

Traffic Modelling of Low Dense Femtocellular Network for Long Term Evolution

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Abstract

One of the features of Long Term Evolution (LTE) is the deployment of femtocells as the underlain cell of a macrocell without any intervention of frequency planning to offload the traffic. In this paper we used Markov chain to derive the expression of blocking probability for both macro and femtocell in terms of traffic parameters of the network. We developed an analytical model to find the expression of probability of forced termination (*FT*) using combination of mobility model and probability tree considering low dense femtocellular network. Two different trees were designed: a newly originating call which starts its session in a femtocell and that of in a macro cell. The link parameters of small scale fading of wireless network under Multiple Input Multiple Output (MIMO) are combined with the proposed traffic model to get the probability of *FT* of a real-life network. A new state transition chain was also developed including its solution for LTE traffic of variable bandwidth (BW) and a comparison was made with Erlang's traffic model.

Keywords

Rayleigh and Nakagami-*m* Fading, MIMO, RB, Forced Termination, Outage Probability

1. Introduction

Major challenge of 4G/5G mobile cellular network is to enhance the carried traffic capacity. One possible solution is offloading of mobile data traffic from the primary network access to the WiFi infrastructure (for example femtocell of LTE). In [1] and its extended version [2], the authors show the performance of WiFi Direct Device to Device (D2D) technology and demonstrate how cellular

traffic can be effectively offloaded through a WiFi and provides the estimated gains in energy efficiency and capacity from such offloading. Another big problem of outdoor LTE network is its latency, which directly affects its throughput. In LTE eNB maintains a large queue to reduce overflow of burst traffic at the expense of packet delay. In [3] “Adaptive Receiver-Window Adjustment Algorithm” is used to reduce the latency. Variation of throughput and latency against “modulation and coding scheme” (MCS) and number of users are shown explicitly. Still there is a scope to work on the paper, including other traffic parameters like blocking probability and carried traffic. In [4], instead of conventional traffic of user data, the paper proposed a M2M traffic model to reduce the signaling traffic and bandwidth utilization. In [5] the traffic of LTE-WiMAX integrated network is analyzed including the algorithm of traffic simulation. The variation of FTP, HTTP and voice traffic with time is compared explicitly, where the interference is found as the prime factor. Although femtocell offloads traffic of macro cell but the interference of femto and macro cell can deteriorate throughput of the network. The solution, to limit the interference of femtocells due to their uncontrolled placement is found in [6] [7].

The redundant bits of channel coding degrade the throughput of a network. The compromise between source code rate and channel code rate to minimize the number of redundant bits generated by channel coding with an acceptable Mean Opinion Score (MOS) is analyzed in [8]. Here the authors proposed a dynamic adaptation algorithm of joint source-channel code rate for enhancing voice transmission over LTE network. Paper [9] surveys state-of-art mobile data offloading and proposed to use integrated Femto and Wi-Fi to have improved “service performance” and “interference management” with the constraint of non-overlapping femtocells. The traffic model of low dense femtocell network under fading condition is found in [10] considering the concept of [9] with variable BW.

The rest of the paper is organized as follows: Section 2 provides previous analysis of traffic of LTE network; Section 3 gives the analytical model of Macro-Femto Cellular Network based on Markov chain and probability tree, MIMO channel under fading condition is combined with traffic parameter and traffic model of variable bandwidth (BW). Section 4 provides results based on the analysis of Section 3 and verifies it by simulation and finally, section 5 concludes the entire analysis.

2. Previous Work

In [11] the traffic of macro-femto cellular communication system of LTE is modeled by Markov chain. The authors first determined the expression of total call arrival rate of macro and femtocell then separate Markov chains were drawn for macro and femtocell traffic.

The total arrival rate of a macrocell is:

$$\lambda_{Tm} = \lambda_{om} + \lambda_{n,mm} + P_{Bf} \lambda_{of} + \alpha P_{Df} \lambda_{n,ff} + (1 - \alpha) \lambda_{h,ff}; \text{ where } \lambda_{om} \text{ is the newly origi-}$$

nating call at a macrocell, $\lambda_{h,mm}$ → macro to macro handover rate, $P_{Bf}\lambda_{of}$ → a call originated in a femtocell and found that all the channels are occupied then the call will use the channel of a macrocell, $\alpha P_{Df}\lambda_{h,ff}$ → after a femto to femto handover a UE (user equipment) found that $SINR > \tau$ (the probability of getting $SINR > \tau$ is α) but all the channels of the new femtocell are occupied then the channel of a macrocell will be used, $(1 - \alpha)\lambda_{h,ff}$ → the case like before but $SINR < \tau$ hence the channel of a macrocell will be used.

The total arrival rate of a femtocell, $\lambda_{Tf} = (\lambda_{of} + \lambda_{h,mf} + \alpha\lambda_{h,ff} + P_{D,m}\beta\lambda_{h,ff})/N$, where λ_{of} → the arrival rate of newly originated call in femtocells, $\lambda_{h,mf}$ → the rate of handover arrival from macro to femtocells, $\alpha\lambda_{h,ff}$ → the femto to femto handover provided that $SINR > \tau$, where τ is the threshold $SINR$ to maintain communication and $P_{D,m}\beta\lambda_{h,ff}$ → the femto to femto handover provided that received $SINR$ lies between two thresholds τ_1 and τ_2 and $P(\tau_1 < SINR < \tau_2) = \beta$.

Traffic offloading strategy of LTE network is analyzed in [12] using two-dimensional Markov chain, where the product of session arrival and session duration is considered offered traffic. Here one dimension is Licensed Assisted LTE Access (LLA) traffic and the other is WiFi AP traffic. The authors consider CTMC with probability state: $(N_w(t), N_L(t))$, where $N_w(t)$ is the number of WiFi sessions and $N_L(t)$ is the number of offloaded LTE sessions at time $t > 0$. The similar traffic model is found in [13], applied for cognitive radio network (CRN), where arrival rate of PU and SU with their termination rate is considered as the offered traffic. Both models were unable to include the variable bandwidth in the state transition chain.

3. System Model

3.1. Traffic Model of Macro-Femto Cellular Network

In micro-macro cellular system the microcells under a macrocell form the coverage in continuous fashion but the situation is different in LTE with macro-femto combination since femtocells do not form a continuous coverage under a macrocell. Hence the concept of take-back of [14] [15] is not applicable here, visualized from Figure 1. Let the area of the test macrocell is A_m and the

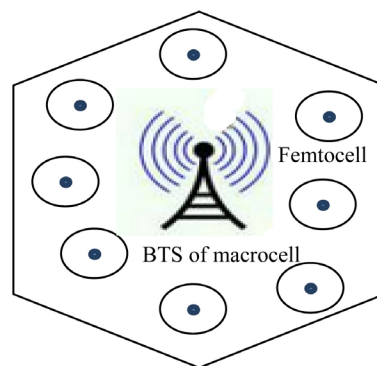


Figure 1. Macro-femto integrated cellular model.

sum of the area of femtocells within the test macro cell is A_f . Let the average call arrival rate inside the test cell is λ_f . The arrival rate of macro and femto cells will be distributed as:

Arrival rate of macrocell is $\lambda_m = \lambda_f (1 - A_f/A_m)$ and that of femtocells, $\lambda_f = \lambda_f A_f/A_m$. In micro-macro cellular system the overflow traffic from microcell is related to macrocell but such concept is not applicable in femto-macro cell hence combined state transition chain of the papers [16] [17] cannot be applied here.

We consider the separates Markov chain of femto and macrocell of [11]; where n is the number of channels (combined data rate/individual user's rate), N is the total number of femtocells within the test macrocell, λ_f is the call arrival rate within the femtocells and λ_h' is the handover arrival rate from surrounding cells as shown in **Figure 2**.

The blocking probability under a femtocell is derived as [18]:

$$B_f = \frac{A^n(\lambda_f, \lambda_{h'}, N)/n!}{\sum_{i=1}^n A^i(\lambda_f, \lambda_{h'}, N)/i!}, \text{ where } A(\lambda_f, \lambda_{h'}, N) = \frac{\lambda_f/N + \lambda_{h'}}{\mu_f} \quad (1)$$

Similarly, the call blocking probability under a macrocell is,

$$B_m = \frac{A^l(\lambda_m, \lambda_h)/l!}{\sum_{i=1}^l A^i(\lambda_m, \lambda_h)/i!}, \text{ where } A(\lambda_m, \lambda_h) = \left\{ \frac{\lambda_m + \lambda_h}{\mu_m} \right\} \quad (2)$$

and l is the number of channels of the test macrocell, λ_m is the call arrival rate within the test macrocell and λ_h is the handover arrival rate from the surrounding cells. The above chain can be improved considering call admission control scheme, where m channels are reserved for handoff calls from the surrounding femtocells. The state transition chain of a macro cell under call admission control is shown in **Figure 3**.

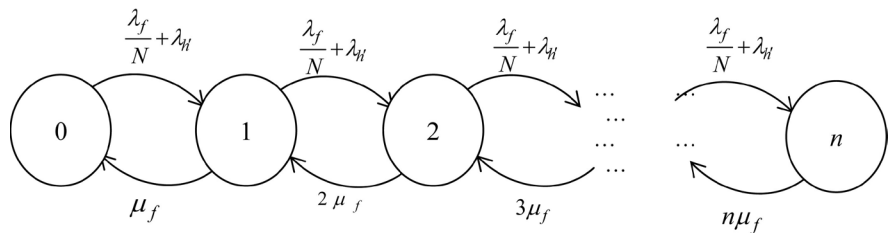


Figure 2. Markov chain of a test femtocell.

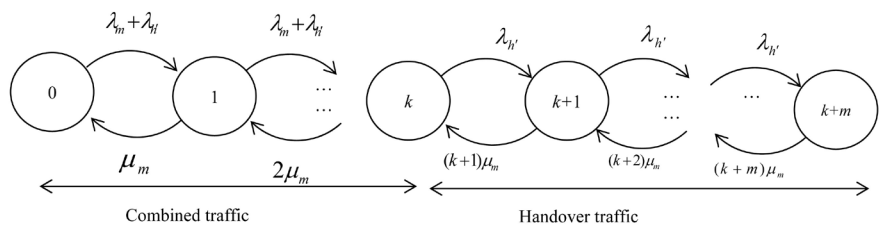


Figure 3. Markov chain of a macrocell under reserved channels for handover calls.

Applying cut equation like [13] we get in the generalized form as:

$$p_x = \frac{p_0 (A_m + A_{h'})^x}{x!}; \text{ where } 0 \leq x \leq k \tag{3}$$

Similarly,

$$p_{k+y} = p_k \frac{A_{h'}^y}{\prod_{i=1}^y (k+i)}; \text{ where } 1 \leq y \leq m \tag{4}$$

The probability of FT is,

$$p_{k+m} = p_k \frac{A_{h'}^m}{\prod_{i=1}^m (k+i)} = p_0 \frac{(A_m + A_{h'})^k}{k! \prod_{i=1}^m (k+i)}. \tag{5}$$

The entire sample space satisfies, $\sum_{i=0}^k p_i + \sum_{j=1}^m p_{k+j} = 1$

Applying normalization condition,

$$p_0 \sum_{i=0}^k \frac{(A_m + A_{h'})^i}{i!} + p_0 \sum_{j=1}^m \frac{(A_m + A_{h'})^k}{k! \prod_{l=1}^j (k+l)} = 1,$$

we obtain,

$$p_0 = \left\{ \sum_{i=0}^k \frac{(A_m + A_{h'})^i}{i!} + \frac{(A_m + A_{h'})^k}{k!} \sum_{j=1}^m \frac{1}{\prod_{l=1}^j (k+l)} \right\}^{-1} \tag{6}$$

Probability of dropping of newly originating call is P_k and probability of forced termination (FT) is P_{k+m} . Because of use of low dense femtocells, we assume that two micro and two femtocells are enough to complete a session. In this context we have to determine the probability that an MS crosses the cell border of a femtocell before completing its session as [19] [20],

$$P_{hf} = \frac{\eta_f}{\mu_f + \eta_f}; \tag{7}$$

where $\eta_f = 2v/\pi R_f$, v is the velocity of MS, R_f is the radius of femtocell and μ_f is the call terminator rate at femtocell. Similarly, for macrocell, the corresponding probability is expressed as,

$$P_{hm} = \frac{\eta_m}{\mu_m + \eta_m} \tag{8}$$

We design a probability tree of FT for a MS, i starts its session in a femtocell i as shown in Figure 4 to relate traffic parameters of (1) to (8). The probability of FT, P_{FTf} is derived as,

$$P_{FTf} = P_{hm} \cdot B_m + P_{hm} (1 - B_m) P_{FTm} + P_{hm} (1 - B_m) \cdot P_{hf} (1 - B_f) \cdot P_{FTf} + P_{hm} (1 - B_m) \cdot P_{hf} B_f \tag{9}$$

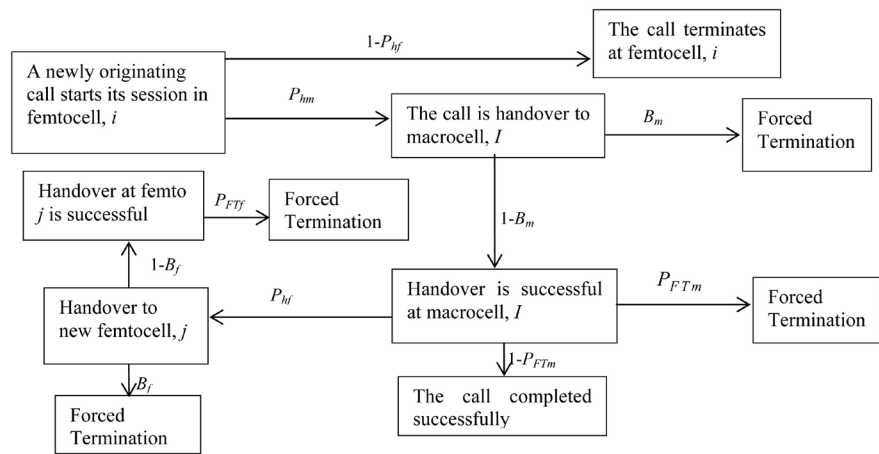


Figure 4. Probability tree of P_{FTf}

Another probability tree is designed like **Figure 5**, when a MS, j starts its session in macro cell I and the corresponding probability of FT is found as:

$$P_{FTm} = P_{hf} (1 - B_f) P_{FTf} + P_{hm} B_m + P_{hm} (1 - B_m) P_{FTm} + P_{hf} B_f \quad (10)$$

Solving the linear Equation (9) and Equation (10) we can easily obtain P_{FTm} and P_{FTf} . Now we have to relate the traffic parameters of this section with small scale fading to get realistic scenario of traffic of wireless network. To combat the fading affect we consider MIMO link discussed in next subsection.

3.2. The MIMO Channel Model of LTE

For successful communication both availability of channel of a cell and instantaneous $SNR \geq \tau$ should be ensured; where τ is the threshold value of instantaneous SNR.

The minimum SNR to maintain QoS of the MIMO link is expressed as [21] [22]:

$$\gamma_{\min} = \tau = \frac{N_t \ln(2)}{E\{\text{trace}(\mathbf{H}^H \mathbf{H})\}} \quad (11)$$

where \mathbf{H} is the $N_t \times N_r$ MIMO channel matrix, N_t is the number of antenna elements of transmit antenna array, N_r is that of the receiver antenna array and $\text{trace}(\mathbf{H}^H \mathbf{H})$ is the sum of diagonal components of the matrix $\mathbf{H}^H \mathbf{H}$.

The trace of $\mathbf{H}^H \mathbf{H}$ can be expressed as,

$$E\{\text{trace}(\mathbf{H}^H \mathbf{H})\} = N_t N_r E[r^2] \quad (12)$$

where r is the random variable of channel gain between the antenna elements. The detail derivation of Equation (11) and Equation (12) are given in [22].

From Equation (11) and Equation (12) we have, $\tau = \frac{\ln(2)}{N_r E[r^2]}$ for STBC.

Let us now concentrate on instantaneous and average SNR γ and γ_{av} of the MIMO link. First of all, we analyze the MIMO link under TAS (Transmit Antenna

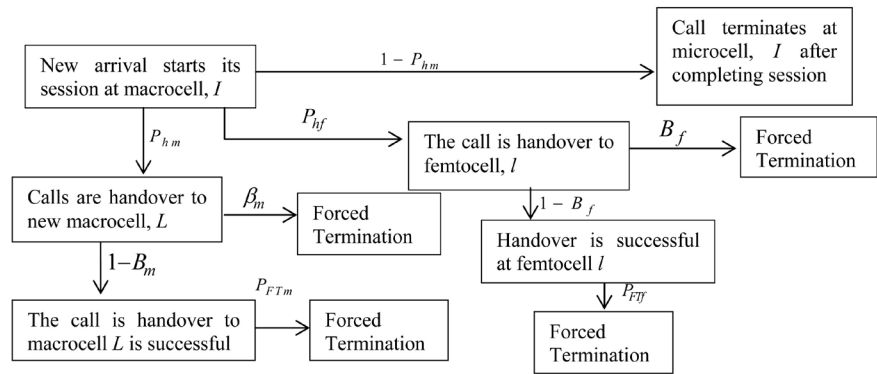


Figure 5. Probability tree of P_{FTm}

Selection) technique then for the complete MIMO. The channel gain vector, selecting the k th antenna element at the transmitting end is,

$$\mathbf{h}_{TR,k} = [h_{1,k} \quad h_{2,k} \quad h_{3,k} \quad \dots \quad h_{N_r,k}] \tag{13}$$

Frobenious norm of $\mathbf{h}_{TR,k}$ is,

$$\|\mathbf{h}_{TR,k}\| = \sqrt{h_{1,k}^2 + h_{2,k}^2 + h_{3,k}^2 + \dots + h_{N_r,k}^2} \tag{14}$$

The transmit antenna element $k \in \{1, 2, 3, \dots, N_t\}$ is selected for maximum value of $\|\mathbf{h}_{TR,k}\|$;

The received signal vector is,

$$\mathbf{Y} = \sqrt{P}\mathbf{h}_{TR,k} + \mathbf{n}; \tag{15}$$

where \mathbf{n} is the noise vector at the receiving end and P is the transmitted signal power.

The selection combiner at the receiving we choose,

$$\mathbf{h}_{TR,k,s} = \max(h_{1,k}, h_{2,k}, h_{3,k}, \dots, h_{N_r,k}) \tag{16}$$

when MRC is used then the weighting vector [23],

$$\mathbf{w} = \frac{[h_{1,k}^* \quad h_{2,k}^* \quad h_{3,k}^* \quad \dots \quad h_{N_r,k}^*]^T}{\sqrt{h_{1,k}^2 + h_{2,k}^2 + h_{3,k}^2 + \dots + h_{N_r,k}^2}} = \frac{\mathbf{h}_{TR,k}^H}{\|\mathbf{h}_{TR,k}\|} \tag{17}$$

The output of MRC at the receiver,

$$y = \sqrt{P}\|\mathbf{h}_{TR,k}\|x + \mathbf{w}^T\mathbf{n} \tag{18}$$

The instantaneous SNR of receiver is,

$$\gamma = \gamma_{av} \|\mathbf{h}_{TR,k}\|^2 \tag{19}$$

If n_b is the variance of the noise vector \mathbf{n} then,

$$\gamma_{av} = \frac{P}{n_b} \tag{20}$$

The weighting vector under TAS of Equation (17) is the contribution of the k th transmit antenna element, hence under the complete MIMO the Equation (17) will be modified as,

$$\mathbf{w} = \sum_{k=1}^{N_r} \frac{\mathbf{h}_{TR,k}^H}{\|\mathbf{h}_{TR,k}\|} \tag{21}$$

The pdf of the random variable, γ under MRC of the MIMO for Rayleigh fading is like [24],

$$f_{\Gamma}(\gamma) = \frac{\gamma^{N_r-1} e^{-\frac{\gamma}{\gamma_{av}}}}{\gamma_{av}^{N_r} \Gamma(N_r)} \tag{22}$$

that of the Nakagami- m case of [25] is,

$$f_{\Gamma}(\gamma) = \left(\frac{m}{\gamma_{av}}\right)^{N_r} \frac{\gamma^{mN_r-1} e^{-\frac{m\gamma}{\gamma_{av}}}}{\Gamma(mN_r)} \tag{23}$$

and the outage probability,

$$P_{outage}(\tau) = \int_0^{\tau} f_{\Gamma}(\gamma) d\gamma \tag{24}$$

where τ is the threshold SNR and it depends on the number of received antennas and the variance of the channel gain of the antenna elements.

Now the probability of FT , considering the outage probability will be,

$$P_{FTm_o} = 1 - (1 - P_{FTm})(1 - P_{out}(\gamma)) \tag{25}$$

And

$$P_{FTf_o} = 1 - (1 - P_{FTf})(1 - P_{out}(\gamma)) \tag{26}$$

The Equation (25) and Equation (26) provides the probability of FT , which depends on the instantaneous SNR, the number of received antenna elements and all traffic parameters will be shown in the result section. In LTE, users deal with traffic of variable BW, hence we have to modify the Markov chain of subsection 3.1. In next subsection we proposed a new state transition chain of variable BW.

3.3. Traffic of Variable Bandwidth

In LTE users can take bandwidth on demand. Here we assume the minimum unit of BW of a user is a pair of RB (resource block). In LTE each frame of 10 ms is divided into 10 subframe of 1 ms, also each sub-frame is divided into two time slots of 0.5 ms each. Each slot contains either six or seven OFDM symbols, depending on the type of channel coding schemes. When normal Cyclic Prefix (CP) is used then a RB contains 7 symbols under each subcarrier of OFDM, under extended CP, 6 symbols under each sub-carrier. Each RB contains 12 subcarriers, hence $12 \times 6 = 72$ symbols in a RB of the extended CP and $12 \times 7 = 84$ symbols in a RB of the normal CP.

If a user can take the highest BW of 3 RB then we can represent the traffic by the state transition chain of **Figure 6**, where RB arrival rate is λ calls/unit time and its termination rate is μ . If k is the highest allowed BW or RB then each probability state will emit k arrivals and maximum possible terminate rate will

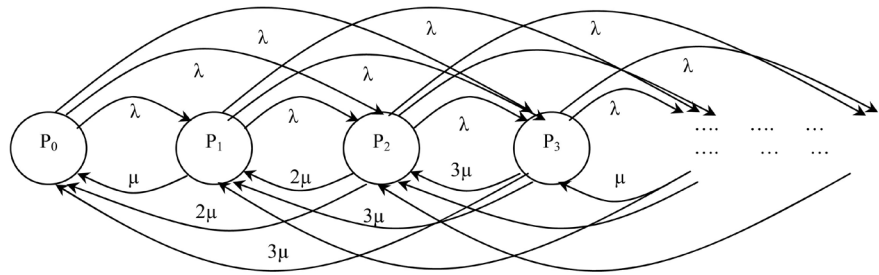


Figure 6. Markov chain of LTE user with variable BW.

be $k\mu$. Applying node equation on each node we get 9 linear equations. Using normalization of entire sample space, we get the following relations.

Applying node equation on nodes of Figure 6 we get,

$$P_x (3A + 3x) = (x + 1)P_{x+1} + (x + 2)P_{x+2} + (x + 3)P_{x+3} + (P_{x-3} + P_{x-2} + P_{x-1})A, \quad (27)$$

for $3 \leq x \leq m - 3$, m is the last state of the chain.

$$P_{m-2} \{2A + 3(m - 2)\} = (m - 1)P_{m-1} + mP_m + (P_{m-5} + P_{m-4} + P_{m-3})A; \quad x = m - 2 \quad (28)$$

$$P_{m-1} (A + 3(m - 1)) = mP_m + (P_{m-4} + P_{m-3} + P_{m-2})A; \quad x = m - 1 \quad (29)$$

$$mP_m = (P_{m-3} + P_{m-2} + P_{m-1})A; \quad x = m \quad (30)$$

For entire sampling space,

$$\sum_{i=0}^m P_i = 1 \quad (31)$$

If normalized probability state of the chain is q_x then, the blocking probability of a user uses k RB will be,

$$B(k) = \sum_{i=0}^k q_{m-i} \quad (32)$$

Combination of analysis of three subsections: 3.1, 3.2 and 3.3 provide the exact traffic model of a LTE network.

4. Results

This section provides the analytical results based on the statistical model of Section 3 and verified by simulation. Taking the following traffic parameters: $\mu_m = \mu_f = 1.2$ calls/min, $v_f = 10$ m/s, $R_f = 20$ m, $v_m = 100$ m/min, $R_m = 1$ Km and $B_f = 0.02$, we obtain the probability of handover to femto and macrocells as: $P_{hf} = 0.21$ and $P_{hm} = 0.05$ respectively. Figure 7 shows the profile of probability of FT (both the cases i.e. when a UE starts its session at macro and femto cell) against the blocking probability of macrocell taking the velocity of users at macro and femto cell as the parameters. The probability of FT increases with increase in both B_m and velocity of the users. Again taking, $\mu_f = 1.8$ calls/min, $v = 10$ m/min, $R_f = 20$ m, we get $P_{hf} = 0.15$. For another set of traffic parameters: $\mu_f = 1.2$ calls/min, $v = 12.5$ m/min, $R_f = 20$ m, we get $P_{hf} = 0.25$. Considering above two sets of parameters, the variation of FT against arrival rate of femtocell is shown in Figure 8.

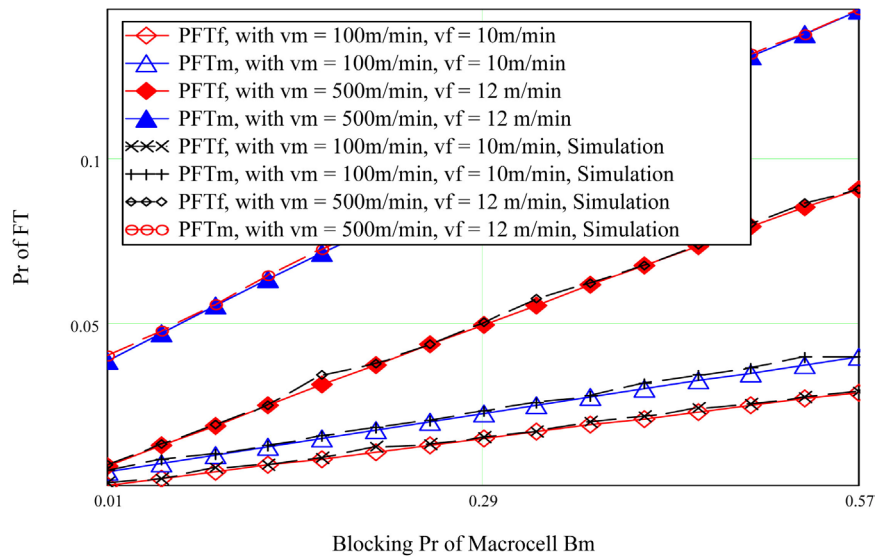


Figure 7. Variation of PFT against Bm.

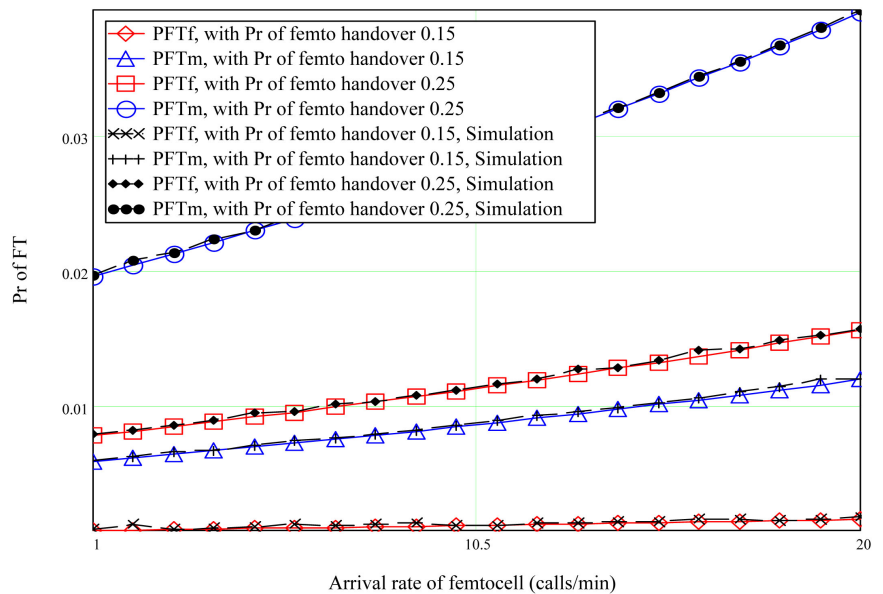


Figure 8. Variation of PFT against λ_f .

Almost similar profile is found as Figure 7 i.e. the P_{FT} increases with increase in both the λ_f and P_{hf}

Next, the probability of FT is varied against the number of channels of femto-cell taking the same traffic parameters shown in Figure 9. In this case, the probability of FT decreases with increase in the number of channels of femtocell. All the analytical results are verified by simulation which provides more than 95% confidence level.

The next part of the result section is related to subsection 3.2; where the traffic parameters are combined with fading parameters of MIMO channel to measure the performance of the network. The variation of P_{FT} against the number of channels of femtocell is shown in Figure 10(a) for average SNR of -2 dB and (b)

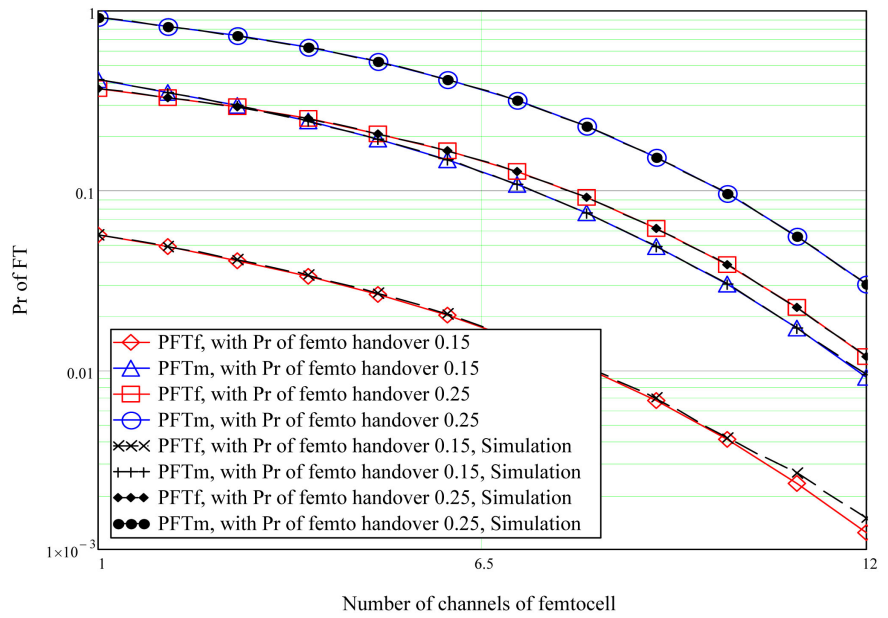


Figure 9. Variation of probability of FT against the number of channels of femtocell.

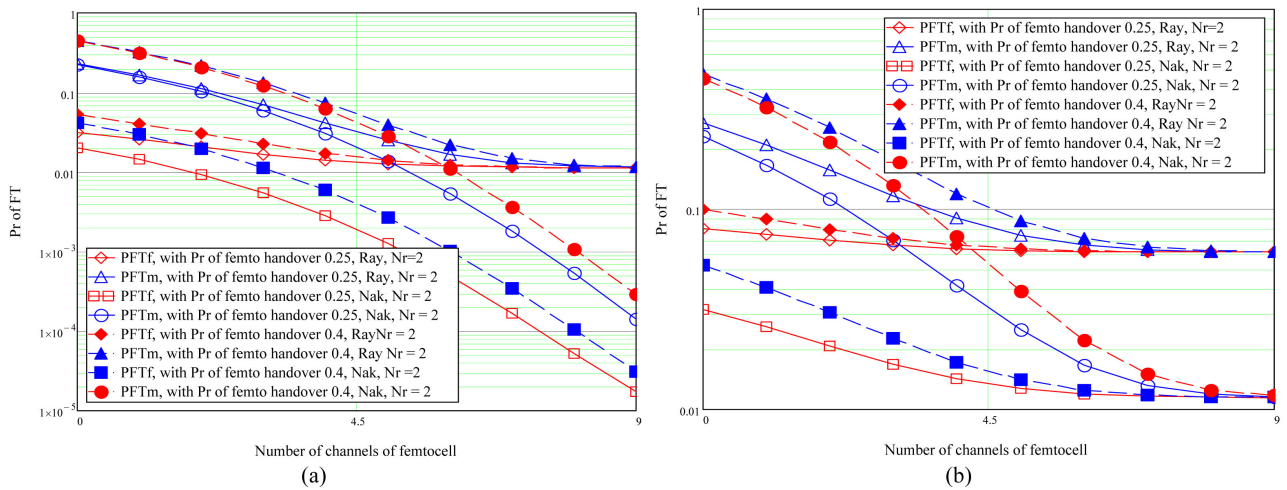


Figure 10. Variation of FT against the number of channels of femtocell.

for average SNR of 2 dB under STBC taking the probability of handover of femtocell as a parameter. The P_{FT} decreases with increase in the number of channels of femtocell but increases with increase in the probability of handover of femtocells. The channel parameters are taken as: average SNR = -2 dB and 2 dB, the standard deviation of channel gain $\sigma = 0.83$, the parameters of Nakagami- m fading $m = 2$, $N_r = 2$. The traffic parameters are taken as: number of femto cells $N_f = 12$, $\lambda_f = 9$ calls/min, $\lambda_{hf} = 4$ calls/min, $\lambda_m = 20$ calls/min, $\lambda_{hm} = 12$ calls/min, $\mu_m = 4.2$ calls/min and $\mu_f = 2$ calls/min. The performance is found better under Nakagami- m fading case compared to the Rayleigh fading environment because of m direct link (between transmitter and receiver) of Nakagami- m fading. Under Rayleigh fading environment there is no direct link between transmitter and receiver hence performance is found very poor at low SNR but when the received

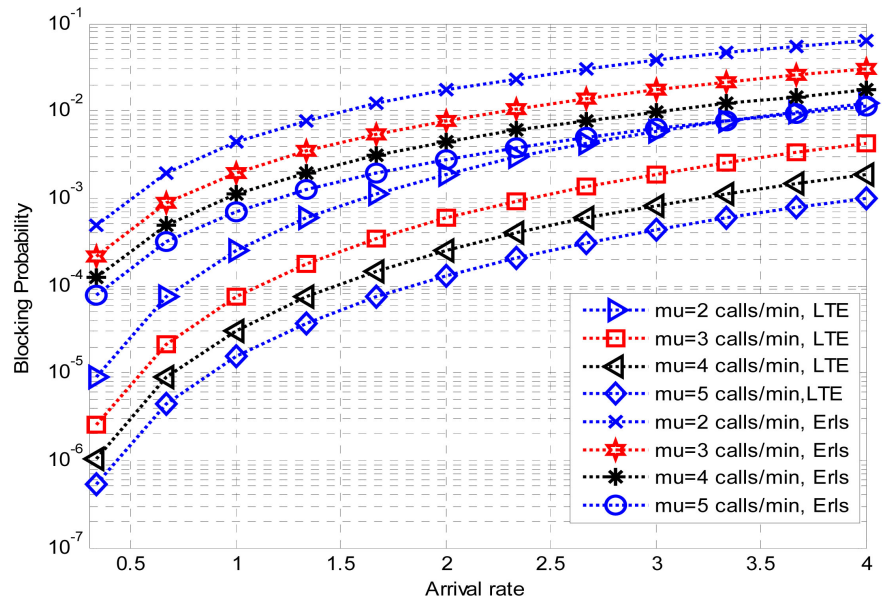


Figure 11. Comparison of proposed LTE traffic.

SNR attains above a threshold the performance of Rayleigh and Nakagami- m environment are merged. The difference between performance at low (-2 dB) and high (2 dB) SNR is found distinct in **Figure 10(a)** and **Figure 10(b)**.

Finally, the call blocking probability of variable BW traffic of LTE and Erlang's model are compared in **Figure 11**. Here Blocking probability is varied against call arrival rate taking termination rate as a parameter provided the number of channels $n = 8$. The blocking probability of variable BW traffic of LTE is found smaller than the case of Erlang's traffic. The arrival rate of the state transition chain of **Figure 6** is λ for any transition, hence each state experiences the total arrival of 3λ , on the other hand the termination rate from probability state P_x is $3\mu_x$. The termination rate of the proposed model is more prominent than the Erlang's model of $M/M/n/K$; hence blocking probability of the proposed model is found smaller than the conventional Erlang's model.

5. Conclusion

The paper combines the traffic model with the outage probability of wireless link under two different small scale fading cases. A new traffic model of variable BW (variable RB for up or down link) is proposed based on Markov chain and comparison is made with $M/M/n/K$ traffic. In future we will combine the wireless link parameters with our proposed traffic model of variable BW. In this paper we consider the pdf of SNR in determining the outage probability but we have the scope to use the pdf of SIR (signal to interference ratio) or $SINR$ to evaluate the same parameter. In this case $SINR$ will be a random variable as the ratio of another two random variables; hence the concept of mixed random variable can be applied for it. We consider $M/M/n/K$ traffic model throughout the paper but in voice data integrated traffic we can consider $M/G/1/K$ traffic model as well.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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