ISSN No. 0976-5697

Volume 2, No. 5, Sept-Oct 2011

International Journal of Advanced Research in Computer Science

RESEARCH PAPER

Available Online at www.ijarcs.info

Energy Efficient Mechanisms in Wireless Sensor Networks: A Survey

Vinay Kumar*
Department of Electronics and Communication Engineering
Motilal Nehru National Institute of Technology
Allahabad, India
vinay2008el03mnnit@gmail.com

Sudarshan Tiwari
Department of Electronics and Communication Engineering
Motilal Nehru National Institute of Technology
Allahabad, India
stiwari@mnnit.ac.in

Abstract: Sensor nodes are generally battery powered, are expected to be remotely deployed, and operated autonomously in unattended environments. The crucial aspects is that, how to reduce the energy consumption of the sensor nodes, so that the network lifetime can be extended. Energy efficient techniques in WSNs facilitate efficient utilization of limited resources of sensor nodes and thus extends network lifetime. In this paper we have discussed the typical components of sensor node which consumes energy and presented a systematic and comprehensive taxonomy of energy conservation schemes. The objective of this paper is to present a state of art survey of different energy efficient techniques reported in the literature of WSNs.

Keywords: Wireless Sensor Networks; Energy and Power Efficiency; Network Life Time; Energy Efficient schemes.

I. INTRODUCTION

A WSNs (Wireless Sensor Networks) consists of large number of sensor nodes deployed over a large geographical area for monitoring physical phenomena like humidity, vibrations, temperature and so on. Micro-Electro-Mechanical System (MEMS) sensor technology has facilitated the development of smart sensors, these smart sensors nodes are small devices with limited power, processing and computation resources. Smart sensors are power constrained devices that have one or more sensors, memory unit, processor, power supply and actuator [1]. WSNs based on specific platform and networking structure enable applications such as pursuit-evasion games [2], environment measurement [3], target tracking [4], intrusion detection [5], smart transportation, home security, machine failure diagnosis and surveillance [6]-[9], military target tracking and surveillance [10-11], natural disaster relief [12], biomedical health monitoring [13-14], and hazardous environment exploration and seismic sensing [15].

In WSNs sensor nodes have limited processing power, communication bandwidth, and storage space which demands very efficient resource utilization. In WSNs the sensor nodes consists of four main subsystems: a sensing subsystem that has one or more sensors for data acquisition; a radio or communication subsystem for wireless data communication; a processing subsystem that has a micro-controller and memory for data processing and a power supply unit. In this survey work, we have surveyed the state-of-art of different energy efficient algorithms reported in the literature of WSNs. Given the importance of the sensor nodes energy consumption for WSNs, rest of paper is organized in following structure Section II presents the basic WSNs architectures. Section III presents energy efficient schemes in WSNs. Section IV presents the conclusion of the paper.

II. WIRELESS SENSOR NETWORK ARCHITECTURE

Networked sensors is not a new technology but it was only in late eighties it became technically feasible to built and deploy sensor networks, thus was born the first generation WSNs. Advances in communication and computing technologies in the late 1990s and early 2000s have resulted in the second generation of sensor network technology. Second generation is the present day sensor network research.

Table (1) shows the commercial generation of sensor networks [17]. There are two type of WSNs, structured and unstructured. In structured WSNs, some or all of the sensor nodes are deployed in a pre planned manner [14] but unstructured WSNs contains a large number of sensor nodes that are deployed in ad hoc random manner [13]. Structured WSNs have advantages of lower network maintenance and management cost due to pre-known structure of sensor nodes deployment. In unstructured WSNs, connectivity management and detection failures are difficult due to random deployment of large number of sensors nodes, but majority of WSNs applications require random deployment of nodes following are some of features that are uniquely associated and required for a WSNs:

a. Varying network size
b. Self organization
c. Long life time network
d. Query and re-tasking
e. Data aggregation
f. Limited communication capabilities
g. Variability channel
h. Ad hoc deployment
i. Failure tolerance
j. Power saving
k. Limited hardware
l. Production costs

TABLE (1): COMMERCIAL GENERATION OF SENSOR NETWORKS [17]

Attributes	**First generation (1980s to 1990)**	**Second generation Early2000s**	**Third generation Late 2000**
Size	larger	Smaller	Small, even a dust particle
Deployment mode	Physically installed or air dropped	Hand placed	Nanotechnology based
Weight	Pound	ounces	Grams or less
Protocol	proprietary	proprietary	Wi-fi, zigbee, Wi-Max
Node architecture	Separate sensing, processing and communication	integrated sensing, processing and communication	Fully integrated sensing, processing and communication
Power supply	Large battery or line feed	AA battery	Solar or nanotechnology based
Life span	Hours, day or longer	Day to week	Month to years
Topology	Point to point ,star and multi hop	Client server and peer to peer	Fully peer to peer

Realizations of WSNs applications require wireless ad hoc networking techniques. Although many protocols have been proposed for traditional wireless ad hoc networks, but are not as such suitable for the direct application in WSNs due to unique features of sensor networks. To describe this point, the differences and similarity between sensor networks and ad hoc networks are discussed [16] some of them are highlighted below:

a. Sensor nodes mainly use a broadcast communication whereas most ad hoc networks are based on point-to-point communications.
b. Sensor nodes are limited in power, computational capacities, and memory, which mean they are resource constrained.
c. Sensor nodes in sensor networks are prone to failures.
d. The topology of a sensor network changes very frequently as compared to traditional ad hoc networks.
e. Number of sensor nodes in a sensor network can be much higher than the nodes in ad hoc networks.
f. Sensor nodes in sensor networks are densely deployed

The only similarity that sensor networks possess with ad hoc networks is that both are infrastructure less networks. To enable wireless sensor applications using sensor technologies, range of technical issues are considered which can be classified in to three major parts as shown in fig.1. The first part is the system; second part is services and third is the communication protocol stack. System deals more with the hardware and software needed for physical implementation of the WSNs. Services deal with the techniques used to bring the system to the efficient utilization of the system resources.

Communication protocol stack is used for efficient routing of information or query to and fro from the nodes to base station. It consists of six protocol layers i.e. application layer, network layer, transport layer, data link layer, MAC layer and physical layer. Implementation of protocols at different layers can effect energy consumption and system efficiency so it is important to minimize the energy usage and optimized communication [18].

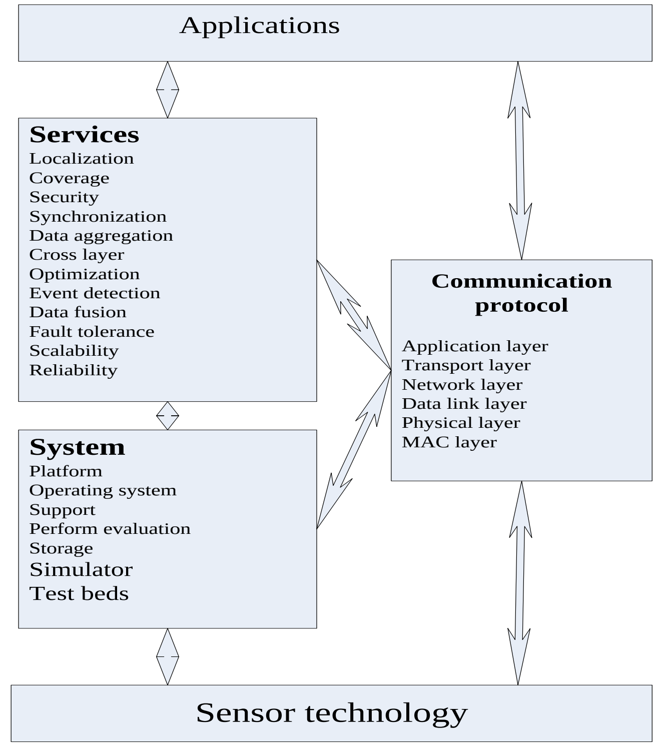
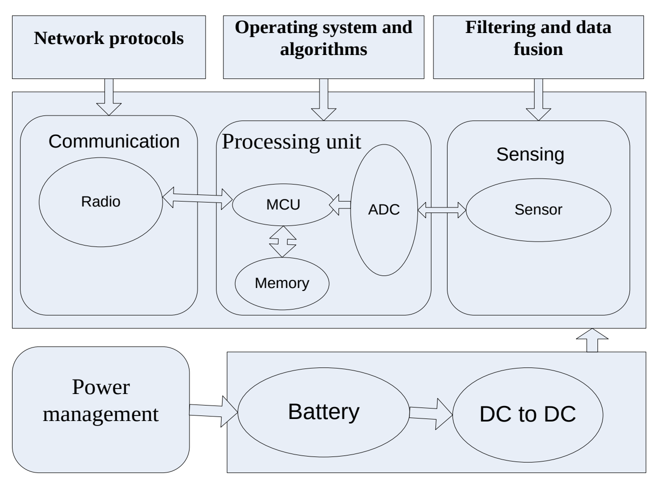


Figure.1: Functional classification of various technical issues in wireless sensor networks

A. *Sensor Node System Architecture:*

Fig.2 shows the basic architecture of a sensor node, it consists of four main subsystems: a sensing subsystem that has one or more sensors for data acquisition: a radio or communication subsystem for wireless data communication; a processing subsystem that has a micro-processor and memory for data processing and with external power supply unit.



A.

Figure .2: Sensor node system architectures

Obviously, the power breakdown depends heavily on the specific node type. It is shown that the power characteristics of stargate sensor node are different from Mote-class sensor node

[19]. There are number of sources for power consumption in sensor including signal sampling, conversion of physical signals to electrical and signal conditioning analog to digital conversion. Table II lists power consumption of some common sensors. The factors that affect selection of sensors nodes for use in WSNs are volume, power consumption, suitability for power cycling, fabrication and assembly compatibility with other components of the system and Packaging. Sensors as shown in Table II depending upon the power consumption of sensor nodes they can be classified into five groups. The on/off sensors belong to the **micro-power** group with power consumption less than 1mW, the second group**, low-power**, having power consumption less than 10 mW. Sensors with **medium-power** group have consumption within the range from 10 mW up to 50 mW which have combination of analog and digital electronics. **High power** group have consumption from 50 mW up to 1 W, high-power group consists of dedicated signal processors and this possibility makes the sensor of this group to be SMART devices. The fifth groups called **ultra high-power** has power consumption greater than 1 W.

Table: II Power Consumption if some Common Sensore[19]

Sensor type	Sensing	Power [mW] consumption
Micro-power		
SFH 5711	Light sensor	9
DSW98A	Smoke alarm	108
SFH 7741	Proximity	21
SFH 7740	Optical Switch	21
ISL29011	Light sensor	27
STCN75	Temperature	4
Low-power		
TSL2550	Light sensor	1155
ADXL202JE	Accelerometer	24
SHT 11	Humidity/temper.	275
MS55ER	BarometricPressure	3
QST108KT6	Touch	7
SG-LINK(1000Ω)	Strain gauge	9
Medium-power		
SG-LINK(350Ω)	Strain gauge	24
iMEMS	Accelerometer	30
OV7649	CCD	44
2200-2600 Series	Pressure	50
High-power		
TI50	Humidity	90
DDT-651	Motion Detector	150
EM-005	Proximity	180
BES 516-371-S49	Proximity	180
EZ/EV-18M	Proximity	195
GPS-9546	GPS	198
LUC-M10	Level sensor	300
CP18,VL18,GM60	Proximity	350
TDA0161	Proximity	420
Ultra high-power		
FCS-GL1/2A4-AP8X-H1141	Flow control	1250
FCBEX11D	CCD	1900/2800
XC56BB	CCD	2200

B. Wireless Sensor System:

Taxonomy of wireless sensor system is shown in fig. 3. There are several internal system issues that required to be highlighted through system platform and OS support, storage, supporting standard, Test beds and diagnostics, and debugging support. **System platform and OS support:** Sensor nodes have different transceiver, processors, and Storage devices. It is a tough to integrate number of sensors on a WSNs platform since sensor hardware is different and raw data processing can be a problem with limited resources in the sensor node. System software such as the OS must be designed to support these sensor platforms. There are two platforms: a Bluetooth-based sensor system [20] and a detection-and-classification system [21]. **Wireless sensor standards:** This is developed with the requirement for low power consumption, standard defines the protocols and functions necessary for sensor nodes to interface with different networks. Some of well known standards are IEEE 802.15.4 [22], ZigBee [23-24], Wireless HART [25-26], ISA100.11 [27], and IETF 6Low PAN [28-30], IEEE 802.15.3 [31], Wibree [32]. **Storage:** Conventional WSNs require that most of data generated must be transferred from sensor nodes to a centralized base station as nodes have limited storage space.

Techniques such as data compression and aggregation are used to reduce the amount of data transferred, thereby reducing energy consumption and communication cost. Storage space in sensor node is limited and communication is expensive, a storage model is necessary to satisfy storage limitation and query requirements. There are several storage methods in terms of assumptions, design goals, operation models, and performance like GEM: Graph Embedding (GEM) [33], TSAR: Two-tier sensor storage architecture (TSAR) [34], MRS: Multi-resolution storage [35]. **Test bed**: They provide to researchers a way to test their protocols, network issues, algorithms and applications. There are several WSN test beds like ORBIT [36], Mote Lab [37], Emu lab [38].**Diagnostics and debugging support:** it is important to have a diagnostic and debugging system that can monitor and measure the sensor node performance of the overall network. Tools call Sympathy [39] that detects and localizes failures.

III. ENERGY EFFICIENT SCHEMES IN WSNS

Network life time is determined by residual energy of the system, hence main and most important challenge in WSNs is the efficient use of energy resources. Different protocols have been proposed to reduce wasteful energy consumption. These protocols can be classified into three different levels. Protocols in the first level work by increasing capacity of networks, by controlling the transmission power level at each sensor node [40-41]. Protocols in the second level make routing decisions based on power or energy optimization goals, [42-45]. Protocols in the third level control the network topology by determining which nodes should participate in the network operation (be awake) and which should not (remain asleep) in network operation [47-49]. Literature shows the energy efficiency is introduced in WSNs using any of the following mechanism.

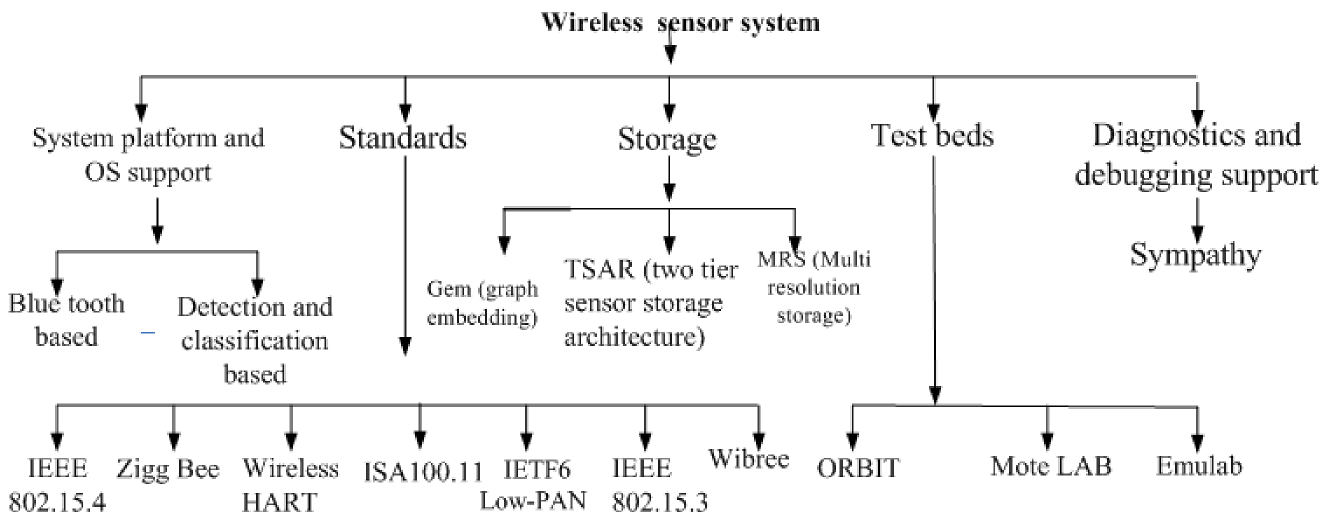


Figure.3: Taxonomy of wireless sensor system

a. Energy conservation mechanism
b. Power conservation mechanism
c. Energy harvesting mechanism
d. Energy efficient routing

A. *Energy Conservation Mechanism:*

Taxonomy of energy conservation is shown in fig.4. This scheme uses techniques like duty cycling, mobility and data-driven approaches. Duty cycling mainly focused on the networking subsystem, it is an energy-conserving technique in which sensor nodes alternate between active and sleep periods depending on network activity. This behavior is usually referred to as duty cycling [49]. Data-driven approaches can also be used to improve the energy efficiency, basically data driven techniques are designed to reduce the amount of sampled data by keeping the sensing accuracy within an acceptable level from the application point of view. In case some of the sensor nodes are mobile, mobility can also be used as a tool for reducing energy consumption.

Fig. 4 presents classification of different energy conservation schemes used in WSN along with relevant referencing and discussions. **Duty cycling** can be achieved through two different approaches, one way is to use node redundancy, which is typical in sensor networks, and select only a minimum number of sensor nodes to remain active for maintaining connectivity and remaining sensor nodes go to sleep to save energy. Finding the optimal subset of sensor nodes that guarantee connectivity is called as topology control. Other way is that the active sensor nodes selected by the topology control protocol need not to maintain their transceiver continuously in on state. They can switch off the transceiver when there is no network activity. Here duty cycling is operated on active nodes as power management. Therefore, topology control and power management are complementary techniques. Power management techniques can be further subdivided into two categories on the basis of layer of the network architecture they are implemented at. Power management can be implemented either MAC protocol with low duty cycle or Wake up/sleep protocol.

Data-driven approaches can be divided in to two categories, data reduction and energy-efficient data acquisition. Data reduction addresses the case of reducing redundancy of data samples, while energy-efficient data acquisition schemes are mainly aimed at reducing the energy spent by the sensing subsystem itself. Data reduction schemes can be further classified in to in-network processing, data compression and data prediction. All these techniques aims in reducing the amount of data to be delivered to the base station but principle behind them are different. In-network processing consists in performing data aggregation at intermediate sensor nodes between the sources and the base station. Data compression can be applied to reduce the amount of information sent by source sensor nodes.

This scheme involves encoding information at sensor nodes which generate data, and decoding it at the sink [50]. Data prediction is an adaptive scheme that can predict the values sensed by sensor nodes within certain error bounds, it is to be used both at the sensors and at the base station. M**obility-based schemes** can be classified on the type of the mobile entity i.e. mobile-sink and / or mobile-relay scheme. A detailed discussion on this point is presented in [51]. Mobile nodes can be divided into two categories, one that can be designed as part of the environment, and other as a part of the network infrastructure. When they are part of the infrastructure, mobility can be controllable but mobile nodes being a part of the environment may not be controllable

B. *Power Conservation Mechanism:*

Taxonomy of power conservation is shown in fig.5. Power conservation mechanism for WSNs may be divided in to two parts [52]: passive and active, in passive mechanism the sensor nodes save power by turning off the radio which is similar to duty cycling. Active power conservation mechanisms, reduces the energy consumption of a sensor node counting on the concept of improving the node's operation instead of turning-off the radio interface module into the power-save mode. These mechanisms can be performed at different Protocol layers like Physical, MAC, and transport layer.

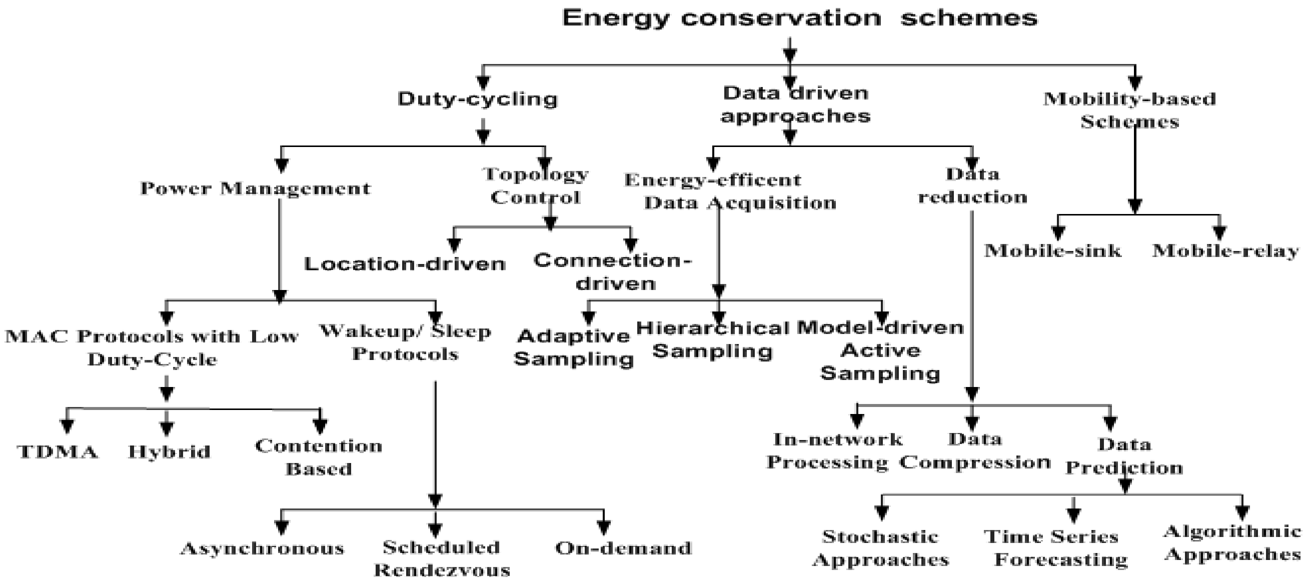


Figure.4: Taxonomy of Energy conservation mechanism

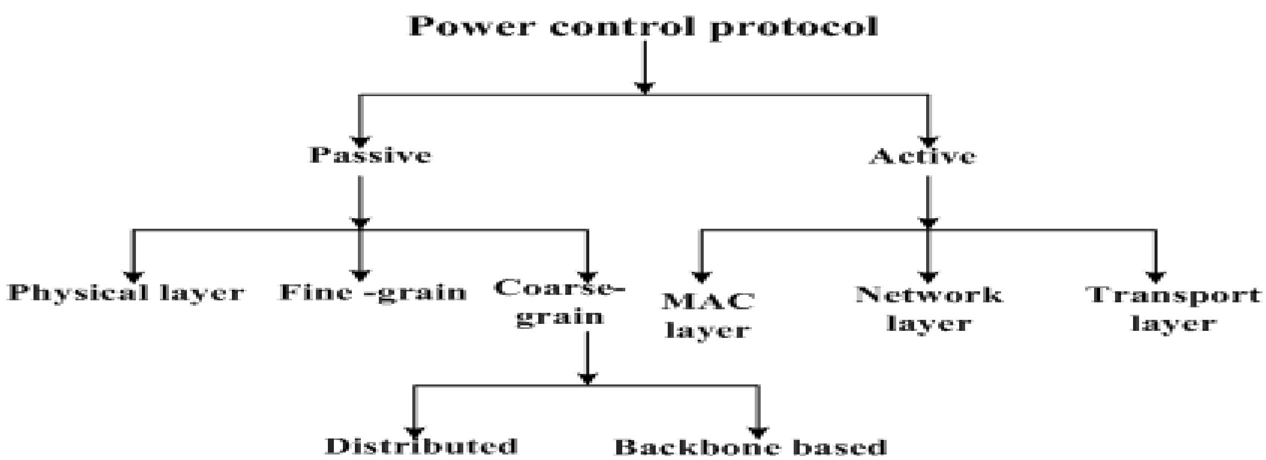


Figure.5: Taxonomy of Power Conservation Mechanshim

Passive power conservation mechanism is also called periodic hibernation, in this mechanism a periodic turn off of the wireless transceiver take place, where the sensor nodes neither transmit nor receive. Passive power conservation mechanisms can be divided into three categories on the basis of control for turning-off the transceiver. Physical Layer Power Conservation (FLPC), Fine-Grain Power Conservation (FGPC) and Coarse-Grain Power Conservation (CGPC). In Physical Layer Power Conservation mechanism, turn-off techniques at the physical layer can facilitate energy savings by maintaining the minimum energy state of the Central Processing Unit (CPU) in idle states. Examples of the passive power conservation mechanisms are Dynamic Voltage Scaling (DVS) [53], and Dynamic Power Management (DPM) [54]. In Fine-Grain Power Conservation (FGPC) mechanism, MAC layer is responsible to decide whether there is a frame transmission that is destined to it, and then turn-off the radio interface module for just one transmission frame. One example of the FGPC algorithm is PAMAS [55]. In Coarse-Grain Power Conservation (CGPC) decide when to Turn-off the radio interface module based on higher layer application information to implement these mechanisms, there are two different approaches i.e. distributed approach and the Backbone-based Approach. SPAN [56] is a very common coarse-grain conservation scheme utilizing a backbone to facilitate routing. **Active Power Conservation Mechanisms** are applied for different protocol layers like MAC, physical, network and transport layer. In MAC Layer it is used by decreasing the chance of frame collision (CSMA CA) and thus resulting in the reduction of energy consumption, used in retransmission. In Network Layer two fundamental power-saving schemes are employed at the network layer, Maximum Lifetime Routing and Power-Aware Routing. In Transport Layer, Transmission Control Protocol (TCP) and Altered TCP (ATCP) [57]. It alters TCP retransmission behavior by reducing unnecessary retransmissions to the minimum achieving lower power consumption and higher throughput. The main features of power conservation mechanisms are summarized in table III.

Table: III Power Conservation Mechanism

Power conservation mechanisms	Utilized techniques	Layer applied to
Passive	Turning of transceiver	Physical, MAC ,Application layers
Active	Network protocol	Physical, MAC, Network ,Application, Transport layers

C. Energy Harvesting:

In this scheme sensor nodes are provided with energy generation capabilities from the surrounding. Various sources for energy harvesting are Solar cell [58, 59], vibration [60], wind turbines, thermoelectric generators, photovoltaic cells, mechanical vibration devices such as piezoelectric devices, electromagnetic devices. Table 3 shows some of the harvesting methods with their power generation capability

Table: IV Different Harvesting Method

Harvesting Method	Power Density
Solar Cells	15 m W/cm^3
Piezoelectric	330 $\mu W/cm^3$
Vibration	116 $\mu W/cm^3$
Thermoelectric	40 $\mu W/cm^3$
Acoustic noise	960 nW/cm^3

Energy harvesting at present cannot supplement the batteries used in the sensor nodes but can help in extending the life of WSNs.

D. Energy Efficient Routing:

Routing in WSNs is very challenging due to some special characteristics that differentiate these networks from other wireless networks like cellular networks, mobile ad hoc networks [61]. First difference is due to scalability, as very large number of sensor nodes may be needed to be deployed simultaneously so it may not be possible to build a universal addressing scheme for the deployment of sensor nodes as the overhead for ID maintenance becomes extremely high. Thus, traditional IP-based protocols may not be suitable for wireless sensor networks. Second difference is that for most applications of sensor networks require the flow of sensed data from multiple sources to a particular sink called base station (BS). This, however, requires the flow of data to be in other forms like multicast, rather than peer to peer. Third is because of the fact that sensor nodes are resource constrained in terms of energy, storage capacities, processing thus, require careful resource management. Fourth is, in most application, sensor nodes in WSNs are generally stationary after deployment except for maybe a few mobile Sensor nodes. Nodes in other wireless networks are free to move, which results in unpredictable topological changes but death of active sensor node also result in unpredictable topological change. Fifth one is that the sensor networks are application-specific which means design requirements of a sensor network change with application. And last one, Position awareness of sensor nodes in WSNs is important since data collection is normally based on the location. Currently, it is not feasible to use Global Positioning System hardware for this purpose the following are the Routing Challenges unique to WSNs [61].

a. Energy consumption without losing accuracy
b. Node deployment:
c. Link heterogeneity
d. Data reporting model
e. Fault tolerance
f. Scalability
g. Network dynamic
h. Transmission media
i. Connectivity
j. Coverage
k. Data aggregation
l. Quality of services

The aim of routing in WSN is to find out and maintain routes in wireless sensor networks. As explained earlier it is not easy because of energy restriction and sudden change in node status cause unpredictable topologies changes. To minimize energy efficiency in wireless sensor networks, routing techniques employ some well known routing tactics to WSN[61] for ex. Clustering, Different node role assignment, Data centric, Data aggregation and in network processing. Research efforts have been made to develop energy efficient Routing algorithms for correlated data gathering with the help of data fusion. Depending on the design methodologies, they can be classified into three parts, Routing-driven [62] Coding-driven [63] and Fusion-driven [64].

Routing-driven algorithms assume that data aggression can be done at any sensor node without additional over head or computation cost. The main goal of these algorithms is to minimize the total communication cost for collecting the data to the base station .This class include, LEACH, PEGASIS and Directed Diffusion

Coding-driven algorithms concentrate on coding techniques at the source sensor nodes for data Reduction; they assume that partial aggregation is possible at every sensor node.

Fusion-driven algorithms chosen routing paths are totally dependent on data correlation among different sensor nodes the scheme derives energy benefit from information reduction resulting from data fusion.

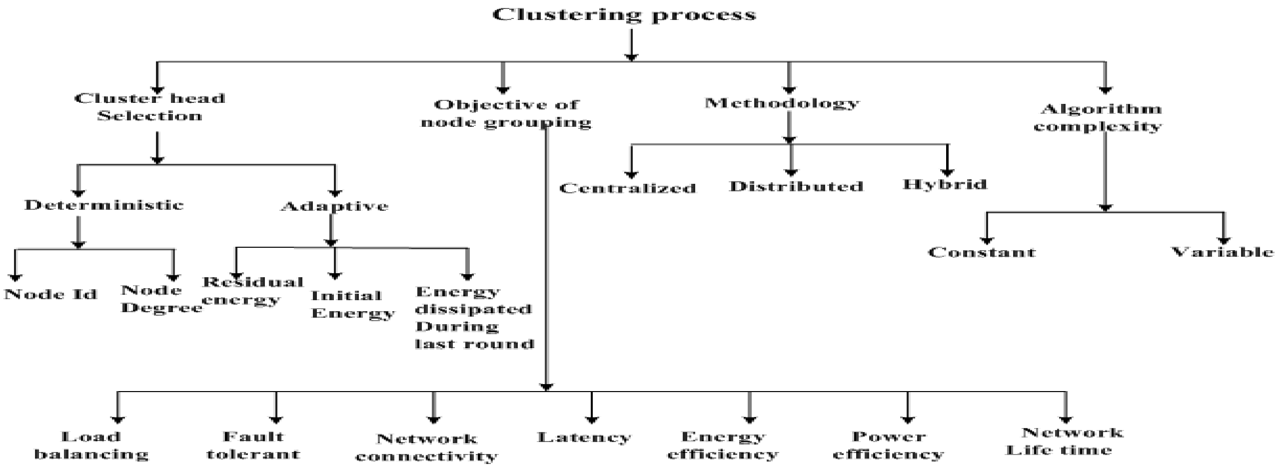


Figure.6: Taxonomy of clustering process

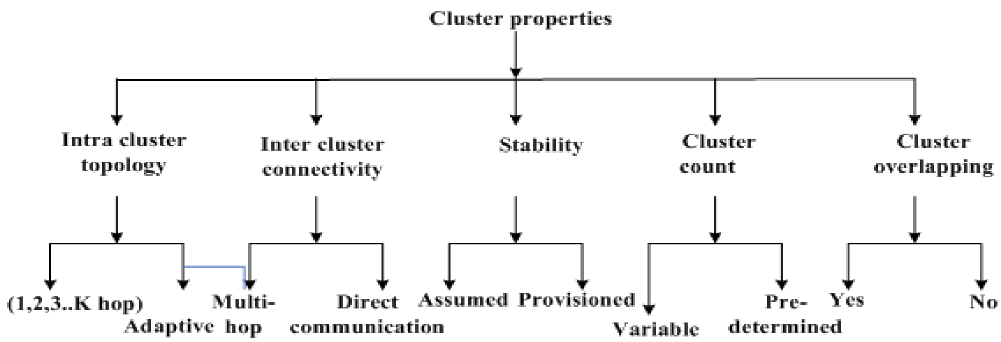


Figure.7: Taxonomy of cluster properties

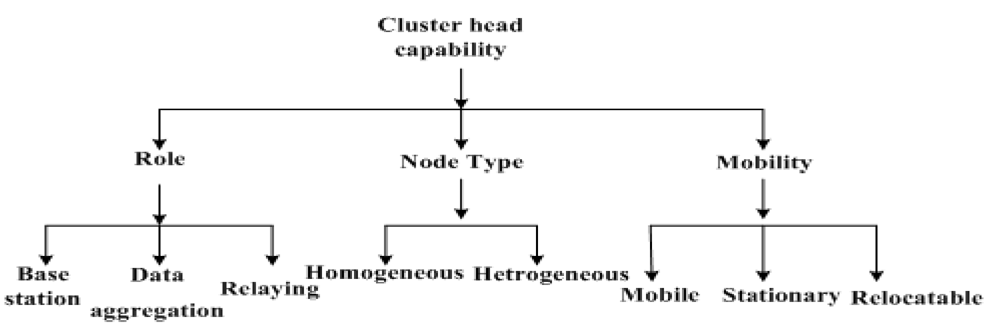


Figure.8: Taxonomy of cluster head capability

A. Hierarchical Routing in WSNS:

Clustering has important applications in high-density sensor networks, because it is much easier to manage a set of cluster representatives (cluster head) from each cluster than to manage whole sensor nodes. In wireless sensors networks the sensor nodes are resource constrained which means they have limited energy; transmit power, memory, and computational capabilities. The sensor nodes can transmit the sensed information to the sink energy consumed by the sensor nodes for communicating data from sensor nodes to the base station is the crucial cause of energy depletion in sensor nodes .Clustered sensor network could be classified as single hop and multi hop, in single hop network sensor node use single step to reach the cluster heads where in multi hop network it uses multi step to reach the cluster head, where cluster head using single hopping for data transmission to the base station.

Overall system scalability, Network Life time, Energy or power Efficiency are the factors which depend on the creation of the optimal number of clusters and spatial position of cluster heads:. A large number of clusters will congest the area with small size clusters and very small number of clusters will exhaust the cluster head with large amount of messages to be transmitted from cluster members. Hence the number of cluster formed should be optimal for extending the life time of wireless sensor networks. Energy efficiency in wireless sensor network can be improved by using any of the following techniques. Firstly, by selecting optimal number of cluster heads considering both the residual energy of the nodes and the total power consumption of the cluster [65]. Second by optimizing the number of sensor nodes in to the cluster by considering the size of the networks and total power consumption of the cluster [66].

In this approach first sub method is to optimize the organization of the cluster to reduces the sum of distance between the normal nodes and their cluster heads second sub method is to assign lowest RF power for normal node that is needed for intra cluster communication and lowest RF power allocation for cluster heads for inter cluster communication [67].Third sub method works with variable RF ranges assigned to different nodes proportional to their distance from the cluster head [68].And last one is K-tree method in which the value of k is optimized to save the energy[69]. Third method uses rotating the roles of cluster heads to equalize the power consumption among cluster heads and normal sensor nodes.

In this approach the first sub method is to Rotate the role of cluster heads with in the cluster, second sub method is to assign each cluster head the approximately same number of nodes, third one is by selecting the cluster head approximately at the center of the cluster, during the rotation of the roles of cluster heads, if the cluster heads would be located at his centre of cluster, energy can saved[59] and last sub method of this approach is to avoid longer transmission range and minimizing numbers of hops needed to cover the whole cluster. **Clustering Process** Fig. 6, 7, 8 shows the taxonomy of clustering process, cluster [properties and cluster head capabilities in WSN. Clustering as a process in WSN may have four main attributes i.e. cluster head selection, clustering objective, clustering methodology, and clustering algorithm.

Process of cluster head selection may be deterministic or adaptive in nature. Literature of WSN shows varied objective of the clustering process and often they are set to meet the application requirement. Clustering methodologies used in WSN may be centralized, decentralized or a combination of both as hybrid. Different algorithms with varying complexity are used for clustering process. Cluster properties are the attributes that clustering schemes try to achieve, some of considered attribute are inter-cluster and intra-cluster topology, stability, Cluster Count, and cluster overlapping.

Cluster head capabilities are the set of different attributes that the cluster head node should possess, which include its role, its type and its mobility. Role of the cluster heads in which the cluster heads can act as a relay in its cluster or perform fusion/aggregation of collected sensor data, sometimes; a cluster head acts as a sink or base station. Type of sensor node in wireless sensor network be a heterogeneous or homogeneous sensor nodes, heterogeneity means they have power full processor, large memory and computational capability. Mobility, in which when cluster heads changes its position, membership of the sensor nodes is dynamically changes and there is a need to maintain clusters. A good cluster head selection approach should satisfy the following requirements: A cluster head selection strategy should periodically reselect clusters and cluster heads to avoid unbalance load on particular nodes, Uniform number of cluster heads should be selected in each round and to achieve same size clusters means the selected cluster heads should be uniformly distributed in the topology.

IV. CONCLUSION

We have surveyed the different approaches for energy saving in wireless sensor networks such as: energy conservation, power conservation, energy harvesting and energy efficient routing. We have got that most of the solutions for energy consumption assumes the energy consumption of the radios is much higher than the energy consumption due to data sampling or data processing. We have also stressed the importance of different approaches such as data-driven and mobility-based schemes. It is worth noting that the considered approaches should not be considered as alternatives, they should rather be exploited together. Energy conservation related to data acquisition has not been explored yet so that there is room for developing convenient techniques to reduce the energy consumption of the sensors.

V. REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “A Survey on Sensor Networks”, IEEE Communications Magazine, Aug. 2002.

[2] B. Sinopoli, C. Sharp, L. Schenato, S. Shaffert, and S. S. Sastry, “Distributed control applications within sensor networks,” Proc. IEEE, vol. 91, no. 8, pp. 1235–1246, Aug. 2003.

[3] K. Dasgupta, K. Kalpakis, and P. Namjoshi, “An efficient clustering-based heuristic for data gathering and aggregation in sensor networks,” Proc. WCNC, vol. 3, pp. 1948–1953, 2003.

[4] F. Zhao, J. Liu, J. Liu, L. Guibas, and J. E. Reich, “Collaborative signal and information processing: An information-directed approach,” Proc. IEEE, vol. 91, no. 8, pp. 1199–1209, Aug. 2003.

[5] Y. Liu, H. Man, and C. Comaniciu, “A game theoretic approach to efficient mixed strategies for intrusion detection,” in Proc. IEEE Int. Conf. Commun., pp. 2201-2206, 2006.

[6] W. Heinzelman, A. Chandrakasan and H. Balakrishnan “distributed Computing, Applications and Technologies for gaining network processing: An information-directed approach,” in, Issue 4, pp.654-659, 2005.

[7] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan,” Energy scalable algorithms and protocols for wireless micro sensor networks” Proc. International Conference on Acoustics, Speech, and Signal Processing, pp. 660-760, June 2000.

[8] N.M.A. Latiff, C.C. Tsimenidis, and B.S. Sharif “Performance Comparison of optimization Algorithm for Clustering in Wireless Sensor Networks”, Mobile adhoc and Sensor Systems, 2007, MASS 2007, IEEE International Conference on volume, Issue 8, pp. 1-4, Oct. 2007.

[9] Y. Haibin, Z. Peng, and L. Wei, "Intelligent Wireless Sensor Networks" ,Beijing Science Press, China, pp.119-139, Jan. 2006.

[10] G. Simon, M. Maroti, A. Ledeczi, G. Balogh, B. Kusy, A. Nadas, G. Pap, J. Sallai, K. Frampton, "Sensor network-based countersniper system" Proceedings of the Second International Conference on Embedded Networked Sensor Systems (Sensys), Baltimore, MD, 2004

[11] J. Yick, B. Mukherjee, D. Ghosal, "Analysis of a Prediction-based Mobility Adaptive Tracking Algorithm", in: Proceedings of the IEEE Second International Conference on Broadband Networks (BROADNETS), Boston, 2005.

[12] M. Castillo-Effen, D.H. Quintela, R. Jordan, W. Westhoff, W. Moreno, " Wireless sensor networks for flash-flood alerting", in: Proceedings of the Fifth IEEE International Caracas Conference on Devices, Circuits, and Systems, Dominican Republic, 2004

[13] G. D. Greenspan, M. Welsh, R.R. Juang, A. Alm, "Vital signs monitoring and patient tracking over a wireless network", in: Proceedings of the 27th IEEE EMBS Annual International Conference, 2005.

[14] K. Lorincz, D. Malan, T.R.F. Fulford-Jones, A. Nawoj, A. Clavel, V. Shnayder, G. Mainland, M. Welsh, S. Moulton, "Sensor networks for emergency response: challenges and opportunities," Pervasive Computing for First Response (Special Issue), IEEE Pervasive Computing, October–December 2004.

[15] G. Wener-Allen, K. Lorincz, M. Ruiz, O. Marcillo, J. Johnson, J. Lees, M. Walsh, "Deploying a wireless sensor network on an active volcano, Data-Driven Applications in Sensor Networks"(Special Issue), IEEE Internet Computing, March/April 2006.

[16] I. Dietrich and F. Dressler, "On the Lifetime of Wireless Sensor Networks," ACM Transactions on Sensor Networks, Vol.5, No.1, Article No. 5, pp 1-38, 2009.

[17] K. sohraby, D.minoli and t. zhati "wireless sensor networks:technology,protocols and approach" 2004.

[18] V. Gutnik and A. P. Chandrakasan, "Embedded Power Supply for Low-Power DSP," IEEE Trans. VLSI Systems, vol. 5, no. 4, pp. 425–35, 1997.

[19] M.K. Stojcev, M.R Kosanovic and L.R. Golubovic, "Power Management and Energy Harvesting Techniques for Wireless Sensor Nodes" Telecommunication in Modern Satellite, Cable, and Broadcasting Services, 2009. TELSIKS '09. 9th International Conference Publication, pp. 65 – 72, 2009.

[20] M. Leopold, M. B. Dydensborg, P. Bonnet, "Bluetooth and sensor networks: a reality check" Proceedings of the Sensys, Los Angeles, CA, 2003.

[21] L. Gu, D. Jia, P. Vicaire, T. Yan, L. Luo, A. Tirumala, Q. Cao, T. he, J.A. Stankovic, T. Abdelzaher, B.H. Krogh, "Lightweight detection and classification for wireless sensor networks in realistic environment", in: Proceedings of the Sensys'05, Los Angeles, CA, 2005

[22] I. Howitt, J.A. Gutierrez "IEEE802.15.4 low rate-wireless personal area network coexistence issues" Wireless Communications and Networking, pp.1481–1486, 2003.

[23] ZigBee: wireless control that simply works http://www.zigbee.org.

[24] ZigBeehttp://www.freescale.com/webapp/sps/site/overview.jsp?nodeId=01J4Fs256577

[25] HART the Logical Wireless Solution, <http://www.hartcomm2.org/hart_protocol/wireless_hart/hart_the_logical_solution.html>.

[26] Draft standard: What's in the April'07 Wireless HART specification,<http://www.controleng.com/article/CA6427951.html>.

[27] ISA100.11a,<http://www.isa.org/MSTemplate.cfm?MicrositeID=1134&CommitteeID=6891>.

[28] 6LoWPAN, <http://6lowpan.net/>.

[29] G. Mulligan, L.W. Group, The 6LoWPAN architecture, in: Proceedings of the EmNets, Cork, Ireland, 2007.

[30] G. Montenegro, N. Kushalnagar, J. Hui, D. Culler, Transmission of IPv6 packets over IEEE 802.15.4 networks, RFC 4944, 2007.

[31] IEEE Standard 802.15.3, Wireless medium access controls (MAC) and physical layer (PHY) specifications for high rate wireless person area networks (WPANs), September 2003.

[32] Wibree, <http://www.wibree.com/>.

[33] J. Newsome, D. Song, "GEM: Graph EMbedding for routing and datacentric storage in sensor networks without geographic information", Proceedings of them Sensys'03, San Diego, CA, 2003.

[34] P. Desnoyers, D. Ganesan, P. Shenoy, "TSAR: a two tier sensor storage architecture using interval skip graphs', in: Proceedings of the Third International Conference on Embedded Networked Sensor Systems (Sensys), San Diego, CA, 2005.

[35] D. Ganesan, B. Greenstein, D. Perelyubskiy, D. Estrin, J. Heidemann, "An evaluation of multi-resolution storage for sensor networks", in:Proceedings of the Sensys'03, Los Angeles, CA, 2003.

[36] D. Raychaudhuri, I. Seskar, M. Ott, S. Ganu, K. Ramachandran, H.Kremo, R. Siracusa, H. Liu, M. Singh, "Overview of the ORBIT radio grid testbed for evaluation of next-generation wireless network protocols", in: Proceedings of the IEEE Wireless Communications and Networking Conference, 2005.

[37] G. Werner-Allen, P. Swieskowski, M. Welsh, "MoteLab: a wireless sensor network testbed", in: ISPN, 2005.

[38] D. Johnson, T. Stack, R. Fish, D.M. Flickinger, L. Stoller, R. Ricci, J. Lepreau, Mobile Emulab: “ a robotic wireless and sensor network testbed”, in: IEEE INFOCOM, 2006.

[39] J.H. Huang, S. Amjad, S. Mishra, CenWits: “A sensor-based loosely coupled search and rescue system using witnesses”, in: Proceedings of the Third International Conference on Embedded Networked Sensor Systems (Sensys), San Diego, CA, 2005.

[40] V. Kawadia and P.R. Kumar, “Power Control and Clustering in Ad Hoc Networks,” Proc. IEEE INFOCOM, Apr. 2003.

[41] S. Narayanaswamy, V. Kawadia, R.S. Sreenivas, and P.R. Kumar, “Power Control in Ad-Hoc Networks: Theory, Architecture, Algorithm and Implementation of the COMPOW protocol,” Proc. European Wireless 2002. Next Generation Wireless Networks: Technologies, Protocols, Services and Applications, pp. 156-162, Feb. 2002.

[42] C. Intanagonwiwat, R. Govindan, and D. Estrin. “Directed diffusion: A Scalable and robust Communication Paradigm for Sensor Networks”. In proceedings of the 6th Annual a ACM/IEEE International Conference on Mobile computing and Networking (MOBICOM), pages 56–67, August 2000.

[43] J. Kulik, W. Heinzelman, and H. Balakrishnan, “Negotiation-Based Protocols for disseminating Information in Wireless Sensor Networks” ACM Wireless Networks, vol. 8, nos. 2-3, pp. 169-185, 1999.

[44] J. Chang and L. Tassiulas, “Energy conserving routing in wireless ad-hoc networks,” IEEE INFOCOM.2000.

[45] W. Heinzelman, A. Chandrakasan and H. Balakrishnan., "An Application-Specific Protocol Architecture for Wireless Microsensor Networks", IEEE Trans. Wireless Communications, Vol. 1, No.4, pp.660-670, October 2002.

[46] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "SPAN: An energy -efficient coordination algorithm for topology maintenance in ad hoc wireless networks," in proceedings of Mobicom’01, pp. 85-96, 2001.

[47] B. Chen, K. Jamieson, H. Balakrishnan, R. Morris, “SPAN: an energy efficient coordination algorithm for topology maintenance in ad hoc wireless networks, ACM Wireless Networks, Vol. 8, Issue 5, 2002.

[48] A.Cerpa and D. Estrin, “ASCENT: Adaptive self-configuring sensor networks topologies,” IEEE Trans. Mobile Computing, vol. 3, no. 3, pp. 272– 285, Jul./Aug. 2004

[49] D. Wei, H. A. Chan, and B. Silombela, “ dynamic cluster algorit Design of Ad Hoc Wireless Sensor Networks”,o Proceedings of the 12th International Conference on Tele communication ICT2005, Cape Town, May 3-5, 2005.

[50] C. Guo, L.C. Zhong, J.M. Rabaey, “Low power distributed MAC for ad hoc sensor radio networks”, in: Proceedings of the IEEE Globecom, pp. 2944–2948, 2001.

[51] G. Wener-Allen, G. Tewari, A. Patel, M. Welsh, R. Nagpal, “Firefly inspired sensor network synchronicity with realistic radio effects”, in: Proceedings of the Third International Conference on Embedded Networked Sensor Systems (Sensys), San Diego, CA, 2005.

[52] N.A. Pantazis, D.D. Vergados “A survey on power control issues in wireless sensor networks” Communications Surveys & Tutorials,IEEE Volume: 9 , Issue: 4 , pp. 86 – 107, 2007.

[53] C. Im, H. Kim, and S. Ha, “Dynamic Voltage Scheduling Techniquefor Low-Power,” Int’l. Symp. Low Power Electronics and Design, Seoul, Korea, pp. 92–95, Aug. 2001.

[54] A. Sinha, and A. Chandrakasan, “Dynamic Power Management in Wireless Sensor Networks,” IEEE Design and Test of Computers, vol. 18, Issue 2, pp. 62–74, 2001.

[55] S. Singh, and C. Raghavendra, “PAMAS: Power Aware Multi-Access Protocol with Signaling for Ad-Hoc Networks,” ACM SIGCOMM Comp. Commun. Review, vol. 28, no. 3, pp. 5–26, 1998.

[56] Y. Shen, B. Guo “Dynamic Power Management based on Wavelet Neural Network in Wireless Sensor Networks” Network and Parallel Computing Workshops, 2007. NPC Workshops. IFIP International Conference, pp.431 – 436, 2007.

[57] J. Liu and S. Singh, “ATCP: TCP for Mobile Ad-Hoc Networks,”IEEE JSAC, Wireless Commun. Series, vol. 19, no. 7, pp. 1300–15, 2001.

[58] V. Raghunathan, A. Kansai, J. Hse, J. Friedman, M. Srivastava, “Design considerations for solar energy harvesting wireless embedded systems”, in: Proceedings of the IPSN, pp.457–462, 2005.

[59] P. Zhang, C.M. Sadler, S.A. Lyon, M. Martonosi, “Hardware design experiences in ZebraNet”, in: Proceedings of the SenSys’04, Baltimore, MD, 2004.

[60] S. Roundy, J.M. Rabaey, P.K. Wright, “Energy Scavenging for Wireless Sensor Networks”, Springer-Verlag, New York, LLC, 2004.

[61] J.N Al-Karaki, A.E Kamal, “Routing techniques in wireless sensor networks: a survey” Wireless Communications, IEEE Volume 11, Issue 6, pp. 6 – 28, Dec. 2004

