# AN ENERGY EFFICIENT DISTRIBUTED PROTOCOL FOR ENSURING COVERAGE AND CONNECTIVITY ($E^3C^2$) OF WIRELESS SENSOR NETWORKS

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***ABSTRACT***

*As wireless sensor networks (WSNs) continue to attract more and more researchers attention, new ideas for applications are continually being developed, many of which involve consistent coverage with good network connectivity of a given area of interest. For the successful operation of the wireless Sensor Network, the active sensor nodes must maintain both coverage and also connectivity. These are two closely related essential prerequisites and they are also very important measurements of quality of service (QoS) for wireless sensor networks. This paper presents the design and analysis of novel protocols that can dynamically configure a sensor network to result in guaranteed degrees of coverage and connectivity. This protocol is simulated using NS2 simulated and compared against a distributed probabilistic coverage-preserving configuration protocol (DPCCP) with SPAN [1] protocol in the literature and show that it activates lesser number of sensor nodes, consumes much lesser energy and maximises the network lifetime significantly.*

***KEYWORDS***

*Coverage, Connectivity ,energy conservation ,power nodes power control*

## 1. INTRODUCTION

During the last decade, with the development of Very Large Scale Integration (VLSI) and Micro Electro Mechanism System (MEMS), embedded computation ,wireless sensor network have attracted a lots of attentions by both researchers and also by developers [2].This wireless sensor network (WSN) is a collection of a large number of tiny devices each with sensing (collection of surrounding information), processing and wireless communication (transmission of the report data to a sink node/base station) capability. A tiny node by itself has severe resource problems, such as limited memory, battery energy, signal processing, and computation and transmitting capabilities; hence it can sense only a small area of interest the environment. But, a group of sensors coordinating with neighbouring nodes can perform a much bigger applications effectively & efficiently. In wireless sensor networks, there are two important prerequisits.They are (a.) Sufficient Sensing Coverage (b.) Sufficient Network Connectivity.

The coverage problem is to study and solve how to make sure that the coverage range meets the desired application requirements. The connectivity problem concentrates on how to make sure that all the active sensor nodes are able to communicate with each other. The Connected coverage (CC) is the integration of coverage problems and also connectivity problems.

A wide range of applications have been envisioned using WSNs [2], such as temperature and environmental conditions monitoring, security surveillance in military and battle-fields, industrial diagnosis, wildlife habitat monitoring, fire detection, object tracking, distant health care and so on.

In most of these applications the environment could be hostile (such as a volcano crater); the replacement of these nodes may not be possible once they are deployed. This will remain untouched for months or years without any battery replacement. So, the development of energy-saving algorithm for the establishment of these sensor networks can prolong their lifetime, what is very essential. Our main goals are:

- To turn on only minimal number of sensor nodes, controlling the density to avoid collision of packets which may lead for packets loss and intern for retransmission and indirectly reducing some problems like radio interference, congestion
- To ensure that this available number of active nodes can cover the area of interest;
- To ensure that the information can flow outside, that is, the active sensor nodes are connected;
- To increase the network lifetime.

The rest of the paper is organized as follows. The related work is reviewed in Section 2. In Section 3 Problem definition & discussions on connected coverage mathematical model are discussed. Performance Evaluation & Simulation result are presented in Section 4. Finally, it is a concluded in Section 5.

## II. RELATED WORK

Tian *et al.* [10] presented the first protocol that guarantees full coverage. They defined the “sponsored area” of sensor node ‘*j*’ by node ‘*i* ’ as the maximal sector of sensor node ‘*j*’s coverage disk that is covered by sensor node ‘*i*’. Whenever a sensor node receives a packet/message from one of its active neighbours, it calculates its covered sponsored region by that sensor node. If the union of all the sponsored region of a sensor node covers the coverage disk of the sensor node, the sensor node turns itself off and opts to sleep. Normally, this method requires good number of working sensors. Moreover, the authors address only the coverage issues without touching the network connectivity problem.

In [13], describes a hybrid approach to study sensor coverage by using a Voronoi diagrams. They provide protocol to determine sensor coverage quality with worst case runtime estimations for different sensor network models and coverage criteria in 2-D or 3-D. This paper does not consider deployment connectivity and the according trade-offs.

SPAN [5] is a randomized with distributed algorithm in which sensor nodes make local decisions on whether the nodes should sleep or actively participate in the process. A node that opts to stay awake and maintain sensor network connectivity is known as *coordinators*. A non-coordinator sensor node elects itself as a coordinator if any two of its neighbours cannot communicate with each other. The non-coordinator sensor node broadcasts locally, its willingness of being a coordinator, delayed by an interval that gives the residual power of a sensor node. The information required for coordinator election is exchanged mutually among neighbours through HELLO messages

The authors [11], proposed an Integer Linear Programming (ILP) formulation and algorithms to solve the Density, Coverage and Connectivity Control Problem (DCCCP) in flat networks subject to sensor either node failures due to mechanical problems or draining of energy from the battery. They present a global algorithm which has a better vision of the sensor network and so can build up good routing topologies using the available sensor nodes. However, spreading the solutions generated by this algorithm can be very expensive in terms of energy, time and sensor network load.

In paper [12], the author presented the problem to improve networks lifetime (in terms of rounds) while preserving both target coverage and connectivity. This not only gives satisfied quality of service (QoS) in sensors networks, but also presents more options to changes the design a power efficient sensor scheduling. They studied and presented the Connected Set Covers (CSC) problem, used to solve the connected target coverage problem. Later they proposed a Three Phase Iterative algorithm to solve the CSC problem named TPICSC.

In [3], Author proposed that the recent research result that significant energy savings achieved by dynamic management of node duty cycles in sensor networks with high node density. In this method, some of the sensor nodes are scheduled to sleep (or enter a power saving mode) while the remaining active nodes provide service without disturbing the network functionality. A fundamental problem is to reduce the number of nodes that remain active mode, while still achieving acceptable quality of service for applications. In particular, maintaining sufficient communication coverage and network connectivity with the active nodes is a critical requirement in sensor networks. The authors provided a geometric analysis that 1) proves sensing coverage implies network connectivity when the sensing range is no more than half of the communication range. Their Simulation results demonstrate that Coverage Configuration Protocol (CCP) and CCP+SPAN+2Hop can effectively configure the network to achieve both requested coverage degrees and satisfactory communication capacity under different ratios of sensing / communication ranges as predicted by geometric analysis.

In [4], author presented a Coverage Configuration Protocol (CCP) that results different degrees of coverage and also maintain communication connectivity. The authors propose that coverage can imply connectivity only when sensors' communication ranges are not less than twice of their sensing ranges ($R_c \geq 2R_s$). Apart from that, they proved that the desired connectivity of boundary sensing nodes and interior nodes are equal to the degree of coverage and twice the degree of coverage, respectively. Each deployed tiny node runs the *k*-coverage eligibility protocol to determine the targeting coverage of a sensor network by observing at how intersection points between sensors' sensing/communicating ranges are covered by their neighbors. For the case when $R_c < 2R_s$, Coverage Configuration Protocol does not guarantee network connectivity. But, the authors integrated CCP with SPAN [5] to provide sensing coverage and along with network communication connectivity.

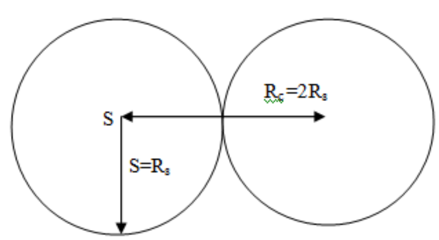



Figure 1: The relation between Sensing Range '$R_s$' and Communication Range '$R_c$'

Tian Ying, Zhang Shu-Fang and Wang Ying ,presented [6] ,which differs from existing protocols in four key ways: (1) They proposed a distributed probabilistic coverage-preserving configuration protocol (DPCCP) based on Neyman-Peason probabilistic detection model; (2) A simplified algorithm on coverage check is developed using Voronoi diagram; (3) Considering the network connectivity, after that, they integrated DPCCP with SPAN to ensure both probabilistic coverage and network connectivity; (4) To evaluate the coverage percentage of their protocol, they proposed an approximate algorithm. Simulation results shows that distributed probabilistic coverage-preserving configuration protocol DPCCP+SPAN can effectively reduce the number of active sensors and prolong the network lifetime on the precondition of probabilistic coverage-preserving and network connectivity. The authors also presented an approximate algorithm to evaluate the coverage percentage of their proposed algorithm. Simulation results showed that their protocol out performs CCP+SPAN presented in [5], which can effectively prolong network lifetime on the precondition of probabilistic coverage preserving and network connectivity.

In [7], the authors consider the target coverage and connectivity issues in wireless sensor networks (WSNs) with multiple sensing units. They reduced the problem to a connected set cover problem and further formulated it as integer programming (IP) constraints. Two distributed schemes, Remaining Energy First Scheme (REFS) and Energy Efficient First Scheme (EEFS), are proposed to solve the coverage and connectivity problems. Both REFS and EEFS have similar inclination that the network lifetime increases with the increase of the number of sensors, but reduces with the increase of the number of targets. However, the EEFS has better performance than REFS.

In [8], authors present an ILP formulation and protocols to solve the Coverage and Connectivity Control Problem (CCCP) in Wireless Sensor Networks subject to sensor node failures due to mechanical problems or when battery dries out of energy. They present an algorithm which has full information of the sensor network and so can build up good topologies using the available active nodes. However, spreading the solutions generated by this protocol can be costly in terms of power, time and load. Thus, they also proposed a local protocol, which is called every time a sensor node failure occurs and solves the problem considering only the failure neighbourhood. By combining both of these protocols the authors obtained a hybrid approach which results from the best features of each one of them.

## III. PROBLEM: Design Goals

In order to extend the whole wireless sensor network lifetime and also to maintain the connected area coverage problem, we present an energy-efficient Connected Coverage Preserving Protocol to select the group of active sensor nodes.

Definition 1: A deployment pattern is called fully optimal if it employs the minimum number of sensors nodes to produce the given sensor coverage and network connectivity requirement, among all patterns.

Definition 2**:** If any sensor node in network is among the communication range of one active node, then the network is said to be covered.

Definition 3: Connected Neighbouring Sensors: Two sensor situated at points u and v are said to be connected with neighbours, if

1. $D(u) \cap D(v) \neq \phi$ , i.e. their sensing convex disc intersect , and
2. $d(u,v) \leq R_c$ , where $R_c$ denotes coverage range

### Assumption Done

- We assume each node knows it location information in terms of coordinates.
- We assume a heterogeneous network with powerful nodes uniformly distributed in a ratio.

### Algorithm Steps

- Each Power node will Query the Normal Nodes to send it location information. A node can be reached by two powerful nodes but it always replies only to the first Power node.
- Each Normal Node sends its location information (x, y) to the power node.
- The power node maintain a list of (X, Y) and broadcasts this to all power nodes neighboring.
- The neighbor power nodes randomly elect a leader to do coverage calculation for particular Set (X, Y). Say which node has highest id will do the coverage calculation.
- Coverage Calculation algorithm will work by choosing the optimal nodes to cover the area using (X, Y) points and switch on schedule.
- Power node will send the Border Sensor and coverage area information to all power nodes.
- Two Power Nodes will determine if they are properly connected via the normal nodes else the node with higher id will choose the border node to ensure connectivity and sends the chosen node to the other power node. This is covered in the connectivity ensured algorithm.
- Once connectivity ensured algorithm runs between all the power nodes, then whole network wide connectivity is ensured.
- Due to this step we know the optimal nodes to ensure connectivity and coverage.

### The use of Power nodes

A power node runs the coverage and connectivity algorithm to ensure optical nodes to be active and their duty cycle.

But once this operation is complete how can they be used.

If a power nodes can formed a network to sink, then it can used a backplane for sending any urgent messages to sink.

Power nodes can sleep and wake up after some configured period of time and query the sensors, In case some sensors have drained in particular area, it can change the duty cycle of the nodes in that area, or it can even enable the sensors in intersection area of two squares.

In this paper, we assumed that nodes know their location. But for some networks when it is not known, we can make it known as following.

Power nodes can be equipped with GPS, so they know location; they can broadcast their locations to the normal sensor nodes. Sensor nodes can easily find their own location by triangulation.

## IV. SIMULATION PARAMETERS

We evaluate our ($E^3C^2$) through NS2 simulation [9]. We use a bounded region of 1000 x 1000 square meters, in which we place nodes using a uniform distribution. We assign the power levels of the nodes such that the transmission range and the sensing range of the nodes are all 250 meters. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. In our simulation, sensor nodes of sizes 50, 100 and 150 are deployed in a 1000 m x 1000 m rectangular region for 50 seconds of simulation time. The simulated traffic is Constant Bit Rate (CBR). To measure the performance of different protocols under different ratios of communication range/sensing range, we varied the communication range by 250,300,350 and 450m, in the network interface. All experimental results presented in this section are averages of ten runs on different randomly chosen scenarios.

The following table summarizes the simulation parameters used

| | |
|---|---|
| No. of Nodes | 50,100,150 and 200 |
| Area Size | 1000 X 1000 |
| MAC Protocol | 802.11 |
| Simulation Time | 50 sec |
| Traffic Source | CBR |
| Packet Size | 512 |
| Transmit Power | 0.360W |
| Receiving Power | 0.395W |
| Idle Power | 0.335W |
| Transmission Range | 250,300,350 and 400 |
| Routing Protocol | AODV |

### Performance Metrics

During experimentation, our proposed $E^3C^2$ protocols' performance is compared with DPCCP+SPAN [AA].In this evaluation; the experimentation is focused mainly on average energy consumption and connected Coverage of sensor.

**Experiment 1:** In experiment 1, we vary the no. of sensor nodes as 50,100,150 and 200 and measure the average energy consumption.

From Fig.2, we can observe that, our proposed $E^3C^2$ protocol consumes less energy when compared with the DPCCP+SPAN algorithm. The transmission range is fixed as 250m.

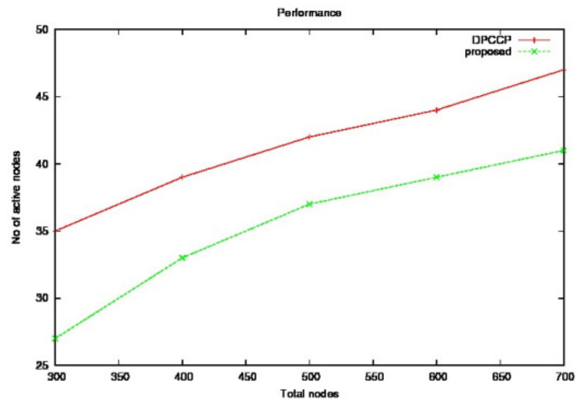



**Figure 2.Performance: Total Nodes vs. Number of Active Nodes**

**Experiment 2:** In experiment 2, we focused on the connected sensor node coverage in terms of active nodes. Fig.3 shows the results of coverage sensor nodes, for network sizes of 50,100,150 and 200.

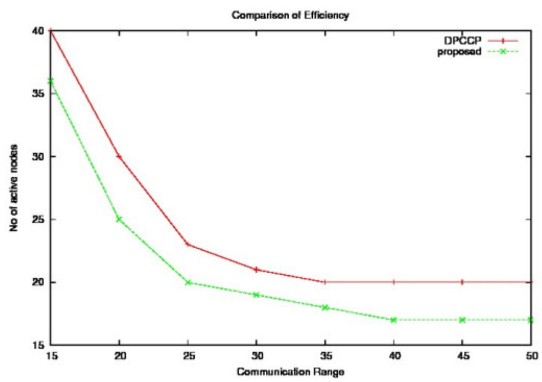



**Figure 3.Comparison of Efficiency: Communication Range vs. No. Of Active Nodes**

**Experiment 3:** In this experiment 3, we changed the transmission range as 250,300,350 and 400, and measured the average power consumption at fixed the no. of nodes as 100. From Fig. 4, we noted that, the energy consumption is significantly reduced in our algorithm $E^3C^2$, when compared with DPCCP+SPAN.

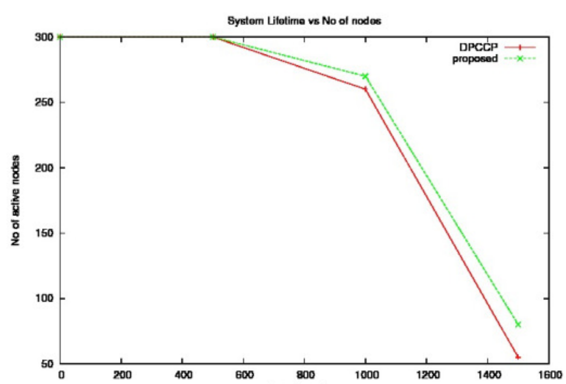



**Figure 4. System Life Time: Round No. Vs. No. of Active Nodes**

**Experiment 4:** In this evaluation, the results of sensor node coverage in terms of active nodes are measured. Fig.5 shows the sensor coverage results for different sensor network sizes for changed transmission range from 250 to 1600.

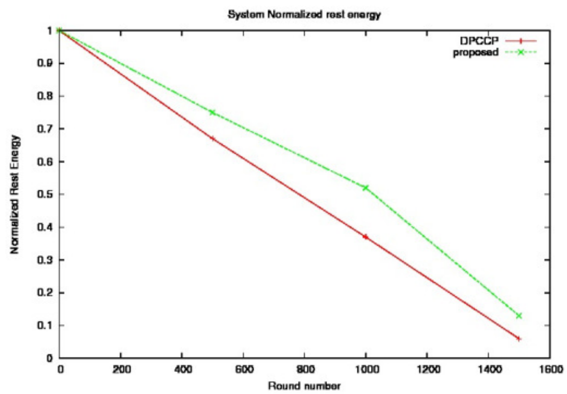
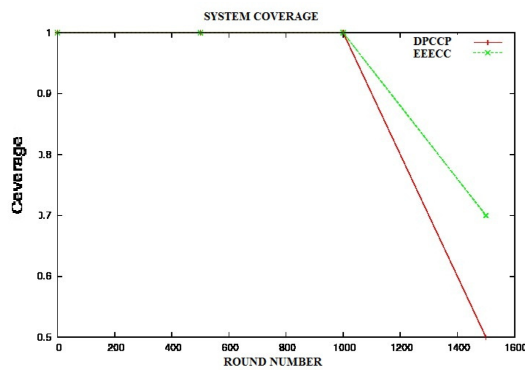



**Figure 5.System Normalised rest energy: Normalised rest energy vs. Round No.**




# V. CONCLUSION & FUTURE WORK

In this work, we presented ($E^3C^2$), a randomized algorithm which is run locally at a sensor node to govern its operation. In this paper, we presented recent energy-efficient connected coverage problems proposed in literature, their formulations and assumptions as well as solutions proposed. Sensor coverage, connectivity and energy are the three important elements for QoS in applications with WSNs. We examined the performance of the protocols using NS2 simulators and showed that our presented results in significant reduction of energy, with strongly connected coverage. Most recent works on the sensor connected coverage problem are still limited to theoretical study. In future, more and more research work will be concentrated on distributed and localized solutions for practical deployment.

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