

## Weighted Earliest Deadline Scheduling and Its Analytical Solution for Admission Control in a Wireless Emergency Network\*

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**Abstract.** For wireless networks operating during emergency conditions, emergency, handoff, and new calls are the main kinds of demand. Different operators will have different policies about which should have higher priority, and how to implement that kind of priority. This paper focuses on applying queuing methods for admission control for the above three types of calls. A Weighted Earliest Deadline scheduling method is introduced and evaluated that provides flexible priority for emergency and handoff traffic. Then an analytical framework for this scheduling method is given and two new computation methods are provided. These allow computation of expiration probability and average waiting time, and are simple to use both for priority queue scheduling and our new Weighted Earliest Deadline scheduling method.

**Keywords:** Emergency traffic, handoff, aging process, scheduling, priority queuing.

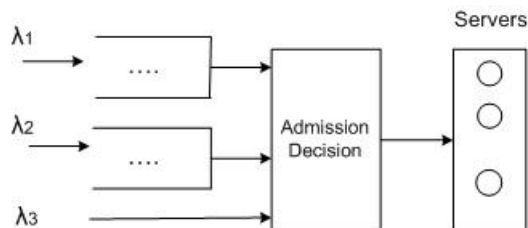
### 1 INTRODUCTION

Network congestion can happen due to a lot of reasons. In this paper, we mainly focus on disaster events as they cause congestion in wireless networks. After disaster events happen, tremendous stress is placed on networks due to the rise in traffic demand, including demand from general calls and emergency calls. As pointed out in [1,2,3], network demand can be up to 5 times of normal. Among the traffic demands, emergency traffic should be given higher priority for saving life and property.

In the wireless cellular network, an ongoing call can handoff to another cell. The goal of a cellular operator is to try to avoid calls being terminated due to lack of resources when moving into a new cell. So, the problem to be studied here is how to simultaneously and effectively support emergency users and handoff calls in a wireless network when congestion happens. The approaches we can use include preemption, delay-based, or resource conservation policies, and each has its advantages and disadvantages [4,5]. In this paper, we mainly focus on the delay-based approach which has been least studied. Our study focuses on a single cell and assumes the following: (1) all call durations are independently, identically, and exponentially distributed, (2) after service is completed, each call is terminated or leaves this cell, and (3) there is no handoff for emergency calls since we assume most emergency users will be stationary within a disaster area. However, for assumption (3), the model given here can be easily extended to a more general situation.

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**Fig. 1.** A Queuing Based Admission Control Policy in a Wireless Network

A delay-based policy can also be called a queuing-based policy. The idea is that when congestion happens, new arrivals of high priority calls will be put into queues, and low priority calls are simply rejected. Figure 1 shows how queuing-based admission control can be implemented for 3 classes of traffic.

When resources become free, the calls waiting in queues will be served first. By using queues, the resource utility will be improved, and high priority calls will more likely be admitted than low priority ones, thus decreasing dropping probabilities for high priority calls. The cost of using this approach is the delay for the admission of high priority calls (because they need to wait in queues), and the increase of dropping rates for low priority calls. In contrast, if queues are not used when congestion happens, all classes of calls will have the same probability to be dropped regardless of the arrival rate of each class.

In [4], a delay-based policy is used for emergency calls without handoff calls considered, while in [6] queuing for handoff calls and new calls is introduced based on use of priority queues. In [7], two queues are used for different handoff calls, priority queuing is used as the basic tool, and calls are allowed to switch priorities. In this paper, we study the case when emergency calls, handoff calls, and general new calls coexist. We are not confined to using only priority queues; instead a flexible queue scheduling method is introduced.

The main contributions of this paper include:

1) Flexible ways to control the admission of emergency traffic and handoff traffic - For our study case, both emergency calls and handoff calls have priority over new calls. But which one has the highest priority will be interpreted differently by various operators. And even when one kind has higher priority over another, it's hard to say that one class should have absolute priority over another like priority queuing would enforce. So, based on the above facts, we bring out the Weighted Earliest Deadline scheduling method. Weighted Earliest Deadline chooses the next calls to be served based on a configurable weighting between the two classes.

2) Analytical representations for the new scheduling method - We provide 2-dimensional Markov chain representations of Weighted Earliest Deadline scheduling, and show how priority queuing is a special case.

3) Low complexity methods for solving the expiration probability and average waiting time in a 2-dimensional Markov aging process - In [6,7] priority queues are used, and they suggest using Mason's rule to compute the expiration probability for low priority calls. But for our case, using Mason's rule would be too complex and would have unacceptable computational complexity, especially when queue length is long. We provide two simpler methods.

The rest of this paper is thus organized: In section 2, the Weighted Earliest Deadline scheduling method is brought out; in section 3, an analytical representation and new simple computation methods are provided. Section 4 provides evaluation of the effectiveness of the Weighted Earliest Deadline scheduling method; in section 5, an implementation example is given; and in section 6,



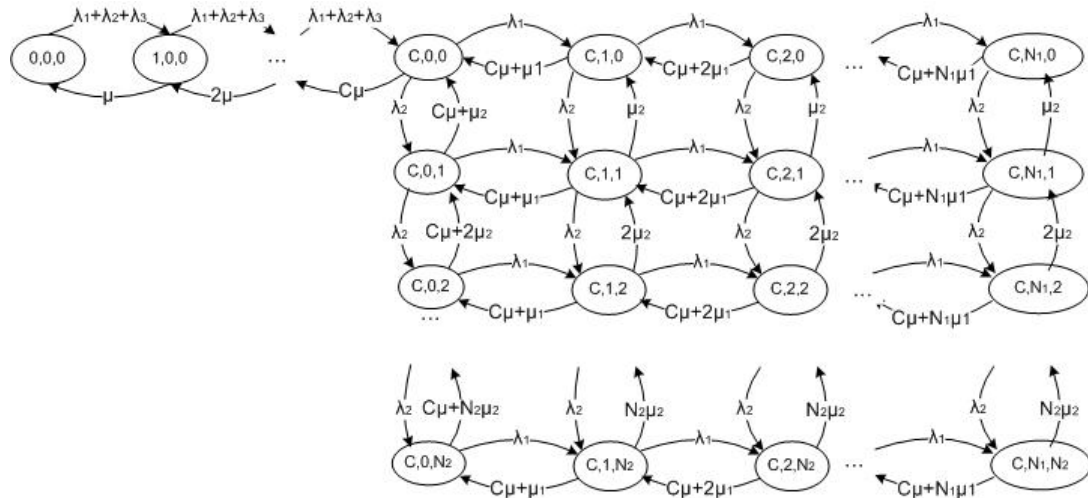


Fig. 2. State Diagram for 3 Classes of Traffic using Priority Queues

chain as shown in Figure 2 where the state  $(C, i, j)$  would correspond to  $C$  calls in progress,  $i$  and  $j$  calls waiting in their respective queues. But when  $b_p \neq 0$  and  $b_p \neq \infty$ , the system can not be represented and analyzed using a priority queue anymore. The remainder of this section will discuss the representation and analysis for this general case.

### 3.1 Analytical framework for Weighted Earliest Deadline scheduling

For scheduling, the servers can be viewed as being split between two queues. Following is the analysis of how this split is represented.

We denote  $T_{l1}, T_{l2}$  as the remaining lifetime for class 1 and 2 calls. The probability for class 1 calls to be served is:  $\Pr(b_p T_{l1} < T_{l2})$ . Define  $X_1 = b_p T_{l1}, X_2 = T_{l2}$ . The remaining lifetime is exponentially distributed and thus has the memoryless property. It can be shown that  $X_1$  is exponentially distributed with rate  $\frac{\mu_1}{b_p}$  and  $X_2$  is exponentially distributed with rate  $\mu_2$ . So:

$$Pr(X_1 < X_2) = \frac{\frac{\mu_1}{b_p}}{\mu_2 + \frac{\mu_1}{b_p}} = \frac{\mu_1}{\mu_1 + b_p \mu_2} \tag{1}$$

Let  $A = \frac{b_p \mu_2}{\mu_1 + b_p \mu_2}$  ( $A \geq 0$  and  $A \leq 1$ ). We can conclude that the actual service rate for class 1 calls leaving the queue and entering into service is  $C\mu(1 - A)$ . This produces the state diagram for Weighted Earliest Deadline scheduling as shown in Figure 3. Note, for example, the differences in Figures 2 and 3 for the departures from state  $(C, 1, 1)$ .

### 3.2 Computation of expiration probability and average waiting time

Due to limited queue length and limited endurance time for waiting, the calls can fail in two ways: immediately rejected (blocked) due to a full queue, or dropped after waiting some time in the queue (expired).



for each class is  $i\mu_1$  and  $j\mu_2$  independently. The average total number of departures per unit time from a state for expirations by class 1 is  $i\mu_1$ . Then, the probability of expiration is the fraction of expirations per unit time over arrivals per unit time, hence  $\frac{i\mu_1}{\lambda_1}$ . For class 2 calls this is  $\frac{j\mu_2}{\lambda_2}$ . Thus, instead of using the equations in (4) which as we will see require rather complex deduction, we can find the overall expiration probability just based on the steady state probability, the expiration rate, and the arrival rate at each state as follows:

$$P_{Exp}^1 = \sum_{i=1}^{N_1} \sum_{j=0}^{N_2} P(C, i, j) \frac{i\mu_1}{\lambda_1} \quad P_{Exp}^2 = \sum_{i=0}^{N_1} \sum_{j=1}^{N_2} P(C, i, j) \frac{j\mu_2}{\lambda_2} \quad (5)$$

Clearly this is a simple approach, but it does not facilitate computation of average waiting times, so we introduce the other computational method in the next section.

**State Transfer Based Computational Method for  $R_1(i, j)$  and  $R_2(i, j)$**  Given there are  $i$  and  $j$  calls in queue 1 and queue 2 respectively, we denote  $S_1(i, j) = 1 - R_1(i, j)$  as the probability for the calls at the tail of queue 1 to be *successfully* served before expiration, where  $i=1\dots N_1$ . Similar definition is given for  $S_2(i, j) = 1 - R_2(i, j)$ , and  $j=1\dots N_2$ .

Now we show how to solve  $S_1(i, j)$  and  $S_2(i, j)$ . Assume that after a new class 1 call arrives, the system enters into a middle state  $(C, i, j)$  where both  $i$  and  $j > 0$  and queues are not full. After this, the system can transfer to states  $(C, i - 1, j)$ ,  $(C, i, j - 1)$ ,  $(C, i + 1, j)$ , or  $(C, i, j + 1)$  with probability  $\frac{C\mu(1-A)+i\mu_1}{C\mu+i\mu_1+j\mu_2+\lambda_1+\lambda_2}$ ,  $\frac{C\mu*A+j\mu_2}{C\mu+i\mu_1+j\mu_2+\lambda_1+\lambda_2}$ ,  $\frac{\lambda_1}{C\mu+i\mu_1+j\mu_2+\lambda_1+\lambda_2}$ ,  $\frac{\lambda_2}{C\mu+i\mu_1+j\mu_2+\lambda_1+\lambda_2}$  respectively.

When transferred to state  $(C, i - 1, j)$ , the probability for the  $i^{th}$  call to expire before any channel is released and any other  $i - 1$  calls expire is  $\frac{\mu_1}{C\mu+i\mu_1+j\mu_2+\lambda_1+\lambda_2}$ . Thus the probability for the  $i^{th}$  call not to expire when transferred into  $(C, i - 1, j)$  is  $\frac{C\mu(1-A)+(i-1)\mu_1}{C\mu+i\mu_1+j\mu_2+\lambda_1+\lambda_2}$ .

It is important to note that if the system is transferred into state  $(C, i + 1, j)$  due to a later arrival, the  $i^{th}$  call in queue 1 which we care about is still in position  $i$ , and the calls behind it will not affect its expiration probability at all. So, the successful probability for the call is still  $S_1(i, j)$ . Then, we can get:

$$S_1(i, j) = \frac{C\mu(1-A) + (i-1)\mu_1}{C\mu + i\mu_1 + j\mu_2 + \lambda_1 + \lambda_2} S_1(i-1, j) + \frac{C\mu * A + j\mu_2}{C\mu + i\mu_1 + j\mu_2 + \lambda_1 + \lambda_2} S_1(i, j-1) \\ + \frac{\lambda_2}{C\mu + i\mu_1 + j\mu_2 + \lambda_1 + \lambda_2} S_1(i, j+1) + \frac{\lambda_1}{C\mu + i\mu_1 + j\mu_2 + \lambda_1 + \lambda_2} S_1(i, j) \quad (6)$$

After simplification this becomes:

$$(C\mu + i\mu_1 + j\mu_2 + \lambda_2)S_1(i, j) = (C\mu * A + j\mu_2)S_1(i, j-1) + \lambda_2 S_1(i, j+1) \\ + (C\mu(1-A) + (i-1)\mu_1)S_1(i-1, j) \quad (7)$$

When considering edge states, for the  $i = 1$  case we have:

(1)  $j = 0$

$$(C\mu + \mu_1 + \lambda_2)S_1(1, 0) = \lambda_2 S_1(1, 1) + C\mu \quad (8)$$

(2)  $j = 1\dots N_2-1$

$$(C\mu + \mu_1 + j\mu_2 + \lambda_2)S_1(1, j) = \lambda_2 S_1(1, j+1) + C\mu(1-A) + (C\mu A + j\mu_2)S_1(1, j-1) \quad (9)$$



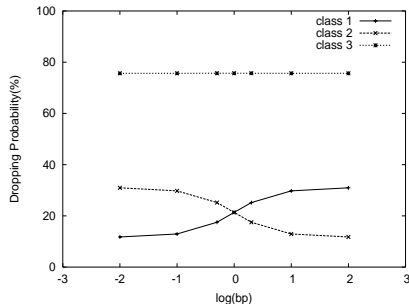


Fig. 4. Dropping Probability vs.  $b_p$

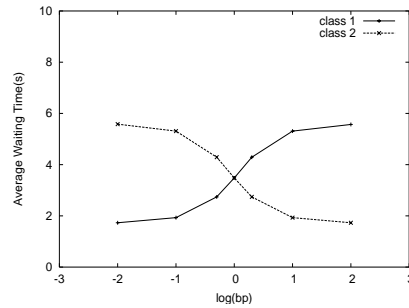


Fig. 5. Avg. Waiting Time vs.  $b_p$

The average waiting times for class 1 and class 2 calls are calculated as:

$$\bar{W}_1 = \sum_{i=0}^{N_1-1} \sum_{j=0}^{N_2} P(C, i, j) W_1(i + 1, j) \quad \bar{W}_2 = \sum_{i=0}^{N_1} \sum_{j=0}^{N_2-1} P(C, i, j) W_2(i, j + 1) \quad (18)$$

#### 4 EVALUATION OF WEIGHTED EARLIEST DEADLINE USING THE ANALYTICAL SOLUTION

Based on the analytical solutions provided above, the Weighted Earliest Deadline scheduling policy can be evaluated. We will see how good is this policy works and how the balance parameter  $b_p$  and different arrival rates affect the dropping rate and average waiting time.

We set the arrival rates for the three classes of traffic to 0.6, 0.6, and 0.2 respectively. The number of channels is 100; both queues' lengths are 10. The average call holding time for all 3 classes is 100 seconds, and the average expiration time for emergency and handoff calls are both 10 seconds (in the examples later in this paper, these conditions hold if not specially specified). Then we change the value of  $b_p$ . From figure 4 we can see that when  $b_p = 0$ , the dropping probability for class 1 is the lowest. With  $b_p$  increases, the dropping probability for class 1 also increases, and for class 2 it decreases, while for class 3 there is almost no change. When  $b_p = 1$ , class 1 and class 2's dropping probabilities are equal, which shows the "balance" achieved. In contrast, if no queuing were used, all 3 classes would have a dropping probability of 30.12%.

In Figure 5, we can see that the effect of  $b_p$  on average waiting time has the same trend as its effect on dropping probability.

Figure 6 shows the effect as the arrival rate of class 3 increases, and it can be seen how dropping rates change for the 3 classes of calls. Here the average expiration time of class 2 calls is set at 5 seconds, and  $b_p$  is fixed at 1, so as expected the performance of emergency and handoff calls is different. The dropping probability of all 3 classes increases as the arrival rate of class 3 increase. And after some investigation we find that dropping probabilities all increase at the same percent, but the average waiting time of class 1 and class 2 (not shown here) didn't change with different  $\lambda_3$  values.

In Figure 7, we show the effect as the arrival rate of class 1 calls increases. The total number of channels is 60, and  $b_p$  is fixed at 1. We find that the average waiting time of class 1 and class 2 also increases as the arrival rate of class 1 increases. And the average waiting time for class 1 can even be more than the average expiration time of 10 seconds. This is because in a really congested case only those calls whose expiration time is very long can wait long enough until there is a free channel. Figures 6 and 7 show that good further research is possible to explain these phenomena analytically through exact or approximate calculations.





scheduling is provided. The main novel contribution of this work is to provide an analytical framework for more flexible queue scheduling when using admission control.

We also find that in some cases the dropping probabilities of emergency and handoff calls are still not ideal by just using the queuing method alone. We have also not yet considered the relationships between different classes of calls and possible retrying after blocking. Promising possibilities for future work include: combining the queuing method with one or two other policies (e.g., using an Upper Limit policy [5] to set a limit on channels used for new calls), system cost optimization by considering both dropping rate and waiting time, and exploiting the relationship between handoff calls and new calls, blocking and retrying, etc. The model presented here, therefore, is a useful tool for answering many of the important questions about how to allocate resources to wireless calls during emergencies.

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