/DSP using TI
Off chip processing for power optimization – ultra-miniature using ARM based running LINUX
Noise reduction: removal of Noise artifact produced by mobility.
Patient types: For post heart operative period not for critical patients.

Collaboration

TCS, India

Summary

Awarded best prototype in wearable computing magazine.

Prof. Bharadwaj Amrutur, IISc Bangalore:

Chair: S.N. Merchant	Presenter: Bharadwaj Amrutur	IISc
	“A WSN project”	

1 faculty: networking, signal processing, electronics, compilers and OS, sensors: interdisciplinary

Detection, location, classification, tracking point events

Integrated mote challenge for low cost:

- Non volatile storage
- RAM
- Sensor
- Sensor electronics
- Processor
- Radio
- Antenna
- Power regulator
- Power source

RAM, sensor electronics, processor makes it big (size)
Including radio and power regulator- to reduce power

- packaging important for form factor, rugged
- throwing motes, what after life of mote ends

Has RF profiling done?

Spread spectrum does not fit into low power

Low power wake-up radio, 20 mA for radio and 1 mA processor

Duty cycling important for longer life of sensors.

Solar driven cells, form factor larger in case of solar cells, if solar source is more efficient then smaller solar panel will result in smaller form factor

Sensor networks Criteria

Interdisciplinary algorithm development in detection and location.
--

Research challenges

A WSN research project is a 3 year project funded by DRDO-CAIR and 11 faculty from four departments.
--

Application Classification

Detection, location, classification and tracking of point events
Detection and mapping of events covering large regions
Estimation of a continuously varying random field
Assistance in Navigation and Guidance
Monitoring of inventory levels

Current work

Detection, location and tracking
- Perimeter Fencing
- Border Surveillance

High Level requirements

Select sensor modalities

Sensor deployment
Distributed signal processing algorithm for interfacing

Border surveillance

- | |
|---------------------|
| - Problem Scenario |
| - Inference |
| - Performance specs |
| - Network lifetime |

Deliverables

- | |
|--------------------------------------|
| - Design plan |
| - Algorithms |
| - Prototype with off the shelf motes |
| - Prototypes of critical |

Design of a Mote
19 milliamps for Tx power
Few milliamps for processors and algorithm processing.

Brain storming Session 1:

**Led by: Prof U B Desai
Prof B. N. Jain
Prof. S. N. Merchant**

Prof U. B. Desai: Introduction to the existing projects done in universities.

Mr. Ramamurthy

- Industry academia interaction and inter academia interaction
- Security
- Real time response
- Radiation resistance

DIT, DST

In addition to funding act as facilitator

Dr. Ram Ramjee (MSR):

Energy inefficient. Energy efficiency needs can be addressed in many ways(using human in the loop in India).

Software aspect was not well understood,

No common API, need for uniform API so that others can use it.

Mr. Soman, Amrita University Coimbatore:

-More specific applications need to be addressed in India.

Mr. Raisinghani, TCS: for agriculture, wired, improving

Prof. Huzur Saran:

- We have 10 times less money than the US. It should be understood that India 10 times slower.
- If serious research is to be done in WSN, then it is okay if one makes sensors a little bigger but get them working and they already add value at the present size.
- identify 2/3 applications, larger , costlier sensors should be fine, one could use smaller number (100/500) of sensors

Dr. Vishal Garg: IIIT Hyderabad:

- There should be hands-on workshops for students
- IT applications to building.
- Gateway for mobiles with blue tooth

Mr. Tiwari, Tata Power:

- Disconnect between domain people and academicians (eg. domain people: defense), need for institutionalization
- delivery (deployment) mechanism so that sensors can be placed
- certain research areas could be identified and evolved over time

Brigadier Kochar:

- Same products can be used in different ways and will come back about this
- Many are defense driven. All the new projects are gaining experience from some of optimization done in WSN research.

Dr. Harish, Airbee:

- willing to work with institutions
- we offer multiple levels of hands on training to students (in Chennai)

Dr. LK Bandhopadhyaya, ISM Dhanbad

- fatal accidents in mines, exposure for gases
- battery life in sensor an issue, solar powered will not work in mine
- Dhanbad a remote place, need addresses for procurement of hardware

Dr. Vishnu Pradhan, IIT Bombay:

- microprocessor was very exciting 30 yrs and now it is embedded everywhere
- look from a national point of view, identify our priorities
- management of WSN that this technology pervades
- research to prototyping, with user benefits
- support, management and operational maintenance

Bell-labs:

- Defense is going through a revolution
- Naval research board has lots of problems
- Need for research in anti jam algorithm, WSN working on a single frequency, it should not be possible to jam WSN at will
- use of UWB for communication
- security
- presently, sensor and analog circuitry kept separately, MEMS is done on silicon and also analog is on silicon, possible to integrate,
- standardization issue, draft initial standard on sensor networks
- after standardization number of customers will be larger
- software, self reliance, otherwise licensing fees would be an issue

Ms. Manisha, Amrita

- encourage students

Mr. Vijay

- Looking at WSN as a thrust area

- proposals should come up
- applications in industrial automation, healthcare

Ms. Duttagupta, ISI, Calcutta

- work at ISI: farmers are from low income group, pesticides should be applied only after prediction using WSN, trained data using neural networks

Ms. Navonita Das, ISI

- Need for a web site for research on WSN

Dr. Mukesh, NIT Suratkal

- flood management as an application
- data can be tampered, security

Brainstorming Session 2

Observations
Is cost an important factor?
Is Cost of sensor, networking, life cycle cost worth the data collected?

Observations
Potential barriers to WSN growth?

Prof. B. N. Jain:

- water most important resource, monitoring quality of water of Ganges
- no of sensors 20,000, cost: RS 20 Crore
- 200 million people lives at stake
- Lives more important, proves the worth of sensor networks
- Need to look at wired sensor network, wireless is not required always, self configuration issue is still there, eg. Agriculture, irrigation, wiring of sensors is feasible, things very simple for wired configuration, energy also not a constraint
- Working together, R&D driven by one or more applications, do everything to make this possible
- New sets of applications of WSN with cell phone as sensors
- Do-able, challenging, important applications must be located
- Seek funding from DIT targeted at collaborations (DARPA identifies problems to be solved and then others bid)

Prof. U. B. Desai:

- are there any barriers to growth, change out mindset (Dr.Pradhan)
- lack of applications (Dr. Venkat Padmanabhan)
- Dr. Venkat P.: PhDs prefer to work in lab since they feel they will earn PhDs. They will not get a PhD like this with implementation and deployment. PhD students are not willing to do hardware kit deployments due to legacy academic practice.

-
- Dr. Jamadagni: farmers do not feel this application as compelling, however like earlier cellular phones revolution
 - Academicians can not give a business models, so Govt. has to keep supporting
 - We need to have a business model, put it together
 - Business kind of planning: why, when, how, how much
 - invite VCs next time
 - academia and industry are not coming together (CSIR funds any project that can be established to make India number 1)
 - Dr. Dinesh: sometimes cost is important sometimes it is not, each parameter has to be optimized. Industry and academia can get together. Just choose a good problem. Then you will make better progress. Why are there not killer applications? Establish success stories. Take specifications, define problems and then bring in people who can solve them.

IIT Kharagpur,

- sensor node need not be low power, wireless
- potential business models should be drawn with flexible models of node
- cost is not an issue

Dr. Dinesh:

- we went to TCS with the idea.
- Academicians need not make business model, they do not want to be second rate businessmen
- We are coming together since industry does business best and academicians to their work best.

Dr. Pradhan:

- use expertise from business schools of IITs / IIMs
- let them make business plan for you
- issues involved
- let them do a market survey, target customers

Prof. Jamadagni:

- create a project that students want to join
- Academicians should have good problems first. Pool of problems.

Prof. B.N.Jain: locating problems that are

- interesting (Academician's responsibility), challenging (Academician's responsibility), important (feedback from user), funded (VC)

Prof. Amrutur

-
- keep working (with DST, DIT funding) worrying about business plans, killer applications etc. since there are many many interesting things, we will make a generation of students who are good at interdisciplinary problems

Prof. Venkat Rangan:

- WSN interdisciplinary, potential barrier
- Need for consortium
- grand challenge like DARPA grand challenge

Prof. U.B.Desai:

- exciting since it is interdisciplinary, very important to have domain experts
- other disciplines are looking at us for collaborations

Dr. Pradhan:

- Academician do academics, industry does business
- DARPA model: identify the person who puts together this interdisciplinary team, DARPA finds out problems
- NSF model: output is publications, patent, researcher find out problem

Prof. U.B.Desai:

- DIT and DST has requested to find out a problem

Prof. Dinesh:

- Application must have 1. impact: either a. societal or b. industrial (list these applications)
- Development of base line capabilities e.g. students are trained, find out what should they be trained on? (list out)

Prof. Jamadagni:

- partnership has to be natural
- institutionalization has problems of its own

Prof. U.B.Desai:

- Mr. Baveja promised that whatever problem is defined they will fund.

Intel recommendation: task force

Prof. U.B.Desai:

- Manpower is an issue

Scheduled chat session:

- chat session : monsoon: 2nd week of June, around 15th June
- Next workshop after 3 to 4 months
- biographies needed

URL: <http://www.ee.iitb.ac.in/~spann/wsnworkshop/index.html>

Appendix D

List of important URLs related to WSN Research, Development and Deployment (RDD)

National (Indian) WSN Projects

Project Title	Location	URL	Description	Contact
AgirSens: WSN for precision Agriculture	IIT Bombay	http://www.ee.iitb.ac.in/ /spann	<ul style="list-style-type: none">• Deployed in Sula Wines and running for almost a year.	U. B. Desai (ubdesai@iith.ac.in) S. N. Merchant (merchant@ee.iitb.ac.in)
WCSN: Wireless Cellular Sensor Networks	IIT Bombay, IIT - Hyderabad, India	http://www.ee.iitb.ac.in/ /spann	<ul style="list-style-type: none">• Developed protocols for Multihop WCSN for pollution monitoring and data aggregation. Soon plan on filed deployment.	U. B. Desai (ubdesai@iith.ac.in) S. N. Merchant (merchant@ee.iitb.ac.in)
Pervasive sensor networks	IIT Bombay, IIT - Hyderabad, India	http://www.iu- atc.com/indiaPartners.h tml	<ul style="list-style-type: none">• Developing protocols for Context aware applications for Multihop WCSN.	U. B. Desai (ubdesai@iith.ac.in) S. N. Merchant (merchant@ee.iitb.ac.in)

SenSlide: WSN for landslide Detection	IIT Bombay, IIT - Hyderabad, India	http://www.ee.iitb.ac.in/ Spann/	<ul style="list-style-type: none"> • Protocols, Phy. layer work and real time field deployment. • SenSlide deployed in a Lab environment. 	U. B. Desai (ubdesai@iith.ac.in) S. N. Merchant (merchant@ee.iitb.ac.in)
Dreamajax Technologies	Bangalore, India	http://www.wsnindia.com/	<ul style="list-style-type: none"> • Provides lab setup of approximately 2Km with external interface for all Research and development 	Dreamajax Technologies Private Limited,Orchid Techscape, STPI Campus, 6th Floor, Cyber Park, Electronics City, Bangalore, India - 560100. Phone:+91 80 66186194
WINSOC (Wireless Sensor Networks with Self- Organisation Capabilities for Critical and Emergency Applications)	India	http://www.amrita.edu/Winsoc/	<ul style="list-style-type: none"> • Wireless Sensor Network is built by the consortium, which put together expertise from big companies, academies, research centers, end-users and SME's, to create a strong synergism between academic world, industries and end-users. • The goal is, to develop a general purpose innovative wireless sensor network having the distributed processing capabilities and, on the other side, to test applications on environmental risk management where heterogeneous networks, composed of nodes having various degree of complexity and capabilities, are made to work under realistic scenarios. 	AMRITA VISHWA VIDYAPEETHAM AMRITAPURI CAMPUS, Amritapuri, Clappana P.O., Kollam - 690 525. Ph: 0476-2896318, 2896328, 2898318. Fax:2896178.

<p>BriMon: A Sensor Network System for Railway Bridge Monitoring</p>	<p>India</p>	<p>http://www.cse.iitb.ac.in/silmaril/br/doku.php?id=proj:brimon</p>	<ul style="list-style-type: none"> • It is critical to have a system to monitor the health of the bridges and report when and where maintenance operations are needed. BriMon is a wireless sensor network based system for such monitoring. 	<p>Bhaskaran Raman <u>Associate Professor</u> Room 406, Kanwal Rekhi (KReSIT) Building <u>Department of Computer Science and Engineering</u> <u>Indian Institute of Technology, Bombay</u> Powai, Mumbai, INDIA 400076 Tel: +91-22-2576-7908, Fax: +91-22-2572-0022 Email: username is br, domain is cse dot iitb dot ac dot in <u>Keep Dow Chemical off IITs, off India, off the world</u></p>
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Sensor Network to monitor WildLife	DAIICT India	http://intranet.daiict.ac.in/~ranjan/research/research.htm	<ul style="list-style-type: none"> • CENSE - A modular Sensor Network Testbed and A Mobility Platform for CENSE • WildCENSE - Sensor Network to monitor WildLife 	<p>Prof. Prabhat Ranjan Professor, DA-IICT Dhirubhai Ambani Institute of Information and Communication Technology Gandhinagar, Gujarat, 382007 Tel. +91 079 30510553 prabhat_ranjan [at] daiict [dot] ac [dot] in</p>
Mobility, Networks, and Systems	Microsoft Research, India	http://research.microsoft.com/en-us/groups/mns/default.aspx	<ul style="list-style-type: none"> • Current Projects • Ongoing research spans the following areas: • DirCast: Improving wireless multicast performance • CocoNet: Wide-area network acceleration • NetPrints: Home network configuration management and diagnosis • Distributed sensing using mobile phones 	<p>Venkat Padmanabhan Microsoft Research India "Scientia" 196/36 2nd Main, Sadashivnagar Bangalore 560 080 India Tel: +91 (80) 6658-6004 Fax: +91 (80) 2361-4657 E-mail: padmanab@microsoft.com</p>

Ad Hoc Networks Research & Applications Group	Indian Institute of Management Calcutta, India	http://www.iimcal.ac.in/research/adhocnet/index.htm	<ul style="list-style-type: none"> • Ad Hoc Network Research & Applications Group provides an environment for research and app. development necessary to support next generation wireless and mobile communication systems. • Our mission is to develop and evaluate advanced and efficient communication strategies for ad hoc wireless networks through implementation and to investigate their applications towards the realization of future ubiquitous society • <u>Agro Sense</u> • <u>Pollution Monitoring</u> • <u>Secured Decentralized Disaster Management Information Network</u> 	Indian Institute of Management Calcutta, India
Embedded Systems Lab	TCS Innovation Labs Bangalore	http://tcsinnovations.com/index.php?option=com_content&task=view&id=85&Itemid=116	<ul style="list-style-type: none"> • The major research areas include error control coding, ubiquitous sensor networks, biomedical & multimedia signal processing, applied electromagnetic, emerging technologies & algorithms for next generation radio communication technologies • Wireless Sensor networks for large scale monitoring 	innovation.info@tcs.com

<p>High Performance Computing and Networking Lab</p>	<p>Indian Institute of technology Madras, Chennai, India</p>	<p>http://hpcn.cse.iitm.ac.in/research.html</p>	<ul style="list-style-type: none"> • Research Interests • Ad hoc Wireless Networks • Wireless Sensor Networks • Optical Networks • Quality of Service in Next Generation Networks 	<p>High Performance Computing & Networking Lab Room No: BSB 358, Dept. of Computer Science & Engineering IIT Madras, Chennai-600 036 Phone: 22575369 Prof. C. Siva Ram Murthy BSB, Room No.357, Dept. of Computer Science & Engineering Indian Institute of Technology Madras, Chennai Phone: 22574361 (office) Fax: 22574361</p>
<p><u>AITIS</u>: Association for Intelligent Transport System</p>	<p>India</p>	<p>http://www.itsindia.org/iv/index.htm</p>	<ul style="list-style-type: none"> • Improving Road Safety 	<p>Email: secretariat@itsindia.org Tel: +91-755-2660635</p>

<p>Geosense: Geo-ICT and Sensor Network for Agri-System</p>	<p>India-Japan (IIT-Bombay of India and NARO-NARC of Japan)</p>	<p>http://www.csre.iitb.ac.in/geosense/geosense-dec2009-workshop</p>	<ul style="list-style-type: none"> • Geo-ICT (location based services, spatial decision making and geo-computations) interlinked with Sensor Networks (SN) and Grid Computing (GC) technologies promises to be an interesting combination for generating host of useful information for various applications such as agriculture, disaster management /mitigation, transportation, security, early warning systems, real time weather and environmental information systems, etc. • Realizing the importance of this integrated system, an initiative was taken up under the Indo-Japan Bilateral Programmed under the DST-JST Strategic Cooperation Programme on Multidisciplinary ICT to develop a real-time Decision Support System (DSS), which will christened as “GeoSense”, to assist the rural stakeholders for improving the rural livelihood, environmental sustenance/security and agriculture productivity which are attracting importance recently due to global climate change. 	<p>Prof. U. B. Desai, Prof S. N. Merchant, EE Dept., IIT Bombay, Powai Mumbai., Ph +91-22-25764478, +91-22-25767455 email: ubdesai@iith.ac.in, merchant@ee.iitb.ac.in</p> <p>Prof. J Adinarayana, Associate Professor, CSRE, Indian Institute of Technology (IIT) Bombay Powai, Mumbai - 400 076. Phone: +91 22 25767689 e-mail: adi@iitb.ac.in</p> <p>Dr. Vasala Madhava Rao, Head (C-GARD) & Prof. & Head (CIT) I/C, National Institute of Rural Development (NIRD), Rajendra Nagar, Hyderabad - 500 030, Phone: +91 40 24008447, e-mail: madhava@nird.gov.in</p>
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International WSN Projects

Project Title	Location	URL	Description	Contact
STaR Project	New South Wales, Australia	http://nicta.com.au/business/business_areas/intelligent_transport_systems	<ul style="list-style-type: none"> Traffic Control and Surveillance 	<p>Geoff Goeldner, Project Manager, Smart Transport and Roads Project, on +612 9376 2107 Geoff.Goeldner@nicta.com.au</p> <p>mail: Locked Bag 9013, Alexandria NSW 1435, Australia Location: Australian Technology Park, 13 Garden Street Eveleigh, NSW 2105 Australia</p>
Wireless Self-sustaining Sensor Network (WSSN)	Vienna University of Technology, Austria	http://www.ict.tuwien.ac.at/wireless/	<ul style="list-style-type: none"> The use of high bit rate low power radio transceivers (≥ 1Mbps) for low data rate and low duty cycle applications The development of an energy efficient MAC Protocol (CSMA-MPS), optimized for high bit rate radio transceivers The design of low cost energy efficient hardware including node design, energy scavenging techniques and storage 	<p>Head of Institute Prof. Dipl.-Ing. Dr.techn. Dietmar Dietrich Location, A-1040 Vienna, Gusshausstrasse 27-29, Building Neues EI, 2th floor Phone +43 1 58801-38401</p>

			<ul style="list-style-type: none"> • Implementation of an energy aware routing protocol • Vertical system integration throughout all protocol layers including hardware 	<p>Fax +43 1 58801-38499 E-Mail sek384@ict.tuwien.ac.at Web http://www.ict.tuwien.ac.at/</p>
TCS-Sensor lab (Theoretical Computer Science and Sensor Nets)	Switzerland	http://tcs.unige.ch/doku.php/web/wirelessnetworks	<ul style="list-style-type: none"> • The TCS-Sensor group is (mainly) interested in • <u>Theoretical Computer Science (TCS)</u> • <u>Wireless Sensor Networks</u> • <u>Algorithm oriented sensor network simulator (AlgoSenSim)</u> 	<p>Centre Universitaire d'Informatique Battelle bâtiment A route de Drize 7 1227 Carouge Geneva, Switzerland</p>
Coopers	Austria	http://www.coopers-ip.eu/	<ul style="list-style-type: none"> • Cooperative Systems for Intelligent Road Safety 	<p>Company: AustriaTech - Gesellschaft des Bundes für technologiepolitische Maßnahmen GmbH Contact Person: Mr. Reinhard Pfliegl Address: Donau-City-Straße 1, 1220 Wien Phone: +43 1 26 33 444 20 Fax : +43 1 26 33 444 10 mail:reinhard.pfliegl@austria tech.org</p>

CVIS	Brussels, Belgium	http://www.cvisproject.org/	<ul style="list-style-type: none"> • Cooperative Vehicle Infrastructure and Service integration 	IP Coordinator Paul Kompfner cvis@mail.ertico.com
i2010	Brussels, Belgium	http://ec.europa.eu/information_society/activities/intelligentcar/index_en.htm	<ul style="list-style-type: none"> • Intelligent Car Initiative 	European Commission Directorate-General Information Society and Media, ICT for Transport BU31 4/66, Avenue de Beaulieu, 31 B-1160 Brussels Email: infso-intelligent-car@ec.europa.eu
Forest fire fighting	Canada	http://nsl.cs.surrey.sfu.ca/wiki/index.php/K-Coverage_and_its_Application_to_Forest_Fire_Detection	<ul style="list-style-type: none"> • Forest Fire Modeling and Early Detection using WSNs. 	Mohamed Hefeeda, Assistant Professor Area: Computer Networks, Multimedia Communications Email: mhefeeda @ cs.sfu.ca Home Page: http://www.cs.sfu.ca/~mhefeeda/ Office: SFU Surrey 4144 Phone: +1-778-782-7577

				Fax: +1-778-782-8116
SEVECOM	France	http://www.sevecom.org/	<ul style="list-style-type: none"> • SEcure VEhicle Communication 	General: info@sevecom.org Antonio Kung Tel: +33 144 70 61 03 Antonio.kung@trialog.com
AIRNET	France	http://www.airnet-project.com/	<ul style="list-style-type: none"> • Airport Network and Mobile Surveillance 	Mr Franck PRESUTTO (project coordinator) presutto@m3systems.net
Cyber Cars	France	http://www.cybercars.org/	<ul style="list-style-type: none"> • Cooperative Vehicles 	Project Leader Michel INRIA - Rocquencourt Research Unit, France michel.parent@inria.fr
CAR-2-CAR	Germany	http://www.car-2-car.org/	<ul style="list-style-type: none"> • Creating and establishing an open European industry standard for CAR 2 CAR communication systems based on wireless LAN components and to guarantee European-wide inter-vehicle operability • To enable the development of active safety applications by specifying, prototyping and demonstrating the CAR 2 CAR system to promote the allocation of a royalty free 	Dr.-Ing. Karl-Oskar Proskawetz c/o GZVB Competence Center GmbH Hermann-Blenk-Straße 17 D-38108 Braunschweig Germany Phone: +49 531 / 354 06-72 E-mail: contact@car-2-car.org

			<p>European wide exclusive frequency band for CAR 2 CAR applications</p> <ul style="list-style-type: none"> To push the harmonization of CAR 2 CAR Communication standards worldwide to develop realistic deployment strategies and business models to speed-up the market penetration 	
wearIT@ work	Germany	http://www.comnets.uni-bremen.de/typo3site/index.php?id=11	<ul style="list-style-type: none"> WSNs in Wearable and Logistic Application 	Andreas Timm-Giel, Koojana Kuladinithi, Markus Becker, Carmelita Görg
COM eSafety	Germany	http://www.comesafety.org/	<ul style="list-style-type: none"> Road Safety 	<p>Rudolf Mietzner – Secretary General c/o Softlab GmbH Zamdorferstrasse 120 D-81677 Munich</p> <p>Phone: +49 89 9926 – 1216 Fax: +49 89 9936 – 1658 E-mail: mietzner(at)comesafety.org</p>
NOW	Germany	http://www.network-on-wheels.de	<ul style="list-style-type: none"> Communication Protocols and Security 	Gerhard Noecker Daimler AG Gerhard.noecker@daimler.co

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Watch-Over	Italy	http://www.watchover-eu.org/	<ul style="list-style-type: none"> • Real time detection and relative localisation of vulnerable road users 	Luisa Andreone Centro Ricerche Fiat - Technologies Division Strada Torino 50, 10043 Orbassano, Torino, Italy Tel. +39 011 9083071
SAFESPOT	Italy	http://www.safespot-eu.org/	<ul style="list-style-type: none"> • Road Safety and related applications 	Project Coordinator Roberto Brignolo Centro Ricerche Fiat strada Torino 50, 10043 Orbassano Torino, Italy tel. +39 011 90 80534 email: safespot@crf.it
Risk monitoring of buildings	Japan	http://de.scientificcommons.org/43502765	<ul style="list-style-type: none"> • Ubiquitous structural monitoring (USM) of buildings with WSNs 	Narito Kurata Kobori Research Complex Kajima Corporation, Tokyo 107-8502 Japan Tel: +81-3-6229-6558, Fax: +81-3-5561-2431 E-mail: kuratangkajima.com Graduate School of Frontier Sciences The University of Tokyo, Chiba 277-8561 Japan

				Tel: +81-47-136-3897, E-mail: {saru, mori}@mlab.t.u-tokyo.ac.jp
TRACKSS	Spain	http://www.trackss.net/	<ul style="list-style-type: none"> Developing new systems for cooperative sensing and predicting flow, infrastructure and environmental conditions surrounding traffic, with a view to improve road transport operations safety and efficiency 	Antonio Marqués Tres Forques, 147 46014 Valencia SPAIN +34 96 313 40 82 technology-projects.etra-id@grupoetra.com
REPOSIT	Spain	http://www.ist-reposit.org/	<ul style="list-style-type: none"> Relative POSitioning for collision avoidance systems 	GMV SISTEMAS, S.A. P.T.B. Parcela 101, Boecillo E-47151 VALLADOLID Tel. +34 983 54 65 54 Fax. +34 983 54 65 53 e-mail: jherrero(at)gmv.es
AIDE	Sweden	http://www.aide-eu.org/	<ul style="list-style-type: none"> Joint effort of several research institutes, universities and manufacturers 	AIDE Coordinator Gustav Markkula (VTEC) Volvo Technology Corporation Intelligent Vehicle Technologies Dept 06320, M1.6 SE-405 08 Gothenburg, Sweden gustav.markkula@volvo.com

The Sensor Network Museum	Switzerland	http://www.btnode.ethz.ch/Projects/SensorNetworkMuseum	<ul style="list-style-type: none"> • BTnodes - A Distributed Environment for Prototyping Ad Hoc Networks 	Head of Laboratory: Prof. Dr. Lothar Thiele Tel.: +41 44 63 27031 Secretariat: Monica Fricker Tel.: +41 44 63 27035 Caterina Sposato Tel.: +41 44 63 27031
Glacsweb	University of Southampton UK	http://envisense.org/glacsweb/	<ul style="list-style-type: none"> • Monitor glacier behaviour using WSNs 	Dr Kirk Martinez phone: +44 (0)2380 594491 fax: +44 (0)2380 592865 email: km@ecs.soton.ac.uk Dept. of Electronics and Computer Science, University of Southampton, Hampshire, SO17 1BJ, UK.

<p>Video Transmission in Wireless Mesh Networks</p>	<p>Ireland, UK</p>	<p>http://www.cs.ucc.ie/misl/research/wmn.php</p>	<ul style="list-style-type: none"> • A Wireless Mesh Network (WMN) consists of nodes that have multiple network interfaces used to form a multi-hop mesh topology. The aim of this project is to develop new algorithms for the efficient delivery of video in WMNs that can operate at multiple transmission rates and using multiple radio frequency channels. 	<p>Wanqing Tu Room 311, Kane building, Computer Science Department, University College Cork,Cork,Ireland Phone: (+353)21-490-3976 Email: wt1 AT cs.ucc.ie</p>
<p>Car-Park Management Using Wireless Sensor Networks</p>	<p>Ireland, UK</p>	<p>http://www.cs.ucc.ie/misl/research/carparking.php</p>	<ul style="list-style-type: none"> • Application for the control and monitoring of car parking space usage 	<p>Professor ,Cormac J. Sreenan Room 318, Kane building, Computer Science Department, University College Cork,Cork,Ireland Phone: (+353)21-490-3629 Email: cjs AT cs.ucc.ie</p>

Data Aggregation in Sensor Networks	Ireland, UK	http://www.cs.ucc.ie/misl/research/data-agg.php	<ul style="list-style-type: none"> • Reliable aggregation. • Successful delivery of aggregate data. 	Jonathan Benson Room 309, Kane building, CS Dept, Uni. College Cork, Cork, Ireland Phone: (+353)21-490-3975 Email: j.benson AT cs.ucc.ie
Visual Art with Wireless Sensor Networks	Ireland, UK	http://www.cs.ucc.ie/misl/research/art.php	<ul style="list-style-type: none"> • Using the MISL sensor network and expertise from the MISL researchers, the space watches, monitors and records the visitor and stores their information, and then remixes previously captured data and subtly infuses it with the viewer's own experiences in the space. 	Cormac Duffy Room 309, Kane building, Computer Science Department, University College Cork, Cork, Ireland Phone: (+353)21-490-3975 Email: cd5 AT cs.ucc.ie
EmNetS - Embedded Networked Sensing	Ireland, UK	http://www.cs.ucc.ie/emnets/	<ul style="list-style-type: none"> • Networking and protocol development requirements for building power efficient and scalable wireless sensor networks for application in the utilities and resource management space. • Develop technology for effective transfer to and exploitation by Irish industry. 	Dirk Pesch, PhD Position: Principle Investigator and Supervisor Office: B169 Email: dpsch@cit.ie Phone: +353 21 4326377

			<ul style="list-style-type: none"> The project will in particular develop a simple, power efficient, self-configuring network protocol stack, a simple and flexible middleware layer, and a remote network management system for wireless sensor networks. The project will also develop a testbed infrastructure, both virtual and physical, for developing and demonstrating sensor network applications for utilities and resource management applications. 	<p>Fax: +353-21-4326625</p>
PATH Project	USA	http://www-path.eecs.berkeley.edu/	<ul style="list-style-type: none"> PATH's mission: applying advanced technology to increase highway capacity and safety, and to reduce traffic congestion, air pollution, and energy consumption. 	<p>California PATH 1357 S.46th Street, Bldg. 452 Richmond, CA 94804-4648 Tel: 510-665-3552 Email: skabardonis@ce.berkeley.edu</p>
Sensor Networks & Wireless Workgroup	USA	http://www.cems.uvm.edu/research/cems/snow/default.php	<ul style="list-style-type: none"> Snow Water Equivalent Monitoring with Wireless Sensor Networks 	<p>Jeff Frolik Electrical and Computer Engineering Department, University of Vermont,33 Colchester Ave, Burlington, VT 05405, U.S.A. Tel: 802.656.0732 FAX: 802.656.3358 E-mail: jfrolik@uvm.edu.</p>

Environmental Monitoring	USA	http://cres.usc.edu/pubdb_html/files_upload/375.pdf http://cres.usc.edu/Home http://blog.xbow.com	<ul style="list-style-type: none"> • Bacterium-inspired Robots for Environmental Monitoring 	<p>Center for Robotics and Embedded Systems (CRES), University of Southern California cres@robotics.usc.edu dhariwal,gaurav,requichag@usc.edu</p>
The ZebraNet Wildlife Tracker	USA	http://www.princeton.edu/~mrm/zebranet.html	<ul style="list-style-type: none"> • ZebraNet is studying power-aware, position-aware computing/communication systems. • The goals are to develop, evaluate, implement, and test systems that integrate computing, wireless communication, and non-volatile storage along with global positioning systems (GPS) and other sensors. • On the biology side, the goal is to use systems to perform novel studies of animal migrations and inter-species interactions. 	<p>Margaret Martonosi Professor Dept. of Electrical Eng. Engineering Quad B216 34 Olden Street Princeton University Princeton, NJ 08544-5263</p> <p>Office: (609) 258-1912 Fax: (609) 258-3745</p>

SEAMONSTER	NASA, USA	http://www.robfatland.net/seamonster/index.php?title=Main_Page	<ul style="list-style-type: none"> • Smart sensor web project designed to support collaborative environmental science with near-real-time recovery of environmental data. • Initial geographic focus is the Lemon Creek watershed near Juneau Alaska with expansions planned onto the Juneau Icefield and into the coastal marine environment of the Alexander Archipelago and the Tongass National Forest. 	NASA, USA
Sensors	USA	http://sensors.cs.umass.edu/index.shtml	<ul style="list-style-type: none"> • Building scalable, energy-efficient sensor networks through the use of heterogeneous sensor modalities, sensor platforms and processors. 	<p>Deepak Ganesan</p> <p>Assistant Professor Department of Computer Science University of Massachusetts, Amherst dganesan@cs.umass.edu</p> <p>Office: CS Building, Room 250 Phone: (413) 545 2450 Fax: (413) 545 1249</p>
ExScal: Extreme Scale Wireless Sensor Networking	USA	http://cast.cse.ohio-state.edu/exscal/	<ul style="list-style-type: none"> • The aim is to investigate the challenges in scaling to a network of 10,000 sensor nodes. • Environmental monitoring, traffic surveillance, battlefield awareness, habitat monitoring, supply chain integration, and weather tracking. 	<p>Anish Arora Professor Computer Science and Engineering 395 Drees Hall The Ohio State University Columbus, OH 43210-1277 USA +1 (614) 292 1836</p>

				fax +1 (614) 292 2911 anish (at) cse (dot) ohio (dash) state (dot) edu
EnArchi	USA	http://adsabs.harvard.edu/abs/2006AGUFMIN22A..08W	<ul style="list-style-type: none"> • A Robust and Manageable Approach for Dynamic Large-scale Sensor Networks 	Wang, X (Sean.Wang@uvm.edu) , The University of Vermont, 33 Colchester Ave., Burlington, VT 05405, United States
Bioscope	USA	http://cres.usc.edu/Research/files/rahimi_thesis_2006.pdf	<ul style="list-style-type: none"> • Actuated Sensor Network for Biological Science 	Mohammad Rahimi http://cres.usc.edu/Research/publications.php
Biomedical	Atlanta, USA	http://www.gatech.edu/news-room/release.php?id=1677	<ul style="list-style-type: none"> • Continuous monitoring air around persons prone to asthma 	Georgia Institute of Technology 75 Fifth Street, N.W., Suite100,Atlanta, Georgia 30308 USA Abby Vogel (404-385- 3364)E-mail: avogel@gatech.edu
Fire tracking	Washington St. Louis, USA	Washington University	<ul style="list-style-type: none"> • Tracking Fires using Mobile Agents in a Wireless Sensor Network 	Chien-Liang Fok Doctoral Student

		in St. Louis		Office Phone: 1 (314) 935-7535 Lab Phone: 1 (314) 935-7526 Fax: 1 (314) 935-7302 liangfok@wustl.edu Computer Science and Engineering Washington University in St. Louis One Brookings Dr., Campus Box 1045 St. Louis, MO 63130-4899
Vision-based Localization	Stanford, USA	http://wsnl.stanford.edu/localization.php	<ul style="list-style-type: none"> • Sensor network localization using visual observations made by image sensors from a beacon agent are used to estimate network node coordinates. 	Andrea Goldsmith Professor of Electrical Engineering Stanford University Packard 371 Department of Electrical Engineering Mail Code 9515 Stanford, CA 94305-9515 Phone: (650) 725-6932 Fax: (650) 723-9251 Email: andrea at ee.stanford.edu
NIST	USA	http://w3.antd.nist.gov/wctg/smartsensors/sensornetworks.html	<ul style="list-style-type: none"> • Distributed detection and estimation • Multi-sensor data fusion 	Information Technology Laboratory NIST, 100 Bureau Drive, Stop 8900,

				Gaithersburg, MD 20899-8900.
University of Wisconsin-Madison	Madison, WI 53706-1691, USA	http://www.ece.wisc.edu/~sensit/	<ul style="list-style-type: none"> • Location-Centric Distributed Computation and Signal Processing in Microsensor Networks 	sensit@ece.wisc.edu
Networks and Mobile Systems	USA	http://nms.csail.mit.edu/#projects	<ul style="list-style-type: none"> • Networking and mobile computing, with an emphasis on designing, implementing, and evaluating network systems, protocols, and applications. 	MIT Computer Science and Artificial Intelligence Laboratory The Stata Center, Building 32 32 Vassar Street Cambridge, MA 02139 USA Tel: 617-253-5851 Fax: 617-258-8682 Email:
Code Blue: Wireless Sensor Networks for Medical Care	Harvard University , United States of America	http://www.eecs.harvard.edu/~mdw/proj/codeblue/	<ul style="list-style-type: none"> • Integration of medical sensors with low-power wireless networks • Wireless ad-hoc routing protocols for critical care; security, robustness, prioritization • Hardware architectures for ultra-low-power sensing, computation, and communication • Interoperation with hospital information systems; privacy and reliability issues • 3D location tracking using radio signal information • Adaptive resource management, congestion control, and bandwidth allocation in wireless networks 	Matt Welsh Associate Professor of Computer Science School of Engineering and Applied Sciences Harvard University Office: 233 Maxwell Dworkin 33 Oxford St. Cambridge, MA 02138 USA Phone: (617) 495-3311

				FAX: (617) 495-2809
DARPA Sensit Project	USA	http://www.eng.auburn.edu/users/lim/sensit.html	<ul style="list-style-type: none"> • Support tactical and surveillance applications using reconfigurable sensor network nodes that are capable of forming impromptu network, being deployed incrementally, and assembling themselves without central administration. • Provide capabilities for sensor networks to adapt dynamically to device failure and degradation and changes in task and network requirements. • Integrate various application-specific network and system services provided by mixed types of sensor nodes and embedded defense applications 	Alvin Lim, Computer Science and Engineering, Auburn University, Auburn, AI 36849, Phone (334) 844-6326 lim@eng.auburn.edu
Sensor Networks & Wireless Workgroup	USA	http://www.emba.uvm.edu/~jfrolik/uvmwan.htm	<ul style="list-style-type: none"> • Projects dealing with architectures and algorithms to characterize and improve the performance of these systems. 	Jeff Frolik, Assistant Professor Electrical and Computer Engineering, University of Vermont Vermont, USA http://www.cems.uvm.edu/~jfrolik/
CITRIS	Berkeley, CA, USA	http://www.tinyos.net/related.html	<ul style="list-style-type: none"> • Sensing Structural Integrity :Sensors report the location and kinematics of damage during and after an earthquake. • Telegraph :A database customized for streaming data such as that found in sensor networks • TinyDB :A query processing system for extracting information from a network of 	Lorie Mariano Event Coordinator (510) 643-2217 (510) 642-1800- fax lorie@eecs.berkeley.edu

			<p>TinyOS sensors.</p> <ul style="list-style-type: none"> • TinyGALS :A programming model for event-driven embedded systems, an EECS project • XYZ On A Chip: Integrated Wireless Sensor Networks for the Control of the Indoor Environment in Buildings 	
Great Duck Island	Berkeley, CA, USA	http://ucberkeley.citris-uc.org/research/projects/great_duck_island	<ul style="list-style-type: none"> • Enable researchers anywhere in the world to engage in non-intrusive monitoring of sensitive wildlife and habitats. • Sensor motes are monitoring the nesting habitat of the Leach's Storm Petrel on the island and relaying their readings into a satellite link that allows researchers to download real-time environmental data over the Internet. 	<p>Email: culler@cs.berkeley.edu Home Page: http://www.cs.berkeley.edu/~culler Department: Electrical, Computer Science (CS)</p>

FireBug	Berkeley, CA, USA	http://firebug.sourceforge.net/	<ul style="list-style-type: none"> • Collecting real time data from wildfires is important for life safety considerations, and allows predictive analysis of evolving fire behavior. • The FireBug system combines state-of-the-art sensor hardware running TinyOS with standard, off-the-shelf World Wide Web and database technology for allowing users to rapidly deploy FireBugs and monitor network behavior. 	<p>Professor NICHOLAS SITAR Phone: (510) 643-8623 Campus Office: 449 Davis Hall Email: nsitar@ce.berkeley.edu</p>
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<p>Engineering Sensor Network Structure for Information Fusion</p>	<p>USA</p>	<p>http://www.ist.arl.psu.edu/eSensIF/</p>	<ul style="list-style-type: none"> • How does network centric organization of sensors affect time critical fusion of dynamic spatial-temporal events in urban environments? • This question has become more pertinent today because of the proliferation of multi-source sensor data due to DoD's paradigm shift to network centric warfare, the urban area monitoring demands of the Global War on Terror, and the collaboration needs of Future Combat System platforms. 	<p>Principal Investigator and Research Thurst Leader</p> <p>Dr. Shashi Phoha sxp26@psu.edu</p>
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SAPHE	UK	http://ubimon.doc.ic.ac.uk/saphe/m338.html	<ul style="list-style-type: none"> • Miniaturized sensing with self-management and configuration for Pervasive Health care • Local data abstraction and sensor fusion inferencing with low power sensor and wireless data path • Processing-on-node technology for context aware sensing • Automated trust-based decision support and "affective computing" for improved human-computer interfacing • Intelligent trend analysis and large scale data mining 	<p>Professor Guang-Zhong Yang: Director of Research Institute of Biomedical Engineering Imperial College, South Kensington London SW7 2AZ</p>
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COUGAR: The Network Is The Database	Cornell University, USA	http://www.cs.cornell.edu/database/cougar/index.php	<ul style="list-style-type: none"> • The widespread distribution and availability of small-scale sensors, actuators, and embedded processors is transforming the physical world into a computing platform. • Sensor networks that combine physical sensing capabilities such as temperature, light, or seismic sensors with networking and computation capabilities will soon become ubiquitous. 	<p>Johannes Gehrke Associate Professor, Department of Computer Sciences 4105B Upson Hall Cornell University Ithaca, NY 14853 johannes [something] cs [is] cornell [here] edu Voice: 607-255-1045; fax: 607-255-4428</p>
NEST	Virginia, USA	http://www.cs.virginia.edu/~control/nest.html	<ul style="list-style-type: none"> • Real-time network coordination and control middleware that abstracts, controls, and ultimately guarantees the desired behavior of large unreliable networks such as those composed of sensors and actuators. • Our networks of sensors and actuators differ from the traditional networked systems in that, in aggregate, they must be highly adaptive, must cope with high rates of component failure, mobility, and reconfiguration, and must export a highly configurable set of parameterized services that may involve coordinating a rich set of sensors and actuators in the network core. • This functionality will be supported by composable microprotocols that allow behavior specification, perform large-scale component coordination, and export the perception of 	<p>John A. Stankovic BP America Professor Department of Computer Science School of Engineering and Applied Science University of Virginia 151 Engineer's Way, P.O. Box 400740 Charlottesville, Virginia 22904-4740 Phone: (434) 982-2275 Fax: (434) 982-2214 Email: stankovic@cs.virginia.edu</p> <p>Office: 228E Olsson Hall,</p>



			customized QoS guarantees.	<u>UVa</u>
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<p>Agilla: A Mobile Agent Middleware for Wireless Sensor Networks</p>	<p>USA</p>	<p>http://mobilab.wustl.edu/projects/agilla/</p>	<ul style="list-style-type: none"> • Positioning Mobile agents in the optimal locations for performing application-specific tasks. Thus saving energy by bringing computation to the data rather than requiring that the data be sent over unreliable wireless links. Thus increasing the utility of a WSN. • Agilla programs to control where mobile agent go and to maintain both their code and state across migrations. 	<p>Chien-Liang Fok Doctoral Student Office Phone: 1 (314) 935-7535 Lab Phone: 1 (314) 935-7526 Fax: 1 (314) 935-7302 liangfok@wustl.edu</p> <p>Computer Science and Engineering Washington University in St. Louis One Brookings Dr., Campus Box 1045 St. Louis, MO 63130-4899</p>
<p>MACSS: MAC Protocols Specific for Sensor Networks</p>	<p>USA</p>	<p>http://www.isi.edu/ilense/macss/</p>	<ul style="list-style-type: none"> • Exploring sensor-net-specific MAC protocol design, improving energy efficiency by allowing radios to sleep when not in use, coordinating the MAC protocol with the physical layer and sensors. • Studying how sensor net applications differ from Internet-style applications. • Releasing of a software 	<p>USC/Information Sciences Institute Suite 1001 4676 Admiralty Way Marina Del Rey, CA 90292-6695 U.S.A. Office: 1140 telephone: +1 (310) 448-8708 e-mail: johnh@isi.edu</p>

<p>DPRG</p> <p>Distributed protocol research group</p>	<p>URBANA USA</p>	<p>http://dprg.cs.uiuc.edu/research?action=topic&topic=Sensor+and+Ad-Hoc+Networks</p> <p>http://dprg.cs.uiuc.edu/docs/adapcode/PID552601.pdf</p>	<ul style="list-style-type: none"> • Sensor Network Code Update System via Network Coding 	<p>Indranil Gupta Office address:3112 Siebel Center Mailing address:MC 258 201 N. Goodwin Ave Urbana, IL 61801 Office phone:1-217-265-5517 E-mail:indy at cs dot uiuc dawt edu</p>
<p>Sensor Networking Laboratory</p>	<p>Louisiana State University USA</p>	<p>http://csc.lsu.edu/sensor_web/</p>	<ul style="list-style-type: none"> • Reliable Query Reporting in Adaptive Sensor Networks • Secure Distribution and Access in Distributed Sensor Networks • Survivable Sensor Networks 	<p>Dr. Arjan Duresi Assistant Professor Department of Computer Science Phone: (225) 578-3902 Email: duresi@csc.lsu.edu URL: http://bit.csc.lsu.edu/~duresi</p>
<p>Samsi Program on Environmental Sensor Networks</p>	<p>USA</p>	<p>http://www.samsi.info/programs/2007sensorneprogram.shtml</p>	<ul style="list-style-type: none"> • Objective of formulating and addressing optimization of data gathering, data analysis, data coverage, modeling and inference when the network itself is a dynamic system of self-organizing nodes to existing environmental networks designed to study biosphere-atmospheric interactions. • Frameworks for adaptive sampling: game-theoretic, reinforced learning, dynamic experimental design. Environmental modeling from sensor networks 	<p>Zoe Cardon 19 T.W. Alexander Drive P.O. Box 14006 Research Triangle Park, NC 27709-4006 Tel: 919.685.9350 Fax: 919.685.9360 info@samsi.info envsensors@samsi.info</p>

SASNet	Canada	http://www.crc.gc.ca/en/html/manetsensor/home/projects/sasnet	<ul style="list-style-type: none"> • To define and demonstrate an intelligent sensor system for military operation in complex terrains for future Canadian Army requirements. • The sensors collaborate in performing sensing tasks and improve detection and tracking performance through multiple observations, geometric diversity, extended detection range and faster response time. • SASNet will apply recent technological developments in wireless, ad-hoc networks, sensors, fusion, information processing, localization and networking. 	<p>Tel.: (613) 991-3313 Fax: (613) 998-5355 E-mail: info@crc.gc.ca Communications Research Centre 3701 Carling Avenue P.O. Box 11490, Stn. H Ottawa, ON K2H 8S2</p>
Dynamic Sensor Networks	USA	http://www.cs.wmich.edu/wsn/projects.html	<ul style="list-style-type: none"> • To arrange the sensors in such a way that the network has the clearest possible picture of its environment; fewer sensors will be located in areas of relatively low interest, while more sensors will be located in areas of high interest in order to increase the data available on those areas. • A fundamental aspect of the network will be its ability to move its sensors dynamically as the environment changes, thus making it adaptable to an ever-changing environment. 	<p>Prof. Ajay Gupta Professor WiSe Lab Department of Computer Science Western Michigan University Phone: (269) 276-3104 Fax : (269) 276-3122</p>
Sensor Networks	USA	http://sparrow.ece.cmu.edu/group/research_projects.html#sensors	<ul style="list-style-type: none"> • Key distribution is the basic task of preloading secret information onto sensor nodes to allow the establishment of shared secret keys for secrecy, authentication and integrity.. • Designing algorithms to detect the presence of 	<p>Adrian Perrig Email Address :perrig@cmu.edu Office CIC (Collaborative Innovation Center) 2107 Telephone 412 268 2242</p>

			falsified aggregation results in sensor networks, thus ensuring the integrity of reported data even in the presence of adversarial sensor nodes.	Mailing Address 2110 CIC 4720 Forbes Avenue Pittsburgh, PA 1521
Visual Sensor Networks	USA	http://inrg.cse.ucsc.edu/vsn.html	<ul style="list-style-type: none"> • VSN (Visual Sensor Networks) intends to address the issues in a visual sensor networks related to network protocols, computer vision algorithms and their interaction. • Setting up a Visual Sensor Network testbed • Handling energy consumption issues 	<p>KatiaObraczka Address 323 Engineering 2 Building Baskin School of Engineering University of California 1156 High Street Santa Cruz, CA 95064</p> <p>Phone and Email Voice: (831) 459-4308 Fax: (831) 459-4829 E-mail: katia@cse.ucsc.edu</p>
Adaptive Communications Networks Research Group	Birmingham Britain	http://www1.aston.ac.uk/eas/research/groups/acnrg/	<ul style="list-style-type: none"> • Techniques involve the design of advanced digital systems for application-specific embedded systems and advanced algorithms for improving network efficiency. • Use of state-of-the-art dynamic field programmable gate array hardware to examine physical implementations of these principles. 	Aston Triangle, Birmingham, B4 7ET. +44 (0)121 204 3000
snBench	Boston USA	http://www.cs.bu.edu/groups/sensorium/Resources.html	<ul style="list-style-type: none"> • To design and implement the programming and run-time infrastructure necessary for developers to specify and deploy truly distributed applications over a heterogeneous network of Sensing Elements (SEs) and of 	Azer Bestavros Professor Department of Computer Science College of Arts & Sciences Boston University

			<p>Computing Elements (CEs).</p> <ul style="list-style-type: none"> • Applications may (1) locate, monitor, and query SEs and CEs for services they support, and (2) initiate, control, or otherwise use such SE and CE services. 	<p>Office: 111 Cummington Street, MCS-276, Boston, MA 02215 Tel: 617.353.9726 / Fax: 617.353.6457 / Email: best@bu.edu</p>
Taskforce on Wireless Sensor Networks	Australia	http://www.eii.edu.au/taskforce0506/wsn	<ul style="list-style-type: none"> • Investigating the use of wireless sensor networks (WSNs) for the creation of an intelligent pervasive infrastructure to extend the usefulness of enterprise information systems in suitable application domains. • Objectives • Perform a survey on WSNs in various domains • Identify emerging WSN research challenges and trends especially related to communication, data processing and storage, and knowledge discovery. • Foster cross-disciplinary collaboration especially between electronic engineers, computer scientists and specific domain experts • Identify significant opportunities for Australian industries e.g. for health, agriculture, steel and gas industries 	<p>Network Convenor Professor Xiaofang Zhou School of Information Technology and Electrical Engineering The University of Queensland Brisbane QLD 4072 Australia Phone: +61 7 3365 2989 Fax: +61 7 3365 3248 Email: zxf@eii.edu.au</p>
Sensor Networks and Pervasive Computing	Germany	http://iv.cs.uni-bonn.de/wg/snpc/	<ul style="list-style-type: none"> • Research of Cooperating Objects. (Combination of embedded systems, wireless sensor networks and pervasive computing technology into coherent systems) 	<p>Coordinator: Prof. Dr. Pedro José Marrón Conet Office: Elke Schulte-Lippert Office hours: Mo-Fr 9-16</p>

			<ul style="list-style-type: none"> • Establishing technical and theoretical foundation for Cooperating objects. • Applications related with the reliable control of physical processes, the self-managing acquisition of the state of the physical world, and the seamless and distraction-free support of human users through computerized devices. 	<p>(A415) Phone: +49 228 73-4430 pjmarron@cs.uni-bonn.de</p>
New Wireless Sensor Network Research	York UK	http://www.elec.york.ac.uk/comms/sensornetworks.html	<ul style="list-style-type: none"> • Investigating energy-efficient medium access control protocol design, including contention-based and schedule-based schemes. • Cognitive routing methodologies for scalability enhancement. • Cross-layer protocol development, combining medium access control with routing functionality. • Security-conscious wireless sensor network design. • The use of aerial platforms to remove the communications burden from energy-constrained nodes within a wireless sensor network. • The deployment of wireless sensors within aircraft, as a replacement for wired infrastructure. 	pdm@ohm.york.ac.uk
Perma Sense	Switzerland	http://cn.cs.unibas.ch/projects/permasense/	<ul style="list-style-type: none"> • To build and customize a set of wireless measurement units for use in remote areas with harsh environmental monitoring conditions. • Gathering of environmental data that helps to 	Christian F. Tschudin Computer Science Department Bernoullistrasse 16

			<p>understand the processes that connect climate change and rock fall in permafrost areas.</p> <ul style="list-style-type: none"> • Enabling easy monitoring of larger permafrost areas with denser sampling, leading to better predictions on the consequences of global warming for alpine regions. 	<p>CH - 4056 Basel, Switzerland Tel: +41 61 267 05 57 Fax: +41 61 267 05 59 E-mail: christian.tschudin@unibas.ch</p>
Security of Wireless Sensor Networks	CAMBRIDGE UK	http://www.cl.cam.ac.uk/research/security/sensornets/	<ul style="list-style-type: none"> • Designing topology consisting of smaller clusters (several dozens) of wireless nodes. • Security of sensor networks from several different angles. 	<p>Tel: +44 (0)1223 763500 Fax: +44 (0)1223 334678 Head of Department: Professor Andy Hopper Email: cb210@cl.cam.ac.uk University of Cambridge Computer Laboratory William Gates Building 15 JJ Thomson Avenue Cambridge CB3 0FD UK</p>
Distributed Sensor Networks	South Africa	http://www.ee.up.ac.za/main/en/research/contactinfo	<ul style="list-style-type: none"> • The research focus is on emerging concepts and technologies adding value to distributed sensing and control networks. • This has strong synergies with the concepts defined by the ITU (International Telecommunications Union) (2005) as the Internet of Things, Forrester Research (2006) as the X Internet and Gartner Research (2006) as the Real World Web. 	<p>Prof. JW (Wimpie) Odendaal Department of Electrical, Electronic and Computer Engineering University of Pretoria 0002, PRETORIA Telephone: (012) 420-3545 Fax: (012) 362-5000 Email: wimpie.odendaal@eng.up.ac.za</p>

Wireless Sensor Research at NIST	USA	http://www.bfrl.nist.gov/WirelessSensor/	<ul style="list-style-type: none"> • Transmitting signals, by exploring new application areas for wireless sensors, by developing efficient means of transmitting messages through networks, and by developing standards to ease their use. 	NIST, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070 Email: inquiries@nist.gov Phone: (301) 975-NIST (6478) or TTY (301) 975-8295
CotsBots	Berkeley, CA, USA	http://www-bsac.eecs.berkeley.edu/projects/cotsbots/	<ul style="list-style-type: none"> • Investigating algorithms using mobile robots for cooperation, and distributed sensing in large (> 50) robot networks 	Sarah Bergbreiter 497 Cory Hall UC Berkeley Berkeley, CA 94720 sbergbre at eecs.berkeley.edu
FPS	Berkeley, CA, USA	http://barbara.stattenfeld.org/fps/	<ul style="list-style-type: none"> • A network protocol for radio power scheduling in wireless sensor networks. 	hohlth@CS.Berkeley.EDU

galC	Berkeley, CA, USA	http://galsc.sourceforge.net/	<ul style="list-style-type: none"> • A Language for Event-Driven Embedded Systems 	
Pico_Radio	Berkeley, CA, USA	http://bwrc.eecs.berkeley.edu/Research/Pico_Radio/	<ul style="list-style-type: none"> • Advancing the field of Wireless Sensor Networks in areas of RF circuit design, networking, positioning, low voltage digital design, antenna design, and low power analog design. • Interdisciplinary collaboration to bring together MEMS devices, energy scavenging, advanced packaging, advanced networking and communications theory, and environmental building applications. 	tufan_at_eecs.berkeley.edu

WSN group at DIS	Italy	http://wiserver.dis.uniroma1.it/cms/	<ul style="list-style-type: none"> • New and innovative solution based on wireless ad-hoc and multi-hop networks consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions (such as temperature, light, humidity, PH etc.). • Testing solutions on simulators (e.g. NS2, OMNET++, TOSSIM) and then deploying them in small, but significant testbeds, typically made of heterogeneous HW (TelosB and SUN SPOT), in order to verify their performances on real environments. 	<p>Alberto Marchetti-Spaccamela Dipartimento di Informatica e Sistemistica "Antonio Ruberti" Sapienza Università di Roma Room B212 e-mail: alberto@dis.uniroma1.it http://www.dis.uniroma1.it/~alberto</p>
Energy Efficient Sensor Networks (EYES)	Germany	http://www.tkn.tu-berlin.de/research/eyes/	<ul style="list-style-type: none"> • Self-organizing and collaborative energy-efficient sensor networks. • Applications like smart spaces, environmental monitoring, active structures, etc. 	<p>Prof. Dr.-Ing. Adam Wolisz EMAIL: awo@ieee.org Technische Universität Berlin, Dept. of Electrical Engineering</p>



				Telecommunication Networks Skr. FT-5, Einsteinufer 25, 10587 Berlin, Germany Phone: (+49 30) 314-22911 (TU Berlin) Fax: (+49 30) 314-23818 (TU Berlin)
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WiSA	Finland	http://www.control.tkk.fi/Research/WiSA/	<ul style="list-style-type: none"> • The objective of the project is to develop wireless sensor and actuator networks for a range of applications, including industrial applications... • Cross-layer optimization approach to develop networking protocols, sensor fusion techniques, and control methods that work in harmony, enabling wide deployment of wireless industrial automation and monitoring applications. • Development of wireless communications (MAC and network layers) distributed data fusion algorithms, sensor network and process diagnostics distributed and hierarchical control principles. 	<p>Lasse Eriksson Lic. Tech. Researcher Office: 3581 Phone: +358 9 451 5231 (office), +358 50 384 1715 (GSM) Email: lasse.eriksson@tkk.fi Mail address: PL 5500, FI-02015 TKK, Finland</p>
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<p>Real-time avalanche and landslide analysis through sensor network</p>	<p>Switzerland</p>	<p>http://www.mics.org/micsCluster.php?groupName=CL2&action=projects#P5</p>	<ul style="list-style-type: none"> • Gaining insight into the dynamics of rapid gravity-driven flows, such as avalanches and earth mass movements, by using a sensor-network based monitoring system. • To improve fluid-mechanics models describing the flow behavior of avalanches. • Applications such as detecting acceleration of a landsliding mass), thus enabling appropriate measures to be taken on time to minimize loss of life or for rescue operations (e.g., to detect skiers buried in an avalanche). 	<p>Edoardo Charbon edoardo.charbon@epfl.ch office(s): INF135 phone(s): [+41 21 69] 36487 fax: +41-21-693-5263</p>
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CarTel		http://cartel.csail.mit.edu/doku.php	<ul style="list-style-type: none"> • Distributed, mobile sensor network and telematics system. • Applications built on top of this system can collect, process, deliver, analyze, and visualize data from sensors located on mobile units such as automobiles and smartphones. • In our deployment, a small embedded computer interfaces with a variety of sensors, processes the collected data, and delivers it to an Internet server. • Applications running on the server analyze this data and provide interesting services to users. 	<p>Hari Balakrishnan Professor Department of EECS Room 32-G940 Computer Science and Artificial Intelligence Laboratory (CSAIL) The Stata Center, 32 Vassar St. Massachusetts Institute of Technology Cambridge, MA 02139</p>
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<p>μAMPS μ-adaptive multi domain power aware sensors</p>	<p>USA</p>	<p>http://www-mtl.mit.edu/researchgroups/icsystems/uamps/</p>	<ul style="list-style-type: none"> • Focus on signal and power conditioning, communication, and collaboration. • Exploring programmable solutions for implementing the above functions. • To provide an energy-efficient and scalable solution for a range of sensor applications. 	<p>Prof. Anantha Chandrakasan Massachusetts Institute of Technology Department of Electrical Engineering and Computer Science 50 Vassar Street, 38-107 Cambridge, MA 02139 tel: +1 (617) 258-7619 fax: +1 (617) 253-5053 e-mail: anantha@mtl.mit.edu</p>
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Envi Sense	UK	http://envisense.org/the-centre.htm	<ul style="list-style-type: none"> • Projects applying pervasive computing technologies in the natural environment. These include larger-scale reconfigurable pervasive computing such as data acquisition for coastal and flood monitoring programmes (Secoas and FloodNet), and high tech designs such as our subglacial probes to study climate change through its effects on glaciers (GlacsWeb). • Using Sensor Networks in conjunction with state of the art software technologies including energy-efficient routing, intelligent agents, the Semantic Web and Grid computing. • Project FloodNet is deploying nodes with significant computational power around a river floodplain. The information returned from the river is processed and used in the adaptive sampling feedback loop, whereby sensor sampling rates are increased in anticipation of flooding events. • Project Secoas is deploying a larger number of smart sensors to measure sea bed movement. The sensors are capable of dynamic self-configuration and use decentralized algorithms that enable automated adaptation to failures, upgrades and requirement changes. • GlacsWeb is monitoring glacier behaviour via different sensors and linking them together into an intelligent web of resources. 	<p>Director Prof David De Roure School of Electronics and Computer Science University of Southampton Southampton SO17 1BJ, UK Email dder@ecs.soton.ac.uk phone +44 (0)23 8059 2418</p>
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MIMO Antenna System - Wireless LAN Networks - Gnomes Sensor Network	USA	http://www.ece.rice.edu/~cavallar/cmclab/	<ul style="list-style-type: none">• Remote monitoring of structures.	Rice University Center for Multimedia Communications
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The disappearing computer	Germany	http://www.disappearing-computer.net/projects.html	<ul style="list-style-type: none"> • Diffusing IT into everyday objects and settings, and to see how this can lead to new ways of supporting and enhancing people's lives that go above and beyond what is possible with the computer today. • Initiative focuses on three-interlinked objectives • Create information artefacts based on new software and hardware architectures that are integrated into everyday objects. • Look at how collections of artefacts can act together, so as to produce new behaviour and new functionality. • Investigate the new approaches for designing for collections of artefacts in everyday settings, and how to ensure that people's experience in these new environments is coherent and engaging. 	Norbert Streit streitz@ipsi.fraunhofer.de Fraunhofer IPSI, Darmstadt, Germany
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<p>BISON</p> <p>Biology-Inspired techniques for Self-Organization in dynamic Networks</p>	<p>Italy</p>	<p>http://www.cs.unibo.it/bison/</p>	<ul style="list-style-type: none"> • BISON explores the use of ideas derived from complex adaptive systems (CAS) to enable the construction of robust and self-organizing information systems for deployment in highly dynamic network environments. We cast solutions to important problems arising in overlay networks and mobile ad-hoc networks as desirable global properties that systems should exhibit. We then search for CAS which can bring about these global properties. 	<p>Prof. Ozalp Babaoglu</p> <p>University of Bologna Department of Computer Science Mura Anteo Zamboni, 7 40127 Bologna Italy</p> <p>Tel: +39 051 2094504 Fax:+39 051 2094510</p>
<p>Embedded WiSeNts</p>	<p>Germany</p>	<p>http://www.embedded-wisents.org/project/project.html</p>	<ul style="list-style-type: none"> • Develop a new research domain, integrating the broad context of embedded systems with ubiquitous computing and wireless sensor networks in support of Cooperating Objects. • Integration of existing research in the field and related fields, supporting teaching and training in the area of Cooperating Objects and developing a technology roadmap to drive the vision forward. • Cooperating Object (CO) (collection of sensors, actuators, controllers) communicate with each other and are able to achieve, more or less autonomously, a common goal. 	<p>Prof. Dr.Ing A Adam Wolisz, Technical university, Berlin</p> <p>E-MAIL: awo@ieee.org</p>

Eyes-energy efficient sensor networks	Netherlands	http://www.eyes.eu.org/index.htm	<ul style="list-style-type: none"> • Development of the architecture and the technology needed for building self-organizing and collaborative sensor networks using reconfigurable smart sensor nodes, which are self-aware, self-reconfigurable and autonomous. This technology will enable the creation of a new generation of sensors, which can effectively network together so as to provide a flexible platform for the support of a large variety of mobile sensor network applications • Both theoretical research results and the implementation of a prototype will be produced. 	<p>Paul Havinga</p> <p>University of Twente Department of Computer Science P.O. Box 217 7500 AE Enschede the Netherlands Tel: +31 53 4894619 Fax: +31 53 4894590 e-mail: havinga@cs.utwente.nl http://www.cs.utwente.nl/~havinga</p>
Smart-Its	Switzerland	http://www.smart-its.org/	<ul style="list-style-type: none"> • Ubiquitous Computing is fundamentally characterized by the connection of things in the world with computation" (M. Weiser) • The Smart-Its project is interested in a far-reaching vision of computation embedded in the world. In this vision, mundane everyday artefacts become augmented as soft media, able to enter into dynamic digital relationships • "Smart-Its" a- small-scale embedded devices that can be attached to everyday objects to augment them with sensing, perception, computation, and communication. • Enabling technology for building and testing ubiquitous computing scenarios, and use them to study emerging functionality and collective 	<p>Prof. Hans Gellersen Department of Computing, Lancaster University Lancaster LA1 4YR, U.K. hwg@comp.lancs.ac.uk Ph. +44 1524 593823, Fax +44 1524 593608</p>

Casa- Collaborative adaptive sensing of atmosphere	USA	http://www.casa.umass.edu/index.php	<ul style="list-style-type: none"> • CASA is a multi-sector partnership among academia, industry, and government dedicated to engineering revolutionary weather-sensing networks. These innovative networks will save lives and property by detecting the region of the lower atmosphere currently below conventional radar range - mapping storms, winds, rain, temperature, humidity, and the flow of airborne hazards. 	<p>David McLaughlin</p> <p>University of Massachusetts Amherst 209 Knowles Engineering Building 151 Holdsworth Way Amherst, MA 01003 Tel 413-577-2221 Fax 413-577-1995</p> <p>webmaster@casa.umass.edu</p>
Cens- centre for embedded network sensing	USA	http://research.cens.ucla.edu/	<ul style="list-style-type: none"> • Developing Embedded Networked Sensing Systems and applying this revolutionary technology to critical scientific and social applications. • Like the Internet, these large-scale, distributed, systems, composed of smart sensors and actuators embedded in the physical world, will eventually infuse the entire world, but at a physical level instead of virtual. • An interdisciplinary and multi-institutional venture, CENS involves hundreds of faculty, engineers, graduate student researchers, and undergraduate students from multiple disciplines at the partner institutions of University of California at Los Angeles (UCLA), University of Southern California 	<p>Center for Embedded Networked Sensing UCLA 3563 Boelter Hall Los Angeles, CA 90095-1596 Tel. (310) 206-2476 Fax. (310) 206-3053</p>

			(USC), University of California Riverside (UCR), California Institute of Technology (Caltech), University of California at Merced (UCM), and California State University at Los Angeles (CSULA).	
PEIR	USA	http://urban.cens.ucla.edu/projects/peir/	<ul style="list-style-type: none"> • PEIR, the Personal Environmental Impact Report, is a new kind of online tool that allows you to use your mobile phone to explore and share how you impact the environment and how the environment impacts you. Taking a step beyond a “footprint calculator” that relies only on your demographics, • PEIR uses location data that is regularly and securely uploaded from mobile phone to create a dynamic and personalized report about your environmental impact and exposure. • PEIR gives greater control over your environmental impact and exposure by allowing you to interactively explore how it creates its results from your activity patterns. • PEIR analysis starts with your location “trace,” a sequence of points collected by a GPS device you carry with you. • For each trip ,a link location trace with data we collect about thousands of neighborhoods in California, data that include the current weather conditions and estimated traffic patterns on local roads and freeways. Information is then analyzed with published scientific models that produce estimates of your exposure and impact in four categories: 	<p>Deborah Estrin</p> <p>Faculty, Computer Science</p> <p>University of California in Los Angeles (UCLA) 3563 Boelter Hall Los Angeles, CA 90095-1596</p> <p>phone:(310) 206-2476</p>

			<ul style="list-style-type: none"> • Smog Exposure (PM 2.5 particulate exposure). 2. Fast food exposure. 3. Carbon impact. 4. Sensitive Site Impact (PM2.5 particulate impact on sensitive sites such as schools and hospitals). 	
<p>ISSNIP</p> <p>ARC Research Network on Intelligent Sensors, Sensor Networks and Information Processing</p>	Australia	http://www.ee.unimelb.edu.au/ISSNIP/	<ul style="list-style-type: none"> • Micro and Nano Sensors • Distributed Sensor Networks • Surveillance and Monitoring • Sensor Fusion and Tracking • Scheduling and Optimization • Machine Intelligence 	<p>M Palaniswami Network Convener Department of Electrical and Electronics Engineering The University of Melbourne Parkville, Victoria - 3010 Australia swami@ee.unimelb.edu.au</p> <p>Tel: +61 - 3 - 83446710 Fax: +61 - 3 - 83446678</p>
<p>SMART DUST</p>	USA	http://robotics.eecs.berkeley.edu/%7Epister/SmartDust/	<ul style="list-style-type: none"> • Goal of the Smart Dust project is to demonstrate that a complete sensor/communication system can be integrated into a cubic millimeter package. • This involves both evolutionary and revolutionary advances in miniaturization, integration, and energy management. . 	<p>Kristofer S.J. Pister Prof. of EECS, Dir., BSAC 497 Cory Hall, Berkeley, CA 94720-1770 Email: pister@eecs.berkeley.edu</p> <p>Ph no: (510) 643-9268 Fax: (510) 643-6637</p>