Cost Effective Coverage and Capacity Optimization in Wireless Cellular Networks

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***Abstract*—Coverage and capacity optimization of the fast growing wireless cellular networks is a tedious task and requires huge investment in network resources. Most techniques for coverage and capacity optimization result into increase in network complexity, radio frequency interferences, capital expenditure (CAPEX) and operational expenses (OPEX). The extensive growth of the wireless cellular industry, high penetration of wireless cellular networks and the need for low cost services to end users coupled with the proliferation of use of multimedia applications demands for other measures to optimize both coverage and capacity in wireless cellular networks. This work presents a cost effective coverage and capacity optimization method for wireless cellular networks that takes into account both CAPEX and OPEX considerations while ensuring guaranteed Quality of Services (QoS) to end users. The method allows incoming traffic overflows into neighbor network to utilize available coverage and capacity in those networks when there are inadequate resources in the home network. Performance evaluation of the formulated method using MATLAB simulations reveals significant improvement of Quality of Services offered to subscribers.**

Keywords—Optimization; Wireless Cellular Networks; Coverage and Capacity; CAPEX and OPEX

I. INTRODUCTION

The wireless cellular network services are growing fast and are coupled with an ever increasing high bit rates and multimedia applications that inevitably translate into demands for better coverage and capacity of the networks to guarantee Quality of Services (QoS) to end users. The global wireless cellular subscriptions stand at 6.8 billion users in 2013 with global penetration rate of 96%. 128% penetration rate in developed countries and 89% in the developing countries [1]. In Tanzania, the mobile cellular subscription reached 27.4 millions in December 2012 with a penetration rate of 61% [2]. Since the availability of radio bandwidth is limited, the available radio frequency (RF) spectrum has to be used efficiently and effectively to address its coverage and capacity needs. The tremendous growth of wireless cellular network services forces network operators to redesign and optimize their network from time to time in order to handle the ever increasing traffic demand while considering the possibility of reducing network deployment costs [3]. Wireless cellular operators face challenges to deliver services at low cost. Despite the industry competition, in Tanzania and African countries, service prices particularly interconnection prices are still high forcing subscribers to own between two to four subscriber identity module (SIM) cards. The high service prices are partly due to high operational expenses (OPEX) coupled with high capital expenditure (CAPEX) encountered when network operators address coverage and capacity problems.

Coverage and capacity optimizations are carried out through cell split and frequency reuse, overlapping of cell layers and dynamic channel allocation techniques [4]. To cater for subscriber demand, RF optimization must ensure minimum blocking/congestion over the air interface [5]. The use of spread spectrum and frequency reuse techniques derives the effectiveness of RF spectrum usage. However, even with higher level of frequency reuse, as with introduction of micro, pico and femto cells, at peak periods, network planners still face network congestions challenges. RF reuse takes place after a safe minimum distance to avoid co-channel interferences and where no two neighbor cells use the same adjacent frequencies to avoid adjacent channel interferences [6]. Cell splitting, overlay and underlay of cells require deployment of new sites, thereby requiring new radio frequencies and equipment for the new sites. The additional of new equipment and sites and radio frequencies tends to over dimension the network [7].

Network coverage differs from one operator to another following the failure of some operators to extend their coverage to rural areas in the pursuit of avoiding more CAPEX and OPEX. In Tanzania where power is erratic, wireless cellular network operators face power supply challenges characterized by frequent power rationing and cut-off. A large part of the network in rural areas runs with standby generators, thus raising OPEX and prices to end users. This has left some of the rural communities with access to single wireless cellular operator or marginalized. Furthermore, wireless cellular network radio resources demand differs significantly between peak and off-peak hours. A large portion of the allocated spectrum is used occasionally, with utilization varying in the range of 15% to 85% in the band below 3 GHz [8]. During peak hours and in highly congested areas, networks are overwhelmed by high volume of incoming traffic while at off peak periods networks are underutilized. Traffic exceeding the network capacity is usually blocked therefore loosing operators' revenue and customers' loyalty [9].

Variation of network coverage and capacity from one location to another and from one wireless network operator to another coupled with spatial and temporal variation of wireless cellular traffic calls for the need to look for other measures to optimize both coverage and capacity in wireless cellular networks. Continual use of frequency reuse, cell splitting, antenna down-tilting and up-tilting, and overlapping of cell layers becomes obsolete as CAPEX and OPEX are escalated resulting into high service prices to end users. In this paper we present a cost effective coverage and capacity optimization method for connection oriented wireless cellular networks that takes into account the capital expenditure and operation expenses while guaranteeing higher quality of services to end users. In section II, we present the state of the art of coverage and capacity optimization in wireless cellular networks. In section III, we present the Network model and assumptions for the cost effective coverage and capacity optimization. In section IV we present the analysis and simulation of the network model and section V concludes our work paving directions for further research.

II. STATE OF THE ART

A. Radio Frequency Planning

The growth of wireless cellular networks requires accurate and efficient RF planning in order to utilize effectively and efficiently the limited RF spectrum and offer high QoS to the end users. The available RF spectrum is divided into a number of channels known as Absolute Radio Frequency Channel Numbers (ARFCNs) that are assigned to each cell. The mobile network evolves from macro cell systems to a mixture of macro, micro, pico and femto cell systems as users and traffic load increases. Fig. 1 presents a GSM architecture [10], a wireless cellular network commonly deployed in many places.

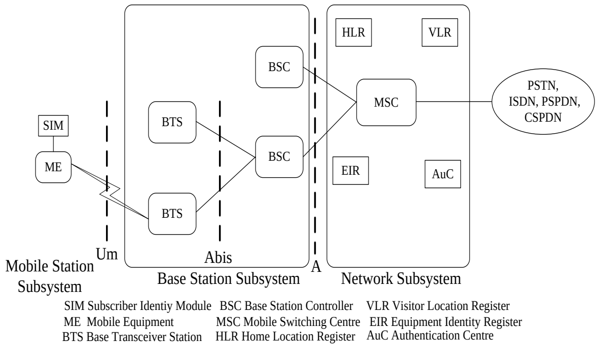

Figure 1: A GSM Architecture

RF channel numbers are reused as much as possible to increase both efficiency and network capacity. During cell planning a number of inputs are considered to ensure better services are offered to end users. Such inputs include the available RF spectrum, Traffic demands and network deployment costs subjects to required Grade of Service (GoS), QoS, Coverage, Capacity, Speech Quality and Channel to Interference (C/I) ratios. Fig. 2 summarizes the inputs to the cell planning. Different RF channel allocation schemes are used based on site location and traffic demands; including the fixed, dynamic and hybrid channel allocation techniques. Two categories of channel allocations are currently in use; the baseband hoping (fixed RF channel assignment) and frequency hopping (dynamic RF channel assignment).

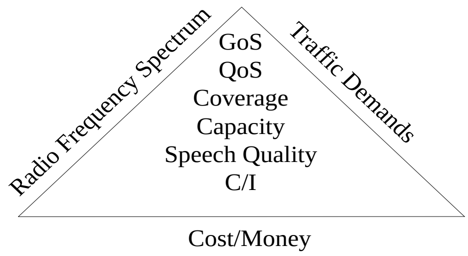

Figure 2: Inputs to cell planning

Baseband hoping schemes are mainly used in rural areas where base transceiver stations (BTS) are far from each other with radio transceivers being assigned a fixed set of RF traffic channels. Fig. 3 presents a 4/12 cell pattern cluster which is common for service areas with low traffic. Frequency hopping schemes are used in towns and cities where huge amount of traffic loads are expected. In the frequency hopping scheme a list of channels are assigned to the given sector and each radio transceiver hops over channels sharing them. Frequency reuse distance varies from one service area to another service area based on traffic demands. Rural areas sites are grouped into bigger clusters whereby a 4×3 cluster is common; hence the effect of co-channel interference is low as the reuse distance is large. Cities and towns have tight frequency reuse pattern due to high traffic loads in these areas with a 1×1 cell cluster being in common use. In order to avoid frequency collision, RF hopping techniques are used with appropriate parameters being set including; the mobile allocation (MA), hopping sequence numbers (HSN), and mobile allocation index offset (MAIO).

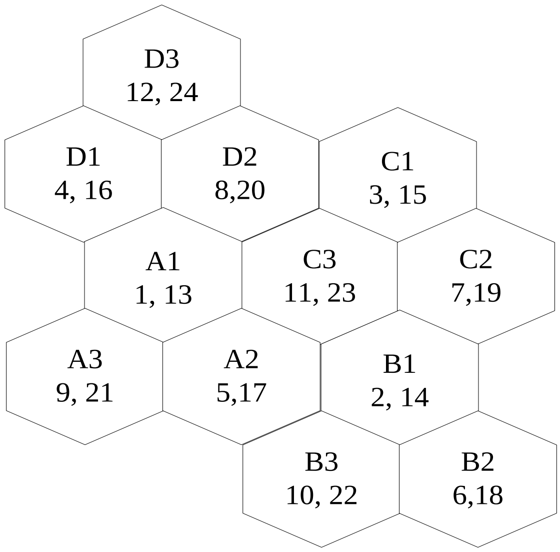

Figure 3: 4/12 cell cluster for a 24 group of channels

Despite the increase in network capacity and RF channel efficiency gained with tight frequency reuse, interference from both co-channels and adjacent channels are introduced into the network and are a potential source of quality impairment. This is common in tight frequency reuse patterns like 1x3 and 1x1 reuse clusters where interference from first and second tier reuse cells are significant due to minimum reuse distance. Furthermore, continual of frequency reuse, cell splitting and overlay/underlay of cell layers require deployment of new sites and use of more RF channels which increases CAPEX and OPEX.

B. Radio Frequency Optimization

In order to guarantee QoS to end users, monitoring and evaluation of wireless cellular networks performance in every 24 hours is required to observe key performance indicators, which include RF traffic channel utilization, Call block rates, Call drop rates, Call success rates, handover success rates, network availability, network accessibility and speech quality. Network optimizations are carried out to identify and address performance abnormalities, network coverage and capacity requirement. Cells with over utilizations are allowed to grow by adding more transceivers if RF traffic channels (TCHs) are available. When the limit of adding more transceivers to a cell is reached, cells with high traffic demands are splitted, overlaid with macro cells, underlaid with femto and pico cells or sectored to use more directional antennas thus increasing RF spectrum and penetration rate. Reducing the reuse distance increases investment cost and co-channel interferences. RF traffic channels in cell with underutilization are relocated to other cells with more traffic demands by reducing the number of transceivers. Cell capacity and coverage are also affected through antenna up-tilting or down-tilting thereby tuning to the capacity or coverage requirement of a given site as the radius/footprint of the site is increased or reduced providing gaps for addition of new sites. Table 1 and 2 presents average RF traffic channel utilization per cell for few sites observed in our survey from two wireless cellular network operators in Dar es Salaam. Observed data in table 1 and 2 reveals a significant differences in traffic loads between one network operator and another and within a given network operator at different service areas. However, the heterogeneity of wireless cellular traffic load calls for repeated optimizations as cells are underutilized and over utilized when temporal and spatial traffic variations occurs. When RF traffic channel utilization exceeds 100%, incoming traffic will automatically face denial of service or service degradations thus the failure to guarantee quality of service to end users. Likewise, traffic loading differs from one network operator to another. While one network experience congestion, another network may face underutilization.

TABLE 1: AVERAGE TRAFFIC CHANNEL UTILIZATION PER CELL FOR SELECTED SITES OF OPERATOR 1 IN DAR ES SALAAM

S/N	**Sample Traffic Channel (TCH) Utilization per cell**				
	Site No.	***Average TCH utilization (%)***	***S/N***	***Site No.***	***Average TCH utilization (%)***
1	Site 1	38.4	17	Site 17	13.7
2	Site 2	35.1	18	Site 18	85.5
3	Site 3	63.0	19	Site 19	26.8
4	Site 4	26.5	20	Site 20	34.7
5	Site 5	66.3	21	Site 21	46.3
6	Site 6	75.1	22	Site 22	83.3
7	Site 7	49.5	23	Site 23	38.8
8	Site 8	60.6	24	Site 24	61.1
9	Site 9	39.0	25	Site 25	65.4
10	Site 10	63.4	26	Site 26	29.9
11	Site 11	54.9	27	Site 27	113.3
12	Site 12	66.1	28	Site 28	55.0
13	Site 13	31.6	29	Site 29	42.0
14	Site 14	40.7	30	Site 30	29.9
15	Site 15	33.2	31	Site 31	56.7
16	Site 16	49.3	32	Site 32	92.0

TABLE 2: AVERAGE TRAFFIC CHANNEL UTILIZATION PER CELL FOR SELECTED SITES OF OPERATOR 2 IN DAR ES SALAAM

S/N	**Sample Traffic Channel (TCH) Utilization per cell**				
	Site No.	***Average TCH utilization (%)***	***S/N***	***Site No.***	***Average TCH utilization (%)***
1	Site 1	25.4	17	Site 17	109.9
2	Site 2	18.8	18	Site 18	129.6
3	Site 3	26.6	19	Site 19	130.2
4	Site 4	16.8	20	Site 20	126.3
5	Site 5	398.8	21	Site 21	122.7
6	Site 6	227.7	22	Site 22	94.1
7	Site 7	137.6	23	Site 23	121.9
8	Site 8	150.5	24	Site 24	74.3
9	Site 9	193.8	25	Site 25	65.8
10	Site 10	139.6	26	Site 26	117.8
11	Site 11	143.3	27	Site 27	68.8
12	Site 12	174.8	28	Site 28	71.7
13	Site 13	152.7	29	Site 29	49.6
14	Site 14	187.5	30	Site 30	85.1
15	Site 15	110.7	31	Site 31	77.9
16	Site 16	142.6	32	Site 32	87.7

C. Quality of Experience

Further to network monitoring and evaluation of traffic reports, drive tests are usually carried out to test network performance and evaluate the quality of service as experienced by end users. Key Performance Indicators (KPI) that are of interest during drive tests include; Call block rates, Call drop rates, Network availability, Network accessibility, Call setup times and System response times. Threshold for KPIs in Tanzania are specified under the electronic and postal communication (Quality of Service) regulations [11]. Call block and drop rates are of particular interest as they contribute significantly to the annoyance created by the network to the end users, loss of network operator revenue and customer loyalties. Network coverage and capacity limitation causes denial of service to incoming traffic thus increasing the number of call blocks and call drops. Co- channel and adjacent channel interference reduces signal quality and speech quality. Table 3 presents a summary of drive tests carried out in Dar es Salaam.

TABLE 3: SUMMARY OF DRIVE TEST RESULTS FOR GSM OPERATORS IN DAR ES SALAAM

S/N	Summary of drive test results			
	Network Operator	*Number of calls made*	*Call block rate (%)*	*Call drop rate (%)*
1	Operator 1	510	12.03	2.50
2	Operator 2	529	3.43	3.04
3	Operator 3	501	12.68	4.60
4	Operator 4	539	2.24	0.93

The drive test results reveal difference in experiences between users of one network and users of another network. While one network experiences more call blocks and call drops other networks might experience few call blocks and drops at a given service area. Furthermore, some of the observed values of call block and drop rates from drive test reports far exceeds the regulation requirement (less than 2% call block rate and less than 3% call drop rate). Thus, the search for alternative approaches for optimizing coverage and capacity in wireless cellular networks is necessary.

III. SYSTEM MODEL

We assume a pure chance type I traffic is offered into a system that works as a loss system (blocked calls are cleared). The call arrivals follow the standard poison traffic model with mean arrival rates λ and service times that are exponentially distributed with mean service rate μ. Mobile stations are randomly distributed in the service area of study and are randomly assigned to their home network from which they buy services regularly. Sequential (ordered) hunting is done when mobile stations arrive at the base transceiver stations such that home network traffic channels are always utilized first. The home network has n_1 traffic channels while the availability of traffic channels n_2 at the neighbor network varies depending on the utilization by its home users. When incoming traffic load exceeds the capacity or lack signal coverage of the home network, extra traffic load overflows into neighbor network. Calls overflowing into the neighbor network are not allowed to return to their home network even when the traffic channels are released. Fig. 4 presents the equivalent traffic channel for a spectrum shared networks where a is the incoming traffic load, a_c is the carried traffic and a_l is the lost traffic load.

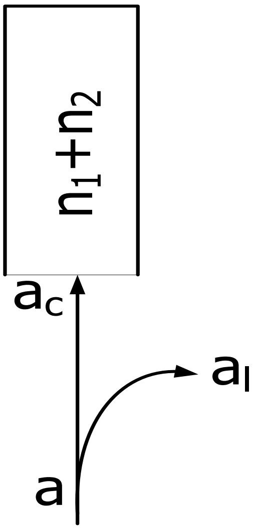

Figure 4: Equivalent Traffic Channels for a Spectrum Shared Network

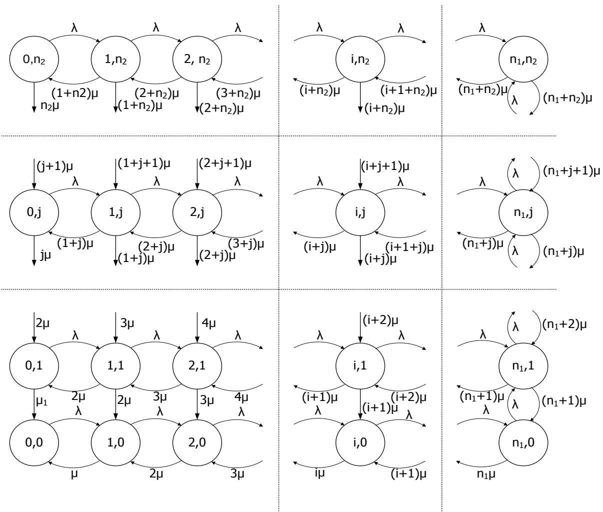

Figure 5: A two dimension Markov chain representation of the system model

A. System Blocking

Incoming traffic load is computed using (1).

$$A = \frac{\lambda}{\mu} \qquad (1)$$

Call blocking for incoming traffic in the home network when there is no traffic overflow is obtained by (2).

$$E_{n1}(A) = \frac{\frac{A^{n1}}{n1!}}{\sum_{j=0}^{n1}\frac{A^j}{j!}} \quad (2)$$

Overflow traffic load mean is obtained by (3).

$$w = A * E_{n1}(A) \quad (3)$$

Overflow traffic load peakedness is obtained by (4).

$$z = \frac{\text{variance}}{\text{mean}} = 1 - w + \frac{A}{n_1 + 1 - A + w} \quad (4)$$

Applying Fredericks and Hayward's approximation method to transform overflow traffic into pure chance traffic type I by dividing the number of channels and overflow traffic by peakedness. Hence, allowing the application of classical traffic formula to compute the traffic blocking.

$$E(n_2, w, z) \sim E\left(\frac{n_2}{z}, \frac{w}{z}, 1\right) \sim E\left(\frac{n_2}{z}, \frac{w}{z}\right) \quad (5)$$

Therefore, call blocking for traffic overflowing into the neighbor network is obtained using (6).

$$w_l = w * E\left(\frac{n_2}{z}, \frac{w}{z}\right)$$

$$w_l = A * E_{n1}(A) * E\left(\frac{n_2}{z}, \frac{w}{z}\right) \quad (6)$$

Then, the system traffic congestion is obtained using (7).

$$S_b = \frac{w_l}{A} = E_{n1}(A) * E\left(\frac{n_2}{z}, \frac{w}{z}\right) \quad (7)$$

Call procedures for the model follows the steps below:-

i. First, network users place their calls randomly and are accepted by the home network.

ii. Coverage and capacity of the home network is monitored. If the network coverage is limited or network becomes congested, negotiations are carried out to obtain coverage or capacities from neighbor network. Availability of coverage and capacity at the neighbor network allows traffic overflows from the home network.

iii. If extra RF traffic channels in the neighbor network are not available, extra incoming traffic load are blocked and cleared.

iv. Calls overflowing into the neighbor network do not return to the home network even when traffic channels become available.

v. Once, coverage and capacity are available in the home network new incoming calls are accepted as usual.

Traffic overflows allows utilization of available network coverage and capacities in other networks without requiring extra licensure of RF spectrum and deployment of new base transceiver stations (BTS), hence reducing both CAPEX and OPEX while guaranteeing better services to network users. Fig. 5 presents the flow chart for the proposed model.

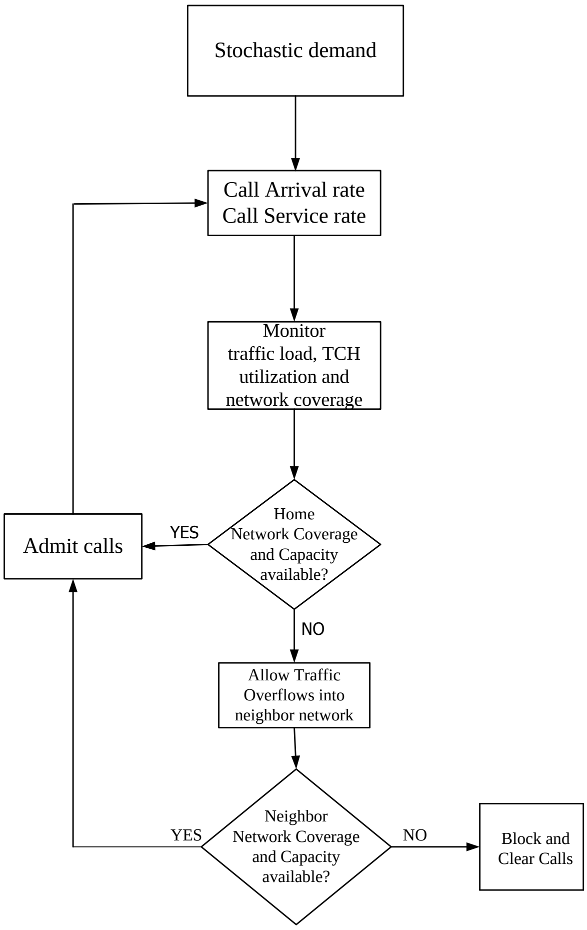

Figure 6: Flow Chart for the Model

IV. ANALYSIS AND SIMULATION

We assume that wireless cellular network operators have non co-located base stations with full coverage in the area of study. We further assume that eight (8) or sixteen (16) traffic channels are available in the home network and traffic channels from neighbor network are available when traffic congestions occurs in the home network. Call blockings are computed using MATLAB simulations when incoming traffic is served by the home network alone with eight and sixteen traffic channels. The results are compared to call blockings obtained when extra incoming traffic load overflows into neighbor networks. Fig. 7 presents simulation results for call blocking in a network with 8 traffic channels compared to call blocking in a network with 16 traffic channels. Fig.8 presents simulation results for a network with 8 traffic channels with and without traffic overflows. Fig.9 presents simulation results for a network with 16 traffic channels with and without traffic overflows.

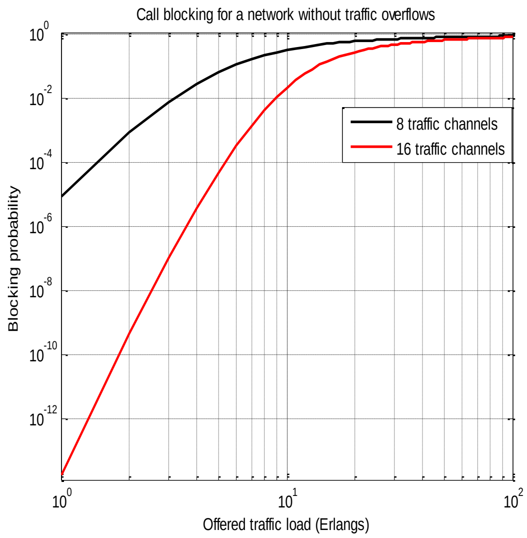

Figure 7: Call blocking for an 8 TCH and 16 TCH network

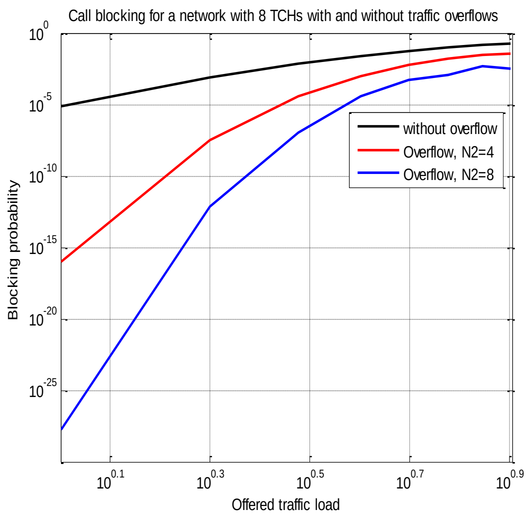

Figure 8: Call blocking for a network with and without traffic overflows

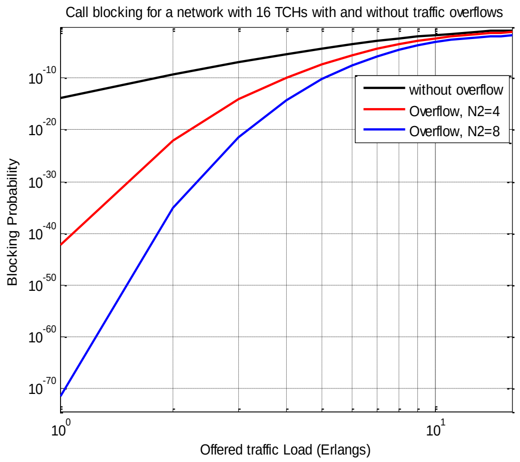

Figure 9: Call blocking for a network with 16 TCHs with and without traffic overflows

V. CONCLUSION

We have presented a cost effective coverage and capacity optimization method for connection oriented wireless cellular networks in this work. The method allows traffic overflows into neighbor networks when coverage and capacity limitations arise within the home network. Extra RF spectrum licensure and deployment of new network nodes are avoided by utilizing available resources at neighbor networks, hence reducing both CAPEX and OPEX. Performance evaluation of the model using MATLAB simulations reveals significant improvement to the QoS offered to subscribers.

REFERENCES

[1] ITU. ICT Facts and Figures [Online]. Available: http://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2013.pdf

[2] TCRA. Telecommunications Statistics December 2012 [Online]. Available: http://www.tcra.go.tz/images/documents/telecommunication/TelCom%20Statistics%20Dec%202012(Final).pdf

[3] K. Tutschku, "Demand-based radio network planning of cellular mobile communication systems," in *INFOCOM'98. Seventeenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, 1998, pp. 1054-1061.

[4] T. S. Rappaport, *Wireless Communications: Principles and Practice*, Second Edition ed. Upper Saddle River, NJ 07458: Prentice Hall PTR, 2009.

[5] B. Haider, M. Zafrullah, and M. Islam, "Radio Frequency Optimization & QoS Evaluation in Operational GSM Network," in *World Congress on Engineering and Computer Science*, 2009.

[6] M. Umair, *et al.*, "Automatic Frequency Planning and Optimization Algorithm for Cellular Networks," in *Proceedings of the World Congress on Engineering*, 2012.

[7] K. Tutschku, N. Gerlich and P. Tran-Gia, "An integrated approach to cellular network planning," in *Proceedings of the 7th International Network Planning Symposium (Networks 96)*, 1996, pp. 185-190.

[8] I. F. Akyildiz, W. Y. Lee, M. C. Vuran and S. Mohanty, "NeXt generation/dynamic spectrum

access/cognitive radio wireless networks: a survey," *Computer Networks*, vol. 50, pp. 2127-2159, 2006.

[9] S. Yaipairoj and F. C. Harmantzis, "Dynamic Pricing with “Alternatives” for Mobile Networks," 2004, pp. 671-676.

[10] J. Scourias, *Overview of GSM: The global system for mobile communications*: University of Waterloo, Computer Science Department, 1996.

[11] TCRA. The Electronic and Postal Communications (Quality of Service) Regulations, 2011 [Online]. Available: http://www.tcra.go.tz/images/documents/regulations/qualityOfService.pdf