Performance Evaluation of Cognitive Radio Network under Limited User Traffic

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Abstract—**Now-a-days optimum utilization of spectrum of a wireless network is performed based on Cognitive Radio (CR) system. In this paper performance of such network is evaluated using two dimensional Markov chain under limited user case. The closed form expression for throughput and call blocking probability is derived in terms of traffic parameters. The impact of number of channel, number of primary and secondary user on throughput and call blocking probability is analyzed.**

Index Terms—O**ptimum, Cognitive Radio, throughput, blocking probability, primary and secondary user, false alarm and misdetection**

I. INTRODUCTION

The rapid growth of wireless devices as well as the advent of a new high data rate, wireless application has led to a dramatic increase in the demand of additional bandwidth for wireless services. Recent studies show that licensed spectrum remains grossly inactive or is rarely utilized continuously across time and space, thereby resulting in spectrum wastage. In order to overcome the imbalance between the increasing demand of spectrum access and the inefficiency in spectrum utilization, a new method is proposed in [1] for dynamically accessing the assigned spectrum where the spectrum is not in use.

A cognitive radio(CR) is a kind of two way radio that automatically changes its transmission or reception parameters based on the active monitoring of several factors in the external and internal radio environment such as radio frequency spectrum, user behavior and network state. Cognitive radio has been recently proposed as a possible solution to improve the utilization of the spectrum where the cognitive network (CN) transmits using the spectrum already allocated to some primary network [2].

In cognitive radio network there are two types of users: (a) Primary Users (PUs) are the licensed user or the priority users who can use a channel in case of availability of the channel; (b) Secondary Users (SUs) are the opportunistic users who can use a channel when it remains unoccupied by Pus [3-4]. To utilize licensed spectrum effectively, CR user must perform spectrum sensing to extract inactive licensed band [4]. Spectrum sensing plays an important role in CR network and is challenged by uncertainties like channel randomness, channel fading or shadowing, aggregate interference, noise uncertainties etc. In [2], fundamental issues specific to CR have been investigated while primary focus of [5] was on signal processing in context of spectrum sensing implementation in CR networks. A survey of various spectrum sensing techniques and the associated challenges has been studied in [6] and [7].In [8] the authors have proposed cognitive receiver equipped with multiple antenna and maximal ratio combining scheme (MRC) to detect the presence of a PU.

In [10] by deriving the exact closed form expressions for the moment-generating function, outage performance, symbol error rate performance, and the ergodic capacity, the authors shown that when the interference channel is deeply faded and the peak transmit power constraint is relaxed, the scheduling scheme achieves full diversity that causes the outage probability and average SER(Symbol Error Rate) to decrease and increases the ergodic capacity and that increasing the number of primary users does not impact the diversity order.

In today's wireless world, some spectrum bands are highly utilized but many spectrum bands moderately or rarely used. This observation has led to the introduction of the Dynamic Spectrum Access (DSA) paradigm where the secondary wireless network is allowed to dynamically choose some parts of licensed radio bands, while causing minimal or no interference to Primary User occupying those frequencies. In [11], the authors proposed distributed power conserving PU detection architecture and investigated the impact of PU detection accuracy on Dynamic Spectrum Access Networks (DSAN) performance and have shown that synchronized network detects PUs more efficiently than non-synchronized. By simulation they have proven that Least-used with Channel Hopping algorithm minimizes packet loss, in comparison to Random and Least-used algorithms.

Any SU in service have to release the channel when a PU needs it to make a call. Therefore a secondary user has always to be in sensing mode to determine whether a traffic channel (usually combination of carrier frequency and time slot)is under use or not by a PU. Statistical model of two signal level hypothesis is used to determine the rate successfully detection of presence or absence of a PU under a traffic channel. If the absence of PU is detected as its occupancy called false alarm, again if the occupancy of PU is detected as its absence called misdetection. The performance of such network is heavily hampered by these two parameters.

In this paper we are concerned about modeling the traffic of such network using state transition under Engset mode actually applicable for as small network like Pico or Femto cell of 4G network.

The paper is organized like: section II provides system model which deals with traffic model of cognitive radio network for limited users based on two dimensional Markov chains, section III depicts the results based on analysis of previous section and finally section IV concludes the entire analysis.

II. SYSTEM MODEL

If a network is in statistical equilibrium, it can be modeled as multidimensional state transition diagram. Here 2-D Markov chain is considered for a network experiencing two types of Poisson's arrival traffic A_1 and A_2. We first consideranetwork of infinite servers or channels and infinite number of users to derive the probability state then we will convert the model for limited user and limited channel case. In this case it is convenient to arrange states x_1 and x_2 in X and Y directions respectfully. Probability state P_{x1x2}i.e. probability of arrival of x_1 and x_2 calls of traffic of type-1 and type-2 respectively shown in Fig.1. Since the system is reversible it is convenient to apply cut equation between nodes.

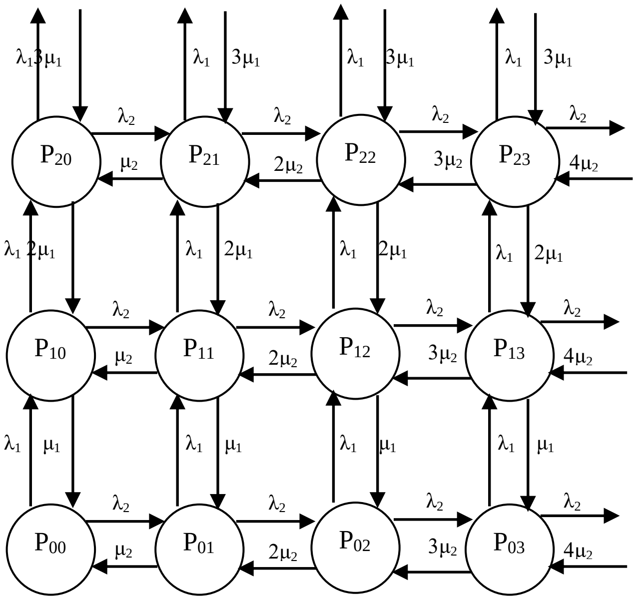


Fig.1. 2-D Markov chain of Poisson traffic

Thex_1th row and x_2th column of Fig.1 are shown in fig.2 (a) and (b) respectively.

Applying cut equations in Fig. 2(a) we get,

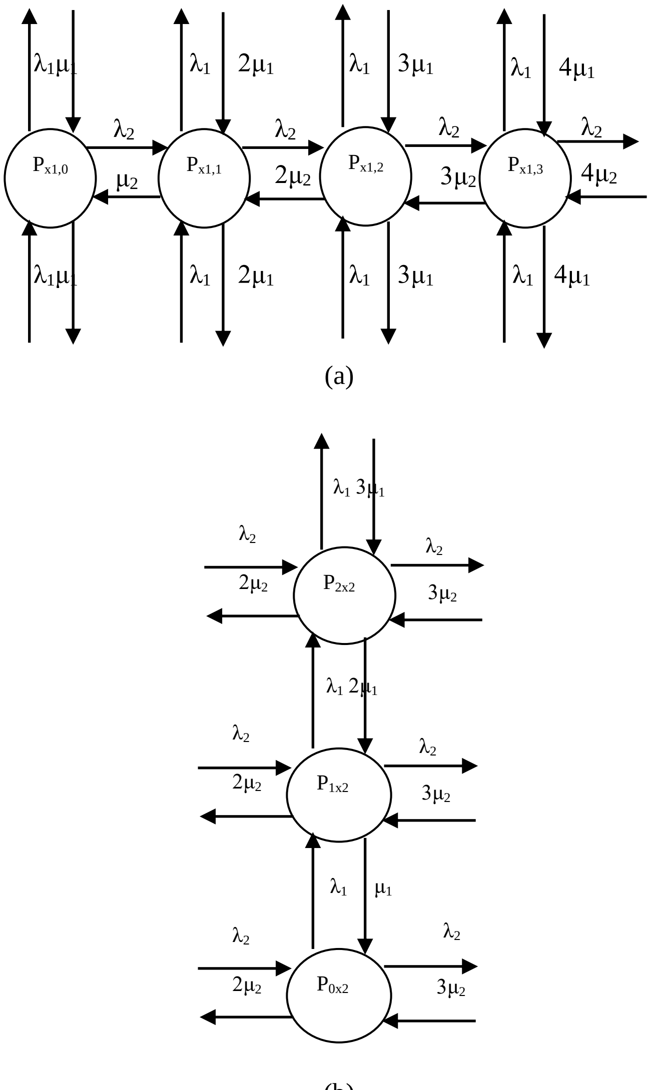
$$P_{x_1x_2} = \frac{A_1^{x_1}}{x_1!}P_{0x_2}\text{ ; where } A_1 = \lambda_1/\mu_1 \tag{1}$$

Again consideringX_1throw of Fig. 2 (b),

$$P_{x_1x_2} = \frac{A_2^{x_2}}{x_2!}P_{x_1 0} \tag{2}$$

Putting $x_2 = 0$ in equation (1),

$$P_{x_1 0} = \frac{A_1^{x_1}}{x_1!}P_{00} \tag{3}$$



(a)

(b)

Fig.2. x_1th column and x_2th row of 2-D chain

From Equation (2) and (3),

$$P_{x_1x_2} = \frac{A_2^{x_2}}{x_2!}\frac{A_1^{x_1}}{x_1!}P_{00} \tag{4}$$

The Entire Probability State,

$$\sum_{x_1=0,x_x=0}^{\infty} P_{x_xx_x} = 1$$

$$\Rightarrow \sum_{x_1=0,x_x=0}^{\infty} \frac{A_2^{x_2}}{x_2!}\frac{A_1^{x_1}}{x_1!}P_{00} = 1$$

$$\Rightarrow P_{00} = e^{-(A_1+A_2)} \tag{5}$$

From Equation (4) and (5),

$$P_{x_1x_x} = \frac{A_1^{x_1}}{x_1!}\frac{A_2^{x_2}}{x_2!}e^{-(A_1+A_2)} \tag{6}$$

For limited server n, the entire sampling space,

$$\sum_{x_1=0}^{n}\sum_{x_2=0}^{n-x_1}\frac{A_1^{x_1}}{x_1!}\frac{A_2^{x_2}}{x_2!}P_{00}=1$$

$$Or,\ P_{00}=\frac{1}{\sum\limits_{x_1=0}^{n}\sum\limits_{x_2=0}^{n-x_1}\frac{A_1^{x_1}}{x_1!}\frac{A_2^{x_2}}{x_2!}} \tag{7}$$

Now any probability state becomes,

$$P_{x_1x_2}=\frac{\frac{A_1^{x_1}}{x_1!}\frac{A_2^{x_2}}{x_2!}}{\sum\limits_{x_1=0}^{n}\sum\limits_{x_2=0}^{n-x_1}\frac{A_1^{x_1}}{x_1!}\frac{A_2^{x_2}}{x_2!}} \tag{8}$$

Blocking Probability is the summation of all state $P_{x_1x_2}$ where $x_1+x_2 = n$ and is expressed as,

$$B_n=\frac{\sum\limits_{x\in A}\sum\limits_{y\in B}P_{x,y}\Big|_{x+y=n}}{\sum\limits_{x_1=0}^{n}\sum\limits_{x_2=0}^{n-x_1}\frac{A_1^{x_1}}{x_1!}\frac{A_2^{x_2}}{x_2!}} \tag{9}$$

For limited trunk case the equation (9) becomes,

$$B_n=\frac{\sum\limits_{x\in A}\sum\limits_{y\in B}\binom{N}{x}a_1^x\binom{M}{y}a_2^y\Big|_{x+y=n}}{\sum\limits_{x_1=0}^{n}\sum\limits_{x_2=0}^{n-x_1}\binom{N}{x_1}a_1^{x_1}\binom{M}{x_2}a_2^{x_2}}\ , \tag{10}$$

where a_1 and a_2 are the offered traffic per user; N and M are the number of users of a_1 and a_2 traffic group respectively.

Using the above concept let us consider the traffic model of cognitive radio network where the traffic parameters are as follows:

M: The number of PU
N: The number of SU
λ_1: Arrival rate of SU/user
λ_2: Arrival rate of PU/user
μ_1: the termination rate of SU
μ_2: the termination rate of PU
A_p: Offered traffic of PU/user
A_s: Offered traffic of SU/user
P_{md}: Probability of misdetection
P_{fa}: Probability of false alarm

The state transition of the network is shown in Fig.3 for $n = 3$ channels.

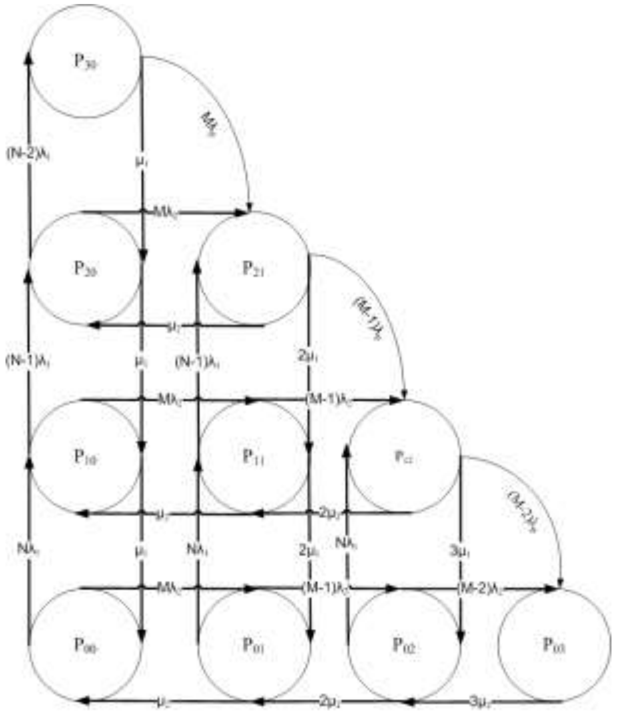


Fig.3. 2-D Markov chain of cognitive radio network under limited user (n = 3)

A channel will experience the traffic,

$As = As\_original\ .\ (1-P_{md}) + As\_original\ .\ P_{fa}$

The entire sample space of the Markov chain is derived as,

$$S(n) = A+L+E+H \tag{11}$$

where,

$$A=\sum_{i=0}^{n-1}\sum_{j=0}^{n-i-1}\binom{M}{i}A_p^i\binom{N}{j}A_s^j$$

$$B=A_p\binom{M}{1}A_p^{n-x-1}\binom{M}{n-x-1}^{n-x-1}A_s^x\binom{N}{x}+A_p^{n-x-1}\binom{M}{n-x-1}A_s^{x+1}\binom{N}{x+1}$$

$$K=\ As.C(N,1).\left(Ap^{n-x}.C(M,n-x).As^{x-1}\ .C(N,x-1)\right)$$

$$L=\sum_{x=1}^{n-1}\left[\frac{B+K}{n+Ap\ .C(M,1)}\right]$$

$$E=\frac{Ap\ .C(M,1).\left(Ap^0\ .C(M,0).As^{n-1}\ .C(N,n-1)\right)}{n+Ap\ .C(M,1)}$$

$$F=Ap\ .\ C(M,1).\left(Ap^{n-1}\ .C(M,n-1).As^0\ \ .C(N,0)\right)$$

$$G=Ap\ .C(M,1).(Ap^{n-1}\ .C(M,1).(Ap^{n-1}\ .C(M,n-1)\ .As^1\ .C(N,1))$$

$$H=\frac{F+G}{n}$$

$$\text{and } C(x,y)=\binom{x}{y}$$

Now the blocking probability for the secondary user,

$$B_s(n)=\frac{L+E+H}{S(n)} \tag{12}$$

And the blocking probability for the primary user,

$$B_p(n)=\frac{H}{S(n)} \tag{13}$$

The throughput for the primary user is

$$Xp\_bar(n) = (1 - Bp(n))\ .\ Ap.\ M \tag{14}$$

And the throughput for the secondary user is

$$Xs\_bar(n) = (1 - Bs(n))\ .\ As\_original\ .\ N. \tag{15}$$

III. RESULT

Fig.4 shows the variation of throughput against number of channels taking, the number of primary users, M = 40; the number of secondary users, N=80; offered traffic of PU, Ap = 0.25Erls/user; offered traffic of SU, As=0.083 Erls/user; probability of misdetection, P_{md}= 0.04; and probability of false alarm, P_f= 0.08. The graph shows that the throughput increases with increase in the number of channels for both the PU and SU. The throughput of PU is far larger than that of SU for the number of channels n<15 because of higher priority of PU. Beyond n = 9 the throughput of PU reaches at saturation level but throughput of SU still rising. For n> 40 both curve merge because of plenty of channel's availability.

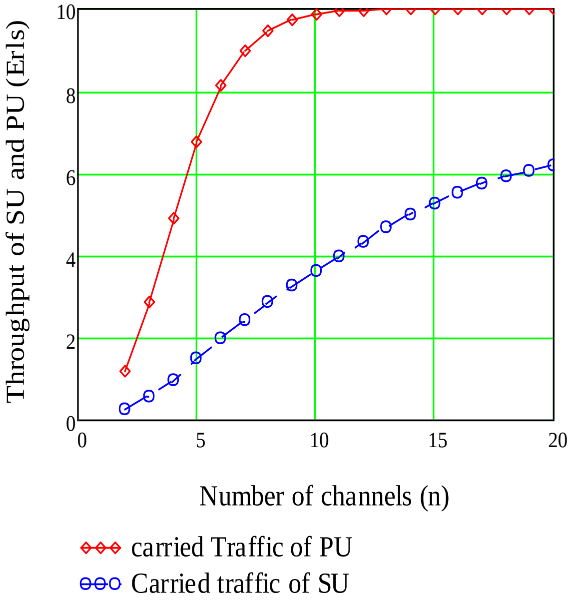


Fig. 4. Throughput of SU and PU (Erls) with the variation of channel

Fig.5 shows the variation of blocking probability against number of channels taking, similar traffic parameters as of Fig.4. The graph shows that the Blocking Probability decreases with increase in the number of channels for both the PU and SU. The blocking probability of PU decreases exponentially but that of SU decreases almost linearly because of higher priority of PU. Beyond n = 10 the blocking probability of PU reaches close to zero level but blocking probability of SU still decreasing. For n> 24 both curve merge because of availability of plenty of channels.

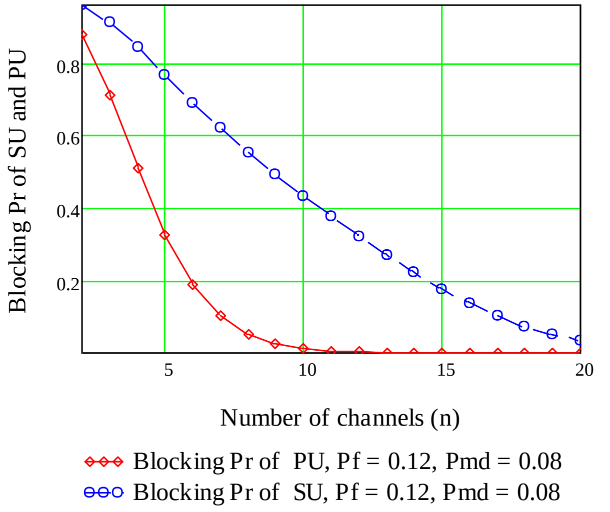


Fig.5. Blocking probability of SU and PU with the variation of channel

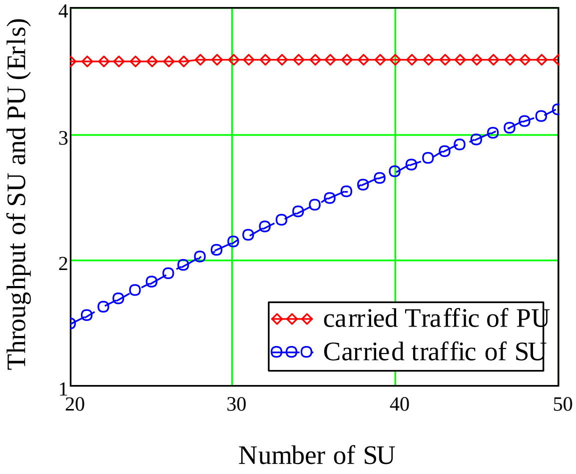


Fig.6. Throughput of SU and PU (Erls) with variation of number of SU

Fig.6 shows the variation of throughput against the number of SU, taking the number of primary users, M =40 and the number of channels, n=8. The graph shows that the throughput increases with increase in the number of SU for the SU, but the throughput of PU is fixed since conceptually performance of PU is independent of SU in a cognitive radio network.

Fig.7 shows the variation of blocking probability against the number of SU, taking the same traffic parameters as of Fig.6. The graph shows that the blocking probability of SU increases with increase in the number of SU but the blocking probability of PU most remains fixed and much below the case of SU.

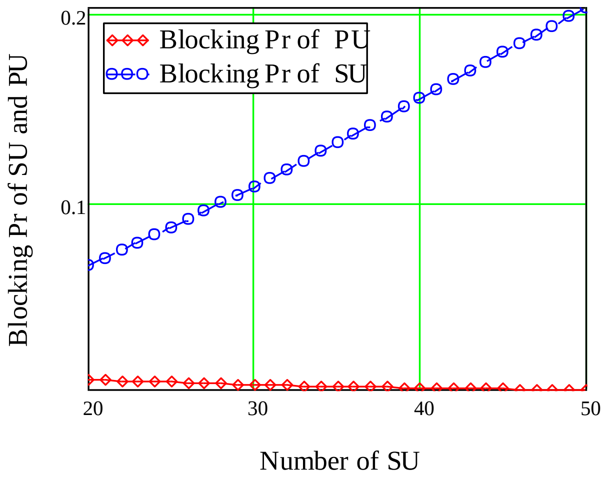


Fig.7. Blocking probability of SU and PU against the number of SU

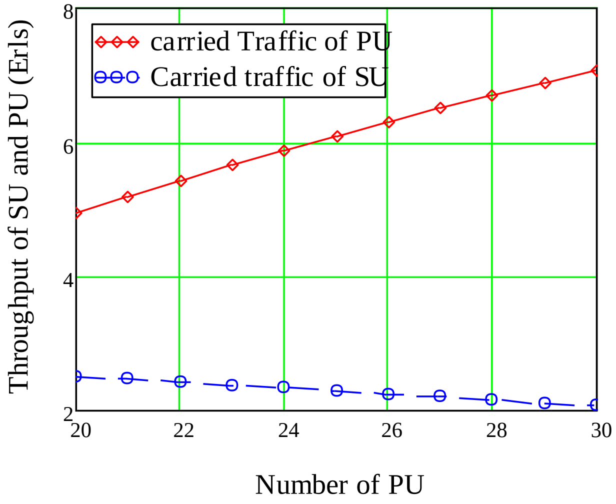


Fig.8. Throughput of SU and PU (Erls) against the number of PU

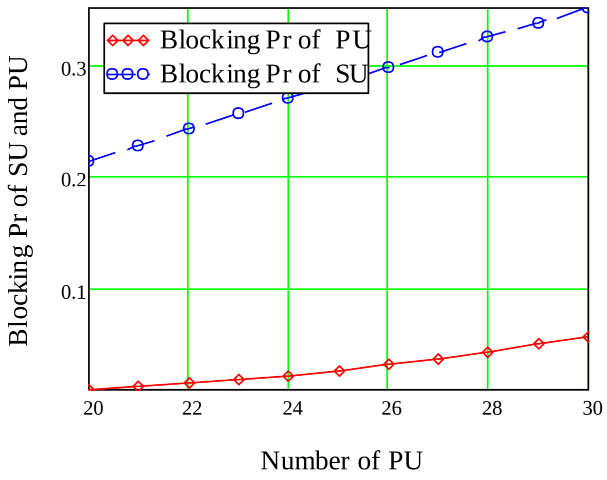


Fig.9. Blocking probability of SU and PU against the number of PU

Fig.8 shows the variation of throughput against the number of PU, taking the number of secondary users, *N*=40. The graph shows that the throughput increases with increase in the number of PU but the throughput of SU is shown decreasing since its opportunity decreases with increase in the number of PU.

Fig.9 shows the variation of the blocking probability against the number of PUs. The graph shows that the blocking probability of both type of users increases linearly but the blocking probability of PU is increasing less rapidly than the case of the secondary user.

IV. CONCLUSION

In this paper we have analyzed the performance of a cognitive radio network using M/M/n/k Traffic model with a 2-D Markov Chain. The result section reveals the performance of the network varying different traffic parameters, provide expected results. Still we have the scope to use M/G/1/K traffic of packet switch network of finite queue. In this case two dimensional traffic models using state transition chain will not be possible because of general PDF of service time. We can apply tabular form of 2-D traffic model of [9] to pave the way for evaluating packet loss probability of PU and SU. Finally, the impact of fading channel on false alarm and misdetection can also be included on the traffic model to observe the performance under different small scale fading.

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