Risk-aware Scheduling for Multi-user Video Streaming over Wireless Multi-hop Networks

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ABSTRACT

To cope with the time-varying network conditions, various error-protection and channel adaptation strategies have been proposed at different layers of the protocol stack. However, these cross-layer strategies can be efficiently optimized only if they act on accurate information about the network conditions and hence, are able to timely adapt to network changes. We analyze the impact of such information feedback on the video quality performances of the collaborative multimedia users sharing the same multi-hop wireless infrastructure. Based on the information feedback, we can estimate the *risk* that packets from different priority and deadline classes will not arrive at their destination before their decoding deadline. Subsequently, cross-layer optimization strategies such as packet scheduling, retransmission (due to transmission error) limit are adapted to jointly consider the estimated risk as well as the impact in terms of distortion of not receiving different priority packets. Our results quantify the risk estimation and its benefit in different network conditions and for various video applications with different delay constraints.

Keywords: cross-layer optimization, multi-user video streaming, wireless multi-hop networks, information feedback.

1. INTRODUCTION

Emerging multi-hop wireless LAN (WLAN) networks provide a low-cost and flexible infrastructure that can be simultaneously utilized by multiple users for a variety of applications, including delay-sensitive multimedia transmission. However, these wireless networks provide only limited Quality of Service (QoS) support for real-time multimedia applications. Hence, efficient solutions for multimedia streaming must accommodate time-varying bandwidths and probabilities of error introduced by the shared nature of the wireless medium and quality of the physical connections. In the studied distributed transmission scenario, multimedia users proactively collaborate in sharing the available wireless resources to maximize their video qualities. To enable optimal usage of the multi-hop infrastructure, the various network entities (source nodes, relay nodes etc.) can timely and accurately exchange information about channel statistics, expected delays, or even packet loss probabilities (due to the deadline expiration of video packets) incurred by previously transmitted multimedia packets from different users and distortion classes across the network. However, this network information feedback usually shares the same resources allocated for the payload (e.g. multimedia) transmission and thus, the resulting overheads need to be explicitly considered for optimized transmission.

In this paper, we introduce the concept of *risk estimation* that determines the probability that a packet will miss its delay deadline. From the estimated risk and the quality impact of the video packet, we proposed novel information feedback driven scheduling and retransmission strategies for each node in the multi-hop wireless network. Unlike the end-to-end feedback that exists in today's networking protocols (such as the rate control in TCP), the information feedback is performed in a distributed (per hop) fashion that explicitly considers the instantaneous delays, which is essential for supporting delay-sensitive multimedia applications. We assume that the video data is streamed in real-time over a directed acyclic overlay network [6] that can be superimposed over any wireless multi-hop network. Our cross-layer solution relies on the users' agreement to collaborate by dynamically adapting the quality of their multimedia applications to accommodate the flows/packets of other users with a higher distortion impact and/or higher probability to miss their decoding deadlines. Unlike commercial multi-user systems, where the incentive to collaborate is minimal, we investigate the proposed approach in an enterprise network setting where source and relay nodes exchange accurate and

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trustable information about their applications and network statistics. In our setting, the importance of the packets is determined based on their contribution to the overall distortion of a particular video as well as their delay deadlines. This information is encapsulated in the header of each transmitted packet and can be easily accessed by the relay nodes.

The paper is organized as follows[2]. Section II introduces the multi-user video streaming specification and problem formulation. In Section III and IV, we present our distributed risk-aware scheduling and retransmission limit solution. The simulation results are in Section V. Section V concludes the paper.

2. MULTI-USER VIDEO STREAMING PROBLEM FORMULATION

We assume that there are V video users (with distinct source-destination pairs) sharing the same multi-hop wireless infrastructure. Similarly, in this paper, we categorized the video units (video packets, video frames) of the video bitstream into several priority classes [3]. We adopt an embedded 3D wavelet codec and construct video classes by truncating the embedded bitstream. We assume that the packets within each class have the same delay deadline, similar to [2]. For a video sequence v, its video classes are characterized by:

- $\boldsymbol{\lambda}_v$, a vector of the quality impact of the various video classes. The video classes are organized in an embedded bitstream in terms of their video quality impact.
- $\mathbf{R}_v$, a vector of the rate requirements of the video classes.
- $\mathbf{d}_v$, a vector of the delay deadlines of the various video classes. Due to the hierarchical temporal structure deployed in 3D wavelet video coders (see [2]), the lower priority packets also have a less stringent delay requirement.
- $\mathbf{L}_v$, a vector of the average packet lengths of the various video classes.
- $\mathbf{P}_v^{succ}$, a vector containing the probabilities of successfully receiving the packets in the various video classes at the destination.

At the client side, the expected received video quality of video v can be modeled using a general video rate-distortion model:

$$Q_v^{rec} = F_v(\boldsymbol{\lambda}_v, \mathbf{R}_v, \mathbf{d}_v, \mathbf{L}_v, \mathbf{P}_v^{succ}), \tag{1}$$

represented by the function $F_v(\cdot)$ and is an increasing function of the available rate (goodput). Importantly, our formulation is not restricted by the choice of rate-quality models. Any model could be deployed in our formulation to determine the prioritization for a specific class f_k (which can be characterized by the elements $\lambda_k, R_k, d_k, L_k, P_k^{succ}$ in the mentioned vectors, where k represents the index of classes across all users, $k = 1, ..., K$) For simplification, with a quality-rate curve of the video stream v, the received video quality can be linearly approximated:

$$Q_v^{rec} = \sum_{f_k \in v} \lambda_k R_k P_k^{succ} . \tag{2}$$

Note that the end-to-end probability P_k^{succ} depends on the network resource, competing users' priorities and the deployed cross-layer transmission strategies. We assume that the client implements a simple error concealment strategy, where the lower priority packets are discarded whenever the higher priority packets are lost. This is because the quality improvement (gain) obtained from decoding the lower priority packets is very limited (in such embedded scalable video coders) whenever the higher priority packets are not received. Hence, we can write:

$$P_k^{succ} = \begin{cases} 0 & \text{, if } P_{k'}^{succ} \neq 1 \text{ and } f_{k'} \prec f_k \\ (1 - P_k) = E[I(D_k \leq d_k)], & \text{otherwise,} \end{cases} \tag{3}$$

where we use the notation $f_{k'} \prec f_k$ to indicate that the class f_k depends on $f_{k'}$. Specifically, if f_k and $f_{k'}$ are classes of the same video stream, $f_{k'} \prec f_k$ means $k' < k$ due to the descending priority ($\lambda_{k'} > \lambda_k$). P_k represents the end-to-end packet loss probability for the packets of class f_k. D_k represents the experienced end-to-end delay for the packets of class f_k. $I(\cdot)$ is an indicator function.

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[2] The paper is based on the work in [6] focusing on the scheduling of sending prioritized video packets from various sources through wireless mesh networks.

An example of the multi-hop wireless network is depicted in Figure 1 with video classes from various sources. We define $\mathbf{STR}_{m_h}$ as the cross-layer transmission strategy vector at the node m_h at the h-th hop, consisting of the packet scheduling policy $\boldsymbol{\pi}_{m_h}$, the MAC retransmission limit $\gamma^{MAX}_{k,m_h,m_{h+1}}$ (we assume that route is determined from an on-demand routing algorithms [4], and hence the next node m_{h+1} is known). Then, in order to maximize overall video qualities, the investigated multi-user wireless video transmission problem can be formulated as a delay-driven cross-layer optimization:

$$\begin{aligned} \mathbf{STR}^{opt}_{m_h} &= \arg\max_{\mathbf{STR}} \sum_{k=1}^{K} \lambda_k R_k P^{succ}_k(\mathbf{STR}_{m_h}, \mathcal{I}_{m_h}) \\ \text{subject to } & D_k(\mathbf{STR}_{m_h}) < d_k,\ k = 1,\ldots,K, \\ \mathbf{STR}_{m_h} &= [\boldsymbol{\pi}_{m_h}, \gamma^{MAX}_{k,m_h,m_{h+1}}], \boldsymbol{\pi} \in APP, \gamma \in \mathbb{N} \end{aligned} \quad (4)$$

where APP is the set of all feasible packet scheduling strategies. $\mathcal{I}_{m_h}$ represents the available information feedback from the nodes in the next hop [6]. The successfully received packets of each class f_k must have their end-to-end delay D_k smaller than their corresponding delay deadline d_k. To solve equation (4), heuristic methods are:

(a) At the MAC layer, we choose the appropriate retransmission limit $\gamma^{MAX}_{k,m_h,m_{h+1}}$ per packet such that its delay constraint is satisfied. Based on our prior results [2], the optimal retransmission strategy is to send the highest priority packet until its successful arrival at the receiver or until its delay deadline expires at an intermediate node. Specifically, let d^{curr} represent the current delay incurred by a particular packet at the current node m_h. The maximum retransmission limit for the packet of class f_k over the link from m_h to m_{h+1} is determined based on the delay deadline d_k (where $\lfloor\cdot\rfloor$ is the floor operation):

$$\gamma^{MAX}_{k,m_h,m_{h+1}} = \left\lfloor \frac{T^{goodput}_{k,m_h,,m_{h+1}}(d_k - d^{curr})}{L_k} \right\rfloor - 1, \quad (5)$$

where $T^{goodput}_{k,m_h,,m_{h+1}}$ represents the goodput over the link from m_h to m_{h+1}.

(b) At the application layer, the packet scheduling policy $\boldsymbol{\pi}_{m_h}$ in the queue of the intermediate node m_h is optimized to first transmit the video packets with larger λ_k, since they have a higher distortion impact on the overall video quality.

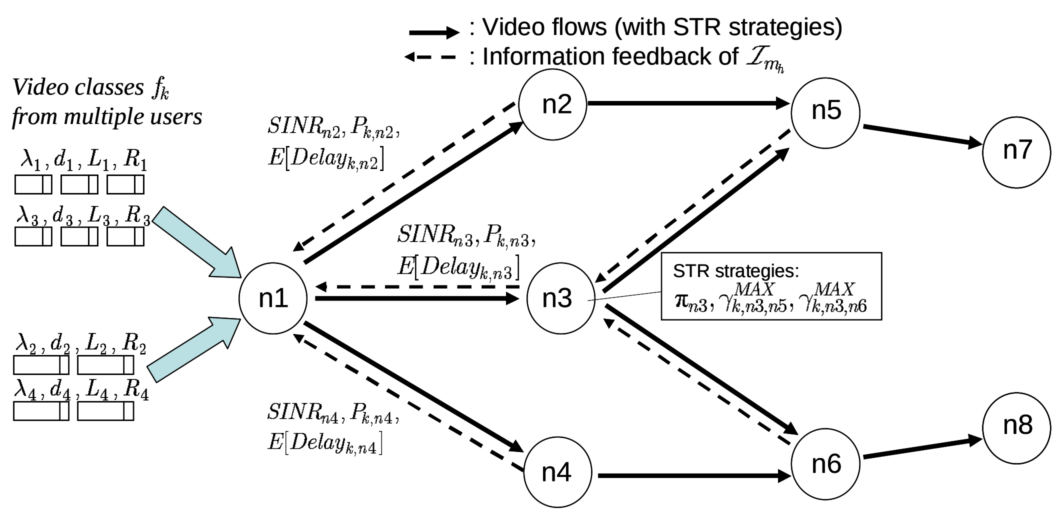

Fig. 1 An example of the multi-hop wireless network with information feedback.

On top of the heuristic method, we propose our risk-aware approach based on the information feedback.

3. RISK-AWARE SCHEDULING OF PRIORITIZED VIDEO PACKETS

3.1 Risk estimation

At each intermediate node m_h, in order to optimize the scheduling of the various video packets, we determine the risk $Risk_{k,m_h}$ ($0 \le Risk_{k,m_h} \le 1$) that the packets of class f_k will miss their delay deadline, based on the probability that the estimated received time at the destination is *after* their delay deadlines. Higher probabilities of packet loss over the network (due to interference, congestion, nodes leaving etc.) will lead to higher risks of packets missing their delay deadlines.

To compute the risk estimation for a packet, we need to consider both the delay deadlines d_k as well as the expected delay $E[Delay_{k,m_h}]$ from the node m_h to the destination node of the class f_k computed from the information feedback $\mathcal{I}_{m_h}$ [1]. The video packets at an intermediate node can be divided into three categories:

(a) "Dropped" packets are video packets with a current cumulative delay d^{curr} exceeding their delay deadline ($d^{curr} > d_k$). These packets will be dropped at the current node and hence, there is no need to compute their risk.

(b) The "almost-dropped" packets have not yet exceeded their delay deadline ($d^{curr} < d_k$), but their current cumulative delay plus the expected delay to reach the destination does exceed their delay deadline, i.e. $d^{curr} + E[Delay_{k,m_h}] > d_k$. We set the risks for these "almost-dropped" packets to be 0, as they have a very high probability of being dropped and hence, they will unnecessarily waste resources that could be used for the successful transmission.

(c) The remaining video packets are "seldom-dropped" packets. Their current cumulative delay plus the expected delay from the current node to the destination is lower than the delay deadline, i.e. $d^{curr} + E[Delay_{k,m_h}] < d_k$. Hence, these packets have a high probability of arriving at the destination on time and their scheduling needs to be optimized to maximize the video quality across the various users. The risk estimation is determined based on the priority queuing analysis, by using the approximation of the waiting time W_{k,m_h} (the queue waiting time for class f_k at intermediate node m_h) tail distribution [6][7]. The proposed risk estimation[3] for the packets in class f_k can be computed as:

$$Risk_{k,m_h}(T^{\mathrm{I}}) = \begin{cases} \mathrm{Prob}(W_{k,m_h} + T^{\mathrm{I}} > E[d_k^{left}]), \text{if } E[d_k^{left}] > 0 \text{ (seldom-dropped packets)} \\ 0 \qquad\qquad\qquad\qquad ,\text{if } E[d_k^{left}] \le 0 \text{ (almost-dropped packets)} \end{cases}, \tag{6}$$

where $E[d_k^{left}] = d_k - d^{curr} - E[Delay_{k,m_h}]$ represents the expected time remaining after a packet reaches its destination. We can determine the probability that the waiting time W_{k,m_h} plus a pre-determined time duration T^{I}, which is a general variable for risk estimation, exceeds the expected time left $E[d_k^{left}]$, and thus, that the packet will be lost. The time duration T^{I} can be viewed as an extension of the waiting time for the packet. Larger T^{I} values lead to higher risks. We encourage interested readers to read the detail of the risk estimation in [6].

3.2 Risk-aware application layer scheduling

In a priority queue, the packet scheduler at an intermediate node transmits first the most important packets (i.e. the packets with the largest λ_k). Each packet is transmitted until the packet is successfully received by the next hop node or until its deadline expires. Assume that there are *L* total video packets at the intermediate node m_h. Let the application layer packet scheduling $\boldsymbol{\pi}_{m_h} = (\pi_1, ..., \pi_l, ..., \pi_L)$, where π_l represents the scheduling order for the video packet

[3] The higher risk packets should be sent earlier, since they are with high probability to exceed their deadlines. However, we do not want to waste our resources on those almost-drop packets, hence the risk estimation for these packets are set to zero.

$l \in \{1, \ldots, L\}$. The heuristic priority scheduling can be written as:

$$\begin{aligned} \boldsymbol{\pi}_{m_h}^{PRI} &= \arg\max_{\boldsymbol{\pi}_{m_h}} \left\{ \sum_{k=1}^{K} \lambda_k \times N_{k,m_h}\left(\boldsymbol{\pi}_{m_h}, T_\pi^{\mathrm{I}}\right) \times L_k \right\} \\ \text{subject to } \boldsymbol{\pi}_{m_h} &= (\pi_1, \ldots, \pi_l, \ldots, \pi_L), \\ \pi_l &= drop, \text{ if } l \in f_k, \text{ and } d_l^{curr} \geq d_k \end{aligned} , \quad (7)$$

where $N_{k,m_h}\left(\boldsymbol{\pi}_{m_h}, T_\pi^{\mathrm{I}}\right)$ is the number of packets of the class f_k that are transmitted during a period of time T_π^{I} using a specific packet scheduling $\boldsymbol{\pi}_{m_h}$. Packet loss is considered in this number due to the delay constraint that drops packets. The notation $\pi_l = drop$ indicates that the packet l is not scheduled due to its deadline expiration.

A packet could be dropped in the future hops, as its deadline is exceeded at these hops, and the transmission time of this packet is wasted. This may results in the loss of other packets that would have arrived on time at their destination. Thus, enabled by the information feedback, an intermediate node gathers the network status and makes a scheduling decision. Instead of always transmitting the most important packet in the queue, some other video packets of the different users that are less important but have a higher packet loss probability (risk) can be sent first. Based on this, we propose a novel Information Feedback Driven packet Scheduling (IFDS). The system map of the IFDS scheduling at an intermediate node is illustrated in Figure 2.

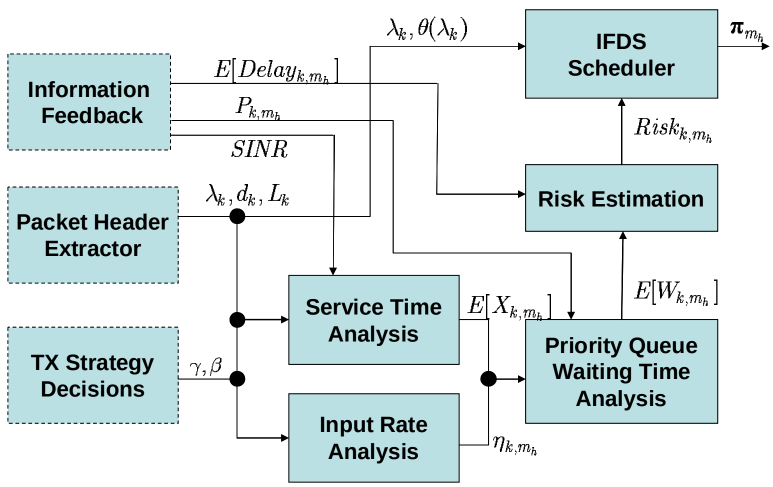

Fig. 2 System map for the IFDS packet scheduling.

For the IFDS scheduling, the video packets ordered in $\boldsymbol{\pi}_{m_h}^{IFDS}$ are transmitted for a pre-determined period of time T_π^{I}. The IFDS scheduling is determined as:

$$\begin{aligned} \boldsymbol{\pi}_{m_h}^{IFDS} &= \arg\max_{\boldsymbol{\pi}_{m_h}} \left\{ \sum_{k=1}^{K} \lambda_k \times N_{k,m_h}(\boldsymbol{\pi}_{m_h}, T_\pi^{\mathrm{I}}) \times L_k \times Risk_{k,m_h}(T_\pi^{\mathrm{I}}) \right\} \\ \text{subject to } \boldsymbol{\pi}_{m_h} &= (\pi_1, \ldots, \pi_l, \ldots, \pi_L), \\ \pi_l &= drop, \text{ if } l \in f_k, \text{ and } d_l^{curr} \geq d_k \end{aligned} . \quad (8)$$

As opposed to the priority queuing scheduling (equation (7)), the risk of losing a certain class $Risk_{k,m_h}(T_\pi^{\mathrm{I}})$ is considered jointly with the packet quality impact. The scheduler sends the packets in the order that maximizes the output video quality weighted by $\lambda_k Risk_{k,m_h}$ within the time interval T_π^{I}. Since different traffic classes have different packet transmission times, the number of packets being transmitted per class $N_{k,m_h}\left(\boldsymbol{\pi}_{m_h}, T_\pi^{\mathrm{I}}\right)$ depends on which packets are sent (scheduling decision). However, the $Risk_{k,m_h}(T_\pi^{\mathrm{I}})$ remains constant and is independent of the scheduling decision within T_π^{I}. Finally, the IFDS scheduling has the following constraint:

$$\boldsymbol{\pi}_{m_h}^{Final} = \begin{Bmatrix} \boldsymbol{\pi}_{m_h}^{IFDS} = (\pi_1, \ldots, \pi_l, \ldots, \pi_{l'}, \ldots, \pi_L) \mid \pi_l \ll \pi_{l'}, \\ \text{only if } \; l \in f_k, \; l' \in f_{k'} \text{ and } \lambda_k > \theta(\lambda_{k'}) \end{Bmatrix}, \tag{9}$$

where the notation $\pi_l \ll \pi_{l'}$ represents that packet l is scheduled before packet l'. If λ_k belongs to user v, the $\theta(\lambda_k)$ is a class dependent threshold, which can be defined as:

$$\theta(\lambda_k \in \text{user } v) = \max_{u \in \{k+1, \ldots, K\}} \{\lambda_u \mid f_u \in \text{the same user } v\}. \tag{10}$$

Equation (10) provides a threshold for a particular class, which is the quality impact value of the next important class of the same user. The reason for the constraint in equation (9) is to avoid sending an unimportant class with high risk (i.e. for the classes of the same user, packets with higher λ_k must be sent first). This is important since the less important classes depend on the more important classes of the same user and hence, their distortion will be significantly impacted if the higher priority packets are lost.

4. RISK-AWARE RETRANSMISSION LIMIT FOR ERROR PROTECTION

For protection over an error-prone wireless link, a retransmission scheme at the MAC layer is adopted. In (5), the video packets should be retransmitted by the MAC until they are received without error or their deadline expires in order to maximize the received video quality. However, if a packet approaches its delay deadline, the risk that it will not reach its destination increases. Hence, similarly to the application layer scheduling strategies discussed in the previous section, we propose a MAC layer information feedback driven retransmission strategy $\gamma_{k,m_h,m_{h+1}}^{IFDS}$ that explicitly considers the risk of losing a packet based on the available information feedback $\mathcal{I}_{m_h}$. Let γ be an integer variable that represents the number of retransmissions for a packet. If the transmission of the packet repeatedly fails, the retransmission should last only until another class of video packets starts to have a higher impact in terms of overall video quality. In the IFDS scheduling policy of the previous section, the scheduler will send packets of class f_k having a larger $\lambda_k Risk_{k,m_h}$ value (see equation (8)). Therefore, the information feedback driven retransmission limit becomes:

$$\begin{aligned} &\gamma_{k,m_h,m_{h+1}}^{IFDS} = \text{maximize } \gamma \\ &\text{subject to } \lambda_k Risk_{k,m_h}\left(T_\gamma^{\mathrm{I}}\right) \geq \lambda_j Risk_{j,m_h}\left(T_\gamma^{\mathrm{I}}\right), \\ &\qquad\qquad \text{for all } j \text{ that } \lambda_j > \theta(\lambda_k), \\ &\qquad\qquad T_\gamma^{\mathrm{I}} = (\gamma+1) \times T_{k,m_h,m_{h+1}}^{packet}, \; \gamma \in \mathbb{N}, \end{aligned} \tag{11}$$

where $T_{k,m_h,m_{h+1}}^{packet}$ represents the average packet transmission time for packets in class f_k at the intermediate node m_h to the next relay m_{h+1}. Equation (11) states that the retransmission limit is the maximum number of retries such that the transmitting packet (of class f_k) has a greater $\lambda_k Risk_{k,m_h}$ than other packets in the queue. Due to the scheduling constraint in equation (9), we only need to check the classes that have a quality impact value larger than the threshold $\theta(\lambda_k)$ in equation (11). Note that the information feedback driven retransmission limit is always smaller than the retransmission limit in equation (5) ($\gamma_{k,m_h,m_{h+1}}^{IFDS} \leq \gamma_{k,m_h,m_{h+1}}^{MAX}$), since when a packet approaches the deadline, it will first belong to the "almost-dropped" packets class, for which $Risk_{k,m_h} = 0$. Thus, another class of packets will be transmitted, thereby terminating the retransmission of the current packet. Consequently, a packet retransmission will first reach the information feedback driven retransmission limit $\gamma_{k,m_h,m_{h+1}}^{IFDS}$ before the delay deadline. Thus, other packets that have a better chance to reach the destinations could be sent earlier.

5. SIMULATION RESULTS

Two video sequences, “Mobile” and “Coastguard” (16 frames per GOP at a frame rate of 30 Hz, CIF format) are sent from distinct sources to their corresponding destinations through the multi-hop wireless network shown in Figure 3. The delay deadlines of the two video sequences are set to 500 ms and 300 ms, respectively. Each of the video sequence is divided into four priority classes with their quality slope parameters λ_k and source rate R_k shown in Table 1. The parameter Tm represents the streaming efficiency of the network. The various efficiency levels are represented by varying the available time fraction for the contention-free period in the polling-based MAC protocol, which induces the various available transmission rates for the video packets over the links. In our simulation, we set Tm = 400 Kbps for the low streaming efficiency case, and Tm = 500 Kbps for the medium streaming efficiency case. The transmission rates of the links in the first hop are, relatively higher than the subsequent links. Consequently, most of the packets of the various classes will be queued at the specific intermediate nodes n1 and n2 (some of them will still be left in the source queues), and the effect of risk estimation can be highlighted for two streams with different delay deadlines.

Three different schemes are compared in Table 2. 1) transmission without prioritization, 2) the heuristic approach in Section II that applies the prioritization scheduling in equation (7), and 3) the risk-aware approach in Section III that applies the proposed IFDS scheduling and retransmission in equation (8) and (11). The results show that the transmission scheduling based on the video packet prioritization at each intermediate node significantly improves the overall video qualities. Importantly, further improvement can be achieved by applying the proposed risk-aware approach and the improvement increases as the streaming efficiency increases.

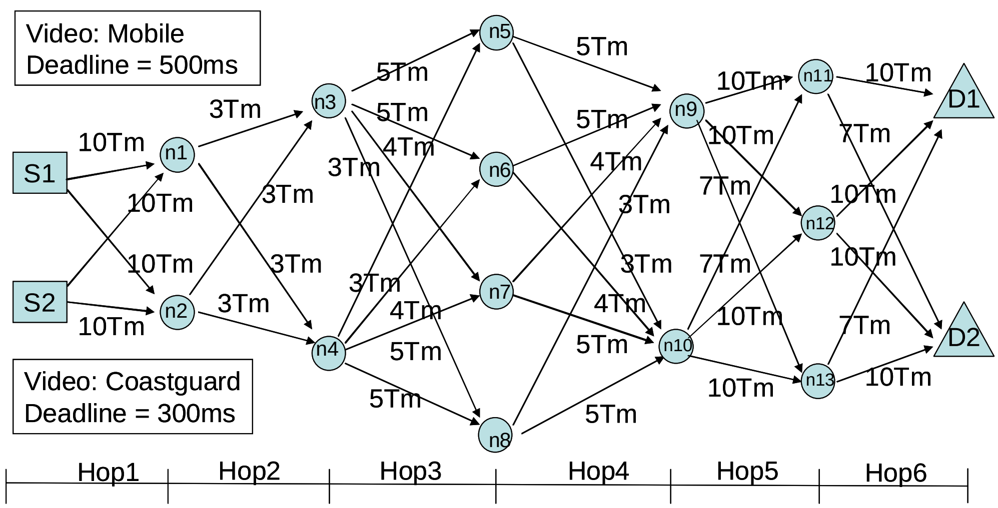

Fig. 3 Network settings for the IFDS risk-aware scheduling of the two video sequences.

Table 1.
Traffic characteristics of the two video streams in the simulation.

Mobile (1668 Kbps)			Coastguard (1500 Kbps)		
f_k	λ_k (dB/Kbps)	R_k (Kbps)	f_k	λ_k (dB/Kbps)	R_k (Kbps)
f_1	0.0340	278	f_2	0.0210	250
f_3	0.0128	166	f_4	0.0128	150
f_6	0.0084	166	f_5	0.0096	150
f_8	0.0062	222	f_7	0.0084	200

Table 2.
Y-PSNR improvement (dB) using the IFDS risk-aware approach.

	Y-PSNR (dB) at low bandwidth Tm = 400 Kbps			Y-PSNR (dB) at medium bandwidth Tm = 500 Kbps		
Delay deadline d_k	"Mobile" 500 ms	"Coastguard" 300 ms	Overall Improvement	"Mobile" 500 ms	"Coastguard" 300 ms	Overall Improvement
Without prioritization	25.05	26.55		25.89	27.32	
Heuristic prioritized method	30.98	29.35	8.73	31.66	30.34	8.79
Risk-aware scheduling	30.16	30.76	9.32	31.22	31.84	9.85

When applying the video packet prioritization, the "Coastguard" sequence has a lower video quality shown in Table 2, due to its smaller delay deadline. Compared to the heuristic prioritized approach that applies prioritization scheme in equation (7), the risk-aware IFDS approach in equation (8) sends more "Coastguard" packets to improve its video quality (due to its stringent delay deadline) without significantly degrading the video quality of the "Mobile" sequence. Hence, the wireless resources are hence shared by the two video applications in a more efficient manner by estimating the risk of losing packets at their destinations based on the information feedback. The overall PSNR improvement increases for more than 1 dB compared to the heuristic prioritized approach when the network streaming efficiency Tm = 500 Kbps.

6. CONCLUSIONS

In this paper, we introduce the risk-aware scheduling and retransmission approach for streaming multiple videos over a multi-hop wireless network based on the information feedback of expected delay. Unlike the end-to-end feedback that exists in today's networking protocols (such as the rate control in TCP), the information feedback is performed in a distributed (per hop) fashion that explicitly considers the instantaneous delays, which is essential for supporting delay-sensitive multimedia applications. The results show significant improvement over the heuristic prioritization approach for different network efficiencies. The proposed distributed cross-layer approach is fully adaptive to the changes in the network, number of users, and the priority schemes of the applications.

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