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# Performance evaluation of finite-source cognitive networks with non-reliable services using simulation

**Hamza Nemouchi*, János Sztrik**

Faculty of Informatics, University of Debrecen
Debrecen, Hungary

**Abstract**

As the evolution of wireless communication technology, the available spectrum resources become scarce. The cognitive radio (CR) is a dynamic spectrum access technique which provides the capability to share a wireless channel between licensed and unlicensed users opportunistically (also called Primary Users - PU and Secondary Users - SU).

In this paper stochastic simulation is used for performance evaluation of cognitive radio network. A finite-source retrial queuing model with two service units is proposed. A priority queue and an orbit are assigned to the PUs and SUs respectively. The proposed queueing system contains two interconnected, not independent sub-systems. The Primary Channel Service (PCS) and the Secondary Channel Service (SCS) are not reliable and the services are assumed to be subject to a random failure with probability $p_1$ and $p_2$ for the PCS and SCS, respectively. The failure of the service may block the servers and the request retransmission process starts immediately.

The novelty of this work is to analyze the effect of the failure probability on the mean and the variance of the response time of the PUs and SUs, and on the Utilization of the PCS and SCS. The inter-event times are supposed to be exponentially, hypo-exponentially, hyper-exponentially and lognormally distributed random variables, depending on different cases during simulation.

By the help of simulation we compare the effect of the non-reliability of the servers in different combination of distributions on the first and second moments of the response times of the requests, and the utilization of the system by illustrating on different figures.

*Keywords:* Retrial queueing systems, simulation, cognitive radio networks, non-reliable servers, performance and reliability measures.

*MSC:* 60K25/68M20/90B22/90B25

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# 1. Introduction

Cognitive radio (CR) has emerged as a promising technology to realize dynamic spectrum access and increase the efficiency of a largely under utilized spectrum. As it was defined in [1, 2], the cognitive radio network (CRN) is a network made up of CRs by extending the radio link features to network layer function and above. By means of CRs cooperation, the network is able to sens its environment, learn from the history, and accordingly decide the best spectrum settings.

In other words, cognitive radio allows efficient use of the available spectrum by defining two types of users in wireless networks: licensed and unlicensed users. An unlicensed user (also called secondary user (SU)) can use the spectrum if it is not being used at that time by licensed users (also called primary user (PU)). When the licensed user appears to use the spectrum, the unlicensed user must find another spectrum to use. see for example [3, 4, 5].

In this paper we introduce a finite-source queueing model with two (non independent) frequency channels. The cognitive radio architecture consists of two main networks: The Primary Channel Service (PCS) and Secondary Channel Service (SCS). The PCS refers to the existing network, wherein the primary users (PUs) have got a licensed frequency which does not suffer from overloading. The SCS does not have a license to operate in a licensed frequency. Hence, SCS is designed to work with PCS to provide the capability to utilize or share the unused spectrum in an opportunistic way. The secondary users have got also a frequency band but it suffers from overloading. In our environment the band of the PUs is modelled 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. The Primary Service Channel (PCS) and Secondary Service Channel (SCS) are not reliable and the services are assumed to be subject to a random failure with probability $p_1$ and $p_2$ of the PUs and SUs, respectively.

Hence, it should be noted that the novelty of this work is to analyse the effect of the failure probability on the mean and the variance response time of the PUs and SUs, and on the utilization of the PCS and SCS. By using simulation we compare the effect of the failure probability on the first and second moments of the response times illustrating in different figures.

# 2. System model

Fig.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 $N1$. 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.

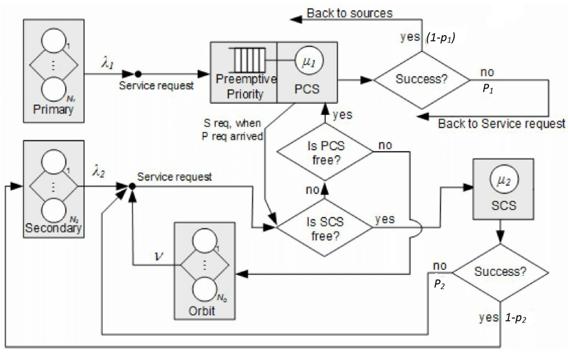


Figure 1: Finite-source retrial queueing system: Modeling the Cognitive Radio Network

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 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 produce a failure of service. In the model this case has a probability $p_1$, and the failed packet is sent back to the appropriate service unit. When the submission, is successful (probabilities $1-p_1$), 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 probability $p_2$ can occur as in the SCS segment.

To create a stochastic process describing the behaviour 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 (normal) 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 this paper, the numerical result are obtained by the validation of the simulation outputs. 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, see [6]. In this work, we deal with more general situation allowing non-exponentially distributed times. The input parameters are collected in Table 1.

| 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 | | $\mu_2$ |
| Primary service error probability | | $p_1$ |
| Secondary service error probability | | $p_2$ |
| Retrial rate | | $\nu$ |

Table 1: List of simulation parameters

# 3. Simulation result

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 [7, 8, 9, 10]. There are many possible combinations of the cases, We considered only the following sample results showing the effect of the failure probability of services on the mean and variance response time and the utilisation of PCS and SCS. For the easier understanding the numerical values of parameters are collected in Table 2.

| No. | $N_1$ | $N_2$ | $\lambda_1$ | $\lambda_2$ | $\mu_1$ | $\mu_2$ | $\nu$ | $p_1$ | $p_2$ |
|---|---|---|---|---|---|---|---|---|---|
| Fig.2 and Fig.3 | 10 | 50 | 0.02 | 0.03 | 1 | 1 | 20 | x - axis | 0.1 |
| Fig.4 and Fig.5 | 10 | 50 | x - axis | 0.03 | 1 | 1 | 20 | 0.3, 0.6 | 0.3, 0.6 |
| Fig.6 and Fig.7 | 10 | 50 | x - axis | 0.03 | 1 | 1 | 20 | 0.3, 0.6 | 0.3, 0.6 |
| Fig.8 and Fig.9 | 10 | 50 | 0.02, 0.06 | 0.03 | 1 | 1 | 20 | x - axis | 0.1 |
| Fig.10 | 10 | 50 | 0.02 | 0.03 | 1 | 1 | 20 | 0.1 | x - axis |

Table 2: Numerical values of simulation parameters

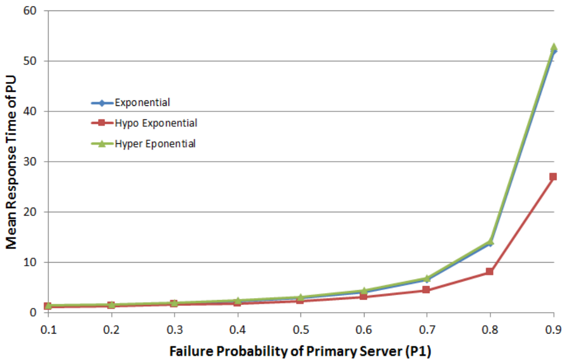


Figure 2: The effect of the failure probability of the PCS on the mean response time of the PUs

Figure 2 and Figure 3 illustrates the effect of the failure probability of the PCS on the mean response time and utilization of the PUs, where the distribution of the inter-request time is exponentially distributed random variable and the service time is exponentially, hypo-exponentially and hyper-exponentially distributed random variable with the same mean. The figures show that increasing the failure probability of the services involves longer response time of the users and more utilization of the channels service. Also, the figures show the effect of the distribution of the service time on the mean response time and the utilization of PCS when the failure probability is increasing, it is the consequence of [11], in where it was proved that the steady-state distribution is sensitive to the distribution of the service time.

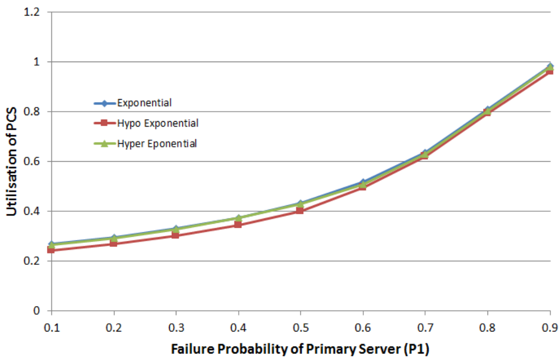


Figure 3: The effect of the failure probability of the PCS on the Utilization of the PCS

The other case of simulation is where the Primary Service Channel (PCS) is less reliable than the Secondary Service Channel (SCS) and where the PCS is more reliable than the SCS, supposing that the inter-request times are exponentially distributed random variable and the service times are hyper-exponentially distributed random variables.

The Figure 4 and Figure 5 show the effect of the failure probability of the servers on the mean response time of the users in terms of the primary inter-request rate ($\lambda_1$).
The Figure 4 shows the difference on the mean response time of the PUs where the PCS is less reliable than the SCS and the contrary case. The Figure 5 shows the effect of the failure probability of the servers on the mean response time of the SUs. As it was expected in the cognitive radio networks, when the PCS is not reliable and increasing the primary arrival intensity ($\lambda_1$), the mean response time of the SUs becomes a constant.

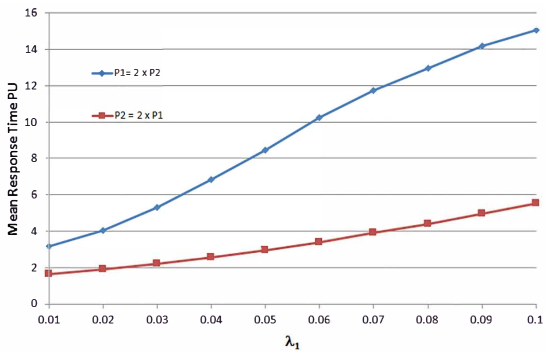


Figure 4: The effect of the failure probability of the services on the mean response time of the PUs vs $\lambda_1$

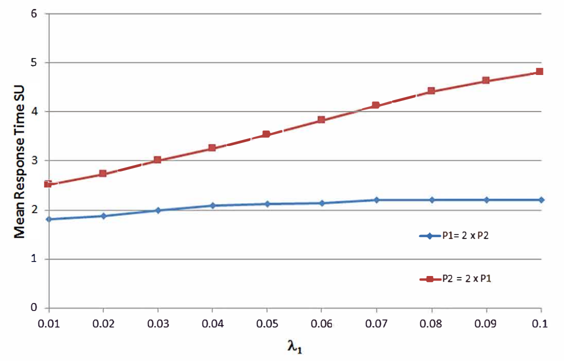


Figure 5: The effect of the failure probability of the services on the mean response time of the SUs vs $\lambda_1$

The Figure 6 and Figure 7 illustrates the effect of the failure probability of the servers ($p_1$ and $p_2$) on the utilization of the servers in terms of the primary inter-request rate ($\lambda_1$).
In the Figure 6, when increasing $\lambda_1$ the utilization of the PCS is almost the same when the PCS is less reliable than the SCS and the opposite case. Hence, in the Figure 7, the utilisation of the SCS becomes a constant when the PCS is less reliable than the SCS and $\lambda 1$ is great.

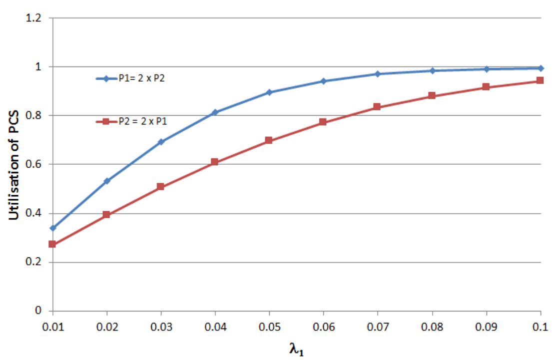


Figure 6: The effect of the failure probability of the services on the utilization of the PCS vs $\lambda_1$

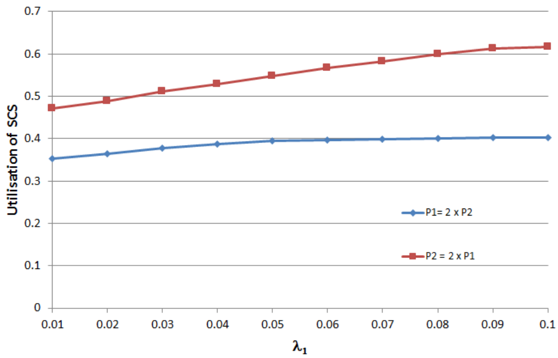


Figure 7: The effect of the failure probability of the services on the utilization of the SCS vs $\lambda_1$

The following figures illustrate the effect of the inter-request time on the mean response time of users and the utilization of the servers in terms of the failure probability of the primary services ($p_1$).

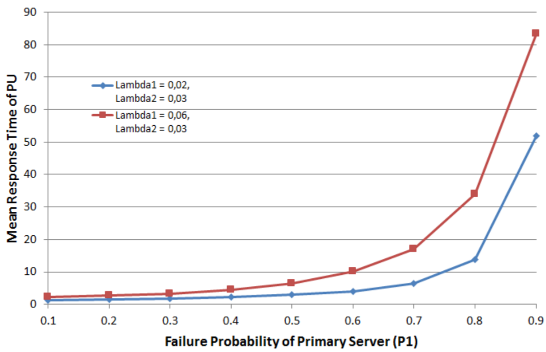


Figure 8: The effect of the inter-request rate on the mean response time of the PUs vs $p_1$

The Figure 8 shows the effect of the primary arrival rate ($\lambda_1$) on the mean response time of the PUs. Here also as it was expected,increasing the primary failure probability ($p_1$) involves longer response time of the PUs. Otherwise, the Figure 9 shows that the mean response time of the SUs is insensitive to the primary arrival rate ($\lambda_1$) when the primary failure probability ($p_1$) is high.

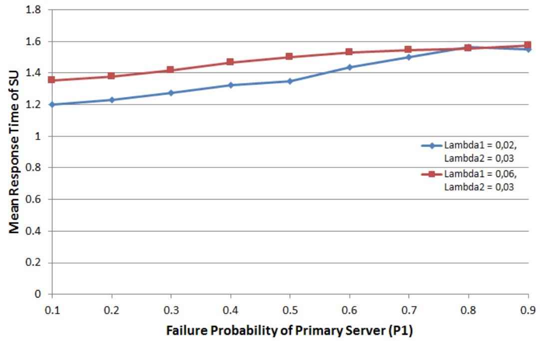


Figure 9: The effect of the inter-request rate on the mean response time of the SUs vs $p_1$

In the Figure 10, according to the cognitive radio networks properties, we see that the utilization of the PCS depends on the failure probability of the SCS ($p_2$). It shows that more the SCS is not reliable, more the utilization of the PCS increase.

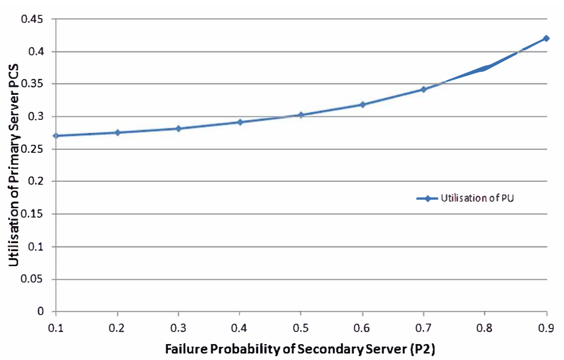


Figure 10: The effect of the failure probability of the SCS on the Utilization of the PCS

# 4. Conclusion

In this paper a finite-source retrial queueing model was proposed with two channels 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 for the secondary packets finding the server busy upon arrival. Simulation was used to obtain several sample examples illustrating the effect of the failure probability of the services on the first and second moments of the response times, also the utilization of the servers.

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