Providing Stochastic Delay Guarantees through Channel Characteristics Based Resource Reservation in Wireless Network

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ABSTRACT

This paper is directed towards providing quality of service guarantees for transmission of multimedia traffic over wireless links. The quality of service guarantees require transmission of packets within prespecified deadlines. Oftentimes, bursty, location dependent channel errors preclude such deadline satisfaction leading to packet drop. Wireless systems need resource reservation to limit such deadline violation related packet drop below acceptable thresholds. The resource reservation depends on the scheduling policy, statistical channel qualities and arrival traffic. We choose Earliest Deadline First as the baseline scheduling policy and design an admission control strategy which provides delay guarantees and limits the packet drop by regulating the number of admitted sessions in accordance with the long term transmission characteristics and arrival traffic of the incoming sessions. We analytically quantify the stochastic packet drop guarantees provided by the framework, and show using simulation that the design results in low packet drop.

Categories and Subject Descriptors

C.2 [**Computer-Communication Networks**]: Network Architecture and Design

General Terms

Algorithms, Design

Keywords

Stochastic delay guarantees, connection admission control, wireless networks

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1. INTRODUCTION

Third generation wireless packet networks will have to support real-time multimedia applications. The real-time applications need Quality of Service (QoS) guarantees from the network. One of the most important QoS requirements is the *packet delay*, which specifies the upper bound on the delay experienced by every packet of the application. For most of the real-time applications packets delayed beyond certain time are not useful. Further, the traffic characteristics and the delay requirements of various applications are different. In this heterogeneous environment, the challenge is to design a methodology that allows us to decide whether the required QoS can be guaranteed. In this paper, we focus on designing such a methodology for a single hop wireless packet network. Obtaining an efficient solution to the one hop problem is an impotent preliminary step toward solving the problem for multi-hop wireless packet networks like ad-hoc networks.

Real time traffic often associates a service deadline with every packet. If the packet is not served before the deadline, then the corresponding information loses its utility, and the packet must be dropped. It is well known that earliest deadline first based scheduling minimizes delay violations and thereby minimizes packet drops[24]. However, the actual amount of this packet drop depends on the traffic load, bandwidth resources and the transmission conditions, and this amount may become unacceptable if the traffic load is not regulated. In other words, an efficient admission control framework is required to ensure that sufficient amount of resources are available to meet the packet drop constraints of the admitted session. The framework will depend on the scheduling policy, as the resource utilization is different for different scheduling policies. We choose Earliest Deadline First (EDF) as an appropriate scheduling strategy on account of its loss optimality properties, and propose an admission control framework which caters towards EDF.

Sessions arrive with specific deadline requirements and estimated channel statistics. The admission control framework admits a session only if the deadline requirements of the incoming session can be met with a high probability. This decision depends on the traffic loads and channel characteristics of the existing sessions, and also those of the incoming session. Thus designing such a framework will involve quantifying delay of any given session in terms of arrival process and channel characteristics of all the contending sessions. The key contribution of the paper is to provide such a quantification, and thereafter present an admission control condition which exploits the statistical multiplexing of traffic load and channel errors of the existing sessions so as to reduce the overall packet drops of the admitted sessions to acceptable values. We corroborate our results using analysis and extensive simulations.

Admission control schemes have been studied extensively in the wireline case[29]. However these schemes do not counter the detrimental effects of *location dependent* and *bursty* channel errors. Admission control conditions need to specifically consider channel statistics while taking admission control decisions, and reserve additional resources for guaranteeing the desired QoS in spite of channel errors. Further location dependent channel errors imply that the channel may be accessible to some users but not to others because of the different fading characteristics, and thus admission control decisions will be different for different sessions, even if the desired delay guarantees and the traffic load are the same.

The existing research in admission control in cellular networks focusses on resource reservation for providing promised QoS to the mobile users during hand-offs [1, 2, 3, 15, 23, 16, 26, 27, 28, 17, 7]. These schemes *assume* the knowledge of resources to be reserved to provide the desired QoS and then obtain the good balance between call dropping and call blocking via resource reservation. In this paper, *we focus on quantifying the resources required to provide packet delay in presence of channel errors.*

Most of the prior wireless scheduling work [5, 19, 20, 21] obtains delay guarantees for sessions that do not experience channel errors. In [19, 20], authors have obtained the worst case delay bound for the sessions with channel errors. However, these bounds hold only for Head of Line (HoL) packets, in other words no bound has been provided for the overall delay experienced by the packet. Another area extensively explored is that of fair scheduling [4, 6, 10, 12, 14, 25]. The main objective in this branch of research has been to distribute available resources fairly among the flows [5, 19, 21, 22, 20], which is important for transmitting data traffic. Major concerns for transmission of real time traffic such as deadline expiry and related packet drop have not been addressed though.

The main contribution of this paper can be summarized as follow. *We propose a channel statistics aware admission control mechanism for EDF scheduler in wireless case. The proposed mechanism guarantees delay bounds to the admitted sessions with a high probability in spite of channel errors. The deadline violation related packet drops are correspondingly probabilistically upper bounded.*

The paper is arranged as follows. We describe our system model in 2. In section 3 we present the admission control algorithm for EDF scheduler. In section 4 we present the simulation results and discussion. We conclude in section 5.

2. SYSTEM MODEL

In this section we define our system model and specify our assumptions. A system that we consider is shown in Figure 1. Further, we assume that a sender node S is transmitting packets to several receivers in its communication range via error-prone wireless channels. The sender node has an admission control scheme and EDF scheduler. We assume

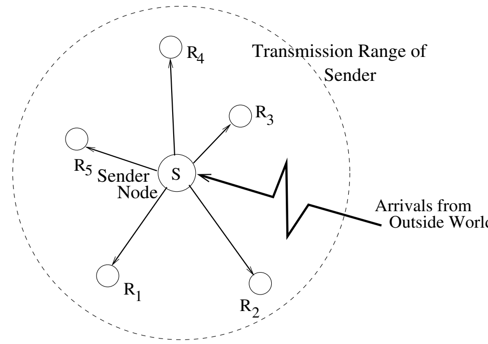

Figure 1: Figure shows a sender node S and its receivers R_1 to R_5. Sessions arrive at the sender from outside world and seek to transfer data to one of the receivers. We do not preclude a possibility of multiple sessions between the sender and a receiver. Dotted circle represents the transmission range of the sender.

that the sessions[1] arrive at the sender dynamically and seek admission. Each arriving session specifies its required delay guarantee and traffic characteristics. Further, as we describe below, each of the receivers periodically communicate the estimates of long term channel error rate to the sender. Using these parameters and the information about the available resources, admission control mechanism at the sender node decides whether the desired delay can be guaranteed[2] If the required packet delay can be guaranteed in the system, then the session is admitted, otherwise it is blocked. Packets that belong to the admitted sessions are served as per EDF scheduling. We next describe each component of our system model in detail.

We assume slotted time axis, where each time slot is of unit length. Every packet has unit length. We assume leaky bucket constrained sessions [9], i.e. the total data arriving from a typical session i in any duration τ is less than or equal to $\sigma_i + \tau\rho_i$, where σ_i is bucket depth and ρ_i is a token replenishment rate. Wireless channel for a session is either *good* or *bad*. In good channel state, the probability of correct reception is 1, while in bad state the probability is 0. There can be many sessions between the sender and a given receiver. We allow the possibility that different sessions between the sender and a receiver can have different channel characteristics. This scenario arises if different coding and/or power control schemes are used for the different sessions.

We note that all the receivers are in the transmission range of the sender. Hence, each receiver can receive all the transmissions from the sender (including transmissions for other receivers). Depending on the quality of reception, a receiver can estimate its channel state parameters. So, we consider a scenario where a receiver estimates its long term channel error rate by observing the quality of receptions. We as-

[1]A session is a stream of packets pertaining to a single application that have to be transmitted from the sender to a specific receiver. We do not preclude a scenario, where multiple sessions exist between the sender and a certain receiver.
[2]All guarantees are in a stochastic sense, i.e., a required delay must be guaranteed with a high probability. We will omit "with high probability" for brevity.

sume that receivers communicate the estimates of the long term channel error rates to the sender periodically. Sender uses these estimates and the leaky bucket parameters of the arrival process to make the admission control decisions.

The EDF scheduler assigns a deadline to a packet as and when it arrives. The deadline of a packet is the sum of its arrival time and the required delay guarantee. In wireline case, EDF schedules packets in the increasing order of their respective deadlines. But in wireless case, to utilize channel bandwidth efficiently, packets that belong to sessions with good channel should be scheduled. We assume a channel state aware EDF scheduling where the packet with the earliest deadline amongst those which experience good channels is scheduled. The underlying assumption is that the scheduler knows the channel state for each session in the beginning of each slot. Such knowledge may not be feasible in real systems. However channel state may be predicted given the transmission feedback in the previous slot. We incorporate a prediction based EDF strategy in our simulations.

We describe the proposed admission control scheme in the next section.

3. ADMISSION CONTROL

In this section we present an admission control algorithm for channel state aware EDF scheduler in wireless case. There has been extensive work in admission control algorithm for EDF scheduler in wireline case[11, 13, 18]. These algorithms does not apply to wireless case as they do not accommodate channel errors. We intuitively explain how channel errors can be taken into consideration while making admission control decision. This will enable the generalization of wireline admission control strategies for operation in the wireless case.

Let us consider a case, where V is the maximum number of erroneous slots in a *busy period*, where *erroneous slot* is a slot in which at least one of the sessions have bad channel. A busy period is defined as the maximum contiguous time interval in which packet from at least one session is waiting for transmission. As shown in Figure 2, in the duration of channel errors sessions can loose service that they would have gotten if the channel were good. The system has to compensate for the lost service. This compensation causes additional delay in the wireless system. When the erroneous slots are bounded above by V in any busy period, the maximum compensation that a system needs to provide is also bounded above by V. Hence, intuitively the excess packet delay over the delay in the system with perfect channel should be no more than the total number of erroneous slots in a busy period. Further, a system in which channel is always good for all the sessions is equivalent to the wireline system. Hence packet delay for a session in wireless case should be equal to the sum of packet delay in a wireline case and V. We shall refer to the delay under EDF in wireline system as *WEDF-delay*. Hence, if D_i is the required packet delay for the session i, then it suffices to check whether $D_i - V$ can be guaranteed in the wireline system under EDF. This observation will allow us to use the admission control schemes designed for wireline system in wireless systems. Formally we state the following result.

Proposition 1. *Every packet of all the admitted sessions meets its deadline if the total number of erroneous slots in a busy period is bounded above by V. Consequently, there is no packet drop in the system.*

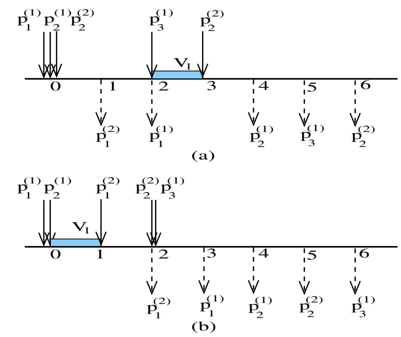

Figure 2: Example to show that the compensation taken by one session affects the delay guarantees of all sessions. Arrows pointing towards and away from the axis represent packet arrivals and departures, respectively. $p_k^{(i)}$ indicates k^{th} packet from i^{th} session. V_1 indicates a time slot in which session 1 has a bad channel. We note that the scheduling is as per EDF. Consider two sessions 1 and 2. The delay requirement for packets of session 1 and 2 are 3 and 2, respectively. We note that these delays can be guaranteed with the perfect channel assumption. In (a) After V_1, $p_2^{(1)}$ takes *immediate compensation* and as a result $p_2^{(2)}$ experiences additional delay of 1 unit. In part (b), session 1 does not seek immediate compensation after V_1, but it takes it eventually. As a result packet $p_2^{(2)}$ again experiences additional delay of 1 unit. Hence as a result of channel error of one unit for session 1, guaranteed delay for both the sessions is increased by 1 unit.

The proof for the proposition is given in [8].

In wireless case, the channel errors are random. Hence, the number of erroneous slots in a busy period are not bounded in general, and thus the above proposition can not be applied directly. Further, the length of busy period and the number of erroneous slots in a busy period are inter-dependent, i.e. the busy period length depends on the number of erroneous slots in the busy period and vice versa (refer to Figure 3). In spite of these issues, now we will show how the above proposition can be generalized to account for random channel errors. We observe that Proposition 1 can be extended simply to obtain the packet drop probability P_d. To illustrate the point, we fix some value for V. The choice of V is not trivial and as we will show later appropriate choice of V allows us to obtain desired balance between session blocking and packet drop. Now, lets assume that the probability of erroneous slots exceeding value V in a busy period of length Z is P_d. So, from Proposition 1 it clear that with probability P_d all the deadlines will be met and system will not have packet drop. Now, the question we need to investigate is "How to compute the drop probability P_d?" For doing this, first we investigate a relation between the number of erroneous slots and the busy period length Z. We note that if the erroneous slots in a busy period were bounded by V, then the maximum length of busy period (Z)

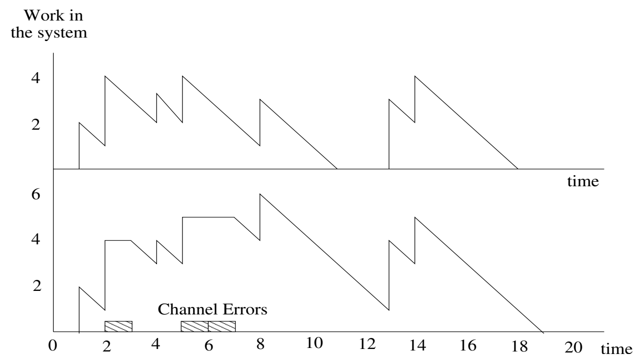

Figure 3: Figure demonstrates the effect of channel errors on the length of the busy periods under EDF. Only the bottom figure experiences channel errors, which lengthen its busy period duration by 7 additional time units (from 12 to 19).

under EDF scheduling is given by the following equation.

$$Z = \frac{\sum_{i \in \mathcal{C}} \sigma_i + V}{1 - \sum_{i \in \mathcal{C}} \rho_i} \text{ if } \sum_{i \in \mathcal{C}} \rho_i < 1 \text{ (stability condition)}, \quad (1)$$

where $\mathcal{C}$ is the set of admitted sessions. The above expression can be explained as follows from the definition of the busy period. The total work which arrives in the system during a busy period must be served during the same busy period. Hence, Z the maximum length of a busy period satisfies $\sum_{i \in \mathcal{C}} \sigma_i + \rho_i Z = Z - V$, where left hand side of the equation is the maximum data that can arrive in duration Z and right hand side is the minimum service that the sessions will obtain in the busy period. Thus equation 1 follows. Now, given this busy period length, we can obtain the probability that the total number of erroneous slots will exceed the value V (denoted by P_d), using the channel parameter estimates obtained from the receivers. We will show the computations in the Section 3.1. We note that the value of V can be chosen so that P_d is small.

Now, the drop probability in the system depends on the value of V. If V is large(small) then the drop probability is small(large). But V can not be made arbitrarily large in order to reduce the drop probability, since increasing V would increase the session blocking. The packet delay in wireless system is WEDF-delay plus V, and hence increasing V would require a decrease in WEDF-delay, which can be guaranteed only if the system has low traffic load. The quantity V can be looked upon as additional resource reservation in anticipation of channel errors. The system does not have any packet drop as long as the total erroneous slots in a busy period are not more than the reservation V. Thus, the choice of V is a policy decision or V can be adjusted dynamically so as to cater to the system requirement.

Based on the above discussion, we propose the following admission control algorithm. The proposed admission control algorithm guarantees the packet drop probability smaller than the acceptable packet drop probability P. The pseudo code for the algorithm is given in Figure 4.

The proposed algorithm works as follows. Whenever a new session arrives, sender node computes the new busy period length Z and the probability P_d that the total number of erroneous slots will exceed the fixed value V. If the drop

Procedure Admission_Control_Algo1()
begin
  Fix V
  When a new session arrives do the following
  Compute new busy period length Z using equation (1);
  Using the channel characteristics compute the probability P_d that the total number of erroneous slots exceed value V in the busy period of length Z;
  if $(P < P_d)$ **then**
    /* The probability that the total number of channel errors exceeding V in a busy period of length Z (P_d) is greater than the required packet drop probability P */
    Block the session;
  else
    Check admission control under EDF in wireline case with $D_i - V$;
    if $D_i - V$ can be guaranteed in wireline system **then**
      Admit the session;
    else
      Block the session;
end

Figure 4: Pseudo code of a general admission control algorithm for an error-prone wireless channel

probability P_d is greater than the permissible value P, then it blocks the session, otherwise it checks if the delay $D_i - V$ can be guaranteed under WEDF. If delay $D_i - V$ can be guaranteed the session is accepted, otherwise it is blocked.

In the following section we discuss the analytical computation of the probability P_d that the total number of channel errors in the duration Z will exceed value V.

3.1 Numerical Computation of Drop Probability P_d

In this section we compute the probability that the total number of erroneous slots in any duration Z exceeds the value V (P_d). Recall that P_d is an upper bound for the packet drop probability. We consider the following analytical model. We assume that the system has admitted N sessions. For each session, we assume a two-state Markovian channel error model as shown in Figure 5. The two states are *good* and *bad*. Let the transition probability from good to bad and from bad to good be α and β, respectively for each session. Furthermore, we assume that the channel state processes are independent.

The number of sessions for whom the channel is in the bad state is a markov process with state space $\{0, 1, \ldots, N\}$. The transition probabilities for this Markov chain can be given as follows.

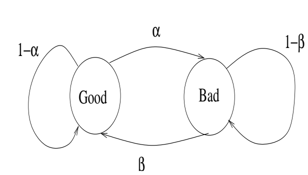

Figure 5: Figure shows two state Markov process for the channel state process.

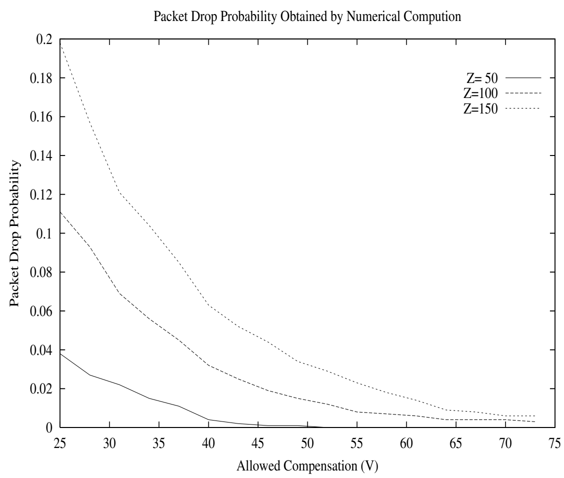

Figure 6: Figure shows packet drop probability for various values of busy period length (Z) and parameter (V). The total number of active sessions are assumed to be 10. Further, we assume that each session has $\alpha = 0.001$ and $\beta = 0.1$.

$$p_{k,k+i} = \sum_{u=0}^{\min\{k,N-(k+i)\}} \binom{k}{u}(1-\beta)^u\beta^{k-u} \times \binom{N-k}{i+u}(1-\alpha)^{i+u}\alpha^{N-(k+i+u)}, \quad \text{where } k+i \le N \tag{2}$$

$$p_{k,k-i} = \sum_{u=i}^{\min\{k,N-(k-i)\}} \binom{k}{u}(1-\beta)^u\beta^{k-u} \times \binom{N-k}{u-i}(1-\alpha)^{u-i}\alpha^{N-(k+u-i)}, \quad \text{where } k-i \ge 0. \tag{3}$$

We observe that the defined Markov chain is (a) finite state space (b) aperiodic and (c) irreducible. Hence using transition probabilities given in equation (2) and (3), we can compute the steady state distribution. In state 0, all the sessions have good channel. The drop probability P_d is the probability that in Z slots Markov process visits state zero less than $Z-V$ times. This probability can be obtained using computational techniques. In Figure 6 we present some numerical results. We note that the numerical results are consistent with the intuition. In particular, the packet drop probability reduces as the value of V increases and increases as the length of busy period increases.

In the above discussion, we have assumed that the transition probabilities for all the sessions are identical. If this is not the case, the number of sessions with a bad channel state is not markovian. Thus the system can only be represented by an $N-$dimensional vector, where each component denotes the channel state of individual sessions. Similar to the previous case, the Markovian structure can be exploited to obtain P_d numerically.

The numerical computations involve calculation of steady state distribution, which can be obtained by solving the ma-

```
Procedure Admission_Control_Algo2()
begin
  When a new session i arrives do the following
  Compute new busy period length Z using equation (1);
  Obtain new value of channel errors in the busy period of length Z
  (V') using V' = Z ∑_{j∈C∪{i}} δ_j;
  if (V' > V) then
    /* the value of channel errors if i were admitted (V') is greater
    than a maximum allowed value (V) */
    Block the session i;
  else
    Check admission control under EDF in wireline case with D_i − V;
    if (D_i − V can be guaranteed in wireline system) then
      Admit the session;
    else
      Block the session;
end
```

Figure 7: Pseudo code of a general admission control algorithm for an error-prone wireless channel

trix equation. This can become computationally prohibitive. Hence we propose a simpler approach to provide packet delay in presence of channel error using EDF scheduler in the following subsection.

3.2 Simplistic Approach

The computationally simple alternative approach is based on the following observation. If δ_i is a long term channel error rate for the session i then the number of erroneous slots for the session in sufficiently long interval L is close to $L\delta_i$ with high probability. This observation follows from the *Strong Law of Large Numbers* or *ergodicity* property of the Markovian channel error models, e.g. Gilbert-Elliot model. Each receiver can estimate the required long term error rate δ_i from the previous transmissions of the sender, and communicate this estimate periodically to the sender node.

If the maximum length of a busy period, Z is small, then the total number of erroneous slots must be few and hence the packet drop rate is low. We need to carefully upper bound the total number of erroneous slots for large values of Z. If Z is sufficiently large, then $Z\sum_{i\in\mathcal{C}}\delta_i$ upper bounds the total number of erroneous slots in a busy period with a high probability. Using this computationally simple estimate for the number of erroneous slots in the busy period, we propose a new admission control algorithm, which uses the same intuition as the previous one, but differs in computing the estimate for the packet drop probability. Recall that in the previous algorithm (refer Figure 4), we have explicitly computed the packet drop probability P_d and then we have ensured that the computed drop probability is smaller than the required value P. In this scheme, we compute the average number of erroneous slots in a busy period of length Z based on the long term channel error rates (denoted by V'). If the computed number of erroneous slots V' is less than the fixed value V, we assume that the system will not have packet drop with high probability. Pseudo code for the algorithm is given in Figure 7.

The proposed algorithm works as follows. Whenever a new session arrives, sender node computes the new busy period length Z and the total long term channel error rate if the arriving session were admitted. If the expected total erroneous slots $Z\sum_{j\in\mathcal{C}\cup\{i\}}\delta_j$ is greater than V, it blocks the session, otherwise it checks if the delay $D_i - V$ can be guar-

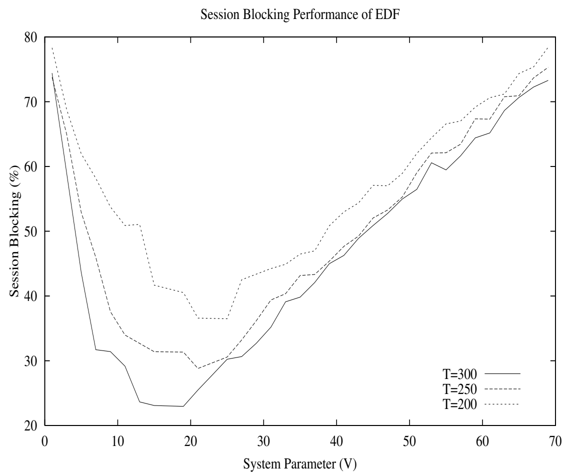

Figure 8: Figure provides session blocking performance of EDF with perfect channel knowledge and the proposed predication based scheme. T denotes the inter-arrival time for the sessions.

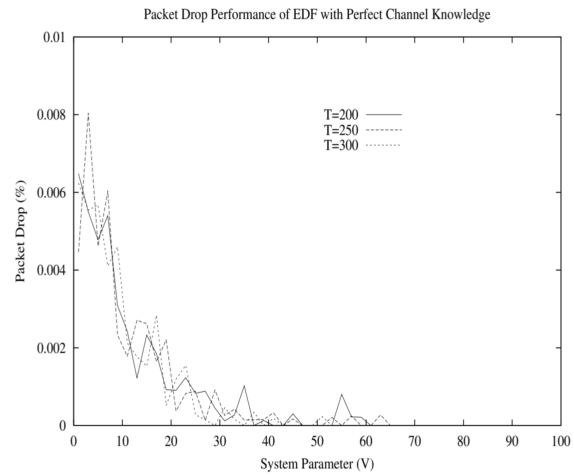

Figure 9: Figure provides packet drop performance of EDF when the scheduler has the perfect knowledge of channel state for every session before packet transmission.

anteed under WEDF. If delay $D_i - V$ can be guaranteed the session is accepted, otherwise it is blocked. In the following section we present the simulation results.

4. SIMULATION RESULTS AND DISCUSSION

In this section, we evaluate the packet drop and session blocking for the proposed admission control algorithm for EDF schedule. We assume that the sessions arrive at a fixed node in a Poisson process with rate λ. An arriving session specifies its leaky bucket parameters. We assume bucket depth σ and token replenishment rate ρ to be uniformly distributed between 0-10 packets and 0-0.1 packets per unit time, respectively. The required delay guarantee for the session is assumed to be uniformly distributed between 5-100 time units. We model error prone wireless channel as an ON-OFF process. The transition probabilities from good to bad and bad to good are 0.001 and 0.1, respectively. These channel parameters correspond to Raleigh fading channel where the mean fade duration is 10 time slots and the channel is good for 99% of the total time [24].

We have performed simulations for two systems (a) when the sender has perfect knowledge of channel state of each session in the beginning of the slot (b) when sender predicts the future channel state based on the outcome of the present transmission. We note that in practice it is difficult to obtain the perfect knowledge of instantaneous channel state for every session and hence option (b) is more suited for practical applications. In (b), we use simple two step prediction model, where if the current transmission is successful the sender assumes that the channel state for the session will be good in the next slots, but if the communication is not successful then sender assumes that the session will have a bad channel for the next $\frac{1}{\beta}$ slots. We note that $\frac{1}{\beta}$ is the expected number of slots for which a session will have erroneous channel, given that it has bad channel in the current slot. Figures 8, 9 and 10 show the performance of the designed admission control scheme for the EDF scheduler in wireless system.

Table 1: The table investigates the reduction in packet drop brought about by additional resource reservation. The chosen channel parameters are $\alpha = 0.03$ and $\beta = 0.1$, and the EDF scheduler has instantaneous knowledge of channel state before packet transmission

T	Packet Drop with resource reservation ($V = 20$) (%)	Packet Drop without resource reservation (%)
200	0.039999	0.220106
250	0.037671	0.206806
300	0.035112	0.166328

We note that the session blocking curve is cup-shaped (see Figure 8). For small values of V, the system reserves less resources for compensating for channel errors, and hence can only accommodate a few sessions with low long term channel error rate (otherwise $Z \sum_{j \in \mathcal{C} \cup \{i\}} \delta_j$ exceeds V). Further, when V is high the session blocking is high again as the guaranteed delay is the sum of the WEDF delay and V, and hence the former must be small so as to compensate for the large value of the latter. The WEDF delay is small only if a few sessions are admitted.

The packet drop performance is intuitive. When the value of V is small the packet drop is higher and the packet drop goes to zero as V becomes large. We note that the overall packet drop performance of the system is better than the calculated packet drop probability (see Figures 9 and 10). This is because the numerical computations do not account for the service given to other sessions when one session has a bad channel, and hence only upper bound the packet drop rate.

Tables 1 and 2 demonstrate that the packet drop can be substantially reduced by reserving additional resources. We examine the drop performances of two schemes: (a) the scheme

Table 2: Comparison of packet drop performances with and without resource reservation for the prediction based EDF scheduling.

T	Packet Drop with resource reservation ($V = 20$) (%)	Packet Drop without resource reservation (%)
200	0.252755	0.967706
250	0.230513	0.824213
300	0.178824	0.537767

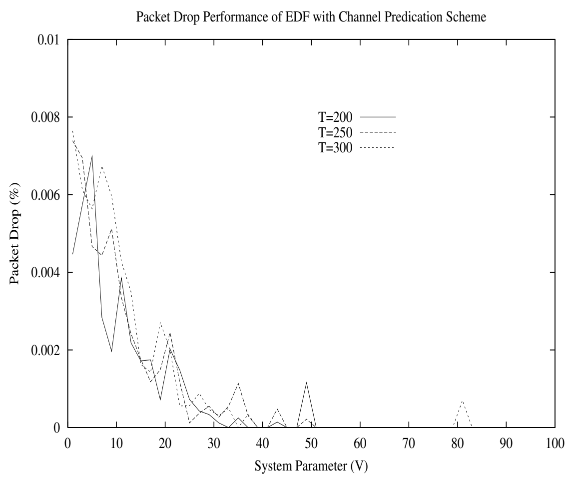

Figure 10: Figure provides packet drop performance of EDF with the proposed two-step prediction scheme.

we propose which reserves additional resources for compensating for channel errors ($V = 20$), and (b) another scheme which does not reserve any resources and admits sessions as long as the WEDF delay is less than the required guarantee, disabling the verification of other admission control criteria. The latter has substantially higher packet drop.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we have proposed connection admission control algorithms to provide stochastic delay guarantees in a single hop wireless network. EDF is used as a baseline scheduler. We have argued that the wireline admission control solutions are not suitable for the wireless case as they do not take into consideration the channel errors which can result in high packet drop on account of deadline expiry. In the proposed approach, we consider channel characteristics of the sessions while taking admission control decisions. As a result, we can provide the delay guarantees with the desired packet drop probability. The guarantees can be provided only if the EDF scheduler uses instantaneous channel states in the scheduling decision mechanism. The channel states in the previous slots can be used to predict the instantaneous channel states if the latter is not known. The analytical guarantees do not hold in this case, but extensive simulation results indicate low packet drop.

The proposed admission control algorithms assume EDF as a baseline scheduler. We are currently looking at admission control schemes for other important scheduling disciplines like fair queueing disciplines. Further, in this paper we have only been able to upper-bound the overall packet drop probability. No bound for the packet drop of individual sessions is obtained. It is entirely possible that excessive channel errors of one session deteriorate the packet drop rate of other sessions. A framework which guarantees individual packet drop rates is a topic for future research. Also, it has been assumed throughout that the sender receives instantaneous feedback after every transmission. We plan to investigate the effects of delayed feedbacks.

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