Call Blocking and Outage Probability in Energy Efficient LTE Networks

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Abstract- **Mobile operators are continuously expanding network infrastructure through deployment of additional base stations to satisfy ever growing user demands. In parallel, number of users is also increasing due to advancement in mobile applications. Enlarged number of users and base stations introduce major problems, such as call blocking and outage probability, due to limited resources and interference caused by frequency reuse, respectively. Both these parameters play key role in estimation of overall system performance. Alongside, energy efficiency is vital parameter to enable portability and longevity of mobile user equipment. This paper investigates call blocking and channel outage probability in reduced early handover (REHO) deployed LTE networks. System level simulations are performed in MATLAB to analyse the performance of REHO before it is compared with LTE standard and other state of art for key performance related parameters including energy efficiency, outage probability and call blocking probability. Besides increased energy efficiency, REHO is also found to be competitive enough in terms of call blocking probability in the presence of Poisson process call arrivals.**

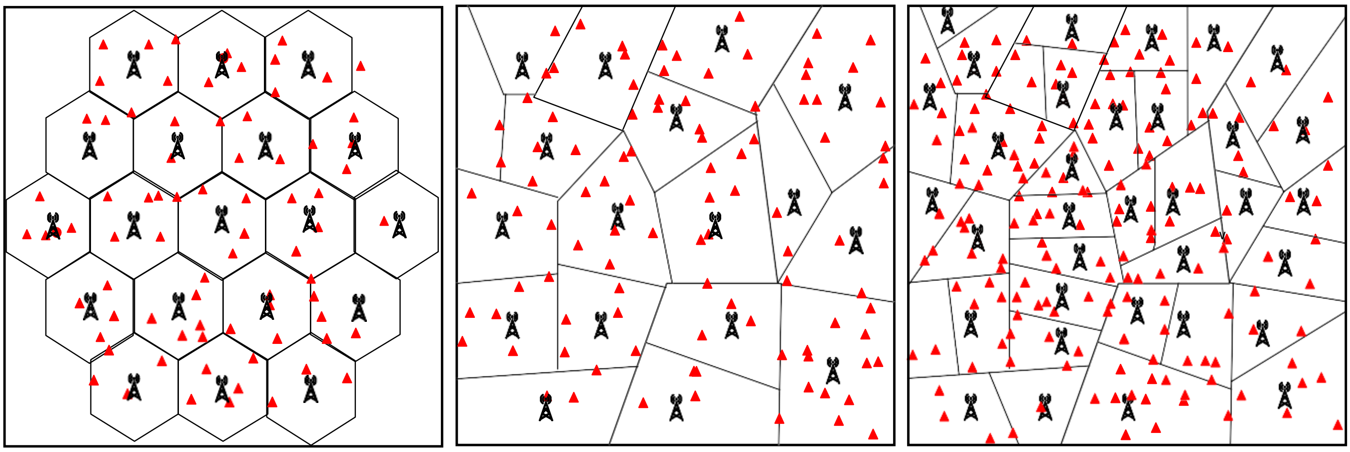
*Index Terms— **LTE networks, Call blocking probability, Outage probability, Energy efficiency***

1. INTRODUCTION

In modern telecommunication, the number of mobile users and their data demands are increasing rapidly due to advancement in smart phones and commercialisation of Long Term Evolution (LTE) systems. These growing trends not only result in increased energy consumption and CO_2 emission, but also effect overall system efficiency in relation to Base Stations (BSs) resources availability. The higher data requirements engage resources over prolonged period of time forcing BSs to discard incoming calls thereby leading towards call blocking as well as outage probability. Subsequently, both number of users and their data demands have become major challenge for operators to provide adequate Quality of Service (QoS). Though literature boasts itself from numerous energy saving proposals where most of them mostly focus on improved energy consumption; however there is strong need to investigate collectively not only energy saving but also the impact of increasing users and their data demands on overall system performance inclusive of outage and call blocking probability. .

To fulfill ever growing requirements of user equipments (UEs) for modern applications, mobile network operators are deploying additional BSs. Consequently, the BSs deployment layout of modern mobile network is becoming random and thus steering away from standard hexagonal patterns as shown in Figure 1a. Stochastic geometry models offers integration of random sizes of cells through appropriate modelling of distributed BSs using random distribution [1]. To analyse the uncertainty which can occur in network, a probabilistic approach called spatial distribution of the said BSs can be modelled using Poisson Point Process (PPP) [2], as shown in Figure 1b. However, research has shown that Hard Core Poisson Process (HCPP) based stochastic modelling helps getting more realistic spatial distribution (Figure 1c). Research work in [3] presents Downlink Signal to Interference plus Noise Interference (SINR) distribution for Orthogonal Frequency Division Multiple Access (OFDMA) based LTE networks using hexagonal model, while it completely ignores random BS distribution. In contrast, downlink SINR for cellular networks using PPP based stochastic model has been investigated in [4]. Another work in [5] investigates both PPP and HCPP stochastic models for downlink performance of OFDMA in LTE networks. Due to increasing number of UEs and cells, the co-channel interference and limited radio resources has become major hurdle. Notably the number of mobile UEs and their data requirements are growing day by day; thus the excessive signals and reuse of frequency outcomes in to co-channel interference. In parallel limited resources directly affect system capacity to accommodate increasing UEs, making both call blocking and outage probability as most important criterion for the cellular networks performance estimation. The call blocking probability occurs when resources are already occupied by other UEs, in contrast outage probability occurs due to the either carrier to noise ratio (CNR) or carrier to interference ratio (CIR). The system performance evaluation in terms of outage probability has been studied in [6] which analyses the influence of fading due to the interfering and chosen UEs on overall system performance. Research work in [7] introduced solution for CNR and CIR under the assumption that all UEs have common average fading power. Further [8] introduces Markov chain based channel access method and analyses outage and call blocking probability together. In the same context, work accomplished in [9] offers closed form outage probability for single UE. Work in [10] examines co-channel interference in microcells where signals are considered with Nakagami [11] appearances. In parallel, [12] investigates co-channel interference through Rician and Rayleigh models by considering both desired and undesired signals. The work in [13] investigates outage probability in unlicensed Device to Device (D2D) communication in LTE systems. In the same context, [14] presents outage probability analysis over various channel conditions. This particular work derives new closed form expressions for the probability density function (PDF) and cumulative distribution function (CDF) of the signal to noise ratio (SNR) of conventional systems operating under Nakagami channel. Work in [15] discusses call blocking probability in the presence of varying mobility models. Authors considered high, low and no traffic profiles for the performance analysis of proposed work. Intelligent resource allocation to achieve reduced call blocking probability in LTE systems is discussed in [16]. On the same lines, [17, 18] propose smart schemes to reduce call blocking probability and improved resource utilisation in LTE networks. Call blocking probability is also examined in [19, 20] where efficient resource management based scheme is proposed to reduce call blocking probability through optimal power assignment. In the same context, work in [21] presents the idea of same resource block allocation to single UE from serving and target cell. This increases the desired signal power for UE thus leading towards spectral efficiency. In other words, both serving and target cell share their resource with each other to utilize them efficiently and results in to lesser call blocking probability. However, call blocking probability will increase when resources of both cells are highly utilized during peak traffic period. Call blocking probability is also examined in [22] which introduces call admission control scheme for cellular networks. Next to this research work conducted in [23] presents Genetic Algorithm scheme which offers reduced call blocking probability for both uniform and variable traffic demand through hybrid resource allocation to the cells. However there is none or very limited work which simultaneously investigates energy efficiency, call blocking and outage probability in LTE cellular networks. In this work, hexagonal BSs deployment pattern is used and paper examines energy saving, call blocking and outage probability for our previously proposed reduced early handover (REHO) [24] scheme for LTE networks. REHO achieves energy efficiency through reduced early handover where users are strapped towards target cell. There could be the cases where target cell capacity reaches at its possible peak and might fail to accommodate more users resulting in to higher call blocking probability. Thus it is important to simultaneously investigate energy efficiency, call blocking probability and outage probability together in REHO deployed networks.

Work presented in [25] offers energy saving through efficient resource allocation which reduces control channels overhead and turns *OFF* idle resources thereby resulting in to improved energy efficiency. In comparison, REHO initiates early handover which allows idle resources to be turned *OFF* earlier thereby resulting into higher energy efficiency as compared to [25]. The idea of BSs switching *ON* and *OFF* for energy saving purposes has been introduced in [26]. This idea lies in the fact that UE will be served by neighbour cells while serving cells are turned *OFF* for energy efficiency. However, said scheme fails to turn *OFF* target cells in the presence of even single UE closely located to BS thus making it impossible to achieve any energy saving. Due to reduced early handover, REHO enables serving cell to turn *OFF* idle resources regardless of UE location and distance thus resulting in to higher energy efficiency compared to [26]. The idea of simultaneous energy saving and coverage expansion with BSs switching *OFF* for improved energy consumption and call blocking has been proposed in [27]. Notably this scheme can result in significantly increased energy consumption when active cell power levels are increased to achieve larger coverage, which in turn is needed due to switching *OFF* of neighbor BSs. Thus, the impression of coverage expansion not only effects overall system energy efficiency but also increases call blocking due to the limited active BSs. In comparison, REHO scheme does not turns *OFF* entire BS, rather it only turns *OFF* idle resources for improved energy efficiency.



(a) (b) (c)

Figure 1. BSs deployment Pattern; a) Hexagonal; b) Poisson Point Process; c) Hard Core Poisson Process

The work presented in this paper typically investigates the impact of increased energy efficiency over the call blocking and channel outage probability. System level simulations are performed in MATLAB to analyse the performance of REHO. REHO scheme is initially comparatively analysed in terms of energy efficiency with other state of art [25-27] and LTE standard, followed by call blocking and outage probability analysis. Besides providing increased energy efficiency, REHO is also found to be competitive enough for call blocking probability in the presence of Poisson process call arrivals and varying data rates.

Rest of the paper is organized as follows. Following introduction in section 1, resource allocation and typical types of interference experienced by cellular networks are presented in section 2. A brief overview of REHO is also added in the same section. Section 3 presents call blocking and outage probability modelling. Performance analysis is presented in section 4 while paper finally concludes in section 5.

2. Resource allocation and INTERFERENCE

The resource allocation methods and radio interference have direct impact on call blocking and outage probability. Therefore, both are discussed briefly in the context of the work in the sections below.

A. Channel/Resource Allocation

Geographical area is usually divided in to number of cells, each to be served by a BS in LTE networks. UEs request resources from BS, which are allocated using channel allocation techniques. The main purpose of channel allocation techniques is to assign resources to the cells in an effective way to minimize call blocking probability. There are numerous resource allocation techniques available in cellular networks [28, 29], while they can be split in three main categories: 1) Fixed channel allocation, 2) Dynamic channel allocation and 3) Hybrid channel allocation.

In fixed channel allocation, static number of resources are uniformly distributed to all clusters, further each cluster equally allocate resources to its BSs which mean all UEs get equal resources. Importantly, the fixed channel allocation fails to provide effective resource utilization. To overcome this drawback, in dynamic channel allocation all resources are placed in central pool and dynamically allocated to the BS depending on calls arrival. The main drawback of this method is that it requires high computation efforts for higher traffic. Hybrid channel allocation divides resources in to fixed and dynamic set. Resources in fixed set are allocated to the BS using fixed channel allocation method regardless of call arrival; while resources in dynamic set are dynamically assigned to BS on the bases of user request. Importantly, all these channel allocation techniques are in use in modern cellular networks. In this work, fixed channel allocation is used where fixed number of resources is uniformly distributed to all clusters in the network.

B. Interference in Cellular Networks

Since number of BSs is increasing day by day, therefore reuse of frequency has become one of the most important factors. Importantly, BSs reuse frequency to provide enough coverage in all geographical area at the cost of different types of interferences, chiefly 1) Co-channel interference, 2) Adjacent channel interference, and 3) Co-site interference.

Co-channel interference occurs between two different BSs, both using the same frequency. Notably there are several techniques to mitigate Co-channel interference in cellular networks where frequency is reused. Adjacent Channel Interference exists between BSs which are using adjacent frequencies in adjacent cells. These types of interference can be reduced by appropriate cellular network design.

Lastly, Co-site interference occurs between transmitters which use adjacent frequencies in same cell. Proper separation between channels can help reduce co site interference.

C. Reduced Early Handover (REHO)

Users in the overlapping areas of serving and target cells receive reference signals from both cells where reference signal value is used to measure Reference Signal Received Power (RSRP) in LTE networks. Users share RSRP measurement reports with serving BS for handover decision. The RSRP measurement process involves three important parameters namely Hysteresis (predefined signal strength), offset and Time to Trigger (TTT). Hysteresis is added in serving cell RSRP to make it better than target cell, while TTT is defined time window used to ensure seamless connectivity. User triggers A3 event (LTE standard procedure) only if target cell RSRP remains better compared to serving cell during TTT. REHO presented in [24] works with parameters of hysteresis and offset and fine tune them in relation to varying velocity, Radio link failure to initiate early handover. REHO adds minimum reduced value of hysteresis (i.e. 1dBm) thus enabling earlier A3 event trigger. This helps serving cell resources to become idle earlier as compared to standard handover which results in prior turning OFF of resources for increased energy saving. Depending upon user velocity, REHO on average results in 35% improved energy consumption compared to LTE standard [24]. This work besides comparing energy efficiency, further investigates call blocking and channel outage probability in energy efficient REHO deployed LTE networks.

3. SYSTEM MODEL

The system model consists of call blocking probability estimation, outage probability model and Poisson process used to generate calls presented in following section.

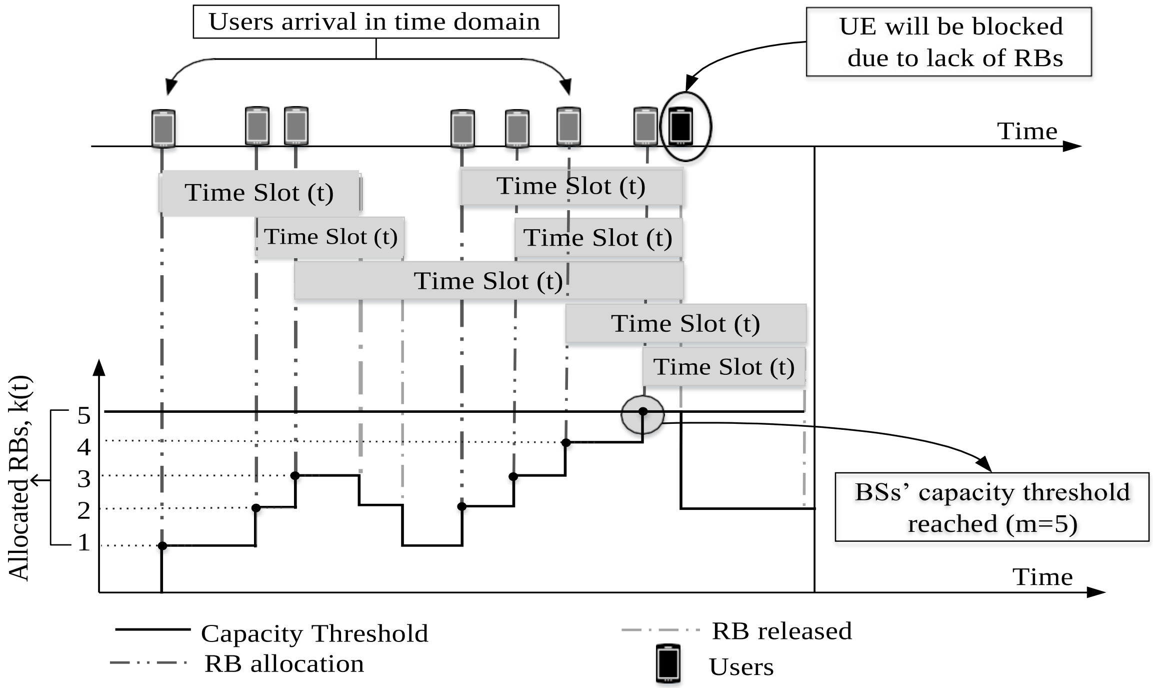


Figure 2. Call blocking probability via *M/M/n/n*

A. Call Blocking Probability Estimation

The call blocking probability must be defined as less than some predefined number during the network planning or deployment. In this context, Erlang function can be employed to estimate minimum number of channels required per cell. The Erlang B formula calculates probability under *M/M/m/m* [30, 31] assumptions listed as follows.

1. *Blocked users call removed*
   - *No line up for users call request*
   - *If any user request resource, then it will be given immediate access to resources if one is available*
   - *User call request will be blocked if all resources are already occupied.*
2. *Users call arrival strictly by poisson process.*
3. *There is finite number of users.*
4. *The resource occupying time duration is exponentially distributed.*
5. *The users call duration time is autonomous.*
6. *The number of resources (i.e. m) available in trunking pool is known.*

Figure 2 presents *M/M/n/n* assumptions where m is assumed to be equal to 5. It can be clearly seen that first five users are allocated with resources; however sixth inbound user has been blocked due to lack of resources. Importantly '*m'* presents number of available resource at the time *(t)* while *k(t)* describes number of occupied resources. Thus, if *k(t)* < *m* then new user request can be served, however new user request will be denied if *k(t)* = *m* as shown in Figure 2. In the same context, the Erlang function [30] is used to calculate blocking probability in a single link with data capacity *C* (trunks) and offered data load with intensity n. This method is employed to estimate probability that users call request will be blocked by the system due to unavailable resources, which are already allocated to other users in network. Importantly call blocking probability over numerous channels carrying many data streams in circuit switched network is calculated using following parameters:

s: data traffic stream
l: channel (link)
D_s*: Offered data rate intensity of traffic stream s*
D_c*: data traffic intensity offered to link/channel*
B_s*: Blocking of data stream of s*
B_l*: call blocking probability in channel* l
R: route of s

Using above mentioned parameters, $l \in R$, also l is on the route of s. The approximate blocking probability for small low traffic can be calculated as $C_{Bp} = \sum_{l \in R} B_l$ [31]. However, if link blocking is independent then blocking probability can be calculated as: $1 - B_s = \prod_{l \in R}(1 - B_l)$. The next step is to estimate reduced load using *Erlang's* fixed-point method. Importantly when blocking is small then intensity of the offered traffic to l (link) can be calculated using *Erlang function* $E_r(C, n)$ as [31]:

$$D_c = \sum_{s:\, l \in R} D_s \quad , \quad B_l = E_r(C_l, D_c). \tag{1}$$

$$\underbrace{s}_{\text{Sum over the data traffic streams using link } l}: l \in R$$

However, if blocking is large then traffic thinning in other links must be considered as:

$$\{ \begin{array}{l} D_s^l \; Trivial\ traffic\ offered\ by\ stream\ s\ to\ l \\ D_c = \sum_{s:\, l\in R} D_s^l \; Sum\ of\ trivial\ traffic\ offered \end{array} \quad (2)$$

$$D_s^l = \{ \begin{array}{ll} 0, & This\ is\ trivial\ factor\ in \\ D_s . \prod_{k\in R-(l)} (1 - B_k)\ ; & other\ channels/links \end{array} \quad (3)$$

$$D_s^l = \{ \begin{array}{ll} 0, & if\ l \notin R \\ D_s . \frac{1}{1-B_l} \prod_{k\in R} (1 - B_k)\ ; & if\ l \in R \end{array} \quad (4)$$

Accordingly, the blocking probability of link l can be written as:

$$B_l = E_r \{C_l, \sum_{s:\, l\in R} D_s \frac{1}{1-B_l} \prod_{k\in R} (1 - B_k)\}. \quad (5)$$

Notably the blocking in channel/link l purely depends on the blocking in other links. Equation (5) is used for single link while multiple equations depends on each other in term of blocking probability.

B. Outage Probability

In this work *Nakagami* and *Rician* fading [32] is considered for outage probability calculation. We assume that P_f is prompt faded power of the wanted signal while $\beta_d = E_s [P_f]$ presents short term average. The P_f is subject to the *Nakagami* fading with its parameter (N_p) and *pdf* of P_f is given by [32]:

$$P_{df}(P_f) = (\frac{N_p}{\beta_d})^{N_p} \frac{P_f^{N_p-1}}{T(N_p)}\ exp\ (-\frac{N_p P_f}{\beta_d}). \quad (6)$$

On the other hand, for *Rician fading* with *Rician factor* (R_g), the pdf converts as follows:

$$P_{df}(P_f) = \frac{R_g + 1}{\beta_d} \exp\ (-R_g - \frac{R_g + 1}{\beta_d} P_f)$$

$$* \ I_r\ (2\sqrt{\frac{R_g(R_g + 1)}{\beta_d}} P_f\ ). \quad (7)$$

The $I_r(.)$ is the r_{th} *Bessel function* [33]. Importantly, N_p=1 for *Nakagami* fading and *Rician*, however it leads towards *Rayleigh* in which case the *pdf* is presented as $P_{df}\ (P_f\ ) = \exp(-\ P_f/\beta_d)/\beta_d$. While the power ($N_i$) of active interference signals $\{i_s\}_{i=1}^{Ns}$ is assumed to be independent and identically distributed (*i.i.d*) with same average fading β_i.Thus the *pdf* of interfering signals $P_{di}\ (i_s)$ is quite similar to equation (6) for the wanted signals, instead with different parameters. In the same context, the entire instantaneous interfering power (I_s) is just a sum of the instantaneous powers of the N_i, which can be calculated as:

$$I_s = \sum_{i=1}^{N_i} i_s. \quad (8)$$

The outage probability, in the system with limited power and interference is presented as CIR, $\lambda = P_f / I_s$ falls below a predefined protection ratio λ_{th}. In other words, instantaneous power of desired signals P_f falls below predefined threshold Tr_{th}. The outage probability can be calculated as:

$$PB_{Out} = P\ [\lambda = \frac{P_f}{I_s} \le \lambda_{th}\ or\ P_f \le Tr_{th}\ ] \quad (9)$$

Above equation can be rewritten in relation of *pdf* of $P_f$and total instantaneous interfering power as I_s, $P_{I_s}(I_s)$ as:

$$PB_{Out} = 1 - \int_{Tr_{th}}^{\infty} * [\int_0^{\frac{P_f}{\lambda_{th}}} P_{I_s}(I_s) d_{I_s}]\ P_{P_f}(P_{P_f})\ d_{P_f} \quad (10)$$

Lets assume that received signals from users is *Rician* distributed with β_d and R_g and there is N_i interference in the system with average fading power β_I . Thus, the total instantaneous power I_s will have *pdf* as follows:

$$P_{I_s}\ (I_s) = \frac{I_s^{N_i-1}}{\beta_d^{N_i}(N_i - 1)} exp\ (-1 \frac{I}{\beta_I}). \quad (11)$$

Once the finite sum representation of the gamma *cdf* applied, equation 7 and 10 gives following outage probability with switching the order of summation and integration as:

$$PB_{Out} = 1 - Q_1 \left(\sqrt{2R_g} \sqrt{\frac{2(R_g + 1)Tr_{th}}{\beta_d}} \right) \quad (12)$$

$$+ \frac{R_g + 1}{\beta_d} \sum_{n=0}^{N_i} \frac{1}{n} * \int_{Tr_{th}}^{\infty} (\frac{P_f}{\lambda_{th}\beta_I})^n$$

$$* \ exp\ [-\ R_g - (\frac{1}{\lambda_{th}\beta_I} + \frac{1 + R_g}{\beta_d})\ P_f\ ]$$

$$* \ I\ (2\sqrt{\frac{R_g(R_g + 1)P_f}{\beta_d}})\ d_{P_f}$$

Notably, the Q_1 describes first order *Marcum Q Function* [34]. The equation (12) can be rewritten using [35] and change of variable in the integral as:

$$PB_{Out} = 1 - Q_1\left(\sqrt{2R_g}, \sqrt{\frac{2(R_g+1)Tr_{th}}{\beta_d}}\right) + \frac{v^2}{2R_g}\sum_{n=0}^{N_i-1}\frac{G_n}{n} wQ_{2n+1,0(v,\,q)} . \quad (13)$$

Thus G_n can be calculated as:

$$G_n = \left(2 + \frac{2(R_g+1)\lambda_{th}\beta_I}{\beta_d}\right)^{-1} * \exp\left[-R_g + R_g\left(1 + \left(\frac{\beta_d}{(R_g+1)\lambda_{th}\beta_I}\right)\right)^{-1}\right] . \quad (14)$$

while v and q can be deliberated as:

$$v = \sqrt{2R_g\left(1 + \frac{\beta_d}{(R_g+1)\lambda_{th}\beta_I}\right)^{-1}}$$

$$q = \sqrt{2\left(1 + R_g + \frac{\beta_d}{\lambda_{th}\beta_I}\right)\frac{Tr_{th}}{\beta_d}}$$

where, $Q_{o,n}(.,.)$ presents *Nuttall Q Function* as defined by [35]:

$$Q_{o,n}(v,q) = \int_q^\infty c^o \, exp\left(-\frac{c^2+v^2}{2}\right) I_n(vc)dx \quad (15)$$

Importantly *Nuttall Q Function* decreases to the generalized *Marcum Q Function* as in [36]:

$$Q_o(v,q) = \int_q^\infty c^o \left(\frac{c}{v}\right)^{o-1} * \exp\left(-\frac{c^2+v^2}{2}\right) * I_o - 1(vc)xdx \quad (16)$$

Thus equation (16) can be further resolved as:

$$Q_{o,n}(v,q) = Q_1(v,q) + \exp\left(-\frac{c^2+v^2}{2}\right) * \sum_{k=1}^{0-1}\left(\frac{q}{v}\right)^k I_k(vq) . \quad (17)$$

This holds when $o = n+1$. Point to be notice that when $o = 1$ and $n = 0$, then the *Nuttall Q Function* reduces to *Marcum Q-Function*. Thus, blocking probability can be calculated using equation (13), (14) and (17) respectively.

C. UEs Arrival through Poisson process

This work employs Poisson process [37] which is one of the most commonly used models to originate calls from large number of independent UEs. The generated calls through the employment of Poisson process are used in call blocking probability estimation. Poisson process presents discrete arrival of calls as shown below Figure 3a:

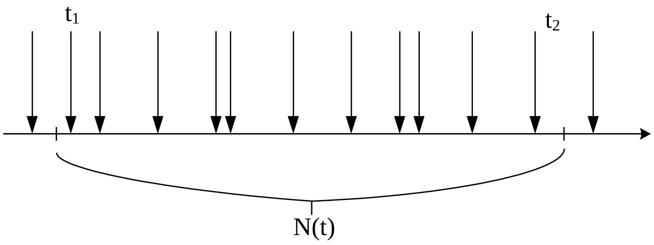
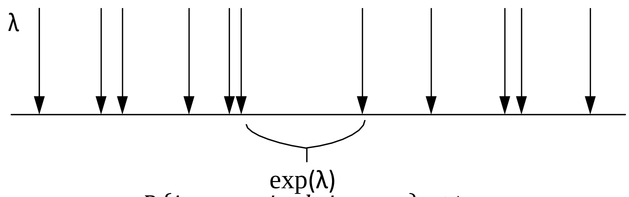


Figure 3a. Discrete calls arrivals

The process can be described by counter process N_t or $N(t)$. The counter presents the number of call arrivals that have occurred in the interval $(0, t)$ or (t_1, t_2). So accordingly,

- *$N(t)$ presents number of calls arrival in interval $(0, t)$ using stochastic process.*
- *$N(t_1, t_2)$ presents number of calls arrival in the interval (t_1, t_2) using incremental process $N(t_2) - N(t_1)$.*

The used *Poisson process* can be characterized as the most random process with a given intensity ⋋. The interarrival times of call is purely autonomous and must follow the *Exponent* (⋋) distribution as shown in below Figure 3b.



$P\{interarrival\ time > t\}e^{-\lambda t}$

Figure 3b. Calls - *Exponent* (⋋) distribution

Since the random choice is made from Poisson process with intensity ⋋ in a way that each call arrival is chosen with probability P_{rb} , thus resulting in to poisson process with intensity P_{rb} ⋋. All calls arrival in the work is generated using Poisson process (Figure 3c).

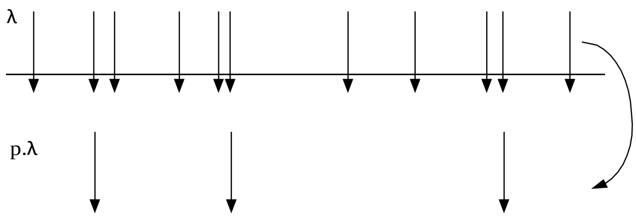


Figure 3c. Calls generation though Poisson process

4. PERFORMANCE ANALYSIS

System level simulations are performed in MATLAB to analyse the performance of REHO before it is compared with 3GPP LTE standard [38, 39] and other state of art [25-27] for key performance related parameters including energy efficiency, outage probability and call blocking probability. The system model consists of cellular LTE network which contain 21 cells each sized 1000 meters. There are 50 UEs randomly distributed in cell while traffic is generated using Poisson process for estimation of call blocking and outage probability as discussed in section 3 above. Numerous performance related parameters including outage probability, call blocking probability and energy efficiency are analysed. Table 1 provides complete system parameters used in simulations.

Table 1. System Parameters

Parameters	Values
Operating Frequency	2.14 GHz
Cell Radius	1000 m
Maximum Transmit power	40W
System Bandwidth	20 MHz
Hysteresis	1dBm REHO, 4dBm LTE
User speed	40 km/h
Offered Traffic Rate	10, 20, 30 and 40Mbps
Resource Distribution	Uniform
Number of RBs	100
Number of UEs	50 / cell
Mobility Model	Random way point
Resource element size	15 kHz
Call Arrival	Poisson process
BS Antenna gain	14 dB
Channel allocation	Fixed / Static
Total Number of cells	21

A. *Energy Efficiency*

Figure 4 presents energy efficiency achieved in REHO while compared to other state of art [25, 26] and LTE standard. This analysis is carried out by comparing REHO with BS switching OFF energy saving scheme [26], Bandwidth expansion based scheme [25] and LTE standard [28]. It can be clearly seen that based on the fact that REHO employs reduced early handover, thus REHO enabled LTE network enjoys highest energy efficiency as compared to the other schemes. The V-BEM energy efficiency is lower than REHO while better then switching OFF scheme. Further BS switching OFF scheme achieves lowest energy efficiency as compared to other two schemes, however still better then LTE standard.

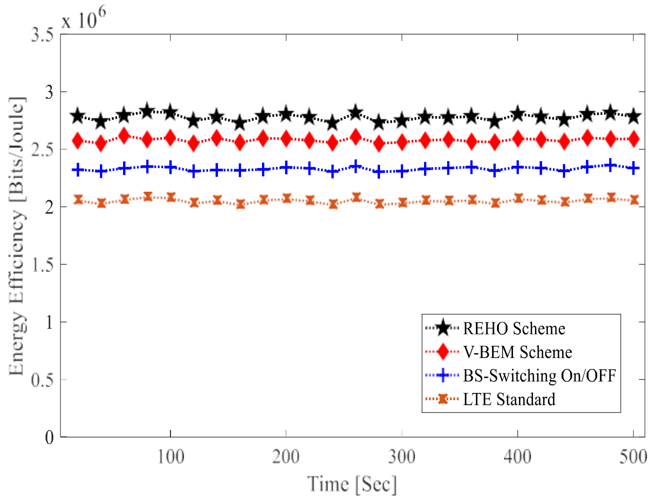


Figure 4. Energy Efficiency Comparative analysis

B. *Call Blocking Probability*

REHO is compared in terms of performance with other state of art which implements call blocking probability, such as EE-BS based scheme [27] and LTE standard whereas QoS threshold is maintained at 2 % [38]. REHO, due to reduced early handover resulted into higher overall system call blocking probability while compared to LTE standard, however it still performed better compared to other state of art, i.e. EE-BS scheme. Further, overall system call blocking probability increased across the board with increase in data rate. Importantly, higher data rate requires more resources thus effecting overall system capacity thereby leading towards higher call blocking probability (Figure 5). LTE standard always remained below 3GPP threshold of 2% whereas REHO exceeded this threshold at data rate of approximately 10 Mbps compared to EE-BS scheme at data rate of approximately 7 Mbps.

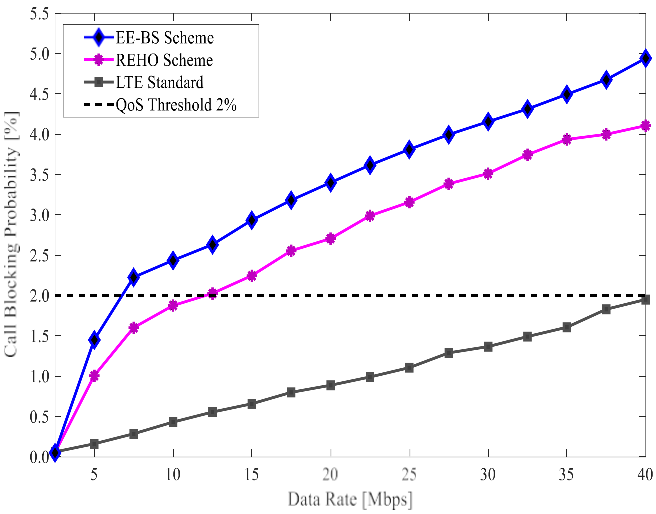


Figure 5. Call Blocking Probability

C. Channel Outage Probability

Since REHO implements early handover, it is vital to investigate the impact of reduced early handover on channel outage probability. Subsequently, outage probability for REHO is investigated at varying data rates for increasing number of UEs, both for outbound handovers at serving cell and inbound handovers at target cell respectively. Serving cell outage probability reduces with increasing outbound handovers due to the fact that it turns off its resource blocks right after reduced early handover thus resulting in reduced channel outage probability due to lesser interference component in the cell (Figure 6). In line with call blocking probability results, outage probability is also higher at higher data rates due to higher level of RBs utilisation, interference and vice versa.

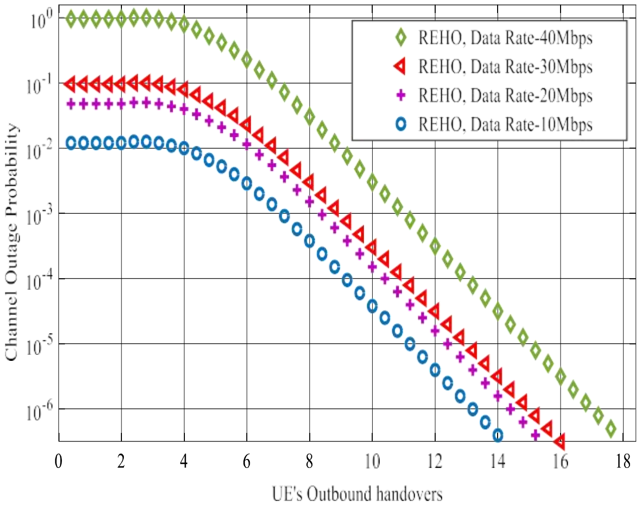


Figure 6. Serving Cell Outage Probability

Figure 7 presents target cell outage probability in relation to the incoming UEs from serving cell. Importantly, incoming users demand additional resources from target cell thereby increases the level of radio signals transmission in cell leading towards higher interference which directly impacts channel outage probability. Further, the outage probability also grows with increasing number of inbound users because higher number of incoming UEs demands more and more resources. Notably the level of interference also imparts from intensity of radio frequency in surrounding area thereby affecting the overall outage probability. In line with channel outage probability for outbound users at serving cell, outage probability for incoming users at target cell is also higher at higher data rates due to higher level of RBs utlisation, interference and vice versa.

Figure 8 presents the impact of varying data rate on outage probability and energy saving. Importantly it can be seen that higher data rate not only reduces overall system energy saving but also increases channel outage probability due to higher transmission signals overhead and interference. In contrast, lower data rates allow BSs to turn *OFF* idle RBs thus resulting in to increased energy saving and low outage probability.

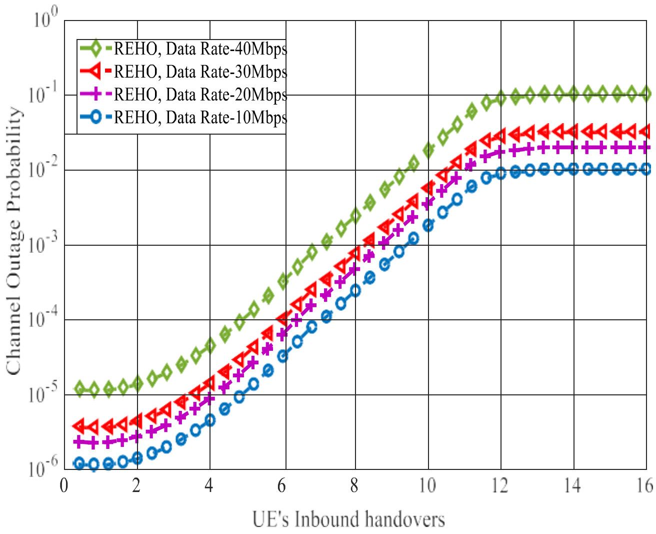


Figure 7. Target Cell Outage probability

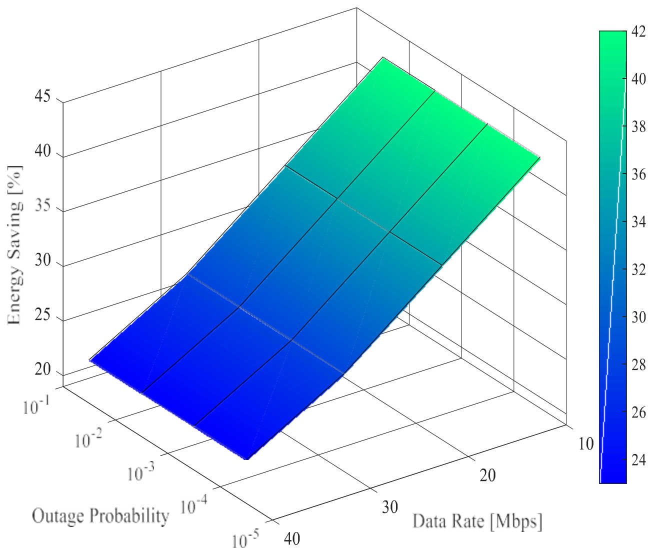


Figure 8. Data rate vs Outage Probability and Energy Saving

Further Figure 9 describes simultaneous analysis of outage probability, call blocking probability and data rate. In line with results presented in Figure 8, again higher data rate also effects call blocking probability (Figure 9). Notably, during peak data rate period, all available resources are engaged with associated UEs which results in to limited resources availability thus leading towards higher call blocking as BSs are unable to accept increasing incoming users. To sum up, higher data demands always impact overall system key performance indicators, such as energy saving, call blocking and channel outage probability, as shown in Figures 8 and 9 respectively. This equally applies to REHO, LTE standard as well as bulk of energy saving schemes presented in literature which mostly achieve energy saving due to turning off of resources.

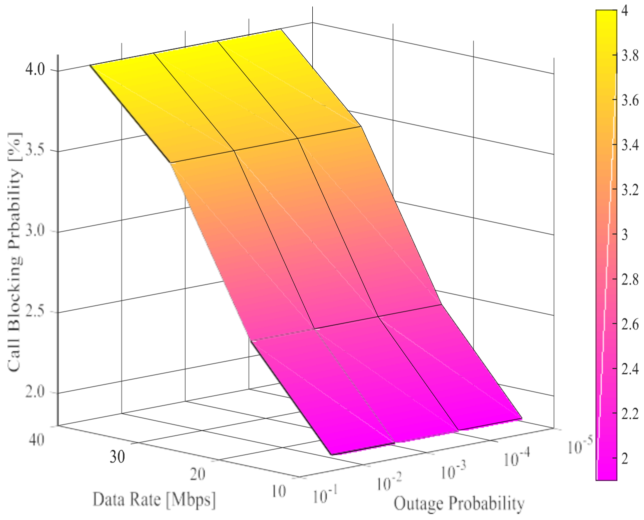


Figure 9. Data rate vs Outage Probability and Call Blocking Probability

5. CONCLUSION

Due to advancement in smart phone and applications, there is rapid increase in number of mobile users and their data demands. Accordingly, cellular networks infrastructure is expanding day by day through the deployment of additional BSs. Additional BSs and rising data demand results in to higher interference and longer resources allocation respectively. Cellular networks reuse frequency for efficient resource utilization which in fact leads toward more interference in network thus resulting in to increased outage probability. In parallel, growing UEs data demand effects overall call blocking probability. Both these parameters play key role in estimation of overall system performance. Alongside, energy efficiency is vital parameter to enable portability and longevity of mobile user equipment. This paper investigates call blocking and channel outage probability in REHO deployed LTE networks. Besides providing increased energy efficiency, REHO is found to be competitive enough for call blocking probability in the presence of Poisson process call arrivals. Since REHO modifies A3 parameters, it is fairly practical and can be easily deployed in existing LTE infrastructure without any major modifications. This work provides a significant insight for key performance indicators of call blocking and channel outage probability in energy efficient REHO deployed LTE networks.

REFERENCES

1. F. Baccelli, “Stochastic Geometry and Architecture of Communication Network,” Telecommunication System, vol. 7, no. 1-3, 1997, pp. 209-227.

2. A. Guo and M. Haenggi, “Spatial Stochastic Models and Metrics for the Structure of Base Stations in Cellular Networks,” IEEE Transactions on Wireless Communications, vol. 12, no. 11, Nov 2013.

3. C. Seol and K. Cheun, “A Statistical Inter-Cell Interference Model for Downlink Cellular OFDMA Networks Under Log-Normal Shadowing and Multipath Rayleigh Fading,” IEEE Transactions on Communications, vol. 57, No. 10, Oct 2009.

4. S. Mukherjee, “Distribution of Downlink SINR in Heterogeneous CellularNetworks,” IEEE Journal on Selected Areas in Communications, vol. 30, No. 3, Apr 2012.

5. S. M. Hasan, M. A. Hayat and M. F. Hossain, "On the downlink SINR and outage probability of stochastic geometry based LTE cellular networks with multi-class services," 2015 18th International Conference on Computer and Information Technology (ICCIT), Dhaka, 2015, pp. 65-69.

6. K. W. Sowerby and A. G. Williamson, “Outage probability calculations for multiple cochannel interferers in cellular mobile radio systems,” Proc. Inst. Elect. Eng. F, vol. 135, pp. 208–215, June 1988.

7. H. Ghavami and S. Shirvani Moghaddam, "Outage probability for underlaying Device to Device communications," *2016 8th International Symposium on Telecommunications (IST)*, Tehran, 2016, pp. 353-358.

8. X. Ge, B. Yang, J. Ye, G. Mao, C. X. Wang and T. Han, "Spatial Spectrum and Energy Efficiency of Random Cellular Networks," in *IEEE Transactions on Communications*, vol. 63, no. 3, pp. 1019-1030, March 2015.

9. J. R. Haug and D. R. Ucci, “Outage probability for microcellular radio systems in a Rayleigh/Rician fading environment,” in Proc. IEEE Int. Conf. Commun. (ICC’92), June 1992, pp. 312.4.1–312.4.5.

10. Y. D. Yao and A. U. H. Sheikh, "Investigations into cochannel interference in microcellular mobile radio systems," in IEEE Transactions on Vehicular Technology, vol. 41, no. 2, pp. 114-123, May 1992.

11. Y. Liu, Y. Yu, Q. Wu, Z. Li, W. j. Lu and H. b. Zhu, "A Closed-form and Stochastic Wall Insertion Loss Model for Dense Small Cell Networks," in *IEEE Access*, vol. PP, no. 99, pp. 1-1, Jan. 2018

12. Y. D. Yao and A. U. H. Sheikh, “Outage probability analysis for microcell mobile radio systems with cochannel interferers in Riciani Rayleigh fading environment,” Electron. Lett., vol. 26, pp. 864-866, June 1990.

13. B. Shang, L. Zhao and K. C. Chen, "Enabling device-to-device communications in LTE-unlicensed spectrum," *2017 IEEE International Conference on Communications (ICC)*, Paris, 2017, pp. 1-6.

14. H. Yasar Lateef, V. Dyo and B. Allen, "Performance analysis of opportunistic relaying and opportunistic hybrid incremental relaying over fading channels," in *IET Communications*, vol. 9, no. 9, pp. 1154-1163, 6 11 2015.

15. U. Sawant and R. Akl, "Subcarrier allocation in LTE network deployment with mobility," *2017 IEEE 8th Annual Ubiquitous Computing, Electronics and Mobile Communication Conference (UEMCON)*, New York City, NY, 2017, pp. 1-8.

16. B. Zeng and L. Yao, "Traffic patten based resource allocation algorithm for hybrid transmission in LTE

networks," *2017 IEEE 3rd Information Technology and Mechatronics Engineering Conference (ITOEC)*, Chongqing, 2017, pp. 81-85.
17. O. O. Omitola and V. M. Srivastava, "A channel borrowing CAC scheme in two-tier LTE/LTE-Advance networks," *2017 4th International Conference on Advanced Computing and Communication Systems (ICACCS)*, Coimbatore, 2017, pp. 1-5.
18. K. B. Ali, M. S. Obaidat, F. Zarai and L. Kamoun, "Markov model-based adaptive CAC scheme for 3GPP LTE femtocell networks," *2015 IEEE International Conference on Communications (ICC)*, London, 2015, pp. 6924-6928.
19. S.-Y. Kim, S. Ryu, C.-H. Cho, and H.-W. Lee, “Performance analysis of a cellular network using frequency reuse partitioning,” Perform. Eval., vol. 70, no. 2, pp. 77–89, Feb. 2013.
20. D. Lopez-Perez, X. Chu, A. Vasilakos, and H. Claussen, “Power minimization based resource allocation for interference mitigation in OFDMA femtocell networks,” IEEE J. Sel. Areas Commun., vol. 32, no. 2, pp. 333–344, Feb. 2014.
21. M. Sawahashi, Y. Kishiyama, A. Morimoto, D. Nishkawa, and M. Tanno, “Coordinated multipoint transmission/reception techniques for LTE-Advanced,” IEEE Trans. Wireless Commun., vol. 17, no. 3, pp. 26–34, Jun. 2010.
22. S. Y. Kim and C. H. Cho, "Call Blocking Probability and Effective Throughput for Call Admission Control of CoMP Joint Transmission," in IEEE Transactions on Vehicular Technology, vol. 66, no. 1, pp. 622-634, Jan. 2017.
23. S. N. Ohatkar and D. S. Bormane, "Channel allocation technique with genetic algorithm for minimizing call blocking probability in cellular network," 2015 International Conference on Industrial Instrumentation and Control (ICIC), Pune, 2015, pp. 783-788.
24. G. A. Safdar and K. Kanwal, "Euclidean Geometry Axioms Assisted Target Cell Boundary Approximation for Improved Energy Efficacy in LTE Systems," in *IEEE Systems Journal*, vol. PP, no. 99, pp. 1-9, Oct. 2017.
25. S. Videv, H. Haas, J. S. Thompson and P. M. Grant, "Energy efficient resource allocation in wireless systems with control channel overhead," 2012 IEEE Wireless Communications and Networking Conference Workshops (WCNCW), Paris, 2012, pp. 64-68.
26. T. En, W. Ye, D. Fei, P. Zhiwen and Y. Xiaohu, "A practical eNB off/on based energy saving scheme for real LTE networks," 2015 17th International Conference on Advanced Communication Technology (ICACT), Seoul, 2015, pp. 12-17.
27. F. Han, Z. Safar and K. J. R. Liu, "Energy-Efficient Base-Station Cooperative Operation with Guaranteed QoS," in IEEE Transactions on Communications, vol. 61, no. 8, pp. 3505-3517, August 2013.
28. Jiangping Jiang et.al, “ On Distributed Dynamic Channel Allocation in Mobile Cellular Networks”, IEEE Transaction on Parallel and Distributed System ,vol.13 No.10 ,2002,pp. 1024-1037
29. Katzela and M. Naghshineh, “Channel Assignment Schemes for Cellular Mobile Telecommunication Systems: A Comprehensive Survey”, IEEE Personal Communication ,Vol. 31, No. 3 ,1996,pp. 10-31
30. A. M. Elshawesh and M. Abdulali, "Dimensioning of Circuit Switched networks by using Simulation code based on Erlang (B) formula," 2014 Global Summit on Computer & Information Technology (GSCIT), Sousse, 2014, pp. 1-5.
31. Jian Ni and S. Tatikonda, "Calculating blocking probabilities for loss networks based on probabilistic graphical models," Proceedings. International Symposium on Information Theory, 2005. ISIT 2005., Adelaide, SA, 2005, pp. 568-572.
32.Hong-Chuan Yang and M. S. Alouini, "Closed-form formulas for the outage probability of wireless communication systems with a minimum signal power constraint," in IEEE Transactions on Vehicular Technology, vol. 51, no. 6, pp. 1689-1698, Nov 2002.
33. R. Salahat, E. Salahat, A. Hakam and T. Assaf, "A simple and efficient approximation to the modified Bessel functions and its applications to Rician fading," 2013 7th IEEE GCC Conference and Exhibition (GCC), Doha, Qatar, 2013, pp. 351-354.
34. I. S. Koh and S. P. Chang, "Uniform bounds of first-order marcum Q-function," in IET Communications, vol. 7, no. 13, pp. 1331-1337, September 4 2013.
35. A. Nuttall, "Some integrals involving the Q_Mfunction (Corresp.)," in IEEE Transactions on Information Theory, vol. 21, no. 1, pp. 95-96, January 1975.
36. P. C. Sofotasios and S. Freear, "A novel representation for the Nuttall Q-function," 2010 IEEE International Conference on Wireless Information Technology and Systems, Honolulu, HI, 2010, pp. 1-4.
37. Tamir Hazan; George Papandreou; Daniel Tarlow, "A Poisson Process Model for Monte Carlo," in Perturbations, Optimization, and Statistics , 1, MIT Press, 2017, pp.412.
38. 3GPP, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Networks (E UTRAN): Overall description", TS 36.300, V10.4.0.
39. 3GPP, "3rd Generation Partnership Project; Technical Specification Group Radio Access Networks; Radio Frequency (RF) system scenarios", TR 25.942, V9.0.0