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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 10 (1): 1-10, 2011
ISSN 1812-5638

Solar Powered Wireless Sensor Networks for Environmental Applications with Energy Efficient Routing Concepts: A Review

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Abstract: Wireless Sensor Networks (WSNs) play an important role in monitoring and collecting data from difficult geographical terrains. They find useful applications in various fields ranging from environmental monitoring to monitoring the patients' conditions in hospitals. The constraints such as limited battery life and less processing capability of the sensors make the processing and routing of WSNs a tedious and challenging task. A great emphasis is laid on the development of alternate sources of power and energy efficient routing protocol to maximize the life of the network. This study reviews the utilization of solar energy to enhance the life of the WSNs in environmental applications and also the various routing algorithms for WSNs. In current scenario, there are always impending threats from militants and terrorists within and out of a country. The sensor networks play a vital role in minimizing the loss of human lives in the event of natural calamities and artificial sabotages. The sensor networks can be successfully deployed in any difficult geographical terrains where manual round-the-clock surveillance is highly impossible. Energy aware routing is immensely helpful to sensor networks in the aspect of extending the life span of the WSNs. The review results show that the performance of solar powered sensor networks is better than that of conventional battery powered WSNs and they work efficiently with increased life span.

Key words: Wireless sensor networks, environmental monitoring, energy aware routing, solar photovoltaics and renewable energy

INTRODUCTION

Sensor networks are considered as a distributed autonomous system for information gathering, performing data-intensive tasks such as habitat monitoring, seismic monitoring, terrain surveillance, intrusion detection and disaster management. A Wireless Sensor Network (WSN) is a network of wireless computing devices with spatially distributed autonomous devices to cooperatively monitor physical or environmental conditions using sensors. WSNs are used to collect data from physically challenging environments. The information of events can be detected, collected, processed and sent to control room or sink by the sensors deployed in WSNs. The tiny nodes (sensors) in WSNs are equipped with substantial processing capabilities of combining the data with adjacent nodes, compressing the data, intelligent gathering and processing of sensed data, understanding and controlling the processes inherent to the system. The sensor network is the network of a large number of sensor nodes which are densely deployed either inside the field or very close to it. The sensing electronics measure ambient conditions related to the environment surrounding the sensor and transform them into an electric signal. Processing such a signal reveals some properties about objects located and/or events happening in the vicinity of the sensor. WSNs are typically battery powered and perform wireless communication to relay data to the base station. A sensor node powered by two AA batteries can work for 3 years with a 1% low duty cycle working mode due to advancements in various technologies (Yu *et al*., 2006). Though the processing capability of individual node is low, they can collectively and collaboratively perform the required task effectively. The sensors are capable of sensing intrusion, vibration, temperature and pressure.

With recent advancements in Application Specific Integrated Circuits (ASIC) design, it is possible to create more compact and efficient electronic circuits suitable for various specific real time applications (Akyildiz *et al*., 2002). Nowadays computing devices have become cheaper, highly mobile, widely distributed and pervasive due to recent advancements in the fields of cellular technology, Global Positioning System (GPS), Radio

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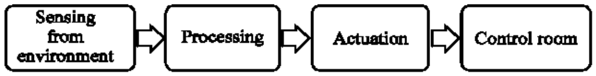

Fig. 1: Basic operations of a sensor

Frequency Identification (RFID), Micro Electro Mechanical System (MEMS) and Advanced Electronics. It is now possible to develop a small sized embedded system of good computing capability with cheaper commercial components which are readily available in the market. A typical wireless sensor node consists of the following components: sensing, computing, communication, actuation and power components.

Figure 1 describes the basic operational phases of a sensor node.

After the initial deployment, sensors become responsible for self-organizing an appropriate network infrastructure with multi-hop connections among them and tend to communicate to their neighbors by finding their locations and forming the topology of the network. The onboard sensors then start collecting acoustic, seismic or magnetic information of the environment through either continuous or event driven working mode. The location and positioning information of an object or event can also be obtained through the GPS or local positioning algorithms. This information can be gathered from the network and appropriately processed to construct a global view of monitoring phenomena. The research team namely the PicoRadio team from UC (University of California) Berkeley has been trying to integrate prototype sensor nodes onto a few chips. Commercial RF circuits enable short distance wireless communication with extremely low power consumption. Commercial products from RF Monolithics, Chipcon, Conexant Systems and National Semiconductor have been used for various sensor nodes, including motes, Medusa, WINS (Wireless Integrated Network Sensors) and μAMPS (Micro Adaptive Multi domain Power aware Sensors).

A large number of distributed sensor nodes capable of co-ordinating among themselves can offer a great advantage over centralized single sensor node based techniques. The sensor nodes use their processing capability locally to perform simple computations and transmit only the required and partially processed data. The deployment of single powerful sensor may not be able to address issues related to Line of Sight and high Signal to Noise Ratio in the environment of large number of obstacles. A single node may cause a number of holes and shadows which can be effectively covered with a distributed deployment. Since the sensor nodes are used in large numbers, they are able to record an event with greater redundancy. In case of failure of one sensor to capture an event, others can keep track of it. The deployment of nodes in large numbers also offers robustness to point failures which is considered important in mission critical tasks. For instance, even when a large number of sensors are destroyed in a natural or man made disasters, the remaining sensors may keep on monitoring the event. The position of sensor nodes need not be predetermined. This allows random deployment in inaccessible terrains or disaster relief operations.

There are two types of wireless communication in WSNs: (1) Small range communication (2) Large range communication. The former is sensor to sensor, multi-hop communication with 50-100 m range and few 100 MHz to few thousand MHz frequency range. No infrastructure is required for such communication where as an Infrastructure is needed for the latter. Distance has no limitation to such a type of communication and it uses mostly single hop to cover a large geographical area. GPS can be integrated with this type of network.

EVOLUTION OF SENSOR NODES

The development of sensor networks has highly been driven by defense applications. Since early 1950s, a system of long-range acoustic sensors namely the Sound Surveillance System (SOSUS) had been deployed in the deep basins of the Atlantic and Pacific oceans for submarine surveillance. SOSUS has recently been replaced by the more sophisticated integrated undersea surveillance system. The network of air defense radars can be regarded as an example for networked large scale sensors. Both ground-based radar systems and airborne warning and control System planes are combined together to form a sophisticated network which provides all-weather surveillance, command, control and communications. The Cooperative Engagement Capability (CEC) was developed in the period between 1980s and 1990s as a military sensor network in which information gathered by multiple radars was shared across the entire system to provide a consistent view of battle field. Another early example of wireless sensor device is the Air Delivered Seismic Intrusion Detector system launched by US Air Force in the Vietnam War. With the advent of digital packet radios for wireless communication networks developed by ALOHAnet Project at Hawaii and DARPA's (Defense Advanced Research Projects Agency) Packet Radio Project in 1970s, wireless communication within the same frequency band using MAC (Medium Access Control) techniques and packet-based multi hop communication became possible (Yu *et al*., 2006).

APPLICATIONS OF WIRELESS SENSOR NETWORKS

Fault tolerance, self organization capability and rapid deployment are the reasons for success of sensor networks in various fields of applications. WSNs can be

Table 1: Some existing sensor networks around the world (Nagel, 2001)

Name of network	Sensor locations	Country and area covered (km^2)
International monitoring system	74	Global 5.1×10^8
Tropical Atmosphere Ocean project	70	Pacific Equator 9.2×10^6
DDG (Deutsche Dermatologische Gesellschaft) traffic network	4000	Germany 3.5×10^5
NOAA (National Oceanic and Atmospheric Administration) Ocean buoys	180	Around U.S. 9.2×10^6

deployed on a global scale for the applications of military surveillance and reconnaissance in battle field, search and rescue operations in case of emergency, infrastructure health monitoring in buildings, environmental applications in the forests and fields, or even in the human bodies for monitoring the conditions of patients. Military Applications include monitoring friendly forces, detection of cross border terrorism, sensing the intrusion of enemies through land or sea, battlefield surveillance, offering logistics in urban warfare and reconnaissance. Environmental applications include forest fire detection, natural disaster monitoring, bio-complexity mapping of the environment, flood detection, precision agriculture and sensing the temperature, humidity, vehicular movement, lighting condition and pressure. Table 1 shows some of the existing WSNs around the world.

ENVIRONMENTAL APPLICATIONS

Environmental monitoring is one of the major applications of WSNs. The vast space involved in such applications requires large number of low cost sensor nodes that can be easily dispersed throughout the region. For instance, WSNs can be applied to study the nature such as glacier monitoring, forest fire alarm, landscape flooding alarm, microclimate and solar radiation mapping, environmental observation and forecasting of rivers, water catchment and eco system monitoring, mining and agriculture. Researchers at University of West Australia are developing a prototype WSN for outdoor fine-grained environmental monitoring of soil water. Such a network can be used to assist salinity management strategies, monitoring irrigated crops, urban irrigation and water movement in forest soils. Some of the existing applications are that Great Duck (bird observation on Great Duck island), Glacier (glacier monitoring), Ocean (ocean water monitoring), Tracking (tracking military vehicles) and sniper (sniper localization). Great Duck Island (GDI) has been developed by the College of the Atlantic for habitat monitoring. It is a 237 acre island located 15 km away from the south of Mount Desert Island, Maine.

Habitat and environmental monitoring represents an important class of sensor network applications (Mainwaring *et al*., 2004). The rock slides or avalanches occur seldom and are difficult to predict, the life span of deployments must last long enough to capture them. The needed characteristics of an environmental monitoring system are autonomy, reliability, robustness and flexibility. 1) Autonomy- Batteries must be able to power the sensors during the entire life. 2) Reliability- The network has to perform simple and predictable operations and prevent unexpected crashes. Human maintenance should be avoided. Achieving reliability is difficult because packet losses are more likely to happen during harsh weather conditions. 3) Robustness- The network must account for a lot of problems such as poor radio connectivity and device failures. 4) Flexibility- One must be able to quickly add, move, or remove sensors at any time (Barrenetxea *et al*., 2008).

The WSN can be used for sensing various natural disasters and forecasting purposes in the event of Tsunami and earthquake. The sensors could monitor moisture and soil conditions so as to have more efficient irrigation of fields and water savings. One of the implemented projects in India is WildCENSE project for Indian Wild Life Monitoring. The goals of the project are to track down the movement and activity of wild life, microclimate, forest fire detection and forest wealth protection.

DEFENSE APPLICATIONS

The sensors can be attached with troops, vehicles, equipments and critical ammunitions. Critical terrains, routes, paths and straits can be rapidly covered with WSN. The movements and activities of the opposite forces can be monitored effectively. The sensors can be used with guidance systems of the intelligent ammunition for targeting purposes. WSN can be used for assessment of battle field damage and reconnaissance of opposing forces and terrains. In defense, WSNs can be used to make continuous monitoring for remote and inaccessible areas along border line of control where human patrolling is highly impossible. The sensors can be dropped from planes to sense the conditions of the critical area where human penetration is highly impossible. They can detect and differentiate the movement made by animals, human beings and vehicles by continuously monitoring the vibrations in the environment. The deployment of soldiers in difficult and rough terrains to safeguard the line of control from intruders is a very difficult and challenging task due to bad climatic conditions, rough regions and glaciers. The WSN plays a crucial role in monitoring along borderline of control and reduce man power required to maintain the security of border.

The benefits of WSNs in defense field can be cited with an example scenario as follows. It is assumed that sensor nodes are deployed by an unmanned aerial vehicle along the way of length 100 km. Within a few minutes, the nodes start communicating amongst themselves, finding their positions, self organizing themselves, establishing a network, synchronizing clocks and lying in wait. Some of the nodes organize themselves as active nodes while the remaining nodes slip into low power mode of sleepy state in the view of consuming less energy. When an activity is detected by any active node, it will wake up all the other nodes in the network. Thus the nodes then collaboratively track down the movements of intruders by aggregating information from various sensors to gather real-time information. The sensor network sends the information to relay nodes in a matter of seconds about the detail of the intruders whether armed or not.

LIMITATIONS IN WSN AND NEED FOR ALTERNATE ENERGY SOURCES

Based on the literature, the various key design issues involved in WSNs are network dynamics and node deployment, transmission media and communication, data delivery models, node capabilities, power consumption, data aggregation, fault tolerance, scalability and sensor network topology. Realization of sensor networks needs to satisfy the constraints introduced by the aforementioned criteria. A major technical challenge for WSNs, however, lies in the node energy constraint and its limited computing resources (Jeong *et al*., 2008). Energy consumption is a dominant factor in the design of large scale sensor networks. Since, these constraints are highly specific to sensor networks, new improved power sources, wireless ad-hoc networking and efficient routing techniques are required (Jiang *et al*., 2009). By providing newly improved power sources like nature based renewable (solar) energy will solve many of the aforementioned constraints.

Energy conservation plays a major role in WSNs since they are designed to be placed in hostile and inaccessible areas. Most of the researchers assumed that the WSN nodes are battery powered. Due to various constraints and non availability of infrastructure in WSN, the nodes have limited capabilities. In the higher energy density batteries and very low power embedded platforms, the amount of available energy on board still severely limits the life span of distributed battery operated WSN systems. The low-level energy constraints of the sensor nodes combined with the data delivery requirements leave a clearly defined energy budget for all other services. The goal is to achieve a self powered system without having necessary frequent maintenance for battery replacement or recharging. WSNs for outdoor environmental applications and defense applications are a class of systems where exploiting renewable energy sources could increase the autonomy of the nodes considerably. These types of energy sources will increase the life of the sensor nodes due to the less consumption of battery power. While battery driven sensors will run out of battery sooner or later, the use of renewable energy sources such as solar power will prolong the life of WSNs.

SOLAR POWERED WIRELESS SENSOR NETWORKS

Solar energy has become more attractive recently because of its environmental benefits. As it is derived from renewable resources, it is non-toxic in nature. Renewable energy is the energy derived from sources that are being replaced by nature, such as water, wind, solar or biomass (Hiremath *et al*., 2009).

Voigt *et al*. (2003a, b) proposed to utilize solar power in wireless sensor networks establishing a topology where some nodes can receive and transmit packets without consuming the limited battery resources dynamically. The solar cells can be utilized to power the sensors as well as to charge the batteries during node idle periods. The stored battery energy can be used to power the nodes during the time periods when sunlight is unavailable. The solar-rich nodes can take over the responsibility of relaying data to the base station. The results have proved that the solar powered method results in energy savings, better performance and prolonged lifetime of the network. Polastre *et al*. (2005) presented an extremely long duration solar power subsystem for the most recent wireless sensor network mote-Telos. Jiang *et al*. (2005) presented Prometheus, a system that intelligently managed energy transfer for perpetual operation without human intervention or servicing. They introduced an efficient multi-stage energy transfer system that reduces the common limitations of single energy storage systems to achieve near perpetual operation.

There are some well known wireless sensor devices such as WINS from UCLA (University of California, Los Angeles), Motes from UC Berkeley, Medusa from UCLA and AMPS from MIT (Massachusetts Institute of Technology). In addition to the above mentioned sensor nodes, there are other commercial products and testbeds for WSNs such as Ember products, Sensoria, WINS, Pluto mote and Gnome testbed. All the aforementioned sensor architectures are based on batteries. As there is slow advancement in the technology of battery in connection

Fig. 2: PicoBeacon from UC Berkeley (Yu *et al*., 2006)

with its capacity, techniques for energy scavenging from the environment have been attractive field of research. In 2003, the UC Berkeley Wireless Research Center presented the first radio transmitter, PicoBeacon (Fig. 2), purely powered by solar and vibrational energy sources. With a custom RF integrated circuitry that was developed for power consumption less than 400 mW, the beacon was able to achieve duty cycles up to 100% for high light conditions and 2.6% for typical ambient vibrational conditions (Yu *et al*., 2006).

Some of the frequently used components of solar powered sensor networks are temperature and relative humidity sensors, ambient light sensors, accelerometer, image sensor, GPS receiver to pinpoint exact location, transceivers, micro-controller and power requirements: battery, solar cells and photovoltaic (PV) module. Other components are control electronics, module mounting hardware, battery box, inter-connecting cables and switches. Taneja *et al*. (2008) provided an empirical and mathematical analysis of two leading competitors (Heliomote and Trio) and developed a taxonomy for the micro-solar design space, identifying key components, design choices, interactions, difficulties and trade-offs. Two different circuit designs implemented in their network are that a sensor node circuit and a computer host circuit. The sensor node gathers data from sensors and forwards the data to a computer host. The computer host interfaces with a personal computer (PC) and receives data from all of the sensor nodes. These nodes are also capable of operating for very long periods on low duty cycles from solar and super-capacitor storage alone.

Wireless sensor networks that harvest power from the environment was proposed by Lattanzi *et al*. (2007) because of its intrinsic capability of providing unbounded lifetime. A battery-less wireless sensor network system that uses the combination of an electric double layer capacitor, equipped with a small solar cell as its energy source was proposed by Minami *et al*. (2005). These nodes adapted their operation to the level of charge available. The authors however, have not reported any results of a long-term deployment. They called it as Solar Biscuit which is a battery-less wireless sensor network system for environmental monitoring applications. Since the amount of energy obtained from a solar cell is small, a sensor node should wait until the capacitor is charged with a sufficient amount of energy. So the sensor nodes wait for a long period for charging the capacitor and then communicate over a short period. This long intermittent behavior of WSN nodes seriously affects the performance of WSN systems. They investigated battery-less WSN systems from this point of view and implemented a prototype system that utilizes solar cells for its energy source.

Corke *et al*. (2007) discussed hardware design principles for long term solar-powered wireless sensor networks and straightforward non-energy aware protocols. They used simple Nickel Metal Hydride (Ni MH) battery technology which does not require complex charging circuitry. They presented data from a long-term deployment that illustrated the use of solar energy and rechargeable batteries to achieve 24×7 operations for over two years. Raghunathan *et al*. (2005) and Lin *et al*. (2005) presented the design, implementation and performance evaluation of the Heliomote - a Mica2 mote with a custom circuit board for solar harvesting equipped with 2 NiMH batteries and a small solar panel. They tested the device for a week and demonstrated that their device was capable of near perpetual operation.

ENERGY STORAGE DEVICES

Besides the Lead Acid and Nickel-cadmium (Ni Cd) batteries, Ni MH, Lithium Ion and Lithium Polymer batteries will find their increased use in PV applications due to inherent merits of each of the technologies. Fuel Cell is another fast developing technology and will be commercially available for PV applications as PV-Fuel cell hybrid systems. Like batteries, supercapacitors are energy storage devices and are almost ideal capacitors, with low equivalent series resistance and very low leakage current. They are now receiving great attention in low PV power applications due to higher power density, ability to withstand hundreds of thousands of charge/discharge cycles without significant degradation in performance, capacity to provide quick bursts of energy and long life about 10 to 20 years (Toledo *et al*., 2010).

SOLAR AWARE CLUSTERING IN WIRELESS SENSOR NETWORKS

Clustering is required to reduce the routing complexity and overhead and for effective energy efficient communication between sensors. Grouping sensor nodes into clusters has been widely analyzed by the research community to achieve the various sensor network objectives. Clustering of the sensor nodes makes the calculations much simpler. The search space for the solution increases as the number of nodes (N) decreases and vice-versa. In order to reduce the burden of mathematical complexity N value should be reduced and this is achieved by clustering. For each cluster one node will act as a cluster head (CH). CH can communicate to the Base Station (BS) as well as to other CHs. These clustering techniques provide various benefits to WSNs. 1) network scalability, 2) reducing the size of the routing table stored at the individual sensor node, 3) conserving bandwidth, 4) stabilizing the network topology, 5) getting increased connectivity thereby achieving reduced delay and 6) increasing the sensor network life are some of them. From the literature the various existing clustering algorithms for WASNs are, 1) Linked Cluster Algorithm (LCA), 2) Adaptive clustering, 3) Hierarchical control clustering, 4) Energy Efficient Hierarchical Clustering (EEHC) and 5) Hybrid energy-efficient distributed clustering and 6) Attribute-based clustering (Abbasi and Younis, 2007).

To explain the clustering concept, the following heuristics are used as an example in WSN. Figure 3 shows the typical example of WSN with 60 randomly deployed sensor nodes. Node 33 can be assumed as a base station. Here the simple and efficient k-means clustering algorithm is used for clustering purpose. The given 60 nodes are divided into 6 clusters. Then the routing concepts can be applied for route calculation within the clusters. Simply speaking k-means clustering is an algorithm to classify or to group the objects based on attributes/features into k number of group. k is a positive integer number. The grouping is done by minimizing the sum of squares of distances between data and the corresponding cluster centroid.

The main idea is to define k centroids, one for each cluster. These centroids should be placed in a cunning way so that different locations show different results. So, the better choice is to place them as much as far away from one another. The next step is to take each point belonging to a given data set and associate it to the nearest centroid. When no point is pending, the first step is completed and an early groupage is done. At this point, k new centroids are recalculated as barycenters of the clusters resulting from the previous step. After having these k new centroids, a new binding has to be done between the same data set points and the nearest new centroid. A loop is generated. As a result

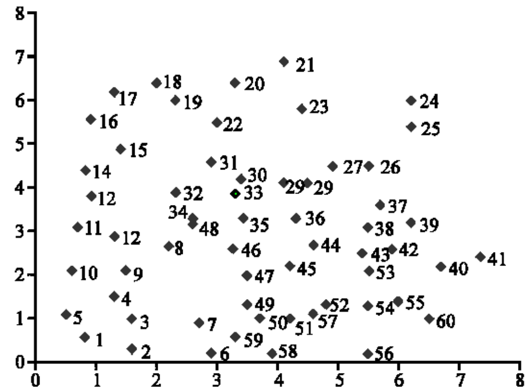

Fig. 3: Typical example for randomly deployed sensors (Nallusamy *et al*., 2010a, b)

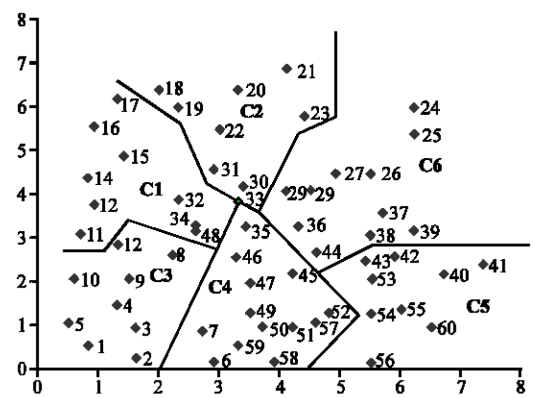

Fig. 4: Clustered sensors after k-means clustering (Nallusamy *et al*., 2010a, b)

of this loop it may be noticed that the k centroids change their location step by step until no more changes are done. In other words, centroids do not move further. The results of k-means clustering for the given example WSN are given in Fig. 4. Approximation algorithms such as k-means clustering and Genetic algorithm based clustering and straight forward routing were proposed by Nallusamy *et al*. (2010a, b).

Voigt *et al*. (2004) proposed to extend LEACH (Low Energy Adaptive Clustering Hierarchy), a well-known cluster-based protocol for sensor networks to become solar-aware. The simulation results show that making LEACH solar-aware significantly extends the lifetime of sensor networks. Visual-based wireless sensor networks have been implemented in several different fields such as environment monitoring, military applications and robotic applications (Fan *et al*., 2007). A solar cell recharging model and a layered clustering model were proposed to deal with the restricted energy consumption under the consideration of visual quality.

SOLAR AWARE ROUTING IN WIRELESS SENSOR NETWORKS

Routing is one of the major issues in the wireless sensor networks. Due to various reasons the routing is difficult in WSN. The global addressing scheme is not possible like IP based other networks 2. The routing takes place from multiple sources to single sink 3.Redundancy in data and 4.Various capacity limitations like battery power and computing limitations. The high power consumption and excessively high data rate of 802.11 protocols are not suitable for WSNs. Recently, the 802.15.4-based ZigBee protocol has been released, which is specifically designed for short range and low data rate Wireless Personal Area Networks (WPAN). Its applicability to WSNs was soon supported by several commercial sensor node products. Some early routing protocols in WSNs are actually existing routing protocols for mobile ad hoc networks. These protocols are hardly applicable to WSNs due to their tendency of high power consumption.

The purpose of the routing algorithm is to find the optimum path between source and destination nodes for data transmission within a specified time. The recent advancements in WSN have led to many new routing protocols specifically designed for sensor networks where efficient energy utilization is an essential consideration (Akkaya and Younis, 2005). Various routing techniques for WSNs are, 1) Data centric, 2) Hierarchical, 3) Location based, 4) Based on network flow or QoS and 5) Energy aware routing (Al-Karaki and Kamal, 2004; Al-Karaki and Al-Mashaqbeh, 2007).

The various routing algorithms are broadly classified as:

- **Address-Centric protocol (AC):** Each sensor independently sends data along the shortest path (SP) to CH
- **Data-Centric protocol (DC):** The sensors send data to the sink, but routing sensors en-route look at the content of the data and perform some form of aggregation function on the data originating at multiple sources to remove redundancy

The routing algorithm SPIN (Sensor Protocols for Information via Negotiation) uses concepts to eliminate redundant data transmission. It introduces a novel negotiation based data dissemination protocol which employs metadata to uniquely identify data items to prevent sending multiple copies of the same data. It also introduces energy awareness into the system which helps to increase the life of the network. LEACH (Low-Energy Adaptive Clustering Hierarchy) is a cluster based protocol to evenly distribute energy load among various sensors in the network. It uses clustering to reduce the amount of global traffic and implement area level aggregation and compression. The action of changing the cluster heads randomly distributes the energy level gradually over the network and the probability of node failure is much more random which results in longer life for WSN.

Directed Diffusion uses low rate flooding and subsequent reinforcement of better paths. It is one of the pioneering works in this field having a number of concepts currently used in various implementations. PEAS keeps only necessary nodes active and puts the rest into sleepy mode to conserve energy. Grid-based Routing and Aggregator Selection Scheme (GRASS) uses exact as well as heuristic approaches to find the minimum number of aggregation points while routing data to the Base-Station (BS). When compared to other schemes, GRASS improves network lifetime significantly. Yang *et al*. (2009) formulated the problem of energy-efficient routing for detection in a wireless sensor network under the Neyman–Pearson detection criterion, which related to both the energy consumption and detection performance in routing. Matrouk and Landfeldt (2009) proposed routing based on energy–temperature transformation, RETT-gen, a scalable energy-efficient clustering and routing protocol designed for wireless sensor networks. The main goal of RETT-gen is to evenly distribute the energy load among all the sensor nodes in the network so that there are no overly-utilized sensor nodes that will run out of energy before the others. Ok *et al*. (2009) introduced a new metric called energy cost which was devised to consider the balance of remaining energy of sensors as well as energy efficiency. This metric gives rise to the design of the distributed energy balanced routing algorithm devised to balance the data traffic of sensor networks in a decentralized manner and consequently prolongs the lifetime of the networks.

The solar aware routing (Voigt *et al*., 2003a, b) allows the routing only through solar powered nodes. This will save the energy of the battery powered nodes. Among the nodes, some of them are solar powered and the rest of them are battery powered.

They proposed two protocols to perform solar aware routing. The results show that both protocols provide significant energy savings when utilizing solar power (Table 3). Incorporating the solar status of nodes in the routing decision is feasible and results in reduction of overall battery consumption. One protocol is a simplified version of directed diffusion based mainly on local interactions between adjacent nodes, the other one is an extension of directed diffusion. The results show that the

Table 2: Some of the existing routing algorithms in WSN

Name of the routing algorithm	Battery powered	Solar powered
Directed diffusion	Yes	Yes
PEAS	Yes	Yes
Energy aware	Yes	No
SPIN	Yes	No
GRASS	Yes	No
Geographic Routing with Environmental Energy Supply (GREES) (Zeng *et al*., 2009)	Yes	Yes

Table 3: Performance of routing algorithms in solar powered WSNs

Name of the routing algorithm in solar powered WSN		Performance Improvement over conventional WSNs (%)
Solar-aware routing with local interaction (Voigt *et al*., 2003)	for 64 nodes	15.1
	for 96 nodes	12.1
Solar aware directed diffusion (Voigt *et al*., 2003a, b)	for 64 nodes	10-20
	for 96 nodes	5-20

former is more suitable for small sensor networks while the latter performs better on larger networks. Lattanzi *et al*. (2007) discussed the problem of optimal routing for energy harvesting wireless sensor networks. They presented a methodology for assessing the energy efficiency of routing algorithms of networks whose nodes drain power from the environment.

Many of the literature results indicate that directed diffusion is a more energy consuming concept due to large number of messages. For real time communications like battle field monitoring an optimal Shortest Path (SP) has to be computed within a very short period of time in terms of milli/micro seconds. Almost all the current multi-hop packet switching networks use SP routing computation based on routing algorithms in the network layer. Normally the weighted links concepts are used here. The weights of the links based on various factors related to routing such as link transmission capacity, battery power, the signal strength of the link and the estimated transmission status. Neural networks (Nallusamy and Duraiswamy, 2009), genetic algorithms (Nallusamy *et al*., 2010a, b) and other soft computing algorithms are able to provide solutions for these types of complicated problems in polynomial time. In solar powered sensor networks a straight forward shortest path between source and CH can be used. This will avoid wasting energy in detours and also incurs less interference in other transmissions when fewer nodes are involved in the transmission. Table 2 shows the various conventional and solar aware routing algorithms in WSNs. Table 3 shows the performance of the routing algorithms in solar powered WSNs.

ENVIRONMENTAL CONSIDERATIONS

A randomly deployed device may not be exposed to direct sunshine and it is not feasible to equip them with auto tracking devices to follow the daylight with respect to changing path of the sun throughout the year. Typically, the batteries last only for a few months or a year and the dead batteries pose an environmental hazard with the hardware left in the environment. Therefore, various energy saving techniques such as energy-efficient routing protocols, medium access control schemes and system onchip technology have been proposed. Although, these techniques are useful for extending the battery life of WSN nodes, none of these techniques provides an essential solution to the battery replacement problem. This is because the energy consumption of a node can never be reduced to zero, even an extremely efficient energy saving technology is used. Therefore, as long as battery-powered nodes are used, an enormous number of dead batteries have to be replaced. In specific application scenarios such as military applications, WSN nodes can be assumed to be disposable. However, in many cases, disposable devices are not acceptable. For example, the WSN nodes which are used to monitor temperature in plastic green houses should not be left open in the environment as the dead batteries and nodes may cause severe health hazards to the lives in and around the area. On the other hand, various kinds of energy conversion devices have been developed to provide electric power without batteries. For example, thermoelectric devices can produce electric power from temperature changes, micro generators can convert vibrations to electric power and solar cells can produce electric power from light sources.

ECONOMIC FEASIBILITY OF SOLAR CELLS FOR SENSORS

Solar energy components are expensive today. However, costs will decline rapidly as technology development drives the cost down in due course. The decreasing prices of PV systems and Balance of System (BOS) components have been driven by (1) solar cell efficiency improvements; (2) manufacturing-technology improvements; (3) increased production; (4) expanding PV market and (5) economy of scale. The advancements in manufacturing processes would enable processing of 150 micron wafers. These improvements, apart from increasing the manufacturing yield, would also result in bringing down the cost of solar cells. Considerable work is also on to combine the lower cost Metallurgical grade silicon with the expensive semiconductor grade silicon to produce low cost cells with a small compromise in efficiency. Such reductions in cost coupled with very negligible operational costs would make solar PV solutions extremely competitive with other forms of alternative energy devices and making it ideal for mass production of low cost cells. This will reduce the cost of the solar powered sensors.

Nowadays lot of commercial and research oriented solar powered sensors are available in the market. Various countries can frame suitable policies to develop efficient solar powered sensors for various applications. The sensor networks will play a vital role in the environmental applications and border line security in due course. The WSNs can be used for many applications by reducing cost and size of the sensors with increase in computing capability through RandD.

CONCLUSION

Sensor Networks are emerging as a great aid in improving the way data is gathered. This development is going to have a great impact on the environmental monitoring and the area of defense. From the review, it is found that solar energy is an efficient alternate energy source for WSNs. By using energy aware efficient clustering and routing concepts the battery and computation overhead will be reduced. The simple clustering like k-means clustering has proved to be effective as it is able to group the nodes into clusters in an optimal manner with reduced convergence time. Solar aware routing within the clusters saves the energy of the battery powered nodes due to its routing capability only through the solar powered nodes. The solar energy based routing concepts increase the performance and life of WSNs compared to other conventional routing algorithms. The large deployment of low cost solar powered sensors and the concepts of energy aware routing are the major reasons for the fast and reliable communication in WSNs. The soft computing based approximation algorithms such as Fuzzy, neural networks and Genetic algorithm concepts can be used to have better convergence of clustering and routing techniques. Suitable policies and increased RandD for solar powered sensor networks will increase the employment as well as the security level of the countries around the world.

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