Energy-Efficient Protocol for Wireless Sensor Networks

C.A.Kandasamy [a,*], S.Yamini [b,1]

***Abstract* — The power consumption of nodes determines the lifetime of the wireless sensor network. Thus, the design of low-power node is very important. The sensors sense physical phenomena in different ways, designing and testing a different coverage protocol for each sensing model is indeed a costly task. To address these challenging tasks a new Probabilistic Coverage Protocol (denoted by PCP) that could employ different sensing models is proposed. PCP works with the common disk sensing model with minimal changes. Simulation exhibits that PCP is robust and it can function correctly in presence of node failures and demonstrates the comparison of PCP with other protocols and show that PCP out performs them in several aspects, including number of activated sensors, total energy consumed, and network lifetime. The analysis and design of our coverage protocol can be extended to the probabilistic K-coverage. K-coverage is needed in several sensor network applications to enhance reliability and accuracy of the network.**

Index Terms — Sensor networks, coverage in sensor networks, probabilistic coverage, coverage protocols.

I. INTRODUCTION

Sensor networks have been proposed for many applications such as forest fire detection, area surveillance, and natural habitat monitoring. A common ground for all such applications is that every sensor can detect an event occurring within its sensing range, and communicate with a sensor inside the communication range to deliver events, or information related to these events, to processing centers for possible actions.

In many of the previous works, the sensing range is assumed to be a uniform disk of radius rs. The disk sensing model assumes that if an event happens at a distance less than or equal to rs from the sensor location, the sensor will deterministically detect this event. On the other hand, an event occurring at distance rs +² cannot be detected at all, even for very small values. In this case, the area is covered if any arbitrary point in the area has a sensor within the range of rs. By ignoring this extra sensing capacity, the disk model Sensor networks have been proposed for many applications such as forest fire detection, area surveillance, and natural habitat monitoring. A common ground for all such applications is that every sensor can detect an event occurring within its sensing range, and communicate with a sensor inside the communication range to deliver events, or information related to these events, to processing centers for possible actions.

Wireless sensor networks are deployed to be used in monitoring applications such as forest fire detection, habitat monitoring, and battled monitoring. The nodes are small devices with a low power processor, small amount of memory, a wireless interface, and a sensing interface. The power of sensors is provided by batteries. The sensing module can be used to detect changes in temperature, light, humidity, or to detect objects using sonar or radio waves.

Sensors are expected to be available at low cost due to mass production. They can be deployed manually for small areas but for large areas, other method like dropping nodes from a plane is used. Various node distributions such as square mesh, triangular mesh, and uniform random deployment are used for different applications. In monitoring applications, we done coverage to measure the quality of monitoring provided by deployed sensors. The sensor network covers the area if all points in the area are covered by at least one sensor. This definition is extended to the case of having multiple sensors covering any arbitrary point. The area is k-covered by the deployed sensors if any arbitrary point is being detected by at least k sensors.

The main task of a sensor network is to collect data from the surveillance area and report it to a base station. To achieve this, sensors can form a network with various architectures depending on the application, sensor types, and power constraints. Sensors can send the data directly to the base station or use a multi-hop path to deliver the data. Several routing mechanisms have been proposed to address energy constraints as well as latency in delivering data in wireless sensor networks[2]. Sensors can also do aggregation when forwarding data to other nodes. This reduces the communication overhead and saves the energy. Regardless of the mechanism used for the delivery of data, it is essential to have all nodes in the network connected to each other to be able to deliver the data.

Power consumption is one of the fundamental concerns in wireless sensor networks. Sensors can last for a few weeks using their batteries. But have to extend their lifetimes into months. The solution is to deploy some extra sensors and distribute the workload between nodes to increase the lifetime. In this case, some protocols are needed to schedule activation and deactivation of nodes while keeping the coverage and connectivity quality. The[3] protocols maintaining the area covered are often referred to as coverage protocols while connectivity protocols guarantee the communication quality between nodes.

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- PCP protocol minimizes the number of activated nodes and consumes much less energy than other protocols.
- It provides quality of communication between nodes in sensor networks.

II. RELATED WORK

2.1 Existing System

- Probabilistic Coverage Protocol (CCANS) is implemented in terms of the number of activated sensors, network lifetime and energy consumption.
- Deterministic Coverage Protocols such as (OGDC, CCP) are implemented for maintaining the connectivity.

2.2 CCANS AND OGDC, CCP

CCANS proposed in terms of the number of activated sensors, network lifetime, and energy consumption. The idea of CCANS is to start all nodes in active mode, then iteratively deactivate nodes that are not needed for coverage. A token is circulated among nodes in the network in a certain manner. The node holding the token calculates the coverage on the grid points around it. If coverage is achieved at these points, it broadcasts a notification to its neighbors, passes the token to another node, and deactivates itself. All redundant nodes are deactivated when the token visits each node in the network. CCANS check only for coverage and not for connectivity.

Several distributed coverage protocols have been pro-posed for the disk model, For example, OGDC tries to minimize the overlap between the sensing circles of activated sensors, while CCP deactivates redundant sensors by checking that all intersection points of sensing circles are covered.

Three node scheduling schemes that estimate the distance to the nearest neighbor, number of neighbors, or the probability of a node being off duty and use one of these metrics to put some sensors in sleep mode. The coverage algorithm tries to find uncovered spots and activate sensors in these areas using information from nearby active sensors.

It has been shown before that covering an area with disks of same radius (r_s) can optimally be done by placing disks on vertices of a triangular lattice, where the side of the triangle is $3r_s$. Optimality here the minimum number of disks required. The idea of PCP is to activate a subset of deployed sensors to construct an approximate triangular lattice on top of the area to be covered. PCP starts by activating any sensor in the area, which is referred as an activator. This sensor activates six other sensors located at vertices of the hexagon centered at that sensor. Each activated sensor, in turn, activates other sensors at vertices of its own hexagon. As illustrated in Fig. 5.3, this process continues till the activated sensors form a virtual triangular lattice over the whole area.

III. PROPOSED SYSTEM

PCP works with the common disk sensing model as well as probabilistic sensing models with minimum changes. One model does not fit all sensor types PCP is designed with limited dependence on sensing model can be used with various sensor types. In the k-coverage ($k \geq 1$) problem each point should be within the sensing range of k or more sensors. Covering each point by multiple sensors is desired for many applications, because it provides redundancy fault tolerance -coverage is necessary for the proper functioning of other applications, such as intrusion detection, data gathering, and object tracking. To illustrate, consider an intrusion detection system in military applications, where [5] k-coverage is essential to identify intruding objects of different sizes. A tank, for instance, is detected by many sensors, while a soldier is detected by only a few. A high degree of coverage makes the classification more precise.

3.1 Triangular Lattice Formation

The distance between the vertices of the triangular lattice as the maximum separation between active nodes, and it is denoted by s. The value of s is determined from the sensing range r_s of sensors. Under the disk sensing model, the maximum separation is set to ¼ $3r_s$. The lattice is approximate because it is constructed in a distributed manner and is controlled by sensor deployment. The initial sensor deployment is not assumed to be on a lattice; it could be any distribution.

Nodes try to form a triangular lattice over the area.

- Single starting node: In the beginning of the protocol, only one node starts as an activator. It is extend to handle multiple starting nodes, which is important for large-scale sensor networks.
- Nodes know their locations: PCP protocol does not require accurate knowledge of global positions because the position information is used only in local decisions to activate nodes.

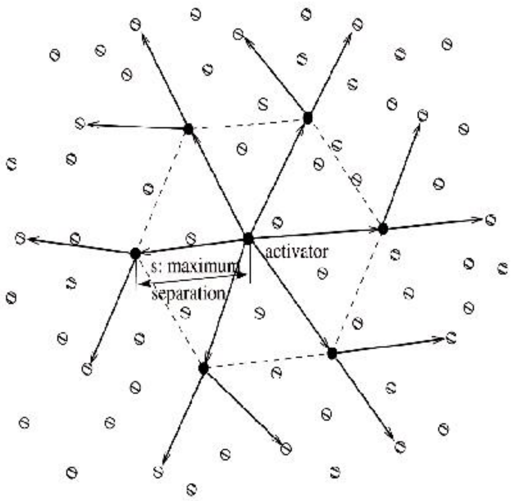

Fig: 3.1 Simplification of the Node Activation Process in PCP. Activated

PCP works in rounds of R seconds each. R is chosen to be much smaller than the average lifetime of sensors. In the beginning of each round, all nodes start running PCP independent of each other. A number of messages will be exchanged between nodes to determine which of them should be on duty (i.e., active) during the current round, and which should sleep till the beginning of the next round. The time it takes the protocol to determine active/sleep nodes is called the convergence time, and it is desired to be as small as possible. After convergence, no node changes its state and no protocol messages are exchanged till the beginning of the next round.

In PCP, a node can be in one of the four states: ACTIVE, SLEEP, WAIT, or START. In the beginning of a round, each node sets its state to be START and selects a random start-up timer T_s inversely proportional to its remaining energy level.

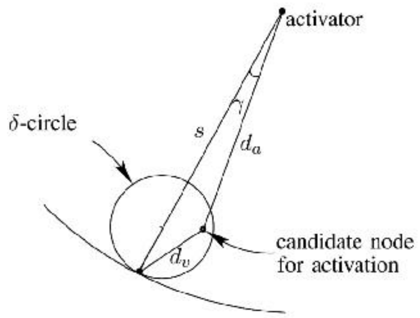

Fig: 3.2 Choosing the Closest Node to a Triangle Vertex

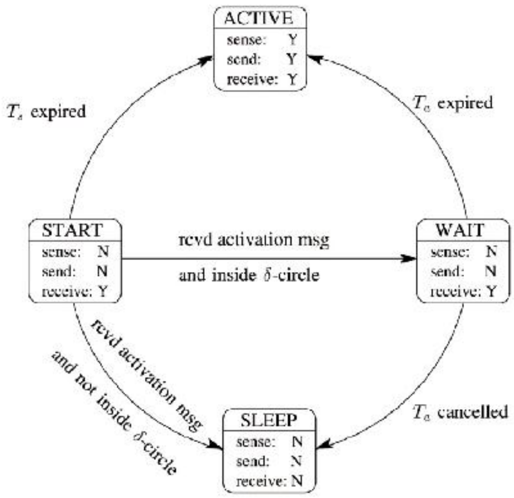

Fig: 3.3 The State Diagram of the PCP

The node with the smallest T_s will become active and broadcast an activation message to all nodes in its communication range. The sender of activation message is called the activator. The activation message contains the coordinates of the activator, and it tries to activate nodes at vertices of the hexagon centered at the activator, hexagon by measuring the distance and angle between itself and the activator. The angle is measured starting from the positive x-axis and going anticlockwise. If the angle is multiple of $_3$=3 and distance is s, then the node sets its state to ACTIVE and it becomes a new activator. Otherwise, it goes to SLEEP state.

PCP tries to activate the closest nodes to hexagon vertices in a distributed manner as follows: where d_v and d_a are the Euclidean distances between the node and the vertex, and the node and the activator, respectively; $_3$ is the angle between the line connecting the node with the activator and the line connecting the vertex with the activator; and $_{3a}$ is a constant[1]. Note that the closer the node gets to the vertex, the smaller the T_a will be. After computing T_a, a node moves to WAIT state and stays in this state till its T_a timer either expires or is canceled. When the smallest T_a timer expires, its corresponding node changes its state to ACTIVE. This node then becomes a new activator and broadcasts an activation message to its neighbors. When receiving the new activation message, nodes in WAIT state cancel their T_a timers and move to SLEEP state.

3.2 Optimization Using δ-Circles

Optimization puts more sensors in sleep mode faster, shortens the protocol convergence time, and thus, saves more energy.

Definition(δ-circle): The smallest circle drawn anywhere in the monitored area such that there is at least one node inside it is called the δ-circle, where δ is the diameter of the circle. The diameter δ is computed from the deployment distribution of nodes. δ is computed for two common deployment schemes: grid and uniform distribution. δ for other schemes can be derived in a similar way. Let us assume that there are n nodes to be deployed on the monitored area. δ-circle concept is to minimize the number of nodes in WAIT state. That is, nodes decide quickly to be either in ACTIVE or SLEEP state. This saves energy because nodes in WAIT state must have their wireless receiving modules turned on, while all modules are turned off in SLEEP state. The savings in energy are significant. PCP achieves this optimization by making only nodes inside δ-circles near to the six vertices of the hexagon stay in WAIT state; all others move to SLEEP state once they determine that they are outside of all δ-circles. Nodes inside δ-circles compute activation timers, as described above, to choose the closest node the vertex to be active. Fig. 5.4 shows one of the six δ-circles of a given activator. Note that the centers of the δ-circles are located at a distance of δ =2 from the activator and at angles that are multiple of δ=3. The state diagram of the PCP protocol is illustrated in Fig.

5.5 the figure shows the status of the sensing, sending, and receiving modules in each state of the node. The PCP protocol does not require that δ to be static throughout the lifetime of the sensor network. Rather, δ can be changed to account for node failures or decreasing node density with the time. For example, δ can be doubled after certain number of rounds of the protocol. This only requires each node to keep a counter on the number of elapsed rounds. Also note that during transition between rounds, active nodes in the finished round stay active for a short period in the new round while they are participating in the protocol.

This period is approximately equal to the expected convergence time. After this short period, these nodes will move to states determined by the protocol in the new round.

3.3 Multiple Starting Nodes

PCP starts with only one node as an activator. For large-scale sensor networks, it may be desired to have multiple starting nodes such that the coverage protocol converges faster in each round. Faster convergence means that nodes move quicker from START or WAIT state to either SLEEP or ACTIVE state, which reduces the total energy consumed in the network. This is because START and WAIT are temporary states and they consume more energy than the SLEEP state. Multiple starting nodes, however, could increase the number of activated sensors because of the potential overlap between subareas that are covered due to different starting nodes. The impact of multiple starting nodes on number of activated nodes, convergence time, and total energy consumed in the network will be studied.

3.4 Coverage Using Disk Sensing Model In the disk sensing model, all events within the sensing range r_s, are deterministically detected by the sensor. On the other hand, events happening further cannot be detected at all. The coverage under disk sensing model is often referred to as Deterministic Coverage and defined as following:

Definition 1 (Deterministic Coverage) an area A is deterministically covered by n sensors if 9i; (1 · i · n), such that $d_i(x) < r_s$ for every point x in A, where $d_i(x)$ is the distance between sensor i and point x.
Based on the above definition each point in the area is covered by at least one sensor. However, some applications require multiple sensors monitoring every point at the same time for several reasons.

Definition 2 (k-Coverage) An area A is k-covered by n sensors if for every point x in A, there are at least k sensors with distance of at most r_s from x.
The disk sensing model simplifies the coverage problem. In fact, optimal solutions for it can be obtained efficiently. As covering an area with disks of same radius (r_s) can optimally be done by placing disks on vertices of a triangular lattice, where the side of the triangle is $^{P}3r_s$.

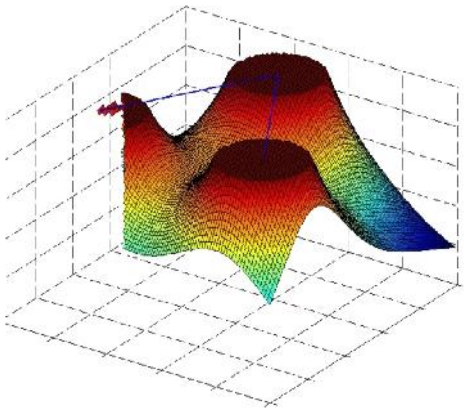

Fig: 3.4 The Sensing Capacity of Three Sensors that Use the Exponential Sensing Model and Deployed at Vertices of an Equi-Lateral Triangle

This triangular lattice idea can be used in designing a coverage protocol that activates a minimal subset of deployed sensors to ensure coverage as follows. The protocol works by rest activating any sensor in the area.

This sensor activates six other sensors located at vertices of the hexagon centered at that sensor. Each activated sensor in turn activates other sensors at vertices of its own hexagon. This process continues till the activated sensors form a virtual triangular lattice over the whole. Fig The least-covered point by these three sensors is at the center of the triangle.

Activating sensors in this way minimizes the overlap between the sensing ranges of sensors. The above protocol is idealistic and many practical issues need to be addressed.

3.5 Coverage Using Probabilistic Sensing Models

Under probabilistic sensing models, the sensing range is no longer a disk. Furthermore, the overlap among sensing ranges of different sensors is not clearly defined. Therefore, the overlap minimization idea may not work with probabilistic coverage protocols that seek to optimize the number of activated sensors. For such protocols, a new method is proposed for activating the minimum number of sensors while ensuring the monitored area is probabilistically covered.

Definition 3 (Probabilistic Coverage)
An area A is probabilistically covered by n sensor with threshold parameter µ (0 < µ <=1) if P (x) = 1 ¡ $^{Qn}{}_{i=1}$(1 - $p_i(x)$) >=µ for every point x in A, where $p_i(x)$ is the probability that sensor i detects an event occurring at x.Note that P (x) in the above definition measures the collective probability from all n sensors to cover point x, $p_i(x)$ is specified by the adopted sensing model, and the coverage threshold parameter µ depends the requirements of the target application. If we set µ = 1And $p_i(x)$ as a binary function that takes on either 0 or 1 in the above definition, It is to get the commonly-used deterministic coverage definition with the disk sensing model.

Definition 4 (Least-covered Point) A point x within an area A is called the least-covered point of A if P (x) · P (y) for all y =6 x in A.
The main idea of Probabilistic Coverage Protocol is to ensure that the least-covered point in the monitored area has a probability of being sensed that is at least µ. To implement this idea in a distributed protocol with no global knowledge, the area is divided into smaller subareas. For each subarea, determine the least-covered point in that subarea, and activate the minimum number of sensors required to cover the least-covered point with a probability more than or equal to µ. To enable this protocol to work optimally under the disk sensing model as well as probabilistic sensing models, divide the monitored area into equi-lateral triangles forming a triangular lattice. Then compute the location of the least-covered point in each triangle. Next compute the maximum length of the triangle side at which the probability of sensing at the least-covered point.
Knowing this maximum length, the[6] coverage protocol functions in the same manner as described it tries to activate nodes at vertices of the lattice triangles. This activation process is described Notice that this is an idealistic version of our protocol to describe the core idea. Practical considerations, such as inaccuracies in node locations, are handled later. Notice also that the main difference between the deterministic and probabilistic coverage protocols is that the former tries to minimize the overlap between sensing ranges, while the latter stretches the separation between active sensors to its maximum while ensuring that the coverage at the least-covered point exceeds a given threshold µ.
Refer the maximum length of the triangle side as the maximum separation between any two active sensors, and denote it by s. computing s depends only on the sensing model used. In the next sub section, derive s for two sensing models: the exponential sensing model and the disk sensing model.
Computing s for other sensing models can be done in a similar way. Then emphasize that the operation of PCP does not change by changing the sensing model. The only parameter that needs to be determined and given to PCP is the maximum separation between any two active sensors s, which is computed from the sensing model.

ALGORITHM
Algorithm for Probabilistic Coverage Protocol is Distributed Randomized K-Coverage (DRKC).

Basic idea:

- Model k-coverage as a hitting set problem
- Design an approximation algorithm for hitting set

DRKC Sender

1. while (true) {
2. /* initialize parameters */
3. weight = 1, totalWeight = n, netSize = 1;
4. curCoverage = 0, state = TEMP;
5. while (netSize ≤ n) {
6. /* activate neighbors to achieve k coverage */
7. if (netSize × (weight/totalWeight) > rand()) {
8. state = ACTIVE;
9. reqCoverage = k − curCoverage;
10.Pa=reqCoverage/(neighborSize − curCoverage);
11. broadcast an ACTIVATE message containing Pa and reqCoverage to neighbors;
12. }
13. wait for NOTIFY messages;
14. /* verify k-Coverage */
15. if (curCoverage ≥ k) { break; }
16. /* update variables for next iteration */
17. if (1/(n − netSize) > rand())
{ weight = weight × 2; }
18. netSize = netSize × 2;
19. totalWeight = totalWeight + totalWeight/n;
20. }
21. if (state 6= ACTIVE) { state = SLEEP; }
22. wait until end of round;
23.}

DRKC Receiver

/* upon receiving a message msg */
1. if (msg.type == ACTIVATE and msg.Pa > rand()) } /* chosen to be active */
2. /* wait random time to reduce collision */
3. send a NOTIFY message to msg.source after int rand(0, msg.reqCoverage) × Tm sec;
4. state = ACTIVE;
5. }
6. update (neighborSize, curCoverage); /* based on msg.source */

IV. IMPLEMENTATION

4.1 Protocol Implementation

Some results from the NS-2 implementation with reasonable network sizes (up to 1,000 nodes) are presented. Most results, however, are based on the simulator because it supports much larger networks, which need to rigorously evaluate the protocol.

The following parameters are used in this experiment. Uniformly at random deploy 20,000 sensors over a 1 km. Two sensing models are used : The disk sensing model with a sensing range of r_s ¼ 15 m and the exponential sensing model with sensing capacity decay factor $_3$ ¼ 0:05, and set the r_s ¼ 15 m as the threshold value below which sensing is achieved with probability 1. The energy model in which is based on the Mote hardware specifications was employed. In this model, the node power consumption in transmission, reception, idle, and sleep modes is 60, 12, 12, and 0.03 mW, respectively. The initial energy of a node is assumed to be 60 Joules, which allows a node to operate for about 5,000 seconds in reception/idle modes.

While comparing various coverage protocols, assume that the wireless communication channel has a bandwidth of 40 Kbps. Since the message sizes in all protocols are almost the same, assume that the average message size is 34 bytes, which is the same size used in [4].Then ignore the propagation delay because it is negligible for the 1 km. This results is a message transmission time $_{3m}$ ¼ 6:8 ms. Repeat each experiment 10 times with different seeds and report the averages in all of our results. Report the minimum and maximum values if they do not clutter the figures. Note that the simulated sensor network in each experiment replica has 20,000 nodes, and the measured statistics are collected from all of them. Therefore, believe that combining the data from 10 different replicas and each with 20,000 nodes yields statistically significant results. Finally, mention that in most experiments, each single replica took several hours of running time on a decent multicore Linux server. Furthermore, processing the huge traces created in these large-scale experiments consumed many CPU hours.

V. RESULT

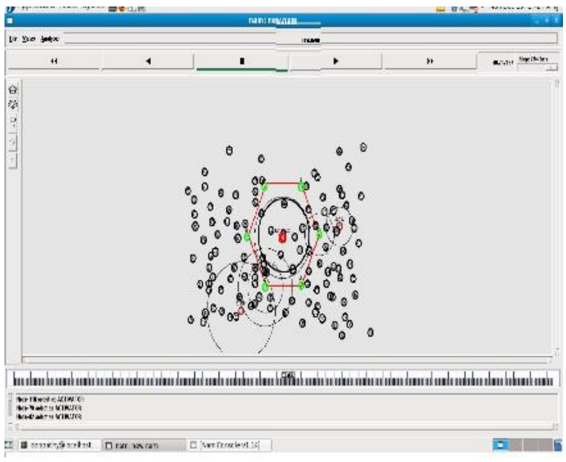

Fig. 5.1 Simplification of the Node Activation Process in PCP

The above figure shows that PCP is to activate a subset of deployed sensors to construct an approximate triangular lattice on top of the area to be covered. PCP starts by activating any sensor in the area, which referred as an activator. This sensor activates six other sensors located at vertices of the hexagon centered at that sensor. Each activated sensor, in turn, activates other sensors at vertices of its own hexagon.

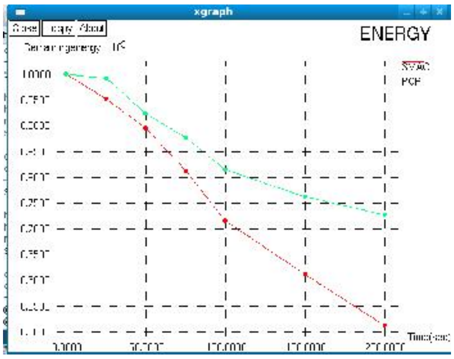

Fig: 5.2 Energy Consumption

The figure shows that as SMAC activates more nodes and exchanges more messages than PCP, protocol distributes the load uniformly across all deployed nodes is showed. This is critical in order to keep nodes alive for the longest possible period, and thus to prolong the network lifetime.

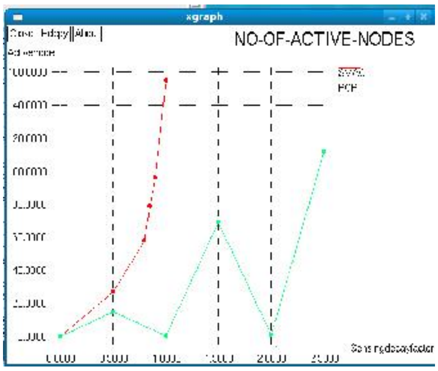

Fig. 5.3 The Average Number of Nodes Activated by PCP and SMAC

Figure shows the average number of nodes activated by PCP and SMAC for different values of the sensing decay factor and the coverage threshold. As the figure shows, PCP activates a much smaller number of nodes than SMAC, while ensuring the same level of probabilistic coverage. This is significant because it indicates that the sensor network could last much longer using our protocol.

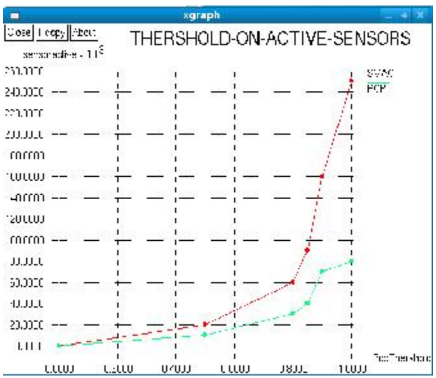

Fig 5.4. Shows that threshold -on-active sensors

An experiment is conducted to assess the potential savings in number of active nodes fig shows the results for different values for sensing decay factor. The fig indicates that saving of up to 30 percent in number of active nodes can be achieved, which means less energy consumed and ultimately longer lifetime for the sensor network.

VI. Conclusion and Future Work

In this project, a fully distributed, probabilistic coverage protocol has been proposed. A key feature of PCP protocol is that it can be used with different sensing models, with minimal changes. The analytical results are verified using simulations. An approximation algorithm has been proposed for computing near-optimal hitting sets efficiently. Simulation results show that the distributed algorithm converges faster and consumes much less energy than previous algorithms. The analysis and design of the coverage protocol can be extended to the probabilistic k-coverage case. K-coverage is needed in several sensor network applications to enhance reliability and accuracy of the network. Using probabilistic sensing models in the k-coverage case is expected to yield even higher savings in the number of activated sensors. Another extension is to consider probabilistic communication models, in addition to the probabilistic sensing models, in the design and operation of the protocol. The simulation demonstrates that PCP is robust, and it can function correctly in presence of random node failures, inaccuracies in node locations, and imperfect time synchronization of nodes.

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Biography

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