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VBS: A Technique to Improve Lifetime of Wireless Sensor Networks

Prashanth Kumar[1], Vidya[2]

M.Tech scholar, Department of Computer Science, Alva's Institute of Engineering and Technology, Moodbidri, Karnataka, India[1]

Assistant Professor, Department of Computer Science, Alva's Institute of Engineering and Technology, Moodbidri, Karnataka, India[2]

Abstract: Wireless Sensor Networks (WSNs) are important in almost all applications which provide longer and low-cost supervising and motivating. In WSN applications, batteries are the main source of energy for sensor nodes where saving energy becomes more tedious. Today, almost every applications of WSN require sensor nodes which are unused to achieve fault tolerance and Quality of Service (QoS) during sensing. Similarly, the same unused nodes may not be necessary for multiple node communication because of the fewer loads in the traffic and the firm wireless links. This thesis presents a novel sleep-scheduling technique called Virtual Backbone Scheduling (VBS). VBS designed for WSNs consists of sensor nodes which are redundant. VBS forms multiple overlapped backbones which work alternatively to prolong the lifetime of the network. Here backbone sensor nodes only forwards the traffic, while rest of the sensor nodes turns off its radios to save energy. The alternative working of multiple backbones ensures that the entire network energy is distributed among all sensor nodes is balanced and thus a longer network lifetime can obtained against the existing techniques. Maximum Lifetime Backbone Scheduling (MLBS) is formulated as the scheduling problem of VBS. Approximation algorithms based on the Schedule Transition Graph (STG) and Virtual Scheduling Graph (VSG) is proposed. Theoretical analysis and simulation studies verify that VBS is superior to the existing techniques.

Keywords: Sensor nodes, WSN, VSB, STG, VSG.

I. INTRODUCTION

Wireless Sensor Networks (WSNs), have been dominant in the field of networks from past few years and it is an important technology for several applications involving long-term and low-cost monitoring, such as battlefield reconnaissance, building inspection, security surveillance, etc. In WSNs, battery is the single energy source of the sensor node. Sensor nodes works on batteries for several months to a few years without replenish. Hence, energy efficiency is bit tedious in WSNs.

In WSNs, the radios of sensor nodes consume much of the energy. Hence several techniques were been proposed to minimize the energy consumption. In this paper, focus is on Backbone Scheduling (BS), that automatically turns off the radio of the sensor nodes that are not required, to save energy.

It allows only a fraction of some of the sensor nodes in the WSN network to turn on their radio to forward messages, that creates a backbone. Since WSNs support redundancy, the communication quality is not affected. It is also ensured that the redundancy has no impact on the connectivity of the network.

This feature of redundancy creates more necessary wireless links, which makes creation of communication backbones easier to save energy. Connected Dominating Set (CDS) algorithms are used to create the backbones.

II. LITERATURE SURVEY

W.Ye[4] presented a Sensor MAC , explicitly for WSN. In this paper the main concern was towards reducing the energy that was consumed by nodes. To reduce energy consumption different techniques were introduced in this paper. These techniques were followed in S-MAC.Firstly a technique called virtual clusters was introduced which auto-synchronizes on sleep schedule. The second technique called channel signaling tries to make the nodes sleep when other nodes is transmitting. The third technique called message passing mainly tries to reduce the latency that may occur in the nodes that uses the concept of store and forward during the transmission.

Medium access control (MAC) is an important technique that enables the successful operation of the network. One fundamental task of the MAC protocol is to avoid collisions to ensure that two nodes do not transmit at the same time. Typical examples for wireless voice and data communication networks include the time division multiple access (TDMA), code division multiple access (CDMA), and contention-based protocols like IEEE 802.11.

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The following attributes are considered during the design of a good MAC protocols. Firstly the energy efficiency. sensor nodes are to be battery powered, and it is very difficult to change or recharge batteries for these nodes. Prolonging network lifetime of a node is a critical issue. Scalability is another attribute that identifies how the nodes respond to the change in network size, node density and topology. A node may die after sometime or may be added late or may join some other network. A good MAC proto col should support all network changes. Some other attributes include fairness, latency, throughput and bandwidth utilization which are primary concerns in traditional wireless voice and secondary in sensor networks.

This paper mainly presented a sensor-MAC (S-MAC), a new MAC protocol explicitly designed for wireless sensor networks. Reducing energy consumption is the primary goal and the protocol has good scalability and collision avoidance capability and it can be achieved by the usage of a combined scheduling and contention scheme.

To achieve the primary goal of energy efficiency, we need to identify the main sources that cause inefficient use of energy. First is the collision which indicates that during a transmitted packet corruption, the packet will be resent which increases energy usage as well as latency. Secondly, overhearing, where a node picks up packets meant for other nodes. Thirdly, control packet overhead, where sending and receiving of control packets utilizes more energy than the transmission of data packets. Finally, inefficiency meaning idle listening, where nodes try to listen to packets that are yet to be sent.

The Limitations of this paper was that the latency was increased. Whenever numerous numbers of frames were to be sent, it requires more time. It also resulted in high cost of retransmission.

Y. Li[6] proposed 2 protocols to conserve energy in sensor networks. Sleep and wake-up MAC protocol which establishes and maintains a schedule about every nodes listening to data and its sleep time. These protocols maintained network connectivity by detecting and tracking the neighbors operating on different schedules .Here nodes that share same schedule is called virtual Nodes sharing same schedule is called virtual cluster and the nodes that have neighbors in two clusters is called border nodes. The author proposed 2 different algorithms that reduce energy consumption and latency. They are Global Schedule Algorithm (GSA) and Fast Path Algorithm (FPA). GSA converges all nodes on a single schedule whereas FPA tries to eliminate the latency that may be caused in a multi-hop network.

Wireless sensor networks use many small, wireless sensors to sense the environment. Wireless sensors are battery operated with many nodes placed in target environment and changing battery is impossible or bit difficult. The radio consumes more energy and only way to minimize energy is to keep the radio off for longer durations. Multiple schedules may occur in large networks inspite of protocols being designed to promote single schedule. Sometimes when node fails to hear an existing schedule at beginning it creates a new schedule which generate different schedules. If nodes are moving, they can easily move between different parts of the network with different schedules. The border nodes will exhaust their batteries more rapidly than other nodes, by listening to traffic constantly resulting in network partition.

Two optimizations proposed to reduce this cost. Firstly, Adaptive listen in S-MAC uses the RTS-CTS mechanism to wake up neighbors. Secondly, T-MAC uses a future request-to- send scheme lets a node on third hop to know it has a message by sending a future-request-to-send (FRTS) packet, reducing the sleep delay.

The GSA algorithm converges all the nodes on a single schedule. It uses 3 components to converge. Firstly, It uniquely identifies ID present on each schedule. A problem exists here. Whenever a system or node is rebooted it starts with same ID. This creates a complexity in the network that might lead to a confusion of which is actually the right node. An solution to this problem is to assign with a new ID each time a node is rebooted. Secondly, the way to propagate new schedule to other nodes. Whenever a new schedule is created, the time of the schedule is recorded and this schedule which is newly generated is to be advertised to all other nodes. This new schedule has to be updated at every node .If this schedule is same as already existing one then the lower schedule wins the race. In case if it is different from already existing schedule then the nodes must switch to new schedule. Finally the way to discover new schedules must be considered.

The FPA algorithm manages schedule in a multi-hop path, which avoids a schedule miss and adds additional wake-up periods called fast path schedules. Firstly it determines the path and establishes fast path in it. Next it determines how the established fast paths interact to standard schedules, adaptive listen and future request to send. At the beginning single sink establishes fast path from all nodes and at this moment it generates a fast path request to source node. Once the request is received at source it begins generating fast path. The major disadvantage of this paper is that there is no standard mechanism that could help removing tis fast path established.

The drawbacks of this paper were the border nodes consumed huge amount of energy by listening or sending data. It also increased latency in multi-hop network.

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R.Cohen[8] presented an algorithm for maximizing the lifetime of sensor network. It also proposed a sensor wake up frequency depending on the sensors location in routing path. The information gathered by sensors are delivered to centralized node called gateway which is assumed to have highest processing capability than the sensor nodes. Sensors turn on and off their communication hardware to minimize energy consumption. Two neighbor sensor nodes can communicate only if they are in active mode.

Two synchronization models implemented namely Global synchronization and local synchronization. In global synchronization all the sensors must wake up at same time. Data must be transmitted rapidly between two nodes even if not in range. In large mesh network global synchronization is difficult to achieve and is inefficient. In local synchronization each node selects only its active duty cycle. It is necessary to inform neighbor nodes about the selection.

The rest of the nodes should wake up its neighboring nodes. A node wishing to send a data must wake up its neighbor during its duty cycle. This communication model imposes a clear trade-off between the delay encountered by a packet and the time during which the sensor along the route are in active mode. Solution to this trade-off period includes the following aspects.

- The data delivery model.
- The expected amount of data to be delivered.
- The routing scheme.
- Processing of packets by intermediate nodes.

The major drawback in this paper was it failed to find the frequency associated to each node and its upper bound values.

III. EXISTING SYSTEM

It is a single backbone system that does not improve the network lifetime. An alternative idea is to construct multiple disjointed CDSs and let them function alternatively and is termed as Connected Domatic Partition (CDP) problem. Figure below shows an example of two disjoint backbones.

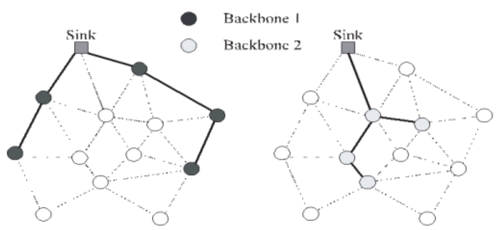

Figure 1: Example of rotating two disjoint backbones in a (duty-cycled) WSN.

IV. PROPOSED SYSTEM

Virtual Backbone Scheduling (VBS), a novel algorithm that enables fine-grained sleep scheduling is been proposed. VBS creates multiple overlapped backbones such that the energy is equally utilized between all sensor nodes.

Thus, the energy of all sensor nodes present in the network is fully used, which improves the lifetime of the network. An example of this is illustrated in below.

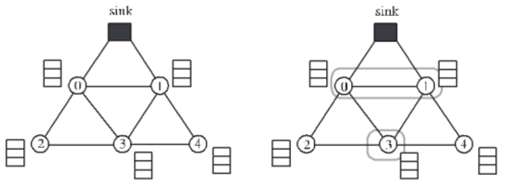

Figure 2: Network of five nodes for VBS Technique

The figure above depicts a network of five sensor nodes and one sink. The stack represents the initial energy of each node. Suppose if all sensor nodes consume 1 unit of energy per unit time, then each sensor node has the capability to work continuously for 3 unit time. Since only one disjointed CDS, which is sink; 0;1, sink; 0;3, or sink; 1; 3, can be constructed, the lifetime of network is extended to 3 units of time. On the other hand, VBS schedules sink; 0; 1 to work for 1, sink; 0; 3 for 1, and sink; 1; 3 to work for 2 units of time, which improves the lifetime of network by 4 units of time. These are overlapping backbones. The example indicates that scheduling on a finer granularity can overcome the redundancy present in the network and hence achieve a longer lifetime for the network than the CDP-based approach.

V. ALGORITHMS

A Scheduling Transition Graph-based Approximation Algorithm.

The first centralized approximation algorithm is based on a new concept called Schedule Transition Graph (STG). A STG is used to model a schedule in a WSN. Figure below gives an example.

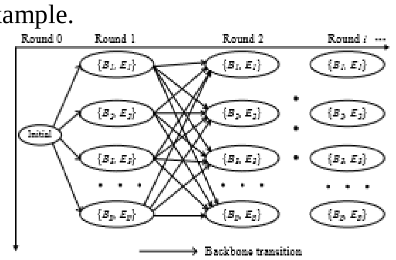

Figure 3 : Schedule Transition Graph (STG) Illustration

As shown in the figure, the horizontal axis represents the time scale, counted in rounds. In each round, possible states are listed vertically, which are represented by ellipses. The number of possible states for each round is equal to the number of backbones. Each state contains a backbone and the corresponding energy levels. The state and the backbone have a one-to-one mapping. An initial state is placed at round 0 and is connected with all states in

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the first round to represent a starting point. Unidirected transition edges connect states in one round to those in the next round. No backwards edges is allowed.

Each edge represents the time elapse of one round. Since energy is used in each round, each edge also represents the consumption of energy. The residual energy of all nodes is obtained by subtracting the energy level after a transition from the starting state of each transition edge. No transition is allowed if the energy of any sensor node of a state is depleted. It is clear that a directed path from the initial state corresponds to a schedule. Thus, the MLBS problem is to find the longest path in the STG.

Algorithm 1: STG based Algorithm
1: int CURR ROUND 0;
2: repeat
3: for each state S do
4: Get associated energy levels of S;
5: Prune the resultant energy levels using the $min()$ function; 6: Select the energy level with the maximal minimum energy value.
7: Set S's energy level the energy level with the maximum summation among the resultant energy levels;
8: end for
9: CURR ROUND = CURR ROUND +1;
10: until all the energy levels of the states in CURR ROUND are zero;
11: Return the schedule represented by the path ending in CURR ROUND

B. Virtual Scheduling Graph-based Approximation Algorithm
In STG, the energy and structure of the WSN are modeled separately. Virtual Scheduling Graph (VSG) can model the energy and structure together, which facilitates an elegant greedy algorithm. In a VSG, a sensor node in the original network graph is converted into multiple virtual nodes which are connected in such a way that their degrees represent the energy of the corresponding sensor node. A schedule can be obtained by applying any CDS construction algorithm on the VSG.

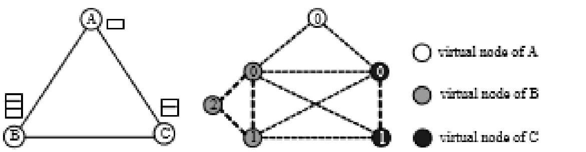

Figure 4 : Virtual Scheduling Graph (VSG) Illustration

In a VSG every sensor node consumes a fixed amount of energy, in each round while functioning as a backbone node. Virtual node is defined as a node that corresponds to a sensor node that consists some energy. The parent node is called the ancestor. An ancestor is divided into virtual nodes. The virtual nodes of the same ancestor form a virtual group. Two virtual groups are neighbors if their ancestors are neighbors in the original graph. A virtual node is isolated if it does not connect with any virtual node of other virtual groups.

Algorithm 2: VSG-based algorithm
1: S {};
2: Construct the VSG $Gs(V',E')$ of $G(V,E)$;
3: repeat
4: Apply the marking process on $Gs(V',E')$;
5: Apply Rules 1&2 or Rule K on the induced graph;
6: Construct the PMCDS C' from the resultant CDS C;
7: Remove the highest indexed virtual nodes of the ancestors whose virtual nodes is in C' from $Gs(V',E')$;
8: Find the corresponding CDS Ci of C' in G;
9: S $S \cup \{\langle Ci,Ti \rangle\}$;
10: until Any ancestor's virtual nodes are all eliminated from $Gs(V',E')$;
11: return S.

C. Iterative Local Replacement Algorithm
A distributed implementation of VBS is called Iterative Local Replacement(ILR). In an ILR, every backbone sensor node finds its replacement node to form a new CDS which helps in maintaining the connectivity of the network. Two issues must be considered in the design:

Execution time: In each round, a backbone node that decides to switch its status collects or updates the information of its neighbors to find replacement nodes. The time used to perform these operations should be minimized. Quality of the results: Generally, more information yields better results, thereby achieving a longer lifetime.

These two issues are contradictory. Various algorithms are available and must be investigated carefully to choose the most appropriate one. Two general optimizations are applied. Firstly, Updated information of topology is not required since sensor nodes are static. Secondly, Working status of sensor nodes is used to estimate the energy consumed by the nodes and also eliminates the usage of message exchanging technique of ILR. When all the nodes present in the backbone start the replacement concurrently, many sensor nodes may compete for the shared channel, resulting in packet collision and loss. This may result in increased execution time and heavy energy consumption. Hence a control-based scheme is introduced in this which ensures that the sensor nodes do not perform node replacement concurrently. A switching probability is assigned to each backbone node. At the end of each round, backbone nodes switch statuses according to the probability assigned. This probability is related to the residual energy of the backbone node and its neighbors. Backbone nodes with lower energy supplies are more "eager" to switch statuses, which helps in balancing the energy consumption of sensor nodes. There is a threshold to stop the replacement when the residual energy is low;

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replacement becomes too expensive when there is not much energy left in the sensor nodes. The larger the efficiency is, better results can be obtained. The switching probability will be set to zero when the residual energy of the backbone node is greater than the mean of its neighbors. The pseudocode is listed in Algorithm. 3. ILR. A backbone node that decides to switch broadcasts a message to "hold" h-hop neighbors, which keeps them awake for a longer time in order to complete the replacement. It then notifies its replacement nodes after the calculation is completed.

The backbone node uses distributed algorithms, Rules 1&2 or Rule K, to find its replacement sensor nodes. The replacement sensor nodes found by the backbone node will be notified and will start working as backbone nodes in the next round**.**

Algorithm 3: ILR based Algorithm
1: loop
2: At the beginning of each round;
3: Sensor node N computes the switching probability $Pswitch$ using Eq. 2;
4: if Decide to switch then
5: Collect or update the h-hop information of N;
6: Apply the marking process on the subgraph;
7: Apply Rules 1&2 or Rule K on the induced graph using the residual energy as the priority;
8: R The IDs of sensor nodes have more residual energy and can form a new CDS by replacing N;
9: Notify each sensor node $N' \in R$;
10: end if
11: end loop

VI. SYSTEM DESIGN

System Design is a process of defining the architecture, component, modules, interfaces and data for a system to satisfy the specified requirement. Unified Modeling Language(UML) is used for modeling system specifications.

A. *Use Case Diagram*

Use case diagrams are a set of use cases, actors and their relationships. They represent the use case view of a system. A use case represents a particular functionality of a system. In the use case diagram there are 3 actors namely Admin, Sink and Source .

The user tries to register by entering the IP address. Sink executes STG, VSG algorithms for calculating the backbone and later on the calculated backbone information is been broadcasted to the network.

After the backbone information is been broadcasted, sink changes from sending mode to receiving mode and starts receiving the information from selected backbone through selected Port ID. The received data is displayed at the sink terminal.

As the sink broadcast the backbone information, it is received by the sensor nodes. According to the information sent by the sink node the duty cycling of backbone nodes will start. The collected information is sent back to the sink, from the respective backbone. The sensor switches according to time scheduling.

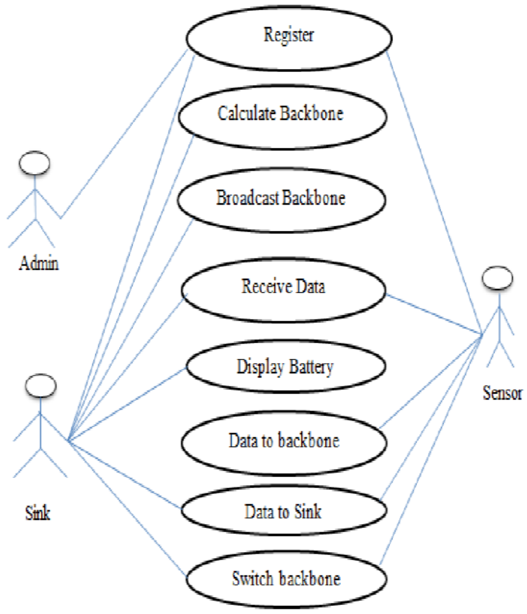

Figure 5: Use Case Diagram

B. *Data Flow diagram*

A DFD is often used as a preliminary step to create an overview of the system, which can later be elaborated.

1. Level 0 Data Flow Diagram

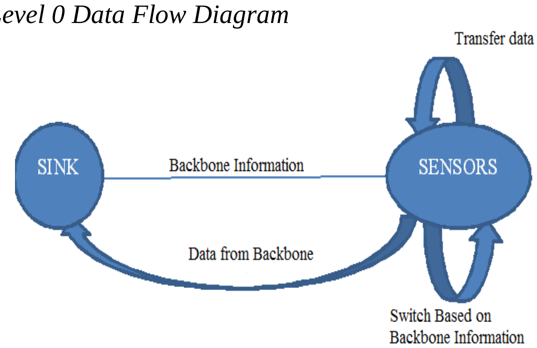

Figure 6: Level 0 Data flow diagram

2. Level 1 Data Flow Diagram

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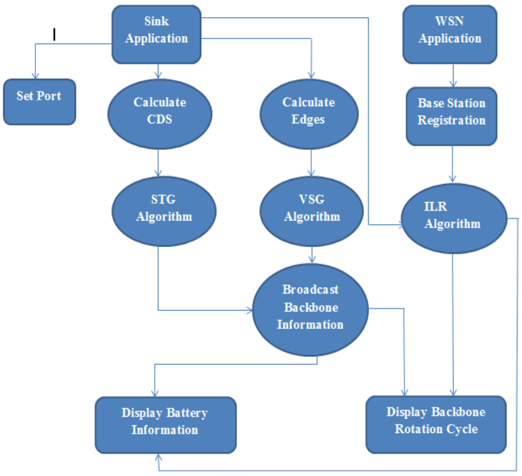

Figure 7: Level 1 DFD

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