Evaluating the Deployment Problem of a Wireless Sensor Network on the University of Nigeria, Nuskka Campus for the ....

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Evaluating the Deployment Problem of a Wireless Sensor Network on the University of Nigeria, Nuskka Campus for the Detection & Tracking of Vehicles

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Abstract—This paper provides an analysis on the deployment of a Wireless Sensor Network (WSN) on The University of Nigeria, Nsukka (UNN) campus for vehicle detection and tracking. The need for such a network for this particular community will be to provide accurate monitoring information of vehicles coming in and out of the campus environment. This, in time, will help in showing the statistics analysis of vehicles per parking on campus and provide surveillance information essential for the security and well being of the university community. The deployment techniques of a WSN have significant impact on its operational performance. This paper, therefore, focuses on the deployment strategies that will make vehicle detection and tracking a realization on The UNN campus.

Index Terms— Coverage, Connectivity, Deployment, University of Nigeria Nsukka, Wireless Sensor Networks.

1 Introduction

In today's world, modern technology has enabled the development, production, and improvement of antennas, processors, data storage, and radio transceivers for smaller sizes, better power and energy consumption, and more efficient processing capabilities. For Wireless Sensor Networks, technology advances particularly in the micro-electro-mechanical, wireless communications, and digital electronics fields; have made it possible to develop tiny inexpensive sensors with low power consumption and reliable performance in sensing capabilities [1][2]. It is without a doubt that advances in Wireless Sensor technology has opened doors to newer technologies for a more modern and technological world.

Wireless Sensor Networks (WSNs) consists of several nodes that must communicate and co-operate with each other to perform specific tasks. The operation of the nodes is to sense and process data of a detected event and to communicate that processed information wirelessly to other sensor nodes. The information is usually routed down from node to node until it reaches a sink node or a Base Station (BS) where all information is gathered and observed by an administrator. With sensing and detection as its main abilities, WSNs are well suited for the following applications [3][4][5]:

- *Military Applications*: These include services such as battlefield surveillance, targeting, battle damage assessment, surveillance of opposing forces, and detection of nuclear, biological, and chemical attack.
- *Environmental Applications*: These include habitat monitoring, agriculture research, fire detection and traffic control. So in this aspect, ground sensors can monitor local moisture levels, wind speed and direction, humidity, and temperature of different environmental services.
- *Health Applications*: In this scenario, sensors can be designed to monitor patient health, control drug administration, and track and monitor patients and doctors inside a hospital. It is known that in nursing homes, pressure sensors and orientation sensors are designed to detect muscle activity, vital sign monitoring, and dietary monitoring. All these services help in the fast reaction of emergency situations which can consequently reduce costs in the health industry.
- *Home Application*: These include Smart Environment and the concept of the Intelligent Home. The intelligent home is a customary network of sensors that detect situations such as the opening of the front door which communicates with other devices such as the turning on of a kettle to boil some water, or the turning of the TV or the air conditioner or the lights in the home. In addition sensors can be placed to monitor the temperature of the home and can be effectively used for security automation.
- *Applications in the Oil and Gas Industry*: Wireless Sensor Networks can be used to remotely monitor pipelines, natural gas leaks, corrosion, Hydrogen Sulphide (H2S), equipment condition, and real-time reservoir status. Data gathered by the sensor devices can help Oil and Gas industries improve platform safety, prevent problems and errors, optimize operations, and reduce operating costs.

In vehicle detection and monitoring, WSNs can be used to estimate the vehicle's speed and direction as the target moves

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through the sensor network. This all depends on the environmental signature the vehicle gives off and the placement of the sensor nodes around the Region of Interest (ROI) that is to be monitored.

The sensor nodes of a WSN can either be deployed randomly or according to a defined distribution over an ROI. This deployment can have significant impact on the operational performance of the sensor network and introduce several inherent problems in terms of detection, coverage, and connectivity. Additionally, each individual sensor device has uncompromising and limited resources such as battery power, signal processing and memory constraints, and computation and communication capabilities [6]. It is therefore imperative that careful planning is pursued when deploying a WSN on any ROI for any application.

The University of Nigeria, Nsukka (UNN) campus is located in Enugu State of Nigeria and is about 75 km south from the capital also named Enugu. It has a land mass of 871.38 hectares and is situated in an asymmetrical shape at the north east side of the Nsukka town. The campus consists of university buildings occupying the western half of the region and conservation areas occupying the northeast and southern part of the campus. Within the conservation areas, the region is free of buildings, where grass covered hills occupy the northern tip and a large hill occupies the northeast and southern part of the terrain [7].

Due to its grassy and hilly terrain, the northeast and southern part of the UNN campus is relatively free of human contact; leaving the western part containing most of the development of the university, e.g. buildings, roads, parking areas and etc. Therefore, within this western part of campus, vehicles, private and public, are used as a means of transportation. Consequently, with the increasing number of vehicles, due to the increasing number of staffs and students; surveillance information is needed to know the vehicles per parking on campus and to ensure the security of the community. The deployment of a wireless sensor network for the detection and tracking of vehicles aims to mitigate any compromise of security, whether its theft or terrorism, and at the same time provide essential information for the development of the UNN campus.

2 Related works and motivation

Works on vehicle detection and tracking with Wireless Sensor Networks have been pursued at different levels. Acoustic sensors were used in Source [5] to detect and track a vehicle based on the sound pressure it gives off. However, it was discovered that modeling the network with acoustic sensors was not appropriate for slow moving vehicles and targets in stop and go traffic, which are some of the situations vehicles face on the UNN campus.

Source [8] discussed on video and acoustic sensors for vehicle detection and tracking. In this scenario, detection was first accomplished using acoustic sensors that provided a rough estimate of the vehicle direction-of-arrival (DOA). The initial DOA estimate gave the rough vehicle location in video, where Markov-Chain Monte Carl techniques were used for audio-visual tracking. The method introduced in [8] served as an upgrade to the basic approach of [5], however, issues relating to high battery consumption of the video and acoustic sensors meant installation and maintenance costs will be high.

Vehicle detection and tracking using magnetic sensors were both discussed in Sources [9] and [10]. In [9] an experiment was conducted to test and measure the earth's magnetic field of a moving target using magnetic sensors. The experiment consisted of mica2 motes as sensor nodes; a robot as the target and a presumed vehicle; and a sink node as the Base Station (BS). The mica2 motes comprised of a magnetic sensor board, a microprocessor board, and a battery unit. The robot had a small magnet placed in front of it and a microprocessor board connected to it for real time measurement of the magnetic field from the robot. The sink node consisted of a microprocessor board that ran a BS program, and a computer that received information on the position and speed of the robot. Through the experiment, results were able to show the accuracy of the tracking and detection system given the right distance from the magnetic sensor nodes. Infact, results proved to be more reliable and precise than that of the acoustic approach of detection.

Source [10] went on to show the practical deployment of magnetic sensors for vehicle detection and tracking. MICA developers and U.S Air Force Research Labs used sensors of the Rene mote hardware equipped with an MTS magnetic sensor board to perform a real world vehicle tracking scenario. These sensors were dropped from an unmanned aircraft along a road, and once on the ground they created a wireless sensor network that detected a passing vehicle from its magnetic signature. The network was able to estimate the vehicle's direction and speed which also established the vehicle's location in the region. All data was collected by the unmanned aircraft as it flew back over the WSN. That data was then transmitted back to a central base station where administration work took over.

Current technologies are available for the tracking and monitoring of vehicles. GPS, a more modern form of technology, can provide accurate vehicle location information that can be viewed on maps over the internet or on a custom specialised software [11]. The advantage of such technology is the extreme accuracy and precision of the surveillance data, and most importantly the ease that comes with the monitoring process of targets. However, the disadvantage, which overhauls any benefits of the technology, is the cost. It is estimated that GPS tracking systems can cost up to tens of thousands of dollars depending on the number of vehicles to be tracked [12]. This does not include the satellite devices that are needed to make the system operationable.

Another technology associated with vehicle surveillance is the GSM based form of tracking. In this scenario, tracking begins when a GSM signal is detected within the vehicle. In other words, a GSM based hardware along with a particular SIM card, which is also the vehicle's ID number, is placed in the vehicle to be tracked. A call is made to the SIM and the vehicle has the capability of receiving the call auto-

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matically, establishing connection with the existing GSM network through the BSC. A specialised remote software is then used to do the tracking of the vehicle and most importantly, do the handover and collect monitoring information as the vehicle moves from cell to cell [13]. This form of technology does have its advantages over the GPS based system and will be more appealing in countries such as Nigeria, where the existing GSM network architecture is already in place. However, with the complete dependency on the network provider of which an organisation such as UNN will be to the absolute mercy to, the GSM form of tracking will not be an entirely attractive option to venture into for the monitoring of vehicles.

A survey on The University of Nigeria, Nsukka was carried out by Source [7]. This included work on the geographical layout of university buildings in relation to the design of a campus wide network for the institution. This paper aims to capitalize on the work done by [7] but in the limelight of Wireless Sensor Networks. In addition, in Nigeria, research on WSNs is still at the infant stage and has not kicked off. This study hopes to fire up that learning by using UNN as a case study. It is the wish that this will motivate others in Nigeria on the research of WSNs for various applications other than vehicle detection and tracking.

3 Survey on the Deployment of a WSN on the UNN Campus

In investigating the deployment problem of a WSN on The UNN campus, two performance measures were looked into. These were namely the coverage and connectivity performance of the WSN in relation to the different deployment strategies. Work done by [7] provided a detailed map layout of road routes and building locations of the university west campus. This map can be seen in Figure 3.0-1.

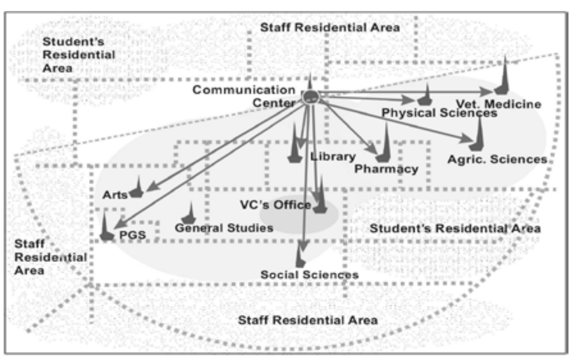

Figure 3.0-1: Aerial mapping of UNN west campus [7]

The map of Figure 3.0-1 was used as a blueprint to analyse the deployment issue of a WSN. It was also assumed, due to its vicinity to other buildings and its known facilities; the Computer Communication Center (CCC) was designated as the central base station to which all detected information of the WSN was routed to and administered.

3.1 Deployment

Wireless Sensor Networks can either be deployed randomly or at a pre-determined location. Random deployment usually involves large scale deployment of sensor nodes dropped from an aircraft around a location that may or may not be defined. Pre-determined deployment is where nodes are usually carefully placed by hand or by a robot around a predefined ROI. Consequently, the significant constraints associated with both random and predetermined placements are the costs and availability of the sensor nodes.

In this study, a pre-determined placement strategy was approached. This involved taking the blueprint map of Figure 3.0-1 and splitting it into a series of adjacent grid squares as shown in Figure 3.1-1.

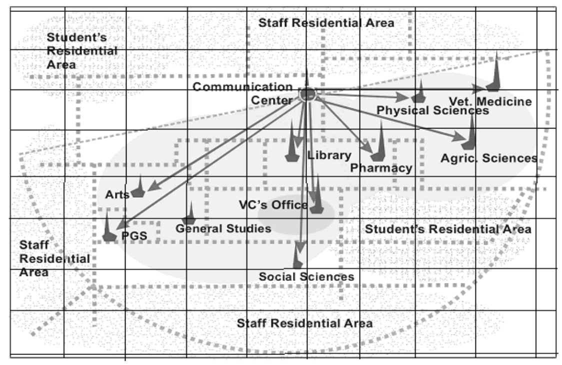

Figure 3.1-1: Grid square map of UNN west campus

The spacing between each intercepting grid point was determined by the communication range capability of the sensor device. Most modern sensor nodes are capable of communicating up to a range of 100 meters and higher, depending if there is a clear line of sight between all communicating nodes and the BS. In essence, grid based deployment can be approached by three methods. These are namely Square Grid Deployment, Equilateral Triangle Grid Deployment, and Hexagon Grid Deployment [14][15]. Figure 3.1-2 shows these models.

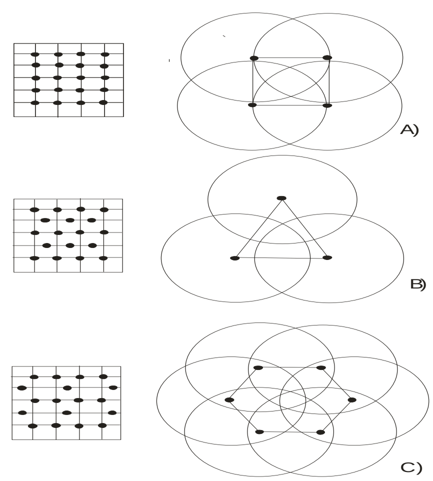

Figure 3.1-2: Deployment models for grid based deployment: A) Square Grid Deployment, B) Equilateral Triangle Grid Deployment, C) Hexagon Grid Deployment.

Each model has its own unique advantages and disadvantages. For this study, however, cost was the determining

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factor on which model approach was the best in the deployment of the WSN on The UNN campus.

3.2 Coverage and Connectivity

The deployment strategies of WSNs influence the Quality of Service (QoS) of the network. Adequate QoS depends on the coverage or how well the sensor network can sense and monitor an ROI. Sensor nodes have limited and uncompromising resources at their disposal. Therefore, to come up with a deployment strategy that will reduce cost, minimize node to node communication, and at the same time provide a high degree of coverage while maintaining connectivity is the utmost performance goal.

Connectivity between two adjacent sensor nodes is achieved when their respective coverage overlap each other; or in mathematical terms, when their Euclidean distance is less than the communication range. When the coverage of two sensors don't overlap, then it is assumed that their Euclidean distance is greater than their communication range and the sensors are not connected. This highlights the extreme relationship between coverage and connectivity in WSNs. Infact, the two are intertwined and need each other for the technology to perform adequately.

The algorithm in determing coverage and connectivity first consisted of having a sink node deployed at the CCC which also represented the central BS. The remaining nodes were deployed at the corresponding grid point locations of the map. The X and Y coordinates of the nodes were gathered and the distance between each and every node was calculated. Connectivity was then determined based on the given sensing range (SR) and the calculated distance matrix. In other words, a comparison was made between a calculated distance between two nodes and the SR. If the distance was less than the SR, then the nodes were connected; if not, then the nodes were not connected.

Coverage was determined by first creating an area map of the connected wireless sensor network. Each individual point of the map was gathered and used to calculate the Euclidean distance with the coordinates of the individual nodes. If the Euclidean distance of the entire connected WSN was less than the SR, then coverage was achieved and a coverage percentage calculated. Figure 3.2-1 illustrates this notion for two sensors S_i and S_j.

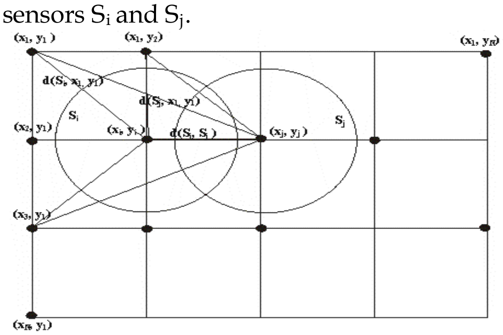


Figure 3.2-1: Illustration to determine coverage and connectivity.

4 Evaluating the Deployment Strategies

To analyze and evaluate the strategy to pursue for a low cost deployment of a WSN for the tracking and monitoring of vehicles on The UNN campus, the MATLAB software was used and some criterias were followed. (Tables 1-2)

Table 1: Component cost

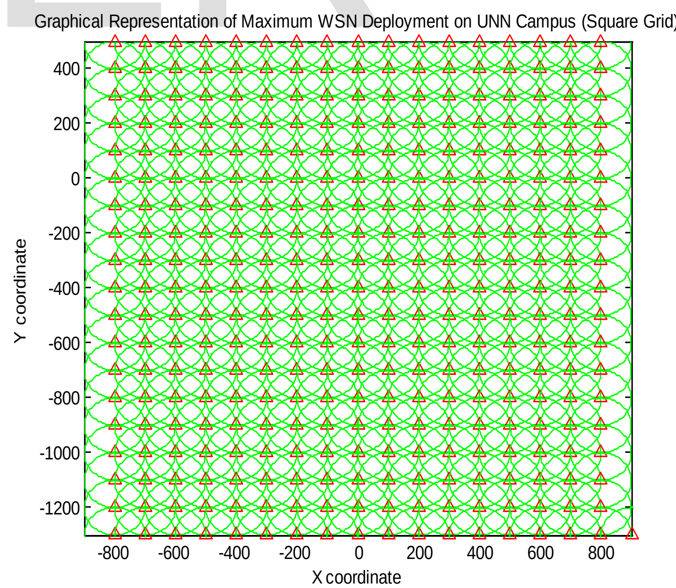
Item	Cost (Naira)
Rene mote hardware	16,251.00
MTS magnetic sensor board	12,188.00
TOTAL COST	**28,439 per sensor**

Table 2: Operating criteria

Dimensions of ROI	1.80 x 1.80 km^2
Ideal number of sensors to be deployed	$200 \leq N \leq 250$
Communication sensing range	SR = 100 m
Coverage radius for each sensor	$r \leq 100$ m
Ideal coverage method for entire ROI	Blanket

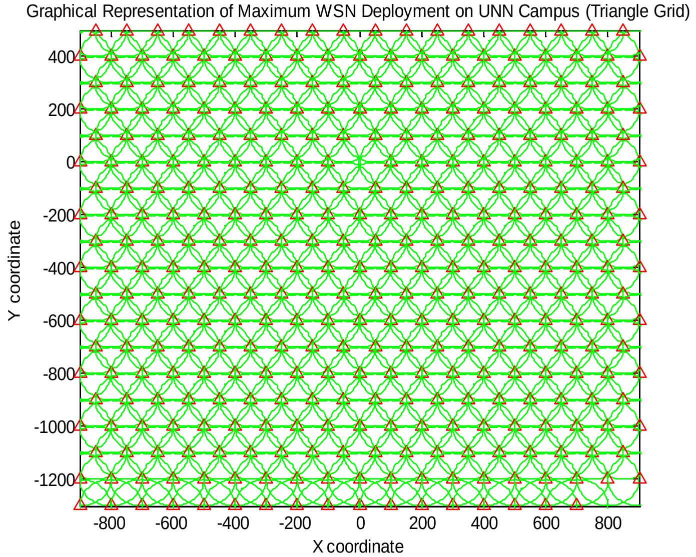
4.1 Results

The following are the results for the three predetermined grid based deployment methods.



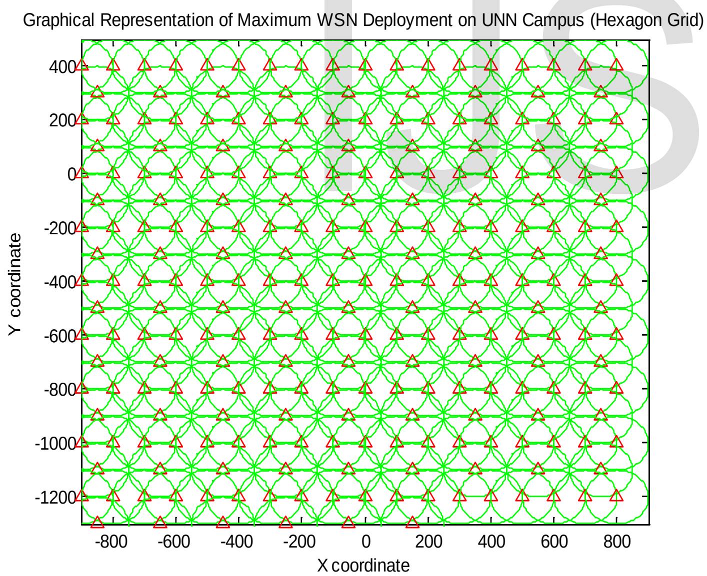
No. of sensors to achieve coverage of 100%	325

Figure 4.1-1: Graphical representation of no. of sensors to achieve 100% coverage for square grid deployment on UNN campus



No. of sensors to achieve coverage of 100%	300

Figure 4.1-2: Graphical representation of no. of sensors to achieve 100% coverage for triangle grid deployment on UNN campus



No. of sensors to achieve coverage of 100%	250

Figure 4.1-3: Graphical representation of no. of sensors to achieve 100% coverage for hexagon grid deployment on UNN campus

From the above results, it was necessary to know the linear relationship between the number of sensors deployed and the gradual coverage percentage for each deployment method. Figure 4.1-4 shows this relationship.

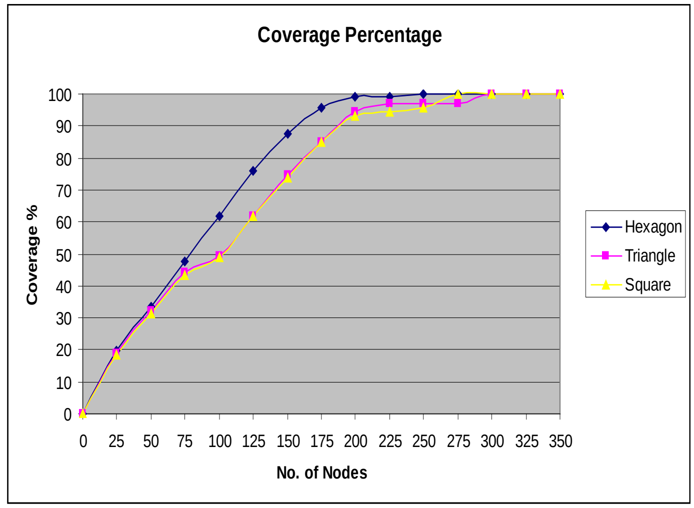


Figure 4.1-4: No. of sensors vs. Coverage percentage per method

From Figures 4.1-1 to 4.1-4, it can be seen that the hexagon grid deployment proved to be a far more superior method of deployment than the other two. It covered more area for less, establishing itself as a cheaper and more efficient approach than the square grid and triangle grid. Figures 4.1-5 to 4.1-6 shows this superiority.

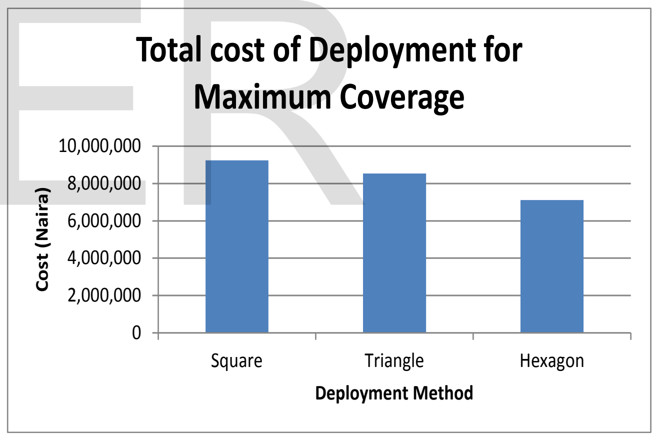


Figure 4.1-5: Cost of deployment per method

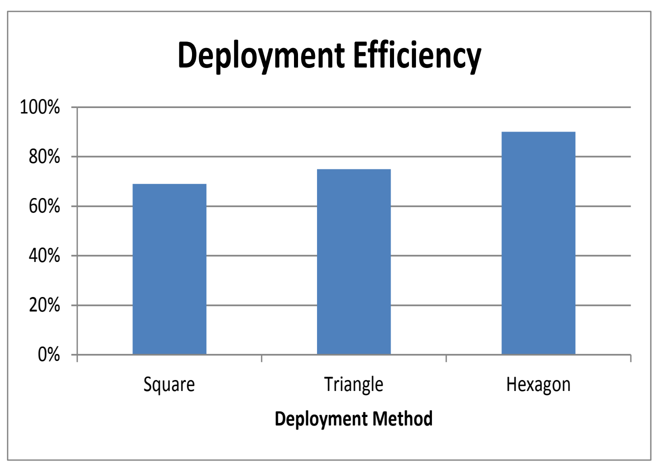


Figure 4.1-6: Deployment efficiency per method

5 Practical Realization on UNN Campus

With the best deployment method determined, namely the hexagon grid deployment, a practical realization of a Wireless Sensor Network for vehicle detection and tracking on The UNN campus can be observed. Looking at Figure 3.0-1, it was noticed that most vehicle activity happened within the center of campus, and the staff and student residential areas. In achieving useful area coverage, sensors can be distributed in only those designated areas in the hexagon grid fashion of deployment. Figure 5.0-1 illustrates this notion.

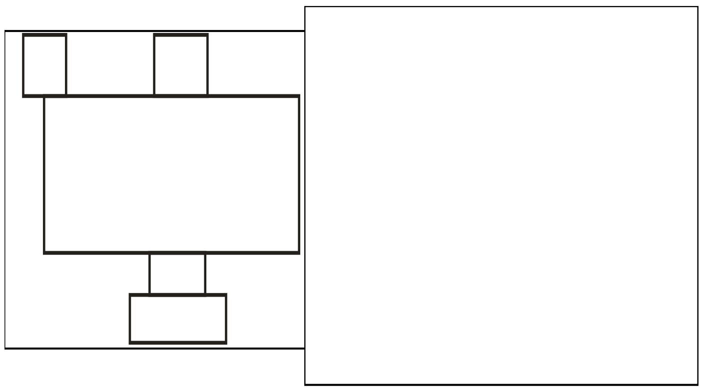


Figure 5.0-1: Optimum Deployment on UNN campus

The new distribution of Figure 5.0-1 achieved total area coverage of 74% at a cost of ₦3,981,460. It is important to mention that the new deployment of the WSN can all be affected by infrastruture and environmental changes of the campus area which can happen in the future. For the time being, with a basic cost of ₦3,981,460, the deployment of a wireless sensor network for vehicle detection and tracking can be realised on The University of Nigeria, Nsukka campus.

6 Conclusion

This paper provided a study on the deployment of a wireless sensor network on The UNN campus for vehicle detection and tracking. It showed that given the right deployment technique, the futuristic technology of WSNs can be realised on The UNN campus. This study, however, did not venture deep into other factors that can affect this realisation. For example, deployment in this case would mean carefully placing the sensors by hand at their corresponding locations which can be time consuming and practically incovienient. In addition, physical obstacles such as buildings and trees were not taken into consideration. It is therefore essential that future studies tackle these issues to ensure a more efficient, cost productive, and convienient approach of deployment is achieved.

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Nathan David was born on the 10th June 1969 in India and he is currently married. He occupys the positon Senior lecturer in the department of Electronic Engineering and has the following educational qualifications: University of Nigeria, Nsukka M.Engr Electronic Engr 2000 – 2003; Anambra State University of Technology,Enugu PGD, Business Administration 1990 – 1991; Anambra State University of Technology, Enugu B. Engr. Computer Science and Engineering 1985 – 1990