Toward Efficient Resource Utilizations in Wireless Cellular Networks: A Case Study of Tanzania

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ABSTRACT
The growth of wireless cellular network industry coupled with higher demands for data rates and proliferation of multimedia applications cause traffic congestions in wireless cellular networks during busy hour periods. This brings challenges to network optimizers and planners in ensuring better quality of services are guaranteed to subscribers at affordable costs. Network throughput performance requires efficient utilization of resources which are scarce and expensive. Repeated radio frequency reuse, cell splitting and sectoring, overlay and underlay of cells and dynamic spectrum allocation tends to over dimension network resources. Spatial and temporal wireless cellular network traffic variations coupled with mobility of subscribers add another dimension to the challenge as network resources are underutilized when traffic load is low. In this work, a generic model that optimizes network resource utilization in connection oriented wireless cellular networks is formulated. The model takes into account the aspects of efficient resource utilization, operation expenses (OPEX) of the network operator and quality of services offered to subscribers.

Keywords - Network resource utilization; Wireless cellular networks; Quality of service; CAPEX; OPEX; Generic model.

1. INTRODUCTION
The use of cellular network services is growing fast coupled with high data rates and demand for more bandwidth due to the shift to multimedia applications. The global mobile cellular subscription stands at 6.8 billion users in 2013 with global penetration rate of 96%. 128% penetration rate in developed world and 89% in developing countries [1]. In Tanzania, mobile cellular subscriptions reached 27.4 million in March 2012 with a penetration rate of 61% [2]. The proliferation of the use of smart phones and tablet PCs that supports high data rates together with the needs for new services like video conferences, e-learning, e-commerce, e-government and telemedicine doubtless accelerates and creates new traffic demand [3], [4], [5], hence requiring more network resources. These resources include RF spectrum (RF traffic channels), radio transceivers, power supply, processing power, and infrastructure. The current wireless cellular industry growth trend demands for efficient allocation of network resources [6] to reduce the capital expenditure (CAPEX) and operation expenses (OPEX) of wireless cellular network operators while guaranteeing best quality of service to end users at affordable costs. In particular utilization and efficiency of radio frequency spectrum depends on the level of frequency reuse, cell splitting and sectoring, and overlay/underlay of cells which tends to over dimension the network resulting into underutilization when traffic loads are low. Wireless cellular networks have mixtures of macro, micro, pico and femto cells. Regardless of the low costs required to acquire and deploy a femto cell, interaction between macro and femto subscribers requires control to reduce interferences [7].

Efficient resource utilization in wireless cellular networks is complicated because of heterogeneity nature of traffic loading over time and place [8]. Wireless cellular network traffic variations result into inefficient radio frequency spectrum utilization that fluctuates between 15% to 85% in the band below 3 GHz [9]. To exploit such differences in traffic loadings, resource sharing between operators is proposed in [8], [5] & [10] where efficient utilizations is achieved and temporary lack of resources may be avoided depending on the mode of sharing. Physical resource
sharing between wireless network operators and service providers is necessary in order to support efficient, competitive, and innovative wireless communication markets [11]. In wireless cellular networks, sharing can occur at various levels and there could be various combinations including sharing of base station sites, radio transceivers, power supply, cooling equipment, antenna feeder cables, antennas, tower masts, and many more. However, many wireless cellular operators carry out passive sharing only that involves base station locations, buildings and tower masts [12]. Enhanced network resource sharing offers cost savings to network operators following reduction of rollout of new sites, capital expenditures (CAPEX) and operational expenses (OPEX). The radio access part of the wireless cellular network is a major energy killer, accounting for up to more than 70% of the total energy bill for a number of mobile operators [3]. Therefore, optimizing power utilization in wireless cellular networks as a whole will provides valuable means for network operators and enhances efficiency to other resources.

Despite the significance of resource utilization in wireless cellular networks, there is no related work done in Tanzania, thus the necessity of carrying out this study. In this work, we formulate a generic model that takes as inputs the level of available network resources, current network utilization status, interference and quality of service requirements to adjust the system parameters keeping network operation costs low and assuring quality of service to end users. The rest of the paper is organized as follows; section II presents the state of the art of resource utilization in wireless cellular networks in Tanzania, section III presents the system model and the proposed algorithm, section IV concludes our work paving directions for further research.

2. STATE OF THE ART

Understanding the current resource utilization for a particular wireless cellular network is an essential step before starting optimizing it. Surveys were conducted on wireless cellular network operators, characterizing and identifying the status of resource utilizations for each network. Drive tests were done in selected townships to observe the quality of service and experience from the subscriber perspectives. In this section we present the state of the art of resource utilizations and the quality of service experienced by subscribers.

2.1 Radio Frequency Spectrum Utilizations

Wireless cellular networks are regulated by fixed spectrum assignment policies [13]. The radio frequency spectrum is divided into a set of disjoint blocks, which are assigned to different individual wireless cellular network operators on long term basis. In Tanzania, seven companies are licensed to offer wireless cellular network services with either GSM or CDMA technology[2]. The exclusive use of radio frequency spectrum has left some of parts of the country with over utilization of radio frequency traffic channels while other places are underutilizing the networks. Our survey on wireless cellular networks revealed traffic utilization varying in the range of 5% to above 200%. Table 1 presents radio frequency channel utilization per cell extracted randomly from selected sites of one operator in Dar es Salaam, Tanzania. This indicates the possibility of poor quality of service and loss of network revenues as when utilization is above 100%, the network cannot handle all incoming traffic load. As the number of call block and drop rates increase, subscribers are dissatisfied. Cells with high radio frequency utilization require network optimizations using cell splitting, sectoring, underlay or reduction of reuse distance approach. Applications of these approaches do not completely address the problem as traffic load varies with space and time. Thus, networks are over dimensioned.

Table 1: Traffic channel utilizations per cell for selected sites in Dar es Salaam

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Average TCH utilization (%)</th>
<th>Site No.</th>
<th>Average TCH utilization (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65.6</td>
<td>19</td>
<td>33.2</td>
</tr>
<tr>
<td>2</td>
<td>79.7</td>
<td>20</td>
<td>30.6</td>
</tr>
<tr>
<td>3</td>
<td>263.8</td>
<td>21</td>
<td>54.7</td>
</tr>
<tr>
<td>4</td>
<td>242.8</td>
<td>22</td>
<td>108.2</td>
</tr>
<tr>
<td>5</td>
<td>156.3</td>
<td>23</td>
<td>228.9</td>
</tr>
<tr>
<td>6</td>
<td>14.9</td>
<td>24</td>
<td>305.8</td>
</tr>
<tr>
<td>7</td>
<td>9.5</td>
<td>25</td>
<td>230.7</td>
</tr>
<tr>
<td>8</td>
<td>31.7</td>
<td>26</td>
<td>189.6</td>
</tr>
<tr>
<td>9</td>
<td>118.0</td>
<td>27</td>
<td>172.3</td>
</tr>
<tr>
<td>10</td>
<td>51.1</td>
<td>28</td>
<td>63.8</td>
</tr>
<tr>
<td>11</td>
<td>63.8</td>
<td>29</td>
<td>119.5</td>
</tr>
<tr>
<td>12</td>
<td>71.6</td>
<td>30</td>
<td>103.1</td>
</tr>
<tr>
<td>13</td>
<td>26.6</td>
<td>31</td>
<td>39.1</td>
</tr>
<tr>
<td>14</td>
<td>22.9</td>
<td>32</td>
<td>84.5</td>
</tr>
<tr>
<td>15</td>
<td>4.8</td>
<td>33</td>
<td>50.2</td>
</tr>
<tr>
<td>16</td>
<td>23.5</td>
<td>34</td>
<td>50.6</td>
</tr>
<tr>
<td>17</td>
<td>110.0</td>
<td>35</td>
<td>143.3</td>
</tr>
<tr>
<td>18</td>
<td>135.5</td>
<td>36</td>
<td>26.8</td>
</tr>
</tbody>
</table>

2.2 Infrastructure

Each of the wireless cellular network operators deploy and maintain networks with different resources including tower masts, power supply and backups, antenna and feeder cables, and transmission backhauls (Microwave links and Optic fibers). Fig. 1 presents the GSM network architecture [14], [15]. Despite the similarities in the network technology, each operator operates an exclusive
set of network resources. This keeps both CAPEX and OPEX high preventing more network service penetration.

![GSM Network architecture](image)

Figure 1: GSM Network architecture

Few scenarios that are based on passive sharing are implemented particularly sharing site locations, tower masts and buildings. One operator has domestic roaming agreement with well established operators. This assists in improving the network coverage for the new operator.

### 2.3 Power Supply

A large part of the networks especially that resides in the rural areas do not have supply of electricity. In places where the supply of electricity is available, frequent power cut-off and rationing forces wireless cellular network operators to work with power backups mainly from generators and solar. As a result, the costs of access to wireless cellular services for both voice calls and data in Tanzania are still high. Lack of reliable power supply endangers the quality of services to subscribers.

### 2.4 Backhaul Transmission Capacity

Wireless cellular network operators own microwave backhauls for transmission of traffic to the mobile switching centers, which are allocated in Dar es Salaam. Optical fibers are deployed countrywide and are owned by different companies including Tanzania Telecommunication Company Ltd (TTCL), Vodacom (T) Ltd, Tanzania Railway Limited (TRL) and Tanzania Electric Supply Company Ltd (TANESCO). The exclusive use of these resources has until now left the efficacy of these capacities untapped despite the high capital expenditure and operation expenses. Each wireless cellular operator has a network of microwave links across the country. In some areas connections to fiber backbone are prevented by poor infrastructure and site remoteness.

### 2.5 Network Configuration

Tanzanian towns and cities consist of mainly business centers and offices, thus, creating a traffic pattern which changes with high traffic during day periods and low traffic during night periods as subscribers move from town and city centres to residential houses. Traditionally radio frequency spectrum scarcity and capacity requirement have caused deployment of many pico and femto cells in cities like Dar es Salaam and Arusha. These cells are however underutilized during the night periods only consuming the expensive network resources like power supply and processing power. Furthermore, most rural areas have access to only single wireless network operator while the remaining network operators deploy their services only in towns avoiding the higher CAPEX and OPEX if their networks are expanded.

### 2.6 Quality of Experience

Four wireless cellular networks were sampled out through drive tests in Moshi town, Tanzania to test key performance indicators (KPIs) as experienced by subscribers in the GSM technology. Results reveal variations in signal coverage, service accessibility, number of call drops, number of blocks, call setup success rate, and handover success rates. In particular, the observed call block rates were in the range of 5.6% to 10.9% which is above the threshold recommended by the regulator of the Telecommunication sector. In Tanzania the threshold for the traffic channel call block rates is required not to exceed 2.0% while call drop rates are required not to exceed 3.0% [16]. Table 2 summarizes call block and drop rates from our drive tests.

<table>
<thead>
<tr>
<th>S/N.</th>
<th>Network Operator</th>
<th>Number of calls made</th>
<th>Call block rate (%)</th>
<th>Call drop rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Operator 1</td>
<td>165</td>
<td>10.9</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>Operator 2</td>
<td>152</td>
<td>10.5</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>Operator 3</td>
<td>162</td>
<td>5.6</td>
<td>3.1</td>
</tr>
<tr>
<td>4</td>
<td>Operator 4</td>
<td>175</td>
<td>6.9</td>
<td>2.3</td>
</tr>
</tbody>
</table>

### 3. SYSTEM MODEL

To ensure efficient resource utilization, we assume the existence of two wireless cellular networks both with similar access technology to allow resource sharing when such needs arise. Each operator is basically assigned with a certain amount of Absolute Radio Frequency Channel Numbers (ARFCNs) and has its own power supply and backups. Network operators use non co-located base stations with a full coverage in the area of study, therefore antenna for each network are mounted on separate towers. Fig.2. presents possible subscriber connections in a dual operator scenario with spectrum sharing. Mobile stations are randomly distributed in the area of study and are
randomly assigned to their home network from which they buy services regularly. Finally, we allow regular switch on and off of transceivers (TRXs) of base station based on network traffic load, level of interference and resource utilization status. When traffic load is low, few transceivers are switched on while traffic load is high all available transceivers are switched on. Once the traffic load is higher than the capacity of the network inter-operator radio frequency spectrum sharing is activated to exploit and utilize available traffic channels in other networks.

We use standard Poisson traffic model with pure chance traffic type I where call arrivals follows Poisson process with mean rate $\lambda$ and service times that exponentially distributed with mean service rate $\mu$.

Figure 2: An example of tower location in a dual operator scenario.

### 3.1 Scheduling Algorithm

In this paper, we assume a scheduler which is decentralized and works at the base station controller. The scheduler iterates through the base transceiver stations and accesses the resource utilization status, traffic load and interference level. In each case it allows switch off or on of radio transceivers, reduces or increases transmission power to serve operation costs while preserving the quality of service to subscribers. If traffic channels are not enough to serve all incoming traffic load, the scheduler searches for extra capacities from other wireless cellular operators available in the area, hence satisfying network users while network operators gain additional revenue. Fig. 3 presents the flow of activities in the scheduling algorithm.

Below is the proposed generic algorithm for the system model.

```vbnet
Private Sub Resource_Sharing_System() 
    Dim systemDemand, optimizationCheck, availableResourceCheck As Boolean 
    systemDemand = Stochastic_demand_Function() 
    While (systemDemand = True) 
        Call Arrival_Rate() 
        Call Service_Rate() 
        Resource_Utilization_Check() 
        optimizationCheck = Optimization_Check_Func() 
        If (optimizationCheck = True) Then 
            Adjust_System_Parameters() 
            availableResourceCheck = Available_Resources_Check_Func() 
            If (availableResourceCheck = False) Then 
                Initiate_Interoperator_Resource_Sharing() 
            End If 
        End If 
    End While 
End Sub
```

![Diagram of scheduling algorithm](image-url)
4. CONCLUSIONS

We have presented a generic model that optimizes network resource utilizations in wireless cellular networks. The model takes into account the traffic load, resource utilization status and quality of services offered to subscribers. The model allows network resource sharing both in the radio access and in the core network creating efficient resource utilization, efficient network operation and management, reduction of radiation levels, reduction of CAPEX and OPEX, and improvement of the quality of services. Performance evaluation of the model using simulations under different traffic loadings is required to validate its performance. We leave this as a direction for further research.

REFERENCES


