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Advances in Wireless Sensor Networks

BY

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Outline

- Introduction
- What are sensor networks (SNETs)?
- SNET taxonomies
- SNODE physical characteristics
- Research directions
- Potential applications
- WiSense
- Conclusions

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What are sensor networks?

- Sensor networks (SNETs) are composed of multiple interconnected and distributed sensors that collect information on areas or objects of interest.
- Sensor nodes (SNODEs) make up each sensor network and consist of three major components:
  - Parameter, event and object **sensing**
  - Data **processing** and classification
  - Data **communications**
- SNETs applications:

Health, Environment, Military, Home, Manufacturing, Entertainment, Digital lifestyle, etc…

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What's a Sensor Network

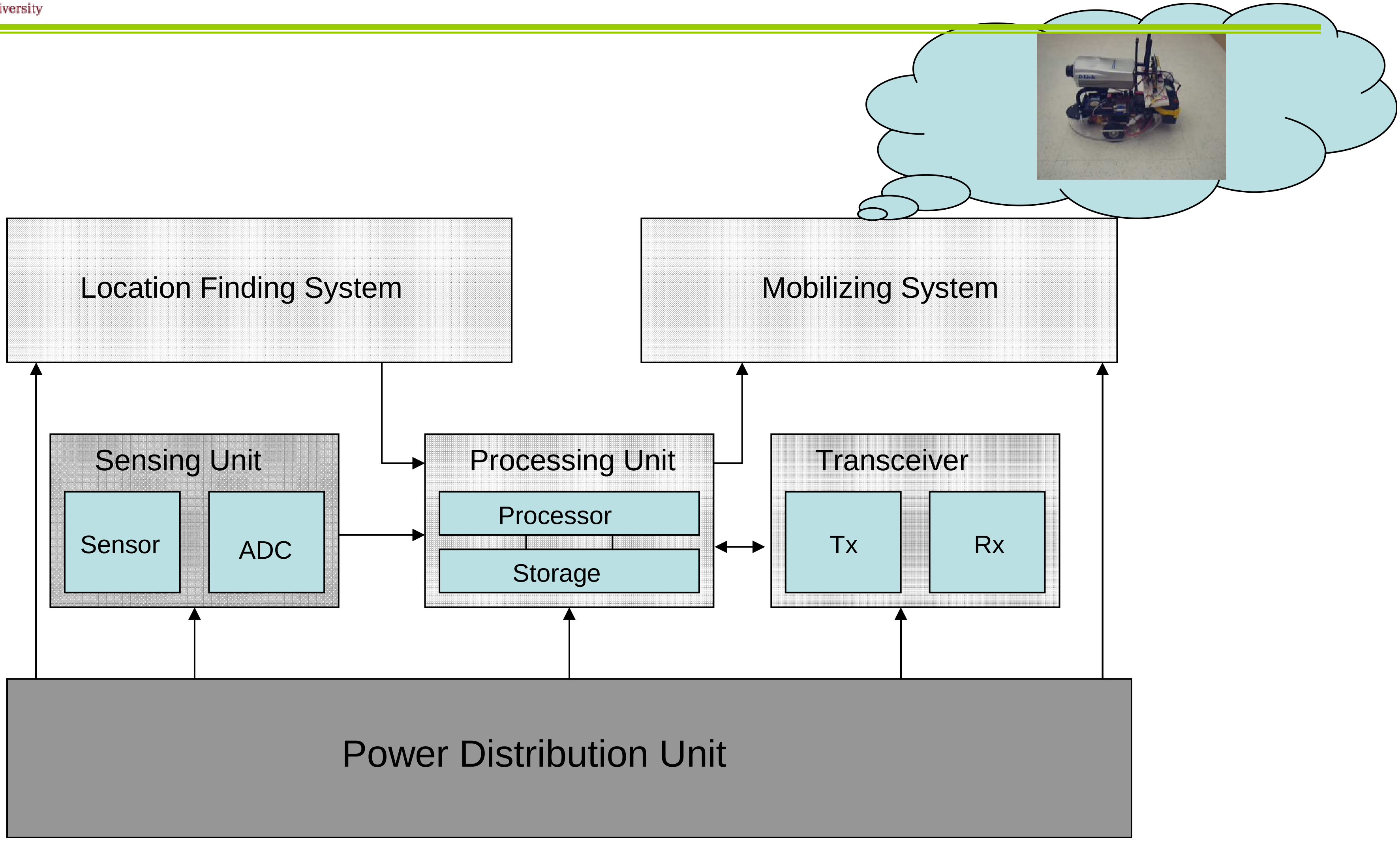
A simple equation:

Sensing + CPU + Radio

=

Thousands of potential applications

Generic Sensor Node Architecture



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Sensor nodes requirements

- Low cost
  - Large number used (much less than 1$)
- Small size
- Energy-efficient
- Operate in high volumetric densities
- Operate unattended
  - At the bottom of an ocean, in a biologically or chemically contaminated field, in a battlefield beyond the enemy lines,…

Platforms

WeC (1999)

250 Kbps, 100m range
512 KB flash
128 KB code
2KB data SRAM
CC2420 radio (2.4 Ghz, 802.15.4)

Telos (2004)

DOT (2001)

MICA (2002)

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SNET Taxonomies

- Hardware realization
  - Three main components re-appear
    - Sensing unit
    - Processing unit
    - Communications unit
  - SNODE must
    - Consume very little power
    - Be autonomous and low-cost
    - Adapt easily to the environment
    - Fit into small packaging

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SNET Taxonomies (Cont'd)

- Today's system-on-chip packages allow for integrated functionalities to reside on the same chip.
  - RF transceiver
    - Data rates are very low
    - Packets are very small
    - Frequency re-use is very high
  - Processor and core memory
    - Small and fast processors
    - ROM and RAM cores
    - Small-footprint RTOS

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SNET Taxonomies (Cont'd)

- Transmission media
  - Radio, infrared or optical media are viable.
  - IR forces the SNODEs to have line-of-sight capabilities which are very inefficient in SNETs.
  - Optical media forces the SNET to use optical fibre, resulting in an obtrusive invasion upon the environment.
  - RF media is the most suitable
    - Standards are becoming available worldwide.
    - Freely licensable bands
    - Transceivers are becoming smaller in size, cheaper in cost and lower in power consumption.
    - RF cores can be built right onto the processing unit.

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SNET Taxonomies (Cont'd)

- Power consumption valuations
  - Sensing unit power factors
    - Depends on the application (e.g. Temperature sensing will consume less power than visual object detection)
    - Could be lowered by turning off the sensing unit whenever possible
  - Processing unit power factors
    - Power saving techniques include dynamic voltage scaling, operating frequency reductions and smaller transistors (hence lower capacitance)
  - Communications unit power factors
    - Start-up time is non-negligible for RF transceivers, thus it is inefficient to turn the latter on and off
    - Main static power consumption parameter of the SNODE
  - Novel techniques have to balance computation and communications

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SNET Taxonomies (Cont'd)

- Communication architectures
  - Hierarchical (military-style) communication scheme
  - Peer-to-peer scheme
  - In either scheme, each SNODE is capable of collecting data, locally processing it and sending it to its neighbors/commanders

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SNET Taxonomies (Cont'd)

- A protocol stack is present on each SNODE
  - Application layer
    - Depends on the overall task being accomplished
  - Transport layer
    - Aids in data flow control throughout the SNET
  - Network layer
    - Involves routing the data amongst the SNODEs and throughout the SNET
  - Data link layer
    - Ensures reliable communication connections between SNODEs
  - Physical layer
    - Encapsulates the modulation, transmission and reception of data

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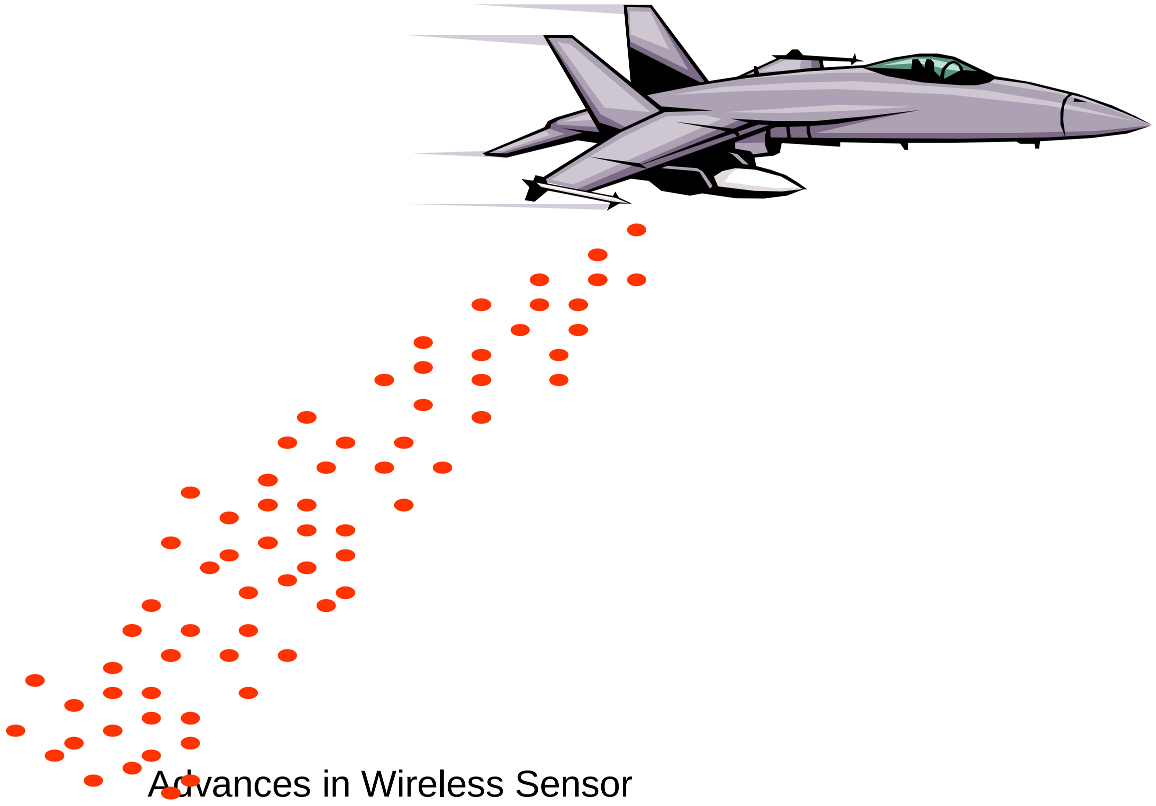
SNODE Physical Characteristics

- Sensor types and characteristics
- Processor support (ideally)
  - Relatively fast, low power consumption, small, on-chip memory, abundance of I/O capabilities, standard interfaces, robust instruction set architecture, availability of development tools, testable and reliable
- Employs computer control for a specific purpose (i.e. embedded system)
- Operating system support (ideally)
  - Multitasking and interrupt support, vast language and microprocessor support, ease of tool compatibility, wide array of services, small (both program and data), scaleable design, availability of debugging tools, standards compatibility, extensive device driver support
- It is imperative to have a low interrupt latency

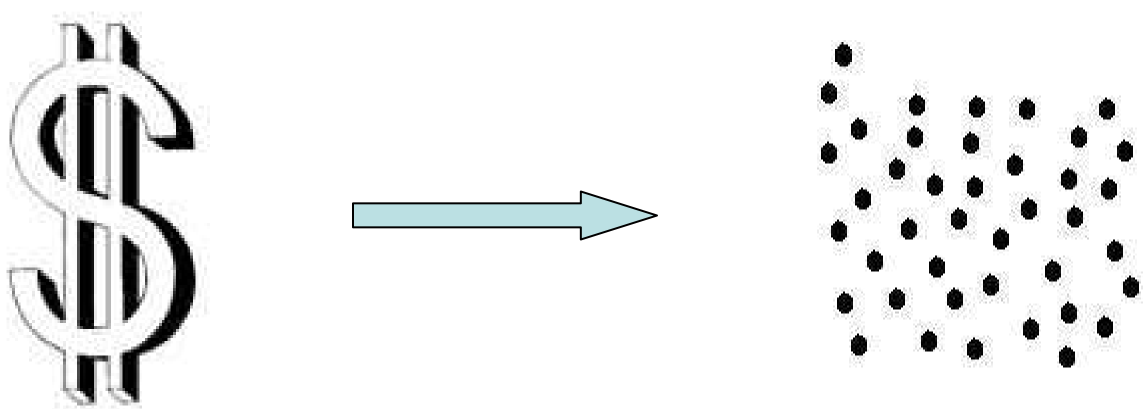
Characteristics

- Sensors are easily deployed.



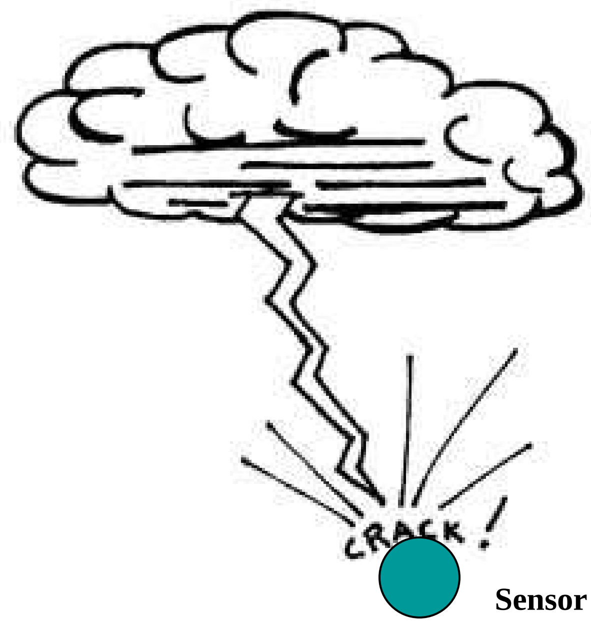
Characteristics

- Sensor are becoming less expensive, and more redundant.



Characteristics

- Sensors are prone to failure.



Characteristics

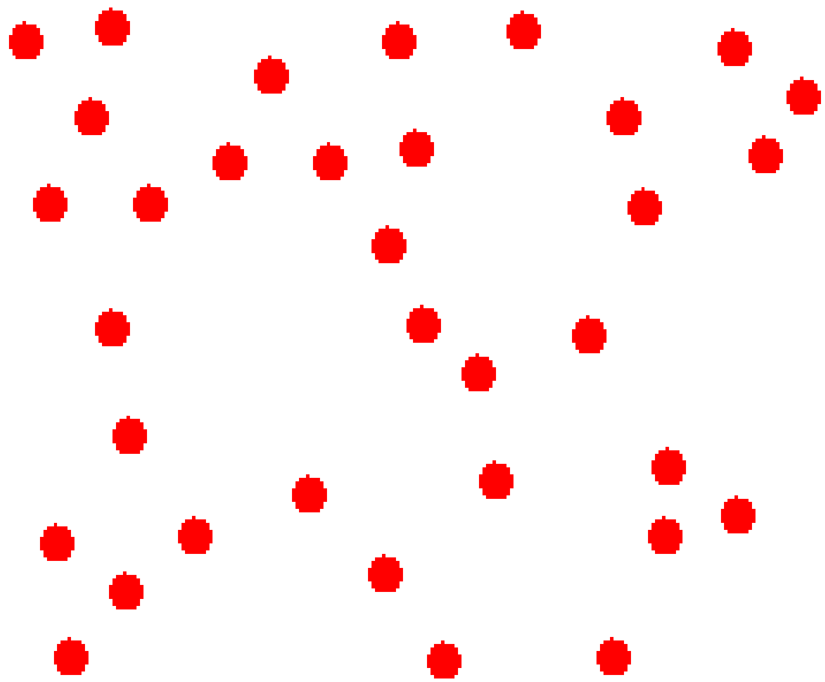
- Sensors are usually inaccessible.

In a jungle

In a war zone

Characteristics

- Sensors are usually dynamic.



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SNODE Physical Characteristics (Cont'd)

- Wireless technologies (ideally)
  - Low power utilization, simple transceiver circuitries, resilient to multipath effects, worldwide medium availability, standards compatibility, freely licensable, decent data transmission rate, wide range of operation
- Due to the limited power supply, researchers are trying to combine all three components (sensing, processing and transceiver) into tiny, low-power, low-cost units

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SNODE Physical Characteristics (Cont'd)

Wireless Technologies

Wireless Technology	Blue Tooth	IrDA	IEEE 802.15.3a Ultrawideband (UWB)	IEEE 802.11a	IEEE 802.11b (Wi-Fi)	IEEE 802.11g	IEEE 802.15.4 (ZigBee)
Data rate (Mb/s)	1-2	4	100-500	54	11	54	250 kbps and 20 kbps
Output power (mw)	100	100 mw/sr	1	40-800	200	65	30
Range (meters)	100	1-2	10	20	100	50	30
Frequency band	2.4 GHz	Infrared	3.1-10.6 GHz	5 GHz	2.4 GHz	2.4GHz	2.4 GHz and 868/915 MHz
Comments	7 active nodes	Very Short-range	Low power, short-range applications	Wireless LANs with high data rate	Wireless LANs with low data rate	Wireless LANs With lower power	Low duty-cycle applications

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Future Research Directions in SNETs

- Design of tiny, low-power, low-cost modules
- Network layer discovery and self-organization algorithms
- Collaborative signal processing and information synthesis
- Tasking and querying interfaces with the SNET
- Security for protection against intrusion and spoofing
- Reconfiguration techniques into suitable SNET configuration

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Potential Applications

- Traditional applications:
  - Health (e.g. vital sign monitoring)
  - Traffic (e.g. monitoring and control)
  - Environment (e.g. natural habitat analysis)
  - Military (e.g. object tracking)
  - Home (e.g. motion detection)
- Are the following far off?
  - Wireless mobile SNETs can inform you of the availability of a free parking spot (even reserves it)
  - Biological SNETs can monitor your health from within your body and can fight off viruses that may enter it
  - Nanorobotic airborne SNETs can swarm towards disaster sites and traffic jams to give their respective audiences as much visual, and overall sensory, information as possible

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Health Applications

- Telemonitoring of human physiological data
- Elderly Assistance.
- Drug administration in hospitals
- Tracking and monitoring doctors and patients inside a hospital
  - Each patient has small sensor nodes that execute different tasks ex: a sensor node to measure blood pressure.

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Challenges

- Must be extremely robust
- Must scale to very large network
- Power constraints
  - In case the sensor is implanted in the body, there is a risk of infections due to the power added from the sensors.
- Security and Interference

Biomedical sensor network significantly reduce overall medical cost

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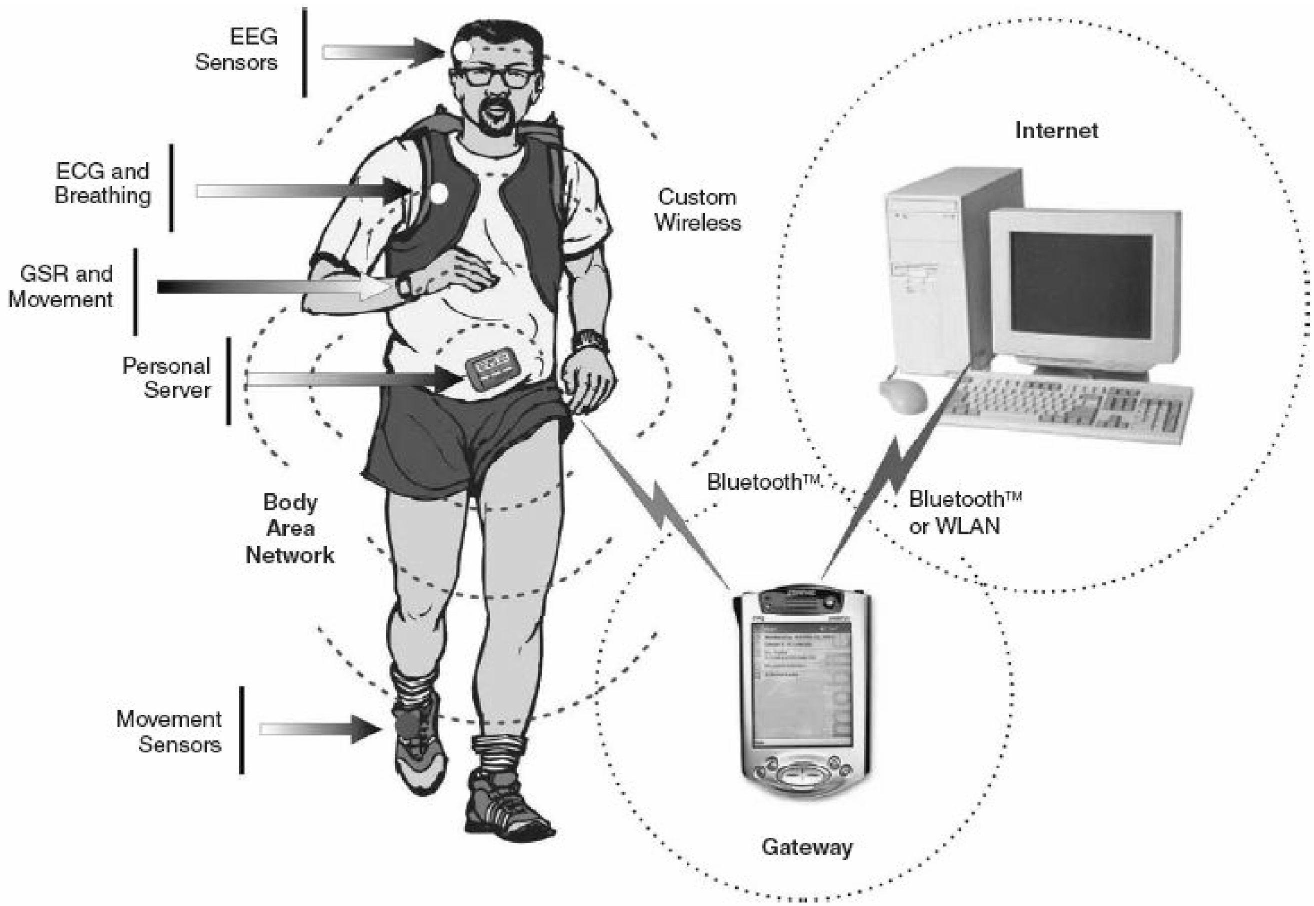
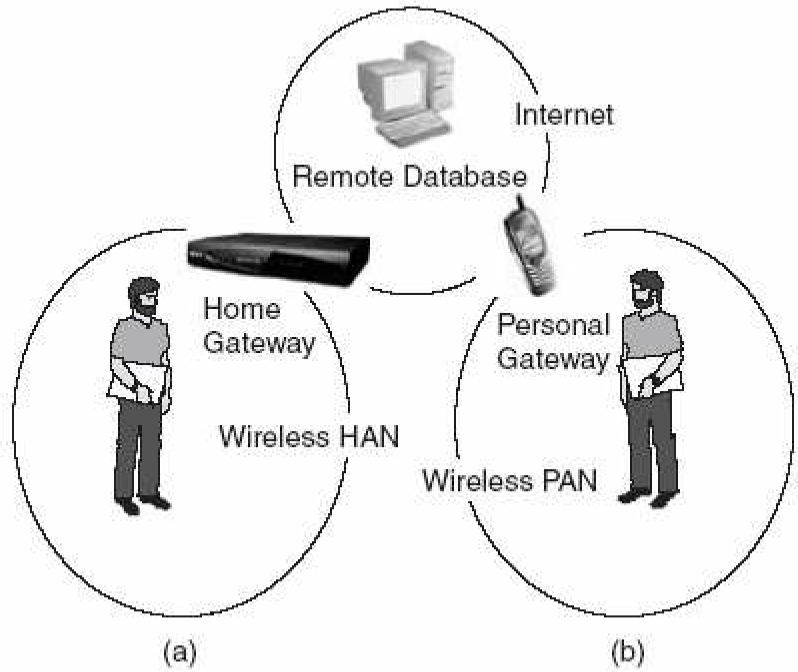


Wireless body area network of intelligent sensors in the telemedical Environment.



Two different models for transferring data from wearable sensors to a central data storage. In the first model (a), there is a home network, to which the sensors connect and which is used in communication. In The other model (b), a mobile device (e.g., a mobile phone) acts as a personal gateway to which the wearable sensor connects and which then transfers the data further to the central data storage by using a cellular network

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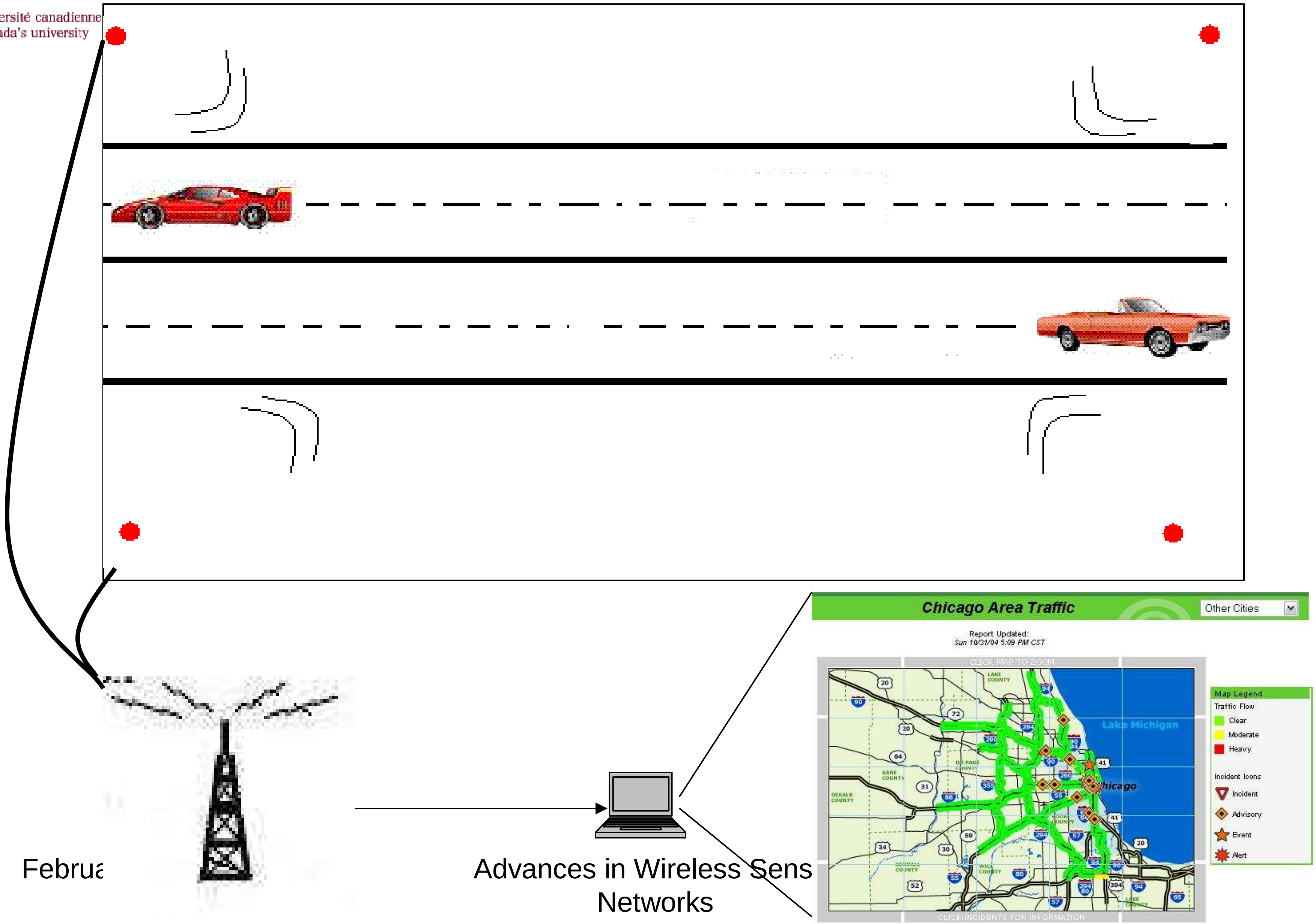
Traffic Sensor Network



Traffic Sensor Network

- Special Characteristics:
  - Sensors' positions are usually predetermined
  - Sensor may have a permanent power supply
  - Sensors are relatively accessible
  - Sensors may be wired

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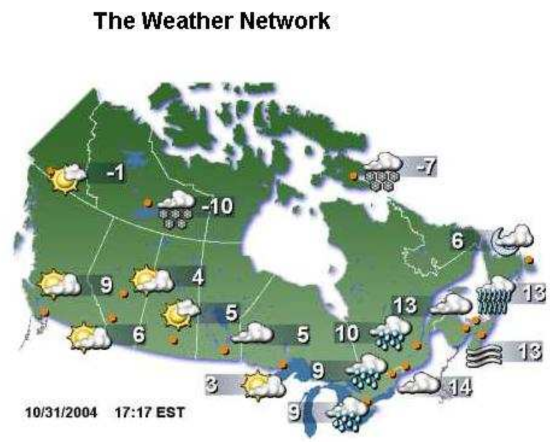
Environment Sensor Network



Weather

Animals

Applications

Water Pollution

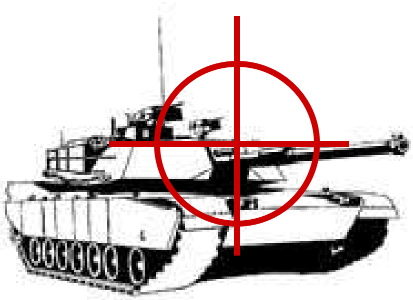
Air Pollution

Environment Sensor Network

- Special Characteristics:
  - Sensors positions may vary due to external influences.
  - Sensors are very prone to failure
  - Sensors are usually inaccessible
  - Environment Sensor networks scale up easily.
  - Sensors must be able to withstand natural elements, and must be environmentally friendly.

Military Sensor Network

- Military surveillance: Target detection, Area monitoring, etc…



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Military Sensor Network

- Special Characteristics:
  - Sensors are usually placed on dynamic nodes
  - Network might be peer to peer or centralized.
  - Network must provide real time data
  - Data must be accurate, so QoS is very high.

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Conclusions

- SNETs provide flexibility, fault-tolerance, high sensing fidelity, low-cost and rapid deployment
- However we must fall back onto standards, when available
- Sensor Networks will become more intelligent and pervasive
- Miniaturization, low-power, reliable and low-cost are key design factors for the next generation wireless sensor networks
- Our research efforts has led to WiSense

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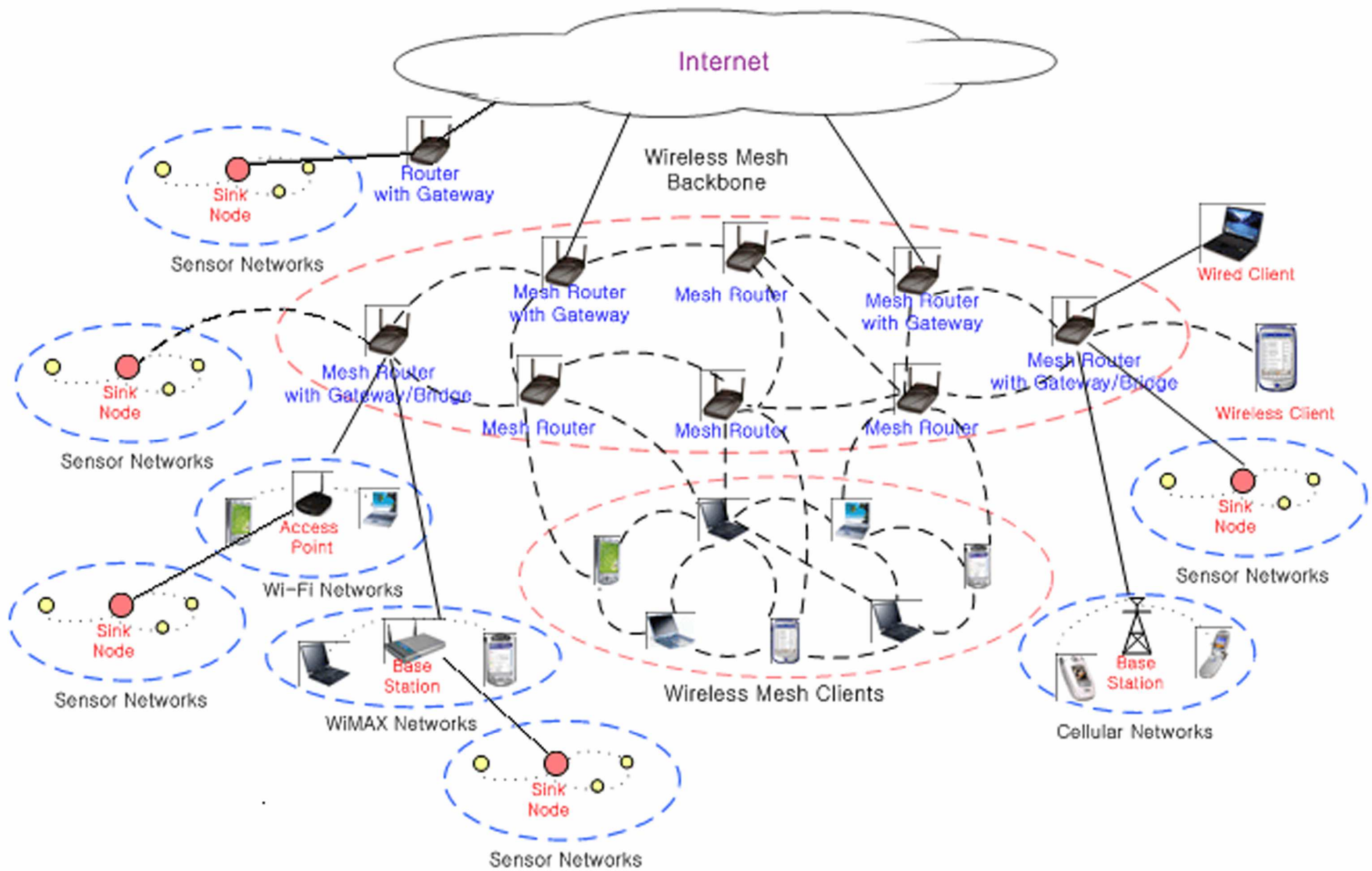
WiSense: Wireless Heterogeneous Sensor Networks in the e-Society

- A newly approved project by MRI ORF-RE program.
- Budget over 5 years: $9,223,800
  ($3,074,600 from ORF)
- University of Ottawa lead.

Objectives

- To develop and facilitate the use of scalable and modular wireless heterogeneous sensor networks in the e-Society with a focus on a limited number of applications
- Investigate architecture, planning and design of efficient, reliable and cost effective sensor networks and internetworking of wireless WiFi, WiMax and sensor network interfaces in a mesh and ad hoc network environment

WiSense Network Environment



The Team

- U of Ottawa:

  H.T. Mouftah (PI), A. Boukerche, D. Makrakis, A. Miri, M. Bolic, X. Bao, L. Peyton

- U of Waterloo:

  S. Shen, P.-H. Ho

- McMaster U:

  T.D. Todd, P. Koutsakis

- Queen’s U:

  H. S. Hassanein, M. IbnKahla, G. Takahara

Industrial Partners

- Bell Canada
- Alcatel-Lucent
- IBM
- Research In Motion
- Freescale Semiconductor
- PacketDNA
- Wireless Network Design & EMC Services

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WiSense Projects

- **Theme 1: Architecture**
  Theme Leaders: Makrakis and Mouftah
  - a) Physical and Link Layers PL: Makrakis
  - b) Wireless Channel & Sensor Traffic Modeling PL: Makrakis and Miri
  - c) Wireless Mesh Networking PL: Mouftah
- **Theme 2: System Design**
  Theme Leader: Hassanein
  - a) Reliable Data Delivery Protocols PL: Takahara and Hassanein
  - b) Energy Efficient Protocols & Algorithms PL: Mouftah
  - c) Cost Efficient Systems Design PL: Hassanein
- **Theme 3: Gateway Access**
  Theme Leader: Terry Todd
  - a) Hybrid WLAN/Sensor Networks Integration PL: Shen
  - b) Outdoor Infrastructure for Hybrid Sensor Networks PL: Todd& Koutsakis
- **Theme 4: Network Security**
  Theme Leader: Shen
  - a) Threat Analysis PL: Shen and Ho
  - b) User Authentication, Location Privacy and Anonymity PL: Boukerche
  - c) Secure, Authenticated Broadcast Protocols PL: Ho
  - d) Side-channel Resistant Cryptographic Solutions PL: Miri
- **Theme 5: Services**
  Theme Leaders: Boukerche and Mouftah
  - a) Emergency Preparedness and Response PL: Boukerche
  - b) Telemedicine PL: Peyton
  - c) Intelligent Vehicular Systems PL: Makrakis
  - d) Intelligent Buildings and Home Security PL: Mouftah
- **Theme 6: Test-bed Development**
  Theme Leader: Mouftah
  - a) Reconfigurable Test-bed PL: Ibnkahla
  - b) RFID/Sensor Network Interfaces PL: Bolic
  - c) Web-Services-based Test-bed PL: Peyton
  - d) Mobile Test-bed Interfaces PL: Makrakis & Bao
  - e) Test-bed System Integration PL: Mouftah

Researchers per Theme

Theme	PhD Students	MSc Students	PDF
Architecture: Makrakis & Mouftah Miri	3	3	2
System Design: Hassanein Takahara, Mouftah	3	2	2
Gateway Access: Todd Shen, Koutsakis	2	2	-
Network Security: Shen Ho, Boukerche, Miri	2	3	1
Services: Boukerche & Mouftah Peyton, Makrakis	2	4	2
Test Bed Development: Mouftah Ibnkahla, Bolic, Peyton, Makrakis, Bao	1	4	1

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Conclusions

WiSense would have the potential to radically changing the nature of wireless communications in the e-Society with more intelligence and pervasiveness.

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Thank you!

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References [1/2]

[1] http://www.eecs.harvard.edu/~mdw/talks/ge-codeblue.pdf

[2] http://arri.uta.edu/acs/networks/Networks03-I-Main.ppt

[3] E. Jovanov, D. Raskovic, J. Price, A. Moore, J. Chapman, A. Krishnamurthy, "Patient Monitoring Using Personal Area Networks of Wireless Intelligent Sensors", Biomedical Sciences Instrumentation, Vol. 37, Proc. 38th Annual Rocky Mountain Bioengineering Symposium, April 2001, Copper Mountain, pp. 373-378, 2001.

[4] http://www.eecs.harvard.edu/~mdw/course/cs263/notes/intro.pdf

[5] http://www.eecs.harvard.edu/~mdw/talks/ge-codeblue.pdf

[6] L. Schwiebert, S.K.S. Gupta and J. Weinmann, "Research Challenges in Wireless Networks of Biomedical Sensors", Proc. Mobicom'2001, pp. 151-165.

[7] Rami Abielmona, "Sensor Networks: Research Challenges in Practical Implementations, Physical Characteristics and Applications", OWRA/IEEE ComSoc/NCIT/CRC Seminar Day, Ottawa, November 2003.

[8] http://www.xbow.com/Support/manuals.htm, 2005 Crossbow Technology, Last viewed: 10 September 2006

[9] Crossbow;"Wireless Systems for Environmental Monitoring", Smart Dust Application Note.

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References [2/2]

[10] I.F. Akyildiz, W.Su, Y. Sankarasubramaniam, E. Cayirci, "Wireless sensor networks: a survey," Computer Networks, vol. 38, pp. 393-422, 2002.

[11] L. Tong, Q. Zhao and S. Adireddy, "Sensor Networks with Mobile Agents", Proc. IEEE Milcom'03, Boston, MA, October 2003.

[12] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "A survey on sensor networks", IEEE Communications Magazine, Volume 40, No 8, Aug. 2002, pp. 102 – 114.

[13] C. Chong and S.P. Kumar, "Sensor networks: evolution, opportunities, and challenges", IEEE Proceedings, Vol. 91, No 8, Aug. 2003, pp. 1247 – 1256.

[14] D. Estrin, D. Culler, K. Pister and G. Sukhatme, "Connecting the physical world with pervasive networks", IEEE Proceedings of the Pervasive Computing, March 2002, pp. 59 – 69.

[15] A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk and J. Anderson, "Applications and OS: Wireless sensor networks for habitat monitoring", Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications, September 2002, pp. 88 – 97.