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Machine Learning for Wireless Sensor Network: A Review, Challenges and Applications

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Abstract

In recent years, there has been a growing attention in wireless sensor networks. In Wireless Sensor Networks (WSNs), collecting sensed information, transforming the information data to the base station in an energy efficient way, and lengthening the network lifetime are main issues.
Sensor nodes in WSNs are energy constrained. So, one of the major design challenges in WSNs is minimizing consumed energy at the sensor nodes. Therefore, a number of routing schemes are designed that make efficient usage of limited energy of the sensor nodes. Hierarchical routing protocols are best known in regard to energy efficiency. By using a clustering technique hierarchical routing protocols greatly reduce energy consumed in collecting and disseminating data.
But, large-scale sensor network unavoidably introduce large amount of data in WSNs to be processed, transmitted and received. Transmitting all data back to a base station for processing and making inferences is merely impossible due to the sensor limited energy and bandwidth constraints. Thus, there is a need for applying Machine Learning (ML) algorithms in WSNs. These algorithms could significantly decrease the amount of data communications and truthfully utilize the distributive characteristic of WSNs. The main goal of this review paper is to demonstrate that ML is a practical approach to a range of complex distributed problems in WSNs and particularly in energy efficient routing.

Keywords: Wireless sensor network, machine learning, routing, neural network, fuzzy logic, evolutionary algorithm, reinforcement learning, and swarm intelligence.

1. Introduction

A collection of various distributed sensors is widely known as Wireless Sensor Network (WSN). Extensively the WSN are used for mainly two applications−monitoring, and tracking [Jennifer Yick et. al.]. In particular in WSN tracking applications the objective of sensor node is to track the animal, enemy, human, traffic, car/bus etc., wherein WSN monitoring applications sensor node is monitor the environment, animal/patient movement, and security detection etc.

In order to develop an application using sensor network technology user has to face various challenges are design and deployment, localization, data aggregation and sensor fusion, energy aware routing and clustering, scheduling, security, quality of service etc.

With the rapid growth in MEMS technology, in the near future it may deploy large-scale sensors in this field. However, large-scale sensor network also unavoidably introduce large amount of data in WSNs to be processed, transmitted and received. Transmitting all data back to a base station for processing and making inferences is merely impossible due to the sensor limited energy and bandwidth constraints. Consequently there is a need for applying Machine Learning (ML) algorithms in WSNs. ML algorithms iteratively learn the properties of the environment and adapt their behavior rapidly. In general neural network, fuzzy logic, evolutionary algorithm, reinforcement learning, and swarm intelligence are different ML algorithms [Raghavendra et. al.] are used in WSNs. These algorithms could significantly reduce the amount of data communications and truly utilize the distributive characteristic of WSNs.

In WSN in order to transmit data from source node to destination node or vice versa is widely known as routing. In WSN routing is very challenging task in comparison with mobile ad hoc networks or cellular networks [K. Akkaya et. al.].

In general, *proactive, reactive and hybrid* [K. Akkaya et. al.] are the three different strategies in routing protocol: *Proactive strategy* referred to as table driven, relies on periodic dissemination of routing information to maintain consistent and accurate routing tables across all sensor nodes of the network. *Reactive strategy* is on-demand, in the sense that the routes are discovered, when a node desires to send a packet. This type of protocol takes into account only the minimum hop count to reach the destination. *Hybrid strategy* incorporates the best features of the proactive and reactive strategies. A hybrid routing strategy can be adopted whereby proactive routing is used within a cluster and reactive routing is used across clusters.

In order to design the routing protocol various challenging factors affecting as minimal computational and memory requirement, automaticity and self-organization, energy efficiency, scalability, architecture matching the characteristics of traffic patterns, and support for in network data aggregation.

In WSN limited battery power and their exchangeability energy is the key factor that affects the routing. Hence, our focus is on energy efficient routing in WSN, which is the current goal of researcher to save energy in WSN. Energy Efficient Routing (EER) is essential for increasing the network lifetime in WSN applications. Most of the routing protocols use clusters in order to extend the network lifetime and to provide energy efficiency. LEACH, PEGASIS and TEEN are cluster based energy efficient protocols.

This review paper is organized as follows. Section 2 presents the theoretical background of EER and the need of EER in WSN. Section 3 discusses the various factors affected in the designing of EER protocols. Reviews of different ML algorithms for EER in WSN are discussed in Section 4. Section 5 presents the concluding remarks with future scope of work in EER using ML algorithms.

2. Energy Efficient Routing

In WSNs, routing protocols can be classified according to the manner in which information is acquired and maintained and the manner in which this information is used to compute paths based on the acquired information.

In WSNs devices are resource constrained and they have a low processing speed, a low storage capacity, a limited communication bandwidth and nodes are also to limited battery powered. Increase the life time of network can be accomplished by employing energy efficient routing protocols. The performance of routing protocols depends on the architecture and design of network. However, the operation of the protocol can affect the energy spent for the transmission of data.

The most energy consumption processes in WSN and *Sensing, Processing and Communication* [Daniel Minoli et. al,]. In *sensing* energy consumption is due to sampling, analogue to digital conversion, and modulation. Also the energy consumption of sensing is related to the sense operation of the node (periodic, sleep/wake, etc.). In *processing* energy consumption is due to sensor controlling, protocol communication, and data processing. In most of the cases this process supports three operation states sleep, idle, and run. Where as in communication process energy consumption depends on route the data from source node to sink node and/or source node to multiple sink nodes, and distance between nodes etc.

In particular, the communication between the nodes in sensor network is the major part of energy consumption. The main task of communication protocols is not only to find the lowest energy path from a source to destination, but also find the most efficient way to extend the networks lifetime and this should be accomplished by using ML algorithms.

After sensing the environmental parameters, the data should be transmitted to the sink node. For two sensor nodes communication the energy consumption for data transmission (E_{Tx}) can be expressed as [Ruqiang Yan et. al].

$$E_{Tx} = E_{e\_tx} * k + \varepsilon_{amp} * d^{\alpha} \tag{1}$$

where k is the number of transmitted data bits; α is a factor valued from 2 to 5, depending on the environment of wireless transmission; d is the distance between two sensor nodes; ε_{amp} is the amplification coefficient to satisfy a minimum bit error rate to ensure reliable reception at the receiver; and E_{e_tx} is the energy dissipated to operate the transceiver, which is given as $E_{e\_tx} = V_{cc} * I_{TP} / K_{data\_rate}$, where Vcc denotes the working voltage, I_{TP} denotes the current for transmission, and K_{data_rate} denotes the data transmission rate.

The energy consumed for receiving a data can be expressed as

$$E_{Rx} = E_{e\_rx} * k \qquad (2)$$

Equation (1) shows that, for a fixed distance, the energy consumed is proportional to the number of data bits. On the other hand, the longer the distance between two sensor nodes is, the more energy will be consumed.

3. Challenges in Energy Efficient Routing

- The design of energy efficient routing protocols in WSNs is influenced by various factors. These factors must endure before efficient communication can be achieved in WSNs [L. Junhai et. al.]. Following are the key factors that any researchers in this field have to consider for EER.
- *Node Deployment:* It is an application-based operation affecting the routing protocol performance, and can be either randomized or deterministic.
- *Node-Link Heterogeneity:* The attendance of heterogeneous set of sensors gives increase to many technical difficulties related to data routing and they have to be overcome.
- *Data Reporting Model:* In WSNs, measurement, data sensing and reporting depend on the application and the time criticality of the data reporting. Data reporting can be classified as both time-driven, event driven, query-driven, and hybrid.
- *Energy Consumption without Dropping Accuracy:* In this case, energy-conserving mechanisms of processing and data communication are more than necessary.
- *Scalability:* WSNs routing protocols should be scalable enough to respond to events, e.g. huge increase of sensor nodes, in the WSNs environment.
- *Network Dynamics:* In many applications, mobility of sensor nodes is necessary. In spite of the fact that most of the network architectures assume that sensor nodes are stationary.
- *Fault Tolerance:* The overall operation of the WSNs should not be affected by the failure of sensor nodes.
- *Connectivity:* In sensor network, sensor nodes connectivity depends on the random distribution of sensor nodes.
- *Transmission Media:* In a multi-hop WSNs, communicating nodes are connected by a wireless medium. One method of MAC design for sensor

networks is to use TDMA based protocols that conserve more energy equated to contention-based protocols like CSMA (e.g., IEEE 802.11).

- *Coverage:* A specified sensor's view of the environment is limited both in accuracy and in range in WSNs; it can only cover a partial physical area of the environment.
- *Quality of Service:* Data should be transported within a certain period of time. However, in a number of applications, maintenance of energy, which is directly connected to network lifetime, is considered relatively more important than the quality of data sent. Thus, energy aware routing protocols are required to capture this requirement.
- *Data Aggregation:* Mixture of data from different sources according to certain aggregation task is known as a data aggregation.

4. EER Protocols for WSN Using Machine Learning Algorithms

In current decade researchers have an attention towards machine learning algorithms used for WSNs because of their silent features as memory and computational requirements, communication costs, wireless ad-hoc nature, restricted energy, mobility and topology changes. There are the two views for ML in WSN applications, namely the *network associated issue* and *application associated issue* [L. Junhai et. al.].

In the *network* associated issue, ML algorithms that have been used for optimal node deployment, localization, security, energy aware routing and clustering, QoS, resource allocation, data aggregation and fusion, and scheduling. Where as in *application* associated issue, ML algorithms that have been used for information processing, event classification and identification of target class, and target tracking. This review paper is project towards network associated issue for EER.

Different ML algorithms are used for energy efficient routing in WSNs. The review and applications of these algorithms discussed as follows:

4.1 Fuzzy Logic based

Fuzzy logic systems (FLS) basically involves of three major processes are fuzzification, inference engine, and defuzzification. When the crisp input is delivered to a FLS, the Inference Engine computes the output set corresponding to each Rule which has IF- THEN structure. Crisp inputs are made fuzzy by the fuzzification process. In general for fuzzification process singleton, Gaussian and Trapezoidal or Triangular function is used. In inference engine the IF part of a rule is its antecedent, and THEN part of a rule is its consequent. For this Mamdani or Sugeno min-max operation is used. Where in defuzzification of FLS finds a crisp output value from the fuzzy solution space. Common defuzzification methods are: maximum, mean-of-maxima, centroid, center-of-sums and center-of-sets.

Zohre and Arabi have proposed fuzzy based algorithm for hybrid EER in WSNs. which uses two algorithms, i.e. EF-Tree (Earliest-First Tree) and SID (Source-Initiated Dissemination) to disseminate data, and works a fuzzy method to choose cluster head, and to shift between two methods, i.e. SID and EF-Tree. In this routing method, the whole network is clustered and the appropriate cluster-head is selected according to fuzzy variables. The name of the suggested method implies that it has a set of features of three methods, i.e. SID, EF-Tree, Fuzzy methods which are performed alternatively and are switched between routings due to conditions. The proposed method is a new work on routing in WSNs which is based on fuzzy and hybrid routing methods for higher flexibility on the sensor network, increase of energy efficiency, an increase of the network life time.

Toleen Jaradat et. al. proposed energy aware routing scheme based on a cross-layer approach for WSNs with the objective to minimize the overall consumed energy; thus, maximizing the network lifetime. The remaining battery reserve capacity, link quality and transmission power for nodes within the local communication range are taken into consideration to determine the next hop relay node to reach the network sink. Parameters from different stack layers (i.e., physical, MAC, and network) are presented to a FLS controller which makes a next hop routing decision. The proposed routing method makes use of a self-adaptive scheme based on a fuzzy control algorithm that adapts according to varying measureable parameters. The proposed method takes into consideration scalability (in terms of the number of nodes), self-learning (i.e., adapt to changes in the ambient environment), and focuses on the entire network longevity (i.e., extend the lifetime of the network as a whole).

Estimating the quality of routes using fuzzy systems to assist the directed diffusion routing protocol is proposed in .Proposed method is effective from the point of view of three metrics: message delay to the sink node, time of death and packet loss rate of the first sensor node. The proposed fuzzy system estimates a quantitative value associated with the quality of each route, in order to support the routing protocol in the selection of several feasible routes. Therefore, based on the route quality, built on the number of hops and the energy level of the nodes that combine a route., the routing protocol should define which route to be used for sending the data collected with the goal of optimizing the necessary time to send a specific number of messages, the packet loss rate and the lifetime of the first sensor node, which is defined as the period that the first sensor node die due to the battery depletion. The Ant colony optimization technique is used for adjusting the rule base of the fuzzy inference system.

Application: FL is well suited for defining and solving complex multi objective functions like design and deployment, scheduling, energy aware routing and clustering.

4.2 Neural Network based

Neural Network (NN) is mathematical models of some function *F: X! Y.* Their initial inspiration comes from biological networks of neurons. They consist of simple nodes or neurons, interconnected with each other. Simple functions are usually associated with each node (like addition) and weights are assigned to the connections between the nodes. Data is flowing from the input through the whole network, using the connections between the nodes and arriving at the output neurons. The most important property of NN is their ability to *learn* - the weights between the neurons are the real computational power and have to be adjusted such that the output is exactly the mapped function. For learning or *training* of neural networks, a set of training data is needed, where possible inputs are already mapped to the needed output. For example, in the case of a classification problem of hand-written numbers, different pictures (input) are classified as numbers (output).

Neeraj Kumar et. al. address the issue of EER and clustering in WSNs using NN with the objective of maximizing the network lifetime. In the proposed method, the problem is formulated as linear programming with specified constraints. Cluster head selection is done using adaptive learning in NN followed by routing and data transmission. Define an efficient metric to be used in taking the selection of next hop in routing. This NN based algorithm compared with existing routing protocol LEACH in terms of residual energy and number of alive nodes. The result shows better performance than LEACH.

Wenhui Zhao et. al. present an intelligent method based on self-organizing NN which optimizes the routing according to the amount of energy of each node in the network and its computation power. MODABER is a wireless sensor node made in the Artificial Intelligence Research Center of University of Isfahan. This wireless sensor node has such an especial features on which this project is constructed. This method presents a solution with low computational complexity for problem of frequency interference.

NN approach is proposed by Veena K.N. et. al. to find the efficient convergecast route from sensor nodes to sink. The Hop Field Neural Network used to find the convergecast route found efficient in minimizing power, and time delay of the network. This method presents a capability of the NN as a computational tool for solving constrained optimization problem. The proposed method facilitates a possible convergecast routing algorithm for future high speed sensor networks due to the fact that hardware implemented NN can achieve an extremely high response speed.

According to the architecture of NN, a dynamic-cluster energy-aware routing algorithm has been proposed in [17]. Firstly, the event data dynamically selects a temporary cluster header. Then the temporary cluster-header switches all the data it receives, and the moved data reflects the general instance of the region. In this way it has reduced the information that has to be forwarded and has reduced the energy consumption of the whole network. The support of the network is originated by genetic-tree algorithm. It will timely update the trunk of the genetic-tree in order to trade off the energy consumption of the whole network. So it has increased the lifetime of the network greatly. The result of simulation shows that it is a quite effective energy saving routing algorithm.

Application: NN are feasible solution to centralized problems like sensor fusion and data mining, energy aware routing and clustering, scheduling. Further feasible application areas for neural networks are optimal sensor and sink placement, localization etc.

4.3 Evolutionary Algorithm based

Evolutionary Algorithm (EA) model the natural evolution, which is the process of adaptation with the aim of improving existence capabilities through processes such as natural selection, survival-of-the-fittest, reproduction, mutation, competition and symbiosis. EAs use a population of solution candidates called chromosomes. Chromosomes are composed of genes, which represent a distinct characteristic. Genetic algorithm, genetic programming, evolutionary programming, gene expression programming, evolution strategy, memetic algorithm, differential evolution, neuroevolution are the techniques of EAs.

Uday K. Chakraborty et. al. developed a memetic algorithm based on differential evolution for solving the routing problem in two tier sensor networks , which solves routing problems of more than a thousand relay nodes. This method uses a new encoding scheme and adopts the differential evolution mutation to provide an improved search mechanism by a novel combination of differential evolution and local search. This algorithm finds a path from every relay node to the base station via other relay nodes such that the energy consumption of the maximum energy consuming relay node is minimized and that improves the network lifetime.

Shamsul Wazed et. al. proposed a Genetic Algorithm based solution for scheduling the data gathering of relay nodes that can significantly extend the lifetime of the relay node sensor network. They have consider a two-tiered sensor network architecture, where higher powered relay nodes act as cluster heads and sensor nodes transmit their data directly to their respective cluster heads. They focus on non-flow-splitting routing schemes, using MHDTM to extend the lifetime of the relay node network. His approach is able to improve network lifetime by almost 200% compared to traditional routing schemes.

Varun K. Sharma et. al. describes a multi objective differential evolution (MODE) algorithm that identifies a set of Pareto optimal routings with respect to these multiple objectives for both single and multipath routing problems. Application of the algorithm to distributed underwater networks incorporating both static and mobile sensor nodes is being assessed. Multiple candidate routes can be produced with this approach which represents the different possible tradeoffs between energy consumption and latency for a communication linkage.

Application: EA have high memory and processing requirements and are very inflexible in case of an environmental change. However, they can be used for some centralized problems like localization, design and deployment, sensor fusion and data mining, energy aware routing and clustering, scheduling.

4.4 Reinforcement Learning based

Reinforcement Learning (RL) is learning what to do and how to map situations to actions so as to maximize an environmental numerical reward signal. The learner is not told which actions to take, as in most forms of ML, but instead he has to take his own action and a discovering the action which yield the most reward by keep on trying them. In the most challenging cases, actions may affect not only the immediate reward but also the next situation and, through out, all subsequent rewards. These two characteristics error and trial search and delayed reward are the two most important distinguishing features of reinforcement learning.

Varun et. al. proposed a tailored Q-Learning algorithm for routing scheme in WSN. Primary goal of author is to make an EER algorithm with help of modified Q-Learning approach to minimize the energy consumption utilized by sensor nodes. This method is a modified version of existing Q-Learning method for WSN that leads to the convergence problem. Simulation results from NS-2 shows that the result of proposed and old Q learning method is same.

Nesrine Ouferhat and Abdelhamid Mellouk proposed a protocol, called energy and delay efficient routing protocol for sensor network (*EDEAR)*, is an adaptive routing; its objective is to find the best path in terms of energy consumed and the end to end delay. With using RL, updates routing tables and thus taking into account all the dynamic parameters that define the traffic. The adaptation of routing is based on changing traffic conditions and minimizing transfer time.

RL based Dynamic Power Management (DPM) technique for a portable, multi-camera traffic monitoring system presents by Umair Ali Khan and Bernhard Rinner. The RL technique used for the DPM of the sensing platform uses a model-free learning algorithm that does not require a priori model of the system. In addition, a tough workload estimator based on an online, Multi-Layer Artificial Neural Network (ML-ANN) is incorporated to the learning algorithm to provide partial information about the workload and to take better decisions according to the changing workload. Based on the estimated workload and a selected power-latency tradeoff parameter, the method learns to use optimal time-out values in sleep and idle modes of the computing hardware.

Application: RL is the most widely used for distributed problems in MANETs and WSNs such as routing, scheduling, medium access control, service positioning etc.

4.5 Swarm Intelligence based

SI is the collective behavior of decentralized, self-organized systems, natural or artificial. SI systems contain typically of a population of simple agents or bodies interacting locally with one another and with their environment. The inspiration often comes from nature, especially biological systems. The agents follow very simple rules, and although there is no centralized control structure dictating how individual agents should behave, local, and to a certain degree random, interactions between such agents lead to the emergence of "intelligent" global behavior, unknown to the individual agents. Natural examples of SI include ant colonies, bird flocking, animal herding, bacterial growth, and fish schooling. The definition of swarm intelligence is still not quite clear. In principle, it should be a multi-agent system that has self-organized behavior that shows some intelligent behavior. The application of swarm principles to robots is called swarm robotics, while 'swarm intelligence' refers to the more general set of algorithms. 'Swarm prediction' has been used in the context of forecasting problems. Ant colony optimization (ACO), artificial bee colony, artificial immune systems and particle swarm optimization are the techniques of swarm intelligence.

Xia Li et. al. presents an energy-efficient routing protocol based on particle swarm clustering algorithm and inter-cluster routing algorithm for WSN , referred to as Adaptive Energy efficient clustering Routing Protocol (AECRP), which is fully considers energy saving, stable transmission and load balancing. The protocol can balance the energy consumption of the network and prolong the lifetime of the network.

Yi-ping chen et.al. proposed, particle swarm optimization algorithm is utilized to search optimal inter-cluster routing path for the optimization of network lifetime. Developed a cluster-based energy efficient routing algorithm which takes into account both energy efficiency and energy balance for prolonging network lifetime. cluster-based energy efficient routing algorithm, clusters are formed by adopting the mechanism of local competition, and energy consumption of each cluster is balanced in each round for solving hot spot problem.

Application: SI is well suited for distributed network scenarios, where mobility and topology changes are of greatest importance, but energy is not limited, like MANETs. SI in WSNs widely used for energy aware routing and clustering, localization, design and deployment etc. Ant colony optimization has been applied mostly to routing and has proved to be an efficient and flexible algorithm.

5. Concluding Remarks

In 21st century there has been a growing interest in wireless sensor networks applications. One of the major challenges in wireless sensor network is to develop an energy-efficient routing protocol in order to increase network lifetime. We present a literature review of energy efficient routing using machine learning and challenges in EER protocol. Hence, our object towards survey of energy efficient routing protocol. We present a survey on machine learning techniques for energy efficient routing. From survey, we found that machine learning techniques properties are more appropriate for optimize the wireless sensor network. Researcher can have further survey on using hybrid machine learning techniques for an energy efficient routing in WSNs.

References

[1] Jennifer Yick, Biswanath Mukherjee, Dipak Ghosal, “Wireless sensor network survey,” *Computer Networks Elsevier 52* , pp 2292–2330, 2008

[2] Raghavendra V. Kulkarni, Anna Förster, Ganesh Kumar Venayagamoorthy, “Computational Intelligence in Wireless Sensor Networks: A Survey,” *IEEE communications surveys & tutorials,* vol. 13, no. 1, pp 68- 96 first quarter 2011

[3] K. Akkaya, M. Younis, “A survey on routing protocols for wireless sensor networks,” *Ad Hoc Networks 3 (3*), pp 325–349,2005

[4] Daniel Minoli, Taieb Znati, Kazem Soharby, "Wireless sensor networks-Technology, Procols and Applications." *Wiley interscience*, 2007

[5] Ruqiang Yan, Hanghang Sun, and Yuning Qian, "Energy-Aware Sensor Node Design With Its Application in Wireless Sensor Networks," *IEEE transactions on instrumentation and measurement*, vol. 62, no. 5, pp 1183-1191, may 2013

[6] L. Junhai, X. Liu, Y. Danxia, "Research on Multicast Routing Protocols for Mobile ad-hoc Networks," *Computer Networks*, Vol. 52, Issue 5, pp. 988-997.2008

[7] Zohre and Arabi, "HERF: A Hybrid Energy Efficient Routing using a Fuzzy Method in Wireless Sensor Networks," *International Conference on Intelligent and Advanced Systems (ICIAS),* pp 1-6, June 2010

[8] Toleen Jaradat, Driss Benhaddou, Manikanden Balakrishnan, Ala Al-Fuqaha, "Energy Efficient Cross-Layer Routing Protocol in Wireless Sensor Networks Based on Fuzzy Logic," *IEEE iwcmc,* pp 177-182, 2013

[9] Ricardo A. L. Rabelo, Jose V. V. Sobral, Harilton S. Araujo, Rodrigo A. R. S. Baluz, and Raimir Holanda Filho, "An Approach Based on Fuzzy Inference System and Ant Colony Optimization for Improving the Performance of Routing Protocols in Wireless Sensor Networks," *IEEE Congress on Evolutionary Computation,* June 20-23, Cancún, México, pp 3244-3245, 2013

[10] Neeraj Kumar, Manoj Kumar, R.B. Patel, "Neural Network Based Energy Efficient Clustering and Routing in Wireless Sensor Networks," *First International Conference on Networks & Communications,* pp 34-39, 2009

[11] Wenhui Zhao, Daxin Liu, Yu Jiang, "Distributed Neural Network Routing Algorithm Based on Global Information of Wireless Sensor Network," *International Conference on Communications and Mobile Computing*, pp 552-555, 2009

[12] Veena K.N., B.P.Vijaya Kumar, "Convergecast in Wireless Sensor Networks: A Neural Network approach," *IEEE 4th International Conference on Internet Multimedia Services Architecture and Application(IMSAA),* 2010

[13] Guo Bin, Li Zhe, Wei Ze-Jun, "A Dynamic-cluster Energy-aware Routing Algorithm Based on Neural Structure in the Wireless Sensor Networks," *The Fifth International Conference on Computer and Information Technology (CIT'05),* 2005

[14] Uday K. Chakraborty , Sajal K. Das, Travis E. Abbott, " Energy-Efficient Routing in Hierarchical Wireless Sensor Networks Using Differential-Evolution-Based Memetic Algorithm," *IEEE World Congress on Computational Intelligence*, June, 10-15, 2012

[15] Shamsul Wazed, Ataul Bari, Arunita Jaekel and Subir Bandyopadhyay, " Genetic Algorithm Based Approach for Extending the Lifetime of Two-Tiered Sensor Networks," *IJCA Special Issue on Intelligent Systems and Data Processing,* pp 83-87, 2007

[16] Feng Xue, Arthur Sanderson, Robert Graves, "Multi-Objective Routing in Wireless Sensor Networks with a Differential Evolution Algorithm," *MIT press journal- Evolutionary computation*, pp 880-885, 2006

[17] Varun K. Sharma & Shiv Shankar Prasad Shukla, Varun Singh, "A Tailored Q- Learning/or Routing in Wireless Sensor Networks," *2nd IEEE International Conference on Parallel, Distributed and Grid Computing*, pp 663-668, 2012

[18] Nesrine Ouferhat, Abdelhamid Mellouk, "Energy and Delay Efficient State Dependent Routing Algorithm in Wireless Sensor Networks," *The 9th IEEE International Workshop on Wireless Local Networks (WLN 2009),* pp 1063-1076, 20-23 October 2009

[19] Umair Ali Khan, Bernhard Rinner, "A Reinforcement Learning Framework For Dynamic Power Management of a Portable, Multi-Camera Traffic Monitoring System," *IEEE International Conference on Green Computing and Communications, Conference on Internet of Things, and Conference on Cyber, Physical and Social Computing,* pp 557-565, 2012

[20] Xia Li, Wang Gang, Liu Zongqi, Zhang Yanyan, "An energy-efficient routing protocol based on particle swarm clustering algorithm and inter-cluster routing algorithm for WSN," *25th Chinese Control and Decision Conference (CCDC),* pp 4029-4033,2013

[21] Yi-ping chen, Yu-zhong chen, "A novel energy efficient routing algorithm for wireless sensor networks," *The 9th International Conference on Machine Learning and Cybernetics*, Qingdao, pp1031-1035, 11-14, July 2010.