Energy Engineering in Wireless Sesnor Network

A Consolidated Classified Summary of Energy Engineering Initiatives in the field of Wireless Sensor Networks

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Abstract— **Energy improvement initiatives in the field of Wireless Sensor Network (WSN) are the current trend of research. Many initiatives of the energy perspectives in WSN have been carried out by the industry vendors, academicians and funded projects at different layers of the network, at different activities like data aggregation- scheduling- synchronization- addressing- routing-encryption, addressing and localization. Energy efficient architecture and design, topology control, protocol models have been proposed in recent times. Energy portfolios, energy models, energy benchmarks are defined to measure and control the energy of different tracking and monitoring system for wireless sensor networks. All the energy improvement initiatives can be classified under Energy Auditing Units to measure the energy consumption, Energy Optimization Techniques to improve the energy in WSN and methods to harvest energy. This paper aims at classifying and consolidating all the energy efficiency initiatives in the field of WSN.**

Keywords-**Energy Efficiency – Wireless Sensor Network – Energy Improvement – Energy Optimization – Energy Harvesting**

I. INTRODUCTION

The Wireless Sensor Network is the collection of sensor motes to sense and communicate the environmental factors like temperature, humidity. Here each of the sensor node lives with the limited battery and getting randomly deployed in the remote regions. The extended lifetime of the sensor network with limited battery is the crucial issue has to be addressed. The sensor node contains at least the following units of A microprocessor, memory, communication (transceiver, receiver and trans-receiver) unit. Some of the activities of the units are more power consuming [1]. For example, The energy consumed by the micro controller unit to execute machine instructions is negligibly small when it is compared to the energy consumed by the communication unit for the transmission of the bits. When the node is with less energy it slows down the process of communication and the dead node with no energy makes the network un-connected and in turn blocks the data propagation through the path. There are initiatives to improve energy at the hardware level, architecture level, application level, algorithmic level, at the data processing methods, with the communication – routing protocols and at software model level. Some of the energy study and energy measures with energy improvement methods are based on the simulation platform, whereas most of the studies are based either on emulation of virtual instrumentation or on the real time test beds. We have to accept one fundamental fact that the energy measures are specific to a

particular hardware setup. However, we work on the application or algorithmic level the energy measure greatly dependent on the hardware it is made of. Most of the researchers' concern is to improve the energy without affecting the performance. This energy study become more popular as the industry automation, body area network wearable sensor applications are time critical and need the zero down time setup. To measure the energy usually researcher defines the energy model constituting the factors and the activities that define the energy for a time period for the network or more. This paper is trying to consolidate all the initiatives in a classified and organized way.

II. METHODS, SCHEMES, TECHNIQUES, STRATEGIES, FRAMEWORKS, DESIGN

Now we have defined the need for energy engineering in WSN and the reality of the growing importance of this study. Usually any problem in the computer science is getting resolved by the method, schemes or certain techniques and the strategies. Even it is common for any domain and fundamental problem solving way, we have to be clear with the basics of these **problem solving ways** before getting into the classification or consolidation of the energy engineering initiatives.

A. METHOD

It is the established, logical, systematic procedure with a defined sequence of steps to achieve certain ends with more accuracy and efficiency. It is usually the prescribed process to achieve an end in a domain.

B. SCHEMES AND TECHNIQUES

An elaborate plan with a vision of the broad picture is the scheme, usually defines the overall arrangement. Techniques are the way of carrying out a work with certain motives.

C. STRATEGIES

Strategy is the guideline or policy to follow throughout the process and application perception.

D. FRAMEWORKS & DESIGN

The Framework is the complete stack template, solution of the proposed system. With the less effort, the framework helps us to create multiple similar solutions. Design is the creation plan or the convention of creation.

III. ENERGY EFFICIENT MAC PROTOCOL DESIGN

Different types of communication protocols are used and designed for Wireless Sensor Networks with different goals. Protocols use new techniques to reduce energy consumption and support self configuration . Zigbee, Bluetooth, MIWI, IEEE 801.15.4 are some of the famous communication protocols. On most of them the physical layer is based on MAC. A new protocol is recommended to improve the latency, energy efficiency and throughput of current MAC protocol for WSNs. A change in the protocol is then proposed to eliminate the need for some nodes to stay awake longer than the other nodes, which improve the energy efficiency, latency and throughput and so increases the life span of a wireless sensor network.

A. ENERGY RELEVANT ISSUES IN TRANSMISSION AND PROTOCOLS OF WSN

MAC sub - layer protocols for WSNs must address the following energy - related issues

– Collisions: The collisions occur when two nodes transmit at the same time. The packets can get corrupted and it may be required to be retransmitted. So a lot of time and energy gets wasted during this transmission and reception. Collisions should be avoided because of the extra energy wasted in frame retransmission[2].

– Overhead: The other major problem is the Control Packet Overhead. These Control Packets do not have any application data, but are needed for the communication. The reception and transmission of these packets is overhead on the sensor network. Control messages and long headers in frames need to be avoided as much as possible, as they involve extra expensive communication costs.

– Overhearing: The other problem is overhearing in which a sensor node may receive packets that are not intended for it. This node could have turned off its radio to save its energy. Overhearing is the energy consumed by the nodes from being always listened and decoding frames that are not meant for them. This is the result of using a shared medium which nodes do not know a priori whether the transmissions are for them or not.

– Idle listening: Idle listening refers to the energy expended by the nodes by having their circuits ON and ready to receive while there is no activity in the network. This is particularly important in WSNs, as nodes use the

channel periodically. Strategies to turn the nodes ON and OFF are very important in WSNs. The idle listening problem in wireless networks can be minimized by putting the radio into sleep mode.

– Complexity: Complexity refers to the energy expended as a result of having to run computationally expensive algorithms and protocols. One of the most important design goals in WSNs is therefore simplicity.
The other important characteristics of the Wireless Sensor Network are fairness, latency, throughput and bandwidth.

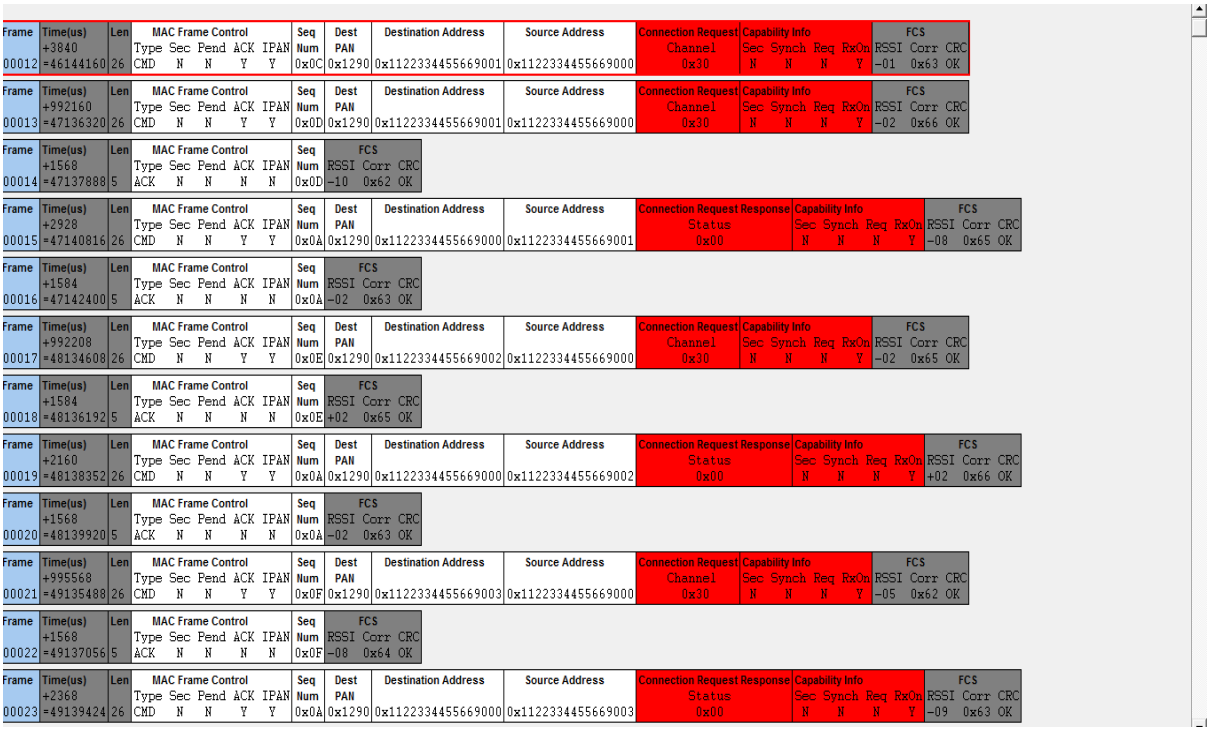

Fig 1 : MAC Protocol Paket Format observed

B. MAC PROTOCOL AS A WIDELY USED PROTOCOL

Many medium access control (MAC) protocols for wireless sensor networks have been considered in the recent years [3]. Most of these protocols have energy, safeguarding as an objective and solve a seemingly simple task: they coordinate the times where a number of node access a shared communication medium. In the case of WSNs, the balance of requirements is different from traditional (wireless) networks. Additional requirements come up, first and foremost, the need to conserve energy[3]. The pattern of these protocols as a widely energy use in the sensor nodes, however, depends on the nature of the application

PROTOCOL	TECHNIQUE
S-MAC Protocol	Energy Efficiency through state changes of sensors (active, sleep)
Timeout-MAC (T-MAC)	Energy Efficiency through adaptive duty cycling
Berkeley Media Access Control for Low-Power Sensor Networks(B-MAC)	Energy Efficiency through preamble sampling dynamic, preamble creation
Wise MAC Protocol	Energy Efficiency through low power listening
TDMA based MAC	Energy Efficiency through state changes on the radio
Traffic-Adaptive Medium Access (TRAMA) Protocol	Energy Efficiency through schedule based mechanism
PAMA (Power Aware Multi Access)	Energy Efficiency through Power Aware Multi Access

Table 1: Energy Efficiency in different MAC Protocol

C. SMAC Outperforms other MAC Protocols

PROTOCOLS	TECNIQUE
SMAC TMAC	The battery utilization is increased Implementing sleep schedules. This protocol is simple to implement, long messages can be efficiently transferred using message passing technique. TMAC's major disadvantage is early sleeping problem in which nodes may sleep as per their activation time and data may get lost especially for long messages.
SMAC BMAC	Advantages of S-MAC includes sleeping, which reduces energy consumption. The protocol adapts easily to changes in topology and has been tested with hardware. Additionally, there is no need for a central entity or for tight synchronization. The main disadvantage is that the preamble creates a large overhead. One example presents 271 bytes of preamble to send 36 bytes of data.
SMAC DSMAC	Using duty cycling concept, S-MAC saves energy for nodes in WSN. Using adaptive listening concept, S-MAC reduces delay in unnecessary waiting time for sleep period and reduces energy consumption. Good scalability and topology management. Does not provide reliability for end to end data delivery. DSMAC lets nodes that are interfering to go to sleep, and this can cause problems when the path goes through one of these nodes. This shows that DSMAC also does not support cross layer concepts. Due to need for dynamic SYNC announcements for each node in WSN and storing the average of consuming energy and delay, DSMAC suffers from this overhead and this will decrease throughput. Delay end to end increased, so DSMAC is not suitable to be used for real time applications without improvement.
SMAC WISE-MAC	Low energy consumption when traffic is low. The Main drawback of Wise MAC is that decentralized sleep listen scheduling results in different sleep and wake-up times for each neighbor of a node.
SMAC TRAMA	Low energy consumption when traffic is low. Time is divided into random access periods.
SMAC PAMA	S-MAC Protocols reduce undesirable energy depletion due to collision, overhearing, packet overhead and idle listening as well as it turns the radio on and off based on the fixed duty cycles. The main disadvantage of PAMAS is that it needs an additional radio for the signalin g channel, which adds to the cost of sensor network devices.

Table 2: S-MAC protocol is that outperforms in different MAC Protocols

IV. ENERGY EFFICIENT ROUTING IN WSN

The significant challenge in the wireless sensor network is the energy saving and increasing the lifetime of the network. It is necessary to implement **ENERGY AWARENESS** in the routing algorithm to increase the energy of the nodes[4]. The different routing algorithms for WSN are,

- Flooding
- Shortest Path Routing Algorithm
- Flow-Based Routing Algorithm
- Distance Vector Routing Algorithm
- Link State Routing Algorithm
- Hierarchical Routing Algorithm
- Broadcast Routing Algorithm
- Multicast Routing Algorithm

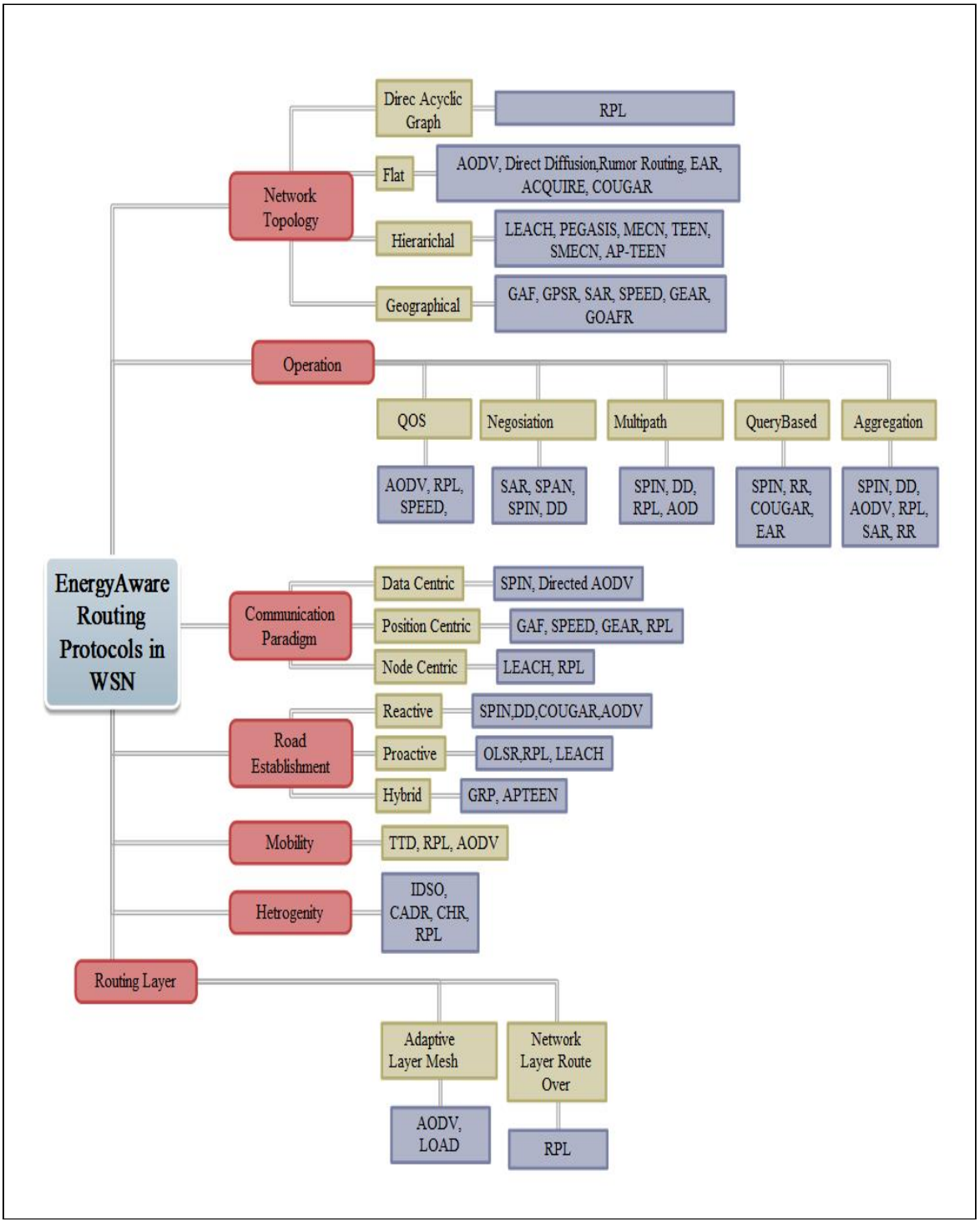

Fig 3 : Energy Aware Routing Protocols in WSN

A. Basics of Routing Mechanism in WSN

A ***routing mechanism*** determines the path to send messages through the network from the source to the destination node. It takes the input as a message's source and destination nodes. It uses information about the state of the network. It gives one or more paths through the network from the source to the destination node.

Wireless sensor network (WSN) is a type of network, includes many smart devices, called sensor nodes, several sinks, randomly deployed in a wide area. These nodes are distributed in order to perform an application-oriented global task. Routing mechanisms can be classified as ***minimal*** or ***non-minimal***. A minimal routing mechanism

until the end of time selects one of the shortest paths between the source and the destination. A non-minimal routing scheme route the message beside a longer path to avoid network congestion[5].

-Sensor scheduling in a wireless network is which that not all the nodes should be kept active for selection in the routes. Reducing the energy wasted in an idle state can also contribute to the energy consumption, where too many deactivate nodes will cause routing difficulties and shorter network lifetime, or even routing failure. Here the protocols maintain network connectivity and coverage. A Sensor scheduling algorithm is proposed to maximize the lifetime of the network[4,6].

- **Connectivity** High node density in sensor networks precludes them from being completely isolated from each other. Therefore, sensor nodes are expected to be highly connected. It may not prevent the network topology from being variable and the network size from being shrunk due to sensor node failures. In addition, connectivity depends on distribution of nodes.

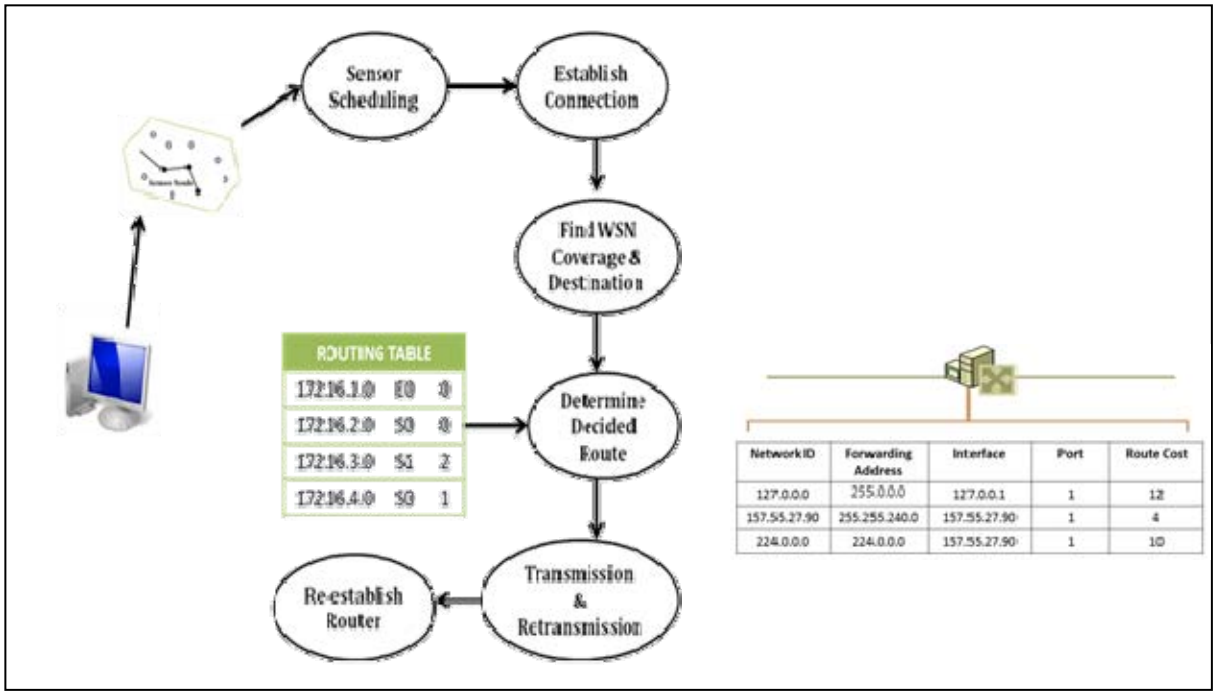

Fig 4: Routing Mehanism in WSN with Sample Routing Table

-Finding Destination and Covrage: Routing uses metrics to evaluate what path will be the best for a packet to travel. It is used by routing algorithms to determine the optimal path to a destination. Routing algorithms fill routing tables with a variety of information. Destination/next hop field tell a router that a particular destination can be reached by sending the packet to a particular router representing the "next hop" on the way to the final destination. While a router receives an incoming packet, it checks the destination address and tries to associate this address with a next hop. Routing is an important class of wireless sensor network that provide sensing coverage over a graphical area. Routing algorithms can successfully find short routing paths based on sensing-covered networks.

-Routing Path and Table Maintenance: The **routing table** stores the addresses of the local sub networks, any static routes configured by the network administrator, and the routes energetically learned by the router using a routing algorithm. The Network Layer software can make all of its routing decisions simply by consulting this table.For a direct delivery, the forwarding IP address is the destination IP address in the IP packet. The interface identifies the physical or logical interface, such as a network adapter that is used to forward the packet to either its destination or the next router. A number used to indicate the cost of the route so the best route among possible multiple routes to the same destination can be selected.

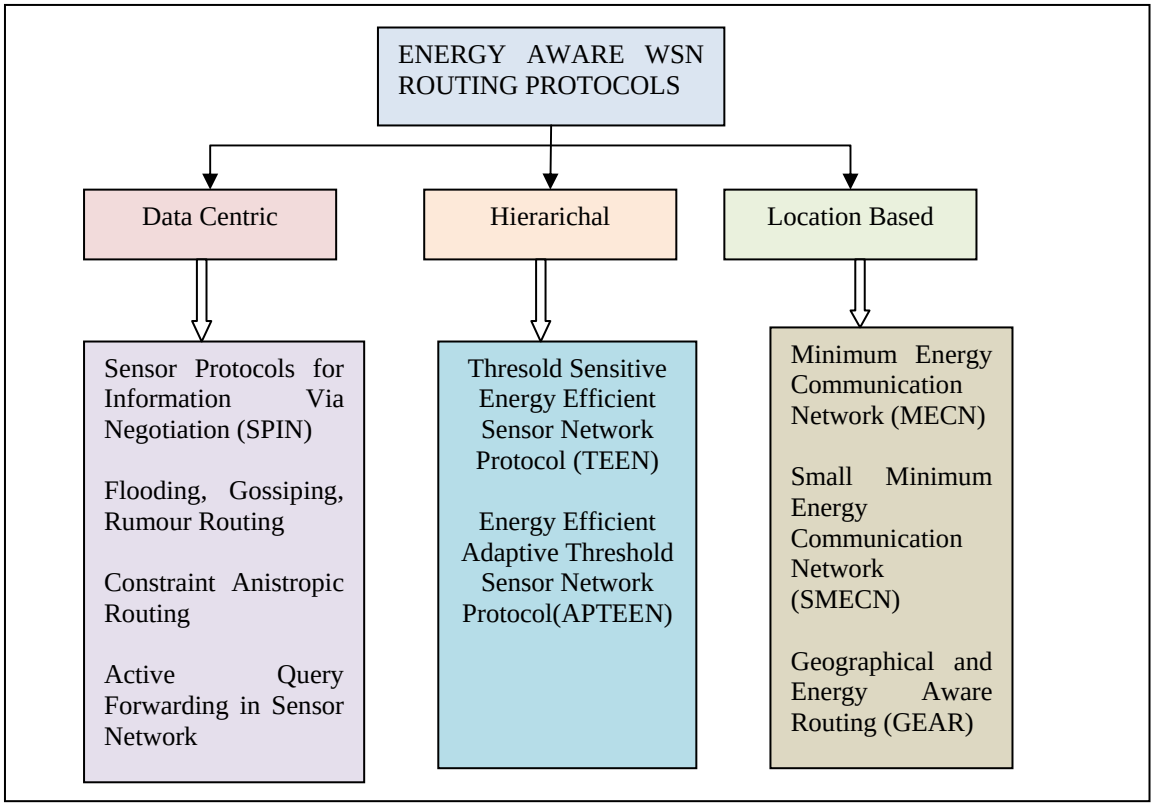

Fig 5: Energy Aware WSN Routing Protocols

V. ENERGY EFFICIENT CLUSTERING IN WSN

The Cluster is the hierarchically structured nodes that have a cluster head and the offspring nodes. All the offspring nodes communicate with the cluster head (CH) and the cluster heads communicate with the base station. The cluster head is capable of data aggregation and do transmit to the base station, whereas the base nodes can only sense and propagate.

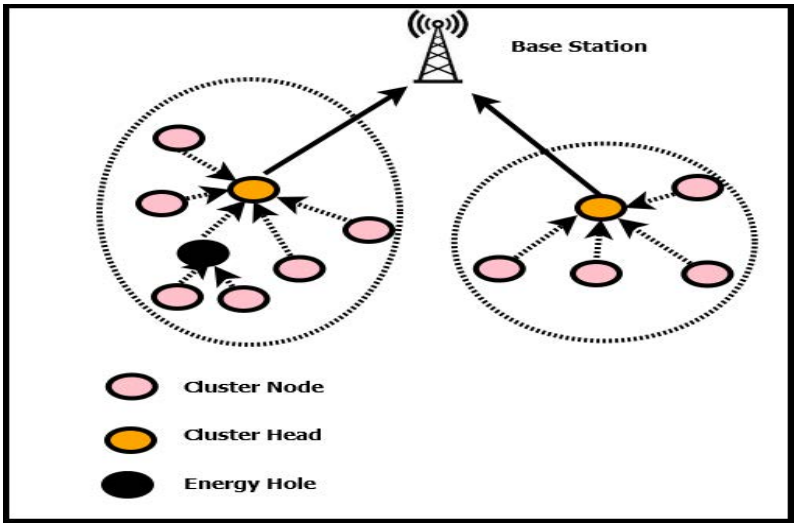

Fig 6: Energy Hole in Cluster of WSN

-Cluster Head Selection: The cluster head is selected with the available nodes based on the factors of residual energy, connectivity, communication cost. One critical factor is the cluster head dissipates more energy than other nodes as it involves more operations.

-Multilevel Clusters : In case of bigger networks the multi level of of clusters with the tree like structure is proposed where the cluster heads communicate to the higher level cluster heads which in turn communicate with the base station.

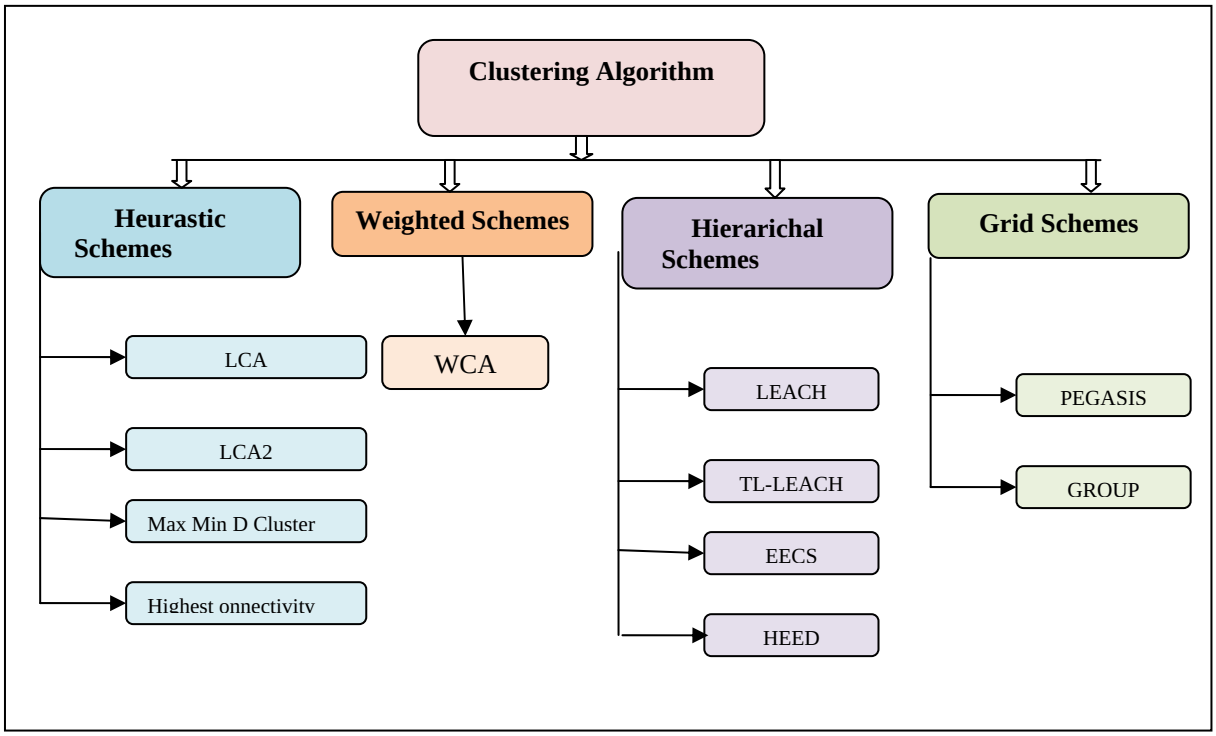

Fig 5 : Different Energy Aware Clustering Schemes in WSN

-Application Dependency: The Application dependency of the

- LEACH (Low Energy Adaptive Clustering Hierarchy): is the protocol in which the nodes send its energy details to the base station at every cycle[5]. The base station acknowledges the node with higher energy as cluster head. Then the cluster head broadcast the connection request to the other nodes and the nodes acknowledge to the cluster becomes the base nodes in the cluster head. In case of LEACH-C, the cluster heads are distributed across the network.

-ERA (Energy Residue Aware Algorithm): Usually, the nodes select the nearest cluster head. Instead that in ERA, part of every round we do calculate the residual energy of cluster head as well the base nodes. So, that all together the nodes select the cluster head not only by the shortest path route, but also by the maximum energy cluster head[6].

-EECHSSDA (Efficient Cluster Head Selection For Data Aggregation): The best part of this algorithm is that every cluster head selects an associate cluster head (ACH). When the cluster head energy goes beyond the bare minimal energy, the ACH will start to act like the cluster head, so the energy spent on cluster head selection can be avoided[5,7].

-HEED(Hybrid Energy Efficient Distributed Clustering): Here the basic principle is there must be one hop communication between the cluster head and there can be multi hop communication between the cluster heads. The inter cluster head communication is decided by the cost of the communication[7].

-HEF(High Energy First Algorithm): Simillar to LEACH, here also the residual energy is calculated at the end of every round. But, here there is going to be the schedulability test at the end of every round or on a time interval for the prediction of the node[6,7].

Clustering Algorithm	CH Selection	Predictability
LEACH	Probability/Random	NO
HEED	Probability/Random	NO
HEF	Residual Energy	YES
EECHSSDA	Average Energy	NO
ERA	Probability/Random	NO
LEACH –C	Residual Energy	NO

Table 4: Energy Aware Clustering Algorithms

VI. ENERGY EFFICIENT DATA AGGREGATION IN WSN

Data aggregation collects the data from the base node to the sink node and make it useful information before passing it to the base station .

Data Accuracy : The accuracy of the data out of data aggregation from different nodes is getting measured in terms of the application need. The data aggregation could be the simple mean or the sum of all the values[8].

Latency : The delay involved in latency is called the latency. The delay in data aggregation should be as minimal as possible. This decision on performance plays the major role in aggregation scheme design.

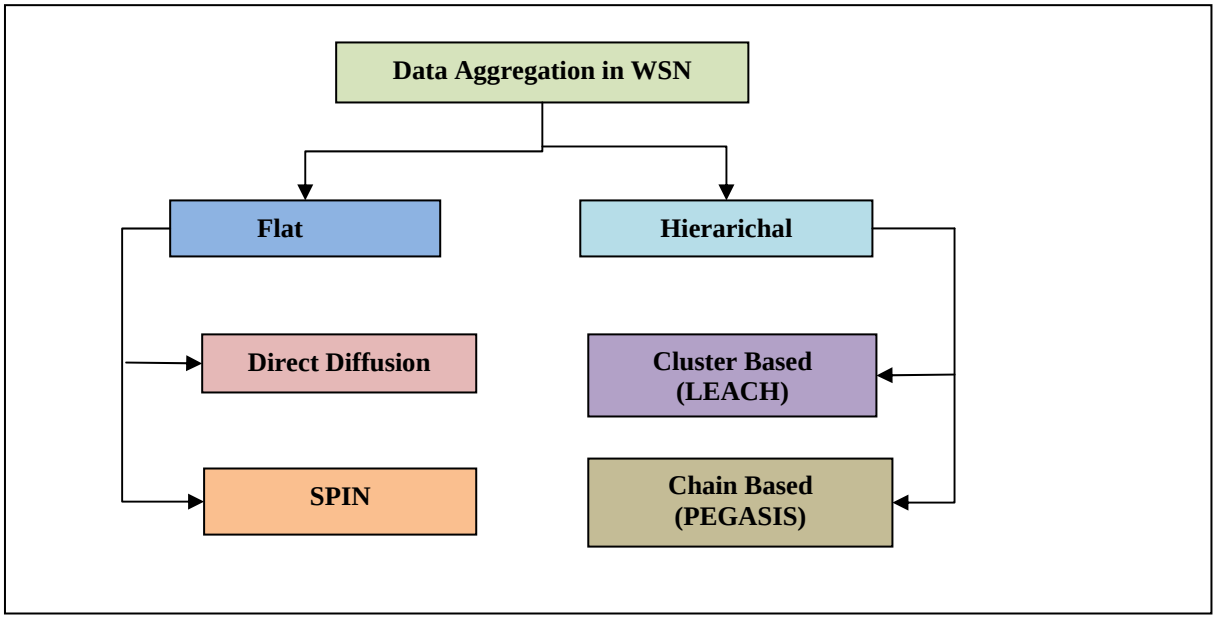

Fig 6 : Data Aggregation Schemes in WSN

-Energy Efficient and Balanced Cluster Based Data Aggregation (EEBCDA) : The network is divided into multiple rectangular region called slim lanes which are further divided into smaller rectangular region called grid. Within the grid, the node with higher energy becomes the cluster head and among the nodes within the region, circulate the cluster heads for data aggregation[9].

- Energy Efficient Spatial Correlation Based Energy Aggregation(EESCBEA) : There are two phases . In the first phase the sink node collects the data from the base nodes after calculating the magnitude similarity and trend. In the second phase, the base nodes send the data to the sink node only on the schedule decided by the sink node[8,9].

Aggregation Algorithm	Energy Efficiency	Accuracy
Spatial Temporal Correlaons Aggregation	Yes	High
Scale Free Aggregation	Yes	High
Redundancy Elimination of Accurate Data Aggregation	Yes	High
Energy Efficient Distributed cluster based data aggregation	Yes	Medium
Polynomial regression base data aggregation	Yes	High

Table 5: Energy Aware Data Aggregation Schemes

VII. ENERGY EFFICIENT LOCALIZATION, ADDRESSING AND CRYPTOGRAPHY

It deals with how to find the localization or the address of the sensor node or sub net of the sensor network. Localization could be proximity based, angle based, range based, probabilistic based on the factor considered. In case of the hardware requirement it could be absolute and relative localization. GPS based localization is called the Anchor based localization. But, even here to avoid too much of power consumption, the cluster head alone will have the GPS system where as the nodes and sub nodes will have the relative positioning. Usually the distance between the nodes are calculated based on the Received Signal Strength (RSSI), Time of Arrival (TOA), Time Difference of Arrival (TDOA)[10]. If we know the direction information instead the distance the triangular method can be used. Here the Angle of Arrival places the major role in finding the node position[11].In case of tri lateration, the node distance is found by the three circle interaction space by solving the simple linear equation. Range free methods give very poor accuracy. RC5, SkipJack, AES are some of the energy efficient encryption algorithms[12].

VIII. ENERGY HARVESTING SYSTEM

All these initiatives talked about the energy optimization and the best way of energy usage But, the energy harvesting system tries to find the alternate energy source so that the nodes can be charged at any point of time. Here the challenges are how to store the harvested energy and when to distribute it to the node. Distributed autonomous load balancing of energy with the residual as well the harvested energy check at the end of periodic duty cycles is very much essential[13]. Energy harvesting system has multiple units like harvesting unit, storing unit, super capacitors, sensors indicate the storage. The photo voltaic technology generates the energy when the semiconductors get the energy from the photon cells. Nanotechnology based harvesting systems generate energy from the nano crystals[14]. The well renowned solar harvesters harvest energy from the harvesting units. The Piezoelectric sensor unit generates the energy from the pressure, wind mills and aqua wave energy generators are some of the energy harvesters from the energy generations from the natural sources. Radio frequency energy generators, additional to the data transmission[15], using the radio waves the energy is created. The thermal energy generators generate energy out of the temperature difference. Modulation schemes are used to control the error in the data transmission. It is all about data representation in the data transmission[16].

Energy Source	Condition
Thermal Energy	In/Out door
Radio Energy	WIFI,GSM
Solar Energy	Outdoor
Wind Energy	Outdoor
Vibration Energy	In/out door
Photo voltaic Energy	Indoor
Polar Energy	Outdoor

Table 6 : Various Energy Sources of the Harvesting Systems

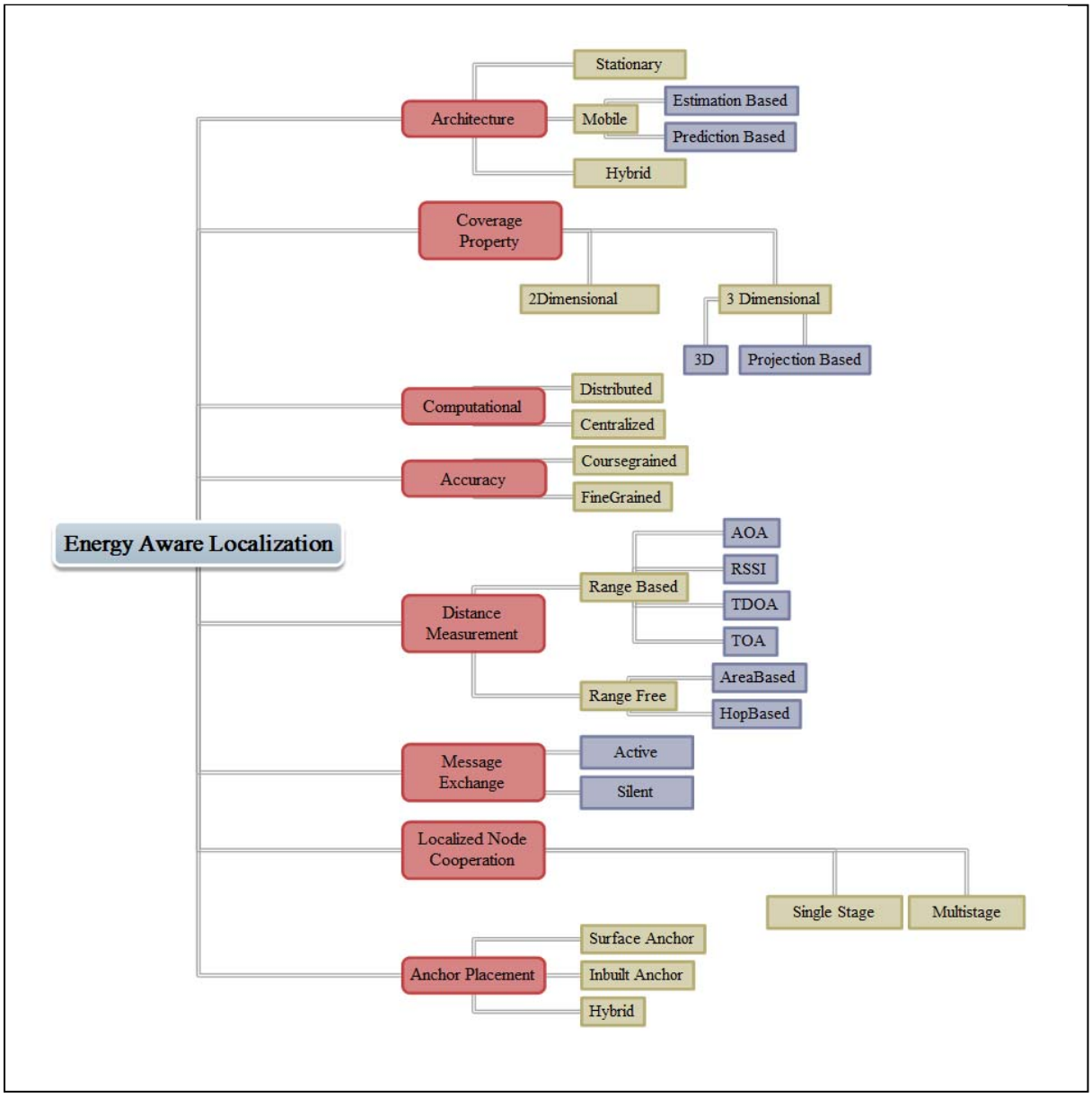

Fig 7 : Localization in Wireless Sensor Network

IX. OUTLOOK

All the energy engineering initiatives can be summarized as

a. Energy Monitoring and Auditing
b. Energy Optimization initiatives
c. Energy Harvesting systems
d. Energy Scavenging Program

	Energy Auditing	**Energy Optimization**	**Energy Harvesting**
Node Level	Power Meter at Node, Energy Trace Technology of TI	SENMA	HUMS
Communication Protocols – Energy Aware Policies	Energy Dissipation Monitoring	E-DEEC, EECS, LEACH, S-MAC	IEEE 802.15.4, EnHANTS, Zigbee
Routing Protocols – Energy Aware Techniques	Predictive Energy aware routing	SPIN, TEEN, AP-TEEN, MECN, SMECN, GEAR	EH-WSN, DEHAR, D-POLLO. PRADA
Data Aggregation Schemes	EPAS	EEBCDA, EESCBEA, LEACH, PEGASIS SPIN, DD. Spatial Temporal Correlaons Aggregation, Scale Free Aggregation, Redundancy Elimination of Accurate Data Aggregation, Energy Efficient Distributed cluster based data aggregation, Polynomial regression base data aggregation	EHLINK, Monjolo
Cluster Head Formation Methods	Minimum Transmission Energy Prediction, ANT CLUST, TPC cluster head election mechanisms	LEACH, ERA, HED, EECHSSDA, HEF	CH-EHS Distributed Systems
Modulation Schemes	BPSK,16 QAM, AWGN	MCS, FEC, ARQ	EA-DVFS (Energy-Aware Dynamic Voltage and Frequency Scaling), DMS, DVS, EPANET, HASS
Encryption / Decryption	Peer Intermediaries of Key Establishment (PIKE), Elliptic Curve Cryptography (ECC) and Elliptic Curve Digital Signature Algorithm (ECDSA)	RC5, SkipJack, AES	WPA2
Localization and Addressing Strategies	RSSI	PCRLB, PCK	EH WSN
Energy Aware Deployment Strategies	LMA LMN, RPAR	LINT, LILT	
Energy Aware Scheduling	TDMA LINK Scheduling, SS-Tree	LSA –Late Scheduling Algorithm	EDF
Energy Aware Architecture Design	DTN	Manna, EPC	DREAMS

Table 7 : Consolidated Survey of Energy Engineering in WSN

X. CONCLUSION

Energy optimization initiatives are more in the communication protocol end as the communication takes more energy. The cluster head formation and cluster head rotations have lots of research contribution than with the energy aware localization schemes. The contributions are not consolidated in many of the later works or the prior improvements are skipped. We need a standardized evaluation of the energy improvement contribution in the field of WSN for standardizing and concentrating on the uncovered areas.

References

[1] Jianhui Zhang, Xingfa Shen, Shaojie Tang, Guojun Dai, Energy efficient joint data aggregation and link scheduling in solar sensor networks, Computer Communications,Elseier, July 2014.

[2] Khemapech, A. Miller and I. Duncan, A Survey of Transmission Power Control in Wireless Sensor Networks, PGNET, 2007

[3] Pranesh Sthapit, Jae-Young Pyun, Medium reservation based sensor MAC protocol for low latency and high energy efficiency, Telecommunication Systems, April 2013, Volume 52, Issue 4, pp 2387-2395.

[4] Ehsan S, A Survey on Energy-Efficient Routing Techniques with QoS Assurances for Wireless Multimedia Sensor Networks, Communications Surveys , Communications Surveys & Tutorials, Volume:14 , Issue: 2 , March 2011.

[5] Moslem Afrashteh Mehr,Cluster Head Election Using Imperialist Competitive Algorithms for Wireless Sensor Networks, International Journal of Mobile Network Communications & Telematics (IJMNCT) Vol. 4, No.3, June 2014.

[6] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[7] Vinay Kumar, Sanjeev Jain and Sudarshan Tiwari, Energy Efficient Clustering Algorithms in Wireless Sensor Networks: A Survey, International Journal of Computer Science Issues, Vol. 8, Issue 5, No 2, September 2011.

[8] Sumit Chaudhary, Neha Singh, Avinav Pathak and A.K Vatsa, Energy Efficient Techniques for Data aggregation and collection in WSN, International Journal of Computer Science, Engineering and Applications (IJCSEA) Vol.2, No.4, August 2012.

[9] Ankit Tripathi, Sanjeev Gupta, Bharti Chourasiya, Survey on Data Aggregation Techniques for Wireless Sensor Networks, International Journal of Advanced Research in Computer and Communication Engineering, Vol. 3, Issue 7, July 2014.

[10] Asma Mesmoudi , Mohammed Feham, Nabila Labraoui, Wireless Sensor Networks Localisation Algorithms - A Comprehensive Survey, International Journal of Computer Networks & Communications (IJCNC) Vol.5, No.6, November 2013.

[11] Dezhong Shang, Baoxian Zhang, Zheng Yao, and Cheng Li, An Energy Efficient Localized Topology Control Algorithm for Wireless Multihop Networks, Journal of Communication and Networks, Vol. 16, No. 4, Aug 2014.

[12] Padmanabhan,Kamalakkannan, Shantharajah, Energy efficient Localization Technique in Wireless Sensor Network, International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 11, November 2013.

[13] Jun Wu,Shigeru Shimamoto, An Energy Efficient Data Secrecy Scheme for Wireless Body Sensor Networks, International Journal of Computer Science and Engineering, Vol.1, No.2, June 2011.

[14] Kirankumar Y. Bendigeri and Jayashree D. Mallapur, Energy Aware Node Placement Algorithm for Wireless Sensor Network, Advance in Electronic and Electric Engineering, Volume 4, Number 6 (2014), pp. 541-548.

[15] Saba Akbari, Energy Harvesting for Wireless Sensor Networks Review, Proceedings of 2014 Federal Conference on Computer Science and Information Systems, ACSIS, Vol.2, pp. 987–992.

[16] I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.