Passive Mobile Cellular Network Infrastructure Sharing: An Analysis of Wind Loading on a Multi-Operator Telecommunication Tower

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Abstract

In order to overcome challenges militating against the rapid deployment of mobile cellular infrastructure, it is technically and economically crucial for a number operators to share mobile cellular infrastructure such as power supply, base station (BTS) cabin and telecommunication tower. For an efficient tower sharing, an analysis of tower's wind loading and the tower bending moment have to be performed. In this work, we performed wind loading analyses for a multi-operator mobile cellular network. It was verified that as the number of operators increase, the wind loading value also increases. This work further observed that as the value of the antenna tilt increases, the tower wind loading proportionately increases. However, as the wind direction deviates from the normal, the wind loading reduces slightly. Finally, for six mobile cellular network operators, with total tower height set at 55m, the bending moment at a rare wind speed of up to 67m/s was evaluated to be $10{,}260\,kNm$. It is vital that the bending moment of the telecommunication tower be lesser than the manufacturer's specified tower bending moment limit. The results obtained from this research can be used to tighten tower survivability criterion. It will also serve as a useful tool to mobile cellular equipment designers and installers.

Keywords

GSM, wind loading, telecommunication tower, multi-operator base station, bending moment, infrastructure sharing, collocation

1. Introduction

In order for mobile cellular network operators to reduce Capital Expenditure (CAPEX) and Operating Expenditure (OPEX), the need arose for them to share network infrastructure such as telecommunication towers, base station cabin, and power supply. There are researches that discuss passive infrastructure sharing among GSM operators, such as the works of Ehiagwina *et al*. (2016), Kadir *et al.* (2016) and Amuda *et al.* (2014). These works reported a thorough overview of related concepts and constraints of a multi-operator mobile cellular base station. Some of the constraints to consider when operators share infrastructure include; receiver sensitivity degradation, electromagnetic radiation limits, wind loading on tower, etc. Meanwhile, towers are flexible structure that are sensitive to ice and wind loading. Figure 1 shows steel lattice masts, which may be a vertical, a truncated cone system, or a combination of both systems whereby the truncated cone base continues beyond a specific height level as a prism (Efthymiou, Kaziolas, & Baniotopoulos, 2007). (Figure 1).

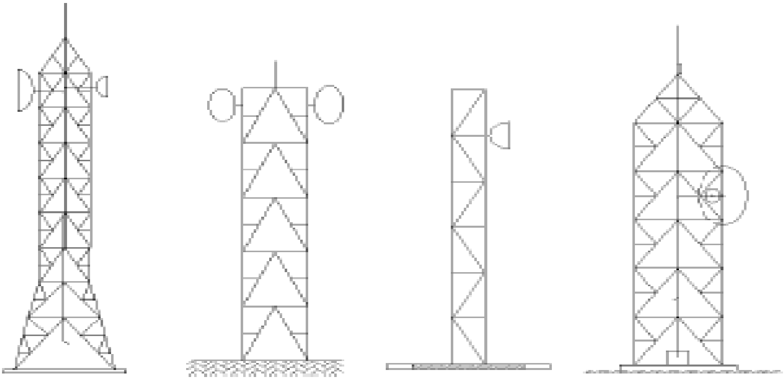

Figure 1 Morphology of steel lattice tower (Efthymiou et al., 2007)

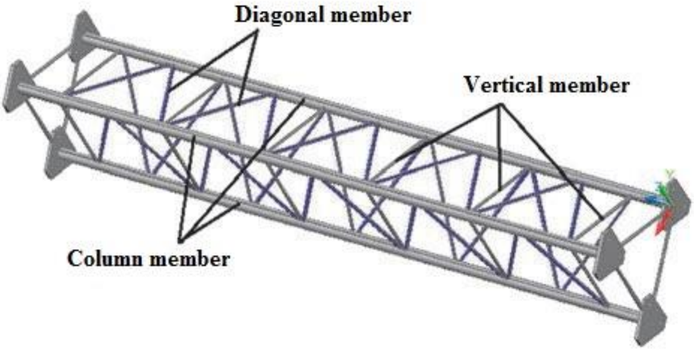

Figure. 2 Steel tower member description (Erdem, 2015)

The components of a typical tower section such as its various members are depicted in Figure 2. A proper analysis has to be carried out so as to guarantee the survival of the tower after sharing because of increased loading associated with tower sharing owing to the greater surface area exposed to wind flow.

2. Review of Related Works

Definition of some wind loading related terms are first presented to ease the understanding of mobile cellular designers and network operators. Such terms include tower survivability, gust factor, bending moment, aeroelastic and plastic deformation. Note however, these terms are described in the context of mobile telecommunication tower. *Tower survivability* refers to the quantified capability of a telecommunication tower to continue to serve the purpose of its design during and after wind and ice loading of a specified magnitude. G*ust factor* is defined as the ratio of the peak wind speed during a specified epoch to the average wind speed of the tower location.

Bending moment refers to the reaction in the form of bending induced in a tower when subjected to wind or ice loading. Whereas, aeroelasticity describes the interaction between aerodynamic forces and elastic non-rigid structures such as a tower. Finally, plastic deformation occurs when a loading results in changes to the shape of the tower. In passive infrastructure sharing, a crucial parameter of interest is the tower wind loading capability. There are a number of research works evaluating loads on towers, some of which are reviewed in this section of the paper. These works examined the following questions: What is the effect of positioning one or more antennas at various heights on the tower? Once the antenna configuration has been determined, how low must the tower be retracted to survive an anticipated wind speed? Which will fail first: the mast or the tower?

Table 1 Wind loading values adapted from Huawei Inc. (2011)

Tower height in *m*	Wind Loading in *kg* when the surface area exposed to wind direction = $15m^2$	Wind Loading in *kg* when the surface area exposed to wind direction = $30m^2$
40	5000	6500
45	5500	7000
50	7000	8000
55	8000	10500
60	9500	12000
65	11000	13500
70	12500	15500

Meanwhile, it was asserted by the Nigerian Communication Commission (2009) that the main loading on the tower is the wind loading. Moreover, as noted by Huawei Inc. (2011), the antenna area accounts for 30% of the total tower area. Therefore, in a multi-operator GSM tower, wind loading on tower will significantly increase owing to additional tower equipment installed. Using the data from (Huawei Inc., 2011), Table 1 shows the estimated wind loading values at various tower heights and areas for a wind speed of 40m/s. However, wind directions and variations of wind speed were not considered.

Both Efthymiou *et al.* (2007) and Rajasekharan and Vijaya (2014) evaluated the effect of seismic loading and other environment actions such as wind and ice loading on telecommunication tower. Specifically, Efthymiou *et al.* (2007) noted that wind loading is the most critical of the considerations. The effects of gust factor and cross-wind on slender mast in wind resistant design (WRD) was assessed by Chien and Jang (2008). Preeti and Mohan (2013) evaluated power transmission tower under different configurations. Nguyen *et al.* (2015) investigated wind-excited response associated with aeroelastic instability of lighting poles and telecommunication towers. Szafran (2015) reported on failure mechanism and modes, along with assessment of plastic deformation of a lattice communication mast observed in a full-scale push over test. Furthermore, the author noted that the failure modes of the compressed tower legs is determined by the tower connecting flanges' diameter and thickness.

Some authors have used a variety of computer software to analyse towers. Some of these are highlighted as follows. Preeti and Dhoopam (2015) considered the effect of wind on communication tower built on roof tops using STAAD pro finite element software owing to its apt graphical capabilities and ease of data entry and outputting. Ballaben and Rosales (2012) studied parameters of dynamic response of wind load on guyed tower using ALGOR software. Similarly, Erdem (2015) analysed guyed steel lattice tower subjected to environmental ice of various thickness values at a height of 1500m using SAP 2000, a finite element program. Existing models for analysing telecommunication tower loading make some assumptions that tend to neglect the following; the tilt angle of the antenna, and the direction of wind flow to the tower. In this paper, we evaluated wind loading on a multi-operator telecommunication tower, while considering tilt angles of installed equipment and wind directions. The rest of this article is sectioned as followed: section 3 describe the mathematical expressions used in the analyses of tower wind loading and bending moment. Section 4 reports on the result of the analysis. Finally, the conclusions reached are presented in section 5.

3. Materials and Method

The pressure or drag on a tower or an antenna on the tower is a function of the shape of the object experiencing the drag. A parameter that accounts for object shape is the drag coefficient. Table 2 indicate various shapes of objects and their corresponding drag coefficients $\left(C_d\right)$. The effect of drag coefficients on tower wind loading is shown in Figure 4.

Table 2: Object shapes and their drag coefficient

Shapes of object (antennas)	Drag coefficient $\left(C_d\right)$
Short cylindrical tube	0.8
Long cylindrical tube	1.2
Long flat plate	2.0

The wind loading on a tower is proportional to the area normal to wind direction. Wind pressure (P_R) expressed in $\mathrm{Kgm^{-1}s^{-2}}$ or $\mathrm{Nm^{-2}}$ is a product of density of air (ρ), (0.122 $\mathrm{Kg/m^3}$) at standard temperature and pressure) and the square of the wind speed (V), and it is shown in Eqn. (1) as:

$$P_R = \rho V^2 \tag{1}$$

Therefore, wind load (F) on the object (e.g. antennas, microwave dish, etc.), is given by eqn. 2, which incorporated the gust factor (G_h), the area (τ_a) normal to the direction of wind and the exposure factor (K_Z) of the telecommunication tower.

$$F = \tau_a P_R C_d K_Z G_h \tag{2}$$

Where K_Z and G_h are evaluated using equations (3) and (4). D_i = the height from the ground to the midpoint of the *i*th tower equipment.

$$K_z = (^{D_i}/_{33})^{2/7} \tag{3}$$

$$G_h = 0.65 + {}^{0.6}\Big/_{(^{D_i}/_{33})^{1/7}} \tag{4}$$

Equations (1) - (4) was combined to developed eqns. (5) and (7), which were used to evaluate the tower wind loading and moment of force when used by multiple mobile cellular operators (O_P) respectively. Equations (5) and (7) took into consideration both the antenna tilt angle and the angle at which the wind strikes the surface area of the tower and its installed antenna

$$\left\{ F_{ij}: F_{ij} = \rho C_d \left[\frac{D_{ij}}{10.058}\right]^{2/7} \left[0.65 + 0.6 \Big/ \left(\frac{H}{10.058}\right)^{1/7} \right] Sin^2 \beta V^2 \left[\sum_{i=j}^{n} \sum_{j=1}^{m} (\tau_{Aij}) \right], \right\} \tag{5}$$

$$F_{ij} \in \mathbb{R}, \forall i \in O_P, \forall j \in O_P \tag{6}$$

$$\left\{ m_B : m_B \in \mathbb{R}, m_B = \sum_{i=1}^{n} \sum_{j=1}^{m} F_{ij} D_{ij}, \forall i \in O_P, \forall j \in O_P \right\} \tag{7}$$

where: F_{ij} = Wind loading exerted on the ith operator's jth equipment, $\tau_{ij} = tower\ section\ area + \sin(90 - \beta) a_{ij}$, a_{ij}= area of the ith operator's jth equipment exposed to the wind direction., β = tilt of the operator's equipment n = number of mobile cellular operator

Equation (5) is in metric system; the loading is in Newton, speed in meter per second (m/s), distances in metre (m) and area in square metre (m^2). Tower section areas are estimated based on available literature and mobile cellular base stations observation. Table 1 shows the tower equipment' height for up to six mobile cellular network operators. Using the figures in Table 2, we sketch fig. 3 to show a layout of equipment placement on the tower by six operators (OP 1- OP 6).

Table 2: Tower equipment of mobile cellular network operators

Tower equipment	D_i, m OP 1	D_i, m OP 2	D_i, m OP 3	D_i, m OP 4	D_i, m OP 5	D_i, m OP 6	A_i, m
Directional antenna (GSM 1800)	20.0	25.8	31.6	37.4	43.2	49.0	0.32
Directional antenna (GSM 900)	21.0	26.8	32.6	38.4	44.2	50.0	0.4
Microwave dish 1	22.2	28.0	33.8	39.6	45.4	51.2	1.13
Microwave dish 2	22.8	28.6	34.4	40.2	46.0	51.8	0.28

4. Result and Discussion

Figure 4 shows variations of wind loading as the number of mobile cellular operators increase. The tower height was fixed at 55m, the wind speed at 15m/s normal to the surface of the tower and tower equipment, and the antenna tilt set at 0^0. It was observed that as the number of mobile network operator increase the wind loading increase linearly.

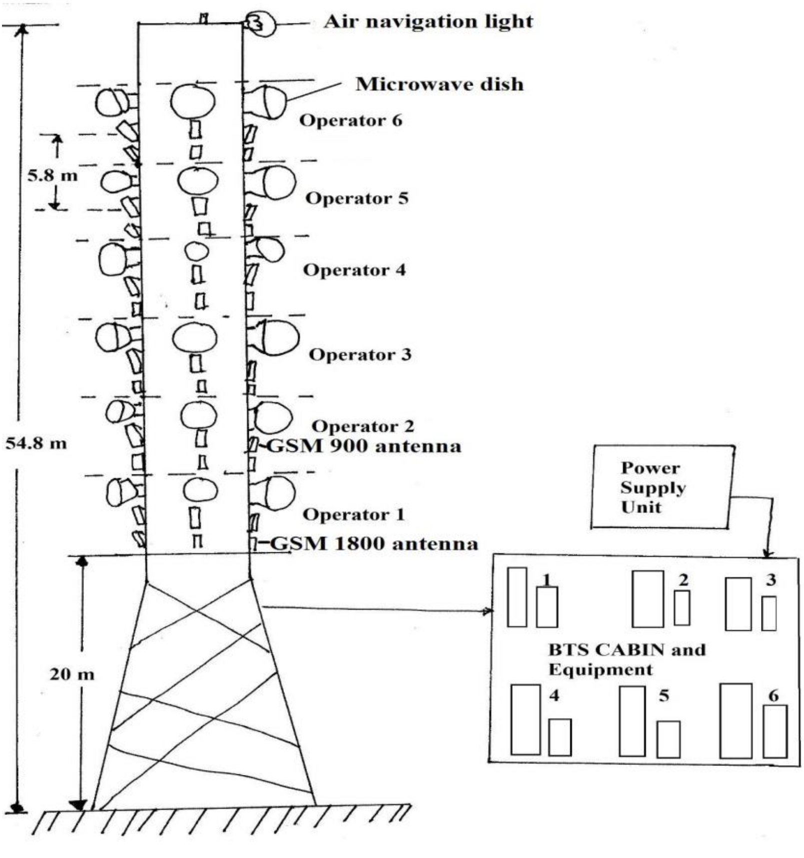

Figure 3 Equipment placement on tower layout (Ehiagwina, 2015)

The position of tower equipment for different operators up to six (6) operators are shown in Tables 2.

How does the tilt angle of the antenna affects the tower wind loading for a shared mobile cellular tower? This is the question that the results of Tables 3 to 5 seek to answer.

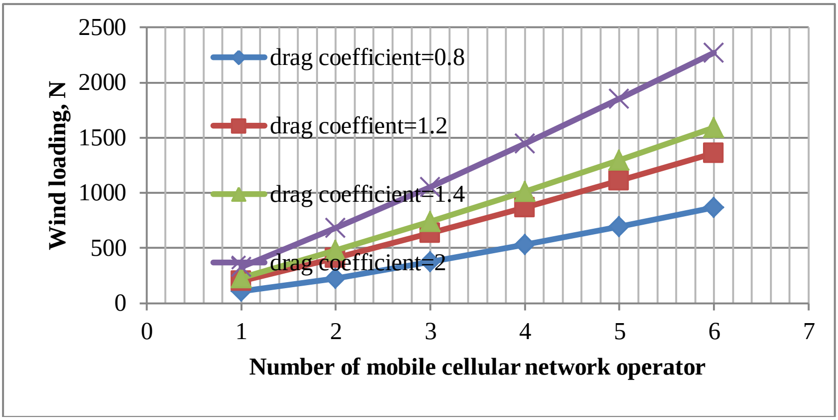

Figure 4 variations in the wind loading with increasing numbers of operators

Table 3 Wind loading values at different antenna tilt for increasing number of operator at C_d=0.8

Mobile cellular operators	Antenna tilt=2 deg.	Antenna tilt=4 deg.	Antenna tilt=6 deg.	Antenna tilt=8 deg.
1	132.73	133.65	134.48	135.26
2	274.82	276.71	278.44	280.03
3	424.92	427.84	430.53	432.98
4	582.09	586.1	589.79	593.13
5	775.61	750.75	755.46	759.75
6	914.92	921.23	927.01	932.28

Table 4: Wind loading values at different antenna tilt for increasing number of operator at C_d=1.2

Mobile cellular operators	Antenna tilt = 2 deg.	Antenna tilt = 4 deg.	Antenna tilt = 6 deg.	Antenna tilt = 8 deg.
1	199.11	200.48	201.73	202.88
2	412.23	415.07	417.67	420.04
3	637.38	641.77	654.79	649.47
4	873.13	897.15	884.66	889.7
5	1118.42	1126.13	1133.22	1139.64
6	1372.39	1381.85	1390.52	1398.42

Table 5 Wind loading values at different antenna tilt for increasing number of operator at C_d=2.0

Mobile cellular Operators	Antenna tilt = 2 deg.	Antenna tilt = 4 deg.	Antenna tilt = 6 deg.	Antenna tilt = 8 deg
1	331.84	334.11	336.21	338.14
2	687.04	691.75	696.1	700.08
3	1062.28	1069.58	076.31	1082.45
4	455.21	1465.2	474.43	1482.83
5	864.02	1876.82	888.64	1899.39
6	287.29	2303.01	317.51	2330.71

It is observable from Tables 3 - 5 that varying the antenna tilts result in slight change on the tower wind loading for multi-operator mobile cellular base station tower. As the degree of antenna tilt angle increase so also the wind loading. When the shift in the antenna tilt angle is large, then the wind loading change becomes significant. Table 6 shows that the greater the deviation from the normal of the wind direction the lower the wind loading. The wind speed was put at 44.7m/s.

The bending moment of the multi-operator mobile cellular network was also evaluated under various scenarios. The result is shown in Figure 5. The drag coefficient chosen was 1.2, the antenna tilt fixed at 80.

Table 6: Wind loading values with different deviations from normal in wind direction for increasing number of operators at C_d=0.8 and antenna tilt=8^0

Number of operators	0^0 Deviation in wind directi	5^0 Deviation in wind directio	10^0 Deviation in wind direction	15^0 Deviation in wind directio
1	1201.1	1196.54	1182.85	1160.19
2	2486.77	2477.32	2448.99	2402.05
3	3845.01	3830.33	3786.59	3714.01
4	5267.22	5247.18	5187.19	5087.76
5	6746.92	6721.24	6644.41	6517.04
6	8279.01	8247.5	8153.23	7996.93

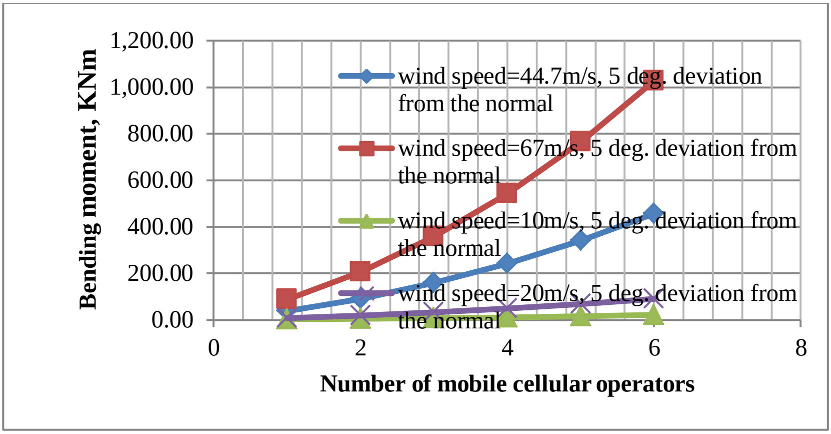

Figure 5: Bending moment of multi-operator mobile cellular network at C_d = 1.2

It can be observed that the wind speed value is a crucial parameter in the evaluation of the wind loading and bending moment. And it is noticeable that the tower bending moment is almost linearly related with the number of mobile cellular network operators. Also as the angular deviation from the normal increases the value of the wind loading decreases. Under a rare condition of a wind speed of 67m/s [150mph], in Nigeria, the bending moment was evaluated to be approximately $10{,}260\,kNm$.

5. Conclusion

The wind loading for the multi-operator mobile cellular network tower increases almost linearly as the number of operators increases. This is because the surface area exposed the direction of wind increases. It was also noticed that a small increase in the antenna tilt angle produce only a slight increase in the wind loading value.

It is recommended that before a telecommunication tower is shared by other cellular operators, a proper analysis of the tower bending moment have to be carried out, and the value obtained should be compared with the engineering specifications from the tower manufacturer. Meanwhile, aerodynamic analysis of a multi-operator mobile cellular tower could be done in a future research to test the validity of eqns. (5) and (7).

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