Performance Evaluation of Finite-Source Cognitive Radio Networks with Collision Using Simulation

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Abstract

***Abstract*—The present paper deals with a finite-source retrial queueing system to model cognitive radio networks. Two non independent frequency bands servicing two classes of users are considered: Primary Users (PUs) and Secondary Users (SUs). PUs have preemptive priority over SUs at the licensed spectrum while Sus are served at the normal spectrum containing an orbit for the retrial users.**

The novelty of this work is that we introduce the server with conflict in the retrial part of the cognitive radio network. Therefore, the arriving secondary customers involve into collision with the secondary customers under service in the SUs, and both joins the orbit. We established a simulation program to model the queueing system and to obtain estimation for the basic performance measures. Since individual users mostly interested in their sojourn time in the system we analyze the impact of the service time distribution (s.t.d) on the expectation and variance of sojourn time of the PUs and SUs, respectively. For illustration various sample examples are derived and Figures are generated for better understanding.

I. Introduction

The introduction of Cognitive Radio technology has aimed a powerful communication protocol [1],[2], it is an important component of the IEEE 802.22 standard used for wireless networks [3]. In Cognitive Radio Networks (CRN), the unlicensed users (SUs) are allowed to access opportunistically the unused licensed bands which is for the licensed users (PUs) if no primary activities are detected. In this situation SUs must react in a cooperative way if a primary user appears. For a detailed overviews of the cognitive radio networks, we refer books [4],[5].

Queueing theoretical methods have been used in [6],[7] to investigate the impact of service failure in a CogInfoCom system. In these papers the authors applied a tool supported approach to obtain the main operational characteristics of the systems. Figures were generated to show the impact of different input parameters especially the failure and repair rates of the servers. In [8] cognitive radio networks were modeled by the help retrial queueing systems containing two finite sources of PUs and SUs, respectively. A multidimensional Markov chain was introduced since by assumption all the inter-event times were exponentially distributed. Similarly to the above mentioned papers [6],[7] the same software package was used to formulate the problem and to solve the balance equations. As a result mean values of the important performance measures were calculated and then illustrated. As a natural generalization of this model in [9] the same system was investigated allowing non-exponentially distributed request generation, service and retrial times. Using stochastic simulation approach estimations for the important characteristics were obtained and several case studies illustrated the impact of the distributions. It should be mentioned that these systems operated without collisions. In the present paper we propose a retrial queueing system with a finite number of sources to analyze the impact of the collision of customers on the performance of the cognitive radio network where both intra-cognitive and inter-cognitive communication may take place. It can be seen that cognitive radio networks are special cases of CogInfoCom systems as it was described in [10],[11],[12]. In [13],[14] retrial queueing systems were treated by the help of an asymptotic method assuming that the request generation and retrial rates tends to zero as the number of sources tend to infinity. Supposing exponentially distributed inter-event times it was proved that the distribution of number of customers in the service facility tends to a normal distribution. Its mean and variance could be calculated analytically. The distribution of the sojourn time was also given. Several examples illustrated the applicability of the asymptotic method comparing the results to distributions obtained by the help of numerical approach. In our new model two interacting service processes are proposed. At the primary service, modeled as priority queueing system, PUs having a licensed frequency band apply preemptive priority discipline to the SUs. At the secondary service, modeled as a retrial queueing system, only SUs having a normal frequency band can appear and collisions take place and the requests go to the orbit if both bands are occupied.

Hence, the novelty of this work is that we introduce a queueing systems with two finite sources to model the performance of cognitive radio networks with collision and to analyze the impact of the s.t.d on the expectation and variance of sojourn time of the PUs and SUs, respectively. Using simulation in several examples comparisons are made and different Figures illustrate the above mentioned problem. One of the advantages of the simulation is that we can give estimations for the variances. Usually the investigation of the distribution of the sojourn time is very complicated and in most cases its Laplace-transform is given. The calculation of the variance is not a simple problem, it can be evaluated by the help of numerical and algorithmic approaches.

II. Operation of the system

The queueing system proposed in this work and illustrated in Figure 1 contains two interacting sub-systems. The first block is for PUs having a single server unit (Primary Channel Service - PCS) with preemptive priority queue, and N_1 sources. Each source generates a high priority requests according to an exponential distribution with parameter λ_1. Whereas, during simulation the service times are assumed to be exponentially, hypo-exponentially and hyper-exponentially distributed random variables with the same intensity μ_1. The second block is for the SUs, where there are N_2 sources, the request generation times of the SUs are supposed to be exponentially distributed random variables with rate λ_2. Here SUs are served in a single server unit (Secondary Channel Service - SCS) according to an exponential, hypo-exponential and hyper-exponential distribution with the same rate μ_2.

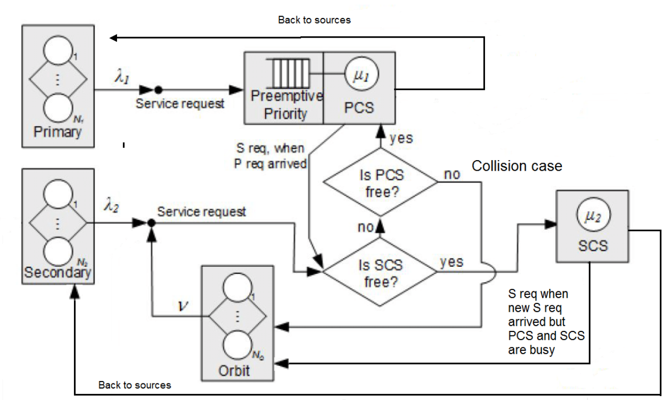

Fig. 1. A finite source retrial queueing system with collision

A generated PU goes to the PCS and if the unit is idle the service of the packet begins immediately. If the server is busy with a PU the packet joins the preemptive priority queue. When the server is busy by a SU, the service process is interrupted and the interrupted task is directed to the SCS. If it is busy, the interrupted job involves into collision with customer under service and both moves into the orbit.

For SUs we have the following operation rules. If at the arrival the SCS is idle the service begins immediately, otherwise the packet senses the PCS. If it is idle the service begins otherwise the packet involves into collision with other SU and both go to the orbit. Retrial customers repeat their demands for service after an exponentially distributed time with parameter ν.

In order to describe the operation of the systems by the help of a stochastic process let us introduce the following notations

- $k_1(t)$ is the number of PUs at time t,
- $k_2(t)$ is the number of SUs at time t,
- $q(t)$ denotes the number of PUs in the priority queue at time t,
- $o(t)$ is the number SUs in the orbit at time t,
- $y(t) = 0$ if PCS is idle, $y(t) = 1$ if PCS is busy with PU, $y(t) = 2$ when PCS is busy with SU at time t,
- $c(t) = 0$ when SCS 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 particular case when all times are exponentially distributed the operation of the system can be described by the help of a continuous-time Markov chain and the most important stationary performance characteristics could be calculated as it has been done in [8] for systems without collision. However, in this paper we generalize the model assuming non-exponentially distributed service times. One of our main aims is to investigate the variance of the sojourn times of request in the system.

Parameter	Maximum	Value at t
Active PUs	N_1	$k_1(t)$
Active SUs	N_2	$k_2(t)$
Generation rate for PUs		λ_1
Generation rate for SUs		λ_2
Customers in priority queue	N_1 - 1	$q(t)$
Customers in orbit	N_2 - 1	$o(t)$
Service intensity at PCS		μ_1
Service intensity at SCS		μ_2
Retrial intensity		ν

III. Simulation results

In this section we would like to show some examples to illustrate the impact of distribution having the same mean but different variance. It can be done, for example by the help of hypo-exponential and hyper-exponential distributions. Of course we could use other distributions as gamma, Weibul, lognormal, Pareto ones but as a start we generate simpler ones. In order to analyze the effect of the distribution of the service times, we used stochastic simulation and standard methods to give estimation for the expectation and variance of the sojourn time of the PUs and SUs, respectively. For the methodology see, for example [15],[16],[17],[18],[19].

Table 1 shows the numerical values of the input parameters.

TABLE I
NUMERICAL VALUES OF THE PARAMETERS

No.	N_1	N_2	λ_1	λ_2	μ_1	μ_2	ν
Fig.2	20	50	x - axis	0.1	1	1	20
Fig.3	20	50	x - axis	0.1	1	1	20
Fig.4	20	50	x - axis	0.1	1	1	20
Fig.5	20	50	0.1	x - axis	1	1	20
Fig.6	20	50	0.1	x - axis	1	1	20
Fig.7	20	50	0.1	x - axis	1	1	20
Fig.8	20	50	0.1	x - axis	1	1	20
Fig.9	20	50	0.1	x - axis	1	1	20

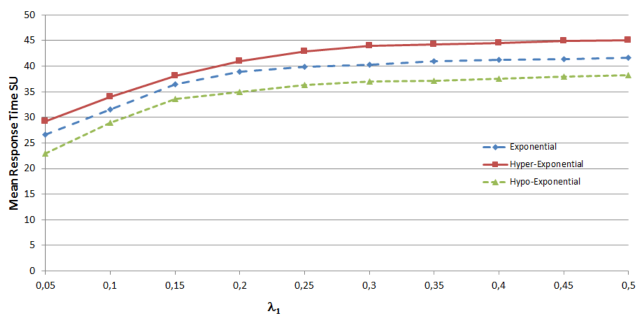

Fig. 2. The impact of the secondary s.t.d of the SUs on the average sojourn time of the SUs vs λ_1

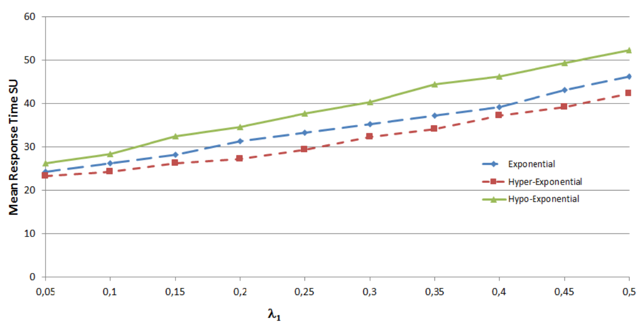

Fig. 3. The impact of the primary s.t.d of the SUs on the average sojourn time of the SUs vs λ_1

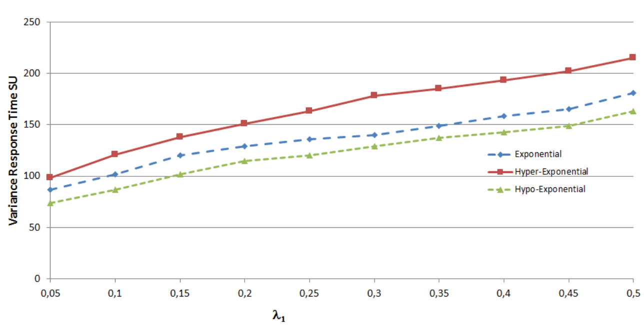

Fig. 4. The impact of the secondary s.t.d of the SUs on the variance of the sojourn time of the SUs vs λ_1

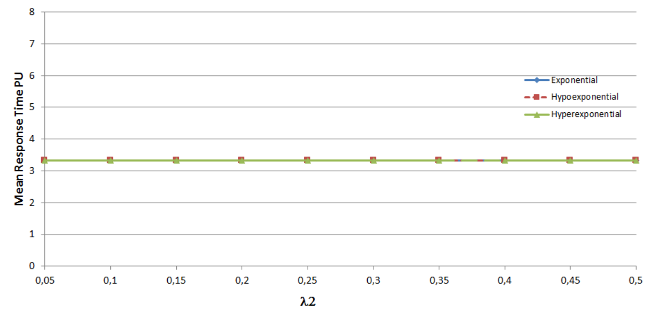

Fig. 5. The impact of the secondary arrival rate (λ_2) on the the average sojourn time of the PUs

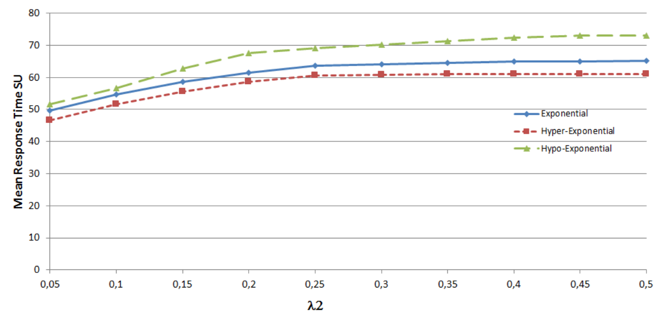

Fig. 6. The impact of the secondary s.t.d of the SUs on the average sojourn time of the SUs vs λ_2

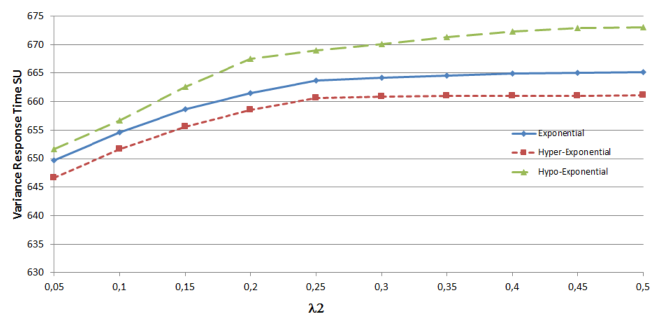

Fig. 7. The impact of the secondary s.t.d of the SUs on the variance of the sojourn time of the SUs vs λ_2

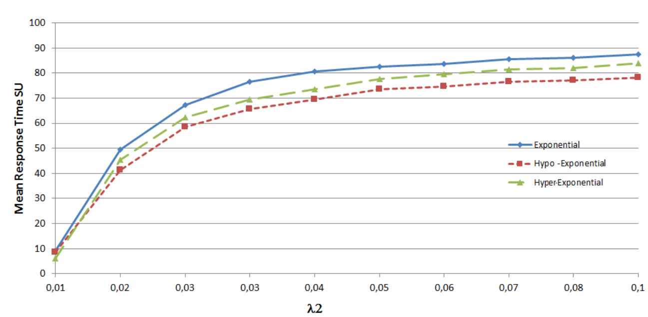

Fig. 8. The effect of the retrial time distribution on the average sojourn time of the SUs vs λ_2

IV. Comments

Figure 2 shows that the distribution of the service time of the secondary packets has an impact on the average sojourn

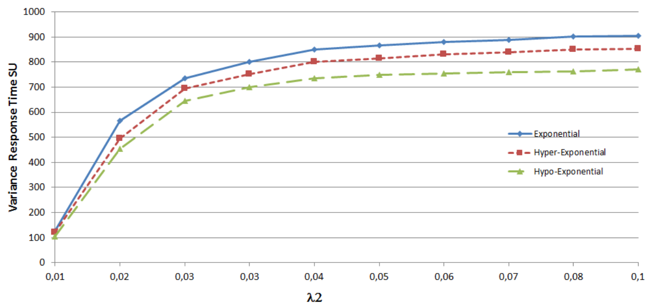

Fig. 9. The effect of the retrial time distribution on the variance of the sojourn time of the SUs vs λ_2

time of the SUs, where the value is greater when the service time is hyper-exponentially distributed, knowing that the service time of the high priority packet is exponentially distributed random variables. The collision at the retrial part of the system involves longer sojourn times as it was expected. Customer spends more time in the system comparing to the finite-source cognitive radio networks without collision[9].

Figures 3 and 4 show the impact of the distribution of the primary service time on the average and the variance of sojourn time of the secondary users, respectively, where the primary arrival rate is increasing. The distribution has an impact on the average and variance of the sojourn time as it was expected and the collision on the secondary part involves longer sojourn time.

Figure 5 illustrates the impact of the secondary arrival rate on the average sojourn time of PUs where the secondary service time is non-exponentially distributed. As the primary users have got a high priority over the secondary users, the average sojourn time of the primary users is insensitive to the generation rate of the SUs, secondary service distribution and the collision in the retrial part of the system. This Figure verifies that the simulation program operates correctly hence the average time is constant as it was expected.

In Figures 6 and 7, the service time of PUs is supposed to be exponentially distributed random variable. Figures show that the average sojourn time of the secondary requests depends on the s.t.d of the low priority packets. As shown previously, increasing the arriving intensity of the secondary calls causes longer sojourn time and the value of its average changes where the distribution of the service time changes.

Figure 8 and Figure 9 illustrate the effect of the distribution of the retrial time on the average and the variance of the sojourn time of the secondary requests when the secondary arriving rate is increasing. In this case, all the other inter-events time are supposed to exponentially distributed. Due to the collision or finding the server busy, when the customers retry to be served after a hypo-exponentially or a hyper-exponentially distributed time, there the average response time will be shorter than retrying after an exponentially distributed time.

V. Conclusion

In this paper, we introduced a finite-source retrial queueing system with two interacting blocks to model the operation of cognitive radio networks with collision of the secondary users. Primary customers have preemptive priority over the secondary ones in servicing at primary service unit. At the secondary service unit an orbit is created for the secondary calls finding the server busy upon arrival and which involves into collision with the customer under service. Stochastic simulation method was used to obtain estimations for the average and variance of the sojourn times of primary and secondary customers illustrating the impact of the distribution of the service and retrial times.

Acknowledgment

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

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