Dynamic Selection of Priority Queueing Discipline in Cognitive Radio Networks

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***Abstract*—In this paper, for the purpose of service differentiation in opportunistic spectrum access (OSA) enabled networks, we take different priority queueing disciplines into account as decision variables in a dynamic optimization model. The objective is to optimize, after the departure of each packet, a weighted utility function of the performance of different classes of cognitive radio traffic by dynamically deciding the priority queueing discipline. A dynamic programming (DP) model, which takes into account the channel availability and channel handover recovery periods of the OSA network, is provided for two classes of traffic to solve this problem. Simulation results are presented.**

I. Introduction

Nowadays, communication links carry different types of traffic with diverse requirements and should thus be able to offer service differentiation to multiple classes of traffic. A classic scheme for this purpose is to use different priority queueing disciplines. However, in opportunistic spectrum access (OSA) enabled networks, the channel (i.e., the server of the queue) is subject to interruptions [1]. It is therefore crucial to develop a mathematical model in order to analyze the traffic metrics, such as throughput and delay, in OSA networks where the operating channel is experiencing frequent failures due to the appearance of primary users or quality variations.

For this aim, we proposed and discussed four priority queueing disciplines in a recent work [2] for an OSA link where the server is subject to interruptions. The duration of the interruption can be the busy period of primary users (single-channel communication when the user stays in the same channel) or the time spent to handover and to find a new channel (multi-channel communication). In [2], [3] we discussed that not only the derived results can be used to evaluate the traffic performance metrics of OSA networks, they can also be employed in a dynamic optimization model to optimize the traffic metrics. This optimization process is the topic of this paper. In cognitive radio (CR) networks, which are equipped with learning and decision-making capabilities, this aspect is interesting since the channel knowledge, obtained from the learning capabilities, can be used to make decisions on the most optimal queueing policy. In such an optimization model, the decision to be made periodically is the priority queueing scheme to be selected among these four proposed disciplines to optimize a traffic metric, such as a weighted function of the waiting packets for each class of traffic. The event which triggers a new decision-making is the state of the system which can be, for instance, the number of waiting packets of different classes in the queue. The main contribution of this paper is thus employing proposed priority queueing disciplines of [2] in an optimization framework for CR links which necessitates finding the inter-departure times and the probability of occurrence of possible events for each one of these four disciplines.

The reminder of the paper is organized as follows. In Section II, we review the queueing model and proposed schemes and discuss the analytical results which are pertinent. In Section III, a dynamic programming model is presented. Results are discussed in IV, and finally Section V concludes the paper with some remarks on future research directions.

II. Priority Queueing for Opportunistic Spectrum Access

Consider a cognitive radio (CR) user operating in an OSA-enabled network with homogeneous channels. This user continues operating over its current operating channel, until it finds the channel unavailable due to the return of primary users or with an unacceptable transmission quality due to deep fading or increased path loss in a vehicular network. In a multi-channel scenario, the CR user starts a recovery process with a random duration to find a new channel and then restarts the operation over this new channel. By modeling the event of missing or vacating the channel as a failure, we can denote the operating and recovery periods as *availability periods* and *time to recovery*, respectively. Let two random variables Y and R represent respectively the length of the availability and recovery periods. As illustrated in Figure 1, the operation of this user can be modeled with alternating renewal processes. From the queueing point of view, the output buffer of the user can be modeled as a queue with random service interruptions. Random interruption implies that both the time of the failure occurrence which triggers a recovery, and the duration of the interruption (recovery time) are random variables. This queuing model was discussed in [3] for a general queue without priority.

A. Queue Performance Results

In this paper and to simplify the presentation, it is assumed that availability periods, Y, are exponentially distributed with parameter α (i.e., $E[Y] = 1/\alpha$). Recovery periods have also

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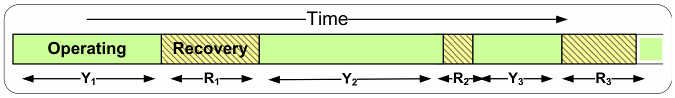

Fig. 1. Queueing model with random service interruptions.

an Exponential distribution with parameter β. Exponential recovery time is a realistic assumption when channel selection is done randomly, by sensing a list of channels one by one, and the user stops after finding the first channel.

In [2], [3], it is shown that for a single class of traffic, the first moment of the *completion time* of a packet can be given by:

$$E[X] = E[T](1 + \alpha E[R]) = E[T](1 + \frac{\alpha}{\beta}). \qquad (1)$$

Completion time stands for the total time that a packet spends in service, including the real service time and the interruptions that may occur during the service [4]. If the real service of the packet is started at time t_1 and it leaves the system at time t_2, the completion time is equal to $t_2 - t_1$. The notation X is used for completion time. The average service rate of all channels are fixed and constant (homogeneous channels), so the distribution of the packet length defines the distribution of the real service time of the packets. The random variable T is used to represent the real service time (transmission time) of the packets.

In this queue, a packet which enters an empty system may arrive during an interruption thus it starts its completion time at the beginning of the next availability period, and the remaining time of the arrival recovery period is considered as waiting time. As recovery periods are exponentially distributed, the remaining time of the recovery period, shown by R_r, is still exponential with parameter β. That is, $E[R_r] = E[R] = \frac{1}{\beta}$. The probability of arrival during an availability period (Y) can be written as [4]:

$$P_{ae}(\lambda) = 1 - \frac{\alpha}{\alpha + \beta + \lambda}, \qquad (2)$$

where λ is the Poisson arrival rate and $P_{ae}(\lambda)$ represents the probability of arrival during an availability period when empty (first packet of a busy period).

When multiple classes of CR traffic are served by such a node, the transmission of any class is suspended during the interruptions. However, after the interruption, different priority disciplines may behave differently. In other words, not only the interaction of different classes of traffic is taken into account (as in classic schemes of preemptive-resume and non-preemptive), the interaction of interruptions and different classes of traffic should also be taken into account.

In [2], we discussed four priority disciplines when two different classes of traffic (high priority (HP) and low priority (LP)) are served by a CR node. They are:

- *Preemptive* where a high-priority class can preempt the server any time;
- *Non-preemptive* where the server can not be preempted when any traffic has already gotten the server, even in the first arrival recovery period;
- *Exceptional Non-preemptive* where the server can not be preempted in general, but it can be preempted in the arrival recovery period, before the start of the real service of low priority packets;
- *Preemptive in case of failure* where the server can not be preempted during the service, but if an interruption occurs, after the interruption, the high priority packet (if any) will be served first.

The Poisson arrival rate of HP and LP packets is represented by λ_1 and λ_2 respectively. The real transmission time (packet length) of LP packets, T_2, is also assumed exponentially distributed. These assumptions are employed for simplicity of analytical calculations. Parameters of HP (LP) traffic are shown by the subindex 1 (2).

For different priority disciplines, it is evident that the completion time of the HP packets is not affected by other classes, so it can be found from Eq. (1). In non-preemptive and exceptional non-preemptive schemes, the completion time of LP packets is not also affected by other classes. The probability of arrival during Y and R in an empty system can still be found from Eq. (2) with an updated arrival rate. For instance, when the system is empty of both packet types, $P_{ae}(\lambda)$ is still valid when $\lambda = \lambda_1 + \lambda_2$, where λ represents the combined arrival rate.

We also make an approximation that the completion time of the packets in such a queue (with no preemption or equivalently in a queue with single traffic class) is also Exponentially distributed; otherwise, it will be out of the scope of this paper to find all the transition probabilities and possible states for a dynamic programming model. Analysis of results in [2] shows that such an approximation is acceptable when the packet length and the recovery periods are exponentially distributed, which is the case in this paper. We thus assume that:

$$X_2 \sim \text{EXP}(\gamma_2) \rightarrow \gamma_2 = \frac{1}{E[X_2]}. \qquad (3)$$

An example is illustrated in Figure 2 which represents the accuracy of this approximation for a realistic scenario which will be discussed in Section IV.

III. Dynamic Programming Model

In the following, we propose a dynamic programming (DP) model [5] where the decision variable is the priority scheme to be selected among four proposed schemes: 'p' for preemptive, 'n' for non-preemptive, 'e' for exceptional non-preemptive and 'f' for preemptive in case of failure. The DP model parameters are as follows:

- *Stage*: The stages of the system are the departure points of any packet. The CR node makes a decision at the departure point which remains valid until the next departure point even if the system is left empty after the departure. The model can be easily extended to arrival points or arrival and departure points.
- *System State*: The state variable, represented in the form (n_1, n_2), is the number of accumulated packets in the HP and LP queues. As the real service time is assumed

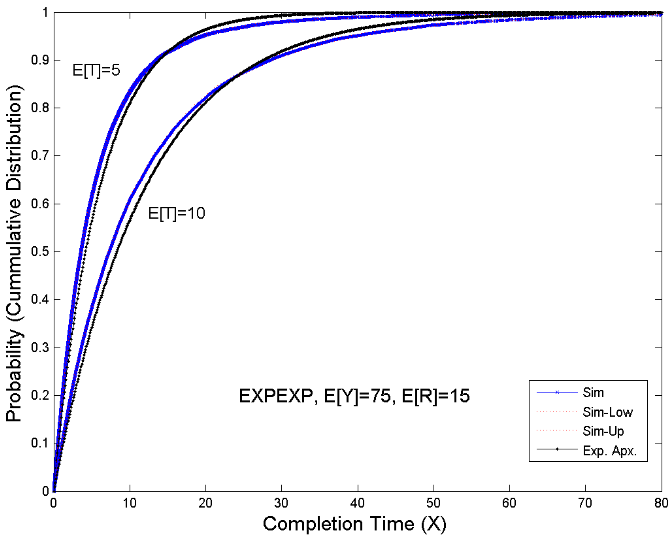

Fig. 2. Completion time of the packets with no preemption, X, can be approximated by an Exponential distribution.

exponentially distributed, it is not necessary to keep the remaining service time as a state variable.

- *Decision variable*: One of four priority disciplines.
- *Immediate cost*: It can be a general function as $F_c(n_1, n_2)$. A linear weighted sum of the number of packets, $(F_c(n_1, n_2) = \omega_1 n_1 + \omega_2 n_2)$, is used in simulation.
- *Transition probabilities*: They are discussed separately for each discipline.

When all transition probabilities are found, the DP equation (Bellman equation [5]) for the average cost per stage can be written as follows:

$$\theta^* + h^*(n_1, n_2) = \min_{n,e,p,f} \Bigg\{ \mathbb{E}\Big[F_c(n_1, n_2) + \sum h^*(m_1, m_2) Pr((n_1, n_2) \to (m_1, m_2)) \Big] \Bigg\}, \tag{4}$$

where θ^* represents the average cost per stage, which is independent of the state, and $h^*(n_1, n_2)$ represents the minimum total cost incurred to reach the state $(0, 0)$ from the state (n_1, n_2). Naturally, we have $h^*(0, 0) = 0$. The main requirement is that the queue should be stable such that the probability to have an empty system of any packet is larger than zero. Without loss of generality, it is assumed that the cost is incurred in the beginning of each stage.

As transition probabilities are case-dependent, in the following, we derive transition probabilities and the inter-departure time (duration of the stage) for different disciplines. Number of Poisson packet arrivals in an interval with the length t is written $a_i(t)$ for the class i of traffic. For any discipline, different major types of states are considered in three different cases: when $n_1 > 0$ in the departure point which implies that the next packet which goes in service will be an HP packet in any discipline; when $n_1 = 0$ and $n_2 > 0$ which implies that the next packet which starts the real service is an LP packet

TABLE I
PROBABILITY OF MAJOR EVENTS WHEN $(n_1 = 0, n_2 = 0)$ FOR NON-PREEMPTIVE DISCIPLINE

Event Number	**Probability**
1	$\frac{\lambda_1}{\lambda_1+\lambda_2} P_{ae}(\lambda)$
2	$\frac{\lambda_1}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda))$
3	$\frac{\lambda_2}{\lambda_1+\lambda_2} P_{ae}(\lambda)$
4	$\frac{\lambda_2}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda))$

(it may not finish the service before the next stage because the service is preempted), and when $n_1 = 0$ and $n_2 = 0$. In the last case, the probability of different possibilities are calculated. Note that in each of these cases, different number of arrivals may be occurred, known as minor events for each major event, where those probabilities (probability of Poisson arrivals) are not presented here, but considered in implementation.

A. Non-Preemptive

$$(n_1 > 0, n_2) \Longrightarrow^n (n_1 + a_1(X_1) - 1, n_2 + a_2(X_1)). \tag{5}$$

An HP packet receives service without any interruption from other packets with a probability equal to one. The next decision is made after X_1 unit of time which is the completion time of the HP packets (inter-departure time).

$$(n_1 = 0, n_2 > 0) \Longrightarrow^n (a_1(X_2), n_2 + a_2(X_2) - 1). \tag{6}$$

An LP packet receives service without any interruption from other packets with a probability equal to one. The next decision is made after X_2 unit of time (LP completion time).

$$(n_1 = 0, n_2 = 0) \Longrightarrow^n$$
$$\begin{cases} (a_1(X_1), a_2(X_1)) & Pr(A_1 < A_2)\&(\text{Arr. in Y}) \\ (a_1(X_1 + R_r), a_2(X_1 + R_r)) & Pr(A_1 < A_2)\&(\text{Arr. in R}) \\ (a_1(X_2), a_2(X_2)) & Pr(A_1 \geq A_2)\&(\text{Arr. in Y}) \\ (a_1(X_2 + R_r), a_2(X_2 + R_r)) & Pr(A_1 \geq A_2)\&(\text{Arr. in R}). \end{cases} \tag{7}$$

Any packet which arrives sooner receives a complete service without any interruption. The next decision is made after $A_i + X_i$ or $A_i + X_i + R_r$. The probability of arrival in Y or R is the same for any class and equal to $P_{ae}(\lambda)$ where $\lambda = \lambda_1 + \lambda_2$. Thus, the probability of the occurrence of any cases above can be written as $\frac{\lambda_i}{\lambda} P_{ae}(\lambda)$ for the first arrival of class i in Y and $\frac{\lambda_i}{\lambda}(1 - P_{ae}(\lambda))$ for the first arrival in R. In both cases, the remaining time of the recovery, R_r, will be still exponential. These probabilities are listed, top-down, in Table I.

B. Exceptional Non-Preemptive

The two first cases are completely similar to non-preemptive discipline. The only difference is when $(n_1 = 0, n_2 = 0)$. It can be written:

$$(n_1 = 0, n_2 = 0) \Longrightarrow^e$$
$$\begin{cases} (a_1(X_1), a_2(X_1)) & \frac{\lambda_1}{\lambda_1+\lambda_2} P_{ae}(\lambda) \\ (a_1(X_1 + R_r), a_2(X_1 + R_r)) & \frac{\lambda_1}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda)) \\ (a_1(X_2), a_2(X_2)) & \frac{\lambda_2}{\lambda_1+\lambda_2} P_{ae}(\lambda) \\ (a_1(X_2 + R_r^{<A_1}), a_2(X_2 + R_r^{<A_1})) & \frac{\lambda_2}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda)) \frac{\beta}{\lambda_1+\beta} \\ (a_1(X_1 + R_r), a_2(A_1^{<R} + R_r + X_1)) & \frac{\lambda_2}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda)) \frac{\lambda_1}{\lambda_1+\beta}. \end{cases} \tag{8}$$

TABLE II

PROBABILITY OF DIFFERENT MAJOR EVENTS WHEN $(n_1 = 0, n_2 > 0)$ FOR PREEMPTIVE DISCIPLINE

Event Number	Probability
1	$\frac{\gamma_2}{\lambda_1+\gamma_2}$
2	$\frac{\lambda_1}{\lambda_1+\gamma_2} P_{ae}(\lambda_1+\gamma_2)$
3	$\frac{\lambda_1}{\lambda_1+\gamma_2}(1 - P_{ae}(\lambda_1+\gamma_2))$

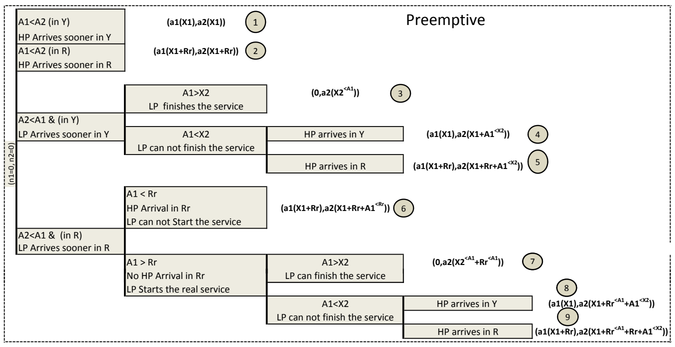

Fig. 3. Possible transitions from the state (0,0) when the decision is the preemptive scheme.

For two last cases, it is worth noting that when no HP arrival occurs in the remaining time of the arrival recovery period R_r, the fact that R_r is shorter than A_1 should be taken into account. Similar discussion is made for A_1 in the last case. Throughout the paper, the notation $Z_1^{<Z_2}$ for two random variables Z_1 and Z_2 is used to represent the conditioned random variable Z_1 such that $Z_1|(Z_1 < Z_2)$.

C. Preemptive

The first case is similar to two previous disciplines as in Eq. (5). For $(n_1 = 0, n_2 > 0)$, we have:

$$
(n_1 = 0, n_2 > 0) \Longrightarrow^p
\begin{cases}
(0, n_2 + a_2(X_2^{<A_1}) - 1) & Pr(A_1 \geq X_2) \\
(a_1(X_1), n_2 + a_2(X_1 + A_1^{<X_2})) & Pr(A_1 < X_2, inY) \\
(a_1(X_1 + R_r), n_2 + a_2(A_1^{<X_2} + X_1 + R_r)) & Pr(A_1 < X_2, inR).
\end{cases}
\tag{9}
$$

LP starts the service. If the HP arrival occurs after X_2, LP finishes the service and the next decision point is an LP departure. But, if an HP packet arrives before X_2 (during Y or R), the service goes to HP. Transition probabilities are listed in Table II.

Possible transitions and associated probabilities for the state $(n_1 = 0, n_2 = 0)$ are presented in Figure 3 and Table III. If an HP packet arrives sooner, the service is given to it until finishing the service. If an LP arrives sooner, we return to the previous case where we had $n_1 = 0$ and $n_2 > 0$.

It should be noted that for the events 5,6,8 and 9, $P_{ae}|(A_1^{<X_2})$ can not be calculated using directly the right hand side of Eq. (2) because the condition of $A_1 < X_2$ makes the distribution of $A_1^{<X_2}$ different. Considering the assumption of Exponential distribution for X_2, the probability of $A_1 < X_2$ can be found equal to $\frac{\lambda_1}{\lambda_1+\gamma_2}$ and $A_1^{<X_2}$ is still exponential with parameter $\lambda_1 + \gamma_2$. Thus, we used $P_{ae}(\lambda_1 + \gamma_2)$.

TABLE III

PROBABILITY OF DIFFERENT EVENTS WHEN $(n_1 = 0, n_2 = 0)$ (FIG. 3).

E.	Probability
1	$\frac{\lambda_1}{\lambda_1+\lambda_2} P_{ae}(\lambda)$
2	$\frac{\lambda_1}{\lambda_1+\lambda_2}(1 - P_{ae}(\lambda))$
3	$\frac{\lambda_2}{\lambda_1+\lambda_2} P_{ae}(\lambda)\ \Pr(A_1 > X_2)$
4	$\frac{\lambda_2}{\lambda_1+\lambda_2} P_{ae}(\lambda)\ \Pr(A_1 \leq X_2)\ P_{ae}(\lambda_1+\gamma_2)$
5	$\frac{\lambda_2}{\lambda_1+\lambda_2} P_{ae}(\lambda)\ \Pr(A_1 \leq X_2)\ (1 - P_{ae}(\lambda_1+\gamma_2))$
6	$\frac{\lambda_2}{\lambda_1+\lambda_2}(1 - P_{ae}(\lambda))\ \frac{\lambda_1}{\lambda_1+\beta}$
7	$\frac{\lambda_2}{\lambda_1+\lambda_2}(1 - P_{ae}(\lambda))\ \frac{\beta}{\lambda_1+\beta}\ \Pr(A_1 > X_2)$
8	$\frac{\lambda_2}{\lambda_1+\lambda_2}(1 - P_{ae}(\lambda))\ \frac{\beta}{\lambda_1+\beta}\ \Pr(A_1 \leq X_2)\ P_{ae}(\lambda_1+\gamma_2)$
9	$\frac{\lambda_2}{\lambda_1+\lambda_2}(1 - P_{ae}(\lambda))\ \frac{\beta}{\lambda_1+\beta}\ \Pr(A_1 \leq X_2)\ (1 - P_{ae}(\lambda_1+\gamma_2))$

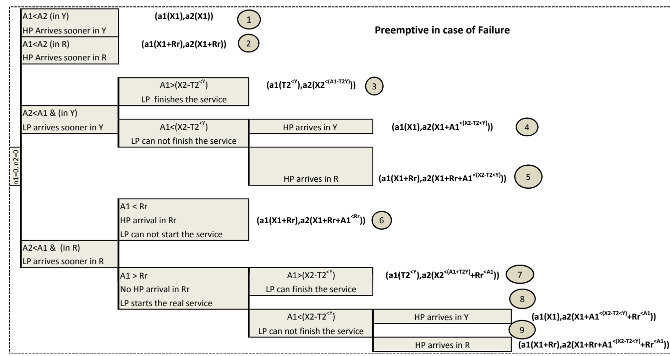

Fig. 4. Possible transitions from the state (0,0) when the decision is the discipline of preemption in case of failure.

D. Preemptive in case of failure

The first case is similar to previous disciplines as in Eq. (5). For the second major case, we have:

$$
(n_1 = 0, n_2 > 0) \Longrightarrow^f
\begin{cases}
(a_1(T_2^{<Y}), n_2 + a_2(X_2^{<(A_1+T_2Y)}) - 1) & Pr(A_1 \geq X_2 - T_2^{<Y}) \\
(a_1(X_1), n_2 + a_2(X_1 + A_1^{<X_2 - T_2^{<Y}})) & Pr(A_1 < X_2 - T_2^{<Y})(inY) \\
(a_1(X_1 + R_r), n_2 + a_2(A_1^{<X_2 - T_2^{<Y}} + X_1 + R_r)) & \\
 & Pr(A_1 < X_2 - T_2^{<Y})(inR).
\end{cases}
\tag{10}
$$

where $T_2^{<Y}$ represents the last part of the completion time of the LP packet in the last operating period. As T_2 is exponentially distributed, in the last part of the transmission, the remaining real service time is still T_2 but with the condition that this is the last part of the transmission. Thus we have $T_2|(T_2 < Y)$. $X_2 - T_2^{<Y}$ stands for the completion time of the LP packet except the last part because we know that the arrival of HP in the last part has no impact on LP completion time, and the HP can not preempt the service from the LP packet. The probability of arrival in Y and R can be found from Eq. (2) based on the condition that $A_1 < (X_2 - T_2^Y)$ represented by A_1^*.

For the third case, possible transitions and associated probabilities are listed in Figure 4 and Table IV respectively.

IV. RESULTS AND DISCUSSIONS

Value Iteration [5] is used to solve the model numerically. The model represents an infinite buffer queue however a lim-

TABLE IV
PROBABILITY OF DIFFERENT MAJOR EVENTS WHEN $(n_1 = 0, n_2 = 0)$ (FIG. 4).

E.	**Probability**
1	$\frac{\lambda_1}{\lambda_1+\lambda_2} P_{ae}(\lambda)$
2	$\frac{\lambda_1}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda))$
3	$\frac{\lambda_2}{\lambda_1+\lambda_2} P_{ae}(\lambda)\ \Pr(A_1 > X_2 - T_2^{<Y})$
4	$\frac{\lambda_2}{\lambda_1+\lambda_2} P_{ae}(\lambda)\ \Pr(A_1 \leq X_2 - T_2^{<Y})\ P_{ae}(A_1^*)$
5	$\frac{\lambda_2}{\lambda_1+\lambda_2} P_{ae}(\lambda)\ \Pr(A_1 \leq X_2 - T_2^{<Y})\ (1 - P_{ae}(A_1^*))$
6	$\frac{\lambda_2}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda))\ \frac{\lambda_1}{\lambda_1+\beta}$
7	$\frac{\lambda_2}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda))\ \frac{\beta}{\lambda_1+\beta}\ \Pr(A_1 > X_2 - T_2^{<Y})$
8	$\frac{\lambda_2}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda))\ \frac{\beta}{\lambda_1+\beta}\ \Pr(A_1 \leq X_2 - T_2^{<Y})\ P_{ae}(A_1^*)$
9	$\frac{\lambda_2}{\lambda_1+\lambda_2} (1 - P_{ae}(\lambda))\ \frac{\beta}{\lambda_1+\beta}\ \Pr(A_1 \leq X_2 - T_2^{<Y})\ (1 - P_{ae}(A_1^*))$

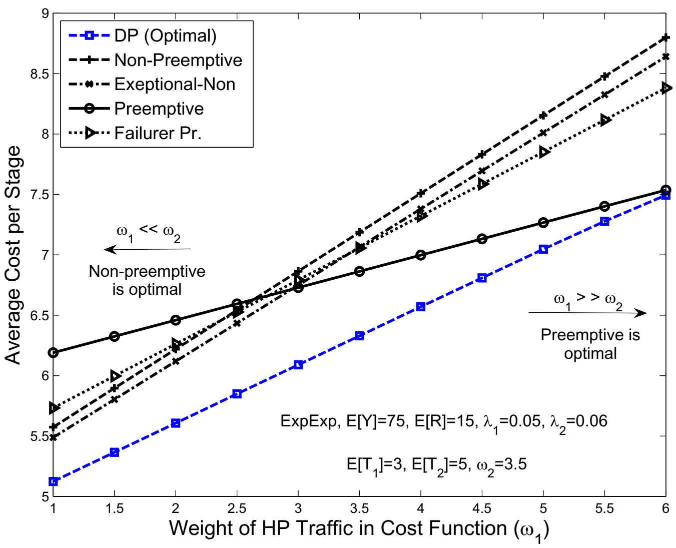

Fig. 5. Optimal average cost per stage for the proposed DP model.

ited large buffer is employed in numerical analysis. To handle the curse of dimensionality, and as finding the probability distribution of all timing parameters is not in the scope of this paper, we use a certainty equivalent controller [5] where instead of the probability distribution of the inter-departure times, their expected value is used. Moreover, for each major event, limited number of Poisson arrivals is considered (maximum nine arrivals in simulation).

In Figure 5, the optimal cost per stage, found by dynamic programming (DP), is compared with the cases that one of the schemes is always used. Due to space limit, we provided the results of only one scenario. It models a realistic scenario when availability periods are much larger than the service time of a single packet ($E[Y] = 75$ and $E[R] = 15$). We have $F_c(n_1, n_2) = \omega_1 n_1 + 3.5 n_2$.

From the definition of queueing disciplines, it can be seen that the preemptive (non-preemptive) and non-preemptive (preemptive) schemes are respectively the most and the least favorable for HP (LP) packets and two other schemes provide an intermediate result. As expected, the optimal decision in states $(n_1 > 0, n_2)$ can be any of the proposed disciplines because for all disciplines, the next state and the inter-departure time (stage duration) is the same (equal to X_1). It is worth noting that giving the priority to an HP packet regardless of the state of the LP queue may seem sub-optimal in general. However, this is included in the definition of all discussed priority disciplines, so it was respected in the dynamic programming model. Naturally, another type of optimization can be selecting the next packet to be served among HP and LP packets, regardless of the priority disciplines.

As can be seen, when ω_1 compared to $\omega_2 = 3.5$ increases, the importance of HP packets increases, so the optimal scheme will be always the preemptive one. In the left hand side, the importance of LP packets implies that the optimal scheme is always the non-preemptive scheme. Note that selecting a lower weight for HP packets ($\omega_1 < \omega_2$) is not realistic and is provided only to show the accuracy of the model.

For states $(n_1 = 0, n_2 > 0)$, the optimal decision is almost independent of the number of accumulated LP packets, so for all of them, the optimal decision is the same. To be noted that in this case, non-preemptive and exceptional non-preemptive schemes provide the same result. Finally for the state $(n_1 = 0, n_2 = 0)$, any decision may result in a different cost.

V. CONCLUSION AND FUTURE WORK

Four different priority disciplines in presence of interruptions were employed as decision variables in a dynamic optimization problem to optimize a joint performance utility function of two classes of cognitive radio (CR) traffic. We saw that the optimal decision mostly depends on the emptiness of the queues and is less sensitive to the exact number of packets in the queues. Such behavior is dictated by the definition of queueing disciplines. In our future work, we thus discuss other DP models, regardless of the priority disciplines, and will solve them analytically to find the relation among the optimal decisions and performance metrics of the queue.

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