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Mathematical Optimization Model Technique for Network Congestion Control in Global System for Mobile Communications

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Abstract

The introduction of Global System for Mobile Communication (GSM) in Nigeria is responsible for significant tremendous teledensity ratio increment, which results in network congestion in most busy areas. In this paper, we applied a Second Order Necessary Condition (a Mathematical Optimization Technique) as a tool in solving the problem of network congestion. One of the GSM providers; Mobile Telecommunication of Nigeria (MTN), was used to demonstrate the usefulness of Second Order Necessary Condition to the control of network congestion at Michael Okpara University of Agriculture, Umudike (MOUAU). Free flow of connection between mobile phone users at different locations within the area of investigation was established, hence congestion controlled.

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1. Introduction

Mobile phones were first introduced in the early 1980s. The underlying technology has gone through phases, known as generations shortly few years after its introduction. The first generation (1G) phones used analogue communication techniques: they were bulky and expensive, and were regarded as luxury items. Mobile phones only became widely used from the mid 1990s, with the introduction of second generation (2G) technologies such as the Global System for Mobile Communications (GSM). These use more powerful digital communication techniques, which have allowed their cost to plummet, and have also allowed them to provide a wider range of services than before. Examples include text messaging, email and basic access to the Internet [5]. Global system for mobile communication (GSM) is a globally accepted standard for digital cellular communication. GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard that formulated specifications for a pan-European mobile cellular radio system operating at 900 MHz [8]. Global system for mobile communications (GSM) is a digital cellular radio network that uses more advanced technology and handles more subscribers than the analog cellular network due to the use of Time Division Multiple Access to divide the channel in time. It offers high quality voice communication and low bandwidth (96kb/sec) data connections for fax and Short Message Service (SMS). Data connection services like browsing, multimedia and e-mail demands on mobile telephone have increased tremendously. GSM) was introduced to solve the problem of capacity, high-level of interference, high power consumption, signaling, inefficient use of radio spectrum and so on, that were faced in the analog mobile system [7].

Congestion simply means ‘full of traffic’. It occurs when too many things or people are seeking for use of a resource that is limited. The Oxford-Advanced Learner’s Dictionary defines congestion as the state of being crowded, blocked or too full of traffic. Congestion is the unavailability of network to the subscriber at the time of making a call. It is the situation when the blocking occurs and no free path can be provided for an offered call [10]. Network congestion is defined as a state of network elements (e.g. switches, concentrators, cross-connects and transmission links) in which the network is not able to meet the negotiated network performance objectives for the already established connections and/or for the new connection requests [6]. It is a network state in which performance degrades due to the saturation of network resources, such as communication links, processor cycles, and memory buffers [4]. Congestion is a problem all GSM service providers are facing and trying to solve. It is a situation that arises when the number of calls emanating or terminating from a particular network is more than the capacity that the network is able to cater for at a particular time. It causes call signals to queue on the transmission channel. Consequently, the rate of transfer of voice signals is reduced or quality of signals received become distorted or both. At worst, the calls will not connect at all [14]. Congestion is a situation whereby the number of calls emanating or terminating from a particular network is beyond the capacity of that network at that point in time. In Nigeria, focus is now geared towards provision of quality service rather than provision of coverage, as complaints of dropped calls and congestion is now rampant [1]. Congestion is the unavailability of network to the subscriber at the time of making a call. Congestion occurs when there are limited resources at the service point, this leads to queues, called traffic or congestion [7]. Congestion is the situation when the blocking occurs and no free path can be provided for an offered call. That is, when a subscriber cannot obtain a connection to the wanted subscriber immediately [15]. The ideal telephone system is a situation where it is possible for all subscribers to talk in pairs simultaneously [10].

According to [7], four elements are related to congestion or indicate that a call could not be completed thus; (i) Traffic channels congestion (TCHC) (ii) Dedicated control channel congestion (DCHC) (iii) Common control channels congestion (CCCHC) (iv) Pulse code modulation congestion (PCMC). Other factors that could lead to congestion are: (v) Inadequate radio channels and infrastructure to support the vast number of subscribers on the network. (vi) Redialling of subscribers when they experience blocking. (vii) Too many users on the network. (viii) Marketing strategies and pricing schemes also affect traffic behaviour since this would have increased the number of subscribers on the network (ix) Use of the old equipment facilities instead of new ones.

Network congestion in voice communication and signal quality degradation are the major problems of the Global System for Mobile Communication (GSM) most especially as customer increases. These are issues that constantly and continuously demand further researches to improve network performance [8]. Network congestion is one of the major problems of GSM service providers as the number of subscribers increase and new services are introduced. All the proposed techniques in literatures for controlling congestion are centered on two principles which are either to reject excessive traffic to prevent over-utilization of network resources or diverting excess load if overload occurs. These techniques do not specify how network resource can be provided to absorb rejected or diverted traffic so that revenue will not be lost during congestion and hence, they do not really address congestion during busy hour [3]. Congestion control refers to the set of actions taken by the network to minimize the intensity, spread, and duration of congestion. It can be said that it is that aspect of a networking protocol that defines how the network deals with congestion [14].

[7], presented some optimization models that can be applied to minimize the problem of congestion on the GSM network in Nigeria. These models are: government and corporate organizations in partnership with GSM operators use of dynamic half rate decoder, national roaming agreement, regionalization and merging GSM networks. [8], proposed a model which focuses on how the voice calls can be managed on the network in order to minimized congestion experienced on the network. It classified calls into different classes according to the type and nature of services offered and they are: special voice (Sv), handoff voice (Hv), retrial voice (Rv) and new voice (Nv). This model was to manage the different calls based on their priority in order to reduce congestion on the GSM network. The implementation of the proposed model was done using C# programming language and the snapshots of the interfaces of the system implementation were analyzed. [9], developed a Combined Model for managing congestion in GSM network based on Call Priority, Handoff Call Buffer and Frequently Recent Call concepts. Based on this Combined model, the performance of the GSM network is extensively evaluated using the key performance indicators which include; Call Set-up Success Rate (CSSR), Call Drop Rate (CDR), Call Completion Success Rate (CCSR) and Traffic Channel Congestion Rate (TCHCR). A comparison of the performance of this Combined Model with the existing system based on mobile cellular network Key Parameter Indicators reveals that this model has an improved performance (Quality of Service) over the existing system.

Traditionally, the main players in the Nigeria telecommunications sector are the Federal Government of Nigeria (FGN), the Ministry of Communications and the telecommunications service providers. The FGN role in telecommunications in Nigeria has been very direct; owner and operator of the incumbent public telecommunications firm. This was shifted with the deregulation of the telecommunications sector in 1992 with the establishment of a regulatory body, the Nigerian Communication Commission (NCC). Since then, the NCC has been in control of telecommunications license issuing to private telephone operators which authorizes private telephone operators to roll out telephone services. This has led to the issuing of GSM licenses to the first set of GSM operators: MTN (Mobile Telecommunication of Nigeria), EWN (Econet Wireless Nigeria, which in 2004 changed to Vee Networks of Nigeria, Vmobile, and was acquired by Celtel in 2006, and currently acquired by Zain Nigeria) and M-Tel (Nigerian Mobile Telecommunications Limited, the mobile subsidiary of the National Carrier, Nigerian Telecommunications Plc, NITEL) in 2001 while Glo (Globacom Limited) joined in 2003[2].

Nigerian is the most populous in Africa with a population of 178.52 million people as at December 2014, according to Nigeria Bureau of Statistics, and the seventh largest in the world. Nigeria's teledensity was 99.39% as at 2014 [1, 12]. In 1960 teledensity ratio in Nigeria was of 0.04 telephones per 100 persons as a result of inadequate investment in the telecommunications industry. However, before 1996 Nigeria's teledensity ratio increased to a meagre 0.3 telephones per 100 persons; and with a slight to 0.4 by 1999 [1, 11]. The liberalization of the telecommunication industry in 2001 with the introduction of Global System for Mobile (GSM) was responsible for a significant teledensity ratio increment within a year of operation. As at 2006 Nigeria had nearly 34 million (33,858,022) connected lines and teledensity of 24.18 the country was one of the fastest growing GSM markets in the world [1]. Presently, the ratio stands at no less than 1:1 with attendant implications of network congestion. Congestion is a serious challenge to most GSM network service providers because it negatively impacts on service level agreement since calls cannot be made or received in areas with no/weak network signals [1].

The power of a receiver or transmitted signal from an antenna or mast is based on the coulomb's law. Coulomb's law states that "the force between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them". That means, the power of the receiver signal p_r is the reciprocal of the square distance from the closest antenna [13].

In this research work, we applied second order necessary condition (a mathematical optimization technique) to establish a free flow of connection between mobile phone users at different locations thereby solving the problem of network congestion. Mobile Telecommunication of Nigeria (MTN), one of the GSM providers in Nigeria was used to demonstrate the usefulness of second order necessary condition in solving network congestion in Michael Okpara University of Agriculture, Umudike (MOUAU). Both the telecommunication network providers and the users can only gain in efficiency and usability if we provide them with the most efficient algorithmic solutions to network congestion.

2. Material and Methods

Study location and data description

This research was conducted in Michael Okpara University of Agriculture, Umudike, Abia State, using the MTN telecommunication network mast located at World Bank Estate beside Winner's Lodge in Umuahia, Abia State, Nigeria, which gives coverage to Michael Okpara University of Agriculture (MOUAU). Every cellular base station is assigned a group of radio channels which are used within a small geographical area. Furthermore, in adjacent cell, the base stations are allocated those channel groups which contains completely the same channel of the neighbouring base station.

Data were given by MTN Telecommunication Nigeria. A mobile user is located at a position between two base station antenna (mast); one for primary base station and other for the neighbouring base station, as shown in Figure 1.

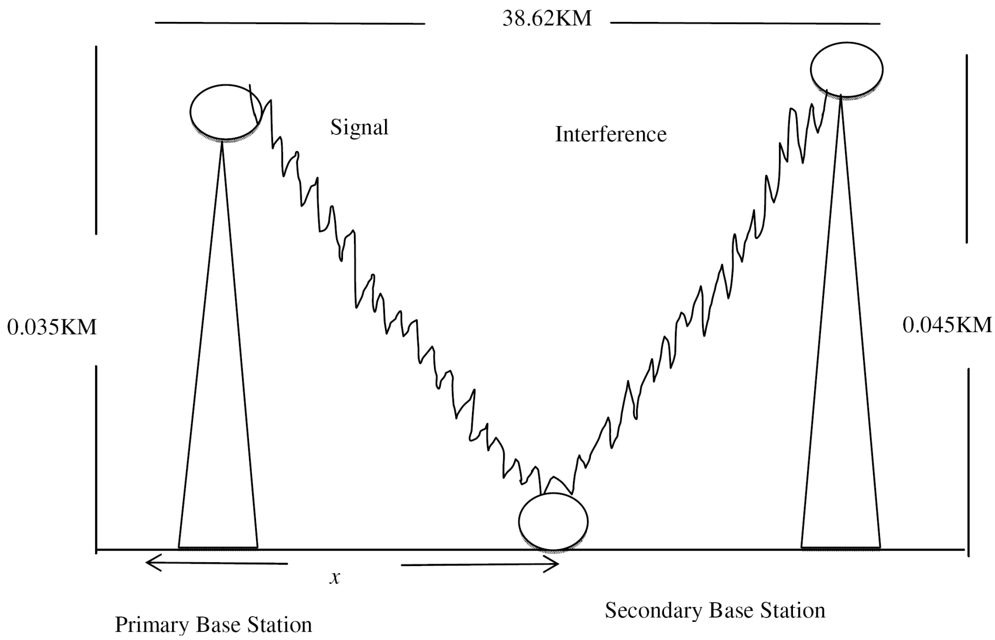

Figure 1. Showing primary and secondary base stations with their heights and distance between them.

However the mast ID STLMTN4542 located at World Bank estate beside Winner's lodge in the city of Umuahia, Abia State, Nigeria in (latitude of 5.5117 and longitude of 7.5304423) considered the primary base station and with height of 35 m. The mast has a site ID of STLMTN1203 and it belongs to MTN Nigeria located in Abia South in the city of ABA, Abia state, South-East Nigeria, in longitude 7.349 and latitude 5.14 and mast height of 45 m and is considered the secondary base station. However the distance between the two masts is 38620 m. Converting the measurement taken in meters to kilometres to reduces any analytical error we have them summarized as;

Primary base station height = 0.045km

Secondary base station height = 0.035km

Distance between Primary base and Secondary base = 38.62km

Let h be the height of the antenna of both the primary base station (PBS) and neighbouring base station (NBS). Let d be the distance between the two difference antennas. Let x be the square distance of the mobile user to the primary base station antenna. Then the square distance from the mobile user to the primary antenna is thus; $h^2 + x^2$.

While the squared distance from the mobile user to the neighbour antenna would be $h^2 + (d - x)^2$.

Then the signal-to-interference ratio R, is a function $F(x)$ of the variables x, h, d. Since the signal-to-interference ratio is the ratio of the received signal power from the Primary Base Station, to they received signals power from the neighbouring Base Station, we have $R = F(x, h, d) = \dfrac{h^2 + x^2}{h^2 + (d - x)^2}$.

Mathematical Optimization Technique: The second order necessary condition which states that if $\nabla^2 f(x)$ is continuous in an open neighborhood of x^* and $\nabla f(x) = 0$ and $\nabla^2 f(x^*)$ is negative definite, then x^* is the maximum point of *f*. For $\nabla^2 f(x)$ to be negative definite it means that $S^T \nabla^2 f(x) S \leq 0, \forall S \in \mathbb{R}^n, S \neq 0$.

The problem we need to solve is, Maximize $F(x, h, d)$

Differentiating with respect to x we have

$$f' = \frac{D(h^2 + x^2)(h^2 + (d - x)^2) - (h^2 + x^2) D(h^2 + (d - x)^2)}{(h^2 + (d - x)^2)^2}$$

$$\Rightarrow f' = \frac{2x(h^2 + (d - x)^2 - 2(d - x)(h^2 + x^2)}{(h^2 + (d - x)^2)^2}$$

$$\Rightarrow f' = \frac{2xd^2 - 6dx^2 + 2xh^2 + 4x^2}{(h^2 + d^2 - 2xd + x^2)^2}.$$

From the second order necessary condition, we equate $\nabla f(x) = 0$, i.e., $f' = 0$.

To get $\nabla^2 f(x^*)$ we differentiate $R = F(x, h, d) = \dfrac{h^2 + x^2}{h^2 + (d - x)^2}$ twice.

To get the second derivative, we have initially that

$$f' = \frac{2xd^2 - 6dx^2 + 2xh^2 + 4x^2}{(h^2 + d^2 - 2xd + x^2)^2}$$

$$f'' = \frac{2d^2 - 12xd + 2h^2 + 12x^2}{(h^2 + d^2 - 2xd + x^2)^2} - \frac{4xd^2 - 12dx^2 + 4xh^2 + 8x^3}{(h^2 + d^2 - 2xd + x^2)^3(-2d + 2x)} = 0$$

$$\Rightarrow 2xd^2 - 6dx^2 + 2xh^2 + 4x^2 = \frac{4xd^2 - 12dx^2 d + 4xh^2 + 8x^3}{(h^2 + d^2 - 2xd + x^2)(-2d + 2x)}$$

$$\Rightarrow \frac{2xd^2 - 6dx^2 + 2xh^2 + 4x^2}{1} = \frac{4xd^2 - 12dx^2 d + 4xh^2 + 8x^3}{(2dh^2 + 2d^3 + 2xh^2 + 2x^3)}.$$

Fixing in our value, we have that

$$d = 38.62,$$

$$h = 0.035.$$

Simplifying, we have

$$12x^2 - 464.4x + 2983 = \frac{463.44x^2 - 5966x + 8x^3}{(2x^3 + 0.0024x + 57602)}.$$

We cross multiply

$$(12x^2 - 464.4x + 2983)(2x^3 + 0.0024x + 57602) = 463.44x^2 - 5966x + 8x^3$$

$$\Rightarrow \quad 24x^5 - 10194.8x^4 + 5966x^3 + 0.0288x^2 + 26621175x + 171826766$$

$$= 463.44x^2 - 5966x + 8x^3$$

$$\Rightarrow \quad 24x^5 - 10194.8x^4 + 5966x^3 + 0.0288x^2 + 26621175x$$

$$+ 171826766 - 463.44x^2 + 5966x - 8x^3 = 0$$

$$\Rightarrow \quad 24x^5 - 10194.86x^4 + 5958x^3 + 68657.56x^2 - 19209x - 171826766 = 0.$$

Using MATLAB we obtain the following as the root of the polynomial equation

$$x_1 = -11.32536$$

$$x_2 = 11.77983$$

$$x_3 = 424.19032$$

$$x_4 = 0.07343 + 11.24746i$$

$$x_5 = 0.07343 - 11.24746i.$$

The result comprises of both real value and complex values. However the complex numbers shows that at the point $x_4 = 0.07343 + 11.24746i$ and $x_5 = 0.07343 - 11.24746i$ network is not guaranteed, while the positive values at the point of x, i.e., $(x_2 = 11.77983 \quad x_3 = 424.19032)$ shows that network is guaranteed. The negative value $x_1 = -11.32536$ shows that the signal comes and goes back.

3. Discussion

We observed that from the problem formulated, based on the result obtained from the mast ID STLMTN4542 located at World Bank estates beside Winner's lodge in the city of Umuahia, Abia State covering Michael Okpara University of Agriculture, Umudike premises which is considered as primary Base Station and the second mast site ID STLMTN1203 located in Abia South in the city of ABA, Abia State, Nigeria, considered as the secondary base station, it showed that: A mobile wireless user is approximately 11.77983 and 424.19032 km away from the primary base station so as to overcome the interference that is coming from any neighbouring base station thereby having good reception of signals.

Based on our result obtained, not at all points the mast covering MOUAU distribute signal. However our results showed that at only the range 11.77983 and 424.19032 km can interference be by passed and in terms of congestion this range would encounter interference if the number of wireless users within the school environment becomes crowded. From the problem formulation, we observed that with a signal high power transmitter (mast), all users shared the same set of frequencies. Due to this the system capacity, in term of maximum number of users that can be supported, offered by this single high power transmitter would hit a limit. The geographical region in which Michael Okpara University is located, uses the same set of frequencies, and because of ongoing development and increased capacity of users, the power level of signal that spills out from one region to a neighboring region hits interference.

4. Conclusion

We have observed how the position of mobile users and proximity of two same telecommunication service provider transmitters (masts) affects good reception to a mobile user. Also from our research the height of a mast is a major factor limiting clear signal from users. We also observed that the mast is located in a rural area, and the height of the mast entails that the tendency of development getting to that geographical zone was not considered before the consideration of the particular height installation of the primary base station mast. Furthermore mathematical concept such as the second order necessary condition (SONC) in optimization theory is a helpful tool in solving telecommunication problem in terms of radio signal free flow not hitting interference.

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