A General Survey on Machine Learning based Energy Efficient Routing Protocols in Wireless Sensor Network

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Abstract **-** Wireless sensor network (WSN) has gained popularity because of its potential applications in diverse fields. The main function of these networks is to collect information by sensing the environment and sending the data to appropriate location. Since the sensors are constrained by energy, while performing various functions the WSN has to make sure that minimum energy is consumed and life of the entire network is increased. Reducing the energy that is being consumed by sensor is one of the significant design challenges for WSN. A number of routing techniques are found in the literature that tries to efficiently utilize the finite energy of the sensor nodes. But when the size of the WSN grows, the volume of data to be gathered, processed and disseminated by the sensor nodes increases largely. Processing and transmitting such a large amount of data is impractical because of the limited energy of the sensors. Thus, there is a need for applying Machine Learning (ML) algorithms in WSNs. This literature survey focuses on the routing protocols used in WSN and implementation of machine learning techniques to optimize the performance of WSN.

Keywords **-** Wireless sensor network, energy efficiency, machine learning, sensor nodes, routing protocols.

I. INTRODUCTION

A WSN has huge number of sensor nodes and because of limited bandwidth these sensors are placed in a very compact way to make the communication possible [1]. As the application of WSN has been growing in diverse fields, research focusing the data processing ability with respect to energy utilized by the sensor node is also increasing. The data processing speed of the sensor are satisfactory as compared to their energy level. The microprocessor technology is much more ahead of battery technology in case of WSN. Sensors operate with batteries and these batteries have to be changed after some time. But in case of WSN this is quite impractical because the sensor in WSN is placed in such areas where people do not have easy access, for example near battle field, under water or geographically dangerous locations. Routing in WSN is very challenging as compared to traditional IP based networks. Since the number of sensors are very large in WSN so maintaining hundreds or thousands of routing table is merely impossible because sensor nodes are constrained by energy. Thus new techniques that address the energy inefficiency of the sensors are highly in demand. Wireless sensor networks are suitable for environment which keeps on changing. The change may be caused by external circumstances. Machine learning techniques can be applied in such scenario to avoid the unnecessary restructuring of WSN [9]. Machine learning techniques provide abilities that can also be applied to increase the life time and other functionalities of WSN. Thus Machine Learning Techniques are great enabler for WSN that can take care of the changing nature of WSN.

II. LITERATURE REVIEW

A. Energy efficient routing protocols in wireless sensor network

Today sensor node exists because of rapid development in the field of electronics and communications. Sensor technology has become so popular because of its desirable properties like low cost, less power consumption and that they can perform many functions [1]. A sensor network contains many sensors and the location of a sensor in the network is insignificant. Because of this reason sensors can be put in areas where people do not have easy access. It also implies that a WSN can organize the sensors in an order when-ever required.

There are many applications of WSN. They are applied in battle fields, fraud detection, pollution monitoring and control, traffic control, health care monitoring, wildlife habitat monitoring and many more [1]. The sensor node in a WSN can communicate with other nodes or to an external computer. In a large geographical area, the larger the sensor nodes used, the greater is the accuracy gained in sensing. Sensing, processing, communicating and a power unit are the major component of a sensor [1].

In recent years large amount of research were conducted to see how the sensor communicate among them during sensing, processing and management of data. In most of the research a significant decrease in the performance of the sensor due to its limited energy and bandwidth were observed. Thus it is understandable that new innovative method to remove the energy inefficiency that decreases the life of the entire network is very necessary.

Traditional ad hoc routing does not meet the requirements of routing in sensor network because IP based addressing is impractical in Wireless Sensor Network. The network layer of the sensor network has the responsibility of handling the routing activity. The network layer is designed by considering the factors like energy constraint of the sensor, data-centric nature of the network and attribute based addressing and that sensor network are location aware.

In WSN, each sensor node has available energy (EA) and certain amount of energy is required for communication with the other nodes. Routes consuming minimum energy (energy efficient routes) can be identified based on Energy

Available and the energy required for transmission along the path. The authors in [1] have explained this using similar figure as figure 1 where A is the source node that senses the environment.

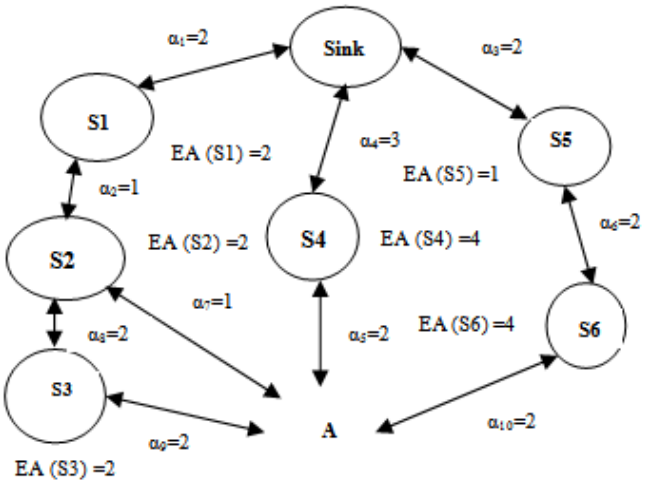

Figure 1: Graph Representation of WSN

The source A can communicate with the destination (sink) Using the following paths

1. Sink-S1-S2-A, total EA=4, total α=4.
2. Sink-S1-S2-S3-A, total EA=6, total α=7.
3. Sink-S4-A, total EA=4, total α=5.
4. Sink-S5-S6-A, total EA=5, total α=6.

A shortest cost path (most energy efficient route) can be selected by considering following approaches-

- **a.** The path that has the maximum total Energy Available is considered.
- **b.** The route that consume minimum energy to send data between the destination and the sensor nodes.
- **c.** The route that takes minimum numbers of nodes to reach the destination.

In [2], authors have mentioned about hierarchical routing protocol. Various groups of the sensors are formed and each group has a special node called head of the group whose role is to communicate and send data to other cluster head or to a base station. In this routing data moves faster to the base station since one cluster head can directly send data to another cluster head skipping several nodes in between. Therefore it can be considered as an energy efficient routing. Threshold Sensitive Energy Efficient Sensor Network Protocol, Minimum Energy Communication Network (MECN), Low Energy Adaptive Clustering Hierarchy, Power Efficient Gathering in Sensor Information System are few protocols of this kind.

The location of the node is used to send data in location based routing [2]. The main characteristics of this scheme are scalability i.e. the size of the network can be increased without increasing the signaling overhead. For this reason this protocol is gaining a great popularity among the research communities [4]. The position of the nodes is identified by using positioning devices like GPS. Sequential Assignment Routing (SAR), Greedy Other Adaptive Force Routing are few examples of this category.

Routing protocols can also be categorized as query based. The main aim is to increase the amount of information gained with low latency and minimum bandwidth. The node which initiates the query can determine the node from which most useful information can be gained by consuming least energy [2]. Directed Diffusion (DD) is an example of query based protocol [7]. The queries are written in High level Languages.

Routing protocols can also be classified as adaptive. In this case, in order to fit to the available amount of energy of a node and the present status of the network, certain system criterion can be controlled. In [5], a balanced topology to manage lifetime and load over WSN have been proposed which is self adaptive.

Multipath routing protocols are the one in which instead of always using the same path for sending data packets, multiple paths can be used. In this way the energy consumed can be decreased and reliability of the sensor network can be increased [6]. In [7] few examples of multipath routing like SPIN, SPEED are explained.

In negotiation based protocols, decision is made to eliminate duplicate data before sending process. Thus it tries to reduce energy consumption by reducing the unnecessary data before processing. This protocol is an advantage over flooding techniques in which repeated data are transmitted from one node to the other [7]. DD, Sequential Assignment Routing (SAR), Sensor Protocol for Information Via Negotiation (SPIN) are few protocols of this kind.

Due to a massive number of sensor nodes in a WSN, it is a bad idea to assign global identification number to each node as it increases the overhead. So address based routing protocol cannot be used in WSN. In data-centric protocols the identification of data generated by sensors can be achieved by attribute-value pair rather than its address. In this way the overhead to maintain a huge set of address for each sensor node are eliminated and so energy can be saved. Few Data-centric protocols like DD, Energy Aware Routing (EAR), SPIN, flooding and gossiping are presented in [7].

Few routing algorithms to maximize the lifetime of networks in Wireless Ad-hoc Networks and wireless sensor networks are also discussed in [18][19][20].

Table 1: Summary Of Routing Protocols

Type of Protocol	***How energy efficiency is achieved?***	***Example***
Hierarchical	By allowing one cluster head to communicate directly with other cluster head skipping several nodes in-between	LEACH, MECN
Location based	By keeping only the information about location of the node instead of keeping the entire routing information	SAR, GOAFR

Type of Protocol	*How energy efficiency is achieved?*	*Example*
Query based	By increasing the amount of information gained with low latency and minimum bandwidth by using high level queries.	Directed Diffusion
Adaptive	By controlling certain system parameters to adjust with available energy and the present status of the network	SPIN
Multipath	By using different paths for transmission instead of always using the same path	SPIN, SPEED
Negotiation based	By deciding to eliminate redundant data and reduce the volume of data before transmission	Directed diffusion, SAR, SPIN
Data- centric	By eliminating the overhead to maintain a huge set of addresses for each sensor node	DD,EAR, Flooding, SPIN

Table I summarizes how the routing protocols achieve energy efficiency with few examples of each type.

B. Use of Machine Learning in Routing Protocols of WSN

There are many challenges of routing process such as collecting exact and sufficient information, processing and analyzing the collected information to find relationship and features in the data and sending the data to various nodes. A lot of energy is required to perform these tasks. Addressing these challenges using a mathematical model is impractical because such model may be very expensive to get or may not be readily available. Use of machine learning techniques to overcome and address these challenges in WSN has been found in the literature [10][11][12].

Wireless sensor networks are suitable for domains that are not static. The change may be caused by external factors. Machine learning techniques can be applied in such areas to avoid the unnecessary restructuring of WSN [9]. Machine learning techniques provide abilities that can also be applied to increase the life time and other functionalities of WSN. Thus Machine Learning Techniques are great enabler for WSN that can take care of the changing nature of WSN. Machine Learning can be Supervised or Unsupervised. In Supervised Learning it is required to provide both the input data and the output. After the training is complete, a new function is derived from the input and output data set. It is just like teacher supervising the learning process. In unsupervised learning only input data is available but no output data set. The main object is to understand the input data set and find some interesting structure in the data. Unsupervised learning is used for unstructured problems whereas supervised learning is appropriate for processes which are quite easy. Machine Learning can be very helpful in Wireless Sensor Network for a number of reasons. For example machine learning can be used for surveying the changing environments, finding new knowledge from dangerous areas where people do not have easy access[9][11][17].

Reinforcement learning is a type of machine learning where an agent (typically a sensor node in sensor network) can learn new thing by interacting with the surrounding environment. Q-learning algorithm is a popular reinforcement learning technique [10].

In [10][11][12][13][14] few machine learning techniques are used in WSN. The constraints of machine learning and future research direction were highlighted. In [11] certain issues of wireless networks that have been worked out using machine-learning based forecasting methods are surveyed and some other problems where these predictions can be applied were listed. In [12] machine learning techniques which have been used to improve the working efficiency of WSN especially with respect to energy and bandwidth are surveyed.

The concept of meta-learning prediction technique has been considered to explain the energy aware in wireless sensor network have been surveyed in [14]. Techniques of data mining like classification, clustering, prediction are used by the author.

In [21], a Machine-Learning-Based protocol has been presented for Underwater Wireless Sensor Networks (UWSN) which can be classified as adaptive protocol. The authors have argued that for WSN, it is more advantageous to use machine learning during the design of routing techniques.

The machine learning technique used in [25] is Genetic algorithm. The advantage of the proposed algorithm called LEACHE-GA is that it automatically finds out threshold probability which is used to form clusters in WSN. In earlier version of LEACH, the users were responsible to provide this value which was extremely difficult to obtain. The result shows an improved performance over LEACH with respect to energy efficiency.

The authors in [26] have used Reinforcement learning technique to develop an algorithm that finds the energy efficient path between the nodes in a WSN. An improved performance comparison was shown with existing Q-routing algorithm. It is always advantageous to use Reinforcement learning because the focus is always on performance.

The authors in [27] have also used reinforcement learning where a sensor node themselves can find out the cost required in sensing and forming optimal clusters. The method of selecting the best clusters was done using Markov Decision Process. The result produced using simulation tools shows 9% improvement in reducing the energy consumed.

The authors in [28] have used non-incremental learning technique to find the best path for communication. The proposed algorithm was designed to overcome the limitations of directed diffusion. The directed diffusion is not

able to find an optimal path for communication as it is not aware of all the nodes in network.

The authors in [29] have proposed reinforcement based learning technique to propose a new routing protocol to gain energy efficiency. An improvement in load balancing of the sensor nodes and network life time was shown by simulation result.

III. ANALYSIS AND OBSERVATIONS

The professionals who work in the field of WSN often seems to refuse the use machine learning in their area of applications. This may be because machine learning techniques need more memory and processing capabilities than other approaches. Also it is observed that there are very limited works done on application of machine learning to unstructured problems which are very complicated in nature such as routing in WSN and their requirement is still not very clear.

But when the volume of data to be handled increases, machine learning becomes one of the important option for those professionals. Sensor node in a WSN produces extremely large data which are repeated in nature and also the data are somehow related to each other. Machine learning techniques can be very beneficial in studying these complicated repeated data and making suitable decisions. Since WSN are mostly suitable in dangerous areas where people do not have easy access, machine learning can be helpful in such unpredictable environments. It can be used to restructure the sensor network automatically. Therefore machine learning techniques can be used to increase the performance of routing protocols in WSN.

The machine learning algorithms that are found to be used in surveyed papers are supervised, unsupervised and reinforcement based learning. It is seen that out of these algorithms, reinforcement learning algorithms are mostly used in Wireless Sensor Network [10] [26][27][29]. It is a technique in which an agent learns how to take the next action based on previous state to increase the total reward. This algorithm needs very less information about its environment and with this information it is able to adjust its routing behavior in the dynamically changing circumstances. Because of this feature, reinforcement learning is very much appropriate for WSN. Q-learning is one such algorithm which is very useful for routing in WSN [10]. Basic Q-learning, Shortest path Q-routing, Energy-aware Q-routing, Lowest Energy path feedback algorithms are few variations of Q-learning algorithm [26].

IV. CONCLUSION

We have studied few routing protocols that are energy efficient and have been designed for WSN and an observation has been made. Many protocols have argued that energy efficiency is key criteria to consider since energy is a very limited resource for sensor nodes. But very few have used machine learning for improvement. The reason may be the higher memory and processing requirement of machine learning techniques. Also a clear and specific finding on application of machine learning techniques in WSN and their actual requirements has not yet been recorded. Machine Learning techniques may be great enabler to improve the functioning of the routing protocols for WSN in terms of energy efficiency and that the overall life of the network can be extended. We strongly believed that above mentioned challenges of routing in WSN can be efficiently solved using machine learning techniques. Therefore these routing algorithms can be more efficient and smarter if machine learning techniques are used to design and implement them.

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