

A Survey Paper on Applications and Challenges in Wireless Sensor Network

Ajaz Ahmed Khan ¹, Mrs Himani Agrawal ²

P.G. Student, Dept. of Electronics and Telecommunication Engineering, Shri Shankarcharya Group of Institutions
Bhilai, Chhattisgarh , India¹

Associate Professor, Dept. of Electronics and Telecommunication Engineering, Shri Shankarcharya Group of
Institutions Bhilai, Chhattisgarh, India²

ABSTRACT: This paper describes the idea of sensor networks that has been created viable by the convergence of wireless communications, micro-machined devices, and digital electronics. First, the potential sensor networks applications and the sensing tasks are explored, and a review of things influencing the design of sensor networks is provided. Then, the communication design for sensor networks is outlined, and also the applications and various factors influencing sensor network design within the literature are explored. Generally Wireless Sensor Network (WSN) consists of many distributed devices spatially, using sensors to monitor various conditions at various points, including temperature, sound, vibration, pressure, motion or pollutants. Most of the significant applications of Wireless Sensor Networks have been described in the paper.

KEYWORDS: wireless sensor networks, micro-machined devices, communication design.

I. INTRODUCTION

Recent advancements in micro-machined devices, wireless communications, and digital electronics have enabled the development of low-priced, low-power, multifunctional sensor nodes that are tiny in size and communicate unmetered in brief distances. These little sensor nodes, that incorporates sensing, data processing, and communicating elements, leverage the concept of sensor networks based on cooperative effort of an outsized number of nodes. Sensor networks represent a major improvement over ancient sensors that are deployed within the following 2 ways [31]:

- Sensors are often positioned far away from the actual phenomenon, i.e., something identified by sense perception. In this approach, massive sensors that use some complicated techniques to differentiate the targets from environmental noise are needed.
- Many sensors that perform only sensing are often deployed. The positions of the sensors and communications topology are fastidiously designed. They transmit time series of the detected phenomenon to the central nodes where computations are performed and information are coalesced. A sensor network consists of a large number of sensor nodes that are densely deployed either within the phenomenon or very near it. The position of sensor nodes needn't be designed or pre-determined. This permits random deployment in inaccessible terrains or disaster relief operations. On the opposite hand, this conjointly implies that sensor network protocols and algorithms should possess self-organizing capabilities. Another distinctive feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an on-board processor. Rather than sending the information to the nodes liable for the fusion, sensor nodes use their processing skills to locally perform easy computations and transmit only the desired and partially processed information. The above described features guarantee a large range of applications for sensor networks. a number of applications areas are health, military, and security. For instance, the physiological data about a patient may be monitored remotely by a doctor. Whereas this is often additional convenient for the patient, it conjointly permits the

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, Januray 2016

doctor to give a better understanding of the patient's current condition. Sensor networks can even be used to find foreign chemical agents within the air and also the water. They can facilitate to spot the kind, concentration, and location of pollutants. In essence, sensor networks can give the top user with intelligence and an improved understanding of the atmosphere. We tend to envision that, in future, wireless sensor networks are going to be an integral part of our lives, more so than the present-day personal computers. Realization of those and alternative sensor network applications need wireless ad hoc networking techniques. Though several protocols and algorithms are proposed for traditional wireless ad hoc networks, they're not compatible for the distinctive features and application necessities of sensor networks. to Illustrate this point, the variations between sensor networks and ad hoc networks [15] are outlined below:

- The number of sensor nodes in a sensor network may be several orders of magnitude more than the nodes in an ad hoc network.
- Sensor nodes are densely deployed.
- Sensor nodes are susceptible to failures.
- The topology of a sensor network changes very often.
- Sensor nodes primarily use broadcast communication paradigm whereas most ad hoc networks are based on point-to-point communications.
- Sensor nodes are restricted in computational capacities, power and memory.
- Sensor nodes might not have global identification (ID) due to the massive quantity of overhead and enormous number of sensors. Since sizable amount of sensor nodes is densely deployed, neighbor nodes could also be very near to each other. Hence, multihop communication in sensor networks is anticipated to consume less power than the standard single hop communication. Moreover, the transmission power levels should be kept low, which is highly desired in covert operations. Multihop communication may also effectively overcome a number of the signal propagation effects experienced in long-distance wireless communication. One amongst the foremost necessary constraints on sensor nodes is the low power consumption demand. Sensor nodes carry restricted, usually irreplaceable, power sources. Therefore, whereas traditional networks aim to attain prime quality of service (QoS) provisions, sensor network protocols should focus totally on power conservation. They need to have built-in trade-off mechanism that provides the end user the choice of prolonging network lifespan at the price of lower throughput or higher transmission delay.

Many researchers are presently engaged in developing schemes that fulfill these needs. in this paper, we present a survey of protocols and algorithms proposed so far for sensor networks. Our aim is to produce an improved understanding of the present analysis problems in this field. We additionally try an investigation into pertaining design constraints and outline the utilization of certain tools to fulfill the design objectives. The rest of the paper is organized as follows: In Section two, we present some potential sensor network applications that show the quality of sensor networks. In Section three, we discuss the factors that influence the sensor network design. We conclude our paper in Section four.

II. SENSOR NETWORKS APPLICATIONS

Sensor networks might incorporates many alternative kinds of sensors like seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic and radar, that are ready to monitor a large variety of ambient conditions that embody the following [23]:

- Temperature

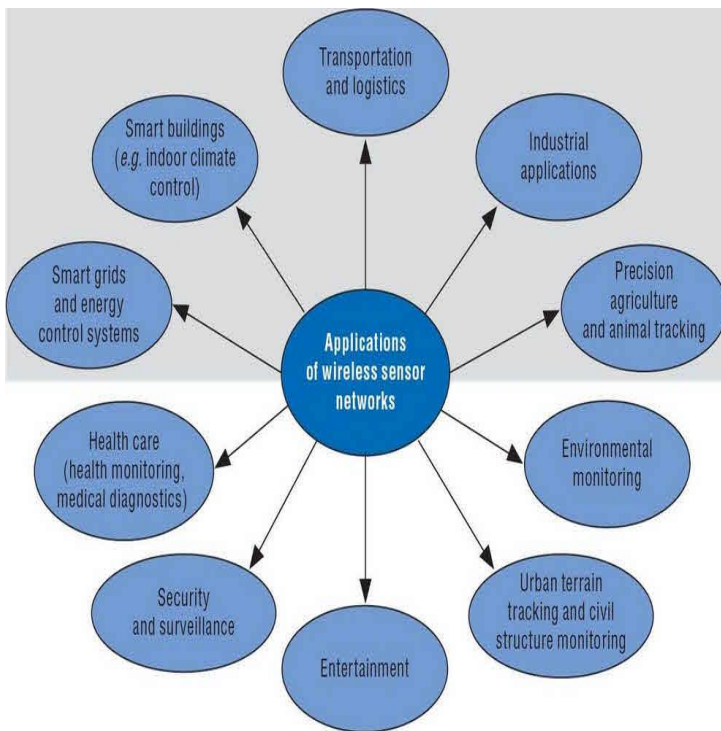


Fig:1 Applications of Wireless Sensor Network

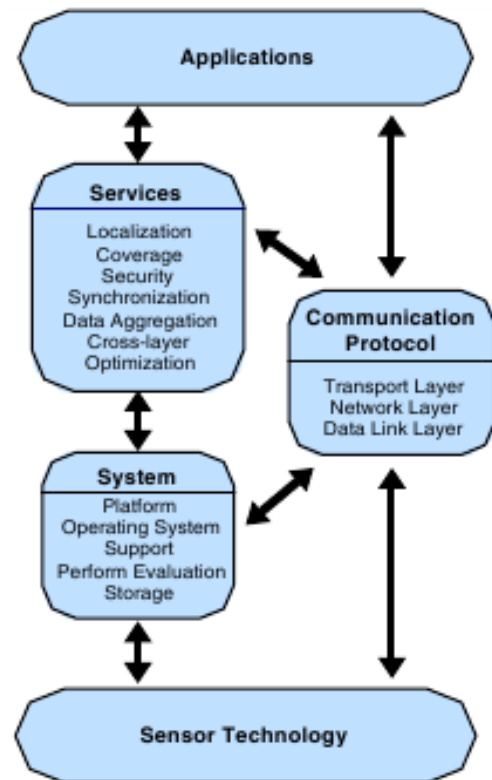


Fig:2 Broad classification of problems in WSN

- Humidity
- Conveyance movement
- Lightning condition
- Pressure
- Soil makeup
- Noise levels
- Presence or absence of certain types of objects
- Mechanical stress levels on connected objects
- Current characteristics like direction, speed and size of an object.

Sensor nodes may be used for event ID, continuous sensing, event detection, location sensing, and local control of actuators. The ideas of micro-sensing and wireless association of these nodes promise several new application areas. we categorize the applications into environment, military, health, home and different commercial areas. It's possible to expand this classification with additional classes like space exploration, chemical processing and disaster relief.

1. Military applications

Wireless sensor networks are often an integral part of military command, control, communications, computing, intelligence, surveillance, reconnaissance mission and targeting (C4ISR) systems. The rapid deployment, self-organization and fault tolerance characteristics of sensor networks make them a really promising sensing technique for military C4ISR. Since sensor networks are based on the dense deployment of disposable and cheap sensor nodes, destruction of some nodes by hostile actions doesn't have an effect on a operation as much as the destruction of a

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, Januray 2016

conventional sensor, that makes sensor networks idea a much better approach for battlefields. a number of the military applications of sensor networks are monitoring friendly forces, equipment and ammunition; battleground surveillance; reconnaissance mission of opposing forces and terrain; targeting; combat casualty assessment; and nuclear, biological and chemical (NBC) attack detection and reconnaissance mission.

Sensor types	Operation scenario			
	Battlefield	Urban	OTW	Force protection
Presence / Intrusion	SHLM, AAP, ASW	SDT		SHLM, AAP, SDT
CBRNE	RCS		VDM	VDM, RCS
Ranging	ASW	EARS, INS	BL, INS	EARS, BL, SDL, PP
Imaging		SDL, MCM	MCM	SDL, MCM, PP
Noise		ATS	ATS	ATS

FIG. 3 CATEGORIES OF MILITARY WIRELESS SENSOR NETWORK OPERATION

Monitoring equipment, friendly forces and ammunition: Leaders and commanders will perpetually monitor the status of friendly troops, the condition and also the handiness of the equipment and also the ammunition in a battleground by the employment of sensor networks. Each equipment, troop, vehicle, and significant ammunition may be connected with tiny sensors that report the status. These reports are gathered in sink nodes and sent to the troop leaders. The information also can be forwarded to the higher levels of the command hierarchy whereas being aggregated with the information from different units at every level.

Battlefield surveillance: Approach routes crucial terrains, ways and straits may be quickly lined with sensor networks and closely watched for the activities of the opposing forces. As the operations evolve and new operational plans are prepared, new sensor networks may be deployed anytime for battleground surveillance.

Reconnaissance mission of opposing forces and terrain: Sensor networks may be deployed in crucial terrains, and a few valuable, detailed, and timely intelligence regarding the opposing forces and terrain may be gathered within minutes before the opposing forces can intercept them.

Targeting: Sensor networks may be incorporated into guiding systems of the intelligent ammunition.

Combat casualty assessment: just before or after attacks, sensor networks may be deployed within the target area to collect the combat casualty assessment information.

Nuclear, biological and chemical attack detection and reconnaissance: In biological and chemical warfare, being near ground zero is very important for timely and correct detection of the agents. Sensor networks deployed in the friendly region and used as a chemical or biological warning system will give the friendly forces with essential response time that drops casualties drastically. We can additionally use sensor networks for elaborated reconnaissance mission after an NBC attack is detected. For instance, we are able to create a nuclear reconnaissance mission while not exposing a rescue team to nuclear radiation.

2. Environmental applications

Some environmental applications of sensor networks embody following the movements of birds, insects, and tiny animals, observing environmental conditions that have an effect on livestock and crops, irrigation, flood detection, chemical/ biological detection, precision agriculture, biological, Earth, and environmental monitoring in marine, soil, and atmospheric contexts, meteorological or geophysical research, forest fire detection, macro-instruments for large-scale Earth monitoring and planetary exploration bio-complexity mapping of the environment and pollution study [2,6-8,10,11,14,21].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

Forest fire detection: Since sensor nodes could also be strategically, randomly, and densely deployed in a forest, sensor nodes will relay the precise origin of the fire to the end users before the fire is spread uncontrollable. Lots of sensing element nodes may be deployed and integrated using radio frequencies/ optical systems. Also, they'll be equipped with effective power scavenging strategies [12], like solar cells; as a result the sensors could also be left unattended for months and even years. The sensor nodes can collaborate with one another to perform distributed sensing and overcome obstacles, like trees and rocks that block wired sensors' line of sight.

A bio-complexity mapping [11] of the environment needs sophisticated approaches to integrate data across temporal and spatial scales [26,7]. The advances of technology within the remote sensing and automatic information assortment have enabled higher spatial, spectral, and temporal resolution at a geometrically declining price per unit area [15]. Alongside these advances, the sensor nodes even have the flexibility to attach with the internet that permits remote users to manage, monitor and observe the bio-complexity of the environment.

Although satellite and airborne sensors are helpful in observing massive biodiversity, e.g., spatial complexity of dominant plant species, they're not fine grain enough to observe tiny size biodiversity that makes up most of the biodiversity in an ecosystem [13]. As a result, there's a necessity for ground level deployment of wireless sensor nodes to observe the bio-complexity [29,30]. One example of bio-complexity mapping of the environment is done at the James Reserve in Southern California [11]. 3 monitoring grids with every grid having 25– 100 sensor nodes are enforced for fixed view multimedia and environmental sensor information loggers.

Flood detection [7]: an example of flood detection is the ALERT system [9] deployed within the United States. Many kinds of sensors deployed in the ALERT system are precipitation, water level and weather sensors. These sensors provide data to the centralized information system in a pre-defined manner. Research projects, such as the cougar Device database Project at cornell university [7] and also the DataSpace project at Rutgers [8], are investigating distributed approaches in interacting with sensor nodes in the sensor field to supply photograph and long-running queries.

Precision Agriculture: Some of the advantages is the ability to observe the pesticides level in the drinking water, the extent of soil erosion, and also the level of air pollution in real time.

3. Health applications

Many of the health applications for sensor networks are providing interfaces for the disabled; telemonitoring of human physiological data; diagnostics; drug administration in hospitals; integrated patient observation; and pursuit, monitoring the movements and internal processes of insects or other small animals and monitoring doctors and patients within a hospital [8, 2, 6, 7, and 28]. Telemonitoring of human physiological information: The physiological data collected by the sensor networks may be kept for an extended amount of time [41], and might be used for medical exploration [6]. The installed sensor networks also can monitor and find older people's behavior, e.g., a fall [9, 16].

These tiny sensor nodes permit the subject a larger freedom of movement and permit doctors to spot pre-defined symptoms earlier [5]. Also, they facilitate a better quality of life for the subjects compared to the treatment centers [5]. Faculty of medicine in Grenoble—France designed the “Health smart Home” to validate the practicability of such system [6]. Tracking and monitoring doctors and patients within a hospital: every patient has tiny and light weight sensor nodes connected to them. Every sensor node has its specific task. For instance, one sensor node may be detecting the heart rate whereas another is detecting the blood pressure. Doctors may carry a sensor node that permits other doctors to find them inside the hospital. Drug administration in hospitals: If sensor nodes may be connected to medications, the probability of obtaining and prescribing the incorrect medication to patients may be reduced, because patient will have sensor nodes that may determine their allergies and needed medications. Computerized systems as delineated in [8] have shown that they will facilitate minimize adverse drug events.

4. Home applications

Home automation: As technology advances, smart sensor nodes and actuators may be buried in appliances, like vacuum cleaners, micro-wave ovens, refrigerators, and VCRs [6]. These sensor nodes within the domestic devices will interact with one another and with the external network via the web or Satellite. They permit end users to manage home devices locally and remotely without much effort.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

Smart environment: Smart environment's design will have 2 completely different views, i.e., human-centered and technology-centered [1]. For the first one that is the human-centered, a smart environment needs to adapt to the wants of the end users in terms of input/output capabilities. For the second that is the technology-centered, new hardware technologies, networking solutions, and middleware services have to be compelled to be developed. A situation of how sensor nodes may be used to produce a smart environment is delineated in [3]. The sensor nodes may be embedded into furnishings and appliances, and that they will communicate with one another and also the room server. {The room|the space|the area} server also can communicate with other room servers to find out about the services they offered, e.g., printing, scanning, and faxing. These room servers and sensor nodes may be integrated with existing embedded devices to become self-organizing, self regulated and adaptational systems based on control theory models as delineated in [3]. Another example of smart environment is the "Residential Laboratory" at Georgia Institute of Technology [2]. The computing and sensing in this environment must be reliable, persistent, and transparent.

5. Alternative commercial applications

Some of the commercial applications are building virtual keyboards, monitoring material fatigue; constructing smart office spaces; managing inventory; vehicle pursuit and detection; monitoring product quality; robot control and guidance in automatic manufacturing environments; environmental control in office buildings; interactive museums; plant process control and automation; monitoring disaster area; interactive toys; transportation; smart structures with sensor nodes embedded inside; plant instrumentation; local control of actuators; detecting and monitoring automobile thefts; machine diagnosis and instrumentation of semiconductor process chambers, rotating machinery, wind tunnels, and anechoic chambers [2,8,14,23,24].

Environmental control in office buildings: The heat and air conditioning of most buildings are centrally controlled. Therefore, the temperature within {a room/an area/a space} will vary by few degrees; one facet can be hotter than the opposite because there's just one control within the room and also the air flow from the central system is not evenly distributed. A distributed wireless sensor network system may be installed to regulate the air flow and temperature in several parts of the room. It's estimated that such distributed technology will cut back energy consumption by 2 quadrillion British Thermal Units (BTUs) in the United States, which amounts to saving of \$55 billion annually and reducing thirty five million metric tons of carbon emissions [7].

Interactive museums: In the future, kids will be able to interact with objects in museums to learn more regarding them. These objects will be able to reply to their touch and speech. Also, kids will take part in real time cause-and-effect experiments, which may teach them about science and environment. Additionally, the wireless sensor networks will offer paging and localization within the museum. An example of such museums is the San Francisco Exploratorium that features a combination of data measurements and cause and- effect experiments [1].

Detecting and monitoring automotive thefts: Sensor nodes are being deployed to find and identify threats within a geographical area and these threats will be reported to remote end users by the internet for analysis [6].

Managing inventory control: Every item in a warehouse might have a sensor node attached. The end users will determine the exact location of the item and tally the amount of items within the same category. If the end users wish to insert new inventories, all the users have to be compelled to do is to connect the suitable sensor nodes to the inventories. The end users will track and find where the inventories are at all times.

Vehicle tracking and detection: There are 2 approaches as delineated in [12] to trace and detect the vehicle: first, the line of bearing of the vehicle is set locally within the clusters, it is then forwarded to the base station, and second, the raw data collected by the sensor nodes are forwarded to the base station so that the location of the vehicle can be determined.

III. FACTORS INFLUENCING SENSOR NETWORK DESIGN

A sensor network design is influenced by several factors that embrace fault tolerance; production costs; operating environment; scalability sensor network topology; transmission media; hardware constraints; and power consumption. These factors are addressed by several researchers as surveyed in this paper. However, none of those studies contains a fully integrated view of all factors that are driving the design of sensor networks and sensor nodes. These factors are

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

vital because they function as a guideline to design a protocol or an algorithm for sensor networks. Additionally, these influencing factors may be used to compare different schemes.

1. Fault tolerance

Some sensor nodes might fail or be blocked because of lack of power, have physical damage or environmental interference. The failure of sensor nodes mustn't have an effect on the overall task of the sensor network. This is the dependability or fault tolerance issue. Fault tolerance is the ability to sustain sensor network functionalities without any interruption because of sensor node failures [30, 25, and 5]. The dependability or fault tolerance of a sensor node is modeled in [30] using the Poisson distribution to capture the probability of not having a failure within the time interval $(0; t)$: where k and t are the failure rate of sensor node k and the time period, respectively. Note that protocols and algorithms are also designed to deal with the extent of fault tolerance needed by the sensor networks. If the environment where the sensor nodes are deployed has very little interference, then the protocols may be a lot relaxed. For instance, if sensor nodes are being deployed in a house to keep track of humidity and temperature levels, the fault tolerance demand could also be low since this type of sensor networks is not easily damaged or interfered by environmental noise. On the opposite hand, if sensor nodes are being deployed in a battleground for surveillance and detection, then the fault tolerance needs to be high because the sensed information are crucial and sensor nodes may be destroyed by hostile actions. As a result, the fault tolerance level depends on the application of the sensor networks, and also the schemes should be developed accordingly.

2. Scalability

The number of sensor nodes deployed in learning a phenomenon may be in the order of thousands or hundreds. Depending on the application, the number might reach an extreme price of millions. The new schemes must be able to work with this variety of nodes. They have to additionally utilize the high density nature of the sensor networks. The density will vary from few sensor nodes to few hundred sensor nodes in a region, which might be less than ten m in diameter [14]. The density may be calculated according to [8] as where N is the number of scattered sensor nodes in region A ; and R , the radio transmission range. Basically, provides the number of nodes within the transmission radius of every node in region A . additionally, the number of nodes in a region may be used to indicate the node density. The node density depends on the application in which the sensor nodes are deployed. For machine identification application, the node density is around three hundred sensor nodes in a 5.5 m² region, and the density for the vehicle tracking application is around ten sensor nodes per region [7]. In general, the density may be as high as twenty sensor nodes/m³ [7]. A home could contain around 2 dozens of home appliances containing sensor nodes [6], however this number can grow if sensor nodes are embedded into furnishings and other miscellaneous items. For habitat monitoring application, the number of sensor nodes ranges from twenty five to one hundred per region [11]. The density will be very high when an individual usually containing hundreds of sensor nodes, which are embedded in eye glasses, jewelry, clothing, shoes, watch, and human body, is sitting inside a stadium watching a basketball, football, or baseball game.

IV. CONCLUSION

WSNs are designed for specific applications, unlike other network. Applications include, but are not restricted to, environmental monitoring, surveillance systems, industrial machine monitoring, and military target tracking. Every application differs in features and needs. To support this diversity of applications, the development of latest communication protocols, algorithms, designs, and services are required. The flexibility, fault tolerance, high sensing fidelity, rapid deployment characteristics and low-cost of sensor networks create many new and exciting application areas for remote sensing. This wide range of application areas will make sensor networks an integral part of our lives, in future. However, certain needs have to be satisfied for realization of sensor network, the constraints introduced by factors such as power consumption, scalability, hardware, topology change, cost, environment and fault tolerance. Since these constraints are highly stringent and specific for sensor networks, new wireless ad hoc networking techniques are required.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 1, January 2016

REFERENCES

- [1] G.D. Abowd, J.P.G. Sterbenz, "Final report on the interagency workshop on research issues for smart environments", IEEE Personal Communications (October 2000) 36–40.
- [2] J. Agre, L. Clare, "An integrated architecture for cooperative sensing networks", IEEE Computer Magazine (May 2000) 106–108.
- [3] I.F. Akyildiz, W. Su, "A power aware enhanced routing (PAER) protocol for sensor networks", Georgia Tech Technical Report, January 2002, submitted for publication.
- [4] A. Bakre, B.R. Badrinath, "I-TCP: indirect TCP for mobile hosts", Proceedings of the 15th International Conference on Distributed Computing Systems, Vancouver, BC, May 1995, pp. 136–143.
- [5] P. Bauer, M. Sichertiu, R. Istepanian, K. Premaratne, "The mobile patient: wireless distributed sensor networks for patient monitoring and care", Proceedings 2000 IEEE EMBS International Conference on Information Technology Applications in Biomedicine, 2000, pp. 17–21.
- [6] M. Bhardwaj, T. Garnett, A.P. Chandrakasan, "Upper bounds on the lifetime of sensor networks", IEEE International Conference on Communications ICC'01, Helsinki, Finland, June 2001.
- [7] P. Bonnet, J. Gehrke, P. Seshadri, "Querying the physical world", IEEE Personal Communications (October 2000) 10–15.
- [8] N. Bulusu, D. Estrin, L. Girod, J. Heidemann, "Scalable coordination for wireless sensor networks: self-configuring localization systems", International Symposium on Communication Theory and Applications (ISCTA 2001), Ambleside, UK, July 2001.
- [9] B.G. Celler et al., "An instrumentation system for the remote monitoring of changes in functional health status of the elderly", International Conference IEEE-EMBS, New York, 1994, pp. 908–909. Table 5 Current research projects Project name Research area HTTP location SensoNet [3] Transport
- [10] A. Cerpa, D. Estrin, "ASCENT: adaptive self-configuring sensor networks topologies", UCLA Computer Science Department Technical Report UCLA/CSDTR-01-0009, May 2001.
- [11] A. Cerpa, J. Elson, M. Hamilton, J. Zhao, "Habitat monitoring: application driver for wireless communications technology", ACM SIGCOMM'2000, Costa Rica, April 2001.
- [12] A. Chandrakasan, R. Amiratharajah, S. Cho, J. Goodman, G. Konduri, J. Kulik, W. Rabiner, A. Wang, "Design considerations for distributed micro-sensor systems", Proceedings of the IEEE 1999 Custom Integrated Circuits Conference, San Diego, CA, May 1999, pp. 279–286.
- [13] C. Chien, I. Elgorriaga, C. McConaghy, "Low-power directsequence spread-spectrum modem architecture for distributed wireless sensor networks", ISLPED'01, Huntington Beach, California, August 2001.
- [14] S. Cho, A. Chandrakasan, "Energy-efficient protocols for low duty cycle wireless microsensor", Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, Maui, HI Vol. 2 (2000), p. 10.
- [15] R. Colwell, Testimony of Dr. Rita Colwell, Director, National Science Foundation, Before the Basic Research Subcommittee, House Science Committee, "Hearing on Remote Sensing as a Research and Management Tool," September 1998.
- [16] G. Coyle et al., "Home telecare for the elderly, Journal of Telemedicine and Telecare" 1 (1995) 183–184.
- [17] R.J. Cramer, M.Z. Win, R.A. Scholtz, "Impulse radio multipath characteristics and diversity reception", IEEE International Conference on Communications ICC'98 Vol. 3 (1998), pp. 1650–1654.
- [18] J.M. Cramer, R.A. Scholtz, M.Z. Win, "On the analysis of UWB communication channels", IEEE MILCOM'99, 1999, pp. 1191–1195.
- [19] DSN Team, "Multilateration Poster", SensIT Workshop, St. Petersburg, FL, April 2001.
- [20] J. Elson, D. Estrin, Random, "ephemeral transaction identifiers in dynamic sensor networks", Proceedings 21st International Conference on Distributed Computing Systems, Mesa, AZ, April 2001, pp. 459–468.
- [21] I.A. Essa, "Ubiquitous sensing for smart and aware environments", IEEE Personal Communications (October 2000) 47–49.
- [22] D. Estrin, L. Girod, G. Pottie, M. Srivastava, "Instrumenting the world with wireless sensor networks", International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2001), Salt Lake City, Utah, May 2001.
- [23] D. Estrin, R. Govindan, J. Heidemann, S. Kumar, "Next century challenges: scalable coordination in sensor networks", ACM MobiCom'99, Washington, USA, 1999, pp. 263–270.
- [24] D. Estrin, R. Govindan, J. Heidemann, "Embedding the Internet", Communication ACM 43 (2000) 38–41.
- [25] P. Favre et al., A 2V, 600 IA, 1 GHz "BiCMOS super regenerative receiver for ISM applications", IEEE Journal of Solid State Circuits 33 (1998) 2186–2196.
- [26] M. Gell-Mann, "What is complexity? Complexity", 1995.
- [27] L. Girod, D. Estrin, "Robust range estimation using acoustic and multimodal sensing", Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001), Maui, Hawaii, October 2001.
- [28] K. Govil, E. Chan, H. Wasserman, "Comparing algorithms for dynamic speed-setting of a low-power CPU", Proceedings of ACM MobiCom'95, Berkeley, CA, November 1995, pp. 13–25.
- [29] M.P. Hamilton, M. Flaxman, "Scientific data visualization and biological diversity: new tools for spatializing multimedia observations of species and ecosystems, Landscape and Urban Planning" 21 (1992) 285–297.
- [30] M.P. Hamilton, "Hummercams, robots, and the virtual reserve", Directors Notebook, February 6, 2000, available from <http://www.jamesreserve.edu/news.html>.
- [31] T. Gao, D. Greenspan, M. Welsh, R.R. Juang, "A. Alm, Vital signs monitoring and patient tracking over a wireless network", Proceedings of the 27th IEEE EMBS Annual International Conference