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Engineering Process Management for Enhancement of in-Building RF Coverage of Mobile Networks

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Abstract

In this paper, the main aim is to propose an engineering process management for enhancement of in-building Radio Frequency (RF) coverage of mobile networks for customers. Mobile service providers are currently in need of efficient engineering process management that would be able to provide in-building coverage solutions in order to satisfy the customer's expectation. This can be achieved by providing an end-to-end customer management guideline which involves a method of task escalation that will be able to handle customer complaints by providing solutions to enhance the coverage at a given location. The demand for better cellular coverage and higher data rates entails the RF design planners to find possible ways to bring the signal source closer to the mobile user. Therefore, the proposed method is to implement a Distributed Antenna System (DAS) in order to enhance the reception in a building. A DAS incorporates the usage of external antennas, in-building antennas, cables, connectors, splitters, directional couplers, and coverage enhancers such as repeaters. A site survey is done initially at the affected areas to obtain pre-coverage measurements performed at the affected area. Then, a proper design plan which will include installation floor plans and link budget calculations will be done to ensure the design proposed is attainable. A performance test will then be performed to ensure that the solution provided is able to strengthen the coverage signal for the customers inside the building.

***Keywords:** Radio Frequency (RF), in-building coverage, Distributed Antenna System (DAS), Mobile service.*

1. Introduction

Today, wireless communication systems have grown in proficiency and popularity. Currently, there are numerous mobile service providers that provide data, voice and video communication capabilities to mobile units such as mobile phones, tablets, laptops and many more. With that being said, wireless communications have grown more and used more widely with the rise in the number of service providers. Not only that, an increase in wireless technological capabilities available now has also contributed to this. However, there is also a limitation on such communications which is currently being faced by the service providers today which is the ability to attain satisfactory signal coverage within a home or large office buildings. There are a variety of factors which contributes to the poor Radio Frequency (RF) coverage in and around buildings or a home.

Generally, RF technology which is also sometimes known as wireless technology, is basically the utilization of electromagnetic wave spectrum between 3Hz and 300GHz. It is possibly one of the most significant wireless technologies founded in today's modern society. Mobile service providers today utilize RF technology to its fullest

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potential in order to meet the customer's demands. Therefore, understanding RF coverage and capacity requirements are crucial for the industry to find ways and methods to improve the coverage for customers [1].

One method currently being used widely by the mobile service providers is conducting site surveys. One of the main aspects of a wireless site survey is to better comprehend and verify the RF coverage and capacity requirements based on the network design [2]. The different factors which can affect the poor coverage will have to be properly studied and taken into consideration along which the solutions which can be provided once an analysis of the data obtained is done. The testing will then verify the enhancement of the RF coverage. Not only that, in order to have a more efficient telecommunication solutioning process, a proper engineering project management is required to resolve this. This is also vital for current telecommunication service providers who require a more improved system which also includes better technical solutioning methods in order to satisfy customers.

Mobile communications today is one of the most talked about topic around the globe. The usage of mobile phones is flourishing even more after its evolution to smartphones. This however, proves to be a problem in disguise for mobile service providers as there is a bigger demand now on the existing spectrum due to higher data traffic. Places such as offices, buildings, airports, schools, shopping malls and houses can sometimes have very weak reception due to this. This can lead up to many different kinds of problems in these places such as drop calls, missed opportunities and also revenue loss. Furthermore, these problems can greatly affect an organization's development, viability and durability in the current world as competition is a key factor to survive in the industry. There is a constant need for smooth and strong wireless coverage for businesses to thrive. For example, for mobile service operators, problems such as weak coverage, interruptions in connection and very low quality of signals will annoy customers and reduce productivity. Therefore, mobile service providers currently require an improved solutioning process of improving the RF coverage for customers in order to meet the current industry demand [3].

Mobile network operators today will face many problems when energy-efficient housing develops more widely. It is stated that houses which are made of modern construction materials are needed to attain satisfactory level of energy efficiency. However, that in turn will affect the radio signal propagation profoundly. [4] suggested to increase the level of awareness of probable radio signal coverage issues in modern residential structures. In this research, the material attenuation measurements were provided for different isolation materials. Also, a proper discussion is provided to understand which materials are better for the construction of residential buildings. Lastly, the usage of indoor and outdoor coverage enhancers is also deliberated on how they can combat coverage issues. The results shows that the usage of glass wool and polyurethane insulator without aluminum was not causing any attenuation towards the radio frequency (RF) signal after analyzing the measurements. However, the usage of energy efficient windows and polyurethane insulator with aluminum provides a high attenuation. [5] studied the importance and factors that impacts antenna isolation. This is noted to be crucial for network planners as they have to provide careful concerns in selecting suitable sites and determining the optimum repeater operating parameters. The methodology used to achieve the objective is by conducting a study on how to better implement a repeater system and analyze the antenna isolation measurements. The results shows that it is very important that the measurement of the antenna isolation is performed because it is to ensure that the minimum required antenna isolation is met for the proposed repeater maximum operating gain. Also, it is also noted that the antenna isolation must be at least 15dB larger than the repeater gain. Not only that, the antenna isolation measurement also shows that the antenna isolation can be improved by increasing the attenuation in the feedback path between two antennas.

[6] conducted a study on the factors that influences the strength of in-building radio frequency

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coverage by implementing an indoor radio wave propagation model. It is noted that diffraction, reflection and scattering are the three basic mechanisms that can cause radio signal distortions and propagation losses. Other factors that can affect the radio wave propagation are the location of the antenna and the type of building structure. The methodology used to achieve the aim was by implementing the radio wave propagation model in a multi storied building. The model is basically a measurement system which comprises of a measurement transmitter and receiver with an automated data collection that will then express the path loss and attenuation.

[7] conducted a study on the evolution of mobile cellular networks and how it compares to each other respectively. The authors discussed the cellular networks from the first generation and how the industry has grown till the fourth generation and also by carrying out a comparison between them. The results shows the remarkable growth of wireless generations as it was noted that there were many attempts to reduce the number of technologies to a single global standard. 1G has achieved the basic mobile voice using analog techniques while 2G has led to more capacity and coverage using digital techniques. On the other hand, 3G has opened a new mobile broadband experience at higher data speeds. 4G is then noted to further improve the third generation by providing better data speeds, image and video qualities.

There are various propagation models that are used to analyze the Global System for Mobile Communication (GSM) and Universal Mobile Telecommunications Service (UMTS) for urban area coverage measurement. [8] investigated the difference between indoor and outdoor propagation which in this case are the signal levels in a middle urban area for GSM 900 (2G) and UMTS 2100 (3G) systems. A measuring software called Nemo Handy was used to measure the signal coverage in 2G and 3G cellular networks. Another measurement software called Nemo Outdoor was also used to analyze the measurement results and the results were then compared with the signal levels acquired by using the COST 231 propagation model. The COST 231 model was used in this paper as it is based on the Okumura-Hata model for urban areas but it lengthens the range of the Hata model frequencies up to 2000 MHz instead of 1500 MHz. The measurements were carried out on two types of buildings mentioned above which are the old ones (made of brick and stone) and new ones (made of concrete and glass surfaces). The results obtained after performing the measurements were that the new buildings have better indoor coverage than old ones for GSM 900. The same observation can also be noted for the UMTS 2100 system.

The impact of repeaters on Code Division Multiple Access (CDMA) system performance have been studied by [9].The authors investigated the option of utilizing a repeater as a means of lengthening cell coverage instead of only covering dead spots where signal coverage is not satisfactory.A simulation model was then used to investigate three scenarios which are system without repeater, single cell system with repeater, and multiple cells with repeater. The overall results obtained from the simulation was noted that for single cells with repeaters, the coverage increases while sustaining and unchanged level of capacity. Furthermore, for the multiple cells scenario, the usage of the repeater increases the coverage and system capacity by 2-3 users. It was also noted from the results that the noise floor in the base station did not affect the system performance. Nevertheless, when the noise floor surpasses a certain threshold whereby in the simulation case of -98dB, the capacity begins to decrease. This is due to the limited range of power of the transmitters which were unable to overcome the noise floor.

There are several effects of user-deployed, co-channel femtocells on the call drop probability in a residential area. [10]investigated the effect of the added handovers which are caused by a co-channel femtocell on the dropped call rate of users and to also focus on the significance of power control in the deployment of femtocells. The methodology used to achieve the aim above was by firstly describing the calculation of handover probabilities for macrocell users. Secondly, a simulation was then carried out to investigate and

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discuss the probabilities of drop calls in a larger scale residential area. Lastly, the influence on the signaling was then analyzed and discussed. The results were then observed and discussed in the paper. It was noted from the results that if the power adaption techniques are applied, the increase in drop probabilities due to the femtocell deployment are low. Therefore, it also shows the significance of auto-configuration in the deployment of femtocells.

Site surveys are generally the most widely used method of obtaining coverage measurements. A drive test measurement between Maxis 2G and 3G networks was basically done in a university campus by [11] to measure and analyze the Received Signal Strength (RSS) and signal quality between the 2G and 3G network of one of Malaysia's largest mobile service provider which in this case is Maxis. The methodology used the Nemo Handy software as method for the test drive measurements. The measurements taken for both 2G & 3G were done in the morning, afternoon and evening for three days without the presence of rain while another measurement was taken on a rainy day to observe any difference in the RSS. It was noted that for the 2G RSS, the best performance was during the evenings where the received signal level (Rx level) obtained is -74.815dBm. On the other hand, for the 3G RSS, the best performance was during the mornings where the Received Signal Code Power (RSCP) obtained was -88.08dBm. The temperature was noted to be an influence that affects the RSS. Overall, the 3G network was noted to have a better RSS compared to the 2G network.

A performance assessment of High Speed Downlink Packet Access (HSDPA) networks from outdoor drive test measurementsdone by [12]to assess the prospects of standard drive test tools to execute diagnostics of the Radio Access Network (RAN). This is due to the introduction of HSDPA technology to help support the growth of 3G networks which in turn adds more limitations to the RAN. The methodology used in this paper was by taking measurements at one of the universities in Valencia and by conducting a test on the HSDPA network of one of the local 3G operators in Spain. The Nemo Outdoor software was used to perform the drive test and the RAN diagnostics was then acquired using the measure parameters obtained in the drive test. Once the RAN diagnostics was attained, a few issues were noticed and discussed which relates to the poor coverage levels. The results were obtained and discussed after the measuring and analyzing the HSDPA network using the methodology stated above. The results that were shown basically show an overall decent performance. However, a few configuration issues were noted as well but could potentially be corrected in the optimization stage. Not only that, it is also observed that regular coverage issues can be identified using standard drive test equipment and tools in an optimization process of the Universal Terrestrial Radio Access Network (UTRAN). The adjustment of the configuration is essentially critical in the optimization stage in order to guarantee decent Quality of Service (QoS) when the number of users starts to increase.

Therefore, the aim of this papaer is to propose an engineering process management for enhancement of in-building RF coverage of mobile networks for customers.

2. Proposed System Methodology

The proposed methodology for this project is basically designed to provide a standard on how mobile service providers can enhance the RF coverage for their customers. This is achieved by providing an end-to-end customer management guideline which involves a method of task escalation that will be able to handle customer complaints by providing solutions to enhance the coverage at a given location as shown in Figure1. There are 8 tasks that have to be governed from the start where the complaint is received till the end where the issue is resolved. These 8 tasks also have their respective Service Level Agreement (SLA) time frame.

Task 1 – Desktop Analysis

The first task is where a desktop analysis is performed. Any customer complaint that will be escalated to the technical department is basically referred to as an incident or Trouble Ticket (TT). The TT is analyzed as a preliminary step to

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investigate the performance of the respective serving site or to find out if the customer already has an existing solution which was previously installed at the location. Also, it is to further investigate and analyze the TT created in order to provide a more suitable solution. Therefore, task 1 is given the name as desktop analysis due to the fact that the analysis of the complaint will only be done on a computer at this stage.

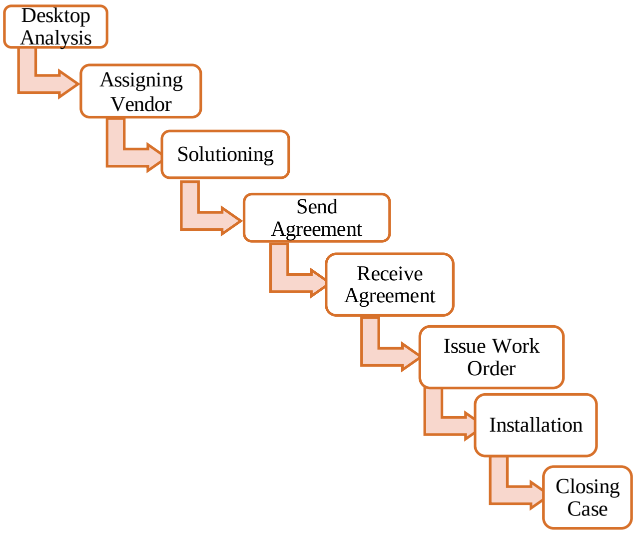

Figure1: Flow of Task Escalation

Task 2 – Assigning Vendor for Walk Test

This task basically involves assigning a vendor to perform a Walk Test at the customer's location to further investigate the status of the coverage in the area. This task will only be performed after performing the preliminary checking in task 1 to ensure that the serving site has no active performance issues or abnormalities so that a walk test can be arranged at the customer's location to further investigate the status of the coverage in the area. The vendors will then be contacted via email to provide them details such as the incident number, customer name and address of the customer. The respective vendor assigned will then contact the account manager in charge of the customer to inform him/her on the appointment date for the Walk Test.

Task 3 – Solutioning

Upon receiving the Walk Test report, the technical team will then have to check and verify if the report contains the necessary data and coverage check lists and plots. Then the report will then be escalated to a solutioning team who are tasked with analyzing the Walk Test report and further investigating the problem faced by the customer. This task is to be completed within the SLA of 3 working days.

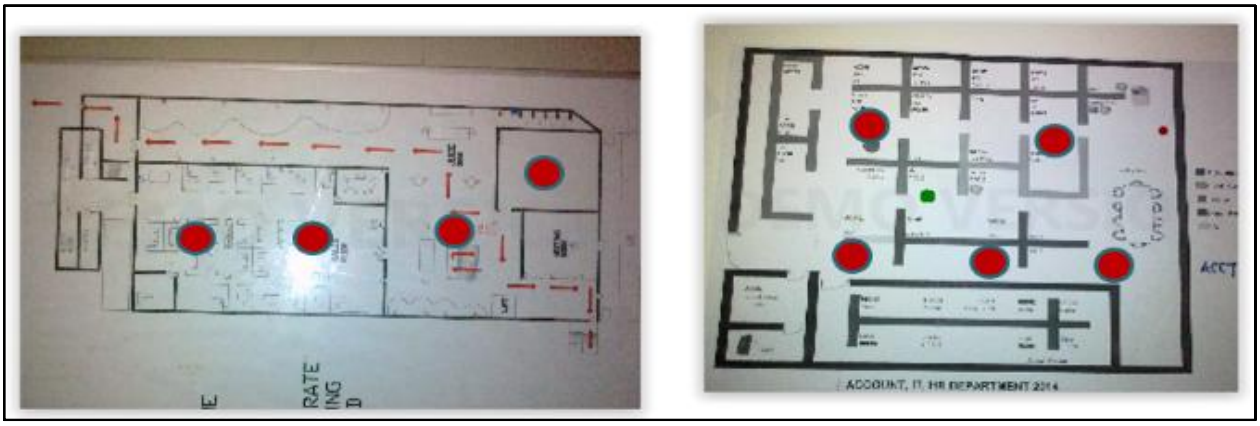

Figure 2: Example of Proposed Solution Location

Task 4 – Send Agreement

After the solutioning team provides a final solution along with a detailed reasoning for choosing it, the key account manager of the department who is responsible of overseeing all the agreements being made for customers will then be contacted. The account manager will then need to prepare the installation agreement policy which will then be sent to the customer immediately. The purpose of the agreement is for the customer to understand and agree to the terms and conditions of the installation for the proposed solution. For example, some of the terms of the agreement include the following:

- Responsibility of mobile service provider in installing, maintaining, removing and/or replacing the equipment.
- The mobile operator's ownership of the equipmen.
- Securities of the equipment & insurance by the mobile service provider.
- Power source and broadband connection for the equipment should be provided by the customer.
- The customer must allow the mobile service provider a free, continuous and uninterrupted access to the equipment for maintenance.
- Duration of the agreement.
- The mobile service provider's permission to terminate this agreement with one month's notice.
- Governing Law.
- No amendments unless agreed by both parties

The list shown above describes some of the contents of the agreement that will be sent to the customer. The customer must then read the agreement thoroughly and then decide to agree to the given conditions. If the customer agrees to the agreement, the signature or official stamp of the customer will be needed at the last page of the agreement. If the customer does not agree, then the agreement will be sent back to the technical department to proceed closing the case with remarks. Task 4 is required to be completed within the SLA of 1 working day.

Task 5 – Receive Agreement

Upon sending the customer the agreement, the customer is required to provide an official signature if the customer agrees to comply with the agreement. Task 5 is required to be completed within the SLA of 14 working days.

Task 6 – Issue Work Order

When the agreement is received back from the customer, the work order for the installation will then be prepared. The work order will include details such as the customer's location, problem faced, solution proposed, location of the equipment that will be installed and also the estimation time of completion. The work order will then be escalated to the roll out team to carry out the installation at the customer's premise. Task 6 is required to be completed within the SLA of 1 working day.

Task 7 – Installation

The installation of the proposed solution will then take place at this task. Once the technical team has sent out the work order to the roll out team, they will then liaise with the customer regarding the date of the installation that will be carried out. Once confirmed, the roll out team will then proceed installing the proposed solution and also test out the performance of the equipment after installation. This is to verify that the equipment installed is functioning as it should be. The roll out team will then provide a built report to confirm the functionality of the equipment and to confirm the installation was completed. Task 7 does not have a fixed period where it should be completed as it depends on the type of solution, availability of the customer and also the amount equipment and cables needed to install. However, task 7 should not take more than the SLA of 30 working days.

Task 8 – Closing Case

Once the installation is completed and the built report is received, the case can then be closed. The technical team will then run a final checking on the overall tasking order to make sure that everything has been completed before proceeding to close the case. The details of the end-to-end solutioning which includes all the tasks above will be recorded in a Microsoft Excel database in order to keep track of the work done. Figure 3 basically shows the flowchart of the overall task escalation which has been explained with detail above. The flowchart below will provide a better understanding on how the 8 tasks are escalated and how the technical department of a mobile service provider company will be able to govern the overall 'End-to-End Enterprise Customer Management' process.

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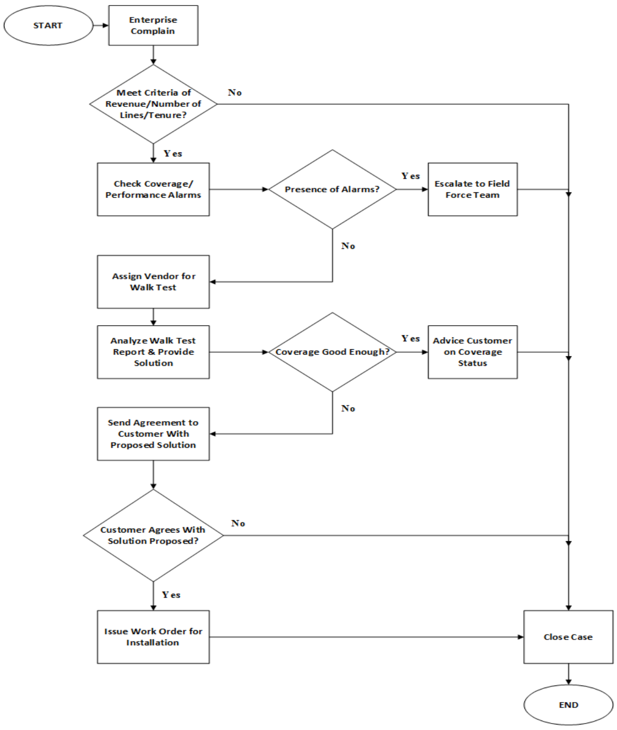

Figure 3: Flowchart of Task Escalation

3. Block Diagram of Overall System

Figure 4 shows the overall block diagram of the entire system. The diagram basically illustrates how the DAS is implemented in a building as a solution to boost the RF coverage for customers inside. The design was introduced because people also desired an indoor mobile connection instead of just outside of a building. However, a macro cellular network which is the wide coverage area distributed by cell towers which are linked, had issues penetrating through certain windows and walls of a building. Thus, the design shown in figure 4 was created as a solution to the problem. A IBS can contain several different technologies with each having their own functions. With that being said, all IBS are basically designed to primarily boost the macro wireless network through the deployment of indoor coverage in a certain area to deliver continuous connectivity for individuals inside.

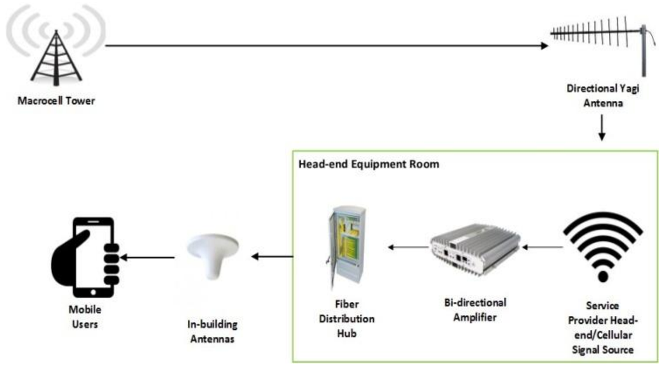

Figure 4: Block diagram for an in-building passive DAS implementation

A. Macrocell Tower

The first block shown in Figure 4 represents a macrocell tower. A macrocell is basically a cell in a cellular network that provides RF coverage served by a high powered mobile base station tower. Furthermore, a macrocell is a represented but a wireless network area that has a radius of a few hundred meters up to tens of kilometers. The coverage area covered is much larger compared to a microcell. These macrocell base stations use high powered antennas which are usually installed at a height of around 30 meters or higher at the top of a tall building or tower. The antennas normally have a transmission power between 5 watts and 10 watts (37-40 dBm). The BTS equipment is typically kept at the base of the tower or a room inside the building so that the temperature can be preserved.

B. Directional Yagi Antenna

The DAS generally uses an outdoor, directional antenna in order to retrieve good cellular signal. The cellular signal retrieved is then conveyed to an amplifier equipment which helps to boost the signal strength. The amplified signal which will then be retransmitted locally by the amplifier unit will basically provide a significantly enhanced signal strength to the mobile users. Therefore, the antenna element of a DAS is crucial as it represents the gateway for the cellular signal from the microcell to be distributed to the entire building. The location for which the antenna should be installed at must be considered carefully in order to provide the desired coverage [13].

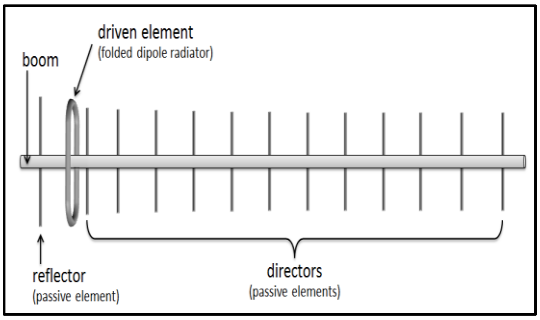

Figure 5: External directional Yagi Uda antenna

C. Cellular Signal Source

Generally, a DAS is not capable of generating the cellular signal because it only helps to distribute the signal as the name suggests. A cellular signal has to be fed into the DAS from an external source which in this case is the macrocell tower. The signal is fed into the system through an external directional antenna which is usually mounted on the roof of the building. The macrocell towers are usually constructed by the various local mobile service providers which are responsible of radiating their cellular signal to the users.

D. Bi-directional Amplifier

A bi-directional amplifier or more commonly known as a repeater is basically a device which helps to increase the signal power within an area between mobile equipment and cell towers. It functions in an uplink and downlink direction. Repeaters are typically used in an area that has either poor coverage for indoor or outdoor environments. For example, certain indoor areas which may be blocked by obstacles might require coverage enhancements. A repeater system basically consists of a donor antenna and a server antenna. The repeater uses a donor antenna which in this case is an external directional yagi antenna to collect the cellular signal and amplifies it which is then retransmitted through a server antenna mounted near the area to be covered.

E. Fiber Distribution Hub

Once the cellular signal is received by the bi-directional amplifier, the DAS requires a method of distributing the amplified signal throughout the building. Therefore, a fiber distribution hub is basically a booth that houses the connection between the coaxial cables, splitters and couplers which will be used to distributed the signal to the internal antennas mounted around the building.

Careful planning is needed here because theoretically, the further the internal antenna is from the cellular signal source, the more attenuation losses there will be. Thus, the design of the DAS requires some antenna isolation analysis and link budget calculations to ensure that the output power at each antenna is identical. Generally, there are three types of splitters which are commonly used in a DAS which are shown in table 1.

Table 1: Type of splitters

Type	Loss (dB)
Two-Way Splitter	-3.25
Three-Way Splitter	-5.05
Four-Way Splitter	-6.25

F. In-building Antennas

There are basically two types of in-building antenna that can be implemented in a DAS which are omni-directional antennas and panel antennas. Examples of these antennas are shown in Figure 6 where the left antenna represents the omni antenna whereas the right antenna represents the panel antenna. The range of these indoor antennas are reliant on these factors:

- Any form of physical obstacles
- Power produced from the repeater
- Coverage signal received and distributed from external antenna

Figure 6: Types of in-building antennas

An omni-directional antenna can radiate and obtain signals from all sides and are basically best suited to be installed at locations with a 360° view such as ceilings. It can provide coverage across one floor but it is not suitable in providing coverage across multiple floors. Unlike the omni antenna, panel

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antennas can only provide coverage at a targeted area but can still radiate a very strong signal. It can be installed walls to provide coverage in areas like a narrow hallway.

G. Working Principle of Overall System

Figure 7 shows the working principle of the entire DAS in the form of a flow chart. The flowchart basically explains the flow of how the DAS can provide customers with an enhanced cellular coverage in a building with a proper RF design plan.

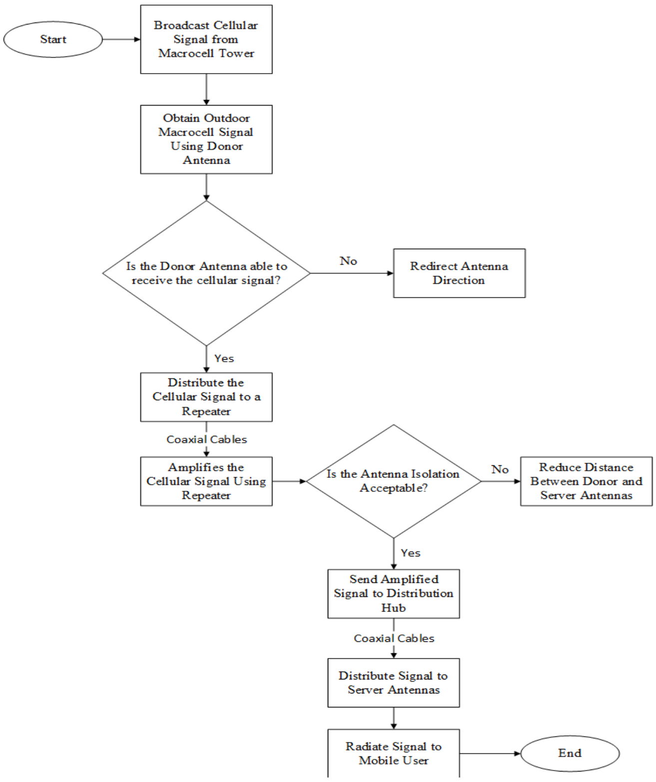

Figure 7: Flowchart of a DAS working principle

4. Testing and results

H. Coverage Testing for Pico Repeater Deployment

The test is done to basically prove if the solution provided is able to rectify the problem at hand. In this case, a pre-and post-coverage test is done to verify if the solution provided is able to increase the in-building coverage quality and performance. The findings that were obtained for this project can be categorized as preliminary results and post-results to show the difference between before installation of the solution and after. The preliminary results basically represent the walk test measurements obtained while the post-results represent the coverage measurements obtained after installation. Below is the Pico Repeater Deployment Procedure

1. Investigate problem being faced by customer at location mentioned.
2. Examine status of the KPI parameters of the coverage using the Field Force Analysis Tool (FF) and the Customer Analysis Tool (CAT).
3. Perform walk test at the site of complaint.
4. Obtain coverage results through static testing and standard walk test.
5. Compile pre-walk test photos, coverage results, link budget calculation, proposed antenna location in pictures and floor plan into a report.
6. Perform analysis on coverage results with installation planner to obtain solutions.
7. Investigate coverage area to verify if a pico repeater is sufficient to strengthen coverage.
8. Discuss solution proposed with customer and obtain approval.
9. Carry out installation design of proposed solution.
10. Perform coverage testing after installation and obtain results.

I. Walk Test Measurements

This section basically relates to task 2 which was explained previously in the proposed methodology in chapter 3 where a walk test report will be made based on the findings obtained during the site survey. The coverage of the affected area is measured using a software called Nemo Outdoor. Table 2, 3 and 4shows the coverage results for a static test which was done in a stationary position at the affected areas. From all three tables mentioned, we can deduce that the coverage for the 2G and 3G networks were very poor.

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Table 2: Results for static test point for ground floor office

Test method / Parameters	Short Call						Remarks
	2G			3G			
	Cell ID	Rx Lev	Rx Qual	Cell ID	RSCP	Ec/No	
Serving Cell (Times)	42698	-98	2	195	-105.8	-17.2	Poor 2G and 3G signal coverage & quality
	42698	-102	4	195	-104.5	-16.4	
	42698	-105	6	195	-101.2	-12.8	
	42698	-95	4	195	-105.5	-19.3	
	42698	-103	7	144	-109.5	-22.5	
No of Call	5	5	5	5	5	5	
Call Block	0	0	0	0	0	0	
Drop call	0	0	0	0	0	0	

Test method / Parameters	Throughput Test	Remarks
	HSDPA	
Serving Cell	195	
No of Call (Times)	1	
Average RLC Throughput DL (Kbps)	3222.13	
PDP context drop	-	-

The static test was performed by making 5 short calls on the network which can be noted in all three tables where each call is represented by a cell identification number of the nearby cell tower. However, during each call test made, it was noted that there were no blocked or drop calls. This means that the problem lies with the signal strength being weak in the affected area.

Table 3: Results for static test point for ground floor main store

Test method / Parameters	Short Call						Remarks
	2G			3G			
	Cell ID	Rx Lev	Rx Qual	Cell ID	RSCP	Ec/No	
Serving Cell (Times)	43033	-98	1	195	-103.3	-9.4	Poor 2G and 3G signal coverage & quality
	43033	-100	5	195	-102.0	-9.1	
	44042	-100	0	195	-102.2	-11.8	
	42698	-99	0	195	-107.3	-13.8	
	43033	-97	2	195	-103.8	-12.0	
No of Call	5	5	5	5	5	5	
Call Block	0	0	0	0	0	0	
Drop call	0	0	0	0	0	0	

Test method / Parameters	Throughput Test	Remarks
	HSDPA	
Serving Cell	195	
No of Call (Times)	1	
Average RLC Throughput DL (Kbps)	3771.63	
PDP context drop	-	-

Table 4: Results for static test point for 1st floor office

Test method / Parameters	Short Call						Remarks
	2G			3G			
	Cell ID	Rx Lev	Rx Qual	Cell ID	RSCP	Ec/No	
Serving Cell (Times)	42698	-98	5	195	-104.0	-14.7	Poor 2G and 3G signal coverage & quality
	42698	-102	5	195	-106.6	-12.3	
	42698	-100	3	195	-101.2	-12.9	
	42698	-90	4	195	-101.3	-13.4	
	42699	-86	4	195	-106.0	-15.6	
No of Call	5	5	5	5	5	5	
Call Block	0	0	0	0	0	0	
Drop call	0	0	0	0	0	0	

Test method / Parameters	Throughput Test	Remarks
	HSDPA	
Serving Cell	195	
No of Call (Times)	1	
Average RLC Throughput DL (Kbps)	2340.48	
PDP context drop	-	-

J. COVERAGE & QUALITY PLOTTING

Figure 8, 9 and 10 are basically the indoor coverage and quality plots for the 2G, 3G and LTE networks that have been generated using the Nemo Analyzer software. Figure 8 shows the coverage plot which includes the receiver signal level (2G) and the RSCP (3G) coverage mapping for the affected area. The outline drawn on the plot basically represents the walk path taken while performing the coverage test. For example, Figure 8 also shows two panels on the bottom which shows various colors to represent the range of values which determines whether it is decent or bad. The red circular dot symbolizes the worse range for each parameter while the green or blue circular dot symbolizes the best range. Therefore, the walk path outline will be replaced with these colors to specify levels of coverage for each area affected. Similar coverage plots will be done to obtain the outdoor coverage status as well.

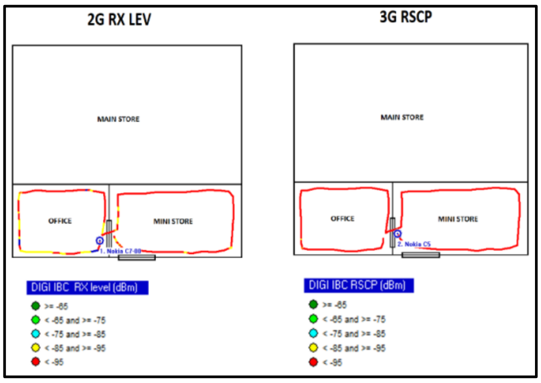

Figure 8: Indoor 2G/3G coverage plot at ground floor

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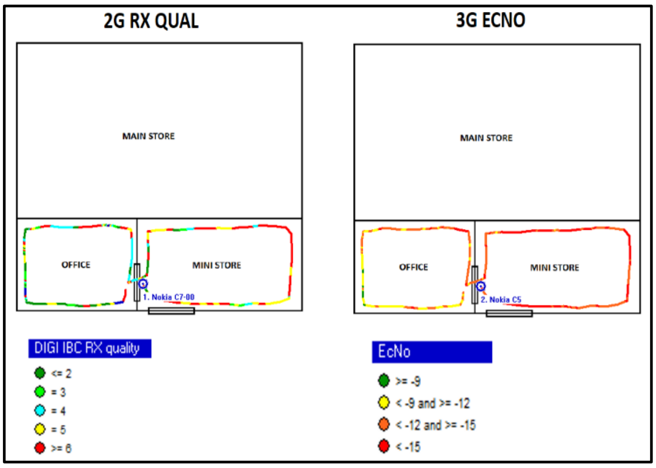

Figure 9: Indoor 2G/3G quality plot at ground floor

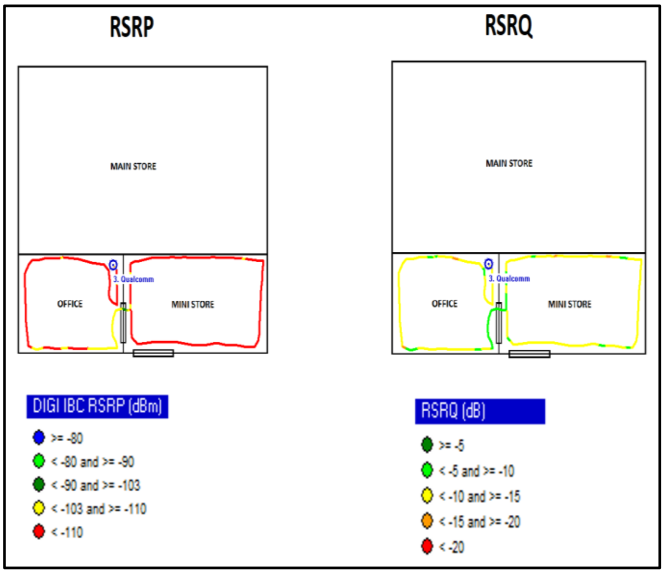

Figure 10: Indoor LTE coverage & quality plot at ground floor

K. Radio Link Control Throughput Test

On the other hand, Figure 11 and 12 shows the results obtained for the Radio Link Control (RLC) for HSDPA and LTE networks respectively. The RLC is basically responsible for the user data to be delivered without errors and in sequence. For example, figure 11 shows the indoor HSDPA average RLC throughput results when the application throughout downlink is used on the software. A coverage plot is generated similarly as previously explained and a panel of colors are used to represent the range of the throughput in terms of bits per second (bps). Not only that, a RLC throughput downlink graph is also generate and a table where the certain parameter values are shown such as the average throughput, standard deviation, and variance.

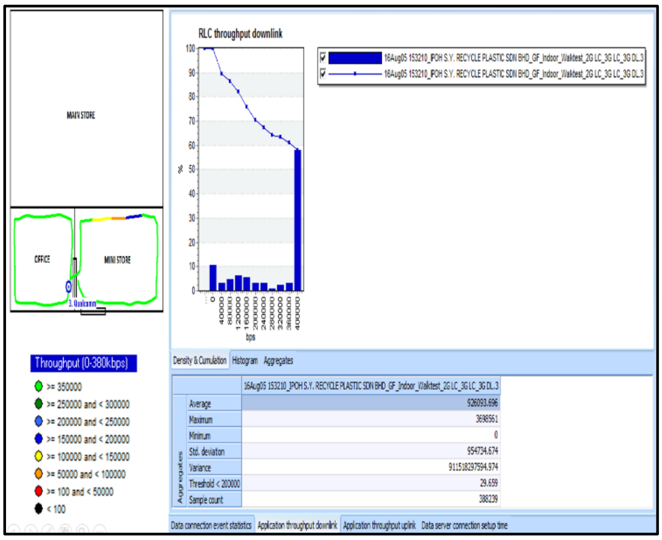

Figure 11: Indoor HSDPA average RLC throughput

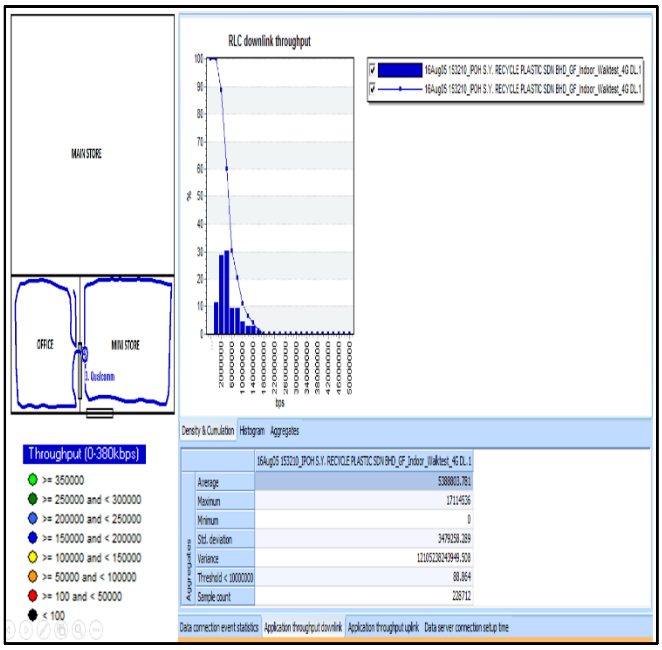

Figure 12: Indoor LTE average RLC throughput

5. Conclusion

Today, wireless communications have grown more and used more widely with the rise in the number of service providers. An increase in wireless technological capabilities available now has also contributed to this. However, there is also a limitation on such communications which is currently being faced by the service providers today which is the ability to attain satisfactory signal coverage within a home or large office buildings. This is due to a variety of factors which contributes to the poor Radio Frequency (RF) coverage in and around buildings or a home. The usage of mobile phones is flourishing even more after its evolution to smartphones. This however, proves to be a problem in disguise for mobile service providers as there is a bigger demand now on the existing spectrum due to higher data traffic. Places such as offices, buildings, airports, schools, shopping malls and houses can sometimes have very weak reception due to this. This can lead up to many different kinds of problems in these places such as drop calls, missed opportunities and also revenue loss.Problems such as weak coverage, interruptions in connection and very low quality of signals will annoy customers and reduce productivity.

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