Tower sharing and the associated constraints in multi-operator GSM base transceiver station

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Abstract: Communication has witnessed a tremendous boost in Nigeria since the introduction of Global Systems for Mobile communication (GSM). However, congestion of GSM towers in the metropolis poses an environmental issue. The capital-intensive nature of wireless services has forced two or more operators to share a common tower without any conflicts of interest. In order to ensure a hitch-free operation, mutual agreement among the operators and regulatory bodies is required. The techniques of GSM infrastructure sharing, its benefits, constraints, and technical and health implications are presented in this article. The results of sensitivity analysis and the implications on the coverage and quality of service were highlighted. Moreover, the effects of adding more BTS antennas to a tower were investigated in terms of additional dynamic loading caused by wind, and increased radiation intensity. The study would be useful for radio engineers in the planning and design stages of a GSM network.

Keywords: cell towers; infrastructure deployment; quality of service; tower height; microwave link; wind loading.

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1 Introduction

The introduction of Global Systems for Mobile communication (GSM) has changed the telecommunication systems in Nigeria. Owing to its numerous benefits, GSM technology has grown rapidly in the last decade. The number of cell phones and cell towers are increasing both in Nigeria and the world at large. According to Koutitas and Demesticahas (2010), in the fixed line networks, over 70% of the overall power consumption exists in the user segment and less than 30% is due to operator.

But in contrast, in the mobile networks, about 10% of the overall power consumption corresponds to cellular user and 90% is incurred by the operators' expenditure.

The cost of providing mobile service is huge, because the service providers invest more on infrastructure deployment in order to meet the growing demand of users. The high infrastructure content of mobile communications technology has a strong effect on quality of service (QoS) and tariffs charges. The cost includes both capital expenditure (CAPEX) and operation expenditure (OPEX). The CAPEX includes the costs of tower installation, license acquisition, radio equipment, site acquisition and generator installation. While OPEX comprises operational costs such as staff employment and training staff, system upgrades and fuelling and maintenance of the generator. As a result of the huge capital incurred by the operators, there is a rising need for the mobile telecom industry to reduce the cost of infrastructure deployment. Several GSM operators in Nigeria, and the world at large, now come together on the basis of mutual agreements to consider infrastructure sharing as a means of cost reduction. Nigeria Communications Commission (NCC), which is the regulatory body in Nigeria, also supports infrastructure sharing, by providing legal and technical guidelines that would ensure unbiased dealing.

2 Benefits and technical constraints of tower sharing

Telecommunications infrastructure sharing is an agreement between two or more GSM (telecom) operators to share infrastructure located in a particular site with the intention of reducing CAPEX and OPEX. In order to spread and reduce the increasing investments by GSM operators, competitors are now becoming business associates. Also, owing to complaints from public that the numbers of telecom tower in cities are too much, tower sharing reduces the number drastically to a few towers that will meet the requirements of the operators.

2.1 Benefits of tower sharing

According to survey conducted among mobile telecom operators in Nigeria, collocation seems to be the solution to the financial problems associated with deployment and maintenance of mobile networks. The results of the survey are as shown in Figure 1 (Emeka, 2009). Money invested in telecommunication industry is principally influenced by large investment in technology and deployment of infrastructures at a specific area. This is further increased, to a greater extent, by continuous need to improve the quality of such infrastructures for new technologies. Passive infrastructure sharing makes these expenditures to reduce by involving multiple operators in the investment. In a fully developed market, collocation will reduce expenses and more capacity can be created in a congested area where there is not enough space for tower and site. In maturing markets, passive infrastructure sharing may extend coverage into some geographical areas that are not previously served. This is achieved by reducing subscriber acquisition expenses by sharing sites and towers. Also infrastructure sharing reduces the entry barrier for the potential new operators, thereby making the telecoms industry more attractive to new operators. Last but not the least, infrastructure sharing facilitates optimal utilisation of available resources while encouraging competition and availability of services to customers at affordable prices.

2.2 Technical constraints of tower sharing

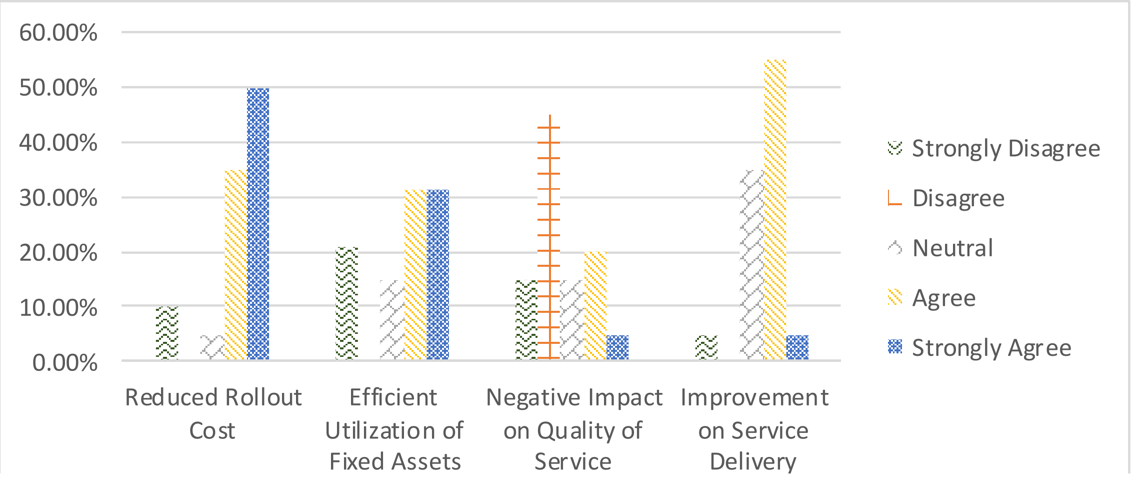
Despite the aforementioned benefits, tower sharing introduces some form of constraints, such as interference and wind loading to mention but a few, to the activities of the concerned operators. The sharing scheme may have adverse effects on the flexibility of their operation if these issues are not properly managed.

There have been a handful of published research works on passive infrastructure sharing. However, most of the reported works only focused on economic and regulatory aspects of tower sharing. For instance, the cost structures of mobile telecoms operations were reported in the work of Idachaba (2011), where infrastructure sharing strategies aimed at reducing the total cost of ownership of mobile services were reviewed. As reported, sharing of electrical energy, air conditioning, towers and links has the capacity of reducing the average cost per site by more than 50% with a cost saving of up to 30% for the individual operator.

More so, there are two major challenges confronting infrastructure sharing in Nigeria, which are severe competition among operators and absence of enforceable regulation/ legislation in favour of infrastructure sharing. The value of infrastructure sharing as a means of achieving cost efficiency and revenue assurance was investigated by Emeka (2009). The case study explored the benefits of infrastructure sharing between two mobile operators in Nigeria without considering the challenges involved. According to NCC Reports (NCC, 2008), most National Regulatory Agencies also paid attention only to the best practices, license, legal guidelines and infrastructure sharing arrangements among operators.

It has been observed that various existing sharing models largely focus only on regulatory issues and vendor perspectives, as reported by Meddour et al. (2011). Quite a large number of sharing models such as business model, technology model, geographical and process models from both technical and economic perspectives were investigated in the study. However, the potential technical challenges were not sufficiently analysed. Even though the strategic rationale behind network sharing, regulatory considerations and environmental issues were reported, little or no attention paid on technical issues.

Figure 1 Results of survey conducted among telecom operators in Nigeria on infrastructure sharing



A centralised data base was suggested by Jiang (2014), which was implemented with the purpose of increasing the process flow for network resource sharing. The benefits of sharing cannot be overemphasised. For example, mobile operators' network outsourcing lead to 20–25% cost reduction. Sharing allows healthy competitions among the operators, while still achieving the above-mentioned benefits, which include higher speed mobile services in the future and also the introduction of innovative products (Vornpuan, 2010). Therefore, the techniques of managing the possible constraints associated with tower sharing are discussed in this paper.

3 Methodology

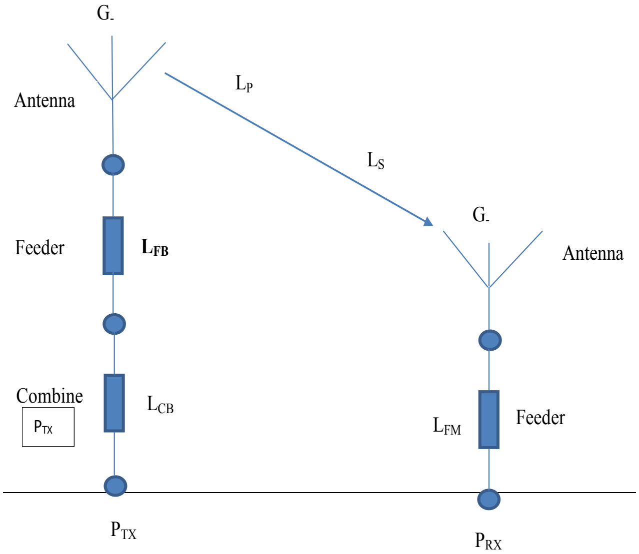
For the purpose of illustration, a sensitivity analysis was first carried out on the communication link in order to study the parameters which are more sensitive to changing variables. In radio transmissions, the transmitter and the receiver are usually separated by a distance far apart with each other while maintaining the required performance. A typical RF transmission system for mobile system is shown in Figure 2. In order to obtain the coverage distance and power received at a BTS boundary, it is required to consider all the possible losses which may occur between the transmitter and receiver. From Figure 2, the received signal strength is given by:

$$P_{RX}\left(dBm\right) = EIRP\left(dB\right) - L_p\left(dB\right) - L_s\left(dB\right) + G_{ms}\left(dBi\right) \quad (1)$$

$$EIRP\left(dB\right) = P_{TX}\left(dB\right) - L_{CB}\left(dB\right) - L_{FB}\left(dB\right) + G_{BTS}\left(dBi\right) \quad (2)$$

where P_{RX} and P_{TX} are received and transmit powers, respectively, EIRP is the effective isotropic radiated power, L_p, L_{CB}, L_{FB} and L_S are the path loss, BTS combiner's loss, BTS feeder loss and the shadow fading, respectively. G_{ms} and G_{BTS} are the gains of mobile station and Base Transceiver Station (BTS), respectively. Note that shadow fading describes the variation of signal due to natural terrain and human-made structures.

Figure 2 Typical radio transmission



If the receiver sensitivity, R_S, is known, then the maximum path loss is given by:

$$L_p\left(dB\right) = EIRP\left(dB\right) - L_s\left(dB\right) - R_s\left(dBm\right) + G_{ms}\left(dBi\right) \quad (3)$$

Hata models closely agree with measured data and are therefore recommended for most path loss predictions (Debus, 2006). These models are used in the design and optimisation of cellular network. For frequency in the range of 150–2000 MHz, the median path loss is expressed as:

$$L_{PU}\left(dB\right) = A + B - ch_{ms} \quad (4)$$

$$L_{PS}\left(dB\right) = L_{PU} - 2\left[\log_{10}\left(\frac{f\left(MHz\right)}{28}\right)\right]^2 - 54 \quad (5)$$

$$L_{PR}\left(dB\right) = L_{PU}\left(dB\right) - 4.78\log_{10} f\left(MHz\right)^2 + 18.33\log_{10} f\left(MHz\right) - 40.94 \quad (6)$$

where:

$$\left.\begin{aligned} A &= 69.55 + 26.16\log_{10} f\left(MHz\right) - 13.82\log_{10} H_{BTS}\left(m\right) \\ B &= \left[44.9 - 6.55\log_{10} H_{BTS}\left(m\right)\right]\log_{10} d\left(km\right) \end{aligned}\right\} \quad (7)$$

where L_{pu}, L_{ps} and L_{PR} are urban, suburban and rural path loss, respectively, f is the operating frequency, H_{BTS} and H_{MS} are BTS and mobile station height, respectively, and d is the separating distance.

By combining equations (3) and (4), the maximum distance can be obtained as follows:

$$d\left(km\right) = \log_{10}^{-1}\left[\frac{C - \begin{pmatrix} 69.55 + 26.16\log_{10} f\left(MHz\right) \\ -13.82\log_{10} H_{BTS}\left(m\right) \end{pmatrix} + ch_{ms}}{44.9 - 6.55\log_{10} H_{BTS}\left(m\right)}\right] \quad (8)$$

where

$$C = EIRP\left(dBm\right) - L_s\left(dB\right) - R_s\left(dBm\right) \quad (9)$$

and

$$\begin{aligned} ch_{ms} &= \left((1.1\log_{10} f\left(MHz\right) - 0.7\right) \\ &\quad H_{MS}\left(m\right) - \left(1.56\log_{10} f\left(MHz\right) - 0.8\right) \end{aligned} \quad (10)$$

Note that ch_{ms} is the correction factor for mobile station height and it is a function of the coverage area. The techniques of estimating collocation parameters that may affect tower sharing are presented in the following subsections. Such parameters include isolation between antennas on a tower, antenna tilting, microwave link QoS, radiation from transmitting antennas and wind loading on tower.

3.1 Estimation of isolation between antennas on a tower

The isolation between co-located BTS antennas operating at the same frequency with the same polarisation is obtained from the following equations. The horizontal isolation (Report ITU-R M.2244, 2011; Recommendation ITU-R SM.337-6, 2008) and vertical space isolation (Recommendation ITU-R SM.337-6, 2008) are given by equations (11) and (12), respectively:

$$\begin{aligned} I_{HI}\left(dB\right) &= 22 + 20\log\left(\frac{d_{HI}\left(m\right)}{\lambda i\left(m\right)}\right) \\ &\quad -\left(G_{Tx} + G_{Rx}\right) - \left(S_{Tx} + S_{Rx}\right);\ d_{HI} \geq 10\lambda \end{aligned} \quad (11)$$

$$I_{VI}\left(dB\right) = 28 + 40\log\left(\frac{h_{VI}\left(m\right)}{\lambda i\left(m\right)}\right) \quad (12)$$

where I_{HI} is the isolation between horizontally separated antennas, d_{HI} is the horizontal distance between the antennas, λ_j is the wavelength of the interfered operator with receiver band, G_{TX} and G_{RX} are the maximum gains of transmitter and receiver antennas, respectively, S_{TX} and G_{RX} are the side lobe gains of the transmitter and receiver antennas, respectively; I_{VI} and I_V are the isolation between vertically separated antennas and vertical distance between antennas, respectively.

3.2 Estimation of antenna tilting

Communication antennas must be tilted so as to cover the desired radius. Depending on the chosen tilt angle, $\theta(^0)$ from the horizontal direction, a geometric cell radius $d(m)$ is given by:

$$d = \frac{H_{BTS}}{\tan\theta} \quad (13)$$

3.3 Estimation of microwave link quality

According to Haslett (2008), the power transmitted from one microwave dish antenna to another depends on the path length, operating frequency $f(MHz)$, antenna size and transmit power P_t, as shown in equations (14)–(16). The gain of microwave antenna (parabolic dish) is given by:

$$G\left(dBi\right) = 18 + 20\log_{10} D_m\left(m\right) + 20\log_{10} f\left(GHz\right) \quad (14)$$

Assume parabolic dishes for both transmit and receive antennas, then the path loss L_p and receive power P_r are obtained from equations (15) and (16), respectively.

$$L_p\left(dB\right) = 32.4 + 20\log_{10} d_{tr}\left(km\right) + 20\log_{10} f\left(MHz\right) \quad (15)$$

$$\begin{aligned} P_r\left(dBm\right) &= P_t\left(dBm\right) - L_p\left(dB\right) \\ &\quad - L_m\left(dB\right) + G_t\left(dBi\right) + G_r\left(dBi\right) \end{aligned} \quad (16)$$

where D_m is the antenna diameter and L_m accounts for other losses.

3.4 Determination of radiation from transmitting antennas

For far field free-space propagation loss, the power density $S(W/m^2)$ is given by (Mazar, 2013):

$$S = \frac{P_t G_t}{4\pi d^2} \quad (17)$$

$$S = \frac{EIRP}{4\pi d^2} \quad (18)$$

$$S = 0.08\frac{P_t}{d^2} \times 10^{\frac{G}{10}}$$

$$d = \sqrt{\frac{P_t G_t}{4\pi S}} \quad (19)$$

For multiple antennas from the same site, the total power density is calculated as the sum of the individual power density from each antenna in the point of interest. The total power density is used to calculate the safety distance from transmitting antenna, as shown in equations (17)–(21).

$$S_t = 0.08N\frac{P_t}{d^2} \tag{20}$$

$$\left.\begin{aligned} d_{eq} &= \sqrt{\frac{EIRP_{eq}}{4\pi S_l}} \\ d_{eq} &= \sqrt{\frac{NP_tG_t}{4\pi S_l}} \\ d_{eq} &= \sqrt{\frac{0.08NP_tG_t}{S_l}} \end{aligned}\right\} \tag{21}$$

where N is the number of transmitting antennas, $d(m)$ is the safety distance from a single transmitting antenna, $d_{eq}(m)$ is the equivalent safety distance from more than one transmitting antennas and $S_l(W/m^2)$ is the power density limit.

3.5 *Estimation wind loading on tower*

BTS antennas not only add load to the tower due to their mass, but also in the form of additional dynamic loading caused by the wind. As proposed by Ferris (2009), wind load is calculated using the following equation:

$$W_L = \frac{1}{2}\rho_a C_{da} V^2 A_A \tag{22}$$

where $W_F(N)$ is the wind force, $\rho_a(kg/m^3)$ is the air density, C_{da} is the drag coefficient, $V(m/s)$ is the wind speed and $A_A(m^2)$ is the antenna area. The wind force must not be greater than the load bearing capacity of the tower.

4 Results and discussions

The results of sensitivity analysis on maximum distance, BTS antenna height and transmit power based on the analytical methods described above are illustrated in this section.

4.1 *Sensitivity analysis*

The sensitivity analysis performed on maximum distance was obtained using equation (8).

This was achieved by altering a single variable in equation (8) and then calculating the change in maximum distance. The process was repeated for each variable in order to extract information on what variable(s) is/are mostly affected by the change. The variables subjected to changes include transmit power, antenna gain, minimum receiver sensitivity, frequency, and transmitter and receiver heights. The transmit power and BTS' height are considered since they are the parameters that can be varied from operator. The site simulation parameters are shown in Table 1 (Nadia and Aditya, 2013; Report ITU-R M.2244, 2011; Haslett, 2008; Mazar, 2013).

Table 1 Site simulation parameters

Parameters	*Values*
Transmitter power, $P_{TX}(W)$	45
Antenna height, $H_{BTS}(m)$	Varied from 20 and above
Transmitting antenna Gain, $G_{BTS}(dB)$	37
Antenna direction (azimuth) (degrees)	120, 240
Antenna area, $A_a(m)$	3 × 0.2
Diameter of microwave dish antennas, $D(m)$	1.8
Latitude (degrees)	4.5469°N
Longitude (degrees)	8.46711°W
BTS combiner loss, $L_{CB}(dB)$	5
BTS feeder cable, $L_{FB}(dB)$	4
Shadow fading, $L_S(dB)$	5
MS antenna gain, $G_{MS}(dB)$	0
MS Feeder Loss, $L_{FM}(dB)$	0
Receiver Sensitivity, $R_S(dBm)$	–102

The results of the sensitivity analysis are shown in Figures 3–5. The BTS antenna height and transmit power are both sensitive to transmission distance. Altering the specified value for any of these variables will affect the transmission distance. It was also observed that GSM 900 antenna covered more area than GSM 1800 antenna, using same height using transmit power. In a shared tower, varying one or more of these parameters may affect coverage area. The results of regression analysis performed on Figures 3–5 are summarised in equation (23). Note that the BTS height, antenna gains, MS height, receiver sensitivity and frequency were all kept constant.

$$d\,(km) = \left.\begin{array}{ll} -0.0041{P_{TX}}^2 + 0.5P_t + 15 & \\ -0.0019{H_{BTS}}^2 + 0.56H_{BTS} + 5.8\,, & (GSM900) \\ -0.00038{H_{BTS}}^2 + 0.26H_{BTS} + 4.9 & (GSM1800) \end{array}\right\} \tag{23}$$

Figure 3 Effects of varying transmit power on transmission distance (see online version for colours)

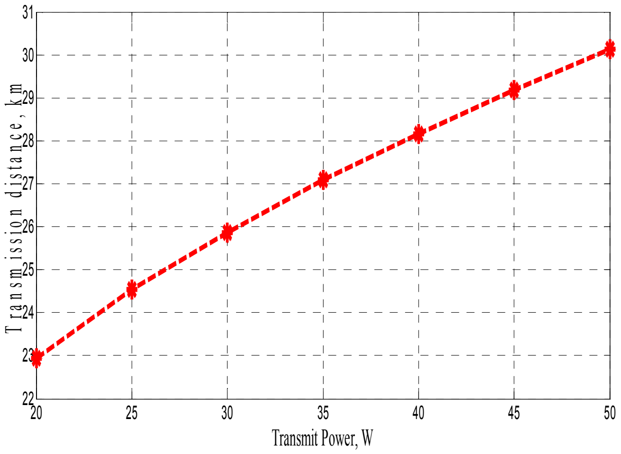


Figure 4 Effects of varying the BTS height on transmission distance for GSM 900 MHz, when transmit power, antenna gains, mobile station height, receiver sensitivity remain constant (see online version for colours)

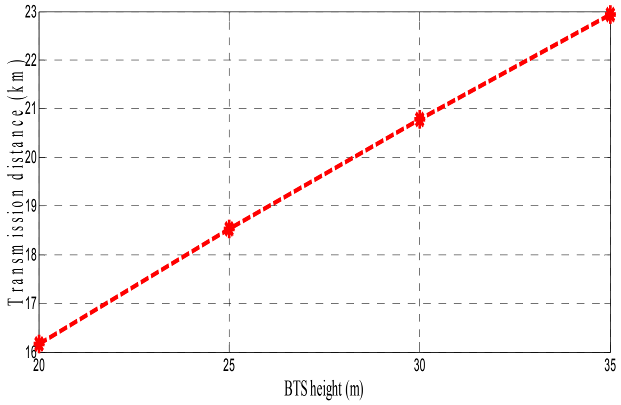
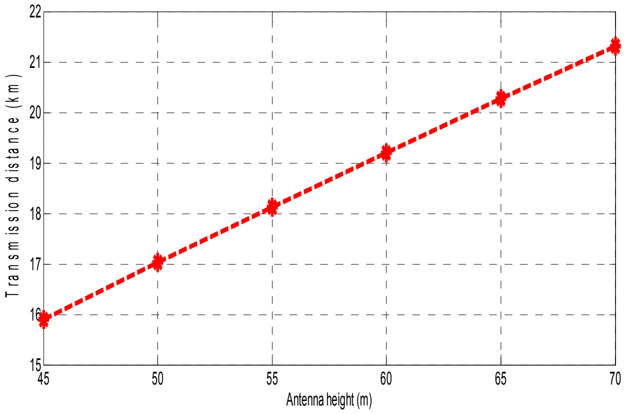


Figure 5 Effects of varying the BTS height on transmission distance for GSM 1800 MHz (the transmit power, antenna gains, mobile station height, receiver sensitivity remain fixed) (see online version for colours)



4.2 Results of technical constraints on tower sharing

4.2.1 Antenna isolation between antennas

Equations (11) and (12) give both the horizontal and vertical space isolation as an alternative to on-site measurement due to high cost, time consumption and disturbance of traffic in active networks. Note that equations (11) and (12) are applicable when $d_{HI} > 10\lambda_i$ and $h_{VI} > \lambda_i$.

Figure 6 Plots of antenna isolation versus horizontal separating distance between antennas on a tower

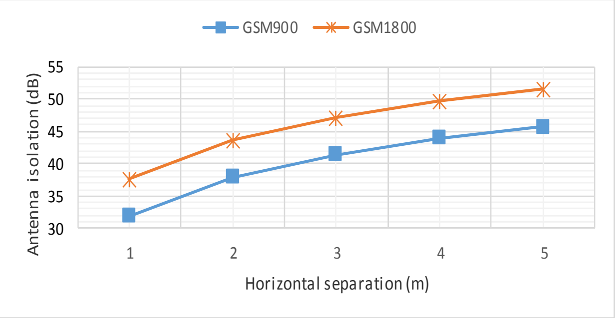
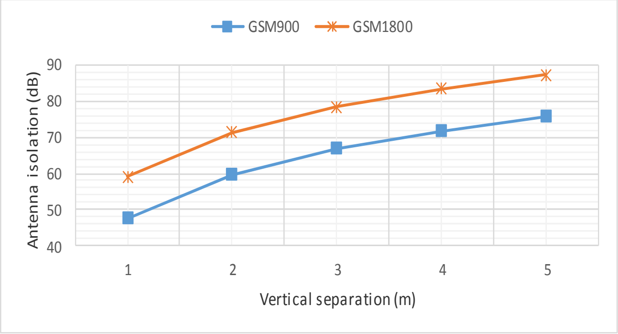


Figure 7 Antenna isolation as a function of vertical separating distance between antennas on a tower



As can be observed in Figures (7) and (8), the larger the antenna separation distances, the higher the isolation. The isolation is also sensitive to operating frequency, as its value is higher for GSM 1800 compared to that of GSM 900. Therefore, a lower antenna height separation can be used in GSM 1800. More also, the isolation is greater for vertical separation distance compared to its horizontal counterpart, since antenna gains are not included in equation (12).

4.2.2 Coverage and quality of service

The power radiated out of a BTS antenna depends on the received signal power at the cell border, which is in turn related to the antenna height. To illustrate the technical constraints earlier mentioned, a BTS, located in Ilorin, Nigeria, with known characteristics was investigated. Assuming the BTS hosts several operators using identical antennas and transmit powers. The antenna height and other system configurations were already shown in Table 1. Suppose the operators' equipment is located at different positions on the tower and each separated by 5 m height. This is to ensure higher vertical space antenna isolation between the antennas and thereby reducing adjacent interference. Using equations (1)–(4), Figures 8 and 9 show the plots of path loss, (urban) L_{pu} against antenna height at 900 and 1800 MHz, respectively. Note that the separation distance and mobile station antenna height are fixed at 20 km and 2 m, respectively.

Figure 8 Path loss and received signal power as a function of antenna height at 900 MHz frequency mobile fixed station height and coverage distance at 2 m and 20 km, respectively

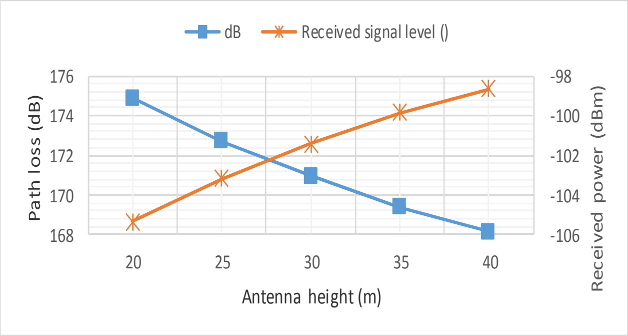
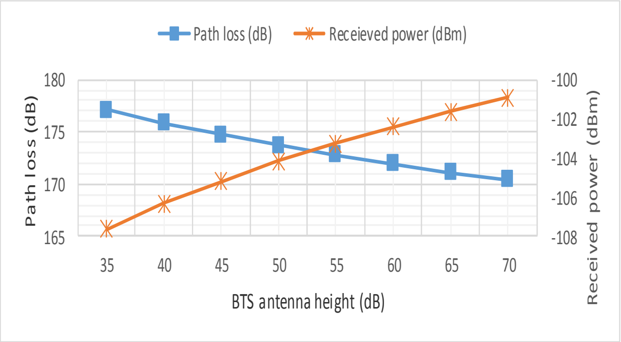


Figure 9 Path loss and received signal power as a function of antenna height at 1800 MHz frequency, with a fixed mobile station height and coverage distance at 2 m and 20 km, respectively

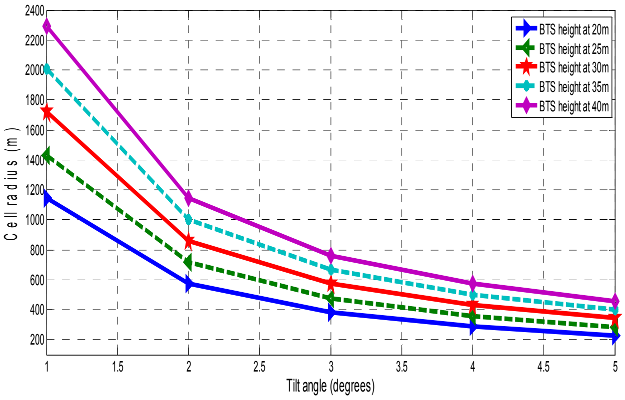


From Figures 8 and 9, it can be seen that path loss at the cell boundary (20 km) depends on the position of the transmitting antenna on the tower. That is, path loss can be reduced by increasing transmitting antenna height, thereby increasing the received signal power. For the most desired coverage, the BTS antenna has to be optimally positioned on the tower. However, mounting the antenna below the optimal height will result in a situation whereby some locations within the cell having received power less than the required threshold. From Figure 8, operator at heights 20 m and 25 m will receive power below threshold for minimum receiver sensitivity of –102 dBm and from Figure 9, operators at heights 35 m to 55 m will also receive power below threshold base on the simulation parameters used. Mounting the antenna at a height above the optimal height will also cause some locations within the cell to have received power beyond the prescribed requirements unnecessarily. From Figure 9, operator at heights 35 m will receive power exceeding requirement.

It will therefore be difficult for all operators to be at the optimum height. This is a major challenge in tower sharing. Operators that will eventually occupy lower and non-optimum positions on a shared tower will not have the same coverage as the operator that occupies the optimal height. This will also affect the QoS, and place these operators at disadvantage against their competitors. To achieve the optimal coverage, the disadvantaged operators will have to invest more on hardware either by increasing the transmit power or the antenna gain. This will reduce the main financial benefits of tower sharing, specifically CAPEX reduction. If the poor QoS persists, many users may switch to other operators with better coverage and service. These disadvantaged operators may lose some of their customers and these results in income loss.

Antenna tilting might be thought as a remedy to coverage problem mentioned above. But the effectiveness of the antenna tilting depends on the height of antenna. Most BTS antennas are tilted within the range of 1° to 5° to the horizontal direction. The cell range is easily evaluated from simple geometry. The cell range is calculated for tilting angles ranging from 1° to 5°. A plot of cell radius as a function of tilting angle was deduced using equation (13). Figure 10 shows the variation of cell radius as a function of tilting angles for various base station antenna heights.

Figure 10 Cell range as a function of tilting angle for various antenna height



It can also be observed from Figure 9 that at a BTS height of 20 m with a 1° tilting angle, the cell range is 1145.7 m and it decreased to 228.0 for 5° tilting angle. When BTS antenna height is at 30 m, the corresponding values are 1718.70 m and 342.90 m, respectively. For an increase in BTS antenna height from 20 m to 30 m, the cell radius increased by 573 m for 1° and 114.9 m at 5° tilting angle. It will also be seen from Figure 9 that at a BTS height of 20 m, increasing the antenna tilting angle from 3° to 5° with height restriction decreases the cell range from 381.62 m to 228.60 m and this reduced the cell range by 153.02 m. This limits the cell range (coverage) to small geographical area resulting in the cell not achieving the desired coverage. At the same BTS height, decreasing the antenna tilting angle from 3° to 1° with height restriction increases the cell range from 381.62 m to 1145.72 m and this increases the cell range by 746.1 m. This projects the signal beyond the coverage range which may result in interference with other cells. This effect will be much more pronounced at higher antenna height. Antenna tilting only cannot therefore be used as remedy to constraints of non-optimum antenna height.

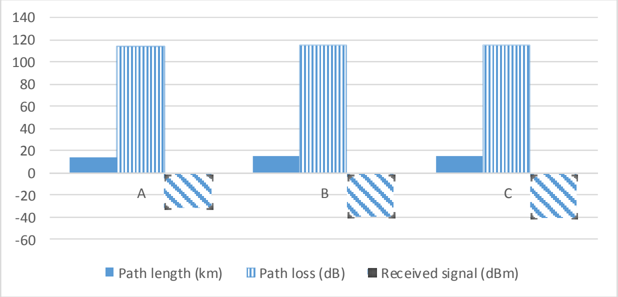
4.2.3 Effects of changing dish diameter on microwave link performance

Different planning methods employed by each operator normally result in different cell structures covering different area and thus necessitate placement of BTSs in different locations. This therefore results in different path length (distance) between individual operators in a shared tower. Creating a microwave link and maintaining it for optimal performance is vitally important in telecommunication. The quality of signal transmission in microwave depends on the direction of two stations. Microwave alignment is required to ensure good reception of received signal level. A zero (0) degree alignment is best for most paths, as it is mostly obtained in a single operator tower. But in a shared tower, owing to the presence of many operators, significant differences may exist between the antenna heights. It will then be necessary to tilt the antennas for optimum reception. Tilting of the antennas may slightly increase the path length. Also since most of the towers are constructed to accommodate a single operator, there might be needs to compromise the size of microwave dish antenna if such towers are to be shared by other operators to reduce the effect of wind loading. All these will surely have an effect on the microwave link quality as illustrated below. Table 2 shows the simulation parameters for microwave link for three operators. Operator A, being the hosts, is expected to occupy the optimum position, while operators B and C are expected to occupy lower position. To reduce the effect of wind loading on the tower, the size of microwave dish antenna for operators B and C may need to be reduced. The path loss and the received signal power for microwave link were calculated using equations (14)–(16), with transmit power of 20 W. It will be observed from Figure 11 that the path loss varies (though very small) due to different path length. It will also be observed that due to lower diameter of microwave dish antenna used by operators B and C, there is reduction in microwave link quality for these operators. Operator B will experienced an 8.04 dB reduction in the link signal at the receiving end while operator C will experienced an 8.61 dB reduction. These reductions in the link quality are as a result of compromising the size of microwave dish antenna.

Table 2 Microwave link simulation parameters

	Path length (km)	*Dish diameter (m)*	*Height (m)*
A	14	1.8	35
B	15	1.2	30
C	16	1.2	25

Figure 11 Microwave link simulation results



4.2.4 *The effects of tower sharing on safety distance from a BTS site*

The calculation of power density of the radiation from a BTS is obtained from the antenna's transmit power and gain, and by knowing the location of the exposed person. In a shared tower, all the antennas are directed towards the GSM users and there will be multiple emissions from the site. To show this effect in a shared tower, all the operators transmit in the same direction. Table 3 shows the parameters.

Table 3 Simulation parameters for safety distance

Parameters	*Value*
Frequency, $f(MHz)$	900
Power Density Limit $S_l(W/m^2)$	0.1
Transmit Power, $P_t(W)$	45
Antenna Gain, $G_t(dBi)$	37

Figure 12 Relationship between power density and separating distance from a radiating antenna (see online version for colours)

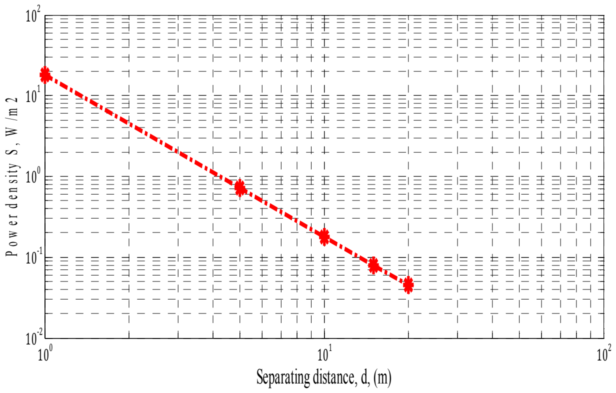
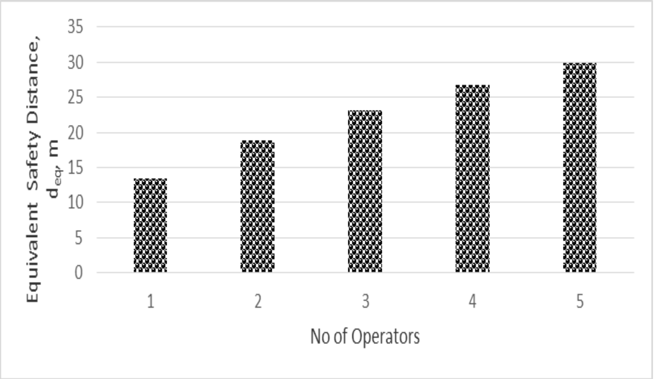


Figure13 Cumulative safety distance from a shared tower

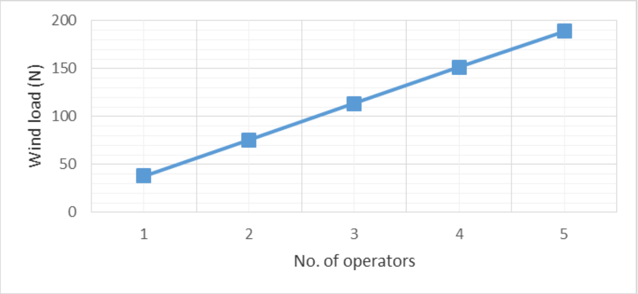


The results of safety distance are shown in Figures 12 and 13, using equations (17)(21) and the simulation parameters shown in Table 3. It will be observed that the radiation intensity (W/m^2) diminishes with increasing square of the distance (m) from the antenna. From Figure 13, it will be observed that as more antennas are added to the tower, the safety distance from the transmitting antennas increased at the used power density limit. Multiple-antenna emissions from a tower will increase power density. This in turn increases the safety distance from buildings and restricts tower construction near buildings where people (mobile users) are living. Such distance may not be available in urban and suburban areas and this poses another technical constraint.

4.2.5 *Effect of antenna wind loading on tower*

Tower loading includes communication accessories mounted onto the tower earlier or later. Addition of more BTS antennas to a tower increases the load owing to their weight and also in form of additional dynamic loading caused by wind. Towers are normally designed to carry specific maximum load. Also from published materials, wind speed and wind direction affect the received signals. It is therefore important to consider effect of wind loading in sharing. Equation (22) is used to obtain the wind loading force on antennas. Note that the drag coefficient (c_{da}) is taking to be one (1) and each operator uses three-sector and two-microwave dish antennas. The antennas were subjected to a wind speed of 3 m/s. The antennas' dimensions are given in Table 3.

Figure 14 Effect of wind loading on BTS antennas (see online version for colours)



It will be observed from Figure 14 that the wind load increased by 37.83 N as the number of operator increases. Towers that were initially designed for single operator are therefore incompatible to sharing. Any effort to share such towers may put the people and other properties around these towers at risks. If a new tower is to be constructed, it requires planning among the participating operators. The operators have different plans for roll-out and cannot coordinate site locations in a new area unless they have the same roll-out plans. This underlines other constraints to tower sharing.

5 Conclusions

A GSM infrastructure sharing technique is proposed in this work, based on existing models available to GSM operators and the benefits derivable from such scheme are presented. The constraints limiting optimal performance of a shared tower and the associated risks to lives and properties are also discussed. From the sensitivity analysis performed on the shared tower, the following observations were made: (i) variation of transmit power and antenna height has effects on coverage distance, (ii) use of non-optimum antenna height and varying path length have negative effects on cell coverage, signal strength and microwave link quality, (iii) addition of more BTS antennas to a tower increases the load owing to their weights and additional dynamic loading caused by wind, and (iv) the radiation intensity increases with increasing number of transmitting antennas on a tower, thereby implying that people living around the tower might be further exposed to radiation hazards. This therefore leads to increased safety distance from the tower and prevents tower construction near buildings.

The optimum location for the shared tower in order to maximise coverage and signal quality for all operators must therefore be investigated. Future research works should focus on using a third party (Tower Company) that will apply a pricing model in order to avoid unfair treatment among operators.

References

Debus, W. (2006) *RF Path Loss & Transmission Distance Calculations*, Technical Memorandum, Axonn, LLC, 4 August.

Emeka, O. (2009) *Telecom Infrastructure Sharing as a Strategy for Cost Optimization and Revenue Generation – A Case Study of MTN Nigeria/Zain Nigeria Collocation*, MBA Thesis Submitted to Blekinge Institute of Technology, Karlskrona, Sweden.

Ferris, M. (2009) *Wind Loading on Base Station Antennas*, A White Paper from Commscope, ANDREW Solutions.

Haslett, C. (2008) *Essentials of Radio Wave Propagation*, Cambridge University Press, New York, 978-0-52187565-3.

Idachaba, F.E. (2011) 'Telecom cost reduction in Nigeria through infrastructure sharing between operators', *The Pacific Journal of Science and Technology*, Vol. 11, pp.272–276.

Jiang, H. (2014) 'The sharing telecommunication information resources management system based on B/S model and GIS', *TELKOMNIKA, Indonesian Journal of Electrical Engineering*, Vol. 12, No. 3, pp.2384–2389.

Koutitas, G. and Demesticahas, P. (2010) 'A review of energy saving efficiency in telecommunication networks', *Telfor Journal*, Vol. 2, No. 1, pp.2–7.

Mazar, H. (2013) *Technical Limits of Human Exposure to RF from Cellular Base Stations and Handsets*, Professional presentation of the Ministry of Communications to the Experts of Ministry of Environmental Protection, Human-Exposure Monitoring Laboratories and Cellular Operators, 11 April, Jerusalem.

Meddour, D-E., Rasheed, T. and Gourhant, Y. (2011) 'On the role of infrastructure sharing for mobile network operators in emerging markets', *Computer Networks*, Vol. 55, No. 7, pp.1576–1591.

NCC (Nigeria Communication Commission) (2008) *Guidelines on Collocation and Infrastructure Sharing*, Lagos, Nigeria.

Recommendation ITU-R SM.337-6 (2008) *Frequency and Distance Separations*, ITU-R. ITU-R, Geneva.

Report ITU-R M.2244 (2011) *Isolation between Antennas of IMT Base Station in the Land Mobile Service*. Available online at: http://www.itu.int/pub/R-REP-M.2244-2011.

Vornpuan, P. (2010) *Infrastructure Sharing in Practice: Sharing Mobile Networks*, Nokia Siemens Networks, 2 September. Available online at: http://www.itu.int/ITU-D/asp/CMS/ASP-CoE/2010/InfraSharing/S12.pdf