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Technical Challenges of Tower Sharing in Multi-Operator Mobile Communication Environments

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ABSTRACT

The traditional mobile communications business model was based on full ownership of network infrastructure. However, network infrastructure sharing has been a trend among mobile network operators. Sharing traditional mobile network infrastructure which were not designed originally for sharing has become prevalent in the face of stiff competition, regulatory requirement and declining revenues. This, despite the reduction in capital expenditure for operators, brings technical challenges with regards to network planning, optimization and expansion in multi-operator shared environments. This paper briefly introduces models of passive infrastructure sharing and their advantages, and investigates the technical challenges which are inherent to communications tower sharing. The effects of non-optimal antenna height on coverage and signal quality, as well as those of tower loading constraints on transmission link quality are investigated among others. Simulation results and on-site measurements confirm these challenges, which may increase the operation expenditure of mobile networks.Our findings challenge the current perception in both academia and industry that passive infrastructure sharing can only produce positive effects, and therefore call for further investigations on the financial benefits of infrastructure sharing.

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1. INTRODUCTION

Wireless communications services have recorded tremendous growth and this hinges on available supporting network infrastructure. The cost of deploying, managing and maintaining network infrastructure is driving the need for innovative models of infrastructure deployment and management within the wireless environment. From the initial full ownership of network infrastructure model, network operators are adopting models of sharing network infrastructure triggered mainly by rapid technological change, fulfillment of regulatory mandates and other constraints.

Mobile network operators' strategy is therefore focused on cost saving activities while maintaining efficient and quality network services. Outsourcing of operations has been a common practice in the mobile communication industry [1]. However, the focus has recently been on sharing network resources for the common benefit of all in a multiple operator environment. To this effect, various models of resource sharing have emerged [2]. These models range from sharing passive infrastructure such as tower, site, trench, power and other "non-intelligent" portions of the mobile network [3], to sharing network resources such as spectrum, the radio access network, the switching centres and others. This latter form of sharing is qualified as active and requires the design of sophisticated algorithms and more "intelligent" forms of collaboration between networks [4]. Due to the actual complexity of active network sharing, players in the telecom industry, academia, as well as regulators have been advocating and encouraging passive infrastructure sharing which presents more practical implementation advantages over the active sharing of resources [4].

Although, a number of publications from both industry and academia on the subject of sharing has been found to be very relevant to the discussion on sharing, much more is required as most of the available researches focus on economical and regulatory aspects of sharing. To this effect, [5] focuses on the economics of sharing with empirical evidence on cost saving. Similarly, [6] discussed applicable models of sharing, from the regulatory and vendor perspective without any technical considerations. [7] performed an investigative dive into various sharing models from the technical and economic perspective. It further introduces saving models in capital expenditure (Capex) and operation expenditures (Opex). Generally, industry experts have focus attention on the strategic issues as far as competition and cost reduction are concerned, and statements to this effect have dominated the argument for sharing, regardless of the technical challenges. Vendors' perspective focuses on economic benefits derived from sharing but failed to quantify economic implications of unsuccessful sharing ([8] and [9]). Even though the authors in [9] approached the issue in a more futuristic manner, questioning how shared networks would be managed, funded and optimized, the potential technical challenges were not sufficiently analysed. Contributions from industry regulators, typically focus on best practices across the world ([10]). [11] is a competition and control oriented paper which attempted to evaluate the control levels of shared parties. Contribution from Mobile network operators also mainly focuses on strategic and economic benefit at the neglect of the technical and managerial challenges that sharing introduces [12]. Even though [13] proposed the formation of centralized GIS data base aimed at improving the process flow for network resources sharing, it focuses on information sharing rather than challenges associated with tower sharing. [14], condidered infrastructuring in cloud computing context and does not address issues with tower sharing.

It can be seen that despite the wide acceptance enjoyed by passive infrastructure sharing, proper literature does not exist which treats potential technical difficulties inherent to this "cost-saving" practice. In light of this, it has become important to investigate the technical challenges associated with sharing towers, which is the aim of this article. The paper highlights issues and factors to be considered by operators in choosing a shared model in order to maximize profit. Simulation and on-site testing are used to expose the technical constraints in sharing passive infrastructure sharing, with a focus on tower sharing. The perceived advantages of the implementation of tower sharing are described through the results of questionnaires distributed to industry players. The impact of non-optimal base station antenna height on cell coverage and quality of service (QoS) is evaluated. Results of drive tests in GSM cells are presented. Transmission network resilience in a tower sharing context is also tested in different microwave antenna size scenarios. Additionally, the impacts of the size of microwave antennae and tower loading constraints on the quality of the microwave transmission links are simulated.

This article contains five sections. After this introductory section, section two describes tower sharing and its inherent opportunities. It also discusses the technical challenges associated with tower sharing. Section three presents the research method by describing tests and simulation environments and conditions. Simulation and test results are presented, analysed and discussed in section four, while a conclusion is drawn in section five.

2. OPPORTUNITIES AND TECHNICAL CHALLENGES OF TOWER SHARING

Sharing communication Tower is one area where mobile network operators have collaborated effectively, due to the relatively high capital investment involved in building individual towers. Tower sharing means common usage of space on a tower. Multiple operators can install their base station antennae and microwave link antennae at different locations on a single tower. The success of this form of sharing is not a consequence of the capital expenditure (Capex) saving opportunity it offers to operators alone. It is also a result of public agitation over the proliferation of communication towers in major cities, as it reduces the number of telecommunication towers needed.

2.1. Opportunities of Tower Sharing

Figure 1, borrowed from [15], depicts the result of a survey conducted among the mobile telecom players in the Republic of Ghana. It shows that tower sharing is perceived to be a solution to almost all the technical and financial issue in deploying and maintaining mobile networks.

Expenditures in the telecom industry are largely dominated by considerable investment in technology and infrastructure deployment. The consideration is further heightened by continuous need to upgrade such infrastructures amidst new technologies. Passive infrastructure sharing reduces these expenditures by spreading the investment among multiple players. Furthermore, cell sites which were considered as low revenue sites have suddenly become profitable due to revenue generated from co-location with a third party. [16] and [17] give a more detailed treatment to financial opportunities associated with passive infrastructure sharing.

In a telecom environment where coverage obligations are part of licensing contract between governments and network operators, sharing has become an attractive option to meet those obligations. Coverage is extended by using towers built by another operator or a third party. QoS is therefore improved in those areas. Furthermore, entry barriers for potential new entrants in the market will be significantly lowered, hence, making the telecoms market more attractive to new investors. Infrastructure sharing will also facilitate operators' migration from infrastructure-driven networks to service-based networks with emphasis on constant innovations and improved customer satisfaction.

These advantages, perceived or real, should not overshadow various challenges associated with tower sharing, as discussed next.

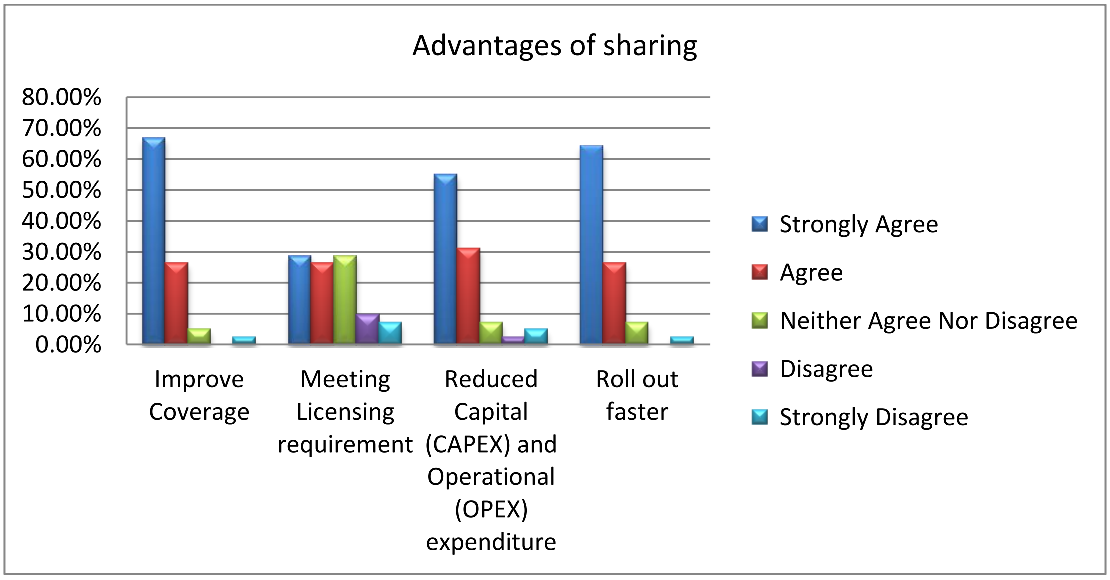

Figure 1. Perceived advantages of tower sharing (from [15])

2.2. Challenges of Tower Sharing

Although it is possible for two networks to coexist, sharing welcomes into the network architecture a form of complexity with the risk of reducing system performance. These new technical threats, if not adequately evaluated, would significantly erode perceived gains inherent to tower sharing. As an example, inappropriate antenna height, as a result of tower sharing, could be a potential threat to meeting QoS obligations. In this section, potential challenges of tower sharing are discussed.

2.2.1. Received Power and Coverage as a Function of Antenna Height

The power a base station is set to radiate depends on the desired received power at the cell boundary, which in turn is related to the height of the transmitting antenna. This is shown by the following propagation models generally used in the design and optimization of cellular networks ([18]).

For operation frequencies in the range 150MHz to 1920MHz (which is the case for most cellular systems),the median value of the propagation path loss is expressed as

$$L_{50}(dB) = L_F + A_{mu}\left(f,d\right) - G\left(h_{te}\right) - G(h_{re}) - G_{AREA} \qquad (1)$$

where the constant L_F is the free space propagation loss. $A_{mu}\left(f,d\right)$ is the median attenuation relative to free space and depends only on the distance d between the transmitter and the receiver, and the frequency *f*. $G\left(h_{te}\right)$ and $G(h_{re})$ are the base station antenna gain factor and the mobile station antenna height gain factor, respectively. Note that h_{te} and h_{re} are the antenna heights at the base station and the mobile station, respectively.

$$G\left(h_{te}\right)=20\log\left(\frac{h_{te}}{200}\right), 1000m>h_{te}>30m \tag{2}$$

$$G\left(h_{re}\right)=\begin{cases}10\log\left(\dfrac{h_{re}}{3}\right), h_{re}\leq 3m\\ 20\log\left(\dfrac{h_{re}}{3}\right), 10m>h_{re}>3m\end{cases} \tag{3}$$

Finally, G_{AREA} is a correction factor depending on the environment type

For urban and suburban areas with operation frequency f_c in the range 1500 MHz to 2000MHz, the median path loss is

$$L_{50}(urban)=46.3+33.9\log f_c-13.82\log h_{te}-a(h_{re})+(44.9-6.55\log h_{te})\log d+C_M \tag{4}$$

C_M (0dB or 3dB) depends on the area type, h_{te} is between 30m and 200m, h_{re} between 1m and 10m, while d lays between 1km and 20km.

Equations (1) to (4) clearly illustrate the dependency of the path loss (therefore of the received power) on the height at which the transmitting base station antenna is located, which in turn determines the coverage area of a cell. It follows that for an optimum coverage, the base station antenna has to be optimally located on the tower. However, variations in antenna height beyond or below the optimal height will cause some locations within the cell to have received power below threshold, while other locations will have received power unnecessarily exceeding the prescribed requirements. These variations in power indicate the challenges antenna height variations poses in cellular system design, because they affect cell coverage and other QoS requirements. Achieving optimum required height for all operators on a shared tower remains a major challenge, if not impossible, in a shared environment, as shown by test and simulation results in the next section of this paper.

2.2.2. Tower Overload and Incompatibility to Sharing

Towers are usually designed with specified permissible loading. In many instances, antennas are placed at a height that does not match specifications. Tower loading covers anything added to the tower, initially or later, that will be exposed to the wind. A critical look at tower loading in an era of sharing passive network infrastructure has become very important. Due to the fact that most existing towers were designed for a single operator, they are incompatible to sharing. Any attempt to share them may result in disastrous safety hazards to people living near these towers.

2.2.3. Inadequate Microwave Link Quality

Tower overload or its avoidance introduces complexity into microwave link design and quality. It is obvious that compromising on optimal microwave antenna size and/or height to prevent overloading affects the quality of the links. Results in the next sections illustrate this fact.

2.2.4. Limited Design Diversity

The implantation of a mobile communication tower is preceded by studies to determine its optimum location, in order to maximize coverage and signal quality across the cell. Any failure in locating this optimum position, or a failure to acquire it would imply a non-optimal network design. Sharing towers therefore replicates traditional failures (i.e. tower location) of existing networks onto the new networks, as diversity of design is limited. This is another technical challenge that can jeopardize the optimization of newly deployed networks.

3. RESEARCH METHOD

To illustrate the technical challenges mentioned in this paper, *Mentum Planet* software was used to run simulations and on-site drive tests were also performed. Simulations were conducted under realistic suburban (Kumasi, Ghana) and rural (Wa, Ghana) environments for GSM (900MHz and 1800MHz). The transmit antennas have a gain of 17dBi. Antenna height and other system configurations are shown in Table 1. Signal strength is measured under each condition and coverage maps are drawn. To show the effect of tower loading constraints on backbone microwave links, a 60-meter backbone tower is considered and is expected to host three operators. Due to constraints imposed by the size, the weight, and the height occupied on the tower by the first two operators'microwave antennae, the third operator is expected to be hosted at a height not more than 25m to installed both GSM and Microwave antenna. Due to weight constraints (to prevent overloading), the originally designed antenna size is altered (reduced) at the implementation phase. The original (planned) parameters and the actually implemented (due to weight constraints) parameters are shown in Table 2.

Table 1. Coverage simulation and test parameters

Site Name	Antenna Type	Longitude	Latitude	Height(m)	Azimuth	Tilt	Terrain Height(m)
Wa	730378	2.6489W	10.2117N	20 50	0, 120, and 240	0 and 4	180.81
Kumasi		1.6221W	6.6252N	20 35	0, 120, and 240	0 and 4	225.02

Table 2. Microwave link simulation parameters

Parameter	Unit	Value (planned)	Value (implemented)
Antenna Diameter	m	1.8	1.2
Rain Region		ITU Region P	ITU Region P
Polarisation		Vertical	Vertical
Antenna Model		ML 6/1 1.8m HP	ML 6/1 1.2m HP
Antenna Height	m	25	25

4. RESULTS AND ANALYSIS

This section presents the simulation and test results, along with their analysis.

4.1 Coverage and QoS

Figure 1 and Figure 2 show coverage results for Wa and Kumassi (Ghana), respectively. It can be seen from both figures that operators that will be forced to occupy lower and non-optimum positions on the shared tower will have a serious coverage disadvantage over their competitors. This is true for both sub-urban and rural areas. Planning and optimization engineers of disadvantaged operator will face a serious challenge, as they may not be able to achieve the same coverage, therefore the same QoS as the others. In those conditions, it will be very difficult, if not impossible, to find any optimization technique that can achieve optimal coverage and signal strength without further investments in hardware. This seriously reduces, if not annihilates the main financial advantage of tower sharing, namely Capex reduction. Furthermore, bad QoS will prompt many users to switch to other operators for a better service. This will result in income lost for the disadvantaged (incoming) operator. This will betray another goal of infrastructure sharing, which is the ease for new operators to penetrate the market.

4.2 Limitations of Antenna Tilting

Antenna tilting plays an important role in cell coverage optimization and might be intuitively considered as a solution to coverage issues described above. However, tiltling efficiency is dependent on the height of the antenna. Applying down-tilt (Mechanical or Electrical) to an antenna with height limitation restricts cell coverage to a relatively smaller geographical area, resulting in cell been classified as low revenue cell. At the contrary, up-tilting an antenna usually throws the signal beyond the desire coverage area, resulting in interference to other cells and hence to signal quality degradation. Excessive up-tilting would also cause outages in areas close to the antenna. Antenna tilting therefore cannot be used as a solution to the challenges resulting from non-optimum antenna height.

4.2 Microwave Link quality

Towers also host microwave antennas for backbone connections. To avoid overloading, restrictions may be put on the weight (diameter) of the "incoming" antennas. Table 2 shows a scenario where planned antenna diameter of 1.8m is replaced with antennas of 1.2m diameter (lower antenna gain). Figure 3 shows the simulation results. At the transmitting side, a drop of 3.5dBm in the equivalent isotropic radiated power (EIRP) can be observed. The smaller antenna gain in the implemented setup is a direct result of the smaller antenna size, as the antenna type is identical for both cases. The free space pathloss being dependent only on the distance between the transmitter and the receiver and the frequency of operation, this parameter is identical for both scenarios. At the receiving side, a 7dBm reduction in received signal strength is observed. Weaker received signal leads to a lower signal-to-noise ratio, therefore to a lower microwave capacity according to Shanoon capacity formula. This limited capacity of the microwave backbone link for the last operator underlines another technical drawback of tower sharing.

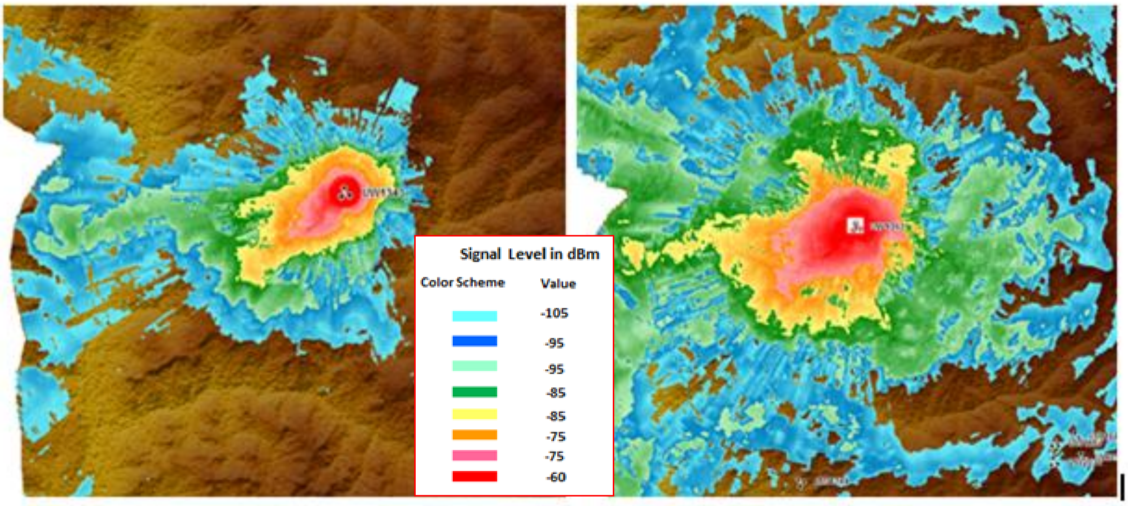

Figure 1. Coverage for Wa: (a) 20m antenna height. (b) 50m antenna height

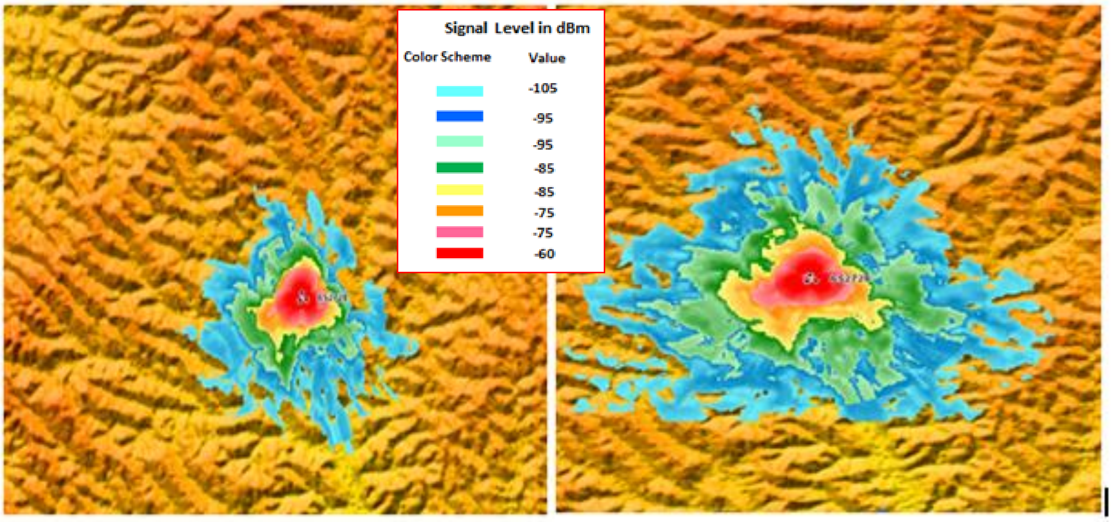

Figure 2. Coverage for Kumasi: (a) 20m antenna height. (b) 50m antenna height

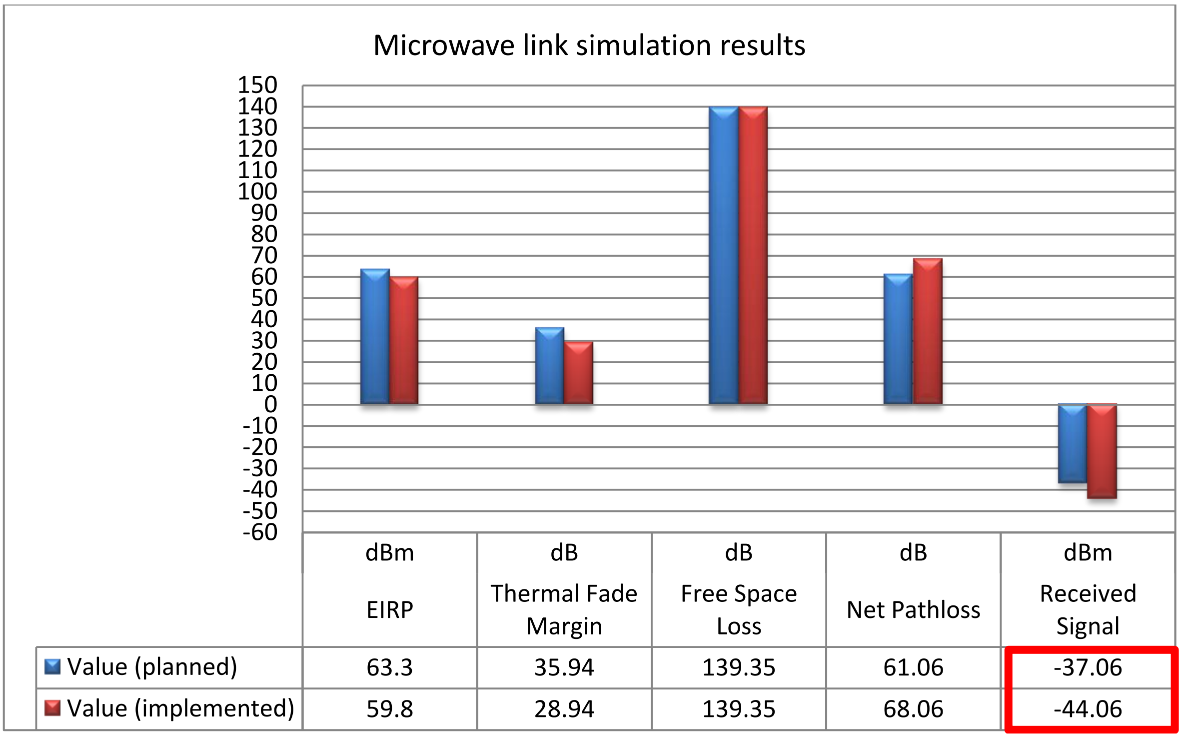

Figure 3. Microwave link simulation results

5. Conclusion

In sum, this paper presented the perceived advantages of sharing mobile communication towers. It also identified potential technical challenges that may override the actual effects of these advantages. Simulation and measurement results showed that constraints on tower loading and non-optimal antenna height negatively impact cell coverage, signal strength, QoS achievement, and backbone microwave links. These adverse effects will undeniably result in income reduction for some operators. What could be the extent of this reduction, and, could it overshadow the Capex and Opex reduction which are inherent to infrastructure sharing? If yes, what threshold should operators be considering in deciding whether to use existing towers or not? For tower sharing companies, what pricing model should be applied in order to attract new operators? These questions and many others are to be addressed if knowledgeable decisions are to be made on tower and other infrastructure sharing.

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