# An Efficient Coverage Scheme to Maximize Life-Time in Wireless Sensor Networks

BY

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**Dedicated to**

***My wife***

**Who Prayer and Perseverance led to this accomplishment**

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In the name of Allah, the Most Gracious and the Most Merciful All praises and glory be to Allah (SWT) for blessing me with opportunities abound and showering upon me his mercy and guidance all through the life. I pray that He continues the same the rest of my life. And may his peace and blessings of Allah be upon Prophet Muhammad, a guidance and inspiration to our lives.

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**THESIS ABSTRACT**

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Title: An Efficient Coverage Scheme to Maximize Life-Time in Wireless Sensor Networks

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## Abstract

In wireless sensor networks, sensors are densely deployed. The number of sensors deployed is usually higher than optimum required due to the lack of precise sensor placement, especially when the interest region is inaccessible. Thus it is possible to turn some sensors off while guaranteeing the complete coverage of the interest region.

Coverage is one of the fundamental issues in wireless sensor networks. For the coverage problem, one must ensure that the interest region is under monitor all time although some sensor nodes may fail. It's an important design objective to maximize the network lifetime by minimizing energy consumed in the sensor networks.

In this thesis some algorithms proposed recently for coverage in literature are discussed. After a review on them, RID is selected -random Independent deployment- that will be suitable for the new model and fits for applications of dense deployment in hostile fields. The Kumar analytical model for RID is programmed. After that simulation is done for the new model and an efficient scheduling scheme is applied to maximize lifetime of the sensor networks by deploying Satellite-node(SN). The new model called SWSN (satellite wireless sensor networks). The new scheme is compared with the old one and find SWSN system will be not visible if it use the SN for sending data to satellite. Thus, because SN consume huge power but still it is a good if we use continues power source. In addition, SWSN&WSN are combined by send request by satellite and the replay will return by the old system and find this will decrees the consumption of the power in communication by 50% not in this only but at all the WSN.

**THESIS ABSTRACT (ARABIC)**


## ملخص الرسالة

**الاســــــــــم : خالد مبارك العفاري**

**عنوان الرسالة: مخطط تغطية فعال لزيادة وقت عمل شبكات عقد الاستشعار اللاسلكي**

**التخصــــص :هندسة شبكات**

**تاريخ التخرج: حزيران 2010**

في شبكات الاستشعار اللاسلكية يتم نشر عقد الاستشعار بكثافة مما يجعل عددها في المنطقة المطلوب تغطيتها أكثر من الاحتياج وذلك لعدم القدرة على تحديد مكان وضعها خصوصا إذا كانت المنطقة المستهدفة لا يمكن الوصول إليها، ولذلك يمكن إيقاف عمل بعضها مؤقتا مع ضمان التغطية الكاملة للمنطقة المستهدفة .

التغطية هي واحدة من القضايا الأساسية في شبكات الاستشعار اللاسلكية في التغطية ، لا بد من التأكد من أن المنطقة المستخدمة تحت مراقبة كل الوقت على الرغم من أن بعض عقد الاستشعار قد تفشل. إنه هدف تصميمي مهم لزيادة عمر الشبكة عن طريق تقليل الطاقة المستهلكة في عقد الاستشعار.

في هذه الأطروحة تناقش بعض الخوارزميات المقترحة مؤخرا للتغطية في الأبحاث، وبعد استعراضها تم دراسة خوارزم التحديد العشوائي المستقل للنشر والذي يكون مناسب للنموذج الجديد ويناسب لتطبيقات النشر الكثيفة في المناطق المعادية. النموذج التحليلي لكومار والذي يمثل التحديد العشوائي المستقل تمت برمجته باستخدام لغة الجافا. بعد ذلك تمت عمل محاكاة بين هذا النموذج والنموذج الجديد الذي تم فيه إضافة العقد التي تستطيع التواصل مع الأقمار الصناعية لزيادة عمر الشبكة. يسمى الشبكات اللاسلكية الفضائية SWSN . بعد المقارنة تبين عدم إمكانية استخدام النموذج الجديد وذلك لان الإرسال إلى القمر الصناعي يحتاج إلى طاقة كبيرة، مع ذلك يمكن استخدامه في الأماكن التي يوجد فيها مصدر طاقة دائم. وأيضا تم دمج النظام القديم والجديد بحيث يستخدم الجديد لاستقبال الطلبات والقديم لجمع النتائج وهذا قلل استهلاك الطاقة بحوالي 50% في كل شبكات الاستشعار اللاسلكية

## CHAPTER 1

## INTRODUCTION

Wireless communication and micro-sensing MEMS technologies have been desired for decades. Due to the huge advancements made in wireless technology this dream has become a reality. It is now possible to create wireless sensor networks. With the loss of a physical wire restriction to connect the nodes, the potential for sensor networks has blossomed [8]. Often, in the past, the desire to gather information was simply not feasible due to the difficulty of laying down a sensor network capable of gathering the data. Today, sensor networks consisting of many inexpensive wireless nodes are able to gather, process and store environmental information. They are also capable of communicating with neighboring nodes, increasing the amount of data that can be collected. An obvious demonstrator of how well these systems work is the fact that the sensor market has increased at a rate of 200 percent a year [38]. However, there are still some challenges with these systems that need to be overcome. Current research is involved in improvement of sensor networks by advancement in the physical and media access layers [12] of the sensors and in routing of data.

As is often the case in advancing technologies, networking distributed sensors were first created and used for military, and later industrial applications. The first systems, which were for the most part small scale and wired, became functional in the 1970s. It was not until twenty years later that technology had advanced to such a degree as to make large-scale embedded wireless sensor networks possible. These networks

would use the wireless technology and low-power VLSI design of nodes to make a dense sensing network.

Area coverage has been and continues to be an issue in wireless sensor networks due to the arbitrary manner in which the sensors may be spread. How well the area of the network functions is basically determined by how well the sensing field is monitored or tracked by the sensors. Theoretical coverage-related solutions can be derived from computational geometry. These mathematical solutions cannot be directly applied to wireless sensor networks, but they are useful in establishing a theoretical background of the coverage issue. The purpose of this thesis is to review the recent progress in sensor deployment schemes and develop a new scheme to improve area coverage in wireless sensor networks. The amount of literature dedicated to the problems involved with coverage in wireless sensor networks has grown in the last few years. Two particular problems that have been addressed are coverage versus connectivity issues in deployment, and surveillance and exposure. One factor that has not as yet been addressed to date is the expansion of live time coverage.

While some works are targeted at particular applications, the underlying theme remains related to the coverage issue. For example, to reduce sensors' on-duty time, sensors that share the common sensing region and tasks may be turned off to conserve energy and extend the network lifetime.

### 1.1 What are Sensors and sensor networks?

Sensors are small, low cost, low power devices that do sensing, processing, and communication (see Fig 1.) Sensors have limited memory, power, and computation capacities.

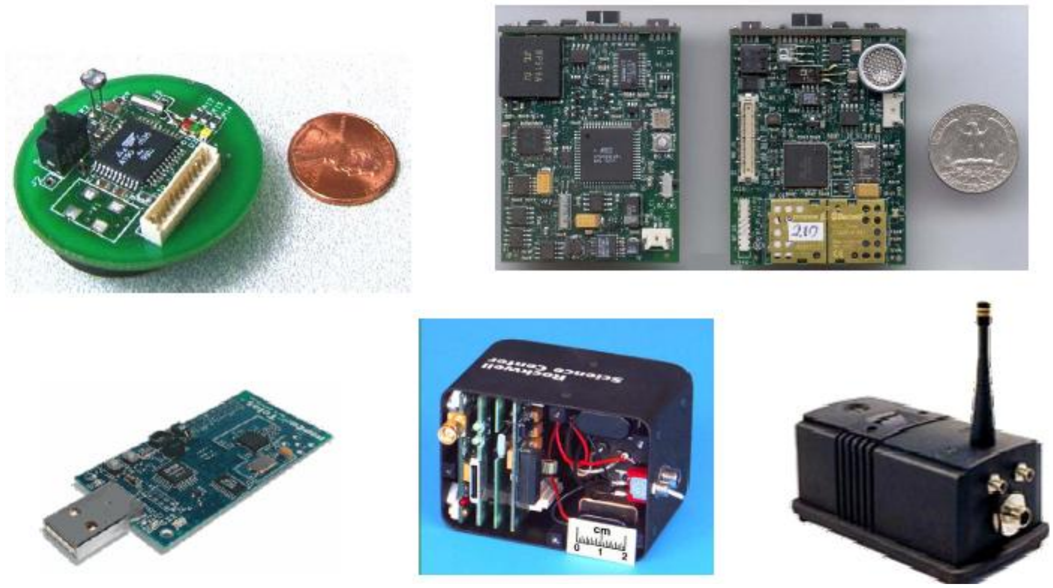


**Figure 1: Sensor Platforms**

A wireless sensor network (WSN) is a set of sensor nodes deployed in a given area. (Fig 2.) The nodes form a network of wireless links capable of collecting, relaying, and processing sensor readings from the physical world in which they are set. Operational models vary greatly due to the wide range of applications in which they are used, but the basic duties of the wireless sensor network remain the same. [1]

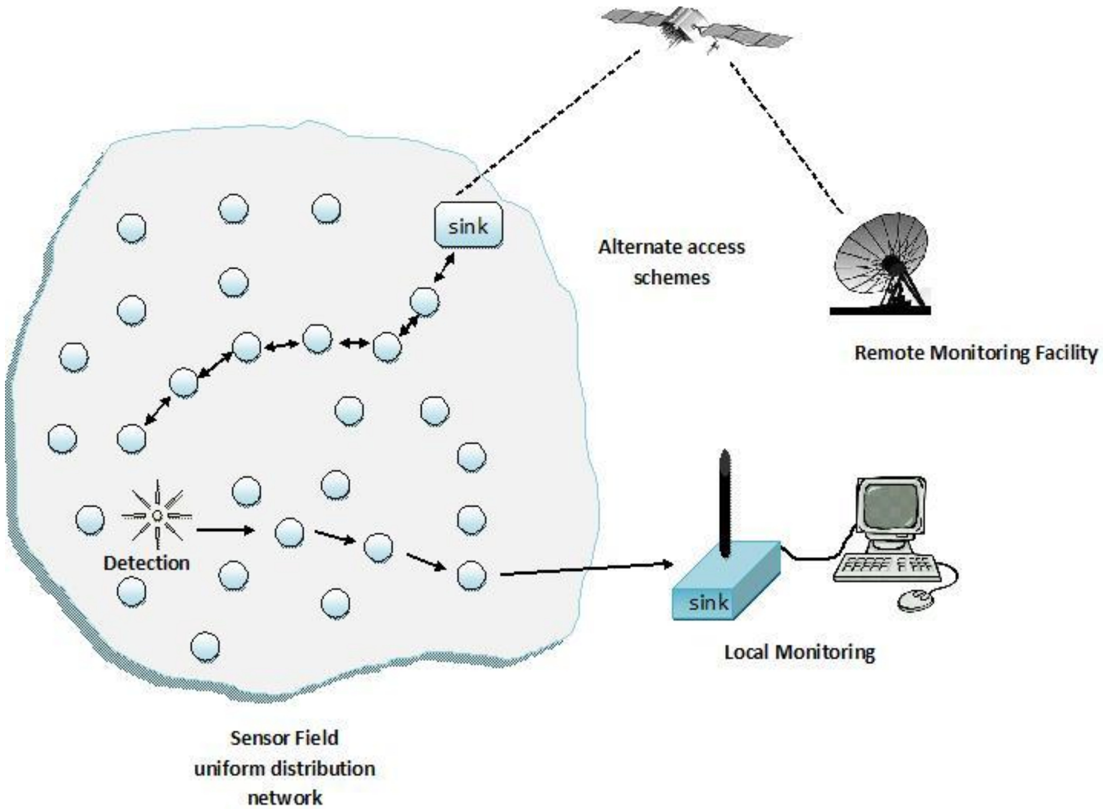



**Figure2 : Sensor Networks**

### 1.2 Wireless sensor devices

Typically a wireless sensor network (WSN) consists of a group of Sensors, a Memory Processor, a Radio transceiver, a Power source and optionally a GPS, (Figure 3.) Details of these components are as follows:

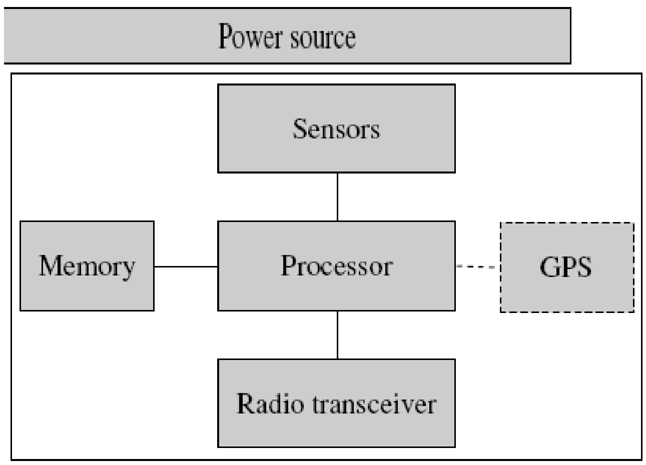



**Figure 3: Basic Wireless Sensor Network Device**

**Low-power processor:** Is the brain of the node. It processes the information it derives locally as well as the information received from communication with the other sensors. There is a wide range of these processors on the market to allow for flexibility in the sensing rage and computational power needed for any given wireless sensor network. Lately the market has widened to include ‘satellite-nodes’ as one of the options in this selection. In the future, WSN devices may have increased processor power that would enable the use of more advanced low-power design techniques including dynamic voltage scaling and efficient sleep modes. The goal of these advances being energy conservation.

**Memory/storage:** Storage in WSN devices includes both random access and read-only memory. Program memory provides the instructions executed by the processor, and the data memory stores the sensor measurements and other local information in both raw and processed form. The largest constraint on the size of memory is cost.

**Radio transceiver:** WSN devices include a low-rate, short-range wireless radio. The radio communication is often the largest single contributor to power usage in the WSN. The available transceivers have limited capabilities, but steps are being taken to improve their cost, spectral efficiency, tuning capability, and immunity to noise, fading, and interference.

**Sensors:** Many of the desired applications of WNS devices require multi-modal sensing, so each device may have several sensors for various data gathering such as, temperature, light, humidity, pressure, or chemical makeup, and may include accelerometers, and magnetometers. These sensors are most often low-rate data sensors because of bandwidth and power constraints.

**Global positioning system (GPS):** In many WSN applications, the need to identify an event location or the source of the sensed data is vital. For this reason, each sensor measurement needs a location stamp. While sensor position can be pre-configured at the time of deployment, this is not always feasible. The potential for GPS interrogation to obtain location is possible in an outdoor environment, but only a small percentage of the nodes may be GPS capable. The biggest factor in the number of sensors with GPS capability being limited by environmental conditions and economic restraints. Therefore,

the other nodes that are not GPS capable, must obtain their position indirectly through network localization algorithms.

**Power source:** To provide the most flexible deployment of WSN devices, they are dependent on battery power (e.g. using LiMH AA batteries). Occasionally some of the nodes may be wired to a continuous power source, and with the use of energy harvesting techniques some power renewal may be achieved, but overall, these networks are dependent on battery power. Therefore the most critical limitation of WSNs is limited battery energy.

Networking the sensors is a primary concern in most applications of WSNs. Most use either a single-hop star topology, or a multi-hop tree structure for the purpose of gathering the locally sensed data. The single-hop star topology is the most simple, consisting of one node designated as the sink, and all data from the other sensor nodes being sent to the sink node. The multi-hop tree structure is more complex, having some nodes that act as both sources and as routers for other sources. The multi-hop configuration is advantageous in networks with lower transmit power settings, or where the area covered by the nodes is vast. Often intermediate nodes are inserted in the routing that not only pass on the packets of data but examine and process the data prior to passing it on. This is referred to as intelligent in-network processing and is used to improve the quality of the collected information.

### 1.3 Applications of wireless sensor networks

The numbers and uses of WSN devices is growing rapidly, although many of the applications are currently still in a research and development stage. Below is a short list of the applications currently on the market.

#### 1.3.1. Military surveillance and target tracking:

As with many other technological advances, wireless sensor networks originated primarily in military-related research. Their advantage in being used for surveillance and to provide battlefield intelligence regarding the location, numbers, movement, and identity of troops and vehicles, and for detection of chemical, biological, and nuclear weapons is obvious. The original research programs that resulted in the creation of WSNs were funded by the US Defense Advanced Research Projects Agency (DARPA)[26] and this funding is still ongoing. Many of the leading US researchers and entrepreneurs in this area have been and currently are being funded by these DARPA programs.

#### 1.3.2 Civil Structures:

Sensor networks are used to monitoring the condition of civil structures, [27] such as buildings, bridges, roads, and even aircraft. Structural health monitoring, [37] uses sensor networks to continuously study the structures and note any changes or damage. These networks can provide a large amount of information on cracks, structural damage,

and other changes in the status of the monitored structure in a timely fashion and eliminates the need for manual, visual, or x-ray inspections. Not only does this save the cost of the labor and equipment used for inspections, a WSN returns a large amount of data in a more timely fashion.

### 1.3.3 Industrial and commercial networked sensing:

Industrial manufacturing facilities have always been dependent on sensors and actuators in quality control. Many of them use data gathering to acquire the necessary real time information that allows for adjustment of any part of the process to improve the yield. With the use of real time monitoring, separate processes can be adjusted, such as changes in temperature, chemical mixes, or humidity. The use of wired systems to accomplish this task is costly in terms of installation, maintenance, and upgrading [28]. Wireless sensor networks can reduce the costs and improve the flexibility of monitoring systems when compared to their wired relatives. Several companies have wireless sensor networks for this application on the commercial market, and the development of standards, such as the IEEE 802.15.4 [29] indicate that there is a very large potential for these products. In addition to manufacturing applications, there are collaborative efforts such as the Zigbee Alliance [30] developing the potential for 'smart-homes' to be offered on the commercial market to consumers.

### 1.3.4 Sensor Applications Utilizing Satellites

Satellite to node integration for transmission of gathered, processed data is highly desired. The advantages of this configuration include reduction in system installation and maintenance costs, better data processing across the network nodes, and the elimination of cables for data transfer. This enhancement would certainly make the use of WSNs more economically feasible. In addition, it increases the system tolerance in the case of a partial system failure. The remaining parts of the system could still perform their function. The primary use of these satellite sensing networks are in the areas of environmental and habitat monitoring, ocean monitoring research and structural health monitoring. In these types of situations, cable and terrestrial installations are not capable of being economically installed and maintained. The use of satellite and integrated sensor networks can improve global coverage, bandwidth allocation, broadcast and multicast ability and rapid deployment. Even the electrical power can be self-contained in some applications. Below is a brief summary of the potential benefits of using sensor networks coupled with a satellite system.

The scientific community has long desired better ways of monitoring habitats and environmental changes. The desired goal is long-term data collection on a large scale and at frequently small resolutions. In many situations, it is impossible to used wired sensors with any degree of success to achieve this goal. On the other hand, with the wireless technology, sensor networks composed of many networked micro-sensors can be distributed throughout the natural setting. In a typical application used to collect data from a particular habitat, the sensors are laid down in dense patches. Each of these patches monitors a specific piece of the habitat but the sensors need to be heterogeneous

in their sensing abilities, storage size and processing power. The sample data from the multitude of patches is sent through the network to an on-site data center. [36] The data center transmits the information via satellite to a monitoring station. The advantages of using this system in areas difficult to access such as isolated islands, ships, planes, rivers, and rural and urban areas, is obvious.

Another potential use of these systems is for tracking ocean data. The richness and biodiversity evident in the oceans and coastal areas has long been under threat from pollution, over-fishing and modifications of the natural environment. Until satellite deployment, it was impossible to achieve repetitive, wide-area monitoring of the worlds oceans. The sensors currently used in satellite oceanographic study include both passive and active sensors to record the amount of incident energy, which is returned from the imaged surface. The information collected to date has drastically changed the scientific understanding of many of the ocean processes and has demonstrated that they are interlinked. Further, it delivers information on an eclectic grouping of geophysical and biological parameters and other ocean phenomena. [35] This data is vital for the long-term goal of sustained development and management of the many oceanic natural resources.

### 1.4 Design challenges

Wireless sensor networks have some serious design challenges, which make them an interesting engineering exercise. These issues cannot be acceptably resolved with current technology.

**1. Extended lifetime:** The main advantage of WSNs relies on their ability to be deployed and functional for several years without the need of constant maintenance. This advantage is negated if there is a constant requirement to replace the batteries, which

provide the nodes their energy. The current battery capability is severely limited. **In full active mode, each node will consume the power in a typical alkaline battery (50 watt-hours) in less than a month.** In a large network, this is unacceptable due to cost and man-hours required to replace the batteries alone. Potential hardware improvements to battery design and the use of energy harvesting techniques will improve this situation, but cannot be expected to overcome this limitation. This is the defining reason most protocol designs in wireless sensor networks rate energy efficiency as the number one goal.

**2. Robustness:** The challenge of minimizing device failures is another key problem with the wireless sensor systems. The ideal would be for the system to degrade due to component failures over a long period of time. This can be a particularly difficult to achieve in extremely harsh or hostile environments. It is vital, therefore, that protocol designs incorporate built-in mechanisms to maintain system robustness, insuring that system performance not be sensitive to individual device failures. The ultimate goal of WSNs is to provide fine-grained coverage over a large scale which requires a large number of components. Cost considerations often require that these be inexpensive. However, inexpensive devices can often be unreliable and are more prone to failures. The solution to this problem lies in the improvement and lowered cost of individual devices as well as improved design protocols to insure the integrity of the system.

**3. Synergy:** Advances in technology resulting from the application of Moore's law have increased device capabilities in terms of processing power, memory, storage, radio transceiver performance, and even accuracy of sensing (given a fixed cost). But

even with these gains, if economic considerations dictate that the cost per node be drastically reduced by an amount of 50 percent every 18 months [38], it is expected that the capabilities of individual nodes will remain constrained to some extent. This extends the design challenge with regards to synergistic protocols, which ensure that the system as a whole is more capable than the sum of the capabilities of its individual components. The protocols must provide an efficient collaborative use of storage, computation, and communication resources.

**4. Scalability:** To accomplish the coverage of a large area, while maintaining fine granularity sensing, the size of the wireless sensor network could reach into the tens of thousands, perhaps millions of nodes. This creates a problem with data retrieval. Although there are fundamental limits on data handling and throughput, which will impact the scalability of networks, protocols can improve the potential scale of the application by using localized communication, and by creating sensor networks that utilize hierarchical architectures. However before networks can be deployed on such a large scale, basic problems such as failure handling and *in situ* reprogramming must be addressed.

**5. Heterogeneity:** Not every sensor need have the same capabilities with regard to computation, communication and sensing. Designs that incorporate a two-tier, cluster-based network architecture require only a small number of devices with higher computational capability, coupled with a large number of low-capability components. In addition, if the network uses multiple sensing modalities, efficient sensor fusion

techniques is required.  The biggest challenge in design concerning heterogeneity is the right combination of device capabilities for a given application.

**6. Self-configuration:** The primary advantage to wireless sensor networks is their ability to be autonomous.  In order to function in this condition, nodes must be able to configure their own network topology: localize, synchronize, and calibrate themselves; coordinate inter-node communication; and determine other important operating parameters. This makes autonomous operation a key design feature. Only when this is achieved can the network achieve its goal of being unattended.

**7. Self-optimization and adaptation:** Traditionally, each engineering system is designed based on well-modeled operating conditions and optimized *a priori* for maximum efficiency.  This presents two challenges for wireless sensor networks.  First, it is often impossible to model the operating conditions prior to deployment of the WSN, and second, the environment in which the WSN is deployed may be subject to drastic change over time.  With these problems in mind, it is vital that networks have the ability to learn from sensor and network measurements over time and use this knowledge to continually improve their performance.  Adaptable networks must gather, analyze, and respond to environmental dynamics.

**8. Systematic design:** A wireless sensor network, like any other engineering design, is faced with the choice of design for a narrow application, which can be

optimized for best performance, or a more general design that is applicable in more settings, but sacrifices some of the efficiency. While performance optimization is extremely important, particularly in consideration of the severe resource constraints in wireless sensor networks, it is obvious that other factors such as run-time adaptation, systematic design methodologies, allowing for reuse, modularity are required for the systems to be practical.

**9. Privacy and security:** The large scale, prevalence, and sensitivity of the information collected by wireless sensor networks (as well as their potential deployment in hostile locations) give rise to the final key challenge of ensuring both privacy and security.

# CHAPTER 2

# COVERAGE PROBLEM

## 2.1 Coverage Problem in Other Fields

The problem of coverage can be faced in different fields, each having its own special meaning, terminologies and objectives. The solution to the coverage problem is to blanket the desired area using the minimum number of ‘observers’ required to achieve this goal. The area can be planar or volumetric, and the sensors can have limited capabilities.

For example, the Art Gallery Problem [7] requires determining the number and placement of sensors in order to meet the condition that every point in the art gallery room is seen by at least one observer. This problem has a linear time solution for the 2D case. The 3D version is much more difficult.

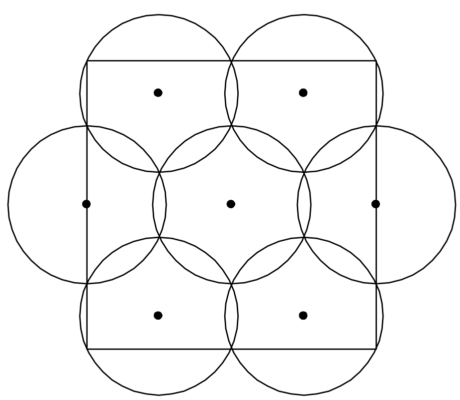


**Figure 4: An Example of An Optimal Covering With 7 Circles.**

Another related problem in computational geometry is referred to as the circle covering problem. [11] The solution to this problem is to arrange circles on a plane in such a manner that the circles can fully cover the entire plane. Given a fixed number of circles, the goal is to minimize the radius of circles. This issue is discussed in [3] for the covering of a rectangle. The mathematics demonstrates that covering of five or seven circles is optimal [3]. The optimal covering of seven circles is shown in Fig.2.1.

## 2.2 Coverage Problem in WSN

The coverage problem in WSN hinges on the basic question**: How well do the sensors observe the physical space?** In wireless sensor networks, the goal is to deploy sensors in a service area in such a manner that the entire service area is within sensing range of at least one sensor. As in [6] the coverage is a measure of the quality of service (QoS) of the sensing function. The large variety of sensors and applications make this difficult to measure, keeping in mind the goal of having every location in the area of interest within the range of at least one sensor.

Selection of sensors for any given network can be based on several factors. A few of the determining factors are; size, weight, cost restrictions, processor power, communication capabilities and limited battery resources. Since it is often difficult to replace batteries in deployed sensors, low power consumption is crucial. Energy conservation is a primary goal, both in the hardware and architectural design, and in the algorithms and protocols of the network design. Network lifetime is defined as the time interval the network is able to perform the sensing functions and to transmit data to the sink. The wireless sensor networks are considered to have a lifetime of around one year.

In order to maximize the usability of the network the energy consumption of each device and the network as a whole must be at a minimum. In addition, it is important that the number of sensors be kept as low as possible, especially in a deterministic node deployment.

### 2.3 Fundamental Coverage Problems in Wireless Sensor Networks

An important problem is to identify fundamental concepts of coverage that apply to a class of applications. The main concepts of full coverage will be discussed in this thesis.

A wireless sensor network is said to provide full coverage in a region if every point in the region is within the monitoring range of some sensor. The network is said to provide k-full coverage, or simply k-coverage, if every point in the region is within the monitoring range of at least k distinct sensors [29].For this concept of coverage, several fundamental problems need to be addressed.

### 2.3.1 Optimal Deployment Pattern

For a given concept of coverage criterion (say k-coverage), the challenge of sensor deployment, is to pattern the individual sensors to insure the network has the desired amount of coverage with the fewest possible sensors to achieve that coverage.

A known method of deploying sensors to achieve 1-coverage is to place them on the vertices of a triangular lattice. [4] This method assumes that all sensors in the sensing area are disks of a known and uniform radius. The minimum number of sensors needed for the desired area and quality of coverage is termed the optimal deployment pattern. This can help determine other patterns of deployment that are used in actual practice.

### 2.3.2 Critical Conditions

Optimal deployment patterns are only useful if it is possible to place the sensors where desired. In some applications, particularly in harsh or rugged terrains, individual sensor placement may not be achievable. In these circumstances, a probability distribution is likely to be followed to determine sensor placement. The inherent problem of deriving critical conditions using probabilistic deployment is to establish the minimum number of sensors needed to achieve a desired quality of monitoring.

### 2.3.3 Coverage Determination

Once a wireless sensor network is in place, it is likely that some sensors will fail over time for various reasons. These reasons range from physical failure due to environmental factors, (wind, rain, heat or impact damage), to battery failures or

reprogramming failures, etc. The problem of coverage determination become one of determining if a currently deployed sensor network can provide the desired quality of monitoring with its currently active sensors. An algorithm designed for this purpose will produce a "yes/no" answer.

### 2.3.4 Coverage Restoration

If a deployed wireless sensor network does not provide the desired quality of monitoring (determined using a coverage determination algorithm), the deployment of additional sensors is needed to restore the necessary quality of monitoring. This is termed the coverage restoration. It requires that the number and location of additional sensors be determined that will restore network monitoring at the desired quality level. The optimal deployment pattern is a special case of the coverage restoration problem. If no sensors are active, the solution to coverage restoration will result in the optimal deployment pattern.

### 2.3.5 Optimal Sleep Wakeup

A wireless sensor network is subject to numerous types of faults once it is deployed which will eliminate some individual sensors over time. Redundant sensors can be put in place to compensate for these unanticipated failures. The redundant sensors can be put to sleep, in turns, to increase the network lifetime. Since the lifetime of each sensor is limited to a month or so, increasing the maximum lifetime of a network by exploiting redundancy in the network is an important solution. The goal of optimal sleep wakeup is to design a schedule for the sleep and wakeup of individual sensors in such a

manner that the lifetime of the wireless sensor network is maximized while maintaining the desired quality of monitoring with the set of active sensors.

### 2.4 Objective of this work:

Review and examine the coverage problem and scheduling schemas in wireless sensor networks, which are important for development of WSN applications. In addition, examine the RID (random independent deployment) analytical model by Kumar, which uses randomized independent scheduling mechanism of the sensors, and compare it to the results of the simulation. Finally, examine the potential of upgrading the system by the addition of ‘satellite nodes’ and test their enhancement of the coverage problem [16] for the application areas that require satellite links.

# CHAPTER 3

## Scheduling Mechanisms

Sensor networks have a wide variety of applications, some of which, e.g., natural habitat monitoring, require a large number of tiny sensors and these sensors usually operate on limited battery power. Individual sensors can last only 100–120 hours on a pair of AAA batteries in the active mode [16]. Since the number of sensors is huge and they may be deployed in remote, and sometimes unreachable environments, it is usually difficult, if not impossible, to recharge or replace their batteries. This problem is further increased by the fact that battery capacity has only doubled in the last 35 years [17]. Therefore optimal energy consumption of the sensor network to increase its lifetime is a chief design objective, especially for networks that are aimed to last for several months to a year.

To minimize energy consumption and extend network lifetime with some level of coverage, a common technique is to put some sensors in the sleep mode and put the others in the active mode for the sensing and communication tasks. When a sensor is in the sleep mode, it is shut down except for a low-power timer to wake up the sensor at a later time [18]; therefore it consumes only a tiny fraction of the energy consumed in the active mode [16, 19]. Moreover, in cluster-based networks, cluster heads are usually selected in a way that minimizes the total energy consumption and they may rotate among the sensors to balance energy consumption.

There are many scheduling mechanisms published in the literature. Each scheduling mechanism has its own assumptions that are inherent to that specific

application. The design assumptions include detection model, sensing area, transmission range, failure model, time synchronization, location information, and distance information. There are also different assumptions about network structure and sensor deployment strategy. Furthermore, while all the mechanisms have a common design objective, to maximize network lifetime with some level of coverage, they may also have different objectives determined by their specific applications.

While it is unfair to compare the scheduling mechanisms without considering the different assumptions and objectives, some of them are more applicable than others, or at least easier to apply. For example, some of these proposed mechanisms require a large degree of time-synchronization with complicated interactions and task distribution between sensors. This paper reviews the main and most well known scheduling mechanisms found in the literature. Thus to find the scheduling that can be applied and start to work more in evaluate and enhancement it to get my new system. In the scenario below, the network is assumed to be flat, i.e., every sensor has the same role and functionality.

**Selected Methods for WSN Scheduling Mechanisms**

### 3.1. Sponsored Sector

This mechanism, proposed by Tian and Georgana [20] allows a sensor to turn off only if its sensing area is *completely* covered by its neighbors' sensing areas—the neighbors are called the *off-duty sponsors* of this node, and the sector that a neighbor covers in its sensing area is referred to as a *sponsored sector*. Each sensor uses its neighbors' location information and sensing range to determine the sponsored sectors and

evaluates their central angles. If the entire 360° area of the central angle is covered, then the node is eligible to enter the off-duty mode.

Note that this mechanism only considers those neighbors within a node's sensing area to be potential off-duty sponsors, i.e., neighbors in the ( r , 2r) range are ignored even if their coverage may overlap with this node's sensing area. As a result, the Sponsored Sector mechanism may underestimate the number of sensors that can be turned off.

The operation of Sponsored Sector is divided into rounds. In each round, the sensors start in a *self-scheduling phase,* in which they obtain neighbors' location information and decide whether or not to turn off. Then the on-duty sensors enter a sensing phase in which they gather sensing data. Obviously, the energy saving depends on the length of the self-scheduling phase in comparison to the duration of each round; the quicker the sensors stabilize in the self-scheduling phase, the more energy will be saved.

In summary, the Sponsored Sector mechanism has the following major characteristics: (1) nodes need accurate location information (2) nodes are time-synchronized so they know the beginning of each round (3) there is a message overhead for advertising location information and scheduling (but only at the beginning of each round) (4) nodes maintain a per-neighbor state to keep track of the number of active neighbors (5) in each round, working nodes never go back to sleep and (6) the off-duty eligibility rule is relatively conservative compared to some of the other mechanisms. The set of working nodes may be different in different rounds, so energy consumption may still be balanced among the nodes, but due to the conservative off-duty eligibility, the resulting energy saving may not be as high as other mechanisms.

### 3.2 Maximization of Sensor Network Life (MSNL)

Berman et al. [21] formulated the sleep-scheduling problem as a maximization problem with constraints on battery lifetime and sensing coverage. They also presented a centralized and a distributed algorithm to maximize network lifetime while achieving k-coverage. Their distributed mechanism can guarantee a *specific degree* of sensing coverage (assuming that the sensor density is high enough) in contrast to the aforementioned Sponsored Sector mechanism which preserves the *existing* coverage degree. In this mechanism, each sensor is in one of three states: *active*, *idle* or *vulnerable*. In the vulnerable state, if a sensor discovers that part of its sensing area cannot be covered by any of its active or vulnerable neighbors, it immediately enters the *active* state. If its sensing area is covered by either active or vulnerable neighbors with a higher energy level, it becomes *idle*.

In summary, the above mechanism can guarantee a *specific degree* of sensing coverage. Below are the major characteristics of this algorithm: (1) nodes need accurate location information (2) although nodes are not time-synchronized, they have semi-synchronous monitoring schedules (due to global reshuffles) (3) nodes need to broadcast their state and energy level in addition to their location and (4) nodes cannot completely turn themselves off in the idle state.

### 3.3 Probing Environment and Adaptive Sensing (PEAS)

Ye et al. [22] developed a mechanism called PEAS (Probing Environment and Adaptive Sensing) that can extend the lifetime of a high-density sensor network in a harsh environment. What distinguish this work from the previous studies is its assumptions. First, it assumes that sensor nodes may fail frequently and unexpectedly, which makes

synchronized sleeping algorithms infeasible because they depend on the predictability of sensors' lifetime. Second, it assumes that the sensor network is so dense that the total number of sensors may be orders of magnitude higher than the number of working nodes. As a result, it is infeasible for nodes to maintain per-neighbor state. Lastly, it assumes that nodes do not have location information. The authors argue that these assumptions lead to a design that is more robust against failures and easier to implement in a real sensor network.

PEAS conserve energy by separating all the working nodes by a minimum distance of $c$. After sleeping for a random period, each node broadcasts a message (probe) within a set transmission range to determine if there is a working neighbor nearby. A node will enter the on-duty mode only if it receives no replies from working neighbors; otherwise it will stay in the off-duty mode. In the same paper, Ye et al. proved that PEAS can guarantee *asymptotic connectivity* as long as the sensor network satisfies the two conditions of sensor density and probing range.

In summary, PEAS achieves asymptotic network connectivity. Below are the major characteristics of PEAS: (1) nodes are assumed to be randomly and uniformly distributed (2) nodes do not need accurate location information (3) nodes have asynchronous schedules (4) unlike most of the surveyed mechanisms, nodes do not maintain per-neighbor state (5) working nodes never go back to sleep, which may result in unbalanced energy consumption and (6) nodes adapt their probing rate to control the overall message overhead.

### 3.4 Lightweight Deployment-Aware Scheduling (LDAS)

Wu et al. [23] proposed a distributed scheduling mechanism called LDAS (Lightweight Deployment-Aware Scheduling). Like PEAS, LDAS does not need accurate location information. Since it is difficult, if not impossible, to determine whether a node's sensing area is *absolutely* covered by other nodes without location information the goal here is to provide *statistical* guarantees on sensing coverage. Note that PEAS [22] does not assume the knowledge of location information either, but this work is complementary to PEAS [22] as the latter guarantees *asymptotic network connectivity*. LDAS assumes that each working node has a mechanism to know the number of working nodes in its neighborhood. When the number of working neighbors exceeds a threshold determined by the application's requirement on sensing coverage, the node randomly selects some of its neighbors to turn off and sends tickets to them. When a node collects enough tickets from its neighbors, it may enter the off-duty mode after a random back-off period.

In summary, LDAS can achieve a specific level of partial sensing coverage in a statistical sense. Below are the major characteristics of LDAS: (1) nodes are assumed to be randomly and uniformly distributed over the coverage area (2) Like PEAS, LDAS does not require accurate location information (3) each node needs to know how many sensors are within its sensing range and (4) energy consumption is balanced among the nodes since the longer a node works, the more tickets it may accumulate and the more likely it will be to turned off.

### 3.5. Optimal Geographic Density Control (OGDC)

Zhang and Hou proved that 1-coverage implies 1-connectivity when the ratio between the radio transmission range and the sensing range is at least two [24]. Assuming that this condition is satisfied, Zhang and Hou further proposed a distributed mechanism, Optimal Geographic Density Control (OGDC), to maximize the number of sleeping sensors while ensuring that the working sensors provide complete 1-coverage and 1-connectivity [24]. OGDC tries to minimize the overlapping area between the working sensors. A sensor is turned on only if it minimizes the overlapping area with the existing working sensors and if it covers an intersection point of two working sensors. A sensor can verify whether it satisfies these conditions using its own location and the working sensors' locations. OGDC's protocol is quite similar to that of the Sponsored Sector mechanism, except they use different on-duty/off-duty eligibility rules. These rules make the OGDC less conservative in comparison to the Sponsored Sector mechanism when turning off sensors.

In summary, OGDC can maintain both 1-coverage and 1-connectivity when the radio transmission range is at least twice the sensing range. It has the following major characteristics: (1) nodes need accurate location information (2) nodes need to maintain time synchronization (3) there is message overhead for advertising location information and scheduling *only at the beginning of each round* and (4) in each round, working nodes never go back to sleep. Different nodes may be working in different rounds so energy consumption may still be balanced among all the nodes.

### 3.6. Coverage Configuration Protocol (CCP)

Wang et al. proposed an integrated coverage and connectivity configuration protocol called CCP [25]. This protocol aims to maximize the number of sleeping nodes, while maintaining both k-coverage and k-connectivity. Note that while the OGDC mechanism ensures 1-coverage and 1-connectivity, CCP's capability is based on the theorem that k-coverage implies k-connectivity when the transmission range is maintained at two times the sensing range. To ensure k-coverage, a node only needs to check whether the intersection points inside its sensing area are k-covered (based on a theorem proved in [25] also).

Nodes running CCP are in one of three modes: ACTIVE, LISTEN and SLEEP. Each node is initially in the ACTIVE mode and when it receives a message, it determines whether it should go to SLEEP. If so, it enters the LISTEN mode and starts a random timer (the LISTEN mode could be either the on-duty mode or the TR-on-duty mode in our terminology). When this timer expires and if the node is still eligible to sleep, it will enter into the SLEEP mode. Otherwise, it will stay in the LISTEN mode. In the SLEEP mode, a node will also set a random timer. When the timer expires, it will enter the LISTEN mode and check if it is still eligible to sleep. If eligibility is met, it will go back to sleep. Otherwise, it will enter the ACTIVE mode.

Below are the major characteristics of CCP: (1) CCP requires accurate location information (2) each node needs to maintain a neighborhood table (3) nodes have asynchronous sleep schedules and (4) working nodes may go back to sleep, so that the energy consumption is balanced among all the nodes.

### 3.7. Random independent scheduling (RIS)

In [19], Kumar et al. adopt the Randomized Independent Scheduling (RIS) mechanism to extend network lifetime while achieving asymptotic k-coverage. RIS assumes that time is divided into cycles based on a *time synchronization* method. At the beginning of a cycle, each sensor independently decides whether to become active with probability p or go to sleep with probability 1-p. Thus the network lifetime is increased by a factor close to 1/p (i.e., p determines the network lifetime).

Furthermore, Kumar et al. derived the conditions for *asymptotic* k-*coverage* when RIS is used with three different sensor deployment strategies—grid, random uniform, and 2-dimensional Poisson. Their results can be applied in several ways. First, the number of sensors that should be initially deployed can be determined in order to ensure asymptotic k-coverage. Second, the number of additional sensors needed or the new value of p when dynamically reconfiguring the network to a different degree of coverage can be calculated. Note that these results only apply to the RIS mechanism.

RIS is a self-scheduling mechanism. It has the following major characteristics: (1) it does not require location or distance information (2) nodes do not maintain a neighborhood table and (3) the sensors do not dynamically evaluate their situation. Because there is no dynamic evaluation, the basic RIS mechanism is not robust against unexpected failures that destroy the sensors before they run out of energy. One simple solution is to let the base station periodically evaluate the network performance. The base station can then take action to retrieve the required coverage by reconfiguring the sensors' parameters or by increasing the sensor density.

RIS scheduling is more practical in real applications because of the assumption of random deployment, which is the only deployment possible for some applications. Also, it does not need location or distance information of the sensors, which make the process easier and cheaper. It can save the overhead that is necessary with other scheduling. Therefore, this scheduling mechanism was chosen to be the basis of the proposed new scheduling scheme. The following chapter summarizes the analytical model for random deployment. In fact, the original work by Kumer et al [19] solved the problem for grid, random and Poisson deployment, however, there was no simulation done for random deployment.

## CHAPTER 4

## RANDOMIZED INDEPENDENT SCHEDULING MODEL

In this chapter the analytical model for WSN using Kumar's random deployment is examined. The model is changed to calculate the coverage using squares for representation of the sensing range instead of circles. In addition, a program is used to execute the analytical model of Kumar and compare the results with those found in Kumar's study.

### 4.1 Definitions

*n*: number of sensors deployed

*p*: probability that a sensor will remain active

*r*: sensing radius

1-*coverage*: a point in the region is 1-covered if it is within the sensing radius of at least one active sensor. The region is 1-covered if every point in it is 1-covered.

*K-coverage*: a point in the region is *k*-covered if it is within the sensing radius of *k* or more active sensors. The region is *k*-covered if every point in it is *k*-covered.

*Slowly growing function*: A function $\phi(np)$ is slowly growing if it is monotonically increasing, goes to infinity as $n \to \infty$ and is $o(\log(\log(np)))$.

We write $g(x) = o(f(x))$ iff $\lim_{x\to\infty} g(x)/f(x) = 0$, $g(x) = \omega(f(x))$ iff $\lim_{x\to\infty} g(x)/f(x) = \infty$, and $g(x) \approx f(x)$ iff $\lim_{x\to\infty} g(x)/f(x) = 1$

$$c(n) = \frac{n p \pi r^2}{\log(n p)}$$

For each point $u \in L$, let $A(u)$ denote the event that $u$ is covered; and $\overline{A(u)}$, its negation.

Ak (u) and its negative

E(x) == expected value

$\phi^{'}(np) = \phi(np) - o(c(n))$

*Nr*(*u*) denote the number of active sensors in *Dr*(*u*), and *Pi*(*u*) = *Pr*[*Nr*(*u*) = *i*]

*Dr*(*u*): the disc of radius *r* centered at the point *u*.

The exploration begins by demonstrating that if a certain (finite) set of points in the unit square is *k*-covered by a sensor network with a certain sensing radius, then the entire region is *k*-covered by the same sensor network with a slightly larger sensing radius. The set of points that have been used, denoted by *L*, is the set of all grid-points of a $\sqrt{l} \times \sqrt{l}$ virtual grid on the unit square region as illustrated in Figure 1. The *L* in the next lemma refers to this set. With this result, when desiring to show the unit square is *k*-covered, we will only need to show that *L*, with an appropriate value of *l*, is *k*-covered.

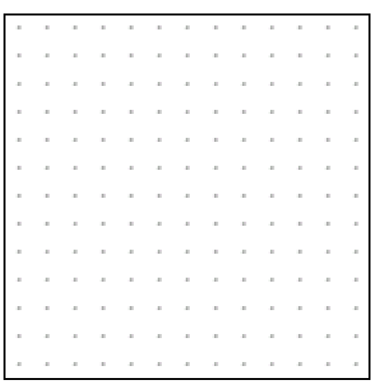


**Figure 5: The Unit Square Region Tiled With a Virtual Grid with l = 169 Points**

**4.2 Theory No. 1:**

Let $r'$, $r$ and $l$ be constants such that $r' = r - 1/\sqrt{2l}$, and let $L$ be the set of all grid points of the $\sqrt{l} \times \sqrt{l}$ virtual grid. If $L$ is $k$-covered by a network with sensing radius $r'$, then the entire unit square region is $k$-covered by the same network but with sensing radius $r$.

**Proof:**

Let $v$ be an arbitrary point in the square region. Without loss of generality, we may assume it is inside the square formed by some set of four points $a$, $b$, $c$, and $d$ on the virtual grid as shown in Figure 2. Also, without loss of generality, we may assume that it is closest to the point $a$. By assumption, there exist at least $k$ active sensors that cover point $a$. Let one of these be located at point $u$ as shown in Figure 2. Then, $d(u, a) < r'$. From triangle inequality,

$$d(u,v) \le d(u,a) + d(a,v) < r' + \frac{1}{\sqrt{2l}} = r$$

The same holds for the other active sensors covering point $a$. Therefore, we conclude that every point in the region is $k$-covered by using a sensing radius of $r$; if all the points on the virtual grid are $k$-covered using a sensing radius of $r'$. So we need a bit larger radius to include coverage of the area between the virtual grid points.

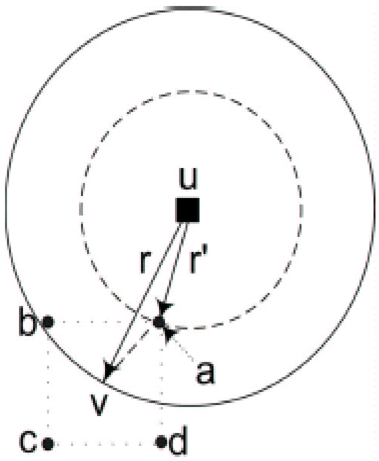



**Figure 6: A set of Four Nearest Points on the Virtual Grid.**

## 4.3 Random Uniform Distribution

In uniform distribution, *n* nodes are distributed uniformly over the square region of unit area as illustrated in Figure 3. Under this distribution, each node has an equal likelihood of being at any location in the region; and the probability of a given node being in any sub region of area is R.

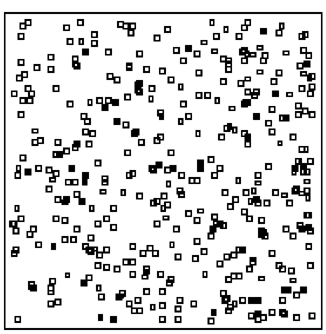


**Figure 7: Random Uniform Deployment of Sensors on A Unit Square with N = 400 and P = 0.1. The Filled Squares Represent Active Sensors.**

## 4.4 Theorem No. 2

Let *n* sensors be deployed uniformly over a unit square region. If, for some slowly growing function $\phi(np)$, *p* and *r* satisfy:

$$c(n) = 1 + \frac{\phi(np) + k\log(\log(np))}{\log(np)}$$

For sufficiently large *n*, the unit square region is almost always k-covered.

**Proof:**

Here, we prove a corresponding claim: If *p* and *r* satisfy:

$$c(n) = 1 + \frac{\phi(np) + k\log(\log(np))}{\log(np)} \qquad (1.1)$$

then *L* is *k*-covered, where *L* contains *l* grid points, with $l = (np)\phi^{'}(np)\log(np)$ (1.2).

To prove this:

For points $u \in L$, event $\overline{A(u)}$ occurs if all the sensors in disc Dr (u) are inactive.

The number of sensors that are within disc Dr (u) is $m \geq m_l = \pi r^2 n$. Thus:

$$\Pr[\overline{A(u)}] = (1-p)^m \leq (1-p)^{m_l} \leq e^{-pm_l}$$

It can be easily verified that $pm_l = c\log(np)$

Therefore,

$$\Pr[\overline{A(u)}] \leq e^{-pm_l} = (np)^{-c}$$

And

$$\Pr[A(u)] \geq 1-(np)^{-c}$$

Now: $P_0(u) = \Pr[\overline{A(u)}]$

Let $\delta > 0$ be any constant such that $\limsup_{n\to\infty} p < 1-\delta$; such a constant exists since by assumption (Sec. 4.1), $\limsup_{n\to\infty} p < 1$.

And: $P_i(u) = \binom{m}{i} p^i (1-p)^{m_l - i} \le (np)^{-c} \beta^i$

Where $\beta = \dfrac{ec\log(np)}{\delta}$, and the relation … was used.

The event $\overline{A_k(u)}$ occurs if less k sensors are active in the disc Dr (u). Therefore,

$$\Pr[\overline{A_k(u)}] = \sum_{i=0}^{k-1} P_i(u) \le \sum_{i=0}^{k-1} (np)^{-c} \beta^i \approx (np)^{-c} \beta^{k-1}$$

$$\Rightarrow \Pr[A_k(u)] = 1-(np)^{-c} \beta^{k-1}$$

For any point $i \in L$, Let $X_k(i)$ is an indicator random variable of event $\overline{A_k(i)}$ assuming a value of 1 if the virtual grid point *i* is not *k*-covered, and 0 otherwise. Let $X_k$ be the number of points in *L* which are not *k*-covered, i.e., $X_k = X_k(1) + X_k(2) + ... + X_k(l)$. $L$ is *k*-covered iff $X_k = 0$. $X_k > 0$ is a sufficient condition that *L* is not *k*-covered.

It is clear that:

$$\mathrm{E}[X_k(u)] = \Pr[\overline{A_k(u)}] \le (np)^{-c} \beta^{k-1}$$

$$\Rightarrow \mathrm{E}[X_k] = l \Pr[\overline{A_k(u)}] \le l (np)^{-c} \beta^{k-1}$$

Since $X_k$ is a nonnegative integral valued random variable, $\Pr[X_k > 0] \le \mathrm{E}[X_k]$, and therefore, we have

$$\Pr[\bigcup_{i \in L} A_k(i)] = 1 - \Pr[X_k > 0]$$
$$\ge 1 - l\,(np)^{-c}\,\beta^{k-1} \qquad (1.3)$$

Now substituting with the assumptions (1.1), (1.2), we have:

$$\log(l\,(np)^{-c}\,\beta^{k-1}) = -\phi(np) + \log(\phi^{'}(np)) + (k-1)\log(\frac{ec}{\delta}) \qquad (1.4)$$

The right hand side of (1.4) approaches $-\infty$ forcing the right hand side of (1.3) to approach 1, which implies that all the grid points on the virtual grid are *k*-covered. Exploiting theorem 1 then concludes that all the points in the unit square region are *k*-covered.

**Corollary:** Let *n* sensors be deployed uniformly over a unit square region. If, for some slowly growing $\phi(np)$, *p* and *r* satisfy

$$c(n) \ge 1 + \frac{\phi(np) + k\log(\log(np))}{\log(np)}$$

For sufficiently large *n*, then the entire square region is almost always *k*-covered.

**4.5 The square representation**

If the analytical model is changed to represent the sensing range of wireless sensor using a square instead of a circle representation (see fig 8.), the analytical model will be the same except the following:

$$c(n) = \frac{np(2r)^2}{\log(np)}$$ and the reset will be the same.

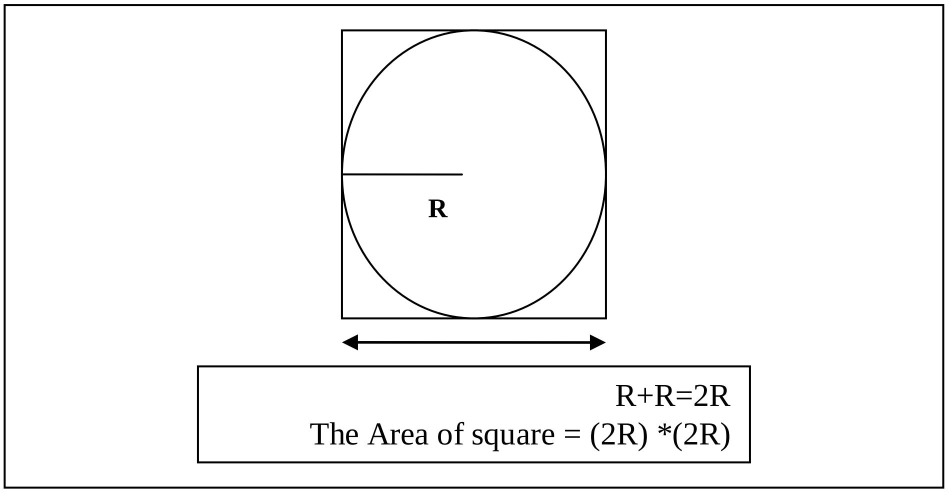



**Figure 8: The Square Relative to the Circle**

## 4.6 The Analytical results

Software called mathematic is used to program the analytical model for both circle and square. In addition, the program is checked for validity by substituting the same variables used in Kumar's work and comparing the outcomes. Since these agree, we know we have a valid program for an analytical model and we are ready for simulation. The simulation follows in the next chapter.

# CHAPTER 5

## SIMULATION METHODOLOGY, RESULTS AND ANALYSIS

5.1 Simulation Methodology

In this chapter the simulation methodology, results and analysis are presented. The coverage problem for K-coverage is modeled using the java program for the random deployment (with and without SN.) The number of sensors needed for each level of coverage is calculated and the result is compared with the analytical model results using the same parameters. However, Kumar did not do a simulation for random deployment, only an analytical model. In this way we evaluate our code, Kumar's model, and the new square analytical model. Next the new scheduling SWSN (satellite wireless sensor networks) is studied and its performance compared to random deployment, with regards to coverage, power consumption and delay.

### 5.1 Simulation Model

Our first set of simulations is based on the communication model. Nodes are randomly distributed in a 100 u × 100 u (u is unit) region that is covered by a set of active nodes chosen randomly. These become active with probability (p); some nodes are turned off for energy conservation with probability (1-p). All nodes have the same sensing range of 1.5 u, and communication range of twice the sensing range (3 u). On the other hand the SN does not do any sensing but is used for communication and its range is similar to the communication node of the normal sensor. The N (N number of sensor deployed) is changed to measure the network coverage under different range ratios. N starts from a best-case senario, in which each sensor will sense 5 cells with no overlapping. Since we

need the wireless sensor network to work ten times we need at least ten sensors for each 5 cells. In our case we have 10000 cells, so the minimum number should be:

$$N_{\min} = \frac{10 \times 10{,}000}{5} = 20{,}000\,Sensors$$

The average of 100 runs on different period of operation is taken. In each round, a sensor is checked to see whether it works or not. If it works, it will be used in the network for sensing, communication or coverage.

### 5.2 Model Formulatio

The problem is formulated in the following way:

The area is assumed to be a two dimensional array. Since it is square area $\sqrt{l} \times \sqrt{l}$ this virtual grid is used for simplifying the problem and dividing the area to small cells. (See fig 9.)

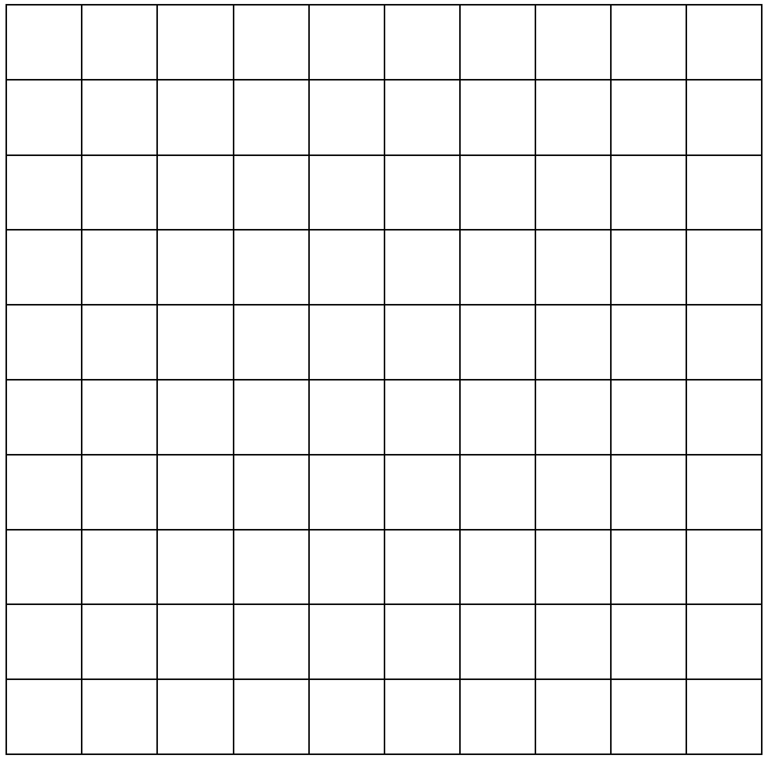


**Figure9 : The Area is Divided to Virtual Grid**

When a sensor is allocated in a cell, it is assumed that it can sense the cell allocated inside, up, down, left and right of the cell. (See fig 10.) Each sensor will sense five cells. However, the SN node communication range can cover two cells in each direction with a total of 13 cells. (figure 10.)

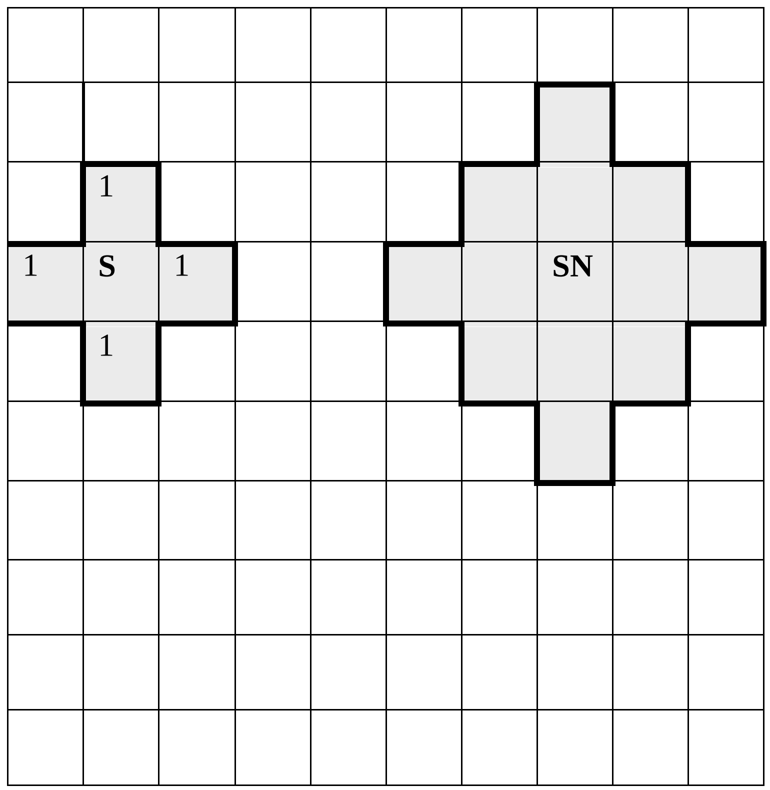



**Figure10 : The Sensing Rang for S and Communication Rang For SN**

The flow diagram for the simulation is as follows:

N: number of sensors to be deployed.

C: counter.

T: time.

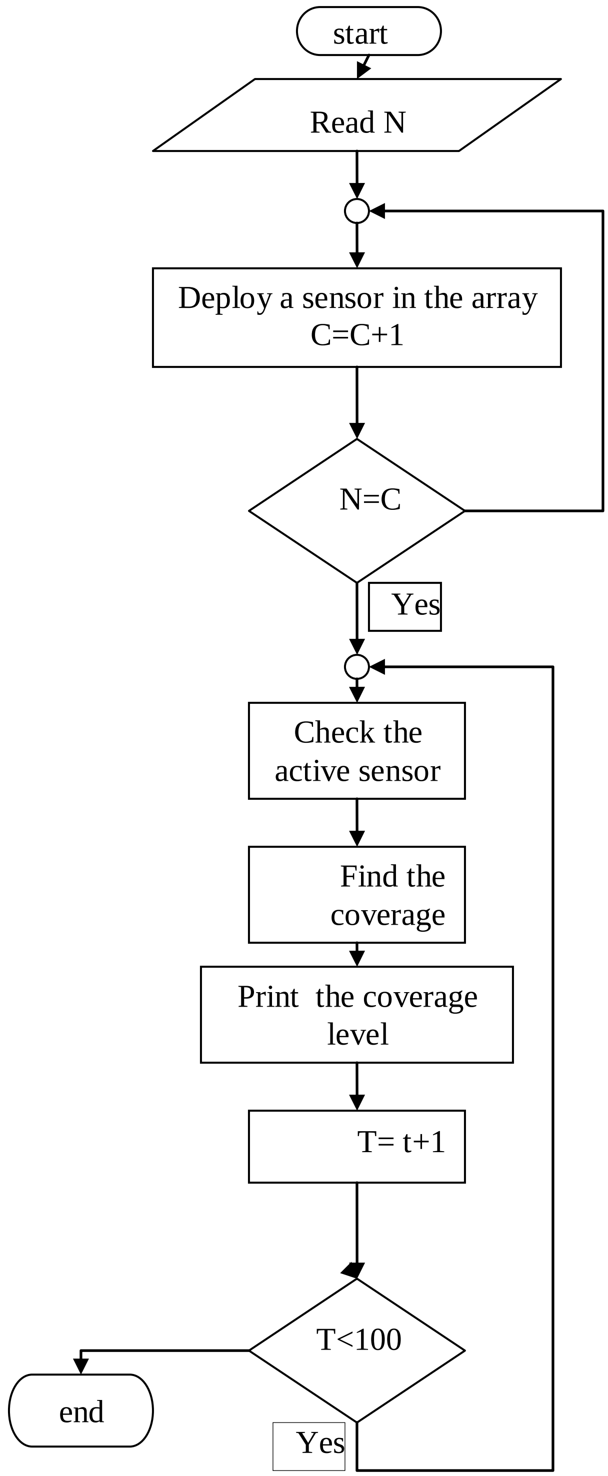


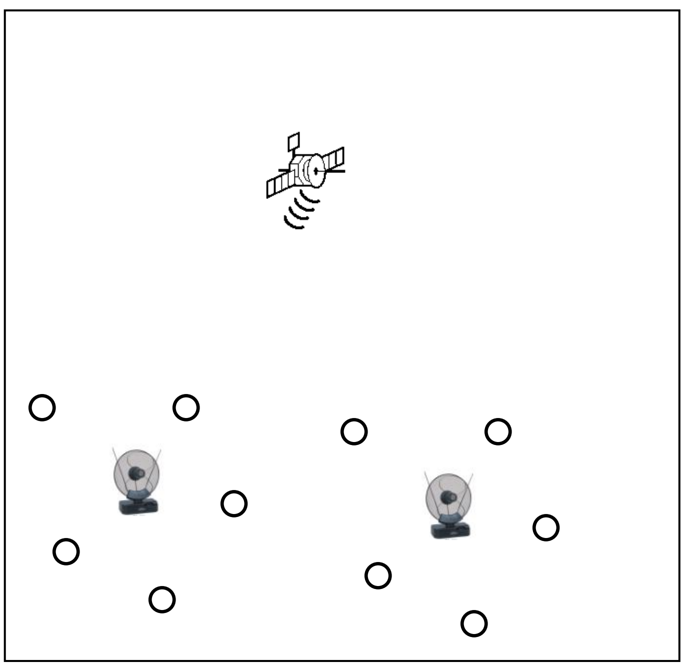

**Figure11 : The Flow Chart for the Deployment Process and Coverage**

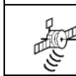
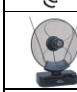
After this clarification of how the coverage is, we examine the scenario for communication in the network that will be the basis for calculating the performance of the WSN consumptions. One has to include all stages of the process. The trigger process, with all stages, in the two cases (Sat-to-SN & S-to-SN) is shown schematically in the figures below:

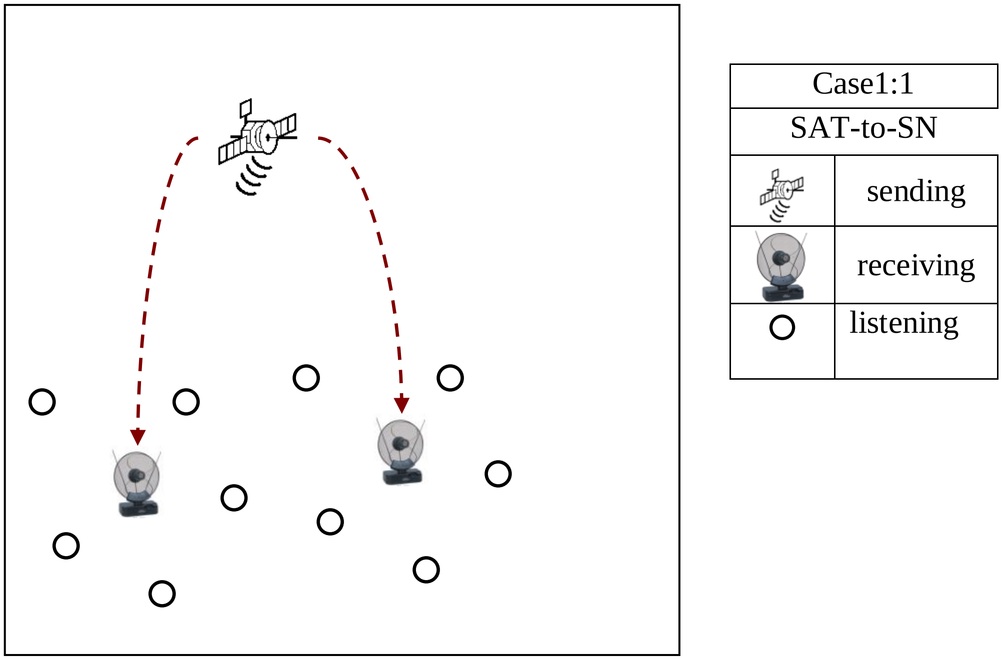
 : Satellite

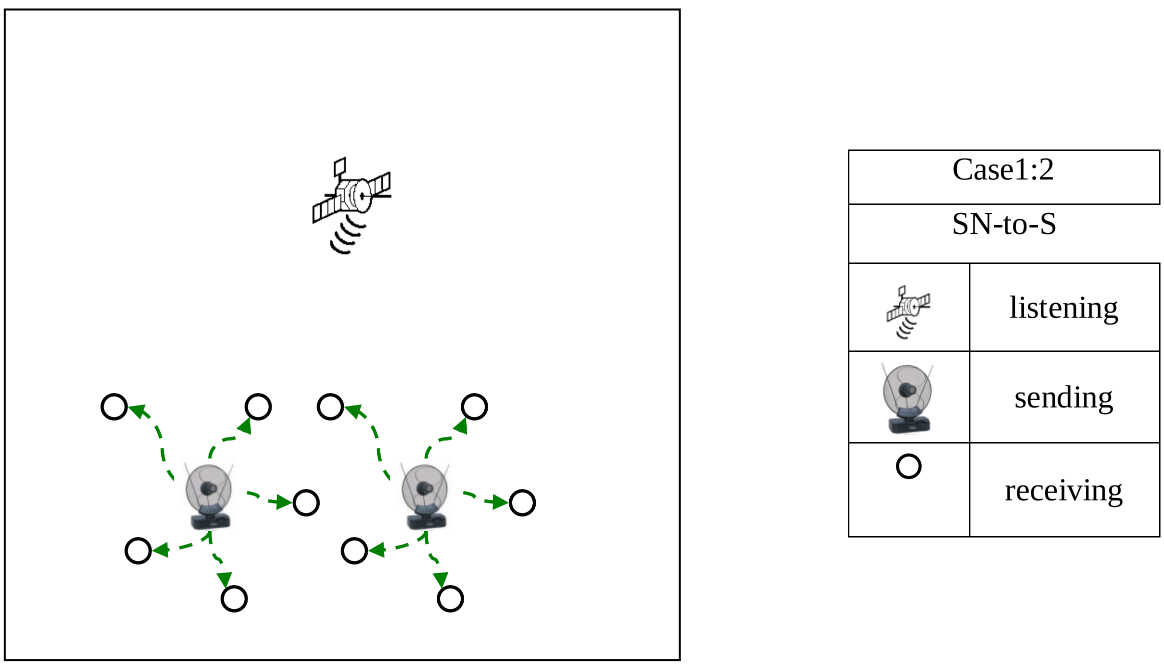
 : SN

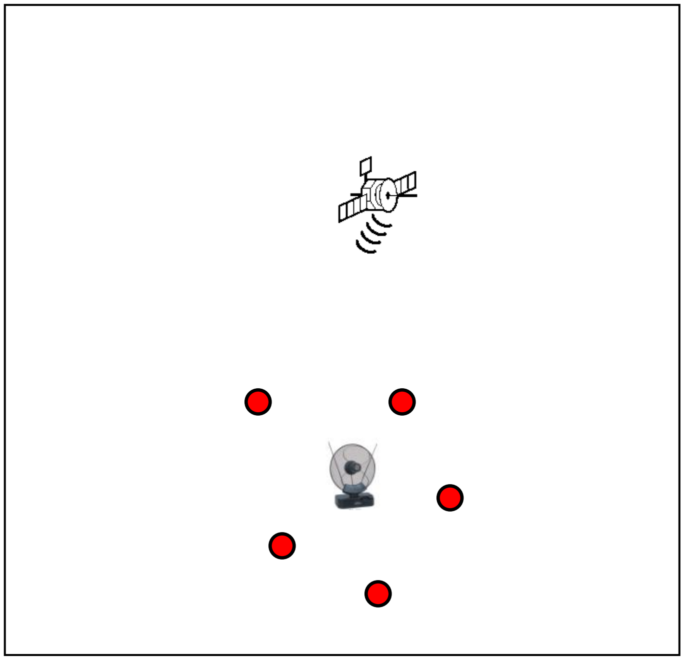
:Sensor node



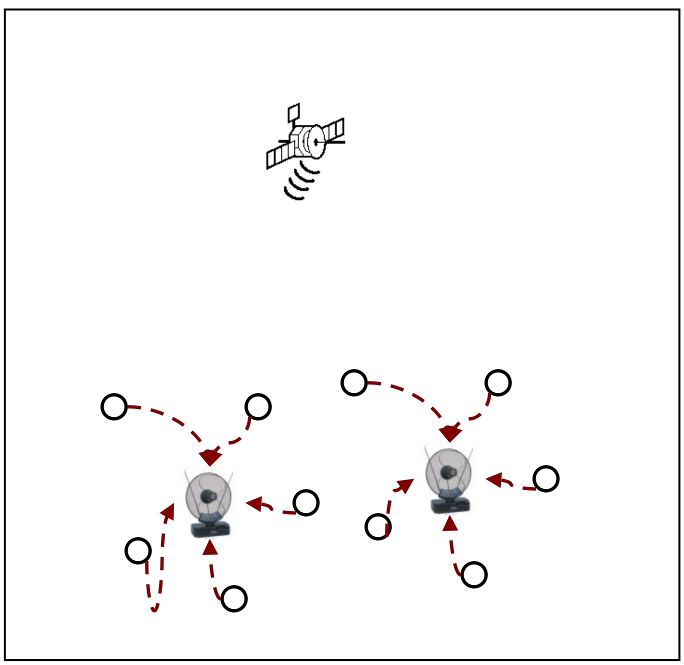
| Case1:0 | |
|---|---|
| | |
|  | listening |
|  | listening |
|  | listening |


Case1:1
SAT-to-SN
sending
receiving
listening

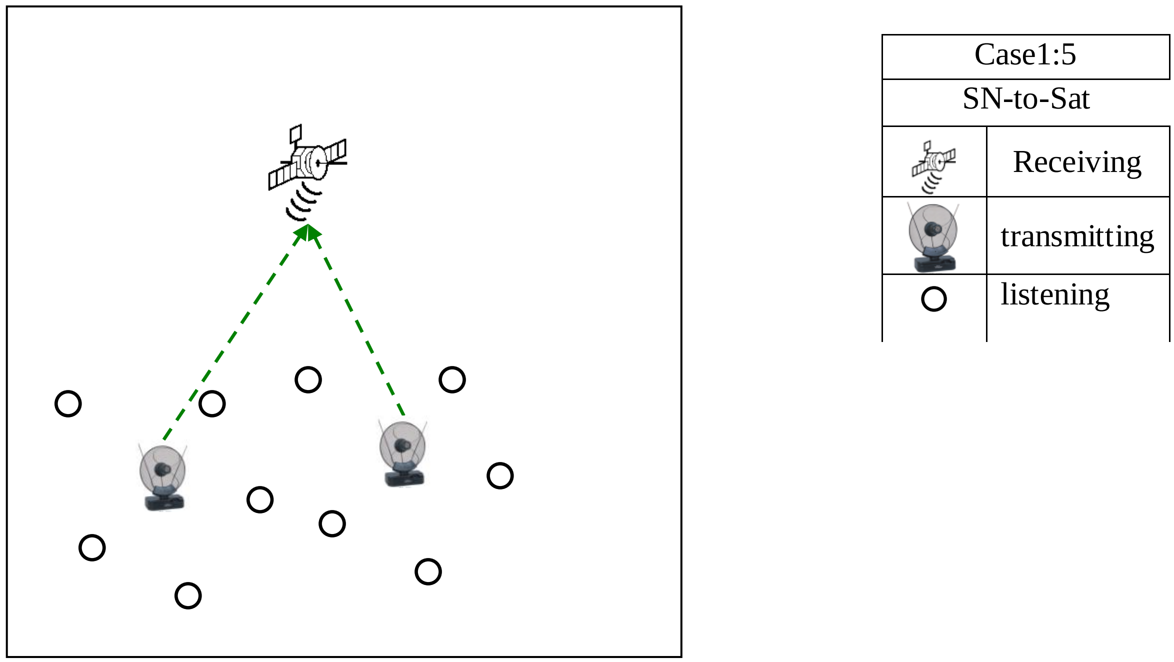

Case1:2
SN-to-S
listening
sending
receiving



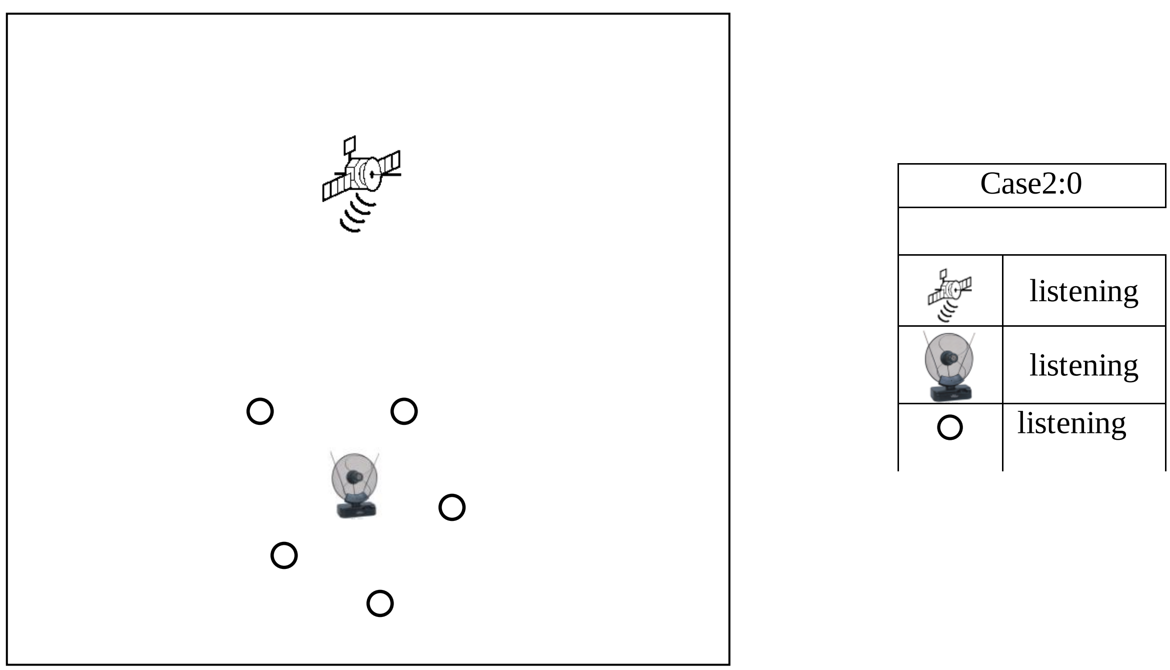
| Case1:3 | |
|---|---|
| | |
| | listening |
| | listening |
| ○ | processing |

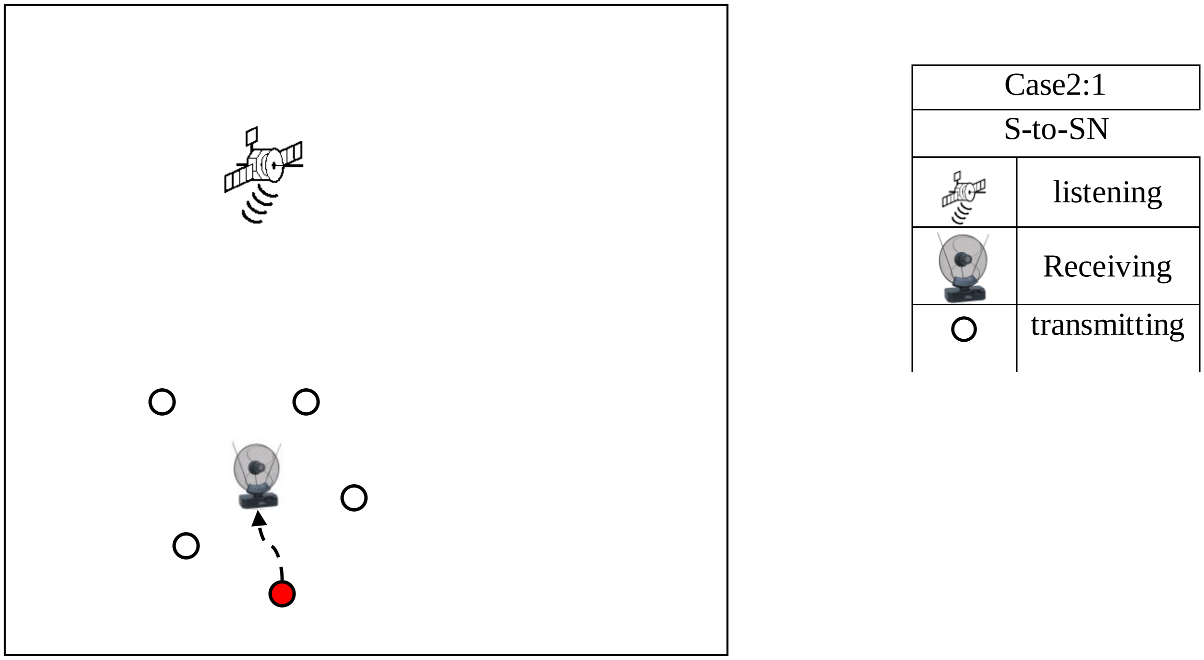


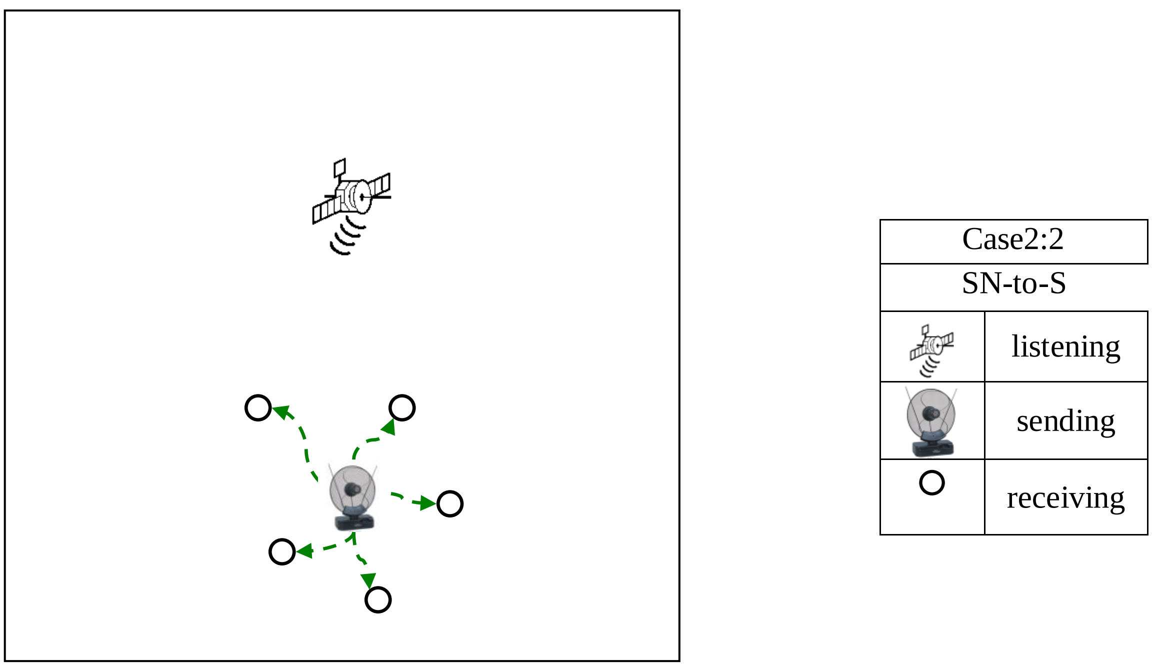
| Case1:4 | |
|---|---|
| S-to-SN | |
| | listening |
| | Receiving & Processing |
| ○ | transmitting |

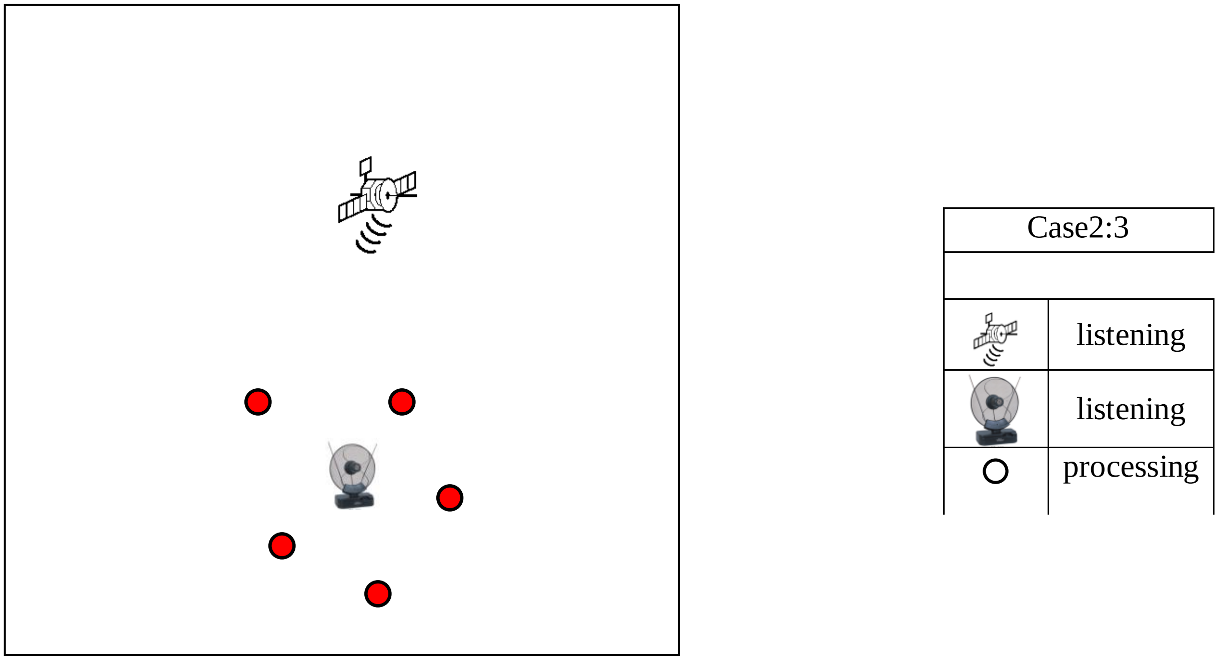

Case1:5
SN-to-Sat
Receiving
transmitting
listening

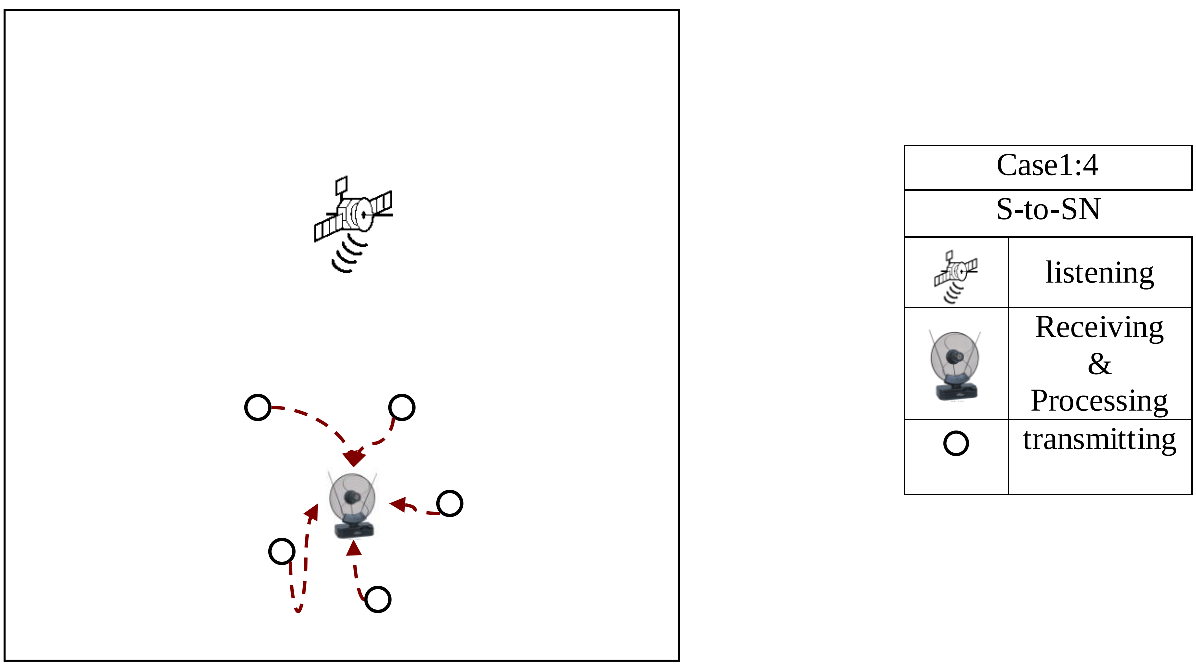
**Case 2:**

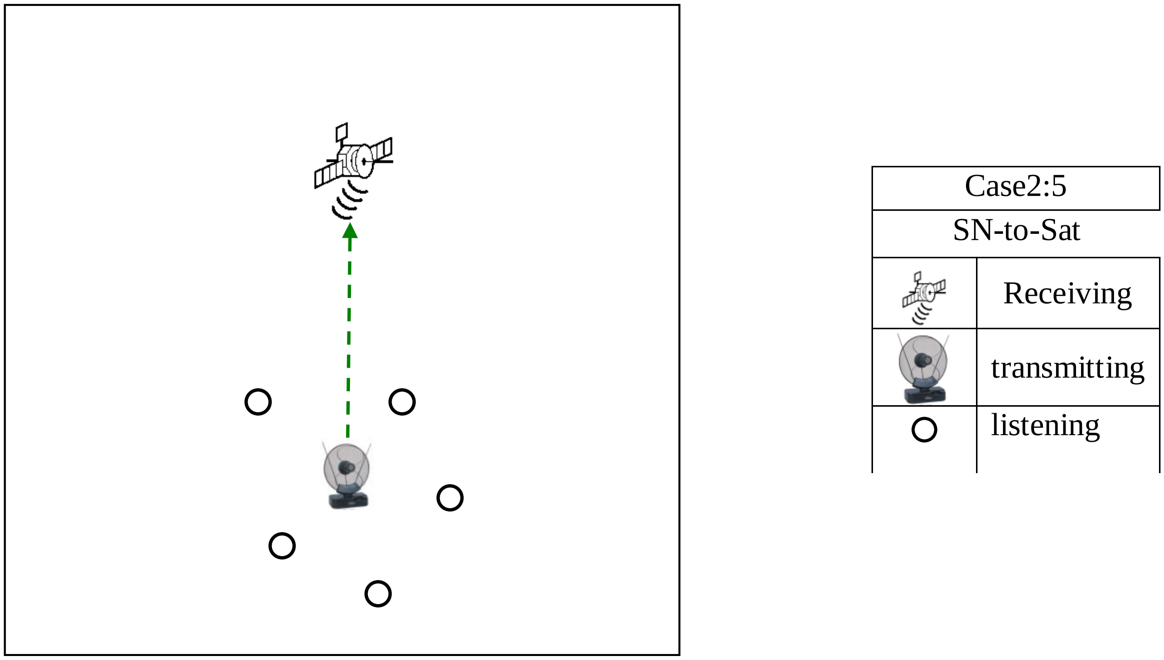

Case2:0
listening
listening
listening


Case2:1
S-to-SN
listening
Receiving
transmitting


Case2:2
SN-to-S
listening
sending
receiving


Case2:3
listening
listening
processing


Case1:4
S-to-SN
listening
Receiving & Processing
transmitting




The two scenarios that describe the communications in the WSN are the same for both networks: WSN and SWSN.

Let us take an example for the execution of the programmed model for WSN to clarify the idea of coverage. The following example is the active sensors at the time of simulation distributed in different locations randomly using uniform distribution. These results are drawn from the real simulations for model 10*10 and the number of sensors is 1000 and the p=0.1.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **0** | **0** | **0** | **0** | **2** | **1** | **0** | **1** | **2** | **1** |
| **1** | **2** | **2** | **2** | **2** | **0** | **0** | **2** | **2** | **1** |
| **1** | **2** | **1** | **2** | **2** | **1** | **1** | **2** | **0** | **2** |
| **0** | **1** | **2** | **3** | **1** | **2** | **0** | **2** | **1** | **0** |
| **1** | **3** | **5** | **0** | **1** | **1** | **4** | **1** | **1** | **1** |
| **3** | **1** | **2** | **2** | **1** | **3** | **0** | **1** | **3** | **0** |
| **2** | **2** | **0** | **3** | **1** | **2** | **0** | **2** | **1** | **2** |
| **5** | **2** | **1** | **1** | **2** | **4** | **3** | **1** | **4** | **3** |
| **2** | **2** | **1** | **0** | **0** | **2** | **2** | **2** | **0** | **1** |
| **3** | **2** | **2** | **3** | **0** | **1** | **3** | **0** | **0** | **1** |

**Figure12 : The Location of Active Sensors**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **2** | **4** | **5** | **3** | **2** | **5** | **6** | **4** |
| **4** | **7** | **7** | **8** | **8** | **4** | **3** | **7** | **7** | **6** |
| **4** | **7** | **9** | **10** | **8** | **6** | **4** | **7** | **7** | **3** |
| **3** | **8** | **12** | **8** | **9** | **5** | **9** | **6** | **4** | **4** |
| **7** | **11** | **12** | **11** | **4** | **11** | **6** | **9** | **7** | **2** |
| **7** | **11** | **10** | **8** | **8** | **7** | **8** | **7** | **6** | **6** |
| **12** | **7** | **8** | **7** | **9** | **10** | **7** | **5** | **12** | **6** |
| **11** | **12** | **5** | **7** | **8** | **13** | **10** | **12** | **9** | **10** |
| **12** | **9** | **6** | **5** | **4** | **9** | **12** | **5** | **7** | **5** |
| **7** | **9** | **8** | **5** | **4** | **6** | **6** | **5** | **1** | **2** |

**Figure 13: The Level of Coverage for Each Cell**

The coverage percentage to the area for WSN:

K1=100%

K2=98%

K3=93%

K4=89%

K5=78%

SN are allocated in the following locations:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 3 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 3 | 0 | 1 | 1 | 0 |
| 0 | 0 | 0 | 2 | 0 | 1 | 0 | 1 | 1 | 0 |
| 4 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 1 |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 |

**Figure14 : The Location of SN**

## Coverage for SN

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 3 | 4 | 3 | 3 | 1 | 1 | 2 | 2 |
| 0 | 2 | 4 | 6 | 5 | 4 | 2 | 2 | 3 | 2 |
| 1 | 3 | 7 | 6 | 8 | 3 | 2 | 3 | 4 | 4 |
| 1 | 6 | 7 | 9 | 6 | 7 | 3 | 4 | 5 | 5 |
| 4 | 4 | 8 | 11 | 10 | 7 | 7 | 7 | 7 | 4 |
| 5 | 6 | 8 | 12 | 10 | 9 | 9 | 10 | 9 | 6 |
| 6 | 9 | 7 | 6 | 11 | 11 | 11 | 9 | 9 | 7 |
| 8 | 7 | 9 | 8 | 7 | 9 | 9 | 10 | 8 | 6 |
| 8 | 8 | 5 | 6 | 5 | 5 | 4 | 6 | 7 | 4 |
| 7 | 6 | 4 | 2 | 3 | 4 | 2 | 3 | 3 | 2 |

**Figure15 : The Level of Coverage for Each Cell**

The coverage percentage to the area

K1=97%

K2=93%

K3=83%

In the same way, the simulation for the model 100*100 is done and the results are collected simulation models in the following table and figure.

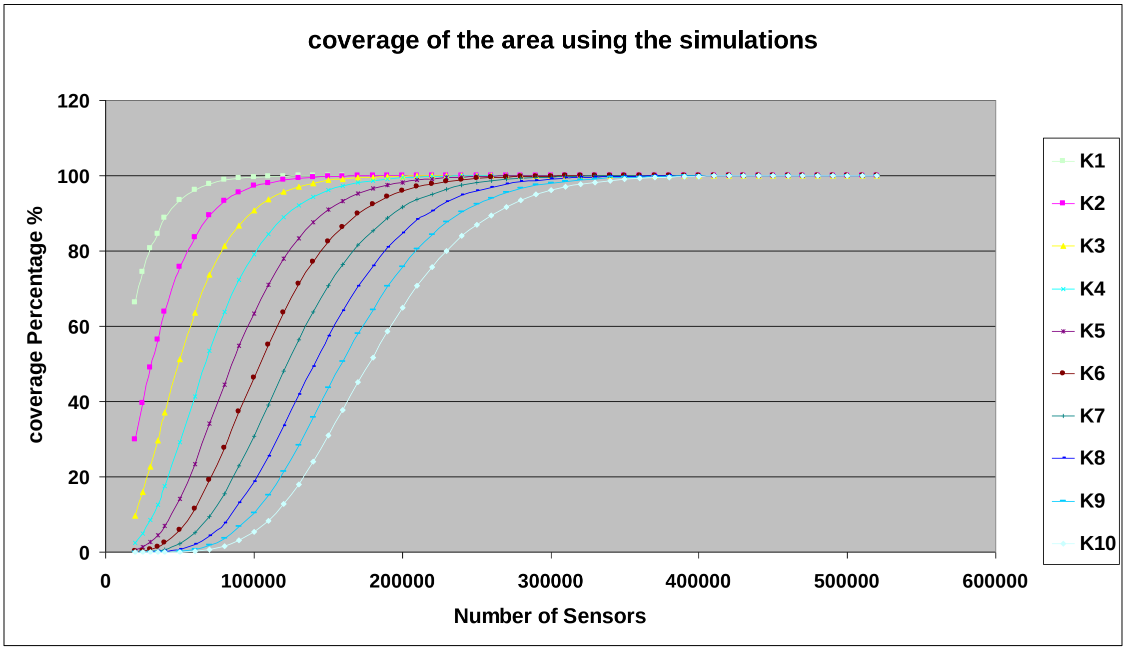



**Figure16 : The Coverage Level for the Normal Sensor Network**

**Table 1: The Results For K-Coverage Of Simulation**

| Coverage Level | simulation |
|---|---|
| k1 | 170000 |
| K2 | 210000 |
| k3 | 270000 |
| k4 | 300000 |
| k5 | 330000 |
| k6 | 380000 |
| k7 | 400000 |
| k8 | 440000 |
| k9 | 460000 |
| k10 | 500000 |

After that the results for the model 100*100 is collected from the analytical models and compared with the results from simulation models in the following table and figure.

**Table 2: The Results For K-Coverage Of Simulation And Analytical Model Comparing**

| Coverage Level | Analytical (circular sensing area) | Analytical (square sensing area) | simulation |
|---|---|---|---|
| k1 | 205144 | 157597 | 170000 |
| K2 | 240541 | 185141 | 210000 |
| k3 | 275944 | 212692 | 270000 |
| k4 | 311370 | 240265 | 300000 |
| k5 | 346830 | 267866 | 330000 |
| k6 | 382328 | 295500 | 380000 |
| k7 | 417867 | 323168 | 400000 |
| k8 | 453448 | 350872 | 440000 |
| k9 | 489072 | 378611 | 460000 |
| k10 | 524738 | 406384 | 500000 |

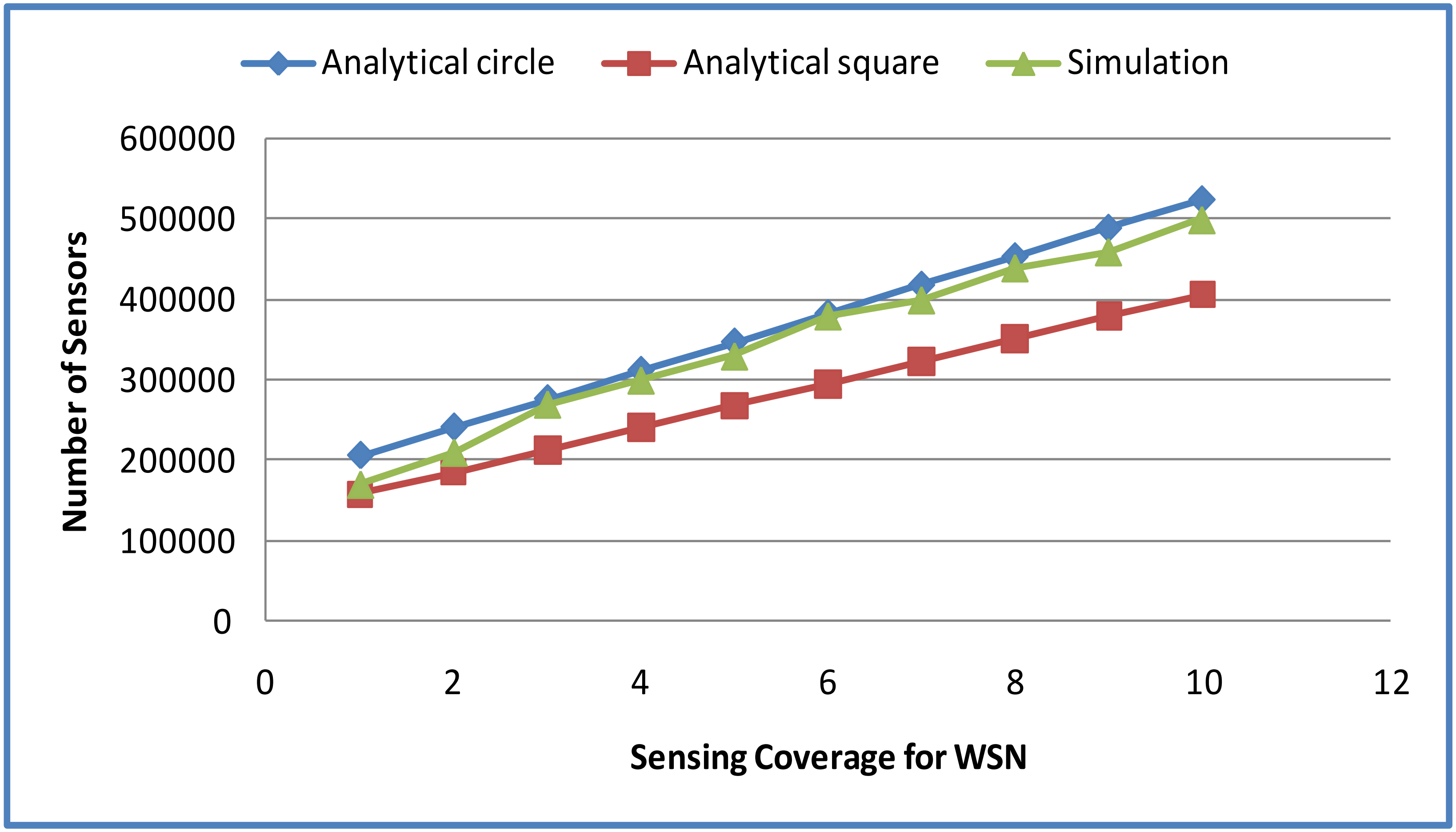



**Figure 17: K-coverage of Simulation and Analytical Model Comparing**

Figure 17 shows the square analytical model is close to the simulation results when K = 1 and 2. However, the analytical model with a circle radius is similar to the simulation results in the range 95-99%, which supports the established results.

Out of the simulation results we observe that some cells are covered by more than 50 sensors in active mode at the same time. This results in loss of energy and causes interference. This problem can be solved by:

1- Organizing the deployment of the wireless sensors. One can predict the location of the sensors if the plane throws them gradually.

Another suggestion to solve this problem is to use a scheme which checks the sensors before they become active. Even if a sensor is due by probability to become active, the media has the ability to determine if there is a specific level or threshold met which would allow the sensor to return to sleep. It can be a sub type of Probing Environment and Adaptive Sensing (PEAS) [22]. (See fig 18.)

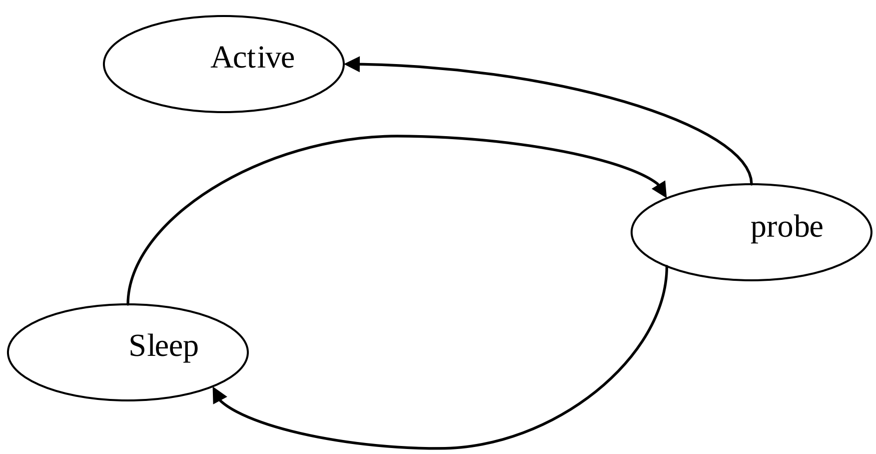



**Figure18 : Stat for PEAS**

## 5.3 Energy Calculation

To compare energy, one specific process should be chosen. The ‘trigger’ process is chosen where a signal from the satellite triggers the network to send back data from the field. The comparison was made between two configurations: one with only normal sensors in the network, and other with SN. To understand, the following information about GPS is necessary.

The Global Positioning System (GPS) is a great technological success story. It was developed by the Department of Defense (DoD) primarily for the U.S. military to provide precise estimates of position, velocity, and time [31]. The history of development of GPS is recounted in [32] and [33]. A comprehensive treatment of the system, signals, performance, and applications can be found in [34].

The energy consumption needed when transmitting to satellite is higher than the transmission between the sensors due to the distance. For example, the satellite networks in the LEO (low earth orbit) that are in the range between (1414 Globlestar-3500) Km, consume approximately one watt of power and work with a low data rate [34]. By contrast, using one watt of power, a mobile phone can work for 120 hours in normal mode or about 4 hours of continuous voice use. In this simulation the power consumed in communication with satellite is about 1-0.6 watt per transmission. It is higher compared to 50*10E-6 watts. In other words, each transmission to the satellite will consume as much power as about 12,000-20,000 transmissions between the nodes. Power consumption is compared in the normal system WSN and SWSN to find the threshold at which adding SN will improve the network.

To calculate the power consumption in SWSN we can use the following:

$$E_{SN} = (P_{receiv.(\mathrm{SN} \leftarrow \mathrm{SAT})} \times t_{receiv.(\mathrm{SN} \leftarrow \mathrm{SAT})} + P_{process(\mathrm{SN})} \times t_{processs(\mathrm{SN})} + P_{trans(\mathrm{SN} \rightarrow \mathrm{SAT})} \times t_{trans(\mathrm{SN} \rightarrow \mathrm{SAT})})$$
$$+ (P_{trans(\mathrm{SN} \rightarrow \mathrm{S})} \times t_{trans(\mathrm{SN} \rightarrow \mathrm{S})} + P_{receiv.(\mathrm{S} \rightarrow \mathrm{SN})} \times t_{receiv.(\mathrm{S} \rightarrow \mathrm{SN})})$$

$$E_{S} = (P_{receiv.(\mathrm{SN} \rightarrow \mathrm{S})} \times t_{receiv.(\mathrm{SN} \rightarrow \mathrm{S})} + P_{trans(\mathrm{S} \rightarrow \mathrm{SN})} \times t_{trans(\mathrm{S} \rightarrow \mathrm{SN})} + P_{sens.(\mathrm{S})} \times t_{\mathrm{sens}} + P_{process(\mathrm{S})} \times t_{processs(\mathrm{S})})$$

$$E_{Sc} = n_{Sa} \times (P_{receiv.(\mathrm{SN} \rightarrow \mathrm{S})} \times t_{receiv.(\mathrm{SN} \rightarrow \mathrm{S})} + P_{trans(\mathrm{S} \rightarrow \mathrm{SN})} \times t_{trans(\mathrm{S} \rightarrow \mathrm{SN})} + P_{sens.(\mathrm{S})} \times t_{\mathrm{sens}} + P_{process(\mathrm{S})} \times t_{processs(\mathrm{S})})$$

$E_{SN}$ : energy consumed by SN (satellite node) in each communication

$E_{S}$ : energy consumed by each S (sensor node) in each communication

$P_{receiv.(\mathrm{SN} \leftarrow \mathrm{SAT})}$ : Power consumed by SN for receiving request from the satellite

$t_{receiv.(\mathrm{SN} \leftarrow \mathrm{SAT})}$ : Time consumed by SN for receiving request from the satellite

$P_{trans(\mathrm{SN} \rightarrow \mathrm{SAT})}$ : Power consumed by SN for transmitting replay to the satellite

$P_{sens.(\mathrm{S})}$ : Power consumed by S for sensing function.

$E_{Sc}$ : total consumed by the entire S node under the SN

$n_{Sa}$ : number of active sensor under the SN

Our goal is to compare and contrast the WSN and SWSN protocols. The following assumption is made to establish a generic model.

The energy consumed by SN & S is considered. However the energy consumed by satellite will not be taken into consideration.

The sensing and processing in nodes consume the same amount of time and power in both cases with or without SN, so their values are ignored.

The consumption of the power in sensors during sleep mode is the same for both systems, so it can be ignored.

The active mode is considered to be a complete communication (send, receive, listening.) The amount of energy needed for the data to go take one hop will be our energy unit.

The only difference between the two systems is the communication between satellite and SN in the SWSN.

Therefore, the WSN and SWSN can be compared depending on the number of hops as energy unit.

From the simulation program the following results for the energy consumption in SWSN and WSN can be drawn. The number of deployed sensors is the same, and is adequate for 1-K coverage. However, the number of active sensors will be different each time because they work randomly. (table 3.)

**Table 3: The Power Consumption in Simulation for 1-k**

**The power consumption in 1-k coverage by simulation from sensors to sink**

| | | power in old | the power consumption in SWSN | | |
|---|---|---|---|---|---|
| # Sensor | # Active Sensor | # unit S to sink | #SN | #unit S-to-SN | #unit SN-Sat |
| 170000 | 18654 | 1252210 | 8500 | 18654 | 136000000 |
| 170000 | 18875 | 1268770 | 8500 | 18875 | 136000000 |
| 170000 | 18448 | 1242029 | 8500 | 18448 | 136000000 |
| 170000 | 18477 | 1240028 | 8500 | 18477 | 136000000 |
| 170000 | 18562 | 1241948 | 8500 | 18562 | 136000000 |
| 170000 | 18863 | 1266500 | 8500 | 18863 | 136000000 |
| 170000 | 18827 | 1264205 | 8500 | 18827 | 136000000 |
| 170000 | 18794 | 1267866 | 8500 | 18794 | 136000000 |
| 170000 | 18758 | 1262621 | 8500 | 18758 | 136000000 |
| Average | 18695 | 1256242 | 8500 | 18695 | 136000000 |

The energy consumed by the SWSN is about fifty times more than that consumed by WSN, see table 1.

**Table 4: Average Power Consumption for 1-Coverage**

| Energy in WSN | Energy of SWSN |
|---|---|
| 2,512,484 | 136,037,390 |

The following table attempts to find what is the acceptable threshold for making a SN viable for the 100*100 unit model when comparing the power consumed by S & SN.

**Table 5: The Acceptable Threshold For Making A SN Viable For The 100*100 Unit Model**

| WSN | | | SWSN |
|---|---|---|---|
| The power of old | earth | to sat | power of SWSN |
| 2512484 | 37390 | 16000 | 136037390 |
| 2512484 | 37390 | 14000 | 119037390 |
| 2512484 | 37390 | 12000 | 102037390 |
| 2512484 | 37390 | 10000 | 85037390 |
| 2512484 | 37390 | 8000 | 68037390 |
| 2512484 | 37390 | 6000 | 51037390 |
| 2512484 | 37390 | 4000 | 34037390 |
| 2512484 | 37390 | 2000 | 17037390 |
| 2512484 | 37390 | 1000 | 8537390 |
| 2512484 | 37390 | 500 | 4287390 |
| 2512484 | 37390 | 400 | 3437390 |
| 2512484 | 37390 | 300 | 2587390 |
| 2512484 | 37390 | 290 | 2502390 |

It is shown that the acceptable threshold is when the power consumed by one communication to satellite is 290 times the cost of power consumption between two sensors. The use of the SN will be viable. However, this is not the case.

Examination of the lower bound by the following formula:

**RUD(random uniform distribution ) without SN**

In our model we have the following area

100*100 = 10000 cell

Since the best-case senario has each sensor covering 5 cells, to cover the area we need at least 20,000 sensors with probability of 0.1 to cover the ten thousands location for 1-k :

10000/5 = 2000 active sensors

If the data is sent to super–nodes in the corners of the area the best case will be one hop and the worst case will be 50 hops so the average is 25 hops. Assuming all sensors have data to send the total hops for sending will be :

2000* 25 = 50000 units

**RUD (random uniform distribution) with SN**

On the other hand, for the system with SN all of the sensors will be one hop from the SN. In addition, each cell is covered by one sensor. Therefore, we can say:

2000 * 1 = 2000 units

We have to add the cost of sending data from SN to satellite. This will be the number of SN multiplied by 16,000, (the average of 12,000-20,000.)

From the above calculation it is clear the normal sensors in the system with SN in a worst case senario, will have longer life-time by a factor of 25 times. This is because the normal sensors send to all other sensors around them not only to the sink. Thus when both system is working in active mode continually. In fact this is not a bond for improvement because the increases in the active number of sensor will increase the percentage of improvement between the two systems.

Let us take another example

This is small covering problem and power consumption to clarify the idea:

Assuming 10×10 area, this is the allocation of the sensors in 100 location this means we need at least: 100/5=20 active sensors.

Each sensor needs to send to the sink a minimum of 1 and maximum of 10 times, making the average:

20*2.5=50 units

This is the number of hops needed by all sensors to reach the sink node without SN. This is the lower bound.

**RUD with SN**

Each 13 cells will have one SN, in this case, we have 20 active sensors communicating with the SN by one hop. The total number of hops for the network is:

20 units

As we have seen, the power needed without SN is 2.5 times greater when compared to a model having a SN. If we ignore the communication to the satellite, the following table is for the power consumption in both systems

**Table 6: Comparing Between SWN And SN**

| | units of power | | | | | |
|---|---|---|---|---|---|---|
| Edge of area | #SN | (SN-Sat) | (S-SN) | SWSN | WSN | percentage |
| 10 | 8 | 123077 | 20 | 123097 | 100 | 0.001 |
| 20 | 31 | 492308 | 80 | 492388 | 800 | 0.002 |
| 30 | 69 | 1107692 | 180 | 1107872 | 2700 | 0.002 |
| 40 | 123 | 1969231 | 320 | 1969551 | 6400 | 0.003 |
| 50 | 192 | 3076923 | 500 | 3077423 | 12500 | 0.004 |
| 60 | 277 | 4430769 | 720 | 4431489 | 21600 | 0.005 |
| 70 | 377 | 6030769 | 980 | 6031749 | 34300 | 0.006 |
| 80 | 492 | 7876923 | 1280 | 7878203 | 51200 | 0.006 |
| 90 | 623 | 9969231 | 1620 | 9970851 | 72900 | 0.007 |
| 100 | 769 | 12307692 | 2000 | 12309692 | 100000 | 0.008 |
| 1000 | 76923 | 1230769231 | 200000 | 1230969231 | 100000000 | 0.081 |

From this table it is clear that the use of SN is not viable due to the huge amount of power needed for sending data to satellite. However, let it be noted, we used the same power source for SN and S. If we use a continuous power source which is viable in some applications, or in the future use nuclear power as the power source for SN, it may become an acceptable model.

In fact, the table above reveals that if the power consumed by SWSN is taken before adding the communication to the satellite it is advantageous compared to the WSN. It is noted the power increased exponentially in the WSN (fig 19.)

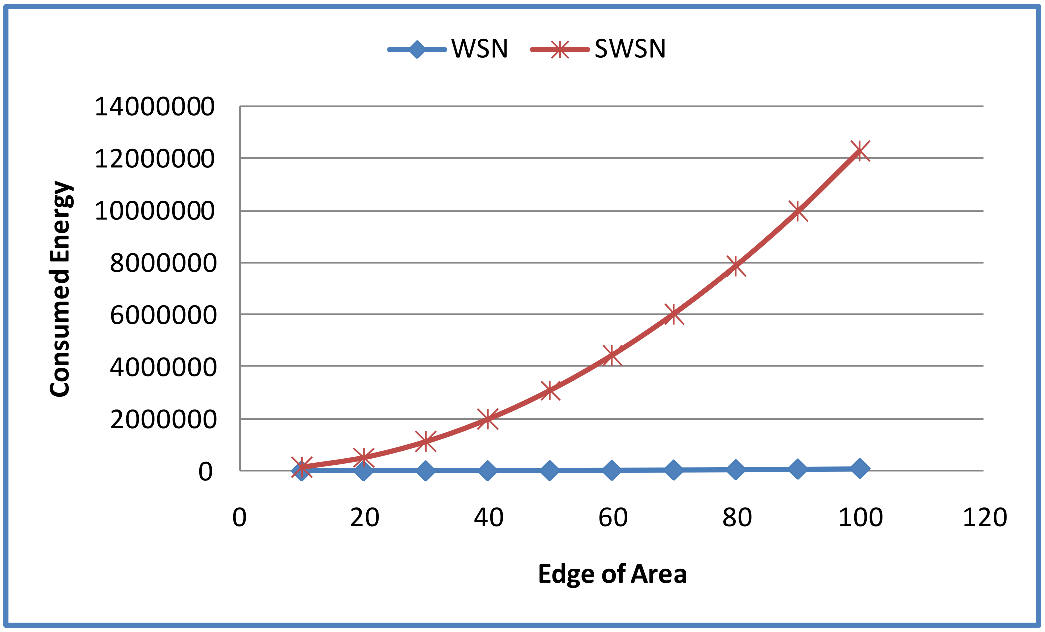



**Figure19 : Consumed Energy of WSN vs SWSN**

In general, if we ignore the consumed power by SN for communication with satellite we note the following:

As the number of active sensors increased or the size of network increased the difference in power consumption in the two system increased.

In simulation the system without the SN nodes near the sink, the sensors die quickly causing the network to become disconnected and stop.

To take the advantage of both SWSN and WSN one can suggest the following: use the satellite and SN to send a trigger to sensors and the reply will be returned by the multi hop system to the sink of the network. This suggestion will reduce the power used in communication by 50 percent, an excellent improvement considering the only addition required is the SN. (fig 20.)

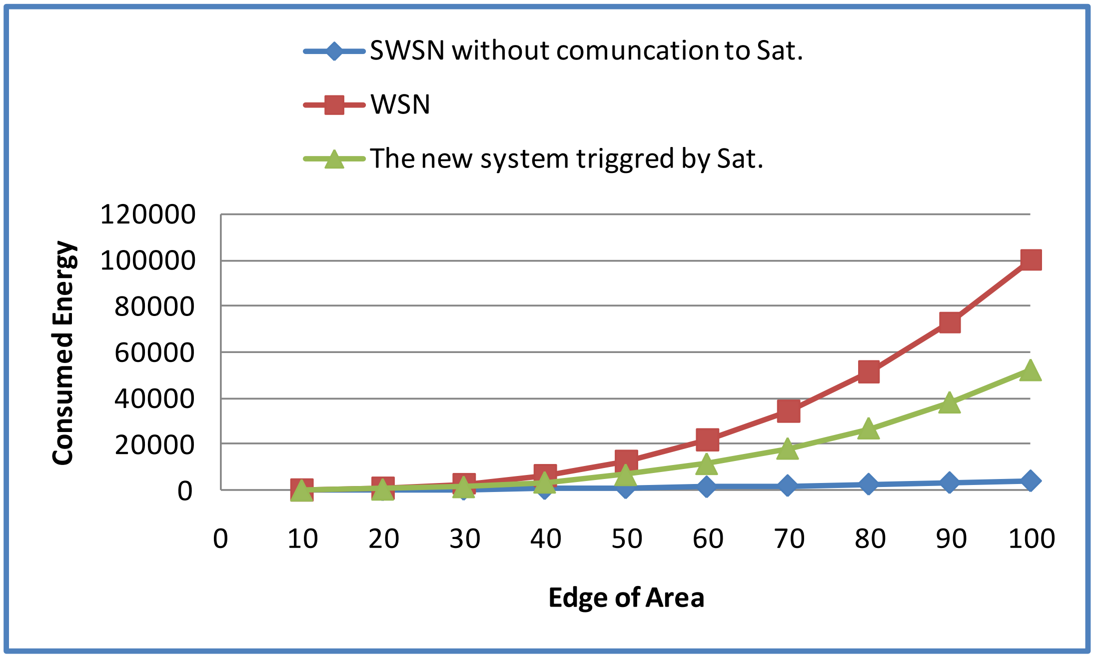



**Figure 20 :Consumed Energy of WSN vs SWSN vs New System**

# Conclusion

This thesis has shown the following:

Studying and comparing existing scheduling schemes for sensors that are densely deployed.

Selecting the RID analytical model established by Kumar and applying it in the mathematic program for use in simulation and development.

Writing a program in java for Kumar model for RID and comparing it to the analytical model.

Checking the validity of the model by comparing it with existent results.

Developing an efficient scheme SWSN to maximize the lifetime of the sensor networks by adding the satellite node.

Finding through simulation a threshold indicating when SN in the system for 100*100 and 1-k coverage is of benefit. This threshold being when the cost of the communication to satellite is about 2000 times the cost between sensors or less.

Even power consumption in the satellite-node is the limitation for this SWSN. However, it is a versatile system and will work for many applications such as in the ocean. It would be the ideal system for observing the pollution from petrol or other chemicals in the ocean as it can communicate with satellite. If nuclear power can be used for these SN, this becomes a possibility for the future.

Merging the SWSN with WSN by sending a trigger by satellite and receiving the reply in ordinary WSN.  Thus saving 50 percent of power consumed in communication. It is an excellent improvement.

In the future, we can study the enhancement of using a satellite to trigger the wireless sensors after adding SN and examine the different scheduling schemes. In addition, another solution would be to use an unmanned aircraft to trigger the wireless sensor network and collect the data.

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