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GSM Coverage Enhancement using Distributed Antenna Systems

A. Musa[1], Segun Agbana[1], Saheed A. Adekanmi[2], Sikirullahi Daniyan[1], and Obinna E. Nwafor[1]
[1]Centre for Telecommunications Research and Development, Kwara State University, Malete, Nigeria
[2]Department of Electrical and Electronics Engineering, Federal Polytechnic Ede, Osun State, Nigeria

Email: *twhid2001@yahoo.com, agbanasegun@yahoo.com, herbssolution001@gmail.com, engrdan3169@gmail.com, eobinna97@yahoo.com*

Abstract
People and businesses need seamless and robust wireless coverage. Lack of coverage, dropped connections, and poor quality signals from Global System for Mobile Communications (GSM) decrease productivity and frustrate users. Today's construction techniques and block materials weaken internal and external wireless communication signals inside buildings which causes poor reception in offices, parking garages, hotels, malls and airports etc. leading to dropped calls, and loss of revenue in some cases. Organization's viability and growth especially in this ever-increasing competitive world depend on employee productivity and access to important information and people when necessary. To achieve a workplace or organization with comprehensive wireless or GSM coverage, Distributed Antenna System (DAS) is employed to distribute and enhance the cellular signal of mobile operators within a building with high quality mobile communication for office indoor environment around Electrical and Computer Engineering department situated within the College of Engineering and Technology building, Kwara State University, Malete. The result presents a significant improvement of the network signal coverage around the areas of interest.

Keywords: *Distributed Antenna System (DAS), GSM network, wireless communications, In-building Solution (IBS), link budget, Radio over Fiber (RoF)*

1. Introduction
Distributed Antenna Systems (DAS) using Radio-over-fiber (RoF) technology have been implemented widely in wireless communications to cover areas with low or no radio reception (Choi and Andrew, 2007). Research has shown that DAS can be used to improve wireless coverage especially in dead spots or areas of poor coverage, high usage and where common cellular sites or small cellular sites cannot be implemented because of aesthetic or zoning reasons. Instead of centralizing antenna modules in the same area, the antennas are geographically distributed in DAS. Each of the distributed antenna units is then connected to a central unit using dedicated fiber-optics or coaxial cables (Sheng and Zhang, 2011).

The DAS has two main applications namely, indoor DAS and outdoor DAS. The indoor DAS are usually deployed in large buildings such as airports, schools, hospitals, malls etc. The indoor DAS, also known as in-building DAS, can be deployed in tunnels, basements and underground car parks and metropolitan stations. Recently, the indoor DAS have received increased interest and attention because more wireless traffic originates from indoor users since it appears people spend most parts of their times indoor. Besides, the indoor users are becoming increasingly dependent on their mobile phones especially smart phones which many people now use to carry out online activities and transactions. This development has necessitated the need for an increased GSM network coverage and capacity that is traditionally shared with other outdoor and indoor users in the same cell.

DAS is one of the most common technologies implemented by network operators to achieve in-building solution (IBS) coverage and capacity. Traditionally, the very macro cell base station deployed in the outdoor

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environment has also been deployed for indoor situation to serve as a signal source to support a network of antennas distributed throughout the location or area (Atawia and Ashour, 2013). A repeater or bidirectional amplifier (BDA) can be alternatively deployed as the signal source for amplification of downlink signals from a donor site and amplification of uplink signals from users inside the building. In both cases, the network equipment manufacturers (NEM) base band processing and radio resources are located centrally either in a DAS head-end equipment room at the location or in the shelter of the donor site in the case of a BDA or repeater. The DAS are capable of accepting radio frequency (RF) inputs from different signal sources, thereby making the NEM and the technology generation i.e. 2G, 3G, 4G neutral. For this reason, a DAS is often found as the IBS system of choice for multi-NEM, multi-operator and multi-technology applications.

However, the wireless mobile communication frequencies do not pass through the building obstacles very easily and this has made the indoor service to be poor and unsatisfactory. In practice, the propagation of RF signals from cell sites to indoor mobile handsets requires a power that is about 20 dB stronger than those in the outdoor communications. This is necessary for signal penetration into or out of the building. Furthermore, suffice to mention that while the building penetration loss increases downward at a rate of ~2 dB per floor, the signal isolation between floors is average of about 20 dB (Palit, 2008). This implies that the indoor coverage provided by outdoor stations is unsatisfactory because of severe signal attenuations caused by walls of building as highlighted earlier. Therefore, good indoor network coverage is provided by indoor type of DAS such that antennas are distributed internally throughout the building for uniform and quality coverage.

Fiber-optics is employed as a connecting infrastructure for such antenna network because of its low loss, high bandwidth, light weight as well as its high immunity to electromagnetic interference (Mousaab, 2016). The indoor DAS network planning must be optimized, and this entails determining number of antenna to be deployed, their optimal points of locations and the power transmitted from each of the antennas. For the optimal configuration, it is important to ensure that the deployment cost is minimized and the wireless coverage is maximized. The power leakage outside the building should also be minimized. The optimized planning has been demonstrated especially where the transmitted power is not equally divided among the antennas but optimized for the antennas in accordance to their areas or locations (Atawia and Ashour, 2013). However, this optimization planning has only involved the active part of the inside plant of the DAS network. It is therefore important to extend the planning of the network to include the outside plant. This mainly include the base transceiver station (BTS)-to-DAS connectivity as well as the topology of the in-building fiber optic network. Today, many different types of DAS (such as passive, active, hybrid and digital) are in existence depending on the method employed to distribute the NEM's radio frequency signals to the remote antennas.

There has been reported cases of poor GSM coverage in substantial parts of Malete, a community hosting Kwara State University (KWASU). By extension, the network coverage within the College of Engineering building where the Department of Electrical and Computer Engineering (ECE) is situated is not any better. Thus, the GSM Coverage enhancement using DAS has been implemented in the ECE department.

The report of this work is presented such that introduction is given in Section One, Section Two reviews the theoretical and related works, methodology and implementation procedures are given in Section Three, while the results and discussion of the results are presented in Section Four. Conclusion is made in Section Five.

2. Theoretical and Related Works Review

The increased deployment of wireless telecommunication systems within buildings and other challenging coverage areas has given way to the idea of DAS. A DAS is a network of antennas that are spaced apart from each other, but are connected to a common source. In this way, the DAS is able to provide a radio or a wireless coverage within a given location or area. The concept of a DAS has many advantages in some applications especially as it comes with better defined coverage (i.e. enables the right coverage to be gained) and lower overall power consumption.

The basic idea behind DAS technology is to deploy different antennas over a required coverage location. When this approach is used, the overall required power becomes lesser because more localized antennas can be

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placed for a small area more effectively, rather than having in place a single and larger antenna that is a compromise for the wider coverage that is needed. Adopting a DAS approach helps in overcoming losses, such as the shadowing and penetration losses, because a line of sight link is available more frequently. This makes the levels of absorption to be lower and the overall power levels also decreased. DAS is increasingly being adopted because it comes with a number of advantages to be gained, even as this is at the cost of a larger and more complicated system. Higher cost is as a result of required additional infrastructure.

Abdallah et. al. (2010) studied coverage extension and capacity enhancement of inband relay deployments in Long Term Evolution (LTE)-advanced networks. The work compared the feasibility and the performance of inband operation modes of Relay Node (RN) deployments within the LTE-advanced framework while using the cell coverage as performance metrics and measures. The evaluation was carried out for three different propagation models in networks with 500 m and 1732 m as inter-site-distances (ISDs). Depending on the deployment environment, the system level simulations showed that the two inband relay deployments presents low to very high gains. It was also shown that the effect of the relaying overhead was not much on coverage extension, but was more evident on throughput of the system.

Liu et. al. (2012) studied the Total Cost of Ownership (TCO) in combination with system performance for technology and economical deployment options of the DAS and femtocells as small cell solutions for efficient in-building wireless communication deployment. In the analysis which focused on LTE enhancement in the enterprise buildings, the unique cost features of DAS and femto systems were discussed and the importance of backhaul visibility in the cost analysis was highlighted. Situation when DAS became more economical for large buildings with low data traffic need was also suggested.

Repetition Coding has been proposed in previous works as an effective technique for achieving the necessary coverage enhancements at cost of longer time for decoding. However, the decoding delay may be unacceptable in low signal conditions where many repetitions are needed to build the required signal-to-noise ratio (SNR). Thus, Annamalai et. al. (2015) proposed the use of Reduced Search (RS) Viterbi to improve decoding performance without necessarily compromising the time-to-decode. The RS Viterbi technique makes use of a priori knowledge of transmitted bits to reduce the size and the complexity of trellis. This, in turn, also reduces probability of choosing incorrect path, i.e. error. The simulation work using the RS Viterbi decoding recorded an SNR gain of up to 2.2 dB against the conventional Viterbi decoding. This was to improve the sensitivity of Machine Type Communication (MTC) devices for better reachability.

Fantini et. al. (2011) enhanced the existing theoretical models for evaluations of capacity by providing analysis from an energy efficiency point of view of two approaches after considering a fully loaded network and the total emitted radio frequency power of the transmitting nodes. Results, obtained in terms of the Energy Consumption Index, show that relays are also valuable tools to reduce the energy consumption of a communication network in addition to the possible improvements in capacity.

However, Cho et. al. (2010) described some practical deployment cases where relay (or repeater) links such as DAS can act as keyholes to degenerate the rank property of Multiple input multiple output (MIMO) communications. In order to get MIMO spatial multiplexing (SM) gain even in those cases, the authors proposed a practical scheme that make use of simple converter in the repeater links devices. The proposed solution was expected to significantly improve the system capacity in a cost-effective manner.

Lei Chen and Di Yuan (2014) mentioned a comparison results of the DAS system with a conventional Array Antenna System (AAS), and demonstrated the effectiveness of the DAS model. Besides, great interests have been shown in DAS due to their many advantages. Shi Z. et. al. (2015) noticed that DAS comes with smaller average access distance, smaller radiated power, stronger received signal and better antenna positions consideration when compared with centralized MIMO systems.

In Figure 1, an overview of the DAS scheme is shown. The major components employed in the system are antennas (Omni, Panel and Donor antenna), repeater (Booster), 2-way splitter, and coaxial cable.

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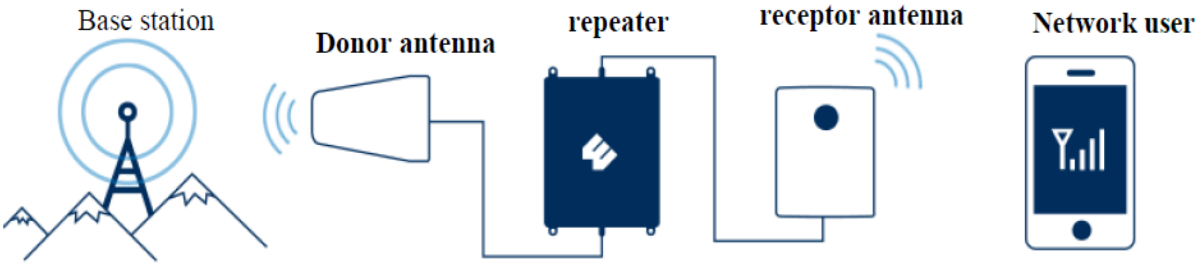


Figure 1. Overview of distributed antenna system

The path loss between the base station and the receiver is one of the most important components in the link budget. The loss factor is a function of the distance between both antennas and environment where the signal is being propagated. Path Loss Slope (PLS) is the model that has been implemented and used in all the simulations. The PLS model is empirical and is derived using curve fitting of the thousand measurement samples in a variety of scenarios. Equation (1) is used to calculate the free space path loss of the antennas installed in the building. The path loss measurement was carried out at different distances from the antenna.

$$FSPL = 20\log_{10} d + 20\log_{10} f + 20\log_{10}\frac{4\pi}{c} - G_{Tx} - G_{Rx} \quad (1)$$

where

f is the frequency, d is the distance between the antennas, G_{Tx} is the gain of the transmitting antenna, G_{Rx} is the gain of the receiving antenna and c is the speed of light in vacuum.

3. Materials and Methods

This section gives details of the materials, methodology and design implementation. RoF based DAS have been implemented in wireless communication networks to cover areas with low or weak radio reception in ECE department, KWASU. The implementation has three procedures which include Technical Site Survey (TSS), design and link budget calculations, and implementation of the system design.

3.1 Technical Site Survey (TSS)

A Technical Site Survey (TSS) was carried out to collect the building information needed for the DAS design and confirm the availability of optimum donor signal required for the booster deployment at the ECE department, KWASU, Malete. During the TSS, the materials and their quantity employed in the design of the DAS was identified. Table 1 shows the materials used for the design. Further, a pre-walk test was conducted to assess the two existing mobile telecommunication coverage within the ECE department and premises. This was done by using TEMS phone and installed software on a laptop in order to confirm the coverage status within the premises and to confirm the best location to mount the outdoor antenna which will pick signals from the nearby site. Figure 2 shows the signal strength and the analysis of one of the existing mobile telecommunication networks.

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Table 1. Distributed Antenna System materials and their quantity

S/N	MATERIALS	QTY
1	23dBm Repeater	1
2	Omni Antenna, 698 - 2700 MHz	3
3	Panel Antenna 698 - 2700 MHz	1
4	11dBi Yagi Antenna 698 - 2700 MHz	1
5	1/2" Cable	51m
7	½" Connector	16
8	2 way splitter	1
9	Right angle adaptor	5
10	Tie wrap	1
11	6dB coupler	2
12	Trucking	14
13	2m Microwave pole	1
14	13A Plug and Socket	1
15	4mm 3core power cable	10m
16	other installation accessories: screw nails etc.	Lots

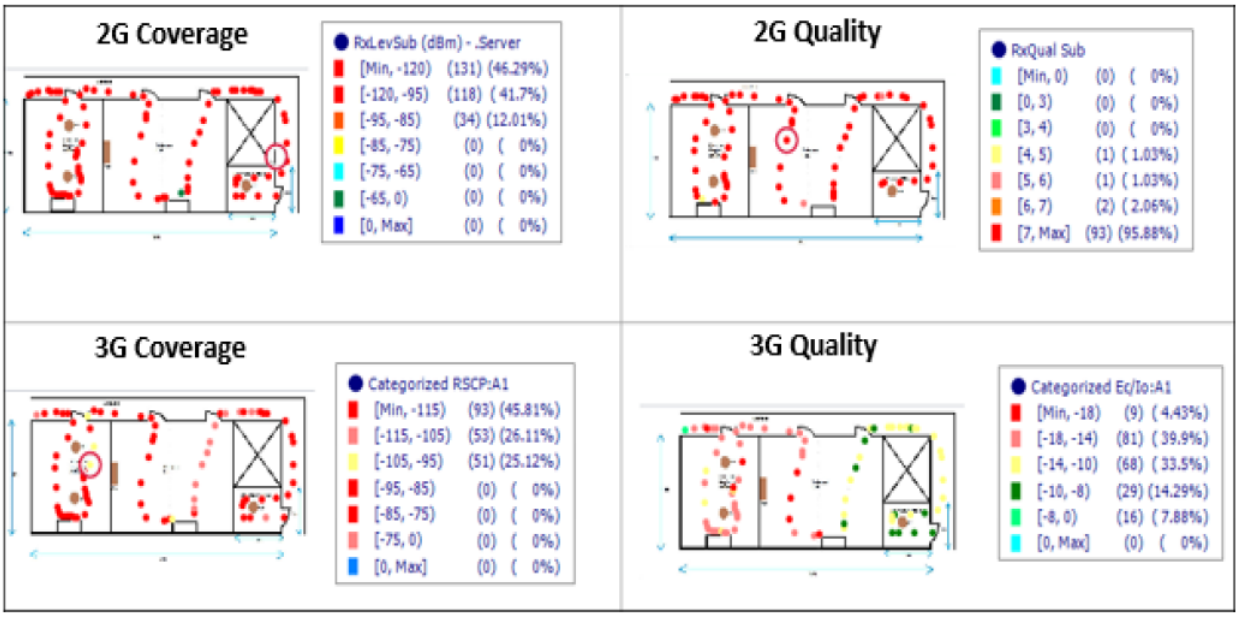
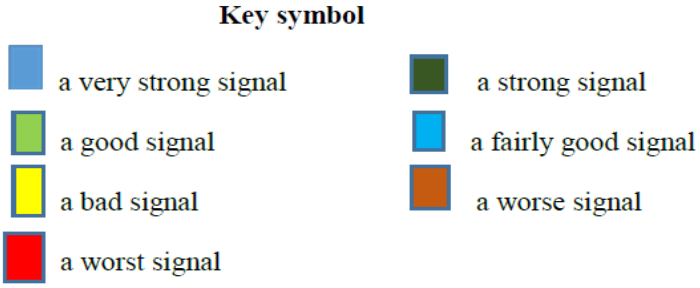


Figure 2. Signal Strength of Network I – Pre Walk Test



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Using the information gathered during the TSS, the antenna types and their locations in each office as well as the type of topology to be employed was then planned. Thus, DAS was deployed in the General Office, Telecommunication Laboratory and a Staff Office of the ECE department. The floor plan design where the research work has been implemented is shown in Figure 3.

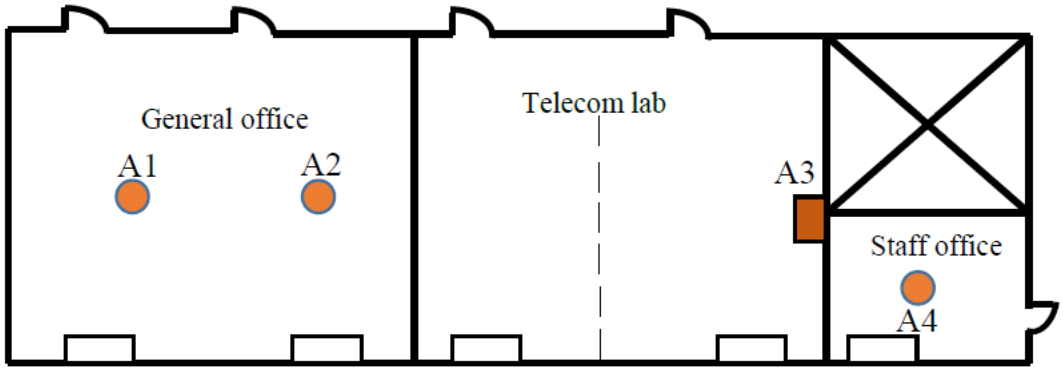


Figure 3. Floor plan design of ECE department, KWASU.

3.2 Implementation of DAS

A Yagi antenna is defined as a directional type of antenna having a single dipole, a reflector, and multiple elements used for point to point or point to multi-point Wi-Fi applications. In this work, Yagi antenna was mounted horizontally on the tower of the building on a pole to intercept weak or poor signal around the building and pass this signal to the booster installed in the building. The antenna is applicable to signal of frequency ranging from 698 MHz – 2700 MHz. The repeater receives the weak signal sent by the Yagi antenna and boosts it. A class of antenna that radiates equal radio power in all directions perpendicular to an axis i.e. azimuthal directions and with power varying with angle to the axis i.e. elevation angle declining to zero on the axis is said to be omnidirectional antenna. The omnidirectional antennas were mounted around the building and they transmit amplified signal coming from the booster via coaxial cable in all directions of the building. They have low gain of 3dB and beam width of 360^0. The weak signal intercepted by the Yagi antenna amplified by the booster to yield a strong signal is emitted by the Omni antennas.

Panel antennas from KP Performance, also known as a flat panel, are a type of lower-cost directional microwave antenna commonly used as an access point when coverage is needed in a single direction over a small area. Flat panel antennas from KPPA are also used as a client-side antenna, instead of a reflector dish, due to their high gain and moderate beam width (20-40 degree) for their relatively small size. A 2-way splitter is a device used to split signal equally in two ways. It is used to split the power from the booster into two ways through the cables to the Omni antenna mounted inside the building. Coupler are used to split antenna feeder power unevenly among output ports. A directional coupler provides coupling of the main signal path to another signal based on the direction of the signal propagation. They are used in in-building solution (IBS) networks to split the signal, unequally, in the mainline. Typical directional couplers operate in around 698 MHz - 2700 MHz of frequency range.

3.3 Design and Link Budget Calculations

The formula expressed in Equation (1) is used to calculate the free space path loss of the antennas installed in the building. In the expression, the free space path loss calculation takes into account the gain on both the transmitting and the receiving antennas. The gain of the antennas offsets the loss by a certain decibel value. If the

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gain at either the transmitting end or the receiving end is ignored, then the FSPL will be a factor of the distance and the frequency.

4. Results and Discussion

This section presents the results and their discussion. This include testing the results of the systems (antenna, splitter, microwave pole, RF cabling, Booster etc.) after the implementation and verification of proper interconnection and configuration of access points. It also includes observation of the system performance, conducting a post-walk test to confirm coverage status, as well as independent operational verification tests by staff of ECE department. Using the loss formulae discussed in Section 2 and expressed in Equation (1), Table 2 and Table 3 which also show the path loss and the gain of the components used in the DAS design for 2G (1800 MHz) and 3G (2100 MHz) connectivity were obtained.

Table 2. Path loss and antenna gain in the DAS for 1800 MHz (2G); ECE Department

Frequency MHz	**1800**	**A1**	**A2**	**A3**	**A4**
cable length 1/2"(m)	-0.1006	30	28	29	33
Total loss 1/2" dB		-3.02	-2.82	-2.92	-3.32
Total Connector Loss(dB)		-0.48	-0.48	-0.48	-0.48
Coupler 6 dB (coupling)	-6.00	1	1	1	
Coupler 6 dB (thru)	-1.70			1	2
Total Coupler Loss(dB)		-6	-6	-7.7	-3.4
Splitter 2 way (dB)	-3.20	1	1		
Total Splitter Loss(dB)		-3.20	-3.20	0.00	0.00
Repeater Output power(dBm)	23	1	1	1	1
Antenna Gain Panel (dBi)	7			1	
Antenna Gain Omni (dBi)	3	1	1		1
Antenna EIRP (dBm)		15.3	15.5	19.9	20.8
Distance (m) (Ant to Mobile)		10	10	10	10
Path Loss (include 16dB obstruction loss)(dB)		83.5	83.5	83.5	83.5
Receive Signal Level (dBm)		-68.2	-68.0	-63.6	-62.7
EIRP Maximum (dBm)	20.8	-62.7			
EIRP Minimum (dBm)	15.3	-68.2			
EIRP Average (dBm)	17.9	-65.6			

Table 3. Path loss and antenna gain in the DAS for 2100 MHz (3G); ECE Department

Frequency MHz	**2100**	**A1**	**A2**	**A3**	**A4**
cable length 1/2"(m)	-0.1096	30	28	29	33
Connector 1/2"	-0.0600	8	8	8	8
Total Connector Loss(dB)		-0.48	-0.48	-0.48	-0.48
Total Jumper Loss(dB)	-0.20961	0.00	0.00	0.00	0.00
Coupler 6 dB (coupling)	-6.00	1	1	1	
Coupler 6 dB (thru)	-1.70			1	2
Total Coupler Loss(dB)		-6	-6	-7.7	-3.4
Splitter 2 way (dB)	-3.20	1	1		
Total Splitter Loss(dB)		-3.20	-3.20	0.00	0.00
Repeater Output power(dBm)	23	1	1	1	1

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Antenna Gain Panel (dBi)	7			1	
Antenna Gain Omni (dBi)	3	1	1		1
Antenna EIRP (dBm)		15.0	15.3	19.6	20.5
Distance (m) (Ant to Mobile)		20	20	20	20
Path Loss (include 16dB obstruction loss)(dB)		90.9	90.9	90.9	90.9
Receive Signal Level (dBm)		-85.8	-85.6	-81.2	-80.4
EIRP Maximum (dBm)	20.5	-80.4			
EIRP Minimum (dBm)	15.0	-85.8			
EIRP Average (dBm)	17.6	-83.3			

Besides, test results were obtained with the use of walk test tool (TEMS phone) for the two existing mobile networks, termed Network I and Network II.

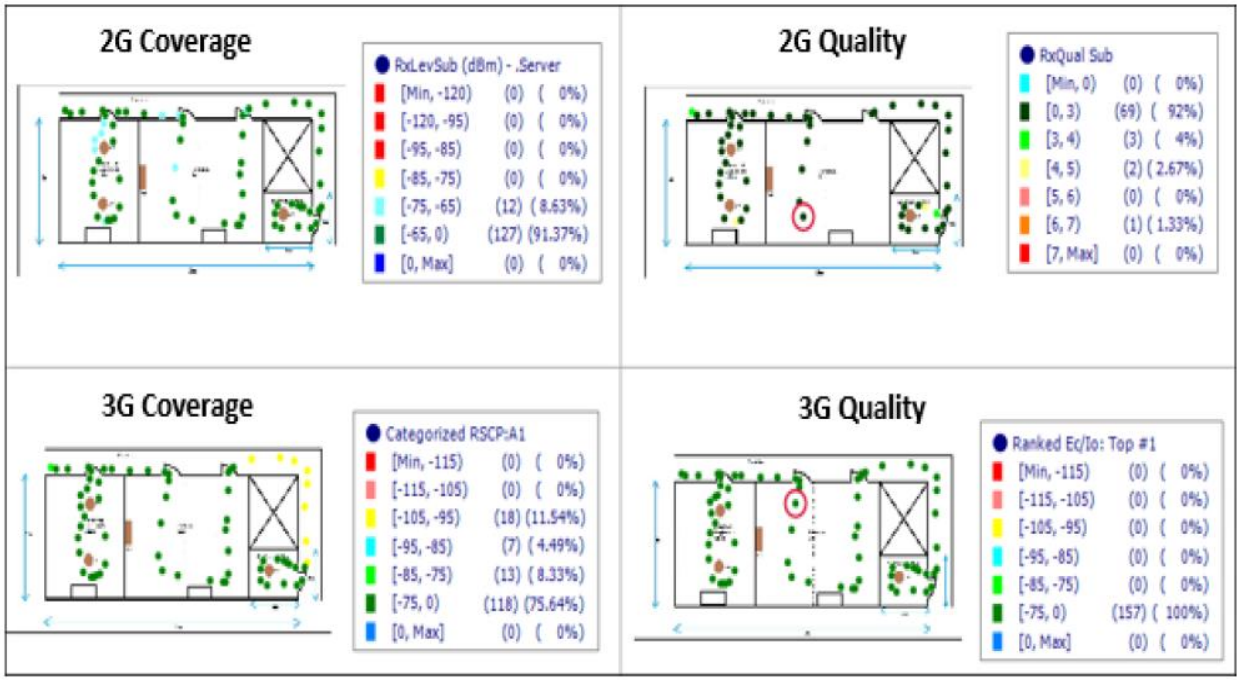


Figure 4. Signal Strength of Network I – Post Walk Test

The pre walk test signal readings carried out before the installation was between –95 dB to –120 dB which shows that the strength of the signal in the offices and the Telecommunication Laboratory was very weak. A good signal ranges from 0 to 80 dB as any signal above this may be deemed to be very bad. However, during the post walk test after the installation, the signal reading improved to a range between –60 dB and –65 dB which shows that the strength of the signal has been enhanced. Consequently, the aim and objective of the work which is to improve the coverage and usage of existing mobile networks for both voice and data within the ECE department have thus been achieved.

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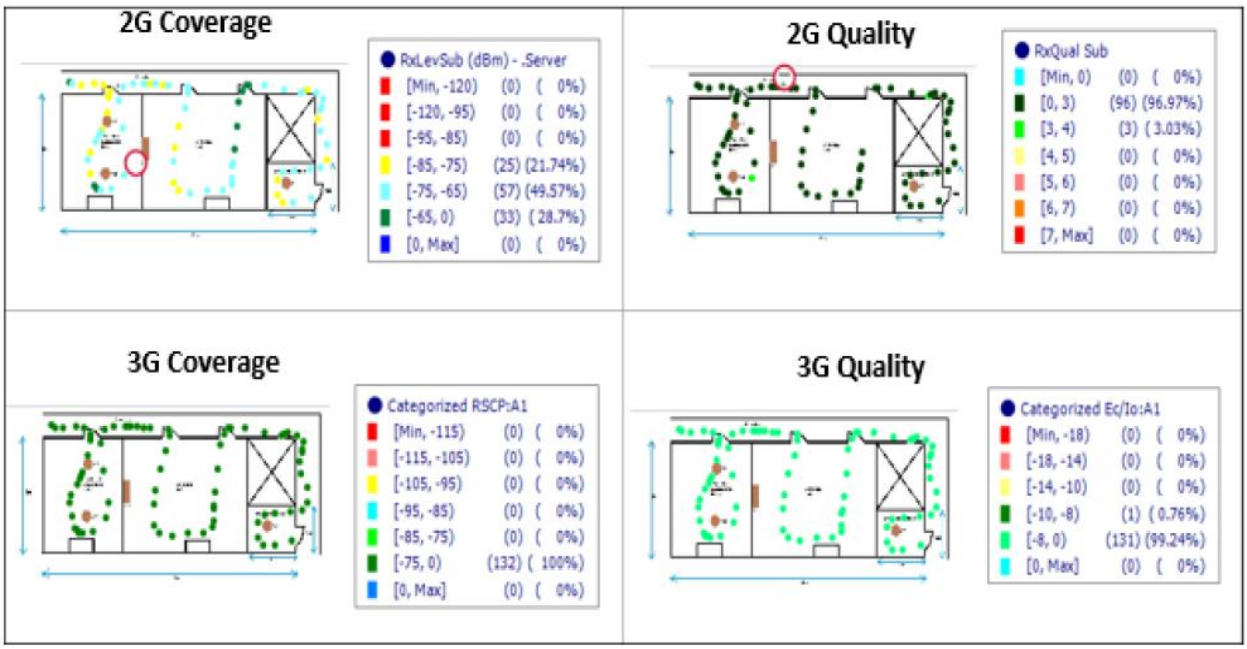
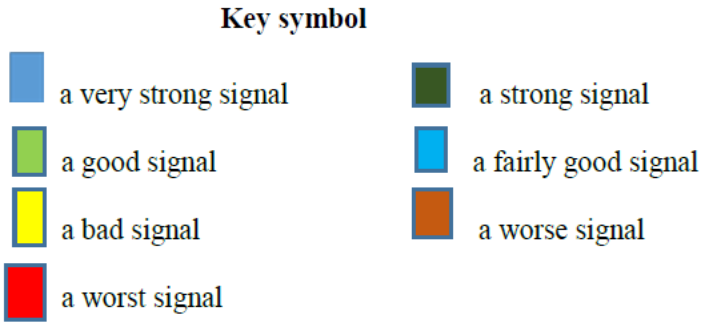


Figure 5. Signal Strength of Network II – Post Walk Test



5. Conclusion

In this work, GSM coverage and usage in the ECE department have been enhanced through the design and implementation of a DAS technology. Furthermore, the work has demonstrated that Quality of Service (QoS) can be retained while saving energy i.e. using less power to maintain the required QoS. The work also confirmed that more antennas lead to better energy efficiency. Users of DAS application need to carefully consider emerging networking technologies such as multiple-input multiple-output (MIMO) and massive MIMO to evaluate how DAS will support them and how these systems will be evolving in the future. DAS have gained more attention especially with the development of MIMO techniques. But hardware costs and computational complexity appear to be a big problem and limitation. New design of redundant cabling infrastructures may also be required to support MIMO. Furthermore, process of optimization could be responsible for determining optimal number of antenna depending on the specific scenario (such as number of users in the area) and the environment. Collaboration and awareness among construction industry professionals in the area of radio signal transmission is necessary. Also, closer collaboration between building contractors, building designers, owners and relevant authorities is key for the necessary knowledge and means to avoid reception problems in building new structures

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or renovation of existing ones. With this, the issue of reception problems caused by the building materials or other circumstances can be avoided or minimized.

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