Improving QoS and Resource Utilization for Multimedia Streaming over 3G

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3G/UMTS Wireless Network

“Hotspots” with good channel conditions

Video Streaming anywhere in the cell

Users of Voice, TCP, ...
Contributions and Agenda

• Overview
• Video Streaming over 3G
• Header Compression
• Congestion Control for Video Flows
• Conclusion and Future Work

How to improve QoS & resource utilization?

How can applications adapt to improve the multimedia quality?

Network
User
Agenda

• Overview
  • Video Streaming over 3G
  • Header Compression

Network

• Congestion Control for Video Flows

User

• Conclusion and Future Work
Overview: 3G/UMTS Network
Overview: 3G/UMTS Problems

- Problems due to the use of IP
  - IP doesn’t support real time streaming requirements
  - Overhead due to packet header

- Problems due to radio conditions
  - Scarce and time varying bandwidth
  - Congestion, wireless losses & large delay
Agenda

• Overview

• **Video Streaming over 3G**
  • Header Compression

• Congestion Control for Video Flows

• Conclusion and Future Work
Video Streaming

- Video Streaming constraints
  - Delay & Jitter
  - Bandwidth
  - Packet loss

Diagram elements:
- Application Server
- Mobile network
- Buffer in the network
- Client buffer
- Playout
- Client
- Application
- File
Video Streaming ...

- Video Streaming
  - Underflow
  - No Playout
  - Packet losses will cause quality distortion
Video Streaming ...

- IP doesn’t support video streaming requirements

- Solution is to provide QoS in UMTS network
  - Different priorities to different flows
  - Service guarantees, ...
UMTS Downlink

- High Speed Downlink Packet Access (HSDPA)
  - Enhanced bit rates: 14.4Mbps
  - Fast and adaptive packet scheduling
- Packet scheduler looks at a term: channel condition, ...
  - Determines which user will be scheduled
  - The chances of a user being scheduled

[Diagram showing the connection between User 1 and User 2 with a Node B and HSDPA Scheduler, with Channel Condition and 2 ms annotations.]
Existing HSDPA Schedulers

- **MAX CI (shown in previous slide)**
  - Looks at instantaneous data rate*: Unfair

- **Proportionally Fair (PF)**
  - Looks at the ratio of: \( \frac{\text{Instantaneous data rate}}{\text{Average throughput}} \)

- **QoS Schedulers**
  - Look at a “QoS function” and the above ratio
    - To satisfy QoS constraints or guarantees

* proportional to channel conditions
Existing HSDPA Schedulers …

- QoS schedulers …
  - QoS function based on the Delta
    - (Throughput guarantee - Average throughput)
  - Guarantee not satisfied:
    - Value of QoS function increases
    - Increases the probability of being scheduled
  - Guarantee satisfied:
    - The probability of being scheduled doesn’t increase
    - To be fair to other users
Existing HSDPA Schedulers …

- How does a QoS function look like?
  - Rate Guarantee (RG) [Hosein 2002]:

\[
B_i(t) = \begin{cases} 
1 + \lambda_i(t) \cdot \beta \cdot \exp(-\beta \cdot (\lambda_i(t) - \lambda_{min}^{(i)})) & \forall i \in QoS, \\
1 & \forall i \in BE,
\end{cases}
\]

\(\alpha\) i.e. a constant in another variant [Lundevall 04]

Best Effort (BE) users without QoS constraints
Existing QoS Schedulers …

- RG and its variant have the following problems:
  - Increase in Best Effort (BE) users deteriorate the QoS
  - Bias towards certain Rate Guarantees
Normalized Rate Guarantee (NRG) Scheduler

- Based on the theory in [Hosein 2002] we propose:

\[
B_i(t) = \begin{cases} 
\lambda_{\text{min}}^{(i)} + \lambda_i(t) \beta \cdot \exp \left( -\beta \cdot \frac{(\lambda_i(t) - \lambda_{\text{min}}^{(i)})}{\lambda_{\text{min}}^{(i)}} \right) & \forall i \in \text{QoS}, \\
\frac{k_{\text{BE}}}{n_{\text{BE}}} & \forall i \in \text{BE}.
\end{cases}
\]
Simulation Platform

- UMTS/HSDPA Simulation Platform
  - EURANE (NS-2 Extension)
  - Detailed implementation
  - SNR traces to simulate physical layer
Simulation Platform …

H.264 video flows

• UM mode
• Per user queues
• DiffServ AQM

Pedestrian A, 3km/h

HSDPA Packet Schedulers
• Max. cell capacity: 3.6Mbps

Cell radius: 500m
How to evaluate video quality?

- **Objective evaluation**
  - PSNR (peak signal to noise ratio)
  - Pixel by pixel comparison

- **Subjective evaluation**
  - Evaluation done by real humans
How to evaluate video quality? …

- The importance of subjective quality evaluation:

Scores:

- 5/5 Excellent
- 1/5 Very annoying
- 3/5 Fair
Pseudo-Subjective Quality Assessment (PSQA) [Rubino et al. 2002]
Results

- 4 video users (384kbps, H.264)
- $Q_{\text{min}}$: Minimum PSQA score after removing lower 5%
- NRG performs better for higher loads
Results …

- Mix of TCP and WWW traffic
- NRG performs better for higher loads
Results …

- Loss Rates for different Rate Guarantees
- For fair comparison
  - Normalized Best Effort term of RG and RG Lundevall variant
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Header Compression for Audio Flows

Robust Header Compression (ROHC)

- Audio Data
- IP/UDP/RTP
- Significant Overhead
- Removes redundant information like IP src, dst...
- Compressed Header
- 2 – 5 bytes

Audio Data

100 bytes

40 – 120 bytes
ROHC Study: Results

○ Tradeoff:
  ● Compression efficiency ↔ Robustness

○ Propose dynamic negotiation
  ● Update parameters: error rate, ...
  ● Efficient when low error ↔ Robust when high error

○ Result: Overall performance improved
  ● Lower loss rate
  ● Better compression efficiency
ROHC Study: Results …

- UDP checksum: Corrupted payload dropped
- Corrupted data may be useful!
- Studied (UDP-Lite + ROHC) vs. (UDP + ROHC)
  - ROHC performance doesn't change
  - Proposed CRC strategies

![Graph showing loss (%) vs. BER for UDP and CRC strategies]
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Congestion Control for Video Flows

- Motivation

- Variable bandwidth, delay ...
- Congestion, packet losses

How can applications adapt to the network conditions?
Existing Schemes

- Congestion control for video
  - TCP: Retransmissions, rate oscillations, ...
  - TFRC [Floyd 2000]
    - Sending Rate is calculated by a TCP model
    - Better Rate Stability
    - TCP Friendly
Simulation Study

- Problem: Rate stability
- Radio conditions → TFRC rate variance similar to TCP
- Improvement with Rate Guarantee (RG) scheduler

Received power for a UE 300m from the BS.\textsuperscript{32}
More Problems: Wireless Losses

- Problem: Two types of losses in wireless Networks
  - Packet drops due to congestion
  - Packet drops due to bad channel conditions
More Problems …

- Inefficiency for TCP, TFRC …
  - Cannot distinguish between these losses.
  - Reduce their sending rate on loss.

- How to distinguish Wireless losses from congestion losses?

- Previous Work have used Round Trip Time variations
  - Not reliable
Wireless Loss Estimation (Background: DiffServ)

- Differential dropping in the DiffServ (Green, Yellow & Red)

  Increasing Congestion

<table>
<thead>
<tr>
<th>Drop Red packets</th>
<th>Drop Red + Yellow packets</th>
<th>Rarely drop Green packets</th>
</tr>
</thead>
</table>

- Video applications mark their packets
Wireless Loss Estimation

- Wireless Loss Estimation in DiffServ (WLED) Networks:
  - Red packets are dropped first on congestion
  - Wireless loss rate ($w$) is correlated with green loss rate
    - If loss of yellow packets is not significant
WLED: Results

- WLED:
  Improves link utilization

- There is no change in other properties:
  - TCP friendliness, loss rate, rate stability
- But, works only with DiffServ aware applications
Congestion Control and Adaptive Retransmissions

- We improved link utilization in case of wireless losses.

- But, lost data still deteriorates the quality!

- Solution: We integrate a scheme to retransmit the lost data.
Congestion Control and Adaptive Retransmissions ...

- **Retransmission Scheme**
  - If packet has the possibility to arrive before its deadline
    - No congestion
      - Enables retransmission schemes
    - Congestion
      - Disable retransmission

- Depending on BW → retransmit either
  - I frames
  - I + P frames or
  - All frames

- WLED scheme integrated
Congestion Control and Adaptive Retransmissions: Results

- 10 WWW users in background

![Graph showing PSNR (dB) vs. Wireless Loss Probability](attachment:image.png)
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Conclusion

- Studied QoS scheduling for video streaming over 3G
  - Subjective quality evaluation

- Proposed a new QoS scheduler
  - Better quality even with high background load
  - Not biased

- Improved header compression performance
  - Updating channel states
  - Lower loss rate with variable UDP-Lite checksum coverage
Conclusion …

- Studied congestion control for video flows
  - TFRC rate stability not better than TCP as reported in previous works

- Proposed a wireless loss estimation scheme
  - Improved the link utilization

- Proposed a retransmission scheme
  - Improved video quality by recovering lost data
Results published in following Papers


Results published in following Papers


Submitted


Future Work

- Call admission control and management for HSDPA
  - Real time PSQA feedback
  - Dynamic rate guarantee negotiation
- Improve the rate stability of TFRC over HSDPA
- Look at the performance of WLED + retransmission in real network
- Congestion control for MPEG4-scalable video codec (SVC)
Thank You !
Appendix
High Speed Downlink Packet Access (HSDPA)

Max CI scheduler chooses a user $i^*$ such that:

$$i^* = \arg \max_i \{ R_i(t) \}$$

*Note that instantaneous data rate is related to the received power.*
Existing HSDPA schedulers

- Proportionally Fair:
  \[ i^* = \arg \max_i \left\{ \frac{R_i(t)}{\lambda_i(t)} \right\} \]
  Average Throughput

- QoS schedulers:
  \[ i^* = \arg \max_i \left\{ B_i(t) \frac{R_i(t)}{\lambda_i(t)} \right\} \]
  Barrier Function
Existing QoS schedulers

- [Hosein 2002] QoS schedulers can be designed based on $U(\lambda)$
  $$i^* = \arg \max_i \{ R_i(t) \cdot U_i'(\lambda_i(t)) \}.$$  
- Rate Guarantee (RG) [Hosein 2002] uses:
  $$U(\lambda) = \log(\lambda) + 1 - \exp \left( -\beta \cdot (\lambda - \lambda_{\text{min}}) \right)$$

Guaranteed Rate
Existing QoS schedulers ...

- RG uses the barrier function:

\[
B_i(t) = \begin{cases} 
1 + \lambda_i(t) \cdot \beta \cdot \exp \left( -\beta \cdot (\lambda_i(t) - \lambda_{\min}^{(i)}) \right) & \forall i \in QoS, \\
1 & \forall i \in BE,
\end{cases}
\]

\(\alpha\) i.e. a constant in another variant [Lundevall 04]
We propose NRG with the following user utility:

\[ U_{QoS}(\lambda) = \lambda_{min} \cdot \left( \log(\lambda) + 1 - \exp \left( -\beta \cdot \frac{\lambda - \lambda_{min}}{\lambda_{min}} \right) \right), \]

\[ U_{BE}(\lambda) = \frac{k_{BE}}{n_{BE}} \log(\lambda). \]
Results

- 4 video users (384kbps, H.264) & 10 TCP long flows
  - Some users may not get good quality
  - Better to drop those users instead of wasting BW
Congestion control and Adaptive Retransmissions: Results …

- Wireless loss probability 0.1 and varying WWW users