Survey on Network Lifetime Maximization Techniques in Wireless Sensor Network

Patil Savita Vijaysinh,Dr,R.K.Prasad

Abstract: Wireless Sensor Networks are increasingly seen as potential solution for wide range of problems. From industrial sensing to disaster recovery engineers are using or planning to use them in broad type of applications. However uncertain and erratic lifetime of these battery-powered networks is still major concern while designing efficient wireless sensor networks. MAC layer scheduling, topology control, energy efficient routing protocols, effective fault tolerance are some of the techniques used by researchers in extending network lifetime of wireless sensor networks. In this paper we review these existing techniques and how they have been used in maximization of network lifetime if wireless sensor networks.

Keywords: Energy Efficiency, MAC Layer, Topology Control.

I. INTRODUCTION

Wireless sensor networking is being applied to solve broad spectrum of problems from environment issues to medical systems. The large numbers of distributed nodes are used in these networks. These nodes have one or more sensors, embedded processors, low power radios and usually they are battery operated. These nodes form a wireless multi hop network and carry out various sensing tasks by using various protocols and algorithms.

However the real life solutions developed using wireless sensor network technology are far from being perfect and are currently grappling with major performance issues. One such major issue is lifetime of these networks. These networks usually are battery operated and hence have limited lifetime. This makes them unattractive for developing many real life solutions and applications. Moreover the charging and replacement of exhausted batteries is very hard and cumbersome in wireless sensor networks as compared to other wireless networks. Therefore developing technologies and algorithms that will solve the energy issues of WSN has been one of the important objectives of researchers.

In subsequent sections we discuss various techniques used by researchers for maximizing wireless sensor network lifetime. We also discuss the how the researchers have applied the technique to get desired output.

II. MAIN CAUSES OF ENERGY CONSUMPTION

The design of MAC protocols for WSNs is mainly impacted by a high energy constraint but also by a low complexity of the nodes, their low computational capabilities and low memory footprints as well as poor synchronization capabilities. A functional MAC for WSNs hence ought to be highly energy-efficient but also ensure high reliability, low access delay and throughput given above impairments. Throughout this paper, we focus on energy efficiency as the prime design driver whilst also describing its consequences on the other design drivers such as reliability, delay and throughput. Designing an energy-efficient MAC protocol requires a thorough understanding of the main causes of energy dissipation, only after which techniques can be found which alleviate their effects.

The following effects seriously impair the energy dissipation of each sensor node:

A. Collisions:

They may happen when a node is within the transmission range of two or more nodes that are simultaneously transmitting so that it does not capture any frame. The energy drained in the transmission and reception of collided frames is just wasted. Due to the large impact of collisions on protocols performance, MAC protocols should feature techniques to reduce or even avoid them.

B. Overhearing:

It happens when a node drains energy receiving irrelevant packets or signals. Irrelevant packets may be for example unicast packets destined to other nodes or redundant broadcast packets. Irrelevant signals include the preambles used in some low power MAC protocols to occupy the communication channel.

C. Overhead:

Protocol overhead may result in energy waste when transmitting and receiving control packets. For example, RTS and CTS control packets used in some protocols do not carry any useful data to applications although their transmission consumes energy. For example, the exchange of RTS/CTS induces high overheads in the range of 40% to 75% of the channel capacity, because data frames are very small in sensor networks.

D. Idle Listening.

It happens when a node does not know when it will be the receiver of a frame, which is generally the situation. In this case, the node keeps its radio on while listening to the channel waiting for potential data frames. The amount of energy wasted whilst the radio is on is considerable even when it is neither receiving nor transmitting frames.

III. TECHNIQUES RELATED WITH MAC LAYER AND SCHEDULING

A sensor node in wireless sensor networks (WSNs) gathers data and forward to sink for further processing. There is a need for designing proper energy efficient communication protocols to increase the lifetime of the network. A key challenging problem in WSNs is to schedule nodes' activities to reduce energy consumption. In paper [1], Yanwei Wu et. al designed TDMA based MAC layer protocol. In this protocol time slots were used for various sensor nodes to schedule their operations. These time slots were used for various radio activities that sensor nodes carry out. However TDMA based scheme may result in inefficient allocation of time slots with possibility of idle time slots where no station sends any data.

In [2] Shibo He et. al. design the distributed MAC layer protocol that schedules the wireless sensor stations. Authors argue the there is strong correlation between MAC layer and routing layer and thus to improve the MAC layer based scheduling it is necessary to consider various routing parameters. They design the protocol using routing, power control, and link-layer random access parameters. They develop a probabilistic mathematical model to improve the MAC layer scheduling by obtaining optimal solution.

Alma et. al. [3] propose a wake up scheduling based scheme for wireless body area sensor networks. Usually in MAC layer based scheduling wireless sensors stations keep doing sensing activity even during idle slots .In this paper based on human body data, various traffic patterns are identified and sensors are scheduled according to various traffic conditions. This scheme effectively utilizes time slots by considering variable traffic conditions but is not applicable for broad spectrum of WSN applications as time intervals identified for wakeup scheduling are only for body area wireless sensor networks.

In [4] Sung-Hwa Hong et.al. propose the Express-MAC protocol (EX-MAC) Which assures end to end latency and at the same time energy efficiency. In WSN applications duty cycling is widely used technique to achieve energy efficiency but this duty cycling may result into latency. Researchers also have to find tradeoff between latency and energy efficiency as it difficult to achieve both objectives at same time. In this paper authors propose a MAC layer based wakeup scheduling scheme which minimizes energy wastage and also assures minimum latency.

In paper Ehsan, S et. al. [5] develop a scheme for energy efficient WSN using cross layer strategy of MAC layer and routing. Authors first identify three MAC layer constraints, which can be correlated with efficient data rate during routing. They develop routing optimization scheme using these MAC layer constraints. These MAC aware routing scheme not only gives energy efficiency but also maximum data rate.

In wireless sensor networks network design parameters usually change with change in application scenarios. . In paper [6] Di Francesco, M et. al. Propose a scheme in which they develop a protocol that assess network's reliability requirements and configures the network's MAC layer according to these reliability requirements. The MAC layer is used for scheduling the stations to achieve energy efficiency. The reliability requirements obtained are used to make network reliable. This paper thus achieves both reliability as well as network lifetime maximization.

In [7] Akhlaq, M et.al. Propose a Recursive Time Synchronization Protocol (RTSP) which accurately synchronizes all the nodes in a network to a global clock. In wireless sensor networks synchronization of nodes is necessary for efficient coordination among nodes. It also improves the data consistency among nodes. However current attempts of node synchronization are not energy efficient. In this paper authors use time stamping based Start of Frame Delimiter byte in MAC layer which helps node in interpreting frame in better way as well as time synchronization. Moreover they select reference nodes who infrequently broadcast these data frame and timestamps are adjusted after every hop. Thus this scheme achieves energy efficiency using modification at MAC layer strategy.

In paper [8] Otal, B et. al. propose a WSN MAC layer based scheduling schemed specifically aimed at healthcare applications in wireless body area networks. In such networks maintaining reliability and message latency at required level is of paramount importance. Therefore achieving network lifetime maximization by considering latency and reliability is tedious task. In this paper authors design a MAC layer scheme that uses fuzzy logic for efficient energy aware radio activation policies. In this scheme various cross layer inputs are taken in to consideration and various radio based activities are scheduled as per the policy which has different scheduling strategy for different cross layer input variables.

In the paper, Liqi Shi [9] et. al. Propose a solution to the scheduling problem in clustered wireless sensor networks (WSNs). To design a scheduling strategy for clustered WSNs they build an optimization mathematical model. To build this model they consider cross layer design of WSN and identify design parameters and constraint variables for formulating an optimization problem. They solve this problem by transforming the model into two simpler sub problems. They use this model to obtain network wide flow distribution. By using this information they design a new algorithm for TDMA based scheduling in MAC layer.

IV. TECHNIQUES RELATED WITH ENERGY EFFICIENT ROUTING

Since energy efficiency is more important for wireless sensor networks than any other networks, more research works have already been done in routing in WSN. In general, data transmission in wireless communication takes more power than data processing. When the nodes are transmitting more number of data, proportionally their battery power also gets depleted. To reduce the data size we can go for data fusion or data aggregation techniques. Data fusion is process in which

the sensed data from different nodes are fused at certain point suitable for the transmission in its reduced size.
Even in the data aggregation concept there are two types of aggregation. The first approach of data aggregation fuses the data gathered from different sources and sends the final fused data in reduced size.
The problem in this approach is in accuracy and precision of data from various sensor nodes. The next approach combines the data from different sources under the single header and forwards it to the base station. Here header packets consolidates and pass it to the base station without any modification to the original data from the sensors that improves accuracy .
Energy is an extremely critical resource for battery-powered wireless sensor networks (WSN), thus it is key challenging problem to design energy-efficient protocol. Most of the existing energy-efficient routing protocols always forward packets along the minimum energy path to the sink to merely minimize energy consumption that causes an unbalanced distribution of residual energy among sensor nodes, and eventually results in a partition of network.

In the paper [10] Fengyuan Ren et. al. Use the concept of potential in physics to design an energy efficient routing protocol in WSN. They use virtual potential field in terms of depth, energy density, and residual energy and residual energy and develop a scheme that forces packets towards sink through the dense energy area. This helps in conservation of energy of low residual energy nodes.

Geographic routing is gaining acceptance among researchers because it can be scaled over large number of nodes very easily. However for successful geographic routing nodes must maintain neighborhood information which is very difficult wireless sensor networks. In WSN network keep changing topology hence designing WSN with geographic routing is a challenge. In paper [11] Haibo Zhang et. al. Propose a novel online geographical routing scheme which is energy efficient. They use energy-optimal forwarding distance and every node obtains its next hop relay position on the straight line towards the sink. Each forwarder selects the neighbor that is closest to its ideal next-hop relay position as the next-hop relay and thus routing is done. They then establish an upper bound on hop count and upper bound on energy consumption. Thus they design energy efficient routing scheme.

In the paper [12] Junyoung Heo et. al., propose a novel energy efficient routing scheme for industrial wireless sensor networks. Industrial WSNs usually have network design requirements such as reliability, redundancy along with energy efficiency. To achieve these objectives in this scheme they develop a model in which every node by using its local information estimates it's the energy cost, delay and reliability of a path to the sink node. Based on this estimation most energy efficient path is selected.

In [13] Huang, H et. al. presents an energy-aware interference-sensitive geographic routing (EIGR) protocol. As we have already seen geographic routing protocols are widely popular because of their scalability. However in their scheme authors have tried to design energy efficient geographic routing scheme. In this scheme energy optimal relay regions are created and each forwarding node adjusts transmission power while reaching to next node.

Use of non-conventional energy source is becoming popular in wireless sensor networks. These non-conventional energy sources are better than traditional battery powered sources but their use in WSN is challenge. In this study, [14] Wu, Y et. al. Propose a centralized power efficient routing algorithm that effectively uses these types of nodes. In this scheme they create clusters of unequal sizes. Cluster heads are then selected from these clusters and energy efficient routing is then established among these cluster heads.

In the paper [15] Kai Lin et. al. propose a cluster based scheme for efficient energy optimization in wireless sensor networks. In this scheme authors design the cluster based WSN taking inspiration from cellular technology and using this structure movement energy efficiency is achieved. This scheme can also be used for multimedia data acquisition and processing.

In many wireless sensor networks, nodes sense distributed data and in such application accurate signal detection is very important. However accurate signal detection and energy efficient routing at same time has been challenge. In their paper Yang [16] et. al. propose a scheme which considers both objectives jointly and develops a mathematical model by formulating combinatorial optimization problem. In this problem routes are considered as a function of the geographic location to be monitored. They develop three route metrics to obtain appropriate trade off between signal detection performance and energy spent on monitoring.

V. TECHNIQUES RELATED WITH TOPOLOGY CONTROL

Topology control is a technique used in wireless sensor networking to alter the underlying network (modeled as a graph) in order to reduce the cost of distributed algorithms if ran over the new resulting graphs. Topology control is a basic technique in distributed algorithm. For instance, a (minimum) spanning tree is used as a backbone to reduce the cost of broadcast from O(m) to O(n), where m and n are the number of edges and vertices in the graph respectively.
The main aim of techniques in this domain is to save energy, reduce interference between nodes and extend lifetime of the network.

Topology control plays an important role in the design of wireless ad hoc and sensor networks; it is capable of constructing networks that have desirable characteristics such as sparser connectivity, lower transmission power, and a smaller node degree.

In paper [17] Chiwewe, T.M et. al. a new distributed topology control technique is presented. In this paper every nodes makes local decision about its transmission power and then topology control is done by using Smart Boundary Yao Gabriel Graph (SBYaoGG).This topology control results into new network topology that preserves global connectivity.

Thus energy efficiency achieved along with reduction of interference.

Adaptive cluster based topologies are being used in wireless sensor networks. In [18] Dahnil, D.P et. al. , present a scheme that uses adaptive cluster based topologies to increase the network lifetime. In this paper the clustered approach is maintains the network connectivity and keeps the node degree optimum. These results into energy conservation and increase in network lifetime.

In [19] Sardellitti, S et. al. present a method to optimize the network topology and the power allocation over each active link in order to minimize the energy consumption during consensus algorithms. These consensus algorithms are increasingly being used for obtaining local information but these algorithms generate huge energy wastage before reaching the consensus. In this paper authors first consider nodes are located arbitrarily but their positions are known and develop topology combinatorial optimization problem and convert into parametric convex problem and then solve with effective algorithms. Then they model network topology as a random geometric graph and optimize the power transmitted by each node, exploiting the asymptotic distributions of the eigenvalues of the adjacency matrix of an RGG

VI. CONCLUSION

From survey of various techniques used it is very clear that all the techniques are contributing towards network lifetime maximization. Hence for developing real life applications that have maximum network lifetime researchers and engineers should pay attention to all these techniques and should develop new algorithms which will solve current issues in these techniques.

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Savita Vijaysinh Patil , Ph.D. Scholar, Bharati Vidyapeeeth Deemeed University, Pune Asst.Professsor in Electronics and Telecommunication Dept.Bharati Vidyapeeth College of Engineering ,Navi Mumbai.

Dr R.K.Prasad
EX-Professor Bharari Vidyapeeth Deemed University College of Engineering , Pune