Inter cell interference modeling and analysis in long term evolution (LTE)

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ABSTRACT

Long Term Evolution (LTE) is promising standard for data rate and system capacity (coverage) in wirelesses communication history. Inter cell interference (ICI) is a dominate impairment of LTE systems. In interference, modeling and analysis have focused on the first tier only, but considering ICI arises from the second tier is very crucial in communication system standard and implementations too. In this research work interference modeling is proposed and analyzed for the first two subsequent tires under various channel environments. The work is analytically quantified with respect to standard parameters and system models using Matlab and other supportive tools. Thus, link level simulation results demonstrate, ICI beyond the first tier becomes active in urban environment and the smaller cell size increases ICI power in LTE.

Keywords: Frequency reuse, Intercell interference, LTE, Shot noise, Tiers
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INTRODUCTION

The main targets of Long-term Evolution (LTE) system are to support high data rate of 100 Mb/s in the downlink (DL) and 50 Mb/s in the uplink (UL), improve cell edge spectrum efficiency, low latency, increased bandwidth (capacity), and improve Quality of Service (QOS). However, these benefits face challenges like high path loss, greater signal attenuation due to higher frequency, transmit power controls problem, interference signals from neighbor cells and others.

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Cell-edge users are highly susceptible to the effects of ICI. Hence, their radio channel is much worse than users closer to the evolved Node Base station (eNB), unless more resources are assigned to them for fairness among users (Sauter, 2010). LTE can be deployed with frequency reuse for reliable transmission (Muzahidar and Rahman, 2014). The data rates may vary substantially and relatively low data rate could be available at the end users. Though the bandwidth is reduced due to frequency reuse larger than one (like FR-3), the signal to interference ratio (SIR) will be increased and correspondingly higher achievable data rate per MHz will be gained for the cell edge users and the impact of interference could be mitigated (Sauter, 2010). The inter carrier interference (ICI) arises when the same frequency is allocated in cells in order to implement frequency reuse to cover large areas and increase capacity of the system. Therefore, data and control channels can experience a significant level of interference from neighbor cells in LTE system that can reduce the achievable spectral efficiency especially at the cell-edge. The employed frequency reuse schemes dictate how the nodes that reuse the frequency resource are close to each other. In addition to this, other factors that influence ICI are transmitting power control schemes, multi-antenna techniques, resource allocation and others. Interference is major limiting factor in the performance of cellular radio; it limits capacity and increases the number of dropped calls. It has a direct correlation with the quality of services (QOS) too. In order to study the impact of ICI in LTE, mathematical models are described and implemented in simulation. Some of the parameters to deal the impact of ICI are signal to interference noise ratio (SINR), SIR computations, and calculation of throughputs at the receiver, coverage and capacity considerations, and antennas' radiation patterns and tilting on the transmitter gains and block error rate (BLER). Transmission over a particular link was possible if the SIR (SINR) was greater than a given threshold, but this leads to an overhead in transmission power resulting in a non-optimal use of spectrum and power resources.

The interference problem will be the driving factor in network planning and optimization in wireless communication system, because of limited resource of bandwidth and transmitter power, so that it is very important to properly model and analysis interference (Amitabhe and Rapeet, 2011; Tabassum, 2012).

Therefore, an important trade - off involving in ICI management to ensure high total system capacity (i.e. sum rate), fairness and reliability for cell- edge user (Khan, 2009; Pijcke *et al.*., 2011; Li *et al.*., 2018; Wei *et al.*., 2019). ICI analysis of Orthogonal Frequency Division multiple Access (OFDMA) systems has been analyzed over rapidly fading Nakagami-m Channels (Zhang *et al.*., 2006). In LTE, ICI is a serious and dominant problem and any technique to minimize those impairment in cellular systems leads directly to increase system capacity and performance but there is no a clear modeling and analyzing the challenge rather applying mitigation techniques between eNodeBs to increase the quality of services (QOS) for cell-edge user in the network system. Most previous works did not consider ICI arises from second tire that has been considered in this work.

Thus, the main objective of this work is to model and analysis ICI based on geometrical layout of LTE network with various channel environments (Rician and Rayleigh fading channel) in urban area for worst scenario. The interference is properly modeled as a shot noise (SN) for the sever condition to provide better throughput and minimum bit error rate for cell edge users in urban area and the ICI for uplink and downlink is analyzed using stochastic geometry layout and statistical analysis.

MATERIALS AND METHODS

The research is conducted by simulation using Matlab software based on the computation obtained from the system network model with the standard LTE parameters. The computational analysis is performed for both uplink and downlinks between eNB and UE. Since noise and interference are one of the governing issues for the performance of a wireless link, this work is properly modeling the interference as a SN and regular hexagonal cell shape is considered to analysis ICI in LTE networks. In our work, the stochastic geometry tool is used to model interference in LTE networks and to model cellular networks by considering the random location of transmitter and receiver nodes which is more realistic assumption and helps us to obtain explicit expression (one can compute explicit expressions for the total interference at a eNB with simultaneous transmissions from randomly located nodes) for important system metrics like SINR. To analysis the performance of the system network of LTE using Matlab software we considered Rician and Rayleigh fading channel environments. The path loss distance between eNB and cell edge user served in a cell sector location for frequency recuse one and there are computed based on the network model. The maximum and average ICI power in the first and second tier with respect to the number of users are simulated for both Rician and Rayleigh fading channel where the ICI is analyzed for both frequency reuse one and three. Finally, based on the obtained simulation results basic concepts are interpreted and conclusion is drawn for the corresponding system network model.

Interference modeling

Proper modeling of ICI in wireless communication is very important for the design and performance analysis of the overall systems network. Interference in almost all pervious works have been modeled as Gaussian noise (Galiotto *et al*., 2015), but Gaussian modeling of interference is not appropriate because the spectrum and the existence of the interference is not constant and continuous rather it exist randomly at some instant of time. Because of the nature of interference and the characteristics of SN, in our work modeling ICI as SN is more appropriate (Lowen and Malvinc, 1990).

The SN process is a very well-studied process for interference modeling. Schottky first introduced it in 1918 in the study of fluctuations in the anode current of a thermionic diode (Islam and Chowdhury, 2013; Akl, 2014). In SN implementation, its properties (moment generating functions, amplitude probability density function, autocorrelation functions and power spectral density) would be considered and analyzed either stochastically or deterministically by impulse response approach. For deterministic and stochastic approach, the impulse response function of SN is expressed by Eq. (1) and (2), respectively.

$$\mathrm{I(t)} = \sum_{j=-\infty}^{\infty} \mathrm{h}(\mathrm{t}-\mathrm{t_j}) \tag{1}$$

$$\mathrm{I(t)} = \sum_{j=-\infty}^{\infty} \mathrm{h}(\mathrm{k_j}, \mathrm{t}-\mathrm{t_j}) \tag{2}$$

Where t_j, h (.), and k_j are random events, impulse response function, random sequence over which the impulse response functions is taken from the events respectively (Steven and Malvinc, 2013). The SN for both continuous and discrete signals is shown in Figure 1.

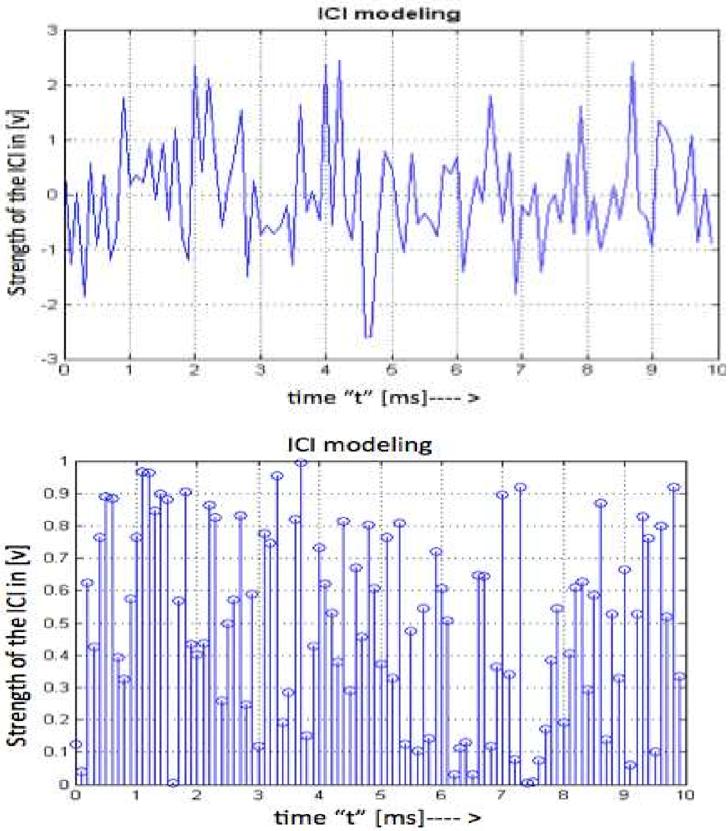

Figure 1. Shot Noise model: SN model in continuous signal (top), and SN model in discrete signal (bottom)

Let's consider the general principle of received signal

$$r(t) = h_{dc}(t)s(t) + \sum_{n_c=1}^{N_c} h_{ic}(t)I_X(t) + n(t) \quad (3)$$

Where $\mathrm{s(t)}$ is the desired transmitted signal, $\mathrm{I_x(t)}$ is the interference signals for $\mathrm{s(t)}$ per user and $\mathrm{h_{dc}(t)}$ and $\mathrm{h_{ic}(t)}$ are channels model of the desired and interfering signals respectively, n(t) is the additive white Gaussian noise at the receiver and $n_c = 1,2 \ldots. N_c$ is number of cells according to our model and tires (Anang, 2011). A stochastic impulse response function can be used to model different random parameters such as channel fluctuation, transmitted power of the nodes, randomness of node distribution, fading states of the channels, and channel access scheme, i.e by relating equation (2) and the expression $\sum_{n_c=1}^{N_c} \mathrm{h_{ic}}\,(\mathrm{t})\mathrm{I_x(t)}$, we can compute total interference power per cell that depends on resource allocation of LTE (number of user per cell) and properties of impulse function as shown (Hossain *et al.,* 2013; Zarrinkoub, 2014).

$$\mathrm{I(t)} = \sum_{n_{uc}}^{N_{Uc}} \mathrm{I_x}(d_{i,\mathrm{eu}}\;, \mathrm{f_i}\;) \tag{4}$$

The total received interference signal in the cell edge area at eNB user, under a random path loss and fading condition of SN is formulated as (Hossain *et al.,* 2013).

$$\mathrm{I}_{\Phi(\mathrm{eu})}(\mathrm{t}) = \sum_{n_{uc}}^{N_{Uc}} \sum_{n_c}^{N} \frac{\mathrm{P_i\, f_i(eu)}}{(|\mathrm{i} - \mathrm{eu}|)^{\beta}} \;\; ; \mathrm{i, eu} \in \mathrm{R}^2 \tag{5}$$

$$\mathrm{I}_{\Phi(\mathrm{eu})}(\mathrm{t}) = \sum_{n_c}^{N} \sum_{n_{uc}}^{N_{Uc}} P_i\, \mathrm{k}\, \mathrm{g_{i,eu}} |\mathrm{i} - \mathrm{eu}\,|^{-\beta} \tag{6}$$

By substitute the path loss distance ($d_{i,\mathrm{eu}} = \mathrm{i} - \mathrm{eu}$), the received interference signal is rewritten as:

$$\mathrm{I}_{\Phi(\mathrm{eu})}(\mathrm{t}) = \sum_{n_c}^{N} \sum_{n_{uc}}^{N_{Uc}} P_i\, \mathrm{k}\, \mathrm{g_{i,eu}}\, \mathrm{d_{i,eu}}^{-\beta} \tag{7}$$

Where: - eu is location of eNB user (eNB is the point of interest that the effect of ICI is computed) at the area of interest that determines the total interference, $n_c \epsilon \{i_1, i_{2\ldots} N\}$ is the set of the interferers per cell, $\mathrm{i} \in \mathrm{R}^2$ is the location of users (Euclidean space), $\mathrm{N_{Uc}}$ is total number of user per cell, P_i is the transmitter power indexed by the interferer location and assumed constant, $\mathrm{g}_{i,\mathrm{eu}}$ is channel gain between i and eu, $d_{i,\mathrm{eu}} = \mathrm{i} - \mathrm{eu}$

is Euclidean distance (path loss distance), $f_i(eu) = k\, g_{i,eu}$ is fading channel distribution, $k = \left(\frac{c}{4\pi fc}\right)^2$ is dimensionless constant (where fc and c are the carrier frequency and speed of light respectively), β is the path-loss exponent, and Φ is area of the cell edge at eNB in the center of system network model which will be shown in the next section.

In this paper the effect of interference channel in the system can be model by the Rician fading and Rayleigh fading channel in a way described in the scenarios Rician/Rician and Rician/Rayleigh fading environment, this is due to that it is highly probable to have a situation where the desired signal experiences line-of-sight condition and the interfering signals experience line of sight and non-line-of-sight condition in case of both uplink and downlink communication (Tabassum, 2012). All mobile users, (both those with the desired cell and out-of-cell interferers) transmit at the same signal power Pd (Anang, 2011; Galiotto *et al.,* 2014). The signal received over L-paths Rican multipath model can be expressed as

$$r(t) = B\cos(2\,\pi\, f_c t) + \sum_{j=1}^{L} A_j \cos\left(2\,\pi\, f_c t + \theta_j\right) \qquad (8)$$

Where B is the amplitude of the line of sight component (B=0 for Rayleigh fading), A_j is the amplitude of the j^{th} reflected wave, θ_j is the phase of the j^{th} reflected wave and j=1, 2…L identifies the reflected and scattered waves.

System network model

The proposed system network model shown in Figure 2 has hexagonal shape network layout for analysis because of its geometric properties and implemented in cellular network design and planning. The following conditions have been considered in system network modeling and analysis: a) Area coverage of each cell is the same, path loss distance ($d_{i,\mathrm{eu}}$) used to calculate the interference in Eq.7 is the shortest distance (line of sight), b) user mobility is restricted in the area of ΔABC of Figure 2 with uniformly distributed and delay profile of the channel consider in this work is extended for urban model, c) two frequency reuse scenarios (FR-1 and FR-3) are considered where FR-1 and FR-3 network model for DL are shown in Figures 4 and 5, respectively, d) channel models considered for desired and interference signals are Rican and Rayleigh, e) resource allocation in all sectors of the cell edge is assumed to be the same; at least on resource block is assigned.

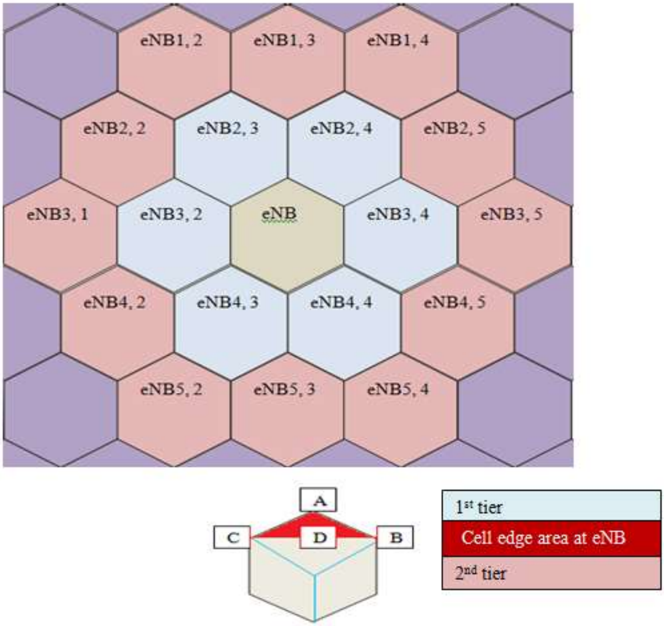

Figure 2. System network model

The basic resources in communication systems are power and bandwidth. 3Gpp LTE standard defines a resource allocation structure in time and frequency domains and it has many spectrum options. A resource element is placed at the intersection of an OFDM symbol and subcarrier, the LTE PHY specification allows an RF carrier that consist of any number of resource block (RB) in the frequency domain, ranging from a minimum of 6 RBs up to a maximum of 110 RBs. This corresponds to transmission bandwidths ranging from 1.4 to 20.0 MHz, with a sub carrier spacing of 15 kHz, and allows for a very high degree of LTE bandwidth flexibility. The RB definition applies equally to both DL and UL transmissions (Zarrinkoub, 2014; Ali *et al.*, 2018). Number of subcarriers to be allocated to each user must be scheduled by the system to facilitate a basic unit of resource allocation in OFDMA. Depending on how the subcarriers are allocated to construct each sub channel, the resource allocation methods are classified into a block, comb, and random (Hybrid) types as shown in Figure 3. In comb type resource allocation parts of the sub-carriers are always reserved as pilot for each symbol some of the subcarriers of an OFDM symbol are pilot tones, and the remaining ones are data carriers whereas block type resource allocation all sub-carriers is used as pilot in a specific period and developed under the assumption of a slowly varying channel. For several applications, a hybrid types arrangement is used, which has both the properties of block and the comb types arrangement. Note that in our work, fixed number of channels allocation (FCA) and comb type resource allocations are applied with coherence interval of 0.032 μs.

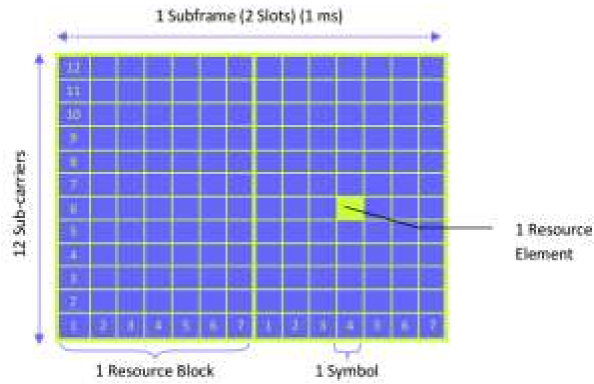

Figure 3. Resource allocations in LTE

Cell edge users in DL experience higher interference coming from the nearby eNB's. The goal of interference modeling and analysis is to show the actual signals arriving to the victim user in a cell from the interfering cells with a simpler and reasonably captured the cumulative effect of the interference, since ICI depends on the position of the receiving user. Molding and analyzing of interference are much challenging due to random nature of the channel state, user mobility, user location, and other unknown parameters. The number of interferer cells $\mathrm{N_c}$ per tier is computed by

$$\mathrm{N_c} = \mathrm{N_{cf}} \times n \tag{9}$$

Where $\mathrm{N_{cf}}$, and n are number of interferer cells in the first tier and the number of tiers, respectively.

FR-1 Network model

The network model for DL of FR- 1 system is shown in Figure 4 in which the corresponding interference and signal to interference ratio for both first and second tires are computed below.

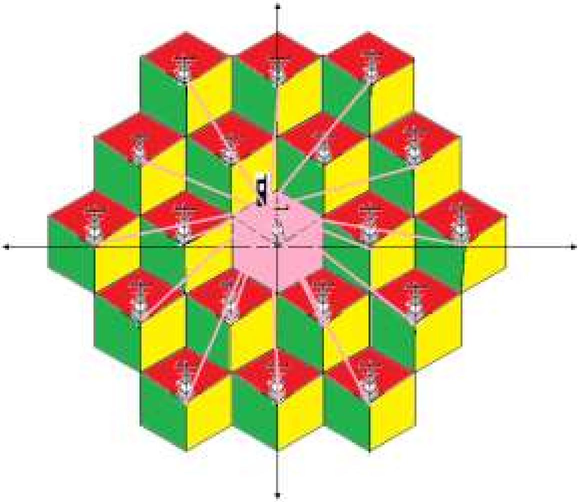

Figure 4. FR-1 Network model for DL

(a) First tier

For this scenario total interference signal arises from the first tier and signal to interference ratio for the first tier are shown in Eq.10 and 11, respectively.

$$I_{sf}(t) = \sum_{n_{cf}=1}^{N_{cf}} \sum_{n_u=1}^{U_c} h_{icf} I_x(t) \tag{10}$$

$$SIR_f = \frac{P_d}{I_{sf}(t)} = \frac{P_d}{\sum_{n_{cf}}^{N_{cf}} \sum_{n_u}^{U_c} h_{icf} I_x(t)} \tag{11}$$

Where $I_{sf}(t)$ total interference signal arises from the first tier,P_d is desired signal power,h_{icf} is interferer channel gain from the first tier to cell edge area at eNB,$I_x(t)$ is interference signal for individual interferer, and SIR_f signal to interference ratio for the first tier.

(b) Second tier

Similarly, for the second-tier scenario the total interference signal arises from the first tier and signal to interference ratio for the first tier are shown in Eq.12 and 13, respectively.

$$I_{ss}(t) = \sum_{n_{cs}=1}^{N_{cs}} \sum_{n_{u=1}}^{U_c} h_{ics} I_x(t) \tag{12}$$

$$SIR_s = \frac{P_d}{I_{ss}(t)} = \frac{P_d}{\sum_{n_{cs}}^{N_{cs}} \sum_{n_u}^{U_c} h_{ics} I_x(t)} \tag{13}$$

Where $I_{ss}(t)$ total interference signal arise from the second tier, P_d is desired signal power, $h_{ics}$is interferer channel gain from the second tier to cell edge area at eNB,$I_x(t)$ interference signal for individual interferer, and $SIR_s$is signal to interference ratio for the second tier.

(c) Cumulative effect of ICI in FR-1 is given by:

$$I_{FR-1}(t) = I_{ss}(t) + I_{sf}(t) \tag{14}$$

$$I_{FR-1}(t) = \sum_{n_{cf}=1}^{N_{cf}} \sum_{n_u=1}^{U_c} h_{icf} I_x(t) + \sum_{n_{cs}=1}^{N_{cs}} \sum_{n_{u=1}}^{U_c} h_{ics} I_x(t) \qquad 15)$$

$$SIR_{Cu} = SIR_s + SIR_f = \frac{P_d \left\{ \sum_{n_{cf}}^{N_{cf}} \sum_{n_u}^{U_c} h_{icf} I_x(t) + \sum_{n_{cs}}^{N_{cs}} \sum_{n_u}^{U_c} h_{ics} I_x(t) \right\}}{\sum_{n_{cs}}^{N_{cs}} \sum_{n_u}^{U_c} h_{ics} I_x(t) + \sum_{n_{cf}}^{N_{cf}} \sum_{n_u}^{U_c} h_{icf} I_x(t)} \tag{16}$$

FR-3 Network model

The network model for DL of FR- 3 system is shown in Figure 5. In this scenario there is no interference signal rise from the first tier, so that total interference signal arises from the second tier and signal to interference ratio are computed as shown in Eq. 12 and 13, respectively.

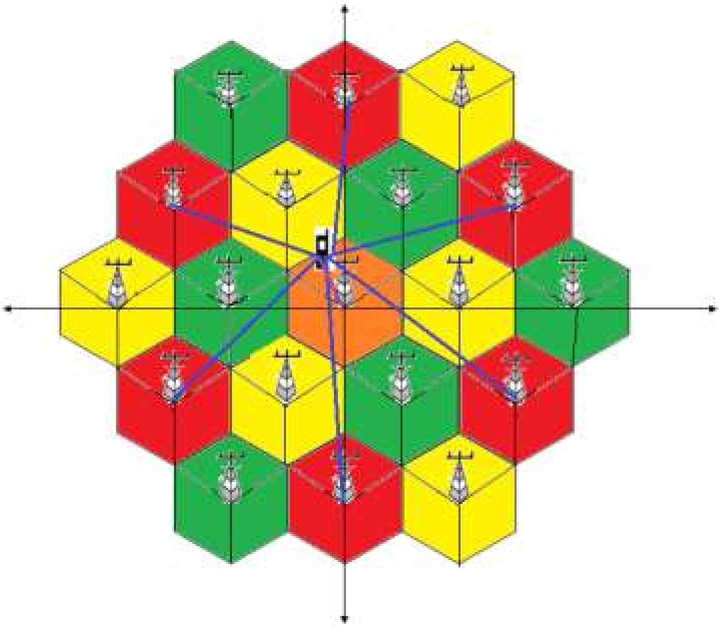

Figure 5. FR-3 Network model in DL

RESULTS AND DISSCUSION

Based on the system network model we provide the simulation results to demonstrate the ICI power for different scenarios. The parameters implemented for simulation are summarized in Table 1. For the simulation of our work number of interferers cell ($\mathrm{N_c} = 6$) in a subsequent tier, number of users per cell ($\mathrm{U_c} = 14$), number of interferer cells in the first tier ($\mathrm{N_{cf}} = 6$) and the number of tiers (n=1) are considered for first tier scenario and $\mathrm{N_c} = 12$, $\mathrm{U_c} = 14$), $\mathrm{N_{cf}} = 6$ and n=2 are considered for second tier scenario.

Figures 6 and 7 show the ICI power versus number of cells in FR-1 scenario for the first and second tiers respectively. The results demonstrate the maximum and averge value of ICI power under various channel conditions, where the ICI power in Rician fading channel is greater than Rayleigh fading channel. Whereas the average ICI power in Rican fading channel model is almost equal to the maximum value of ICI in Rayleigh fading channel.

As the simulation result of Figure 6 specifically indicates interferer arises from the second tier has its own contribution to affect the power level (SIR) of the communication system and the interference power arises from the second tier is almost the same as the first tier, because the number of cell that allocates the same frequency is doubled and the number of participant is twofold. As the radius of the cell is considered to be small, the probability of interference that affects the signal will increase since cell radius affect path loss distance (LOS). The level of interference signal raised from the second tier is strong and affects the QOS of cell-edge users. Thus, the interferer arises from the second tier has its own contribution to affect edge cell user services.

Figure 8 shows the simulation result derived for cumulative and average ICI power under various channel environments for FR-1 network model and can be observed that the cumulative interference under Rician fading channel is higher than Rayleigh fading channel. Similarly, Figure 9 demonstrates the ICI power versus number of cells for FR-3 network scenario. Under this scenario, the strength of the interference signal power is weak and when we compare with that of FR-1 network scenario the interference arises from the second tier because of participant of the network model.

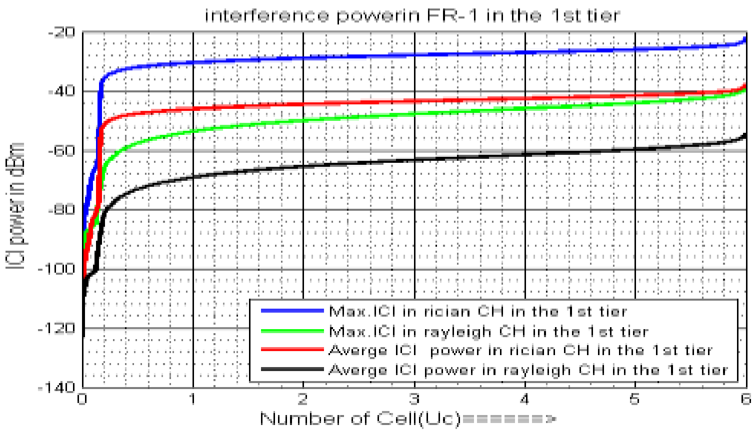

Figure 6. ICI power of the first tier in FR-1 network

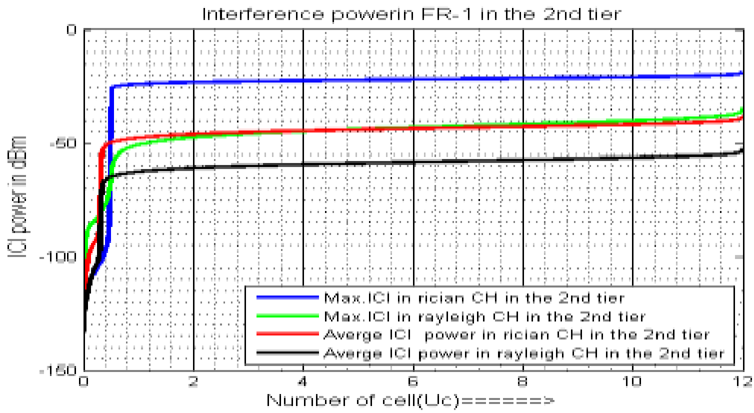

Figure 7. ICI power of the second tier in FR-1 network

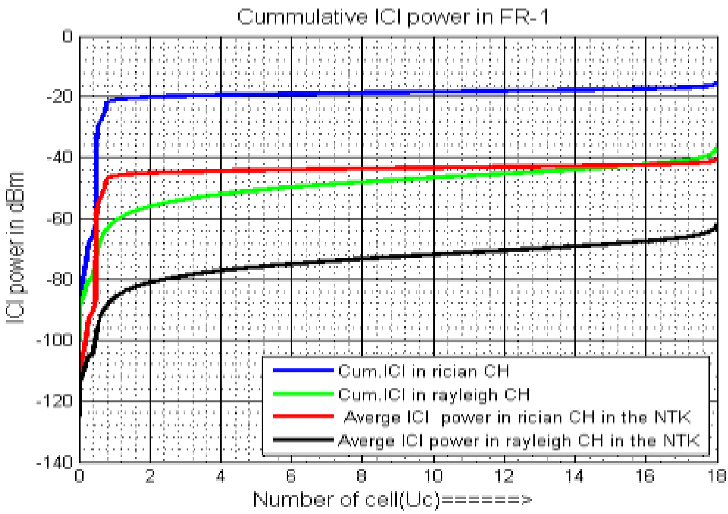

Figure 8. Cumulative and average effect of ICI power under various channel environment for FR-1 network

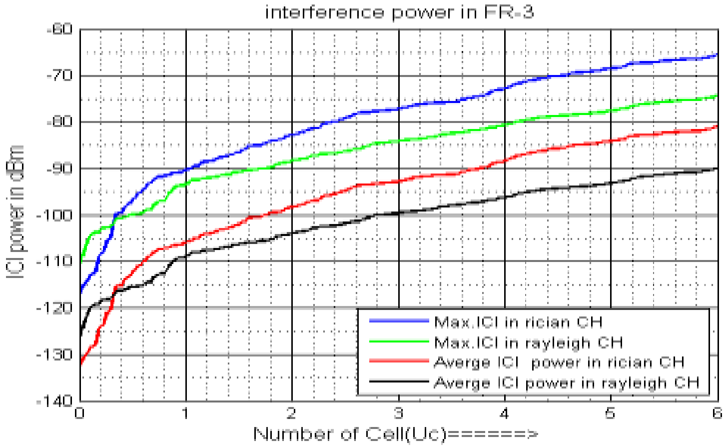

Figure 9. ICI power in FR-3 system network model scenario

CONCLUSIONS

This work focuses on modeling and analyzing of ICI in LTE physical layer under various scenarios and fading channel environments. Gaussian modeling of interference is not appropriate because the spectrum and the existence of the interference are not constant and continuous; rather they exist randomly at some instance of time. Thus, in this work the ICI effect is modeled as shot noise. Based on the system network considered for this work, the simulation results demonstrate how much the strength of the dominant path of the desired signal can be affected by ICI and the whole communication system achieved by a radio link. The results are basically based on resource allocation, path delay, propagation of signal, sector angle applied for the network model and location of eNB. According to the results obtained, the length of cell radius is greater than 1.0324 km in urban areas (specifically in small and medium size city) to minimize the interference in both FR-1 and FR-3. Unlike other works the effect of ICI that rises from the second tier in FR-1 and FR-3 is not neglected in this work and we confirmed that the interference arises from the second tier and has its own contribution to affect the power level of the LTE communication systems. Finally, we observed that the average value of ICI power in FR-3 was greater than FR-1 while the maximum value of ICI power that exist in FR-1 was greater than in FR-3.

REFERENCES

Akl, N., Fahs, J and Dawy, Z. (2014). Statistical intercell interference modeling for capacity-coverage tradeoff analysis in downlink cellular networks. arXiv preprint arXiv:1406.1230.

Ali, M.S., Hossain, E., Al-Dweik, A and Kim, D.I. (2018). Downlink power allocation for CoMP-NOMA in multi-cell networks. *IEEE Transactions on Communications* **66**(9): 3982-3998.

Amitabha, G and Rapeepat, R. (2011). Essentials of LTE and LTE-A. Cambridge University Press.

Anang, K.A., Rpajic, P.B., Eneh, T.I and Nijsure, Y. (2011). Minimum cell size for information capacity increase in cellular wireless network. In 2011 IEEE 73rd Vehicular Technology Conference (VTC Spring) (pp. 1-6).

Galiotto, C., Pratas, N.K., Marchetti, N and Doyle, L. (2015). A stochastic geometry framework for LOS/NLOS propagation in dense small cell networks. In 2015 IEEE International Conference on Communications (ICC) (pp. 2851-2856).

Hossain, E., ElSawy, H and Haenggi, M. (2013). Stochastic geometry for modeling, analysis, and design of multi-tier and cognitive cellular wireless networks: A survey. *IEEE Communications Surveys & Tutorials* **15**(3): 996-1019.

Islam, M.D and Chowdhury, M.N.H. (2013). Study of inter-cell interference and its impact on the quality of video conference traffic in LTE Network. MSc thesis, Blekinge Institute of Technology, Sweden.

Khan, F. (2009). LTE for 4G mobile broadband: Air interface technologies and performance. Cambridge University Press, New York, USA.

Li, A and Masouros, C. (2018). Interference exploitation precoding made practical: Optimal closed-form solutions for PSK modulations. *IEEE Transactions on Wireless Communications* **17**(11): 7661-7676.

Lowen, S.B and Teich, M.C. (1990). Power-law shot noise. *IEEE Transactions on Information Theory* **36**(6): 1302-1318.

Pijcke, B., Zwingelstein-Colin, M., Gazalet, M., Gharbi, M and Corlay, P. (2011). An analytical model for the inter cell interference power in the downlink of wireless cellular networks, EURASIP Journal on wireless communication and Networking.

Rahman, A and Muzahidur, F. (2014), Topology and interference analysis in macro cellular environment. MSc thesis Tamper University of Technology, Finland.

Sauter, M. (2011). From GSM TO LTE: An introduction to mobile networks and mobile broadband, John Wiley & Sons, Ltd.

Tabassum, H. (2012). Modeling and management of inter cell interference in future generation wireless networks. PhD dissertation KAUST, Saudi Arabia.

Wei, Z., Masouros, C., Wong, K.K and Kang, X. (2019). Multi-cell interference exploitation: A new dimension in cell coordination. arXiv preprint arXiv:1901.04058.

Zhang, J., Yang, L.L., Liu, X and Hanzo, L. (2006). Inter-carrier interference analysis of OFDM systems communicating over rapidly-fading Nakagami-m channels. In 2006 IEEE Ninth International Symposium on Spread Spectrum Techniques and Applications (pp. 79-83).

Zarrinkoub, H. (2014). Understanding LTE with MATLAB: from mathematical modeling to simulation and prototyping. John Wiley & Sons.

Table 1. Simulation parameters for all scenarios

Simulation parameter	Values
Data generated distribution	rand
User mobility	30 km/h
Modulation	64QAM
Transmission Time Interval (TTI)	1ms
Subcarriers/ cell with same frequency (No.)	14
Carrier Frequency	2.1 GHz
Bandwidth	20 MHz
Sampling Frequency	30.72 MHz
Subcarrier Spacing (Δf)	15 kHz
FFT Size	2048
Doppler shift (f_d)	58.333Hz
Rican-factor (Rf)	46dB
Time delay (tau) system supported value	15µs
Average path gain (dB)	30
Channel type	Rican & Rayleigh channel