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MULTIPLE GSM OPERATORS' BASE STATIONS COLLOCATION: A CASE STUDY OF UNILORIN

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Abstract

The collocation of GSM Base station of multiple operators involves two or more different GSM operators installing their active devices on a single base station site to reduce running cost while still providing good services to end users considering the necessity to mitigate the interference level to the barest minimum.
Electric power is a fundamental challenge facing telecommunication operations in Nigeria since the cost of powering individual base stations is very high. Furthermore, the cost of alternative power generation makes it more cumbersome.
Both CAPEX and OPEX are increased considerably considering these two along with others such as the cost of land leasing, right of way, regulatory, bureaucratic and communal hurdles. GSM collocation and Infrastructure sharing will help minimize to the barest minimum the aforementioned problems.
This study identifies various aspects of GSM base station collocation in the University of Ilorin, develop the model for the collocation of GSM base stations and make policy recommendations based on the findings of the study.

Keywords: GSM base station, GSM collocation, infrastructure sharing, co-channel interference, CAPEX, OPEX.

1. INTRODUCTION

The Global System for Mobile Communications (GSM) is a communication network system designed by the European Telecommunications Standards Institute (ETSI) to establish protocols and specifications for the second-generation digital cellular networks utilized by mobile telephones [1]. As a replacement for the first generation (1G), this GSM system, which in its original form is described as a digital circuit-switched network system, is optimized for full-duplex voice telephony. The system has been further enhanced and improved over time to include data communications, initially by circuit-switched transport, subsequently, packet data transport via General Packet Radio Services (GPRS) and Enhanced Data rates for GSM Evolution (EDGE) or EGPRS [1]. Then, the development of the third-generation (3G) Universal Mobile Telecommunications System (UMTS) standards are followed by the fourth generation (4G) LTE Advanced standards by the third Generation Partnership Project (3GPP). Other historical aspect progress of GSM technology, such as the fifth-generation (5G) New Radio, are reported in [2 – 7].
The focal technological development that distinguished the 1G mobile phones differently from the previous generation was the deployment of multiple cell sites, and also the ability to handover calls from one site to another site as the user travels between different cells during the course of an ongoing conversation. Officially, the first commercially automated (1G) cellular network was launched in Japan by NTT in 1979. Following this feat, Bell Labs developed another modern commercial cellular technology in 1984. This technology used multiple, centrally controlled base stations, each providing service to a small area referred to as a cell.
These cell sites are set up such that cells partially overlapped each other. In a cellular system, signals between a base station (cell site) and a terminal (user equipment) mainly need to be strong enough to reach between the two ends, so the same channel can be simultaneously used for separate conversations in a different cell (a great achievement).
Figure 1 shows a GSM Architecture:

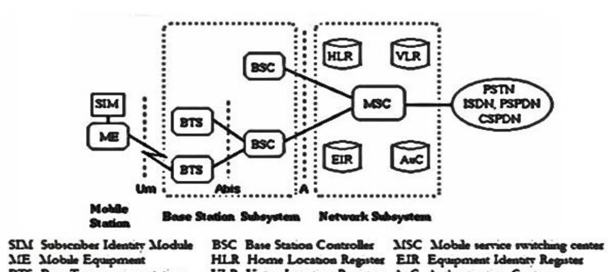

Figure 1: Base Station Subsystem and Network Subsystem [8]
According to statistics, the number of users of the GSM in the world is growing at an exponential rate; with more than 174 million users in Nigeria alone [3]. This makes the country to have a continuous need to install GSM supporting infrastructures to take care of

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increasing users' needs in terms of service delivery. As of December 2013, the number of BTS sites was 28,289; but by projection, Nigeria needed an additional 33,000 BTSs by 2018. Furthermore, serious technical challenges are affecting the rapid installation of base stations, these challenges include environmental congestion, multiple regulations, and taxation, high capital expenditure (CAPEX), anti-competitive practices among some operators.
The table 1 below shows the frequency of the GSM 1800 and UMTS 2100:
Table 1: Frequency of the GSM 1800 and UMTS 2100

SERVICES	UPLINK FREQUENCY RANGE	DOWNLINK FREQUENCY RANGE	NETWORK PROVIDERS
GSM 900	890-915 MH_Z	935 -960 MH_Z	AIRTEL, MTN, GLOBACOM & 9MOBILE
GSM 1800	1710-1785 MH_Z	1805 – 1880 MH_Z	AIRTEL, MTN, GLOBACOM & 9MOBILE
UMTS 2100	1920 – 1980 MH_Z	2110 – 2170 MH_Z	AIRTEL, MTN, GLOBACOM & 9MOBILE

The growth of the Nigerian telecoms market has continued to increase at a geometric rate, thereby sustaining it as one of the fastest-growing telecom markets globally. This, however, has brought with it a huge cost burden on the telecom operators and investors as they have continually expended huge capital expenditures on several telecom assets and infrastructure in other to gain and sustain competitive advantage in the market.
Furthermore, several unrestricted incidences of telecom masts and towers all over Nigeria have been attributed to be partly due to failure of the Nigerian Telecommunication Limited (NITEL) to live up to its duties and responsibilities in the telecommunication sub-sector in over 45 years of her existence [6].This has left new and multiple players in the sub-sector to fend for themselves, as they build their telecommunication infrastructure, including the construction of masts, towers, signal relays, repeaters, and cell sites.
Telecommunication critical infrastructure such as acquiring land for the mast is capital intensive from a business point of view. There is also the problem of getting approval from State Government (SG) and/or the Local Government Authorities (LGA) in the laying of transmission links, such as cables, fiber and even building communication towers in their domain [7, 8]. All these make it more difficult for the Information and Communication Technology (ICT) world, the Public Telecommunication Operations (PTOs) and the Global System for Mobile Telecommunication (GSM) companies in Nigeria to operate profitably and making expansion plans towards meeting Subscriber's growth. Hence, telecommunication operators are encouraged to share these infrastructures as a means of avoiding unnecessary duplication of infrastructures (thus, collocation of these operators in a cluster).
The concept of collocation involves the sharing of resources among competing investors on the same site, and this concept is practiced in the telecommunication business [1. 4]. Today, as the telecom market in Nigeria continues to thrive towards maturity, revenue-on-assets (ROA) and the average revenue per user (ARPU) indices begin to drop. Telecom operators in Nigeria are now beginning to explore new and alternative ways to reduce their capital expenditures (CAPEX) and their operational expenditure (OPEX) on telecom infrastructure.
Presently, key players in the industry are now resorting to sharing network infrastructures as a strategy to substantially reduce their CAPEX and OPEX burden, hence, to survive and realize better returns on their investments [5].
Financial savings achieved with the aid of infrastructure sharing could be used forstaff welfare, improve network services and even introduce value-added services and product offerings that would lead to new streams of revenue generation [6, 9, 10]. Against this background, the study intends to create a collocation model for the GSM Base Station of multiple operators in the University of Ilorin campus.
There is an increasing need for GSM operators and providers in the Nigerian telecommunication industry to maximize profit, cut the cost of capital assets or infrastructure deployed for telecommunication services [11]. The Nigeria telecommunication market is driven by millions of Nigerians' growing demand for telecom services like SMS, voice, data services like internet, email, etc. as well as broadband services like video calling, video conferencing and video messaging, etc. [12].
This study was based on a case study analysis of the current colocation arrangement between, Glo Nigeria, MTN Nigeria Ltd, Airtel Nigeria Ltd and Etisalat [13]. The study seeks to explore the advantages of the infrastructure sharing deal between these multiple companies and also recommend an improved or enhanced framework to sustain this strategy model in the context of the Nigerian telecom industry. The study will rely on secondary data from previous literature to develop a model for the study. The findings of the study will aid GSM operators to face and mitigate several challenges that include theft and vandalization of equipment and also to reduce pressure from authorities to reduce the number of towers scattered over the country.
This study will determine the number of operators who can share passive GSM infrastructure. The results will help in minimizing capital expenditure and operating expenditure.

1.1.1 GUIDELINES AND SPECIFICATIONS FOR TOWER INSTALLATION AND GSM OPERATORS COLLOCATION IN NIGERIA

The Nigerian Communications Commission (NCC) has given guidelines and specifications for the installation of GSM tower in [14]. Maximum allowed tower height in the guidelines for districts delineated as residential is fixed at 25metres and masts should be placed at a minimum setback of 5metres distance to the nearest demised property, excluding fence and also that any mast and tower higher above 30metres in height may only be installed with a clearance certificate duly issued by the Nigerian Airspace Management Authority (NAMA) [14]. Furthermore, passive GSM infrastructure sharing is supported and recommended by the Nigerian Communication Commission and detailed guidelines on collocation and infrastructure sharing are in [15]. The Nigerian Communications Commission has given its support to this new model and has also developed a regulatory model or framework for potential collocates to share infrastructure for the promotion of fair competition and infrastructure sharing amongst telecom licensees. The sharing of telecommunication infrastructure between telecom service providers is becoming the requirement and process of business in the telecommunication industry where competitors are becoming partners to lower the cost of their ever-increasing investments [10]. The degree to and method of infrastructure sharing can differ in countries depending on their individual regulatory and competitive climate. But the question like the developed world, can the developing countries like Nigeria harness and sustain the telecommunication growth. The high cost of constructing telecom infrastructure because of expansion and market entry remains a major concern in Nigeria.

1.1.2 GSM INFRASTRUCTURE PERFORMANCE IN NIGERIA

There is substantial evidence indicating the penchant by consumers not just for mobile lines or Subscriber Identification Module (SIM) cards, but also for good, reliable, and quality services from the operators. Owing to the continuous growth and service requirement, several operators attempt to satisfy the consumers through continuous investment in GSM supporting infrastructure [5]. As at the end of December 2013, which is about thirteen (13) years after full liberalization, the number of total GSM connected lines was 118,470,236 and the number of GSM Base transceiver stations (BTS) sites was 28,289 sites [16]. In spite of this growth trend in telecommunications in Nigeria, some issues have been identified as major sources of impedance to the continuous and rapid future growth of the telecommunication industry. As pointed out in [6], they include poor public power supply, poor security (GSM infrastructure vandalization) and the likes. Furthermore, other sources include high import duty on equipment, which is in the region of 30-70%, scarce resources needed by the operators to expand operations, anti-competitive practices such as the formation of a cartel among big operators, and high operational costs, which is also mentioned in [12].

To mitigate these problems, GSM infrastructure sharing was proposed and implementation began.

Sharing of GSM Base-Stations will reduce the undesirable proliferation of Base Stations. Notably, a proliferation of base stations has its negative visual and also environmental impacts, which usually result in agitations by various environmental activists or the right groups that could be damaging to the image of the network operators [10]. Furthermore, infrastructure sharing among GSM operators can promptly reduce site acquisition time for new telecoms entrants.

1.1.3 GSM INFRASTRUCTURE SHARING IN NIGERIA AND ITS POSSIBLE EFFECTS

A detailed analysis of GSM infrastructure sharing in Nigeria was given in [17]. The rollout of mobile networks demands large capital outlay, leading to higher billing of subscribers by the operators and consequently discouraging operators from researching and thereafter developing novel technology and products in emerging markets like Nigeria. Other problems resulting from the high cost of setting up a GSM network are highlighted in [18]. Meanwhile, technology advancement, such as the launching of 3G and 3.5G technologies on top of the 2G network, and the introduction of '4G' technologies including LTE, is becoming increasingly swift and complex [19].

In order to address this, operators are adopting several techniques, with network sharing emerging as a far radical stratagem to significantly, and continuously minimize network expenditure. According to author in [20], as of 2012 in India, about 60% of mobile network towers were shared by two or more mobile network. And also, the case in Nigeria is not different. However, as noted in [21], sharing of mobile infrastructure could also enhance the migration to novel technologies and deployment of mobile broadband. This is necessary because mobile broadband is a veritable means of making broadband services accessible to more persons and organizations. It was further highlighted in [21] that eventually, mobile network infrastructure sharing can play an important role in increasing access to various information and communication technologies. This can create and promote economic growth. It can also enable nations to meet the objectives established by the World Summit on the Information Society and the Millennium Development Goals of the United Nations.

THE EFFECT OF TELECOMMUNICATION MASTS

Mobile phone base stations and telecommunications masts emit radio frequencies, which is a form of electromagnetic radiation, which covers up to a distance of 3km [22]. Furthermore, author in [22] opined that these radiofrequency waves are essential for effective mobile phone connectivity. Several Scholars have linked radio frequencies from base stations and telecommunication mast to various health issues. According to author in [22], problems associated with telecommunication mast range from changes in cognitive performance, sleep disturbances and higher cancer rates. In a study carried out on telecommunication mast and in a base station in the United Kingdom reveals that cancer and other serious illnesses were discovered in neighborhoods where telecommunication masts were sited [22]. In the same vein residents of Dunanon Local Government District in Northern Ireland, were of the view that, residents that live between 1-5km from masts have several cancer cases which range from lings, prostate, breast cancer, lung cancer, leukemia, lymphoma and hematopoietic cancer [22]. Though several authors have associated indiscriminate location of telecommunication masts and its radiofrequency waves to health issues in neighborhoods where they are cited yet the Nigerian Communications Commission (NCC) has said that citing of telecommunication mast towers near residential areas does not constitute health hazards. NCC claimed that the level of exposure to radiofrequency from Base Stations and wireless networks is so low and insignificant that the temperature increases do not have an effect on human health [23]. This is contrary to the claims according to the researches carried out by the World Health Organization (WHO).

1.2 LITERATURE REVIEW

In a GSM network, there are five cell sizes, these are macro, micro, pico, femto and umbrella cells [7]. The umbrella cell as a concept in GSM traffic management used in urban areas was discussed in detail in [8]. The horizontal radius of a cell is not constant but ranges between a few hundred meters to tens of kilometers.

The cell radius is a function of the antenna height, antenna gain and the propagation terrain [7]. Furthermore, there are different implementations of the concept of an extended cell, in which the cell radius could be doubled or even bigger, depending on such factors as the antenna system, and Timing Advance (TA) [7]. Timing Advance is a set of variables used in controlling the adjustments needed because of the finite travel time of a signal from MS to BTS in a Time Division Multiple Access schemes [9, 10]. The type of terrain also affects TA [11]. In Nigeria, there are five (5) Public Land Mobile Network areas belonging to Airtel Nigeria, EMTS (Etisalat), Glo Mobile, MTN Nigeria, and the defunct M-Tel.

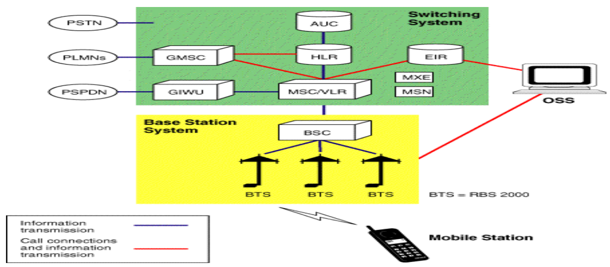

Figure 1: showing the Base Station System and Network Switching System [24]

1.2.1 RELATED WORK

A study that looks at the design and simulation was carried out by author in [25]. The work focuses on the design and model simulation of a single base station site where multiple operators can install their transmission and reception equipment's on a single mask with negligible interferences problem and therefore reducing the number of the base station sites to about one-third of its current number in the community. In [25]was studied the telecom infrastructure sharing as a strategy for cost optimization and revenue generation. The study was on the collocation between MTN Nigeria and Zain Nigeria. The value of infrastructure sharing as a means of achieving cost efficiency and revenue assurance was explored. The benefits of the infrastructure sharing deal between the companies as well as recommendations on improving the framework or the model to sustain this strategy in the context of the Nigeria telecom industry was also explored.

On his part, author in [26] studied and reviewed the cost structure of mobile telecommunication operations and present collocation strategies aimed at reducing the total cost of ownership of mobile telecom service. The study described how the shelter should be placed on the site for each operator and the sharing procedures of the other equipment.

Authors in [27]stated that though, as of December 2013, the number of BTS was 28,289; however, by projection, Nigeria needed an additional 33,000 BTSs by 2018. The study pointed out that there were serious technical challenges dwindling the rapid installation of base stations, such as environmental congestion, high CAPEX, multiple regulations, etc.

In [22] was assessed spatial distribution of telecommunication Base Stations and compliance level of the operators to the NCC regulations in Federal Capital City, Abuja, Nigeria. The study indicated that there are 92 base stations in the city with a low level of compliance (26.1%) with the NCC regulations. Furthermore, the study indicated that 17 base station shows overlapping which can be shut down and will not affect the operation of the operators. The study observed that economic gain was a major propelling factor for the base station sitting rather than standard provided by the NCC. Thus, it was recommended that 17 base stations be shut down so as to attain a high level of compliance with NCC directives.

Authors in [28] studied the effects of colocation arrangement on the cost efficiency of selected GSM firms in Nigeria. The sources of data for their research work were exclusive primary data sources. Primary data sources for the research work were obtained from structured and standardized copies of a questionnaire targeted at 200 respondents. The respondents were professionals or stakeholders in the area of the research interest. Data collected were subjected to multiple regression analysis and it was found that colocation arrangements have a significant effect on cost efficiency. This significance was attributed to the aspects of security and spectrum sharing collocation arrangements.

In [10] was discussed the economic and geographical reasons for infrastructure sharing. The paper emphasized how infrastructure sharing helps to minimize CAPEX as well as OPEX, thereby maximizing profits and performance.

In [29] is paperwork presented at Nigeria Coalition Session by Isabel Ornelas titled Good practice in the regulation of infrastructure sharing. This research work discussed the acceptance of the collocation of base stations in African countries as well as the geographical and economic benefits of collocating. Besides, several collocation policies, guidelines, and models across different African countries were discussed. Table 2 shows works by different authors in the related studies along with the comments by the authors of this paper.

Table 2: Related works and comments.

PUBLICATION	RESEARCH TITLE	LOCATION	COMMENT
F. Ehiagwina, A. Afolabi, T. Surajudeen-Bakinde and O. Fakolujo [30]	Sensitivity Degradation and Antenna Isolation Analysis for Multi-operator Global Systems for Mobile Communication Base Transceiver Stations	Faculty of Engineering, University of Nigeria, Nsukka	This paper analyzed the sensitivity degradation and the effects of spatial separation on antenna isolation requirement of Base Transceiver Station (BTS) receiver for multi-operator mobile cellular systems. The work only focused on antenna used for collocation.
F. Hussain [10]	Examining the Benefits of Infrastructure Sharing and how to Apply it Successfully.	Helios Towers, Lagos, Nigeria.	Economical and Geographical advantages of infrastructure sharing were discussed in this research work. However, the researcher didnot work on the technical aspect of collocation.
E. Onuzuruike [25]	Telecom infrastructure sharing as a strategy for Cost optimization and Revenue Generation.	School of Management, Blekinge institute of technology, Karlskrona, Sweden.	The researcher extensively discussed the cost reduction efficiency that comes with collocation. The study focusedonly on the financial advantages of collocation.
F. Dawodu, M. Osondu [28]	The effects of colocation arrangement on the cost efficiency of selected GSM firms in Nigeria	Academic Research International Journal	The researchers studied the effects of colocation arrangement on the cost efficiency of selected GSM firms in Nigeria. They discussed how these firms have reduced their CAPEX and OPEX by collocating.
I. Ornelas [29]	Good Practices in The Regulation of Infrastructure Sharing	Nigeria Coalition Session	This research work discusses the acceptance of the collocation of base stations in African countries and also discussed the geographical and economic benefits of collocation.

2. RESEARCH METHODOLOGY

The various components found on the existing base stations in the University of Ilorin identifying the unique features of each operator would be analyzed. The possible collocation option, how frequency channels can be allocated to a collocation site and how the calculation of the required number of base stations in the university campus using assumed values would be explained. Furthermore, the diverse options and how co-channel and adjacent channels can be minimized by the use of frequency hopping techniques in collocation base station sites would be described.

2.1 ANALYSIS OF THE EXISTING GSM BASE STATION ON CAMPUS

The study will identify and analyze parameter of the existing base station sites of the multiple operators such as MTN, GLOBACOM, ETISALAT and AIRTEL within the campus. Table 3.1, Table 3 - 5 show the locations of the Base Transceiver Station in UNILORIN for the aforementioned operators and the basic features of each base station.

Table 3: GLOBACOM Base Station Locations, their Number and Type of Antenna

S/№	Address	Number of Antenna	Backbone System
1	Opposite Stadium	6- Mono-band	3 Microwave Link

Table 4: MTN Base Station Locations, their Type and Number of Antenna

S/№	Address	Number of Antenna	Backbone System
1	Beside Mosque, Staff Quarters	3 Dual-band	2 Microwave Link
2	Opposite Maracana Stadium	3 Dual-Band	2 Microwave Link
3	Opposite the School Clinic	3 Dual-Band	7 Microwave Link
4	Beside Faculty of CIS	3 Dual-band	2 Microwave Link
5	Behind the Faculty of Art	5 Wavion Access Point Antenna	2 Microwave Link

Table 5: AIRTEL Base Station Locations, their Number and Type of Antenna

S/no	Address	Number of Antenna	Backbone System
1	Opposite Stadium	6 Mono-band	3 Microwave Link

Table 6: ETISALAT Base Station Locations, their Number and Type of Antenna

S/no	Address	Number of Antenna	Backbone System
1	Behind the school library	3 Dual-band	3 Microwave Link

2.1.1 FEATURES OF BASE STATIONS IN UNILORIN

1. **Height of Mast**: It has been noticed that most base stations in the University of Ilorin use the moderate height of the mast. The tower is quite widely misinterpreted as the BTS itself. However, the height of the antenna in various locations in the school varies with respect to the terrain of the base station cell. For instance, places where most of the buildings are low and the presence of natural features such as hills and trees are less, the antenna height is a bit low. Lastly, the type of system used, usually determine the height of the antenna i.e. GSM 900 antenna are usually higher than that of GSM 1800. A typical BTS tower that holds antennas is shown in figure2.
2. **Use of Sectorial Antenna**: It was observed that most of the existing base stations in the University use three sectorial antennas. Other base stations in the school use six antennas. Three of the antennas were discovered to be for GSM 1800 and the other three are for GSM 900. The three sectorial antennas replaced an Omni-directional antenna, necessitated by the traffic requirement of each cell. Omni-directional antennas decrease the signal as the cell increases i.e. the sectorial antenna is used to cover a large cell.

Table 7:The sectorial antenna direction

S/N	Operators Name	Address	Antenna Azimuth
1	Globacom	Staff Quarters	South, North-West, and North-East
2	Globacom	Behind the school Library	West, North-East, and South-East
3	Airtel	Maracana Stadium	North-East, South-East, and North-West
4	Etisalat	Behind the school library	West, North-East, and South-East
5	MTN	Staff Quarters	South, North-West, and North-East
6	MTN	Beside Faculty of CIS	North-East, South-East, West
7	MTN	Maracana Stadium	South-West, North-West-West, and South-East
8	MTN	Behind the Faculty of Art	North-West, South-West, and South-East
9	MTN	Opposite the school clinic	West, North-East, and South-East

3. **Use of Wavion Access Points**: It was noticed that some MTN sites in the school campus used multiple numbers of wavion access point antenna in their BTS sites Figure3. When brought to an outdoor environment, these aces points suffer from limitations in range and capacity. Wavion's spatially adaptive beam forming technology is designed specifically to address the shortcomings of current outdoor metro Wi-Fi networks. This multiple-antenna technology addresses limitations in coverage, penetration, and capacity of the existing Wi-Fi technology.

Figure 2: showing BTS Mast Tower [32]

Figure 3:Wavion access point Antenna [31]

5. **Backbone system:** This allows for a handshake between all the base stations of each operator. Only microwave link systems were on all the base stations in the school campus for a handshake. Twoor three were found on each base station. The directions of all the microwave link systems show that all the base stations in the University of Ilorin, regardless of the GSM operator, receive their handshake from the base stations that are off-campus.

6. **Power Supply Equipment:** Power supply equipment is used to power the entire BTS on the sites. Due to the charge (penalty) placed on GSM operator for network downtime by the NCC, all GSM operators use redundancy power systems to power their BTS sites. This redundancy power system on sites may either be public utility supply and or power generator. The main reason for using different power sources is due to the power failure of the parallel systems.

7. **Aviation Light:** This is a low-intensity obstruction light that is used at the extreme top of the BTS tower. The purpose of obstruction lighting and marking is to ensure that an obstruction to air navigation remains visible at a range sufficient to permit a pilot to take appropriate action. However, it was observed that most of the base transceiver stations on campus hardly have an Aviation light that is working perfectly.

2.2 ANTENNA DIVERSITY IN COLLOCATION

Diversity is a powerful communication receiver technique that provides wireless link improvement at a relatively low cost. Antenna diversity is a technique used in making two or more antennas to transmit at a particular parameter different from each other. It is usually employed either in a redundancy system or for collocation purposes.

Antenna diversity for collocation options could be done using two methods, which are:

i. Space diversity
ii. Frequency diversity

2.2.1 SPACE DIVERSITY

Space diversity, also known as spatial diversity is an antenna diversity technique where two or more active antennas transmitting simultaneously are separated by physical distance. It offers very good isolation and leads to no interference when antennas are separated by ten times the wavelength of the antenna [32].

For collocation purposes between multiple GSM operators, since the wavelength of GSM 900 is 0.33 meters, the antennas are separated by a vertical distance of 10 X 0.33 m = 3.3m. However, when the system only transmits GSM 1800 with a wave length of 0.16m, the diversity space should not be less than 10 X 0.16. = 1.6m

2.2.2 FREQUENCY DIVERSITY

Frequency diversity is an antenna diversity technique where two or more antennas transmit at different frequency slots wide apart to avoid co-channel and adjacent channel interference [33].This technique seems to be the best option for collocation purposes because it does not necessarily require large spacing between the antennas in its implementation.

This design majorly employs frequency diversity and partly employs a space diversity technique in its implementation. For each cell, each operator is made to transmit at frequency channels far apart from the one at which other operators transmit. Its major complication is just that a proper frequency plan must be done to avoid interference problems.

2.3 FREQUENCY CHANNEL ALLOCATION

For the purpose of channel design for the collocation of three GSM operators such as Glo, Etisalat, and MTN, the channel allocation for each operator is assumed to be 24 channels for GSM 900 and 48 for GSM 1800 MHz. Table 3.6 shows thechannel allocations.

Table 8: showing Frequency Channel Allocation

S/N	Operator	GSM 900	GSM 1800
1	Globacom	1-24	1-48
2	MTN	26-49	50-97
3	Etisalat	51-74	99-146

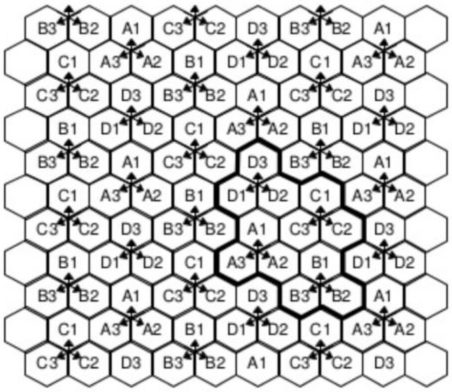

Figure 4: 4/12-Cell pattern [34]

It should be noted that GSM 900 uses 890 – 915 MHz for uplink and 930 – 960 MHz for downlink and has a duplex spacing of 45 MHz while GSM 1800 uses 1710 – 1785 MHz for uplink and 1805 – 1880 MHz for downlink and has a duplex spacing of 95 MHz. The spacing between every adjacent channel (radio frequency channel spacing) is 200 kHz [35].

However, for GSM 900, channel representation $\Longrightarrow$ $F_1 = \{890 + n\,(0.2)\}$ MHz
(with ARFCN $1 \leq n \leq 124$)
$F_2 = \{F_1 + 45\}$ MHz

For GSM 1800, channel representation $\Longrightarrow$ $F_1 = \{1710 + n\,(0.2)\}$ MHz
(with ARFCN $512 \leq n \leq 885$)

Where F_1 is for the uplink and F_2 is for the downlink.

2.4 THE COLLOCATION OPTIONS

Collocation is a phenomenon where two or more operators locate their various RF equipment such as antenna, transmitter, receiver, amplifier, etc. Basically, there are two options in the collocation of GSM base stations, they are:

i. Sharing of active or RF equipment such as antenna and feeder cable.
ii. RF isolation i.e. sharing of physical structures or passive equipment such as mast, site space, power generator, etc.

However, the collocation option employed in the course of this project is the RF isolation.

2.4.1 SHARING OF RF EQUIPMENT

Collocation can be done by operators sharing a single antenna configured to transmit their various signals within a cell. The downside of this technique is that it is almost impossible to control and isolate one operator's RF signal from overpowering the other operators' signal, hereby leading to interference and a large number of denied calls and bad reception of the other operators afterward.

2.4.2 RF ISOLATION

This technique which is the collocation option employed in this study, involves the sharing of passive equipment such as the mast site, power, etc. Unlike the other technique where operators share the same RF equipment, operators have a reasonable amount of control as regards their antenna RF emission hereby reducing the level of interference.

The previously antenna diversity techniques (Frequency and space diversity) discussed are employed to avoid co-channel and adjacent channel interference.

The only limitation is that technically, space diversity technique might not always be efficient because there's a limit to what height an antenna can reach for optimum signal transmission coverage to areas close to the base of the mast (zero-point filling). This problem can be mitigated by using the downtilting technique.

2.5 DESIGN OF COLLOCATION SITE

The following are the antenna recommendations based on the expected traffic demand and terrain for a collocated site:

1. **A number of antennae per site:** For a collocated site, it is recommended for operators to install three antennas covering a 120^0 cell sector each. The height of the antennas does not have to be necessarily the same because the traffic demand per cell and the terrain over which each antenna is transmitting might vary.
2. **Beamwidth:** Basically, the beam width is the measure of the antenna directivity. It could be horizontal or vertical. For highly placed antennas, higher vertical beam width is recommended to correct defects that may arise from poor zero-point filling.
3. **Front-to-back ratio:** This is a measure to describe the level of radiation from the back of a directional antenna, usually ranging from 18dB – 30Db.
   It is calculated as $\frac{F}{B}\text{ ratio} = \frac{Signal\ \ in\ forward\ \ direction}{Signal\ \ in\ reverse\ \ direction}$
4. **Polarization:** Since space is of high importance in collocation, it will be technically advisable to use dual polarization for GSM collocated sites antennas. Therefore, the design recommends that the antenna used in collocated sites should be dual polarized orthogonally ($\pm 45^0$) polarization because dual polarized antenna occupies less space than single polarized antennas and they also mitigate the effects of wave scattering which are commonly experienced in urban and suburban areas.

5. **Direction:** As was stated earlier, this project employs the antenna diversity technique in the collocation option. The direction of antennas placed on the mast should be 30^0wide apart in order to make the RF planning easy and make each operator's cells distinct from each other.
The table below shows the arrangement of each operator's antenna on the mast.

Table 9: showing antenna separation distance

Operators	Antenna 1 position	Antenna 2 position	Antenna 3 position
1	0^0	120^0	240^0
2	30^0	150^0	270^0
3	60^0	180^0	300^0

For collocations involving more than 3 operators, the angular separation (Θ) can be expressed mathematically $\Theta = 90^0 / n \frac{90^o}{n}$

Where Θ = the antenna location on the mast, measured in degrees (^{0}), and;

n = the number of operators intending to collocate on the mast.

6. **Downtilting:** This is a technique used to direct the radiation of an antenna towards a specific area. This can be done electrically or mechanically. Electrical downtilting is employed for antennas placed on lower heights while mechanical downtilting is often used for highly placed antennas. This is because electrical downtilting offers a better interference control while mechanical downtilting corrects directional problems such as zero-point filling (over shooting) that people around the base of a BTS mast might encounter.
7. **Other Parameters:** This design allows for the usage of the other BTS antenna recommendations such as gain, mechanical properties, zero depth filling weight, etc. since they would not affect the implementation of the design.

2.6 FREQUENCY RE-USE DISTANCE

Base station antennas are designed to achieve the desired coverage within a particular cell and by limiting the coverage area within the boundaries of a cell. The same group of channels may be used to cover different cells that are separated from another by distance wide enough to keep interference levels within tolerable limits. The distance between the centers of the cells using the same frequency is determined by the cluster size and the layout of the cell clusters. This distance is called the frequency re-use.

2.7 FREQUENCY HOPPING

This is a technique that involves the use of synthesized frequency hopping to minimize the problem of co-channel and adjacent channel interference in collocation. The system avoids interferences by never staying on the same channel i.e. if a channel is bad, the system just waits for the next good channel.

2.8 PROJECT IMPLEMENTATION REQUIREMENT AND SETUP PROCESS

In this study, the Google earth computer program was employed to map out the proposed collocation area (University of Ilorin PS), Figure 5.

Microsoft excel (a computer program by Microsoft) was used to compute the data that were imported into the Agileto software. The Agileto software a computer program that serves as an RF optimization tool for mobile networks for 2G, 3G, and 4G. It can be used for small, medium and even large clusters of BSCs, RNCs, and TACs. It uses advanced mathematical algorithms and methods to audit telecom networks and help engineers optimize them easily.

Agileto was used to simulate the collocated sites in this work. Data was exported from Microsoft excel program into Agileto, which then, in turn, displays the computed data using the Google earth view.

Figure 5: showing a screenshot from Google earth [36]

Figure 6: showing a screenshot from Agileto [37]

RESULTS AND DISCUSSION

The result of the simulation depicts the project design, showing how the collocated sites will look like.

3.1 COLLOCATION MODELS

According to author in [12], there are three suitable models that can be adopted for the purpose of this collocation. These models are:

i. MODEL A

An operator Shares its infrastructure with another operator

In this collocation model, there assumed to be an already existing mast site of a particular telecommunication operator. Another operator who is interested in collocating on this existing site shall write a collocation request to the telecommunication operator who owns the site notifying and requesting for collocation with the operator. The existing mast site owner shall in return write back to the interested operator if interested in the collocation or if not interested. If not interested, only due to the conditions listed in part 2 of

NCC Terms and Condition for Infrastructure Sharing, the existing mast site owner shall state clearly their reasons for declining the request in accordance with the part 3 of the NCC Terms and Conditions for Infrastructure sharing. However, if interested, the existing mast site owner shall write an affirmative response to the interested operator specifying the contractual terms and conditions in accordance with the Guidelines on collocation and infrastructure sharing issued by the NCC.

ii. MODEL B

Two or more operators agree on joint construction of infrastructure

In this proposed model, two or more telecommunication operators come to an agreement to jointly construct a single or multiple mast site(s) from the scratch.

Their agreement shall be in accordance with the Part IV, General Rules for Collocation/Infrastructure Sharing (C/IS) of the NCC.

iii. MODEL C

A third entity (public utility) leases infrastructure to operators

In this model, an already existing telecommunication infrastructure provider, which has built a mast site independently from scratch to the end is ready to lease the site for collocation. Interested operators shall contact the telecommunication infrastructure providers in writing, stating their interest and requesting for collocation terms. In response, the infrastructure provider will write back to the interested operator with contractual terms and conditions in accordance with the Guidelines on collocation and infrastructure sharing issued by the NCC. After an agreement has been reached, the operator shall install and configure their active equipment and begin transmission.

In this model of collocation, the infrastructure provider will be responsible for the maintenance and security of equipment within the premise. Furthermore, it shall either grant access to representatives of a network provider into the mast site premise at any time for routine monitoring, maintenance or repair purposes. This study is on the third model, and as such, simulations were done based on model C.

a. MAPPING OF PROPOSED COLLOCATION SITE

The first thing done was to make a survey of the total area of the case study (from the school gate to Faculty of Pharmacy) and then make a network mapping in order to ascertain human population distribution around the perimeter so as to determine where coverage and capacity are more needed. A screenshot from the Agile to pro software showed the total area and the mapped-out location for the mast installation. In Figure 7 is shown a screenshot of the mapped-out site from google earth.

b. SIMULATIONRESULT

After carrying out the survey, the deployment of the collocated network operator antennas was simulated. This displayed the radiation extent of each network radios and gave a clear coverage layout, Figure 8.Furthermore, Microsoft Visio was used to make a well-labeled graphical depiction of the resulted collocation sites, Figure 9.The recommended five (5) collocation sites are identified for the area under studies, Figure 8.

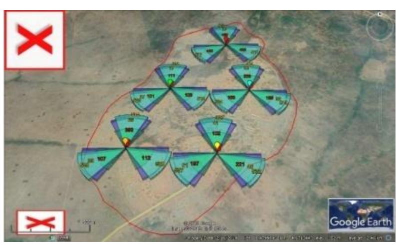

Figure 7: An aerial view of the area of the study [36]

Figure 8: showing proposed collocation sites [36]

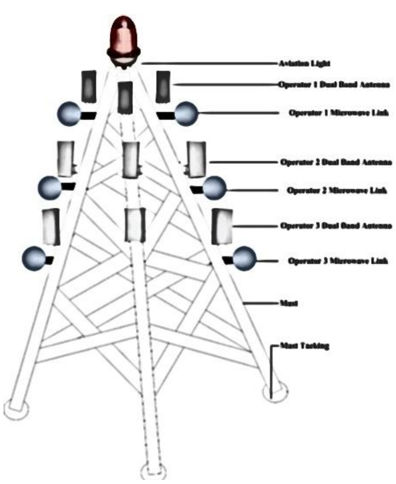

Figure 9: A collocation mast

CONCLUSION

Using suitable collocation parameters, this research work designed and simulated a collocation model. Hence, providing proposed collocation sites within the University of Ilorin.

After all findings and research carried out, it can be deduced that the CAPEX and OPEX required for starting and running a telecommunication network could be reduced drastically. GSM operators can increase RoI. Furthermore, possible environmental hazards (such as carbon monoxide smoke and noise from BTS sites generators and possible radioactive emissions from the emitted radio signals from the BTS sites), and likewise congestion can all be reduced to the barest minimum should collocation be employed. However, it is very important that a proper Radio Frequency (RF) planning is done because if done otherwise, collocation will bring more problems than the solutions it is expected to achieve.

To achieve an optimum result using frequency diversity technique, operators collocating must ensure adequate spacing between the channels allocated to cells in order to mitigate or completely eradicate adjacent and co-channel interference.

This study serves also as a business investment for the telecom servicing company that might want to invest in the collocation of telecom sites in the University of Ilorin.

Further research works could be on how to successfully share active equipment. It is highly recommended for NCC to intensify the collocation campaign and increase its efforts in encouraging operators to embrace collocation and infrastructure sharing since this will evidently help to reduce environmental congestions and possible adverse effects on health.

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