ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 2, Issue 12, December 2013

Wireless Sensor Networks and its Challenges

Gautam Sahu[1], Sarita Misra[2], Urmila Bhanja[3]

[1]BSNL, Bhubaneswar
[2]Eastern Academi of Science and Technology, Orissa

***Abstract* : Sensor networks offer a powerful combination of distributed sensing, computing and communication. They lend themselves to countless applications and, at the same time, offer numerous challenges due to their peculiarities, primarily the stringent energy constraints to which sensing nodes are typically subjected. The distinguishing traits of sensor networks have a direct impact on the hardware design of the nodes at least at four levels: power source, processor, communication hardware, and sensors. Various hardware platforms have already been designed to test the many ideas spawned by the research community and to implement applications to virtually all fields of science and technology. We are convinced that CAS will be able to provide a substantial contribution to the development of this exciting field. This paper gives brief overview about "Wireless Sensor Networks and its Challenges".**

1. Introduction

A Wireless Sensor Networks consists of spatially distributed autonomous sensor nodes to monitor physical, or environment conditions. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance. The more modern networks are bi-directional, also enabling control of sensor activity. The WSN is built of "nodes" – the number of nodes may vary from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery. Sensing, processing and communication are three key elements whose combination in one tiny device gives rise to a vast number of applications [1], [2]. A sensor node might vary in size than that of a shoebox to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth. Internal power sources help to eliminate the need for wires to the nodes and allow greater mobility. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding [3], [4].

Sensor networks provide endless opportunities, but at the same time pose formidable challenges, such as the fact that energy is a scarce and usually non-renewable resource. However, recent advances in low power VLSI, embedded computing, communication hardware, and in general, the convergence of computing and communications, are making this emerging technology a reality [5], [6]. Likewise, advances in nanotechnology and Micro Electro-Mechanical Systems (MEMS) are pushing toward networks of tiny distributed sensors and actuators.

The rest of the paper is organized as follows. Section-2 describes about the sensor Networks and its feature followed by the application of sensor Networks in Section-3. The challenges of a Sensor Network is presented in Section-4 and conclusions in section 5.

2. Sensor Networks and its Features

Now a days WSN are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, habitat monitoring, structural health monitoring, pipeline monitoring, transportation, precision agriculture, supply chain management, and many more [7]. Wireless solutions have other benefits in industrial applications such as enhanced physical mobility, reduced danger of breaking cables, less hassle with connectors and ease of upgrading The WSN is built of "nodes" – the number of nodes may vary from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding. In flooding method more energy will be consumed by the nodes. This technique is generally used urgent message transfer between the nodes, such as critical failure signals. In routing technique, by adopting proper routing protocol much of the energy of a sensor node can be saved and thus increases the lifetime of a node.

3. Applications of Sensor Networks

Possible applications of sensor networks are of interest to the most diverse fields. Environmental monitoring, warfare, child education, surveillance, micro-surgery, and agriculture are only a few examples.

Through joint efforts of the University of California at Berkeley and the College of the Atlantic, environmental monitoring is carried out off the coast of Maine on Great Duck Island by means of a network of Berkeley motes equipped with various sensors [8]. The nodes send their data to a base station which makes them available on the Internet.

Since habitat monitoring is rather sensitive to human presence, the deployment of a sensor network provides a noninvasive approach and a remarkable degree of granularity in data acquisition. The same idea lies behind the Pods project at the University of Hawaii at Manoa [9], where environmental data (air temperature, light, wind, relative humidity and rainfall) are gathered by a network of weather sensors embedded in the communication units deployed in the South-West Rift Zone in Volcanoes National Park on the Big Island of Hawaii. A major concern of the researchers was in this case camouflaging the sensors to make them invisible to curious tourists.

Sensor networks can also be used to monitor and study natural phenomena which intrinsically discourage human presence, such as hurricanes and forest fires, to monitor eruptions at an active volcano.

Similarly animal movement can be seen by using a dynamic sensor network has been created by attaching special collars equipped with a low-power GPS system to the necks of animals to monitor their moves and their behavior [10]. Since the network is designed to operate in an infrastructure-free environment, peer-to-peer swaps of information are used to produce redundant databases so that researchers only have to encounter a few desired animals in order to collect the data.

Intel's Wireless Vineyard [11] is an example of using ubiquitous computing for agricultural monitoring. In this application, the network is expected not only to collect and interpret data, but also to use such data to make decisions aimed at detecting the presence of parasites and enabling the use of the appropriate kind of insecticide. Data collection relies on data mules, small devices carried by people that communicate with the nodes and collect data. In this project, the attention is shifted from reliable information collection to active decision making based on acquired data.

Just as they can be used to monitor nature, sensor networks can likewise be used to monitor human behavior. In the Smart Kindergarten project at UCLA [12], wirelessly-networked, sensor-enhanced toys and other classroom objects supervise the learning process of children and allow unobtrusive monitoring by the teacher. Medical research and healthcare can greatly benefit from sensor networks: vital sign monitoring and accident recognition are the most natural applications. An important issue is the care of the elderly, especially if they are affected by cognitive decline: a network of sensors and actuators could monitor them and even assist them in their daily routine. Smart appliances could help them organize their lives by reminding them of their meals and medications.

Sensors can be used to capture vital signs from patients in real-time and relay the data to handheld computers carried by medical personnel, and wearable sensor nodes can store patient data such as identification, history, and treatments. With these ideas in mind, Harvard University is cooperating with the School of Medicine at Boston University to develop CodeBlue, an infrastructure designed to support wireless medical sensors, PDAs, PCs, and other devices that may be used to monitor and treat patients in various medical scenarios [13]. On the hardware side, the research team has created Vital Dust, a set of devices based on the MICA21 sensor node platform (one of the most popular members of the Berkeley motes family), which collect heart rate, oxygen saturation, and EKG data and relay them over a medium-range (100 m) wireless network to a PDA [14].Interactions between sensor networks and humans are already judged controversial. The US has recently approved the use of a radio-frequency implantable device (VeriChip) on humans, whose intended application is accessing the medical records of a patient in an emergency. Potential future repercussions of this decision have been discussed in the media.

An interesting application to civil engineering is the idea of Smart Buildings: wireless sensor and actuator networks integrated within buildings could allow distributed monitoring and control, improving living conditions and reducing the energy consumption, for instance by controlling temperature and air flow [15], [16]. Military applications are plentiful. An intriguing example is self-healing minefield [17], a self-organizing sensor network where peer-to-peer communication between anti-tank mines is used to respond to attacks and redistribute the mines in order to heal breaches, complicating the progress of enemy troops. Similarly mine identification can aslo be done by WSN [18].

Urban warfare is another application that distributed sensing lends itself to[19]. An ensemble of nodes could be deployed in a urban landscape to detect chemical attacks, or track enemy movements. PinPtr is an ad hoc acoustic sensor network for sniper localization developed at Vanderbilt University [20]. The network detects the muzzle blast and the acoustic shock wave that originate from the sound of gunfire. The arrival times of the acoustic events at different sensor nodes are used to estimate the position of the sniper and send it to the base station with a special data aggregation and routing service.

Going back to peaceful applications, efforts are underway at Carnegie Mellon University and Intel for the design of IrisNet (Internet-scale Resource-Intensive Sensor Network Services) [21], an architecture for a worldwide sensor web based on common computing hardware such as Internet-connected PCs and low-cost sensing hardware such as webcams. The network interface of a PC indeed senses the virtual environment of a LAN or the Internet rather than a physical environment; with an architecture based on the concept of a distributeddatabase [22], this hardware can be

ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 2, Issue 12, December 2013

orchestrated into a global sensor system that responds to queries from users.

Wireless Sensor Networks has wide applications. However, there are several issues to be taken care before Wireless Sensor Networks becomes a reality. The Challenges are discussed in the next section.

4. Challenges

In ad hoc networks, wireless nodes self-organize into an infrastructureless network with a dynamic topology. Sensor networks (such as the one in Figure 1) share these traits, but also have several distinguishing features. The number of nodes in a typical sensor network is much higher than in a typical ad hoc network, and dense deployments are often desired to ensure coverage and connectivity; for these reasons, sensor network hardware must be cheap. Nodes typically have stringent energy limitations, which make them more failure-prone. They are generally assumed to be stationary, but their relatively frequent breakdowns and the volatile nature of the wireless channel nonetheless result in a variable network topology. Ideally, sensor network hardware should be power-efficient, small, inexpensive, and reliable in order to maximize network lifetime, add flexibility, facilitate data collection and minimize the need for maintenance.

External Infrastructure

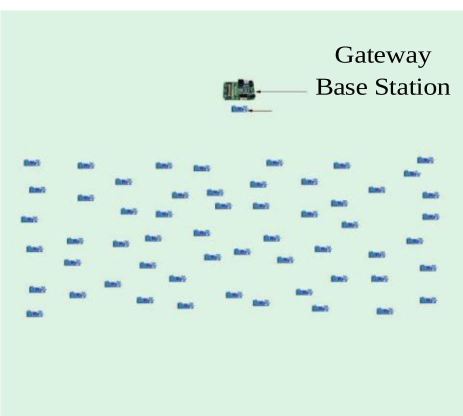

Figure 1. A sensor network with a two-tiered architecture.

Lifetime

Lifetime is extremely critical for most applications, and its primary limiting factor is the energy consumption of the nodes, which need to be self-powering. Although it is often assumed that the transmit power associated with packet transmission accounts for the much share of power consumption, sensing, signal processing and even hardware operation in standby mode consume a consistent amount of power as well [23]. Sleep scheduling is to be done for saving of power of a sensor network and so as to increase the life time of a sensor node as well as that of the network [24]. In some applications, extra power is needed for macro-scale actuation. Many researchers suggest that energy consumption could be reduced by a considerable amount by considering packet splitting and by using better forwarding algorithm [25]. Here they used CRT based packet forwarding solution. Some other researchers suggest the existing interdependencies between individual layers in the network protocol stack. Routing and channel access protocols, for instance, could greatly benefit from an information exchange with the physical layer. At the physical layer, benefits can be obtained with lower radio duty cycles and dynamic modulation scaling (varying the constellation size to minimize energy expenditure [26]). Using low-power mode for the processor or disabling the radio is generally advantageous, even though periodically turning a subsystem on and off may be more costly than always keeping it on. Techniques aimed at reducing the idle mode leakage current in CMOS-based processors are also to be noted [27]. Medium Access Control (MAC) solutions have a direct impact on energy consumption, as some of the primary causes of energy waste are found at the MAC layer: collisions, control packet overhead and idle listening. Powersaving forward error control techniques are not easy to implement due to the high amount of computing power that they require and the fact that long packets are normally not practical. Energy-efficient routing should try not to lose a node due to battery depletion. Many proposed protocols tend to minimize energy consumption on forwarding paths, [28] but if some nodes happen to be located on most forwarding paths (e.g., close to the base station), their lifetime will be reduced as they carry all data coming from all nodes.

Flexibility

Sensor networks should be scalable, and they should be able to dynamically adapt to changes in node density and topology, like in the case of the self-healing minefields. In surveillance applications, most nodes may remain silent as long as nothing interesting happens. However, they must be able to respond to special events that the network intends to study with some degree of granularity. In a self-healing minefield, a number of sensing mines may sleep as long as none of their peers explodes, but need to quickly become operational in the case of an enemy attack. Response time is also very critical in control applications (sensor/actuator networks) in which the network is to provide a delay-guaranteed service. Automated systems need to self-configure and adapt to different conditions. Sensor networks should also be robust to changes in their topology, for instance due to the failure of individual nodes. In particular, connectivity and coverage should always be guaranteed. Connectivity is achieved if the base station can be reached from any node. Coverage can be seen as a measure of quality of service (QOS) in a sensor network [29], as it defines how well a particular area can be observed by a network and characterizes the probability of detection of geographically constrained phenomena or events. Complete coverage is particularly important for surveillance applications.

Maintenance

The only desired form of maintenance in a sensor network is the complete or partial update of the program code in the sensor nodes over the wireless channel. All sensor nodes should be updated, and the restrictions on the size of the new code should be the same as in the case of wired programming. Packet loss must be accounted for and should not impede correct reprogramming. The portion of code always running in the node to guarantee reprogramming support should have a small footprint, and updating procedures should only cause a brief interruption of the normal operation of the node [30]. The functioning of the network as a whole should not be endangered by unavoidable failures of single nodes, which may occur for a number of reasons, from battery depletion to unpredictable external events, and may either be independent or spatially correlated. Self-configuring nodes are necessary to allow the deployment process to run smoothly without human interaction, which should in principle be limited to placing nodes into a given geographical area. It is not desirable to have humans configure nodes for habitat monitoring and destructively interfere with wildlife in the process, or configure nodes for urban warfare monitoring in a hostile environment. The nodes should be able to assess the quality of the network deployment and indicate any problems that may arise, as well as adjust to changing environmental conditions by automatic reconfiguration. Location awareness is important for self-configuration and has definite advantages in terms of routing and security. Time synchronization [31] is advantageous in promoting cooperation among nodes, such as data fusion, channel access, coordination of sleep modi, or security-related interaction.

Data Collection

Data collection is related to network connectivity and coverage. An interesting solution is the use of ubiquitous mobile agents that randomly move around to gather data bridging sensor nodes and access points, whimsically named data MULEs (Mobile Ubiquitous LAN Extensions) in [32]. The predictable mobility of the data sink can be used to save power, as nodes can learn its schedule. A similar concept has been implemented in Intel's Wireless Vineyard. It is often the case that all data are relayed to a base station, but this form of centralized data collection may shorten network lifetime. Relaying data to a data sink causes non-uniform power consumption patterns that may overburden forwarding nodes [33]. This is particularly harsh on nodes providing end links to base stations, which may end up relaying traffic coming from all other nodes, thus forming a critical bottleneck for network throughput. An interesting technique is clustering [34]: nodes team up to form clusters and transmit their information to their cluster heads, which fuse the data and forward it to a sink. Fewer packets are transmitted, and a uniform energy consumption pattern may be achieved by periodic re-clustering. Data redundancy is minimized, as the aggregation process fuses strongly correlated measurements. Many applications require that queries be sent to sensing nodes. This is true, for example, whenever the goal is gathering data regarding a particular area where various sensors have been deployed. So a sensor network can be thought as a database.

.

Security

A sensor network should be able to protect itself and its data from external attacks, but the severe limitations of lower-end sensor node hardware make security a true challenge. Typical encryption schemes, for instance, require large amounts of memory that are unavailable in sensor nodes. Data confidentiality should be preserved by encrypting data with a secret key shared with the intended receiver. Data integrity should be ensured to prevent unauthorized data alteration. An authenticated broadcast must allow the verification of the legitimacy of data and their sender. In a number of commercial applications, a serious disservice to the user of a sensor network is compromising data availability (denial of service), which can be achieved by sleep-deprivation torture: batteries may be drained by continuous service requests or demands for legitimate but intensive tasks [35], preventing the node from entering sleep mode.

Hardware Design Issues

In a sensor node, we can identify a power module, a communication block, a processing unit with internal and/or external memory, and a module for sensing and actuation.

Power

Using stored energy or harvesting energy from the outside world are the two options for the power module. Energy storage may be achieved with the use of batteries or alternative devices such as fuel cells or miniaturized heat engines, whereas energy-scavenging opportunities are provided by solar power, vibrations, acoustic noise, and piezoelectric effects [36]. The vast majority of the existing commercial and research platforms relies on batteries, which dominate the node size. Primary (nonrechargeable) batteries are often chosen, predominantly AA, AAA and coin-type. Alkaline batteries offer a high energy density at a cheap price, offset by a non-flat discharge, a large physical size with respect to a typical sensor node, and a shelf life of only 5 years.

Secondary (rechargeable) batteries are typically not desirable, as they offer a lower energy density and a higher cost, also to be mentioned the fact that in most applications recharging is simply not practical. Fuel cells are rechargeable electrochemical energy- conversion devices where electricity and heat are produced as long as hydrogen is supplied to react with oxygen. Pollution is minimal, as water is the main byproduct of the reaction. The potential of fuel cells for energy storage and power delivery is much higher than the one of traditional battery technologies, but the fact that they require hydrogen complicates their application. Using renewable energy and scavenging techniques is an interesting alternative.

Communication

Most sensor networks use radio communication, even if alternative solutions are offered by laser and infrared. Nearly all radio-based platforms use COTS (Commercial Off-The-Shelf) components. Popular choices include the TR1000 from RFM (used in the MICA motes) and the CC1000 from Chipcon (chosen for the MICA2 platform). More recent solutions use industry standards like IEEE 802.15.4 (MICAz and Telos motes with CC2420 from Chipcon) or pseudo-standards like Bluetooth. Typically, the transmit power ranges between −25 dBm and 10 dBm, while the receiver sensitivity can be as good as −110 dBm. Spread spectrum techniques increase the channel reliability and the noise tolerance by spreading the signal over a wide range of frequencies. Frequency hopping (FH) is a spread spectrum technique used by Bluetooth: the carrier frequency changes 1600 times per second on the basis of a pseudo-random algorithm. However, channel synchronization, hopping sequence search, and the high data rate increase power consumption; this is one of the strongest caveats when using Bluetooth in sensor network nodes. In Direct Sequence Spread Spectrum (DSSS), communication is carried out on a single carrier frequency. The signal is multiplied by a higher rate pseudo-random sequence and thus spread over a wide frequency range (typical DSSS radios have spreading factors between 15 and 100). Ultra Wide Band (UWB) is of great interest for sensor networks since it meets some of their main requirements. UWB is a particular carrier-free spread spectrum technique where the RF signal is spread over a spectrum as large as several GHz. This implies that UWB signals look like noise to conventional radios. Such signals are produced using baseband pulses (for instance, Gaussian monopulses) whose length ranges from 100 ps to 1 ns, and baseband transmission is generally carried out by means of pulse position modulation (PPM). Modulation and demodulation are indeed extremely cheap. UWB provides built-in ranging capabilities (a wideband signal allows a good time resolution and therefore a good location accuracy) [37], allows a very low power consumption, and performs well in the presence of multipath fading. Radios with relatively low bit-rates (up to 100 kbps) are advantageous in terms of power consumption. In most sensor networks, high data rates are not needed, even though they allow shorter transmission times thus permitting lower duty cycles and alleviating channel access contention. It is also desirable for a radio to quickly switch from a sleep mode to an operational mode. Optical transceivers such as lasers offer a strong power advantage, mainly due to their high directionality and the fact that only baseband processing is required. Also, security is intrinsically guaranteed (intercepted signals are altered). However, the need for a line of sight and precise localization makes this option impractical for most applications.

Processing and Computing

Microcontrollers (MCUs), [5] are now the primary choice for processing in sensor nodes. The key metric in the selection of an MCU is power consumption. Sleep mode deserve special attention, as in many applications low duty cycles are essential for lifetime extension. Just as in the case of the radio module, a fast wake-up time is important. Most CPUs used in lower-end sensor nodes have clock speeds of a few MHz. The memory requirements depend on the application and the network topology: data storage is not critical if data are often relayed to a base station. Berkeley motes, UCLA's Medusa MK-2 and ETHZ's BTnodes use low-cost Atmel AVR 8-bit RISC microcontrollers which consume about 1500 pJ/instruction. More sophisticated platforms, such as the Intel iMote and Rockwell WINS nodes, use Intel StrongArm/XScale 32-bit processors.

Sensing

The high sampling rates of modern digital sensors are usually not needed in sensor networks. The power efficiency of sensors and their turn-on and turn-off time are much more important. Additional issues are the physical size of the sensing hardware, fabrication, and assembly compatibility with other components of the system. Packaging requirements come into play, for instance, with chemical sensors which require contact with the environment [7]. Using a microcontroller with an onchip analog comparator is another energy-saving technique which allows the node to avoid sampling values falling outside a certain range. The ADC which complements analog sensors is particularly critical, as its resolution has a direct impact on energy consumption. Fortunately, typical sensor network applications do not have stringent resolution requirements. Micromachining techniques have allowed the miniaturization of many types of sensors. Performance does decrease with sensor size, but for many sensor network applications size matters much more than accuracy. Standard integrated circuits may also be used as temperature sensors (e.g., using the temperature dependence of subthreshold MOSFETs and pn junctions) or light intensity transducers (e.g., using photodiodes or phototransistors). Nanosensors can offer promising solutions for biological and chemical sensors while concurrently meeting the most ambitious miniaturization needs.

4. Conclusion

Sensor networks offer countless challenges, but their versatility and their broad range of applications are eliciting more and more interest from the research community as well as from industry. Sensor networks have the potential of triggering the next revolution in information technology. The challenges in terms of circuits and systems are numerous: the development of low-power communication hardware, low-power microcontrollers, MEMS based sensors and actuators, efficient AD conversion, and energy-scavenging devices is necessary to enhance the potential and the performance of sensor networks. System integration is another major challenge that sensor networks offer to the circuits and systems research community. We believe that CAS can and should have a significant impact in this emerging, exciting area.

5. References

[1] I. F. Akyildiz, T. Melodia, and K. R. Chowdury, "A Survey on Wireless Multimedia Sensor Networks," *Computer Networks (Elsevier)*, vol. 51, no. 4, pp. 921–960, March 2007.

[2] T. Arampatzis, J. Lygeros, and S. Manesis, "A survey of applications of wireless sensors and wireless sensor networks," in *Proc. IEEE Int. Symp.Intell. Control*, 2005, pp. 719–724.

[3] L. LoBello and E. Toscano, "An adaptive approach to topology management in large and dense real-time wireless sensor networks," *IEEE Trans.Ind. Informat.*, vol. 5, no. 3, pp. 314–324, Aug. 2009.

ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 2, Issue 12, December 2013

[4] L.B. Ruiz, L.H.A. Correia, L.F.M. Vieira, D.F. Macedo, E.F. Nakamura, C.M.S. Figueiredo, M.A.M. Vieira, E.H.B. Maia, D. Câmara, A.A.F. Loureiro, J.M.S. Nogueira, D.C. da Silva Jr., and A.O. Fernandes, "Architectures for wireless sensor networks (In Portuguese)," in Proceedings of the 22nd Brazilian Symposium on Computer Networks (SBRC'04), Gramado, Brazil, pp. 167–218, May 2004. Tutorial. ISBN: 85-88442-82-5.
[5] W. Dargie and C. Poellabauer, Fundamentals of Wireless Sensor Networks:Theory and Practice, 1 ed. New York: Wiley, 2010.
[6] C.Y. Chong and S.P. Kumar, "Sensor networks: Evolution, opportunities, and challenges," in IEEE Proceedings, pp. 1247–1254, Aug. 2003.
[7] V. C. Gungor and G. P. Hancke, "Industrial wireless sensor networks: Challenges, design principles, and technical approaches," IEEE Trans. Ind. Electron., vol. 56, no. 10, pp. 4258–4265, Oct. 2009.
[8] A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler, and J. Anderson, "Wireless sensor networks for habitat monitoring," in First ACM Workshop on Wireless Sensor Networks and Applications, Atlanta, GA, Sept. 2002.
[9] E. Biagioni and K. Bridges, "The application of remote sensor technology to assist the recovery of rare and endangered species," International Journal of High Performance Computing Applications, vol. 16, pp. 315–324, Aug. 2002.
[10] W. Xiao, J. Wu, and L. Xie, "Adaptive sensor scheduling for target tracking in wireless sensor network," in Proc. Soc. Photo-Opt. Instrum. Eng. Conf. Ser., 2005, vol. 5910, pp. 104–112.
[11] J. Burrell, T. Brooke, and R. Beckwith, "Vineyard computing: Sensor networks in agricultural production," IEEE Pervasive Computing, vol. 3, no. 1, pp. 38–45, 2004.
[12] M. Srivastava, R. Muntz, and M. Potkonjak, "Smart kindergarten: Sensor-based wireless networks for smart developmental problem-solving enviroments," in Proceedings of the 7th Annual International Conference on Mobile Computing and Networking (MobiCom'01), Rome, Italy, pp. 132–138, 2001.
[13] T. Fulford-Jones, D. Malan, M. Welsh, and S. Moulton, "CodeBlue: An ad hoc sensor network infrastructure for emergency medical care," in International Workshop on Wearable and Implantable Body Sensor Networks, London, UK, 2004.
[14] D. Myung, B. Duncan, D. Malan, M. Welsh, M. Gaynor, and S. Moulton, "Vital dust: Wireless sensors and a sensor network for realtime patient monitoring," in 8th Annual New England Regional Trauma Conference, Burlington, MA, 2002.
[15] S. Kim, S. Pakzad, D. Culler, J. Demmel, G. Fenves, S. Glaser, and M.Turon, "Health monitoring of civil infrastructures using wireless sensornetworks," in Proc. 6th Int. Conf. Inf. Process. Sensor Netw. (IPSN),New York, NY, 2007, pp. 254–263.
[16] N. Xu, S. Rangwala, K. Chintalapudi, D. Ganesan, A. Broad, R Govindan, and D. Estrin, "A wireless sensor network for structural monitoring," in Proc. SenSys, 2004, pp. 13–24.
[17] "Self-healing Mines" http://www.darpa.mil/ato/programs/SHM/.
[18] S. Nazlibilek, O. Kalender, and Y. Ege, "Mine identification and classification by mobile sensor network using magnetic anomaly," IEEE Trans. Instrumen. Meas., vol. 60, no. 3, pp. 1028–1036, Mar. 2011.
[19] T. Chung, J. Burdick, and R. Murray, "A decentralized motion coordination strategy for dynamic target tracking," in Proc. IEEE Int. Conf. Robot. Autom., 2006, pp. 2416–2422.
[20] M. Maroti, G. Simon, A. Ledeczi, and J. Sztipanovits, "Shooter localization in urban terrain," IEEE Computer, vol. 37, pp. 60–61, Aug. 2004.
[21] P. Gibbons, B. Karp, Y. Ke, S. Nath, and S. Seshan, "IrisNet: An architecture for a worldwide sensor web," IEEE Pervasive Computing, vol. 2, no. 4, pp. 22–33, 2003.
[22] P. Gibbons, B. Karp, Y. Ke, S. Nath, and S. Seshan, "IrisNet: An Architecture for Enabling Sensor-Enriched Internet Service," Tech. Rep. IRP-TR-03-04, Intel Research, Pittsburgh, PA, June 2003.
[23] A. Goldsmith and S. Wicker, "Design challenges for energy-constrained ad hoc wireless networks," IEEE Wireless Communications Magazine, vol. 9, pp. 8–27, Aug. 2002
[24] R. Subramanian and F. Fekri, "Sleep Scheduling and Lifetime Maximization in Sensor Networks: Fundamental Limits and Optimal Solutions," IPSN '06: Proc. Fifth Int'l Conf. Information Processing in Sensor Networks, pp. 218-225, 2006.
[25] Giuseppe Campobello, Alessandro Leonardi, and Sergio Palazzo, "Improving Energy Saving and Reliability in Wireless Sensor Networks Using a Simple CRT-Based Packet-Forwarding Solution" IEEE/ACM transactions on networking, Vol. 20, No. 1, February 2012.
[26] C. Schurgers, O. Aberthorne, and M. Srivastava, "Modulation scaling for energy aware communication systems," in Proceedings of the 2001 International Symposium on Low Power Electronics and Design, Huntington Beach, CA, pp. 96–99, Aug. 2001.
[27] A.P. Chandrakasan, R. Min, M. Bhardwaj, S. Cho, and A. Wang, "Power aware wireless microsensor systems," in 28th European Solid-State Circuits Conference (ESSCIRC'02), Florence, Italy, 2002.
[28] G. Campobello, A. Leonar di, and S. Palazzo, "A novel reliable and energy-saving forward ing technique for wireless sensor networks," in Proc. ACM MobiHoc,Ne w Orleans, LA, May 18–21, 2009, pp. 269–278.
[29] Y. Li, C. S. Chen, Y. Song, and Z. Wang, "Real-time QoS support in wireless sensor networks: a survey," in Proc. (FeT'07), Toulouse, France, November 2007.
[30] D. Ganesan, R. Govindan, S. Shenker, and D. Estrin, "Highly resilient, energy efficient multipath routing in wireless sensor networks," in Proceedings of the 2nd ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc'01), Long Beach, CA, pp. 251–254, 2001.
[31] F. Sivrikaya and B. Yener, "Time synchronization in sensor networks: A survey," IEEE Network, vol. 18, pp. 45–50, July–Aug. 2004.
[32] R.C. Shah, S. Roy, S. Jain, and W. Brunette, "Data MULEs: Modeling and analysis of a three-tier architecture for sparse sensor networks," in Ad Hoc Networks Journal, vol. 1, pp. 215–233, Elsevier, Sept. 2003.
[33] E. Fasolo, M. Rossi , J. Widmer, and M. Zorzi, "In-network aggregation techniques for wireless sensor networks: A survey," IEEE Wireless Commun.,vol.14, no. 2, pp. 70–87, Apr. 2007.
[34] O. Younis and S. Fahmy, "HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad-hoc Sensor Networks," in IEEE Transactions on Mobile Computing, vol. 3, pp. 366–379, 2004.
[35] T. Martin, M. Hsiao, D. Ha, and J. Krishnaswami, "Denial-of-service attacks on battery-powered mobile computers," in Proceedings of the 2nd IEEE Pervasive Computing Conference, Orlando, FL, pp. 309–318, Mar. 2004.
[36] S. Roundy, P.Wright, and J. Rabaey, "A study of low level vibrations as a power source for wireless sensor nodes," Computer Communications, vol. 26, pp. 1131–1144, July 2003.
[37] W.C. Chung and D.S. Ha, "An Accurate Ultra WideBand (UWB) Ranging for precision asset location," in International Conference on UWB Systems and Technologies, Reston, VA, Nov. 2002.