A Survey on Applications, Communication Stack and Energy Consumptions in WSNs

Priyanka, Ajay Kumar Singh

Abstract*: *Wireless Sensor networks (WSNs) are a collection of small, tiny sensors that are having sensing, computation capability, and working together with the help of wireless communication. This paper explains the theory of wireless sensor networks. By merging the micro electro-mechanical skill, digital electronics, and wireless exchanges of information features made WSNs viable. This paper discusses about applications of WSNs and some of application area like military, and health low energy consumption requirement are used WSNs vastly. A list of factors that are effect the design of WSNs is provided, and most of the constraint on sensor nodes is low power consumption requirement, here we discuss all constraints that are useful for improvement of WSNs. Here we discuses about communication architecture, algorithms, and protocols refined for layers. Stack of protocols incorporates all layers that are essential for communication. Protocols of routing are provided by network layer that make energy efficient scheme for transmission of data. For the awareness of sensor networks open research issues are discussed. This paper discussed about how nodes are placed in network, energy consumption model for computing the energy in transmission to receiver ends, and traffic patterns. The assessment terms regularly used for making the routing scheme power efficient is discussed here , also discussed all the routing schemes.

Index Terms*: *Wireless Sensor Networks, Application layer, Transport layer, Networking layer, Data link layer, Physical layer, Routing protocols, and Energy efficiency.

I. INTRODUCTION

WSN is made up of collection of wireless nodes they are having limited power, may be mobile or stationary, and located randomly or dynamically. Sensor network are firstly used by military in the middle 70's. With the help of WSN, lots of work carried out resulting in development of WSN applications, and systems. At another side, WSN become a vastly varying requirements subject that provides energy efficient routing scheme or protocols for supporting efficient data delivery to their base station/destination.

To monitor broad range of ambient conditions, many different category of sensor may include in sensor network e.g. thermal, radar, visual, seismic, and low sampling rate magnetic. These sensors are capable to monitor pressure, lightning condition, humidity, vehicular movement, temperature conditions [1]. Location sensing, incident detection, incident ID, and continuous monitoring are also done by using sensor nodes.

This paper is organized as follows: In Section II, explains potential applications of sensor network. In Section III, provides the factor that affect design of sensor network. Section IV, explains the communication model, and investigate the research area in WSN. Section V, explains node placement, energy expenditure model, and traffic patterns of WSNs. We provide route selection policies in energy efficient routing in Section VI. Some routing schemes developed for route data in WSN in Section VII. We conclude the paper in Section VIII.

II. SENSOR NETWORK APPLICATION

A. Applications of Sensor Network in Military

1) Battle Losses Assessment
2) Monitoring Responsive Forces, Tool, and Ammunition
3) Investigation of Opposing Armed Forces, and Terrain
4) Battleground Observation

B. Applications of Sensor Network in Environment

1) For Detection Fire in Forest
2) Biocomplexity Mapping of the Environment [2]: About temporal and spatial scales [3] a classy approach is required for biocomplexity mapping of the environment.
3) Flood Detection [4]: An example of food detection system is positioned in US (ALERT system) [5].
4) Precision Agriculture

C. Applications of Sensor Network in Health

1) Human Physiological Records Telemonitoring: Records of human physiological composed via sensor nodes is store for long period [6], and health examination done with this data record [7]-[8].
2) Observation of Patients inside a Hospital
3) Drug Administration in Hospitals [9].

D. Applications of Sensor Network in Home

1) Home Automation

E. Applications of Sensor Network Commercial

1) Car Thefts Detecting and Monitoring [10]
2) Administration Inventory Control
3) Tracking and Detection of Vehicle [11]

Revised Manuscript Received on December 22, 2018.

Priyanka, Computer Science and Engineering, AKTU/ MIET, Meerut, India.
Ajay Kumar Singh, Computer Science and Engineering, AKTU/ MIET, Meerut, India.

III. FACTORS AFFECT SENSOR NETWORK DESIGN

At the time of designing the sensor network lots of factors are involve which affect the efficient network design. For designing an algorithm or protocol, these factors serve as guidelines for sensor nodes system.

A. *Manufacture Costs*

Before calculate the costs of whole network its essential to know about cost of single node to make the sensor network feasible [12]. It is important that cost of sensor node should be less than Rs. 70.

B. *Scalability*

Growing the number of sensor nodes in network it is depend on the applications. In [13], number of sensor nodes in the field is given by density function: $\mu(Ra)=(Ns\pi Ra2)/Ar$. Where Ar is a region, and Ns is the counting of scattered nodes in the Ar. Radio communication range Ra. Depending upon the communication radius or transmission range of every node provides total nodes present the network by $\mu(Ra)$.

C. *Liability Forbearance i.e. Fault Tolerance*

The liability forbearance refers to capability for handling some set-up function with no break or delay due to failures [14]-[16]. Network overall task should not be affected by the sensor node failure.

D. *Operating Surroundings*

The environment where the sensor nodes may be deploying: inside of outsized storehouse, in natural world, center of bulky equipment, at the underside of an ocean, and in a house or a big house.

E. *Hardware Constraints*

A sensor node consist four components for sensing the environment that works on the sensing object, and store the information i.e. processing unit, transmit the information, and provides the power to do the task. Location finding system that find the location of required data, and send the sense data to processing unit, power generator generates the power and supply to power unit, and mobilize other additional components of a sensor node all these component are application dependent component. Sensing unit has two subunits e.g. sensors and analog to digital converters (ADCs). Processor and small storage unit is attached for accomplish the assign sensing responsibility in processing unit. Sensor node connected with the network by transceiver units. Power generator unit like solar cells provides support for power unit. These nodes must [17]

- Be independent and function unattended
- Having small manufacture price
- Surroundings adaptively
- Function in high volumetric densities
- Use extremely low power

F. *Power Consumption*

Re-organization of the network and re-routing of packets may be requiring after the disfunctioning of some nodes. Sensing, communication and data processing are three domains to calculate the overall power expenditure of the sensor network.

G. *Transmission Media*

Radio, optical or infrared is the links of wireless medium for communication in multihop sensor node networks. Smart dust mote [17] is an interesting development, an autonomous sensing, computing, and communication system that uses optical medium for transmission.

H. *Sensor Network Topology*

There are three issues associated with topology protection, and modification.

1) *Initial Phase of Deployment of Sensor Nodes:* By using the deterministically placement, and random placement of all nodes in the network field. Sensor node are placed through delivering in weaponry shield, missile, placing in plant, falling from an airplane, and placing one by one either by individual person or a machine.

The schemes for initial deployment must reduce necessitate for any pre-preparation, reduce the fixing cost, and help in liability forbearance.

2) *Behaviour Change Cause Another Phase of Deployment:* Alteration in sensor nodes' [18], [19] cause change in sensor topology. Change in sensor nodes are: location, available energy, faulty, task details and reachability. Fixed deployment nature of sensor nodes causes the device failure usually due to depletion of energy.

3) *For Extention the Network Causes Another Phase of Deployment:* Broken nodes replaced by additional nodes.

IV. COMMUNICATION MODEL OF SENSOR NETWORKS

A lot of sensors are spread in a network field made known in figure 1. Abilities of sensor nodes are gathering information, route information turn around to sink. Through internet, sink have connectivity with task manager node. Stack of protocols incorporates data among the networking procedures, power or routing responsiveness, promotes helpful efforts of sensor nodes, and communicates power competently via the wireless communication. The protocol stack shown in figure 2.

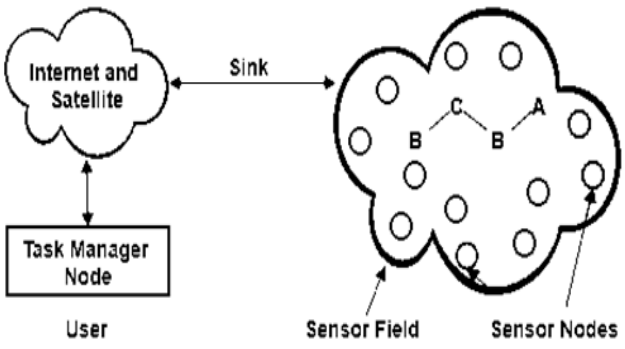

Fig. 1. Network areas with spread sensors

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Several kinds of application software are used by application layer, depending on the sensing tasks. Transport layer takes care of flow of data in application of sensor network. Network layer is used to route the data that collected by transport layer. Data link layer provides support for reducing collision when surroundings are noisy, and sensor nodes are movable.

Transmitting/receiving in addition to robust modulation techniques is addresses by the physical layer. Using the power management plane, we remove duplicate messages that manage the power usages of sensor nodes.

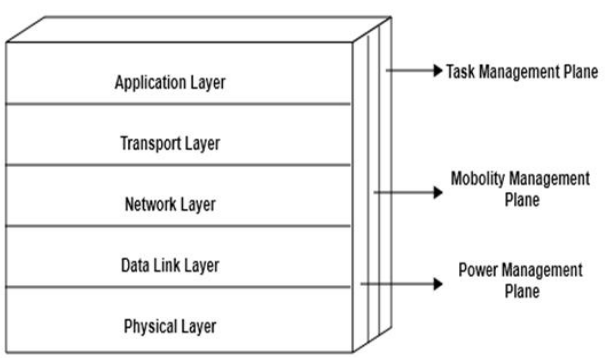

Fig.2. Protocol stack of sensor network

When a node is not able to contribute in routing communication due to low power level then broadcasts a message to its neighbors. For detecting and registers progress report of sensor nodes mobility management plane is used, and a sensor records that maintains their neighbor nodes, and reverse route to user. Sensing tasks of network for a particular area is a schedule that balances by task management plane. All the plane of management are highly desirable because they provide power efficient way to do work, moveable sensor group is used to route information, and distributes energy resources among the nodes. All the sensor node works separately, when these planes is not incorporate with the protocol stack.

These entire concepts is given by the protocol stack of network to reduce the power expenditure of the sensor nodes protocol must know about hardware constraint, transceiver, and it is also capable for using the particular features of micro-processors.

A. Physical Layer

This layer of protocol stack is answerable for signal detection, frequency selection, data encryption, modulation, and carrier frequency generation.

Shadowing and path-loss effects may be overcome successfully by multihop communication in WSNs when a density of nodes in network is as higher. In [11], binary and M-ary modulation schemes are compared. For ranging system Ultra wideband and impulse radio (IR) are used by baseband for many wireless applications [20] mainly in indoor wireless networks [21]. UWB is smart in the sensor network because of easy circuitry of transceiver, and low communication energy.

Research issues related to this layer of protocol stack are as:

- Modulation method
- Hardware plan: small, low-power, sensing, and processing units, low-cost transceiver require to be planned.
- Techniques that overcome or reduce the effects of signal propagation.

B. Data Link Layer

This layer of protocol stack is answerable for error control, medium access, multiplexing of data stream, data frame, point-to-point connections, and point-to-multipoint connections.

1) Error Control

In communication networks error control refers as control the error in transmission process, and two types of error control modes are automatic repeat request (ARQ) and forward error correction (FEC).Another solution provided for sensor network is use of low complexity encoding and decoding error control codes. Effect of error control and large packet size on power effectiveness of networks is determined [22].

2) Medium Access Control

MAC protocol is useful in self-organizing and multihop wireless network. Two objective of MAC protocol needs to be fulfilled good network infrastructure and efficiently sharing of communication resources.

On the basis of their resource sharing mechanisms, traditional MAC schemes can all be classified, and is shown in Table I.

Sensor networks protocol in MAC:

- Based on CSMA [23]
- Hybrid FDMA/ TDMA [11]
- Self-organizing medium access control for sensor networks (SMACS) and Eaves-drop-and-register Algorithm (EAR) [24]

3) Power Conservation Modes of Operation

When transceiver is not required it is turn off to power saver mode. Sensor nodes require short data packets to communicate with network. Using the shorter packets, less energy is consumed. When certain threshold is less than time spent in that mode then the power saving mode is energy efficient.

TABLE I. CATEGORIZATION OF MAC PROTOCOLS

Class	Allotment of resource	Application domain
Predetermined (fixed) allotment	Preset allotment	Handle continuous traffic not barrage traffic, and restricted delay.
Require (demand) base	User requested	Handle multimedia and rate rate traffic, reservation method cause extra overhead provides delay.
Arbitrary (random) access	On the basic of availability of packets for transmission.	Handle barrage traffic and not suitable for delay-sensitive traffic.

Issues related to research in this layer of protocol stack:

- Define new coding schemes for error control.
- Require to set up the lower limit on the energy for providing the ability of self-organizing or re-arrangement of network.
- Introduce the new modes of energy saving for routing.

C. Network Layer

Design a sensor network using principles data centric, power efficient, data aggregation, location awareness, and attribute-based addressing is always an important consideration

1) Energy Efficient Paths:

- A path that requires the minimum energy for transmitting the packets between sensor nodes, and base station called minimum energy path
- A path having the maximal available energy is used
- A path that used minimum hop to hop to reach base station is used
- A path that having the greater minimal available power than the other path is used

The interest dissemination is performed in data-centric routing. In this routing each sensor nodes have a task for sensing. There are two modes for interest dissemination: firstly, which types of data is required for broadcast by the base station [18], in an advertisement availability of data is broadcast by sensor nodes [14], and then waiting for interested base station request. Naming based on attributes [25]-[27], [16] require in data centric scheme of routing. With naming based on attributes, user concerns with query using attributes rather than query a particular sensor node. Data aggregation is another technique for solving implosion, and overlap problems data-centric routing [14]. Clustering techniques [28] are used in routing schemes for making energy efficient schemes. Several routing protocol for sensor networks is shown in Table II.

TABLE II. SOME ROUTING PROTOCOL IN NETWORK LAYER

Network layer routing protocol	Explanation
SMECN [29]	In sensor networks, find a spanning tree that having minimal power route.
Flooding	Data is transmit to each neighbor nodes and not considering that they get data previously or not
Gossiping [30]	Chosen an arbitrarily neighbor and sends data.
SPIN [14]	Three form of communication message is used if node paying attention to get data, and message are ADV, for request the data REQ is used, and to transmit the data DATA message is used.
SAR	Data is transmit through one choosen tree that root is one hop neighbor from base station, that fulfill the QoS metric and efficient power resources management in case of data route back to base station.
LEACH [31]	To reduce the power consumption cluster of nodes is created, and protocol is divided into two parts. Firstly all the nodes in the network join the clusters, and when all the nodes come into clusters then communication is established within the cluster, and between base station and clusters.
Directed diffusion (DD) [18]	For interest dissemination process DD routes data from source to sink by making the gradients of data.

Issues related to open research in Network layer of protocol stack:

- Require new protocols to attend to superior scalability
- Protocols to reduce the effect of high changes in topology

D. Transport Layer

If a system is access through the external network or internet then there is a requirement of transport layer. A method TCP splitting requires if a sensor network cooperate with internet. User and sink node can communicate using TCP and UDP through the satellite or internet. However, UDP protocol is responsible for transmission among the sensor nodes, and sinks as nodes having restricted memory. Another protocol like TCP provides end-to-end communication in the network, and it's not requiring any global addressing. For finding the sink of data packet this protocol depends on the naming based on attributes.

Research issues related in transport layer of protocol stack:

- In sensor networks acknowledgements are too expensive. To solve this problem, introducing new protocol that provides end to end message transmission at the sink, and using traditional UDP/TCP protocol for internet or satellite in the sensor network.

E. Application Layer

For sensor network several application areas are exposed, and projected but still application layer protocols remains a primarily unknown area.

Protocols for this layer are discussed here:

1) *SMP Protocol:* SMP is stands for a sensor management protocol, provides operation of software is responsible to execute the function of administrative such as:

- Establishing policies linked to cluster to the sensor nodes, attribute-based naming, and data aggregation
- Provides security, key distribution, and authentication in communications of data
- Synchronization of time for sensor network and moving sensor nodes
- Configuration and re-configuration of sensor network related query

2) *SQDDP:* SQDDP is stands for a Sensor query, and data dissemination protocol. This protocol is useful for providing the user interface based applications.

3) *TADAP Protocol:* TADAP is stands for a task assignment and data advertisement protocol. Routing is lower level operation provides by software of TADAP protocol of application layer. This software provides the efficient interfaces for internet dissemination.

Research issues related for this layer of protocol stack:

- The Sensor management protocol permits software to carry out administrative responsibilities such as synchronization of time for sensor nodes.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

V. WSN NODES DEPLOYMET, EXPENDITURE MODEL AND TRAFFIC PATTERNS

A. WSNs Nodes Deployment

A wireless system services provided by military for battleground observation, and is discussed in [32]. Furthermore, interference or interruption recognition dilemma or tracking applications are provided in [33]. Using some sensor and actuator a network for house is prepared to make them smarter for providing the services to elderly, handicapped and care of children in the absences of parents [34]. For house supervisation an application is provided in [35]. For providing the large set of applications a lot of work is done on framework of sensor network for developing new complex systems for WSNs [36]-[39].

B. WSN Nodes Energy Expenditure Models

The WSN nodes is divided into four main units: for data acquisition we used sensing unit, for local processing a processing unit is used with memory storage, power supply unit, and radio unit for transmission is used. Energy expenditure of a sensor node depends on the use of energy by their units.

In [40], by using the integrated characteristics of different transceiver that having low power authors represent a reasonable model for power expenditure model. In [41], online accounting energy model is built. For establishing the communication links two status are consider for this model first one is microcontroller and second is radio chip. However, in [42] finite state machines of energy model is used for showing the position of nodes, and transition of their units in network.

In [43], hardware structural design i.e. a base to design a model is used for energy consumption in WSN. CSESM "Communication Subsystem Energy Consumption Model" model is used for exploiting the power consumption of component of sensor node during the routing.

In [44], model associated to energy expenditure of power of CPU of sensor network is depicted. A model that is probabilistic type is represented, which calculates the utilization of energy of sensor node for CPU, and amount of CPU utilization with time.

In [45], new approach of sensor node energy utilization is represented.

1) *Sensor Unit:* This consists of signal modulation, AD Conversion, and sampling. Sense function is a main task of this sensor and most of the part of energy is consumed by sensor unit.

2) *Processing Unit:* The most important actions of this unit are: protocol communication, sensor controlling, and data processing

3) *Radio Transmission Unit:* A task of power amplifier is to decide the power utilization based on communication range to transmit or receiving message. Power amplifier depends on lot of aspects including: definite hardware performance, operating frequency, load characteristics, and DC bias condition

4) Energy Supply Unit: It is depend on node model and manufacturer. Two AA batteries used in MICA. 27mA is used to transmit, and it is upper limit of batteries and 10mA is the receiving standard of AA batteries. 0.001mA is used when network is not working or goes on sleep mode. In [46], deployments of MICA sensor are shown. Some radio models are discussed in [47]-[51].

C. Traffic Patterns in WSNs

Two types of traffic patterns exist in WSN one is single hop, and another one is multi hop traffic. A traffic pattern of multihop types is depends on many factors like number of sending/receiving nodes in the network, and local processing is properly working or not. On the basic of these factor multi-hop patterns of traffic is categorized as:

1) *Hop to Hop Scheme of Routing*: Use of sending information or packet of data from one particular hop (subjective node) to another particular hop.

2) *Local Communication:* Use for broadcasting the position of a node to its neighbors.

3) *Divergence:* It makes use of sending an order or broadcast a message from sink to other nodes of sensor network.

4) *Aggregation:* The relay nodes processes the data packets by using this process it collect the valuable data, and sent it to sink node.

5) *Convergence:* Route data to multiple nodes for a sink node, and it is making use of data collection in WSN.

Primary efforts offered in [52] to explore traffic patterns with mobility.

VI. ROUTE SELECTION POLICIES IN ENERGY EFFICIENT ROUTING

An optimal route is selected based on the distance of links, power used in transmission, and residual energy. These are the parameters regularly used for making the routing scheme power efficient. A project Pico Radio [53] at Berkeley and another one is AMPs at MIT. These two projects are to make power efficient radio or communication model, and also consider their impact on networking. In this model sensor unit used ultra low power sensors for sensing task. Many companies also emerged their commercial efforts for developing new sensor, and these companies are Worldsens, Ember Corporation, Sensoria and Crossbow.

Researcher currently focusing on developing schemes of routing that utilizes a lesser amount of power in stage of communication in WSNs. Consider the two objectives for developing the scheme:

- First is to discover the route that used lowest energy from source node to sink node.
- Find out the way to make longer life span of network in efficient manner.

For the assessment of routing schemes there is number of condition. These conditions are used to judge the efficiency of routine scheme. They are described in following points [54].

1) *Network Life Span:* "A large part or group of node drains their energy or become lifeless".

2) *Reliability and Energy:* There is tradeoff between large number of application features and energy.

3) *Energy Per Packet:* Total required power of node for sending single data packet from their starting position to sink. Increasing network life span is an essential part or objective in WSN, and this is achieved by increasing battery lifetime of nodes or to increase the network survivability.

4) *Average Energy Consumption:* This term is used for network life span and demonstrates the per node average power consumption in network over a time.

5) *Alive Nodes in Network*: It is a term that is also use for evaluation the network life span.

6) *Average Delay in Packet:* It is a term that used for showing one way average delay, and it is obtained at sink node between transmission/reception of packet.

7) *Packet Delivery Ratio:* This term is used for calculating ratio of previously sent data packet and received data packet at base station.

8) *Spending Power in a Round (Power Spent/Round):* It is term that is used for calculating total power used in a round for route the total message in routing procedure. Calculation of power is temporary that provides the idea for developing the new power efficient algorithm.

9) *Packet Dimension:* The amount of time that is required for ending the communication that depends on dimension of packet. Power dissipation is affected by the dimension of packets.

10) *Low Energy Utilization:* A protocol or procedures of routing that consider the two basic ideas. One is considering the residual energy of node, and second is select the energy efficient route for prolonging the life span of network.

11) At Sink Total Received Hello Message: It is a type of term that used for saving the power by routing schemes because by avoiding sending and passing constant packets of data that is not necessary for procedures.

12) Stability of Network: A period that point out all the nodes in the network is working or still alive.

13) *Inactive Node and Listening Mode:* When a node goes to idle/inactive or listening mode it drains their significant amount of energy still they are not sending/receiving data in network.

14) *Route Data Distance:* Significant amount of power is used when distance between sender and receiver of packets is long. For reducing the consumption power developing the routing scheme that select the shortest path for data transmission from sender to receiver in communication stage for WSNs. Energy is inversely proportional to $(\text{distance})^2$.

Chosen a power efficient routing scheme for WSNs is major challenging issue. These policies are: Min hop policy and Load balancing. In [55], two methods of multi hop routine scheme are distinguished. First one minimizes entirety energy utilization, second is to maximize network life span.

VII. SOME ROUTING SCHEMES DEVELOPED FOR ROUTE DATA IN WSN

WSN, firstly introduced flat routing schemes that protocols are not suitable for optimal transmission like DD [18] routing scheme. Some changes introduced in exists protocols, and new protocol is clustering based protocols that are used to collect the data, and transmit it to base station. Some homogeneous routing schemes are Low-Energy Adaptive Clustering Hierarchy (LEACH) [31], and Threshold-Sensitive Energy Efficient Sensor Networks Protocol (TEEN) [56] that improves the result in terms of stability of network and throughput. SEP [57] is "stable election protocol", and gives the concept of energy heterogeneity for clustering to enhance the network lifespan. Distributed Energy Efficient Clustering algorithm (DEEC) [58], and Developed DEEC (DDEEC) [59] are the example of heterogeneous protocols, and provides better stability period. With the help of energy harvesting technology it increases the stability period of network. Some routing schemes solar-aware clustering (sLEACH) [60], and Advanced solar aware LEACH (A-sLEACH) [61] are energy harvesting protocols, provide more stability in network then previous exists protocols.

VIII. CONCLUSION

This paper provides the basic knowledge of wireless sensor network. Various application of WSNs shows that WSNs become a wide area of research, require for many applications, and system development. Realization of sensor networks needs to satisfy the constraints introduced by factors such as fault tolerance (liability forbearance), scalability, manufacture cost, hardware constraints, topology change, operating environment, and power consumption. These constraints are specific for developing the energy efficient WSNs. Stack of protocols explains the needed technologies for different applications. Network layer is playing an important role for the data efficient selection, and their delivery. Node deployment and energy consumption model concept provides the schemes of route finding for data delivery which is energy efficient.

REFERENCES

1. Estrin, D., Govindan, R., Heidemann, J. , and Kumar, S., 1999, August.Next century challenges: Scalable coordination in sensor networks. In *Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking* pp. 263-270. ACM.
2. Cerpa, A., Elson, J., Estrin, D., Girod, L., Hamilton, M. , and Zhao, J., 2001. Habitat monitoring: Application driver for wireless communications technology. *ACM SIGCOMM Computer Communication Review*, *31* 2 supplement, pp. 20-41.
3. Walker, B. and Steffen, W., 1997. An overview of the implications of global change for natural and managed terrestrial ecosystems. *Conservation Ecology*, *1*(2).
4. Bonnet, P., Gehrke, J. and Seshadri, P., 2000. Querying the physical world. *IEEE personal Communications*, *7*(5), pp. 10-15.
5. http://www.alertsystems.org.
6. Johnson, P. and Andrews, D.C., 1996. Remote continuous physiological monitoring in the home. *Journal of telemedicine and telecare*, *2*(2), pp. 107-113.
7. Ogawa, M., Tamura, T. and Togawa, T., 1998, October. Fully automated biosignal acquisition in daily routine through 1 month. In *Engineering in Medicine and Biology Society, 1998. Proceedings of the 20th Annual International Conference of the IEEE* , Vol. 4, pp. 1947-1950.

8. Nam, Y.H., Halm, Z., Chee, Y.J. and Park, K.S., 1998, October. Development of remote diagnosis system integrating digital telemetry for medicine. In Engineering in Medicine and Biology Society, 1998. Proceedings *of the 20th Annual International Conference of the IEEE* , Vol. 3, pp. 1170-1173.
9. Sibbald, B., 2001. Use computerized systems to cut adverse drug events: report.
10. Pottie, G.J., and Kaiser, W.J., 2000. Wireless integrated network sensors. *Communications of the ACM*, *43*(5), pp. 51-58.
11. Shih, E., Cho, S.H., Ickes, N., Min, R., Sinha, A., Wang, A., and Chandrakasan, A., 2001, July. Physical layer driven protocol and algorithm design for energy-efficient wireless sensor networks. In *Proceedings of the 7th annual international conference on Mobile computing and networking*, pp. 272-287. ACM.
12. Rabaey, J., Ammer, J., Da Silva, J.L. and Patel, D., 2000. PicoRadio: Ad-hoc wireless networking of ubiquitous low-energy sensor/monitor nodes. In *VLSI, 2000. Proceedings. IEEE Computer Society Workshop*, pp. 9-12.
13. Bulusu, N., Estrin, D., Girod, L. and Heidemann, J., 2001, July. Scalable coordination for wireless sensor networks: self-configuring localization systems. In *International Symposium on Communication Theory and Applications ISCTA 2001, Ambleside, UK*.
14. Hoblos, G., Staroswiecki, M. and Aitouche, A., 2000. Optimal design of fault tolerant sensor networks. In *Control Applications, 2000. Proceedings of the 2000 IEEE International Conference on* pp. 467-472.
15. Nadig, D., Iyengar, S.S. and Jayasimha, D.N., 1993, April. A new architecture for distributed sensor integration. In *Southeastcon'93, Proceedings., IEEE* pp. 1-8.
16. Shen, C.C., Srisathapornphat, C. and Jaikaeo, C., 2001. Sensor information networking architecture and applications. *IEEE Personal communications*, *8*(4), pp. 52-59.
17. Kahn, J.M., Katz, R.H. and Pister, K.S., 1999, August. Next century challenges: mobile networking for "Smart Dust". In *Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking* pp. 271-278. ACM.
18. Intanagonwiwat, C., Govindan, R. and Estrin, D., 2000, August. Directed diffusion: A scalable and robust communication paradigm for sensor networks. In *Proceedings of the 6th annual international conference on Mobile computing and networking* pp. 56-67. ACM.
19. Meguerdichian, S., Koushanfar, F., Qu, G. and Potkonjak, M., 2001, July. Exposure in wireless ad-hoc sensor networks. In *Proceedings of the 7th annual international conference on Mobile computing and networking* pp. 139-150. ACM.
20. Cramer, J.M., Scholtz, R.A. and Win, M.Z., 1999. On the analysis of UWB communication channels. In *Military Communications Conference Proceedings, 1999. MILCOM 1999. IEEE* Vol. 2, pp. 1191-1195.
21. Ramirez-Mireles, F. and Scholtz, R.A., 1997, August. Performance of equicorrelated ultra-wideband pulse-position-modulated signals in the indoor wireless impulse radio channel. In *Communications, Computers and Signal Processing, 1997. 10 Years PACRIM 1987-1997-Networking the Pacific Rim. 1997 IEEE Pacific Rim Conference* Vol. 2, pp. 640-644.
22. Lettieri, P. and Srivastava, M.B., 1998, March. Adaptive frame length control for improving wireless link throughput, range, and energy efficiency. In *INFOCOM'98. Seventeenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE* Vol. 2, pp. 564-571 .
23. Woo, A. and Culler, D.E., 2001, July. A transmission control scheme for media access in sensor networks. In *Proceedings of the 7th annual international conference on Mobile computing and networking* pp. 221-235 ACM.
24. Sohrabi, K., Gao, J., Ailawadhi, V. and Pottie, G.J., 2000. Protocols for self-organization of a wireless sensor network. *IEEE personal communications*, *7*(5), pp. 16-27
25. Elson, J. and Estrin, D., 2001, April. Random, ephemeral transaction identifiers in dynamic sensor networks. In *Distributed Computing Systems, 2001. 21st International Conference* pp. 459-468.
26. Estrin, D., Girod, L., Pottie, G. and Srivastava, M., 2001. Instrumenting the world with wireless sensor networks. In *Acoustics, Speech, and Signal Processing, 2001. Proceedings.(ICASSP'01). 2001 IEEE International Conference* Vol. 4, pp. 2033-2036.
27. Mirkovic, J., Venkataramani, G.P., Lu, S. and Zhang, L., 2001. A self-organizing approach to data forwarding in large-scale sensor networks. In *Communications, 2001. ICC 2001. IEEE International Conference* Vol. 5, pp. 1357-1361.
28. Vijay Kumar, Sunil Kumar, Dr. Ajay Kumar Singh, "Outlier Detection: A Clustering-based Approach," International Journal of Innovative Science and Modern Engineering, ISSN: 2319–6386, vol. 1, Issue 7, pp. 16-19, 15 June 2013.
29. Li, L. and Halpern, J.Y., 2001, June. Minimum-energy mobile wireless networks revisited. In *Communications, 2001. ICC 2001. IEEE International Conference* Vol. 1, pp. 278-283.
30. Hedetniemi, S.M., Hedetniemi, S.T., and Liestman, A.L., 1988. A survey of gossiping and broadcasting in communication networks. *Networks*, *18*(4), pp. 319-349.
31. Heinzelman, W.R., Chandrakasan, A., and Balakrishnan, H., 2000, January. Energy-efficient communication protocol for wireless microsensor networks. In *System sciences, 2000. Proceedings of the 33rd annual Hawaii international conference on* system science pp. 1-10.
32. Shi, E. and Perrig, A., 2004. Designing secure sensor networks. *IEEE Wireless Communications*, *11*(6), pp. 38-43.
33. Basharat, A., Catbas, N., and Shah, M., 2005, March. A framework for intelligent sensor network with video camera for structural health monitoring of bridges. In *Pervasive Computing and Communications Workshops, 2005. PerCom 2005 Workshops. Third IEEE International Conference* pp. 385-389.
34. Dengler, S., Awad, A., and Dressler, F., 2007, May. Sensor/actuator networks in smart homes for supporting elderly and handicapped people. In *Advanced Information Networking and Applications Workshops, 2007, AINAW'07. 21st International Conference* Vol. 2, pp. 863-868.
35. Li, S.F., 2006, January. Wireless sensor actuator network for light monitoring and control application. In *Consumer Communications and Networking Conference, 2006. CCNC 2006. 3rd IEEE* Vol. 2, pp. 974-978.
36. Lombriser, C., Bharatula, N.B., Roggen, D. and Tröster, G., 2007, June. On-body activity recognition in a dynamic sensor network. In *Proceedings of the ICST 2nd international conference on Body area networks* p. 17. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).
37. Gibbons, P.B., Karp, B., Ke, Y., Nath, S., and Seshan, S., 2003. Irisnet: An architecture for a worldwide sensor web. *IEEE pervasive computing*, *2*(4), pp. 22-33.
38. Srivastava, M., Hansen, M., Burke, J., Parker, A., Reddy, S., Saurabh, G., Allman, M., Paxson, V., and Estrin, D., 2006. Wireless urban sensing systems.
39. Dunkels, A., Gold, R., Marti, S.A., Pears, A., and Uddenfeldt, M., 2005, September. Janus: an architecture for flexible access to sensor networks. In *Proceedings of the 1st ACM workshop on Dynamic interconnection of networks* pp. 48-52. ACM.
40. Wang, Q., Hempstead, M.., and Yang, W., 2006, September. A realistic power consumption model for wireless sensor network devices. In *Sensor and Ad Hoc Communications and Networks, 2006. SECON'06. 2006 3rd Annual IEEE Communications Society* Vol. 1, pp. 286-295.
41. Dunkels, A., Osterlind, F., Tsiftes, N., and He, Z., 2007, June. Software-based on-line energy estimation for sensor nodes. In *Proceedings of the 4th workshop on Embedded networked sensors* pp. 28-32. ACM.
42. Kellner, S., Pink, M., Meier, D., and BlaB, E.O., 2008, January. Towards a realistic energy model for wireless sensor networks. In *Wireless on Demand Network Systems and Services, 2008. WONS 2008. Fifth Annual Conference* pp. 97-100.
43. Wang, Q. and Yang, W., 2007, June. Energy consumption model for power management in wireless sensor networks. In *Sensor, Mesh and Ad Hoc Communications and Networks, 2007. SECON'07. 4th Annual IEEE Communications Society Conference* pp. 142-151.

44. Shareef, A. and Zhu, Y., 2010, September. Energy modeling of wireless sensor nodes based on Petri nets. In *Parallel Processing (ICPP), 2010 39th International Conference* pp. 101-110.
45. Zhou, H.Y., Luo, D.Y., Gao, Y., and Zuo, D.C., 2011. Modeling of node energy consumption for wireless sensor networks. *Wireless Sensor Network*, *3*(01), p. 1-18.
46. Mainwaring, A., Culler, D., Polastre, J., Szewczyk, R., and Anderson, J., 2002, September. Wireless sensor networks for habitat monitoring. In *Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications* pp. 88-97. ACM
47. Deepali Gaur and Ajay Kumar Singh, "Improving Energy Efficiency of Femtocell Network with Limited Backhaul Capacity", International Journal of Computer Trends and Technology (IJCTT), ISSN: 2231-2803, vol. 34, no. 1, pp. 34-39, April 2016, doi: 10.14445/22312803/IJCTT-V34P106.
48. Deepali Gaur and Ajay Kumar Singh, "Analysing Energy Efficiency of Cell Selection Schemes for Femtocell Networks with Limited Backhaul Capacity", International Journal of Computer Trends and Technology (IJCTT), ISSN: 2231-2803, vol. 26, no. 1, pp. 1- 5, August 2015, doi: 10.14445/22312803/IJCTT-V26P101
49. Kapil Kumar, Prateek Sharma, and Ajay Kumar Singh, "Effect on Range of Bluetooth Class 1 Adapter using External Omni Antenna," International Journal of Computer Science and Communication (IJCSC), ISSN: 0973-7391, vol. 3, no. 1, pp. 107-110, Jan.-June. 2012.
50. Ajay K. Singh, P. Kumar, G. Singh, and T. Chakravarty, "Linearizer for pulse-shaping of received pulse in ultra-wideband radio systems" ScienceDirect (Elsevier) Digital Signal Processing, vol. 20, no. 2, March 2009, pp. 496-501, doi:10.1016/j.dsp.2009.08.001.
51. A. K. Singh, P. Kumar, T. Chakravarty, G. Singh., and S. Bhooshan, "A novel digital beamformer with low angle resolution for vehicle tracking radar" Progress In Electromagnetics Research (PIER) vol. 66, pp . 229-237, 2006, doi:10.2528/PIER06112102.
52. Wang, P. and Akyildiz, I.F., 2010, December. Effects of different mobility models on traffic patterns in wireless sensor networks. In *Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE* pp. 1-5.
53. Rabaey, J.M., Ammer, M.J., Da Silva, J.L., Patel, D., and Roundy, S., 2000. PicoRadio supports ad hoc ultra-low power wireless networking. *Computer*, *33*(7), pp. 42-48.
54. Alazzawi, L. and Elkateeb, A., 2009. Performance evaluation of the WSN routing protocols scalability. *Journal of Computer Systems, Networks, and Communications*, *2008*.
55. Ergen, S.C. and Varaiya, P., 2005. On multi-hop routing for energy efficiency. *IEEE Communications Letters*, *9*(10), pp. 880-881.
56. Manjeshwar, A. and Agrawal, D.P., 2001, April. TEEN: a routing protocol for enhanced efficiency in wireless sensor networks. In null (p. 30189a). IEEE.
57. Smaragdakis, G., Matta, I., and Bestavros, A., 2004. SEP: A stable election protocol for clustered heterogeneous wireless sensor networks. Boston University Computer Science Department.
58. Qing, L., Zhu, Q., and Wang, M., 2006. Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. Computer communications, 29(12), pp. 2230-2237.
59. Elbhiri, B., Saadane, R., and Aboutajdine, D., 2010, September. Developed Distributed Energy-Efficient Clustering (DDEEC) for heterogeneous wireless sensor networks. In I/V Communications and Mobile Network (ISVC), 2010 5th International Symposium on (pp. 1-4). IEEE.
60. Voigt, T., Dunkels, A., Alonso, J., Ritter, H., and Schiller, J., 2004, June. Solar-aware clustering in wireless sensor networks. In Computers and Communications, 2004. Proceedings. ISCC 2004. Ninth International Symposium on(Vol. 1, pp. 238-243). IEEE.
61. Islam, J., Islam, M., and Islam, N., 2007, April. A-sleach: An advanced solar aware leach protocol for energy efficient routing in wireless sensor networks. In Networking, 2007. ICN'07. Sixth International Conference on (pp. 4). IEEE.