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An Advanced 3-Mode Base Station Switching Technique for Energy Efficient Cellular Networks

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Abstract

In recent times, energy consumption is being considered as a critical issue in the mobile and cellular industry. This has led to the development of energy efficient techniques for cellular communications. With base station activity being the highest power consumer, base station sleeping has emerged as a major solution for reducing overall power consumption. Much of the existing work in this field is on a 2-state operation of base stations, wherein base stations are either active or in sleep mode. This technique is only useful when the network traffic is low, such as during nights or weekends. This paper proposes an energy-efficient 3-level base station switching solution with advanced threshold-computation algorithms for a multiple data-rate cellular network. Energy efficiency is been achieved by switching the base stations between active, low-power and sleep modes of operation depending upon the traffic levels without significantly compromising the quality of service of the network. The results show a power efficiency that can exceed 50% at very low traffic levels and up to 30% at medium traffic levels. Two tiered traffic levels are used for the mobile users.

Keywords

Cellular networks, Base station utilization, Green radio

Introduction

Cellular and mobile communications being one of the most dominant fields in the present world is utilized in various applications including defense, commercial, medical, automobile, social media and many more. In the recent era, mobile traffic has tended to grow rapidly with around 4.6 billion users worldwide and is expected to exceed 5 billion users by 2019 [1]. With new applications and increasing users every day, the demand for cellular networks requires increase in infrastructure. With more than 4 million base stations across the world, cellular networks consume about 60 TWh per year [2] and this number is estimated to increase in the coming years. The large amounts of energy consumed by cellular networks and the high demand for bandwidths turned out to be a major concern for the wireless communications industry.

Due to economic, financial, operational and environmental concerns, energy efficiency is emerging as a figure of merit [3]. The rapid increase in mobile device users requires more communication capacity which is satisfied by the consumption of more energy, which results in enormous operational costs. Higher infrastructure and operational costs and market saturation leads to a negative effect on mobile operator average revenue per user. The utilization of traditional carbon-based energy sources for powering up energy thirty cellular networks leads to environmental concerns. Information and Communication Technology (ICT) infrastructure is estimated to be responsible for around 5% of the total CO_2 emissions [4]. All the economic and environmental concerns led to growth of research to develop energy efficient cellular networks.

Various research areas have been identified which helps achieve our goal of green networks and can be cat-

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egorized in to four major categories. Firstly, improved infrastructure with energy efficient components can reduce energy consumption. Secondly, efficient coding schemes can help improve data rates for a given power consumption. Developing more efficient coding techniques with better channel utilization in turn improves energy efficiency. Thirdly, eco-friendly energy resources capable of providing the high power demands of cellular networks reduce environmental effects of wireless communications. Lastly, efficient network utilization can also reduce power consumption with minimal changes to the existing infrastructure. This paper focuses on one such technique.

Cellular networks are set up considering maximum traffic loads in a particular region which helps the network operators to provide required quality of service (QoS) to all the users. Due to the large fluctuations present in the traffic conditions during a 24 hour time period, cellular networks receive large number of user requests for the limited bandwidth available in a particular cell. Cellular networks tend to face peak traffic loads in such conditions and this situation occurs during certain periods during a day. All the network infrastructure and resources are fully utilized during these high traffic conditions. However, during some periods such as mid-night, early morning, call traffic tends to go down with very few users utilizing the network. During these low to medium traffic conditions, network resources are underutilized with most of the base stations (BS) either in idle state or serving very few users. As base stations tend to consume more than 80% of the total power required by the cellular network and this static power consumed by a BS does not vary with the number of users being served. Overall power consumed per user is much higher during low traffic conditions compared to high traffic conditions. Whenever a particular network has low traffic and only few of the BSs are capable of serving all the traffic present, energy consumption can be reduced by turning off the remaining BSs. By this method, all the static power consumed by the remaining BSs can be saved. Efficient network utilization deals with BS cooperation and sleeping methodology which switches a BS between active and sleep modes depending up on the traffic conditions in a particular cell and its neighboring cells.

Efficient network utilization schemes are simpler and more efficient for developing green cellular networks immediately without requiring much infrastructural changes. Various algorithms and techniques are developed to improve network utilization. User association is considered to affect the power consumption of the cellular network highly and is also a major player in performance of the network [5]. Interactive sub-channel and power allocation algorithm is implemented to capture the energy efficient and spectrum efficient tradeoff relation and meet device energy efficiency [6]. Device-to-device communication is one such cellular communication architecture to improve energy efficiency [7]. Proposes a nearest neighbor cooperation communication scheme where two neighboring user equipment (UE) exchange data through short range communication and collaborate on their uplink transmissions. Traffic overloading through small cells in heterogeneous networks to improve energy efficiency is proposed in [8].

This paper adopts the new concept of 3 mode base station switching technique to switch BSs between active, low-power and sleep modes depending on the traffic load in the network. In the low power mode, a base station with a smaller coverage area (and consequently lower fixed power consumption) is used. This is similar to microcell BSs in the literature. In the well known 2-mode base station ON-OFF algorithms in literature [9], a low traffic BS is switched off to save energy and neighboring cells increase their coverage areas to accommodate the users. However, this method works only when the network traffic is low. The proposed 3 mode switching algorithm will work even at moderate traffic levels. By allowing a small probability of blocking (set to 1% in this paper), significant energy savings can be leveraged.

In Section II, we introduce the cellular network model considered in this paper. In Section III, the power saving problem is introduced and solutions are proposed. In Section IV, we present simulation results corroborating the ideas. In Section V, we conclude the paper with a summary of the results.

System Model

A typical LTE cellular network structure consisting of multiple cells is considered with one omni-directional BS providing radio access to the mobile users in each cell as shown in the schematic in Figure 1. A BS controller provides intelligence to all the BSs in the network which includes allocation of radio channels, handover decisions etc. To introduce the concept of 3-mode BS switching technique, every BS is considered to be accompanied with a micro base station which is capable of providing coverage to lesser area consuming only a portion of the fixed power consumed by the macro base station. Each cell will have some allocated bandwidth that must be shared between all the incoming user requests by assigning proper amount of physical resource blocks (PRB) to each user. This model is designed for serving multiple data rate requirements and the number of PRBs assigned to each user request depends on the data rate that is required for the particular service requested.

In this paper, a network consisting of N cells $C = \{C_1, C_2, \ldots, C_N\}$ each having a multi-base station: A macro BS and a micro BS, is assumed in a cellular region.

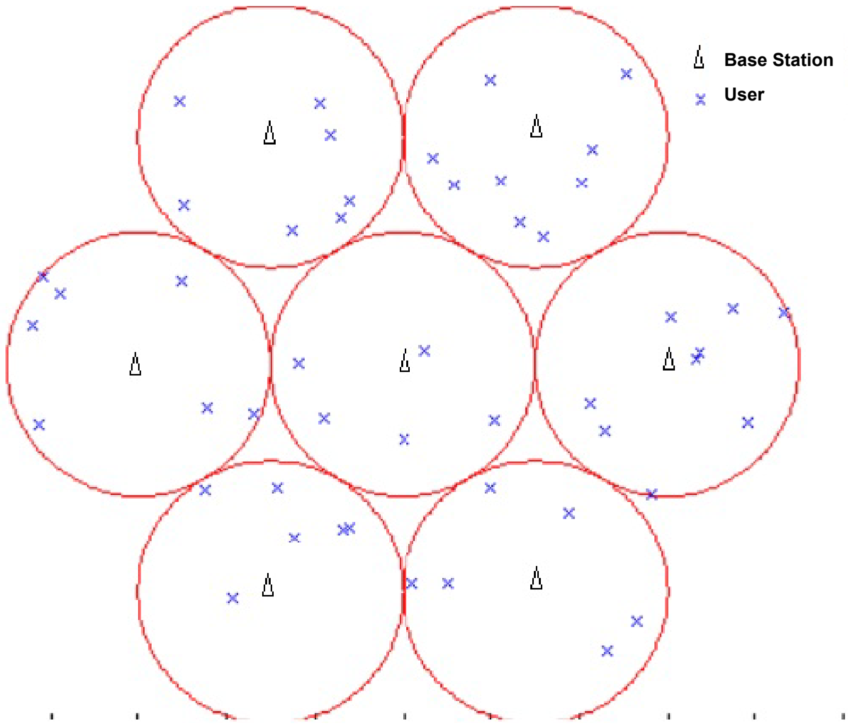

Figure 1: 7-Cell network structure with base stations located at the center of each cell and randomly generated users for traffic load equal to 0.3.

The macro BS are denoted as a set B = $\{B_1, B_2, \ldots, B_N\}$ and micro BS are denoted as μB = $\{\mu B_1, \mu B_2, \ldots, \mu B_N\}$. This network is capable of serving a maximum of M user requests and is denoted as U = $\{U_1, U_2, \ldots, U_M\}$. A variable x is defined to indicate the association of a particular user to a particular cell.

$$xij = \begin{cases} 1 \text{ if } Ui \text{ is served by a BS in cell } Cj \\ 0 \text{ otherwise} \end{cases}$$

Each user request is served by a BS of only one cell at a given point of time and the BS which provides the highest QoS to the user is considered to be the one which serves that user request. Received signal strength is considered to be quantitative measure for QoS in this paper. There are many factors that influence the received signal power which include interference, noise, bandwidth, transmitted signal power. Data rate achieved by UE j is given by:

$$R_j = \sum_{i \in C} x_{ij} \cdot W_{ij} \cdot \log_2\left(1 + \frac{P_{ij} \cdot G_{ij}}{P_{interference} + P_{fixed}}\right)$$

Where W_{ij} is the bandwidth allocated by the BS i to UE j and is equal to **W/NRB,** W is the total bandwidth available for a BS, NRB is the total number of PRBs in each BS, P_{ij} is the transmission power assigned between BS i and UE j, G_{ij} is the channel gain, $P_{interference}$ is the total interference power from the neighboring BSs. P_{noise} is the loss of power due to noise which is very less compared to interference power in wireless cellular networks and hence is neglected in this paper. The total power consumed by a base station is the combination of static power consumed by a BS which is denoted as P_{fixed} and dynamic power used to transmit signals to the UEs that are being served by the BS. Power consumed by the cellular network at any time instant is given by:

$$P_{tot} = \sum_{i \in C} \sum_{j \in U} x_{ij} \cdot A_i \cdot P_{ij} + P_{fixed,\, i}$$

Where P_{ij} is the power transmitted by BS i to serve UE j, Ai is the BS power scaling factor which includes amplifier and feeder losses, $P_{fixed,i}$ is the fixed power that is consumed by a BS i to be up and running.

Problem Formulation

Base station sleeping is widely used technique for energy efficient base station operation. This involves 2 modes of BS operation: Active and sleep. Whenever a BS is in sleep mode, all the neighboring active BSs are responsible to serve the waiting UEs in the cell with sleeping BS. A minimum call blocking probability prevents more BSs to go into sleep mode which limits BS power conservation. A 3-mode BS operation technique that was incorporated in this paper helps increase the BS power conservation by adding a low-power mode in which a micro BS capable of serving lesser area consuming very lower power is co-located with every BS.

Mode factor defines the mode of operation of a particular BS: Active, low power, sleep. Depending up on the traffic at a particular time instance t, mode factor of every BS is first calculated using Algorithm 1.

$$M_i = \begin{cases} 0 & \text{sleep mode} \\ 0.5 & \text{low power mode} \\ 1 & \text{active mode} \end{cases}$$

Once the mode of operation for all the BSs are defined, all the users who are in the cells with BS having $M_i = 0$ and those users who are beyond the micro BS limits in the cell with $M_i = 0.5$ are marked as unserved or waiting users. Base station controller should intelligently allocate the unserved UEs to active BSs without compromising the QoS of any users. Whenever the given M_i values does not satisfy the overall QoS of all the UEs, Algorithm 2 is used to recalculate the M_i values of all the BSs in order to make sure that QoS is guaranteed for all users.

Algorithm 1:

Step 1: A predefined threshold limit for traffic load in a cell is estimated.

Step 2: BS with traffic load below the threshold value is marked with $M_i = 0$.

Step 3: BS whose difference of traffic load for macro and micro BS is below threshold is marked with $M_i = 0.5$.

Step 4: BS which does not satisfy step 2 and 3 are marked with $M_i = 1$.

Algorithm 2:

Step 1: Calculate if every BS in low-power or sleep mode have at least 2 active neighbors or else bring up the BS with highest traffic to active mode.

Step 2: Calculate the PRBs required for unserved UEs and PRBs available with active BSs.

Step 3: If the PRBs required is less than that of the available, bring up the necessary BSs to satisfy the condition in step 2.

Dynamic power consumption of a BS can be reduced by intelligently allocating the UEs to the nearest BS capable of serving it which have more SINR and better QoS. Hence allocating unserved UEs to active BSs is one of the crucial tasks for BSC. In this paper, a more efficient, easier and economic algorithm is provided for the unserved UE allocation which is summarized in Algorithm 3.

Algorithm 3:

Step 1: For every UE, arrange the nearest active BSs with SINR as criteria in descending order.

Step 2: For every BS, arrange all the unserved UEs with power required to serve as criteria in ascending order.

Step 3: Using data from steps 1-2, allocate the unserved UEs to active BSs by minimizing the transmitted power and satisfying required SINR.

Table 1: Simulation parameters.

Parameters	Settings		
Carrier frequency	2 GHz		
Carrier bandwidth	5 MHz		
Max. BS transmit power (MBS/μBS)	43/33 dBm		
Antenna gain (MBS/μBS)	16/10 dBm		
BS antenna height	25 m		
Noise power	-141 dBm/Hz		
Path-loss	Type B (non-line-of-sight, suburban, terrain Type B)		
Shadow standard deviation	8 dB		
Power model parameters			
		A	P_{fixed}
	MBS	32.0	412.4
	μBS	5.5	22.6
Radius of cell	750 m/350 m		

Simulation Results

To evaluate the amount of power consumption savings generated by implementing the 3-mode BS switching technique for a multiple data rate environment, a cellular network consisting of 7 cells shown in Figure 1 is considered with each cell having a BS at the center of the cell region which is accompanied by a micro BS to maintain a low-power mode of operation. A macro and micro BS are considered to cover a region of radius 750 and 300 meters respectively. All the technical specifications of the BSs and channel are summarized in Table 1. Users are allowed to request two types of services: Type 1 requires less data rate and type 2 requires high data rate. Users were randomly located in the considered 7 cell area based on uniform spatial distribution. For a given network traffic rate, Poisson arrival statistics were used to generate data at the users. The proposed algorithms then determine the BSs that are active, in low power and in the sleep mode. To analyze the power savings of this method compared to a network in which all the BSs are active irrespective of the traffic conditions in the region, both models are simulated using Matlab and the results are discussed below.

Mode factor for 3-mode BS operation model is calculated based on a threshold value which is initially considered to be $\partial = 0.6$ [4]. Based on Algorithm 2, threshold value is changed until all the conditions are satisfied which sets the correct value for threshold. Threshold value varies from cell to cell depending on the traffic conditions in the cell and also in neighboring cells. This threshold value is considered to be the initial threshold values every time a BS comes to active mode from sleep or low-power modes. The total bandwidth available in each cell is divided into 25 PRBs [10] and the maximum number of users served in a cell is 25 and feasible when

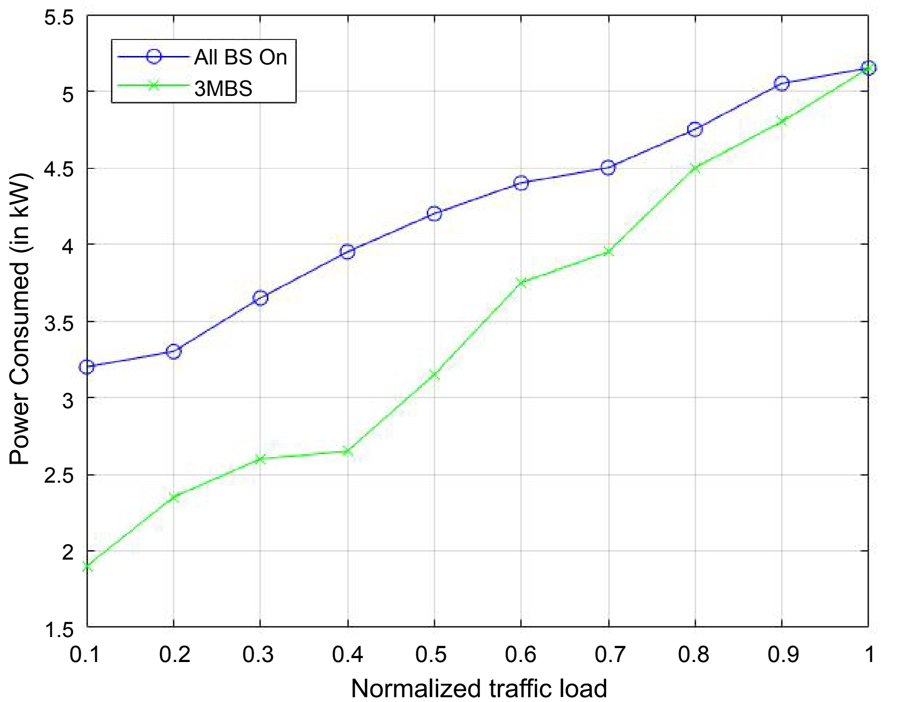

Figure 2: Comparison of total power consumed by 3 mode BS switching with advanced threshold algorithm and power consumed with no BS sleeping (always on).

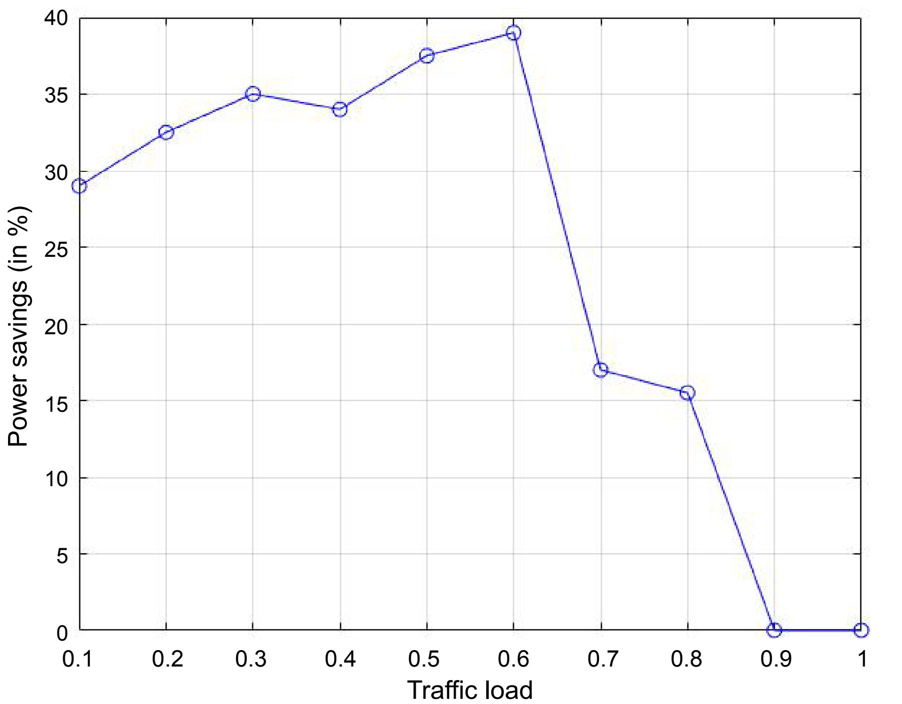

Figure 3: Percentage of power saved by implementing 3-mode BS switching with advanced threshold algorithm.

each user is allocated with only one PRB each. This paper deals with multiple data rate requests and hence the users have the freedom to request a variety of services each of which requires different data rates. To serve multiple data rates, 1 PRB and 2 PRBs are allocated to type-1 and type-2 services.

The power transmitted to each user is calculated so as to ensure the minimum QoS or data rate (within margins of the allowed blockage probability) to the users considering the interference from the neighboring cells. Once required transmitted power to each user in all the cells is calculated, mode factor for all the BSs are calculated depending on the algorithms given in problem formulation section. All the UEs in the sleep-mode BSs and the outer region of the low-power mode BSs have to be handed off to the active BSs to provide service. UE handover is performed using Algorithm 3 and this paper considers UEs requesting any type of service to be equally important and hence the UEs located closer to an active BS have the highest priority while serving. Handovers are performed until all the active BSs have sufficient bandwidth and power to serve the unserved UEs. Depending up on the location of the unserved UE, some UEs may not be able to be served by any of the active BSs and hence result in a call blockage. We consider a call blocking probability of 1% is adequate to maintain the QoS for the network. The two types of services offered by this network requires a data rate of 140 bits/sec and 280 bits/sec respectively.

Most of the BS sleeping techniques and efficient network utilizing techniques [5-8,11,12] achieve approximately 50% energy savings during low traffic loads and have no impact during mid to high traffic conditions. By implementing a 3-mode BS switching technique, power consumption can be reduced even at medium level traffic conditions. Figure 2 compares the overall power consumption by the 3-mode BS switching technique to the power consumption of the network without implementing BS sleeping. This technique provides a power saving of around 30-40% in both low traffic and medium traffic conditions which is shown in Figure 3. As the traffic load goes towards 1, the high number of user requests forces all the BSs to be in active state and so the power consumed by the proposed method will be almost equal to that of without using any BS sleeping and so there is no power savings at high traffic loads. Figure 4 shows the number of BSs operated in 3 different modes in various load conditions. It is clear that at loads 0.6 and 0.7, by operating 6 BSs in active mode and 1 in low power mode would satisfy the UE requests providing the required QoS. Percentage of calls blocked is shown in Figure 5 which demonstrates the blocking probability to be less than 1%. The results generated by the simulations show a satisfactory amount of power savings in both low traffic and medium traffic loads using the proposed switching technique and the handoff mechanism and threshold calculation proves to be more important to minimize call blocking.

Conclusions

This paper deals with a 3-mode BS switching technique with an improved threshold calculation method for providing improved power efficiency for green cellular networks. Mobile users with two different traffic profiles are considered in this paper. With simpler handoff mechanisms, BS switching can be made faster with guaranteed QoS. Introduction of low-power mode eliminates resource wastage due to BS under-utilization. With the micro-BS consuming less static power than macro-BS, operating some BSs in low-power mode during medium traffic conditions will help improve energy efficiency. This paper demonstrates an approximate 50% power savings during low traffic conditions and 15-30% savings during medium traffic conditions with under 1% of call blocking probability.

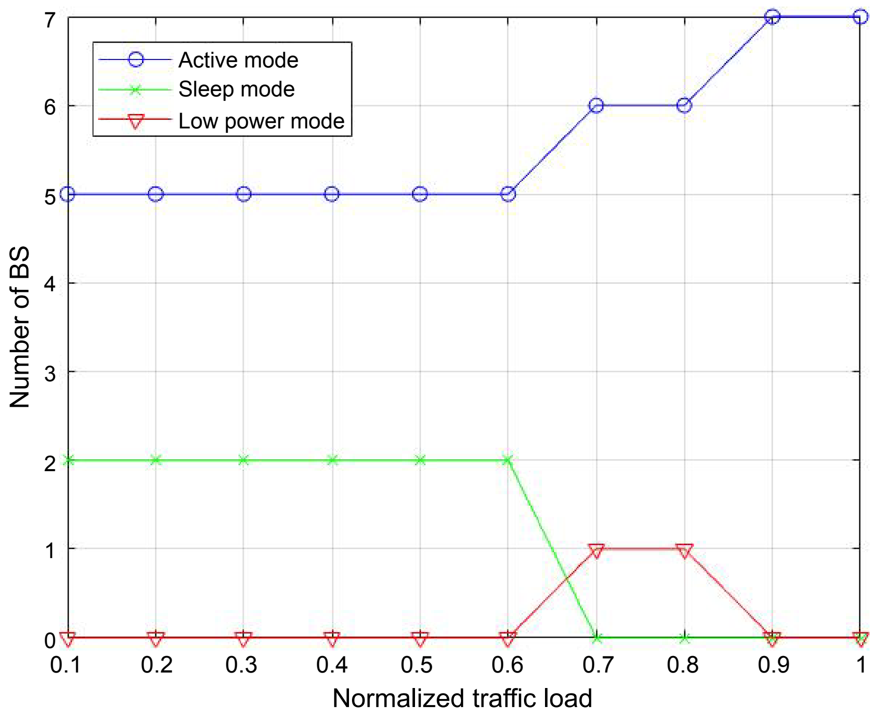

Figure 4: Number of base stations in active, low-power and sleep modes.

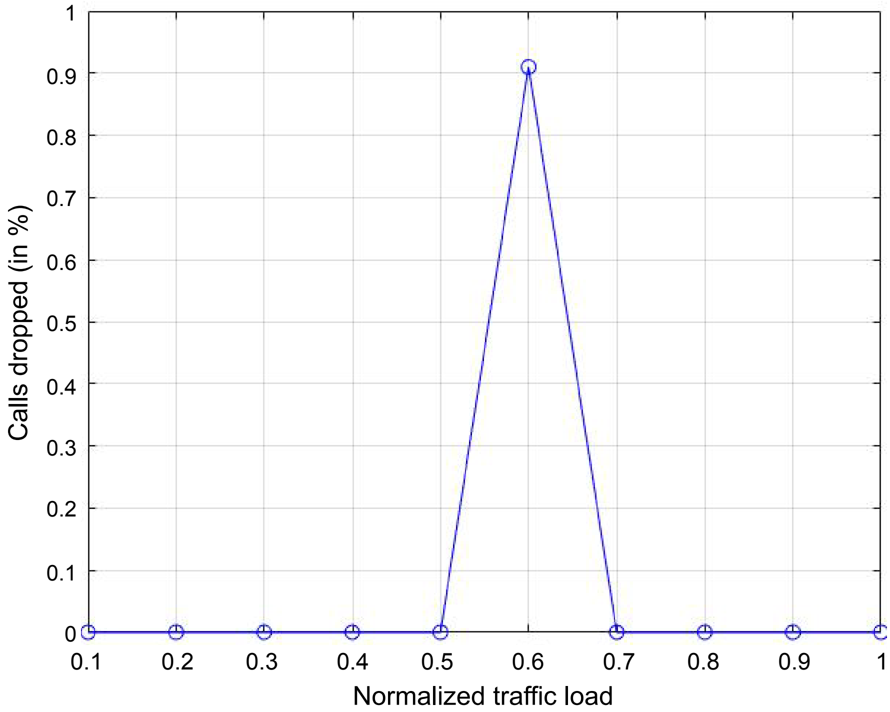

Figure 5: Percentage of dropped calls.

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