# Performance Modeling of Finite-Source Cognitive Radio Networks Using Simulation

Janos Sztrik[1(✉)], Tamás Bérczes[1], Hamza Nemouchi[1], and Agassi Melikov[2]

[1] Faculty of Informatics, University of Debrecen, Debrecen, Hungary
{sztrik.janos,berczes.tamas}@inf.unideb.hu, nemouchih@gmail.com
[2] Azerbaijan National Academy of Sciences, Baku, Azerbaijan
agassi.melikov@gmail.com

**Abstract.** This paper deals with performance modeling of radio frequency licensing. Licensed users (Primary Users - PUs) and normal users (Secondary Users - SUs) are considered. The main idea, is that the SUs are able to access to the available non-licensed radio frequencies.

A finite-source retrial queueing model with two non-independent frequency bands (considered as service units) is proposed for the performance evaluation of the system. A service unit with a priority queue and another service unit with an orbit are assigned to the PUs ans SUs, respectively. The users are classified into two classes: the PUs have got a licensed frequency, while the SUs have got a frequency band, too but it suffers from the overloading. We assume that during the service of the non-overloaded band the PUs have preemptive priority over SUs. The involved inter-event times are supposed to be independent, hypo-exponentially, hyper-exponentially, lognormal distributed random variables, respectively, depending on the different cases during simulation.

The novelty of this work is that we create a new model to analyze the effect of distribution of inter-event time on the mean and variance of the response time of the PUs and SUs.

As the validation of the simulation program a model with exponentially distributed inter-event times is considered in which case a continuous time Markov chain is introduced and by the help of MOSEL (MOdeling Specification and Evaluation Language) tool the main performance measures of the system are derived. In several combinations of the distribution of the involved random variables we compare the effect of their distribution on the first and second moments of the response times illustrating in different figures.

**Keywords:** Finite source queuing systems · Simulation · Cognitive radio networks · Performance evaluation

## 1 Introduction

Cognitive radio has emerged as a promising technology to realize dynamic spectrum access and increase the efficiency of a largely under utilized spectrum. In a


V.M. Vishnevskiy et al. (Eds.): DCCN 2016, CCIS 678, pp. 64–73, 2016.
DOI: 10.1007/978-3-319-51917-3_7

cognitive radio network (CRN), a cognitive or secondary users (SUs) are allowed to use the spectrum by primary users (PUs) as long as the PUs do not use it. This operation is called opportunistic spectrum access, see for example [1,2]. To avoid interference to PUs, SUs must intelligently release the unlicensed spectrum if a licensed user appears as it was treated in [3,4].

In this paper we introduce a finite-source queueing model with two (non independent) frequency channels. According to the CRN modeling the users are divided into two types: the Primary Users (PUs) have got a licensed frequency, which does not suffer from overloading feature. The Secondary Users (SUs) have got a frequency band too, but suffers from overloading. A newly arriving SU request can use the band of PUs (which is not licensed for SUs) if the band of SUs is engaged, in the cognitive way: the non-licensed frequency must be released by the SU when a PU request appears. In our environment the band of the PUs is modeled by a queue where the requests has preemptive priority over the SUs requests. The band of the SUs is described by a retrial queue: if the band is free when the request arrives then it is transmitted. Otherwise, the request goes to the orbit if both bands are busy. We assume that the radio transmission is not reliable, it will fail with a probability $p$ for both channels. If a failure happens then the request retransmission process starts immediately, see for example [3,4].

Hence, it should be noted that the novelty of this work is that we create a new model to analyze the effect of distribution of inter-event time on the mean and variance of the response time of the PUs and SUs. In several combinations of the distribution of the involved random variables and using simulation we compare the effect of their distribution on the first and second moments of the response times illustrating in different figures.

## 2 System Model

Figure 1 illustrates a finite source queueing system which is used to model the considered cognitive radio network. The queueing system contains two interconnected, not independent sub-systems. The first part is for the requests of the PUs. The number of sources is denoted by $N_1$. In order to analyze the effect of the distribution, these sources generate high priority requests with hypo-exponentially, hyper-exponentially and lognormally distributed inter-request times with the same rate $\lambda_1$ or with the same mean $1/\lambda_1$. The generated requests are sent to a single server unit (Primary Channel Service - PCS) with preemptive priority queue. The service times are supposed to be also hypo-exponentially, hyper-exponentially and lognormally distributed with the same rate $\mu_1$ or with the same mean $1/\mu_1$.

The second part is for the requests of the SUs. There are $N_2$ sources, the inter-request times and service times of the single server unit (Secondary Channel Service - SCS) are assumed to be hypo-exponentially, hyper-exponentially and lognormally distributed random variables with rate $\lambda_2$ and $\mu_2$, respectively.

A generated high priority packet goes to the primary service unit. If the unit is idle, the service of the packet begins immediately. If the server is busy with

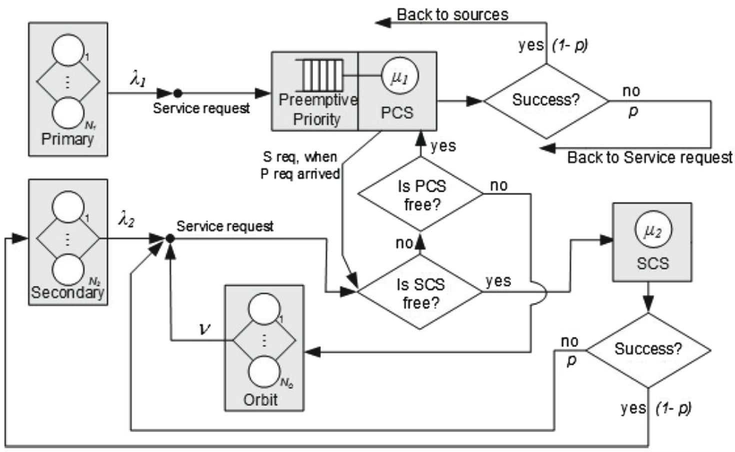


**Fig. 1.** A priority and a retrial queue with components

a high priority request, the packet joins the preemptive priority queue. When the unit is engaged with a request from SUs, the service is interrupted and the interrupted low priority task is sent back to the SCS. Depending on the state of secondary channel the interrupted job is directed to either the server or the orbit. The transmission through the radio channel may produce errors, which can be discovered after the service. In the model this case has a probability $p$, and the failed packet is sent back to the appropriate service unit. When the submission, is successful (probability *1-p*), the requests goes back to the source.

In case of requests from SUs. If the SCS is idle, the service starts, if the SCS is busy, the packet looks for the PCS. In case of an idle PCS, the service of the low priority packet begins at the high priority channel (PCS). If the PCS is busy the packet goes to the orbit. From the orbit it retries to be served after an exponentially distributed time with parameter $\nu$. The same transmission failure with the same probability can occur as in the PCS segment.

To create a stochastic process describing the behavior of the system, the following notations are introduced

- $k_1(t)$ is the number of high priority sources at time t,
- $k_2(t)$ is the number of low priority sources at time t,
- $q(t)$ denotes the number of high priority requests in the priority queue at time t,
- $o(t)$ is the number of requests in the orbit at time t,
- $y(t) = 0$ if there is no job in the PCS unit, $y(t) = 1$ if the PCS unit is busy with a job coming from the high priority class, $y(t) = 2$ when the PCS unit is servicing a job coming from the secondary class at time t,
- $c(t) = 0$ when the SCS unit is idle and $c(t) = 1$, when the SCS is busy at time t.

It is easy to see that

$$k_1(n) = \begin{cases} N_1 - q(t), & y(t) = 0, 2 \\ N_1 - q(t) - 1 & y(t) = 1 \end{cases}$$

$$k_2(n) = \begin{cases} N_2 - o(t) - c(t), & y(t) = 0, 1 \\ N_2 - o(t) - c(t) - 1 & y(t) = 2 \end{cases}$$

In the case of exponentially distributed inter-event time a continuous-time Markov chain can be constructed and the main steady-state performance measures can be obtained, as it was carried out in [4]. The numerical result obtained in this paper were the test result for the validation of the simulation outputs.

However, in this paper we deal with more general situation allowing non-exponentially distributed times. For the sake of easier understanding the input parameters are collected in Table 1.

**Table 1.** List of simulation parameters

| Parameter | Maximum | Value at $t$ |
|---|---|---|
| Active primary sources | $N_1$ | $k_1(t)$ |
| Active secondary sources | $N_2$ | $k_2(t)$ |
| Primary generation rate | | $\lambda_1$ |
| Secondary generation rate | | $\lambda_2$ |
| Requests in priority queue | $N_1 - 1$ | $q(t)$ |
| Requests in orbit | $N_2 - 1$ | $o(t)$ |
| Primary service rate | | $\mu_1$ |
| Secondary service rate | | $\mu_2$ |
| Retrial rate | | $\nu$ |
| Error probability | | $p$ |

## 3 Simulation Results

In order to estimate the mean and variance of the response times of the requests, the batch means method is used which is the most popular confidence interval techniques for the output analysis of a steady-state simulation, see for example [5–7].

There are many possible combinations of the cases, but due to the page limitation we considered only the following sample results showing the effect of the distributions on the mean and variance of the corresponding response times.

For the easier understanding the numerical values of parameters are collected in Table 2.

**Table 2.** Numerical values of model parameters

| No. | $N_1$ | $N_2$ | $\lambda_1$ | $\lambda_2$ | $\mu_1$ | $\mu_2$ | $\nu$ | $p$ |
|---|---|---|---|---|---|---|---|---|
| Figs. 2 and 3 | 10 | 50 | x-axis | 0.03 | 1 | 1 | 20 | 0.1 |
| Figs. 4 and 5 | 10 | 50 | x-axis | 0.03 | 1 | 1 | 20 | 0.1 |
| Figs. 6 and 7 | 10 | 50 | 0.02 | x-axis | 1 | 1 | 20 | 0.1 |
| Fig. 8 | 10 | 50 | 0.02 | 0.03 | 1 | 1 | x-axis | 0.1 |
| Fig. 9 | 10 | 50 | 0.02 | x-axis | 1 | 1 | 20 | 0.1 |

Figures 2 and 3 show that the distribution of the inter-arrival time of the primary packets with the same mean has no effect on the mean and variance of response time of the secondary users, they depend only on their mean supposing that the inter-request time of the SUs and the service time of both servers units are exponentially distributed. It is the consequence of [8] in which it was proved that the steady-state distribution is insensitive to the distribution of the source times, depending only on their means.

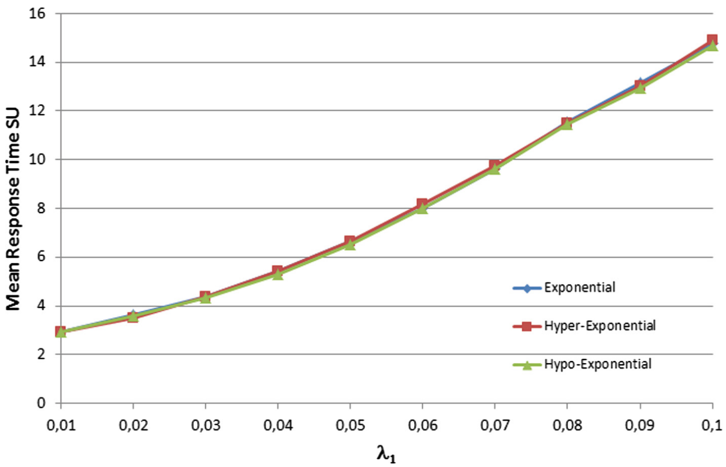


**Fig. 2.** The effect of inter-request time distribution of the PUs on the mean response time of SUs vs $\lambda_1$

The other operation mode is where the service time at the primary server is hyper-exponentially, hypo-exponentially and lognormally distri-buted with the same mean supposing that the inter-arrival time of PUs and SUs, and the service time of the secondary server are exponentially distributed.

Figures 4 and 5 show that the value of the mean response time and variance is greater when the service time is hypo-exponentially distributed, also the mean response time of the secondary users. In the case the service time is lognormally distributed is approximately the same when it is hypo-exponentially distributed.

sztrik.janos@inf.unideb.hu

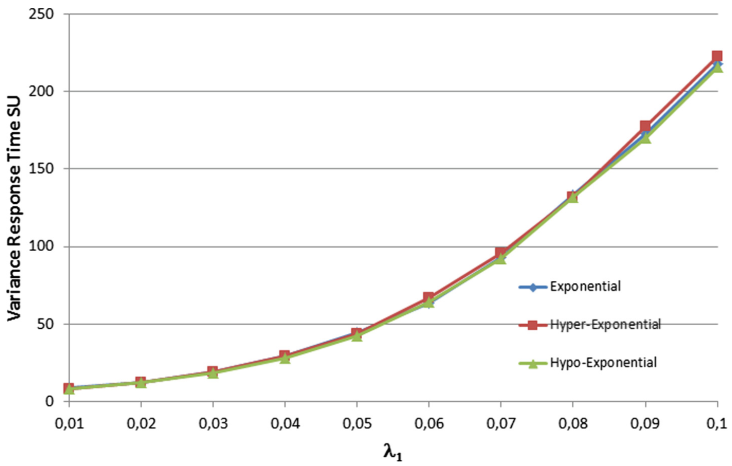


**Fig. 3.** The effect of inter-request time distribution of the PUs on the variance of response time of SUs vs $\lambda_1$

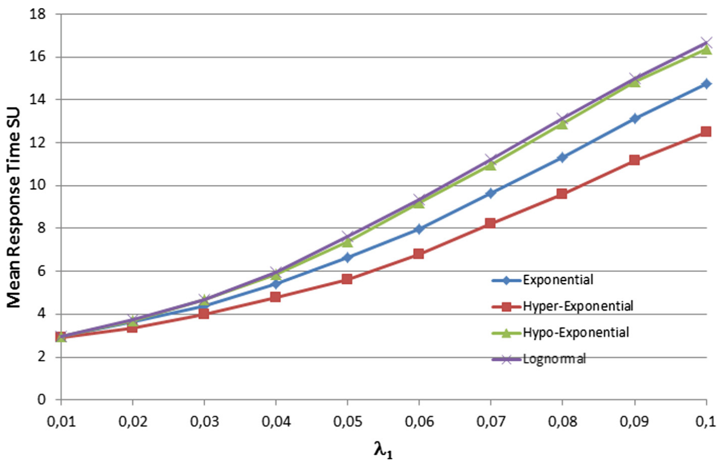


**Fig. 4.** The effect of service time distribution of the PUs on the mean response time of SUs vs $\lambda_1$

In Figs. 6 and 7, the inter-request time for the PUs and SUs is exponentially distributed. In this cases, figures show the effect of the SU's inter-request arrival time on the mean and variance response time of the SUs knowing that the service time of SCS is exponentially, hypo-exponentially, hyper-exponentially and lognormally distributed with the same mean. The value of the squared coefficient of variation for the hypo-exponentially distribution is always less than one and for the hyper-exponentially is always greater than one, therefore the mean and variance of response time of SUs when the service time is hyper-exponentially

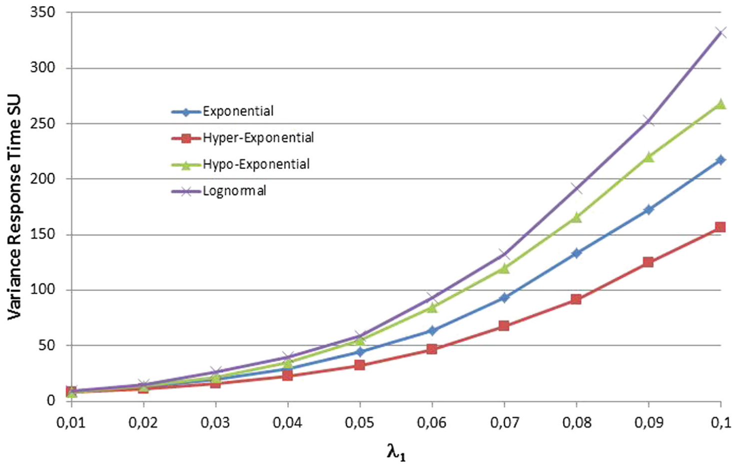


**Fig. 5.** The effect of service time distribution of the PUs on the variance of response time of SUs vs $\lambda_1$

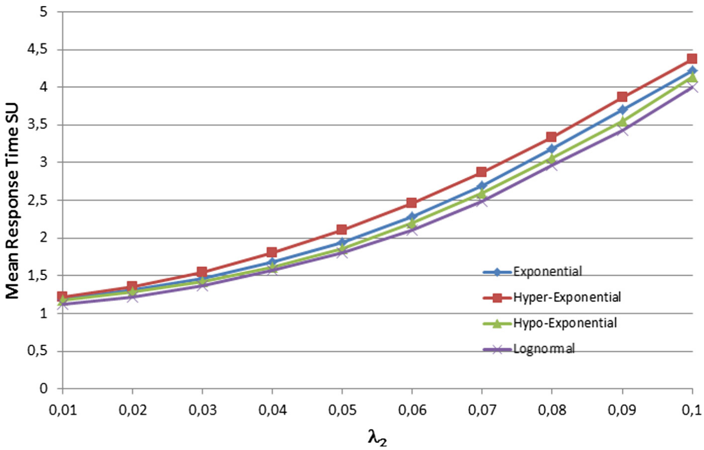


**Fig. 6.** The effect of service time distribution of the SUs on the mean response time of SUs vs $\lambda_2$

is greater than the mean response time of SUs when the service time is hypo-exponentially distributed.

On Fig. 8 the service time distribution of SCS is exponentially, hypo-exponentially, hyper-exponentially and lognormally distributed with the same mean. The service time of PCS and the inter-arrival time of both PUs, SUs are exponentially distributed. Figure shows the effect of the time spent in orbit on the mean response time of the SUs, it was modeled by a variable retrial rate. The result confirms the expectation that is increasing retrial rate involves shorter response times.

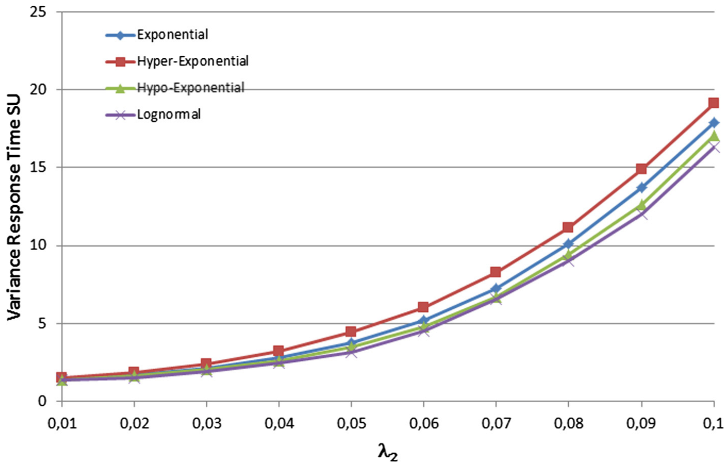


**Fig. 7.** The effect of service time distribution of the SUs on the variance of response time of SUs vs $\lambda_2$

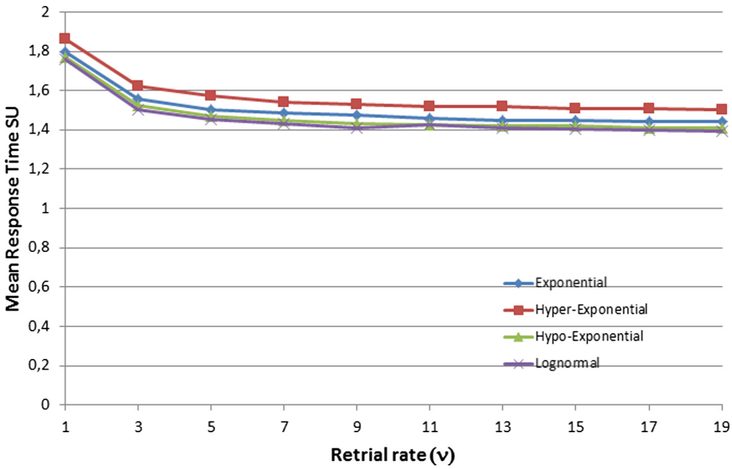


**Fig. 8.** The effect of service time distribution of the SUs on the mean response time of SUs vs the retrial rate $\nu$

On the last figure, we assume that the service time of the PCS is exponentially, hypo-exponentially, hyper-exponentially and lognormally distributed with the same mean. The service time of the SCS and the inter-request time of PUs and SUs are exponentially distributed. The figure shows the effect of the inter-request time of the SUs on the mean response time of SUs. Here again we get what we expected that is increasing arrival intensity involves longer response times.

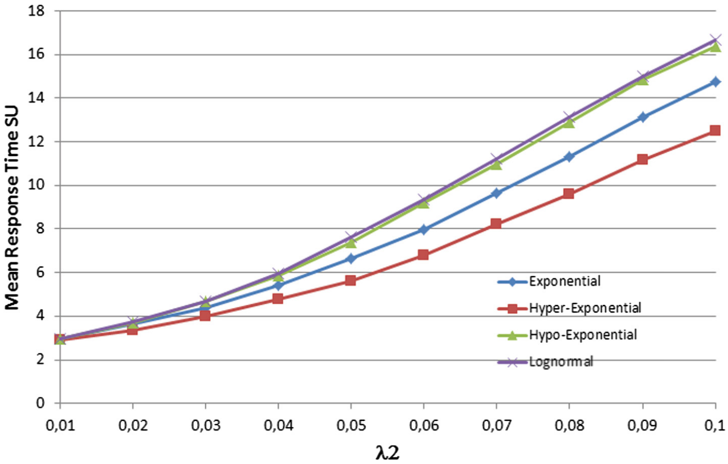


**Fig. 9.** The effect of service time distribution of the PUs on the mean response time of SUs vs $\lambda_2$

## 4 Conclusions

In this paper a finite-source retrial queueing model was proposed with two bands servicing primary and secondary users in a cognitive radio network. Primary users have preemptive priority over the secondary ones in servicing at primary channel. At the secondary channel an orbit is installed for the secondary packets finding the server busy upon arrival. Simulation was used to obtain several sample examples illustrating the effect of the distribution of the inter-events times on the first and second moments of the response times.

**Acknowledgments.** The work of Nemouchi H. was supported by the Stipendium Hungaricum Scholarship.

## References

1. Wong, E.W., Foch, C.H., Adachi, F.: Analysis of cognitive radio spectrum decision for cognitive radio networks. IEEE J. Sel. Areas Commun. **29**, 757–769 (2011)
2. Devroye, N., Vu, M., Tarock, V.: Congnitive radio networks. IEEE Sign. Proces. Mag. **25**, 12–23 (2008)
3. Gao, S., Wang, J.: Performance analysis of a cognitive radio network based on preemptive priority and guard channels. Int. J. Comput. Math. GCOM-2013-0621-A (2014)
4. Sztrik, J., Bérczes, T., Almási, B., Kuki, A., Wang, J.: Performance modeling of finite-source cognitive radio networks. Acta Cybern. **22**, 617–631 (2016)
5. Law, A.M., Kelton, W.D.: Simulation Modeling and Analysis. McGraw-Hill College, New York (1991)

6. White, A.J., Schmidt, J.W., Bennett, G.K.: Analysis of Queueing Systems. Academic Press, INC, New York (1975)
7. Carlstein, E.W., Goldsman, D.: The use of subseries values for estimating the variance of a general statistic from a stationary sequence. Ann. Stat. **14**, 1171–1179 (1986)
8. Sztrik, J.: On the finite-source G/M/r queues. Eur. J. Oper. Res. **20**, 261–268 (1985)