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ENERGY SAVING THROUGH TOPOLOGY CONTROLLED PROTOCOLS IN WSN

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Abstract-In Wireless sensor networks, various energy saving techniques have been proposed and implemented to improve the effective lifetime of the network. Connectivity and coverage of a wireless network must be maintained for the longevity of sensor network along with the energy conservation. In this paper, we will present the concept of energy saving through topology control protocols while providing complete connectivity and coverage. We will go through some topology control protocols like GAF, PEAS and their improvement to analyze how the improved protocol will increase effective lifetime of the wireless network.

Keywords: wireless sensor network, energy saving, connectivity, coverage, effective lifetime.

INTRODUCTION

Wireless sensor networks consist of self-organizing, densely deployed sensor nodes used for various applications like space exploration, disaster relief and agriculture and military etc. It consists of large number of sensor nodes deployed over distant regions to monitor or track unusual events. The focus of research in this field is energy conservation as the energy provided by batteries of sensor nodes is limited and get exhausted very soon. Moreover, batteries of nodes are difficult to replace as they are deployed in sparse areas. The most efficient energy saving technique is duty cycling. Energy is consumed not only in transmitting and receiving but in also in idle state. Duty cycling involves keeping the radio transceiver of sensor nodes in low power sleep mode whenever communication is not required. The node can switch in to active state whenever communication resumes. This leads to significant energy saving in wireless sensor protocols. In topology control protocols, the basic idea is to exploit node redundancy generally found in sensor networks to increase their network lifetime. When there is significant node redundancy, multiple paths exists between nodes, so some intermediate nodes can be turned off .In these protocols, an optimal subset of in a network can be selected and activated to maintain network connectivity, keeping others in Sleep mode. The active nodes also switch between sleep and wake up states to save energy. Topology control protocols are further classified as location driven and connectivity driven. In location driven protocols, location of the nodes is known through some localization technique to decide which node to turn on and when. Unnecessary nodes not required are turned off to conserve energy. In connectivity driven protocols, nodes are dynamically activated and deactivated so that the complete connectivity and sensing coverage is maintained.

COVERAGE AND CONNECTIVITY

Network connectivity and coverage is quite important in wireless sensor network for longevity and can be defined as:

Coverage: In WSN context, it means sensing coverage and communication average. In radio communication, the communication coverage is generally much larger than sensing coverage. Dense coverage by a sensor network means the entire space that can be monitored by the sensor nodes. If a sensor node becomes dysfunctional due to energy depletion, there is a certain amount of that space that can no longer be monitored creating coverage holes. The coverage is defined as the ratio of the monitored space to the entire space.

Connectivity: For multi hop WSNs, it is possible that the network becomes disjointed because some nodes become dysfunctional or energy depleted. The connectivity metric can be used to evaluate how well the network is connected and/or how many nodes have been isolated. A node is an isolated node if the distance between this node and its nearest neighbor is greater than transmission range Rt.

Node scheduling should be aimed to provide complete connectivity and coverage extending the lifetime of the network. Schedulable node set should not contain cut points which are important for network connectivity. It means cut points must always be working and scheduling should focus only on those nodes which could be turned off without negative effects on coverage and connectivity of wireless sensor networks. In ASCENT [2], the nodes assess their connectivity and packet loss through local measurements and make decision of joining the network only if it is beneficial otherwise enter in to sleep state saving energy. The nodes adaptively configure their topology to give complete coverage under stringent energy criteria. SPAN [4] is another connectivity protocol which ensures that enough nodes should stay awake to form a connected backbone in data forwarding topology. It dynamically elects coordinators based on neighbor and connectivity information achieved from a routing protocol. These coordinators stay awake to perform multi-hop routing while others sleep to save energy. These non coordinators periodically check if they should wake up to become a coordinator. In VBS [1], backbone network is created to maintain connectivity. It also uses heterogeneous scheduling in which non backbone sensor nodes keep their radio off to save energy. A. Mutazono et al. proposed a self organized scheduling inspired from calling behavior of Japanese tree frogs which provides energy efficient data transmission [9]. Geometric based activity scheduling scheme (GAS) was proposed to increase network lifetime and target area coverage by San-Yuan Wang et al. [10]. In GAF [3] and PEAS [5] promise network connectivity and coverage based on grid partition while giving significant energy saving.

PROTOCOLS OVERVIEW

A. GAF

Geographical Adaptive Fidelity (GAF) protocol is a location driven protocol in which sensing area is divided in to virtual grids [3]. In Each virtual grid, all nodes are equivalent for routing so, a single node need to remain active as a router at a given time.GAF identifies this node and turn off unnecessary nodes, keeping a constant level of routing fidelity. Node equivalence can be found by location information provided by location finding technique like Global position system (GPS).

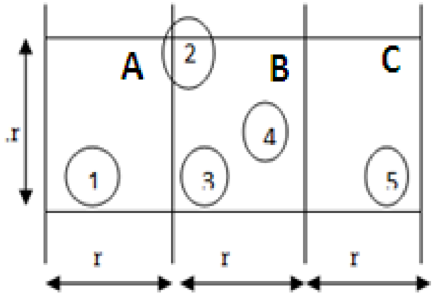

Fig. 1. Virtual Grid in GAF

According to virtual grid definition, any node in adjacent grids can communicate with each other. As shown in figure 1, all nodes in grid A can communicate with any node in adjacent grid B and vice-versa.so, node 1 in grid A can communicate with any of node 2, 3 and 4 in grid B and all nodes in grid B can communicate with node 5 in adjacent grid C. This means node 2, 3 and 4 are equivalent and any two of them can sleep. Moreover , distance between two possible farthest nodes in any two adjacent grids, such as distance between node 2 of grid B and node 5 of grid C must not be larger than R [3].

$$r^2 + (2r)^2 \leq R^2 \qquad (1)$$

or

$$r \leq R / \sqrt{5} \qquad (2)$$

So, size of the grid is based on nominal radio range R such that $r \leq R\backslash \sqrt{5}$ if two adjacent grids want to communicate, where each square grid is of size $r \times r$.

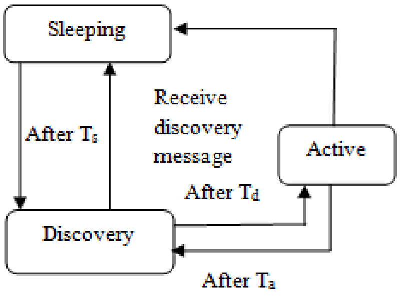

Fig. 2. State Transition diagram in GAF

The node could be in any of three states: Sleeping, Discovery and Active. Initially, nodes are in discovery state and try to find the other nodes in the same grid. After random time T_d which discovery message interval, node enters in to Active state for time Ta (active duration). The estimated node active time is taken less than expected lifetime to employ load balancing strategy. After this time, node goes back to discovery state to give the other nodes of same grid an opportunity to enter in active state and hence balance the load among all nodes. Also, a node in discovery or active state can change state to sleeping when it finds any other equivalent node to handle the routing and saves energy. So, GAF uses load Balancing strategy so that all nodes remain live together as long as possible. Node Ranking is done on various criterions like state based and expected lifetime based. For example, a node in active state is given higher rank than a node in discovery state and if the nodes are in same active states, then a node with longer expected lifetime is given is given preference to be used first. Other nodes use estimated node active time to determine their sleeping period which is generally less then time taken to use up all remaining energy.

Simulation shows that it consumes 40% to 60% less energy than an unmodified ad-hoc routing protocol and allow network lifetime to increase in proportion to node density. It was shown that GAF has longer lifetime than AODV. In AODV, all nodes die at about 450 s of simulation time but in GAF, Even after 900s of simulation time,30% to 40% nodes remain alive depending upon mobility pattern.

B. PEAS

PEAS stands for Probing Environment and Adaptive Sleeping. It is a simple and robust energy conserving protocol that maintains long lived sensor networks. It is simple in the sense that the sensor nodes neither maintain per state node information like AFECA nor needs it to estimate the individual node's lifetime as in GAF. Instead, it probes the region surrounding itself decide when to sleep. In PEAS, a sufficiently large network is divided in to square cells ls, each of size c×c and $c=R_P$ where R_P is the required minimum distance between two working nodes. The protocol guarantees connectivity when the maximum transmitting range (R_T) is:

$$R_T \geq (1+\sqrt{5})\, R_P \qquad (3)$$

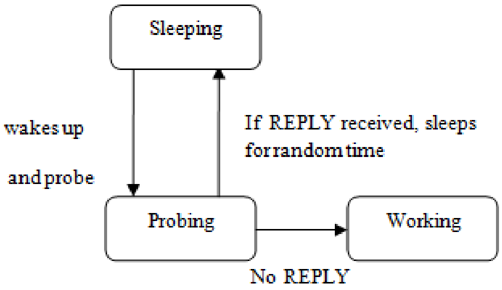

Fig. 3. State Transition diagram in PEAS

PEAS works in three modes: Sleeping, Probing and Working. Initially, Each nodes is assumed to be in the sleeping mode for the duration generated through a probability density function $f(ts) = \lambda e^{-\lambda ts}$, where λ is the probing rate of the node and ts is the sleeping time duration. When the node wakes up, it enters probing mode. In this mode, probe message is sent in probing range Rp to check whether any working node present in neighborhood. The present working nodes responds to probing node through REPLY message. After receiving REPLY message, these probing nodes return back to sleep mode for another random sleep time. If no REPLY message is received, the probing nodes enter in to working mode and works till it dies. The protocol is robust in the sense it performs well in harsh environments where nodes can fail unexpectedly, which makes this protocol different from various existing protocols like GAF, SPAN and ASCENT. Data delivery lifetime, which is the time when the data success ratio drops below a threshold (90%) , drops about 20% in different failure rate which means PEAS keep enough nodes in working state to provide high quality communication connectivity in case there are severe node failures. Moreover, data delivery lifetime is increased which means network can deliver the reports to user for longer time. The average data delivery lifetime increases linearly with increase in number of deployed nodes, increasing network functioning lifetime.

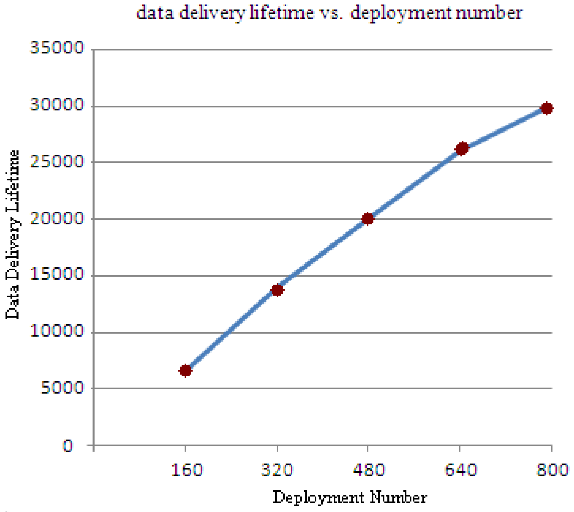

Fig. 4. Data Delivery Lifetime Vs. deployed node number

PEAS also imply Adaptive Sleeping which decides wake up frequency of sleeping nodes. It is done by adjusting the probing rate of each probing nodes to the desired rate. Simulations show that average number of wake ups increases as the number of nodes increases due to adaptive sleeping. PEAS is also robust against node failures as when a node fails or left with no energy, a sleeping node wake ups to replace it and maintains a high coverage. So, PEAS can extend the overall system lifetime in proportional to number of deployed nodes. Energy is consumed in each wake up which consist of transmitting and receiving PROBE and REPLY messages and the wait time by probing mode for REPLY. If wake up energy per node is assumed to be .00316, Energy overhead and its ratio compared with total energy consumption can be calculated as shown in Table 1. Table shows energy overhead is less than .3% of total energy consumption which shows that no excessive energy is consumed to combat failures, which is an advantage of PEAS [5].

Node density	Energy Overhead	Overhead ratio
160	11.58J	.143%
320	34.18 J	.207%
480	58.68J	.236%
640	83.53J	.25%
800	111.11J	.267%

TABLE 1: ENERGY OVERHEAD FOR DIFFERENT NODE DENSITY

C. *Improvement over PEAS*

A node scheduling based on Grid partition was proposed for maintain coverage and connectivity and track the special events also. The monitoring area is divided in to equal grid size of R×R. Location technique like GPS is used by every node to acquire partition information.

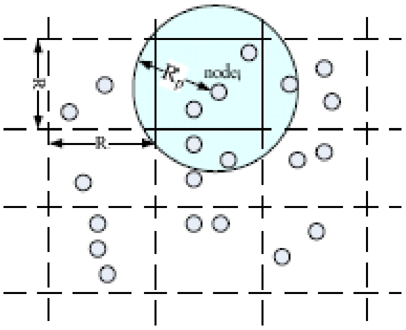

Fig. 5. Grid partition of the network

Coverage in each grid is determined by node position and probing radius (Rp).It is best to choose value of R for proper node coverage in each grid as given by:

$$\sqrt{2}/2\ Rp \le R \le \sqrt{2}Rp \qquad (4)$$

Further to keep connectivity, all cut points must be in working state and there should be no isolated node. Two nearest neighboring nodes can communicate with each other if distance between them is less than transmission radius Rt. Here, R should satisfy the relation:

$$R \le \sqrt{5}/5\ Rt \qquad (5)$$

The algorithm consist of two scheduling methods, one is sleep scheduling for monitoring mode and a node waking up methods for tacking mode. Each node could be in any of four states: Initializing, working, sleeping and assisting.

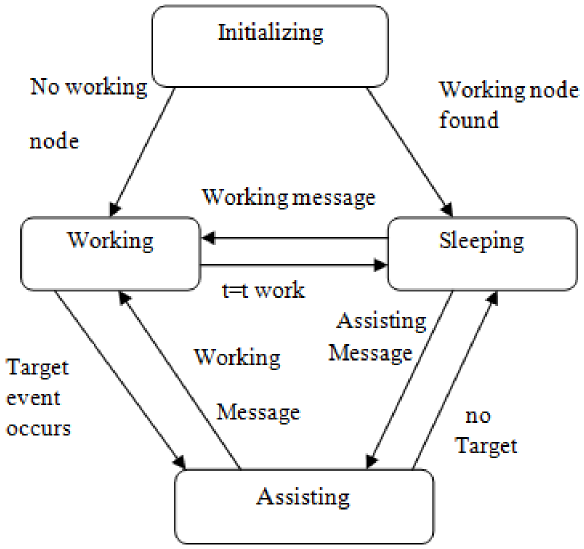

Fig. 6. State diagram of improved protocol

In monitoring mode, initially all nodes are assumed to be in sleeping state. Nodes in the grid send probing message to each other to find any working node. If no working node found, enters in to working mode and set itself as first node in a node queue. If there is one working node then it interacts with the working node to make a node queue and goes back to sleep mode. The queue information is forwarded to the next node when it wakes up for first time. There should be only one working node in each grid and every node in grid should work in turn to increase the network lifetime. So, scheduling is done in each grid through forming a node queue. Currently working node wakes up the next node in queue before it runs out of energy. If the next node in queue is dead, it wakes up the next node that is alive.,

When an unusual event happens or a target enters a grid, more nodes must wake up to track the event and collect the data more precisely. In tracking mode, when the sensor value increases above the threshold value and working nodes send an assisting message to other nodes in grid to wake up them. Nodes enter in to assisting mode and start tracing the event. The nodes in other grids which could perceive the target, wake up to assisting mode whereas some could not perceive the target due being out of range. In this case, these nodes will get back to sleeping mode if the sensor value is below the threshold value to save energy. When the working node has worked for a particular work time, it wakes up the next node in queue by sending working message and enters in to assisting mode. Data is delivered from source to sink using GRAB forwarding protocol [8] as in PEAS.

For simulation, Network parameters are also kept the same such as number of nodes, field area. Simulation results show that nodes completely die at about 85th time slice with radius 4.12 m in comparison to 46th time slice in PEAS, almost double at network scale of 1000 nodes.

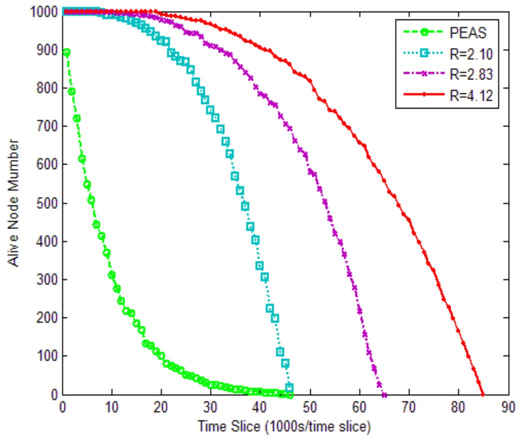

Fig. 7. Node Death process

Network Effective Lifetime is related to coverage and connectivity and is around 35th time slice as compared to 28th time slice in PEAS with 1000 nodes [6]. Figure shows the comparison of all node death time and effective lifetime between PEAS and proposed scheme with different radius. Nodes die at the same time in PEAS and proposed scheme with radius R=2.10 but effective lifetime of latter is 25% longer than former. This proves that slow death rate does not mean longer effective lifetime of the network.

For wake up scheduling, simulation results show that working nodes wake up all sleeping nodes in the particular region to precisely track the target. So, this proposed algorithm can be implemented to monitor periodically and track the exceptional events

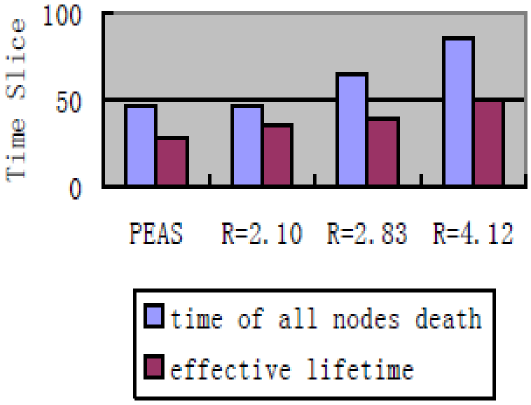

Fig. 8. Comparison of effective Lifetime with PEAS

CONCLUSION

In wireless sensor networks, full connectivity is to be maintained so that the sensor nodes can effectively coordinate with each other to transmit required data to base stations whereas coverage indicates the monitoring quality in a particular area. The requirement of connectivity and coverage should be fulfilled with the constraint of limited energy. It has been observed that connectivity and coverage should be maintained in stable environments as in GAF as well as in unstable environments where nodes could fail unexpectedly such as in PEAS and Improved protocol. This in required to improve the network longevity. Node scheduling should be done to provide coverage and connectivity keeping energy consumption in limit. Simulations show that GAF provides significant energy saving by keeping the radio off as long as possible in addition to working as normal ad hoc routing protocol and therefore increases network lifetime in proportion to node density. In GAF, which node to turn on depends on the residual energy i.e. nodes with higher energy are turned on first whereas in PEAS, no such preference is given to any node. PEAS pays special attention to unexpected node failure unlike GAF by using random wake up algorithm and avoids the overhead of keeping neighbor node information, thus increasing the lifetime of network in proportion to node density. In improved protocol, node scheduling is done in monitoring as well as tracking mode to save energy. It is observed that the improved protocol based on grid partition can performs better than PEAS in terms of effective lifetime of the nodes, providing complete coverage and connectivity making this protocol applicable for complex applications which require unusual events to be tracked precisely.

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