Application-Oriented Multimedia Streaming over Wireless Multihop Networks

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Multimedia Streaming

- Display of audio-visual object simultaneously when transmitting
- Killer applications of current networking
  - Video on demand, video conference, IPTV, on-line game, etc.
  - Hundreds of thousands of streaming media servers deployed
  - Millions or billions of media players every day, e.g., Youtube, PPLive
- For any networks to be successful, to well support the high-quality multimedia streaming is crucial
**Wireless Multihop Network**

- Transmissions are through multiple *wireless connections*, e.g.,
  - wireless mesh network (802.11s), WiMax (802.16j), mobile Ad Hoc networks, vehicle Ad Hoc networks (802.11p), sensor networks
  - Enhance the coverage of communications
  - Cost-effective with fast deployment (war field, rural region)

- Next-generation networks
  - Various access technologies coexist
  - Wireless multihop network provides a *scalable* and *flexible backbone* for different access networks

- To study multimedia streaming over wireless multihop networks is important
Multimedia Streaming over Wireless Multihop Networks: Challenges

- Multimedia applications
  - Multi-dimensional quality of service (QoS) requirements: data throughput, time delay, packet loss ratio, etc.
  - Heterogeneous QoS requirements of different users and applications, e.g., VoIP, live/on-demand video streaming

- Wireless multihop networks
  - Wireless communications suffer from limited bandwidth, scarcity of wireless channel, interference, and severe multipath fading
  - Multihop relays incur more network dynamics [2] due to cross traffic interference, queueing

With heterogenous flows demanding different QoS provision mixed in the network, how to provide users/applications with their desired end-to-end QoS in such dynamic and resource limited networks?

1. Desired QoS (Application/user-oriented)
2. End-to-End QoS
3. Dynamic and resource limited networks
Two Building Blocks

1. End-user Reception: Receiver resource management with given network infrastructure and performance

2. Network Transmission: Network resource allocation with given user requirements on QoS
Outline of the Proposal

1. QoS Mapping: Network QoS ⇔ Application QoS (Chapter 2)

   Our goal: find the mapping function $f(·)$

   1. $(D, F) = f(\lambda, v_a)$  
      Predict the user perceived video quality
   2. $(\lambda, v_a) = f^{-1}(D, F)$  
      Compute the required network QoS resource

2. Optimal Receiver Design (Chapter 3)
   - Optimally manage the receiver playout buffer and determine the playback threshold
Evolution of Media Playback

- Playout Buffer (Dejitter Buffer)
  - Deployed at the receiver to **absorb delay jitters** (delay variance)

  - **Playback is composed of two phases**
    - **Charging phase:** buffer is filled with playback frozen until certain **threshold** \( b \)
    - **Playback phase:** playback starts when \( b \) packets are buffered

- User (Application) QoS
  - **Start-up Delay** \( D \)
  - **Smoothness of media playback**
Model of Playout Buffer

- Our goal: \( (\mathcal{D}, \mathcal{T}) = f(b, \lambda, \nu_a) \)

- Model the playout buffer as a \( G/G/1 \) queue with
  - Mean and variance of interarrival time of pkts \( \frac{1}{\lambda}, \nu_a \)
  - Mean and variance of inter-departure time of pkts \( \frac{1}{\mu}, \nu_s \)
  - Applicable to various networking and video coding schemes

- Diffusion approximation
  - Approximate the movement of queue length \( X(t) \) by the Brown motion process
  - We can get the transient pdf of queue length as a function of the initial buffer size \( x_0 \)
**Infinite Buffer Case: Start-up Delay $\mathcal{D}$**

- First passage time when buffer size $X(t)$ is $b$
  \[ \mathcal{D} = \min\{t | X(0) = 0, X(t) = b, t > 0\} \]

- Model the charging phase using diffusion approximation with $\mu = \nu_s = 0$ and initial buffer size $x_0 = 0$. $\Rightarrow$ pdf of start-up delay
  \[ E(\mathcal{D}) = \frac{b}{\lambda} \quad \text{Var}(\mathcal{D}) = bv_a \]

- Simulation: MPEG-4 VBR video clips with video length $S = 1$ hour

**CDF of the Start-up Delay $\mathcal{D}$**

Application-Oriented Multimedia Streaming over Wireless Multihop Networks
**Infinite Buffer Case: Playback Duration \( T \)**

- **First passage time** when the buffer size \( X(t) \) becomes 0
  
  \[
  T = \min\{t \mid X(0) = b, X(t) = 0, t > 0\}
  \]

- Model the playback phase as a diffusion approximation with initial buffer size \( x_0 = b \) \( \Rightarrow \) pdf of playback duration \( T \)

- Simulation: MPEG-4 VBR video clips with video length \( S = 1 \) hour

**CDF of the Playback Duration \( T \)**
Smoothness of Playback: Likelihood

- Probability of Playback Frozen $\mathcal{P}$ (likelihood)
  - Probability that playback freezes during the media playout
  - Defined as $\mathcal{P} = \Pr(t < S \mid X(0) = b, X(t) = 0)$, where $S$ is the video length, $g_T(t)$ is the pdf of $T$

$$\mathcal{P} \approx \lim_{S \to \infty} \int_0^S g_T(t) dt = \begin{cases} 1, & \text{if } \lambda \leq \mu \\ \exp \left\{ -\frac{2b}{\lambda^3 v_a + \mu^3 v_s} (\lambda - \mu) \right\}, & \text{if } \lambda > \mu \end{cases}$$ (1)

- Increasing $b$ will reduce $\mathcal{P}$ exponentially
- Large variance $v_a$ and $v_s$ also result in large $\mathcal{P}$
Smoothness of Playback: Frequency

- Number of Playback Frozens $\mathcal{F}$ (frequency)
  - $P = 1$ when $\lambda \leq \mu$. How many frozens there are?
  - Consider the renewal process $\mathcal{M} = \mathcal{D} + \mathcal{T}$
  - Using diffusion approximation, the CDF of $\mathcal{F}$ is

\[
P_F(x, t|0) = \Phi \left( \frac{x - \beta_F t}{\sqrt{\alpha_F t}} \right) - \exp \left\{ \frac{2\beta_F x}{\alpha_F} \right\} \Phi \left( -\frac{x + \beta_F t}{\sqrt{\alpha_F t}} \right) \tag{2}\]

CDF of the Number of Playback Frozens $\mathcal{F}$
Denote by

- $N$: Buffer size
- $\mathcal{L}$: packet loss probability (overflow probability)
- $\mathcal{C}$: charging probability (probability playback is frozen, smoothness of playback)

Using diffusion approximation, $\mathcal{L}$ and $\mathcal{C}$ are

$$\mathcal{L} = \left( \frac{-(1-e^{-r})\mu^2 b}{\lambda \beta_T (1-e^{-rb}) e^{r(N-1)}} + \frac{\lambda}{\beta_T} \right)^{-1}$$  \hspace{1cm} (3)

$$\mathcal{C} = \left( -\frac{\mu}{\beta_T} + \frac{\lambda^2}{\beta_T b \mu} \frac{e^{r(N-1)}(1-e^{-rb})}{1-e^{-r}} \right)^{-1}$$  \hspace{1cm} (4)

where $r = \frac{2(\lambda - \mu)}{\lambda^3 v_a + \mu^3 v_s}$
Experimental Evaluation

**Settings**

- $\frac{1}{\lambda} = 35.4\text{ms}$, $v_a = 2.4 \times 10^4$, $\frac{1}{\mu} = 33.6\text{ms}$, $v_s = 102$
- MPEG-4 VBR video clips with video length $S = 1$ hour, $N = 500$ pkts

Packet Loss Probability $L$ with Increasing $b$
More likely to overflow with more packets buffered initially

Charging Probability $C$ with Increasing $b$
Increase because duration of charging phase of each frozen increases
Solution of QoS Mapping

1. \((D, P, F) = f(\lambda, v_a, b)\)
   - Predict the perceived video quality with given network statistics
   - Represented by the achieved density functions

2. \((\lambda, v_a) = f^{-1}(\hat{D}, \hat{P}, \hat{F}, b)\)
   - Input user requirements as
   \[
   \Pr\{D > \hat{D}\} \leq \zeta, \quad P \leq \hat{P}(\lambda > \mu), \quad \Pr\{F > \hat{F}\} \leq \eta(\lambda \leq \mu)
   \]
   where \(\hat{D}, \hat{P}, \hat{F}\) are tolerable start-up delay, probability and number of playback frozen, respectively, input by users. \(\zeta, \eta\): constants input by user. \(0 < \zeta, \eta << 1\)
   - Represented by the feasible region of \(\lambda\) and \(v_a\) such as \((\lambda < \mu)\)

\[
\begin{align*}
\min_{\lambda, v_a} & \quad \frac{1}{\lambda} \\
\text{s.t.,} & \quad b \geq \frac{A}{\hat{F}} + \frac{\sqrt{B\eta(1-\eta)}}{\eta\hat{F}} \quad (P48, (3.6), (3, 7))
\end{align*}
\]
Determine the playback threshold $b$ towards optimal perceived video quality

Chance constrained stochastic optimization problem, mathematically

$$\min_{b} \quad U(D, P, F)$$

s.t.,

$$\Pr \left\{ D > \hat{D} \right\} \leq \zeta$$

$$P \leq \hat{P} \quad \text{(if } \lambda > \mu)$$

$$\Pr \left\{ F > \hat{F} \right\} \leq \eta \quad \text{(if } \lambda \leq \mu)$$

$U(\cdot)$ is the utility or objective function of users

Could be used for VoD (Youtube), P2P (PPStream, PPLive), 3G video streaming
Related Works and Contributions

- QoS mapping to model user's satisfaction [3, 4]
  - Provides the upper bound of jitter free probability (same as $P$) with given channel condition
  - We provide exact solution with closed-form expressions

- Adaptive playout buffer management [5, 6]
  - Optimal buffer control using MDP (Markov Decision Process)
  - Single-hop Raleigh fading channel modeled by FSMC (finite state markov chain)
  - Our approach is general and works for multihop networks

Summary

- Multimedia streaming over wireless multihop networks
  - Multimedia $\Rightarrow$ Multi-dimensional (bandwidth, delay, jitter, pkt loss) and Heterogenous QoS (for different applications)
  - Multihop $\Rightarrow$ End-to-end QoS provision

- Application-oriented streaming
  - Provide application-specific/user desired end-to-end QoS

- Two building blocks: Receiver and Network
  - QoS Mapping to make two blocks talk in the same language

- This work: QoS mapping and Receiver design
  - Application QoS: Start-up delay, smoothness of playback
  - Finite and infinite buffer cases

- Future: End-to-end QoS provision in multihop wireless networks
References


G. Liang and B. Liang, Effect of delay and buffering on jitter-free streaming over random VBR channels, IEEE Trans. on Multimedia.


Q & A

1. Introduction
2. QoS Mapping
3. Infinite Buffer Case
4. Finite Buffer Case
5. Playout Buffer Management
6. Future Works