MuVi: A Multicast Video Delivery Scheme for 4G Cellular Networks

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Motivation

• Video streaming can be one of the dominant applications in 4G and future wireless networks
  – Mobile TV services, live entertainments, live broadcast of sports
  – High quality broadcast of educational content in campus
  – Video teleconferencing
Mobile Video

**Future**

- WiFi: 78% CAGR 2011-2016

**Present**

- WiFi:
  - Not always connected
- 3G Cellular:
  - Limited bandwidth

Cisco Visual Networking Index:
Outline

• Motivation
• WiMAX background
• MuVi
  – Packet value awareness
  – Client’s feedback
  – Utility maximization
  – MCS selection
• Evaluation
• Conclusion
WiMAX background

• Frame structure

![Diagram showing WiMAX frame structure with time and frequency axes. The diagram includes DL Burst1, DL Burst2, MBS Zone, UL Burst1, and UL Burst2.]
# Modulation and Coding Scheme

<table>
<thead>
<tr>
<th>Index</th>
<th>MCS</th>
<th>Data bits per slot</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>BPSK</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>QPSK ¾</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>16 QAM ½</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>16 QAM ¾</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>64 QAM ½</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>64 QAM ⅔</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>64 QAM ¾</td>
<td>4.5</td>
</tr>
<tr>
<td>7</td>
<td>64 QAM ⅗</td>
<td>5</td>
</tr>
</tbody>
</table>
MPEG-4 Encoded Video

- Video sequence consists of different frame types

GOP (Group Of Picture)

1 sec

P and B-frames depend on I and P-frames when decoding
WiMAX Transmission Example
MCS Selection Example

<table>
<thead>
<tr>
<th>Client</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCS</td>
<td>2</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>

Client 1

Client 2

Client 3

Pkt/MCS WiMAX Frame

1: 1
P: 1
B: 1

1: 7
P: 7
B: 7

1: 2
P: 4
B: 7

I: 1
P: 1
B: 1

I: 7
P: 7
B: 7

I: 2
P: 4
B: 7

I: 7
P: 7
B: 7

I: 2
P: 4
B: 7

I: 7
P: 7
B: 7

I: 7
P: 7
B: 7
MCS Selection Example

Guarantee the delivery of important packet
Maximize the resource utilization

1. How to schedule video packets given resource constraints?
2. What MCS will be used for each packet?
MuVi

• **Multicast Video delivery scheme**
  1. Prioritizes video packet value
  2. Incorporates the clients channel condition
  3. Optimizes resource allocation
  4. Adapts the MCS for each video packet
1. Packet Values

• Not all video packets are created equal

MPEG-4 encoded video

The packet value: Dependence of other packet

1. I Packet > P Packet > B Packet
1. Packet Values

• Not all video packets are created equal

The packet value: Depends on the position

2. P1 Packet > P2 Packet
2. Client Feedback

- Channel State Information (CSI):
  Every 5 msec via dedicated uplink channel

Diagram:
- BS (Base Station)
- C1, C2, C3 (Clients)
- SNR (Signal to Noise Ratio) arrows from BS to C1, C2, C3

Jongwon Yoon / MuVi / MobiCom 2012
SNR-MCS Relations

- Incorporating clients feedback

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Incorporating clients feedback
SNR-MCS Table

- Incorporating clients feedback

<table>
<thead>
<tr>
<th>MCS</th>
<th>SNR range (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>(28, ∞)</td>
</tr>
<tr>
<td>6</td>
<td>(26, 28]</td>
</tr>
<tr>
<td>5</td>
<td>(24, 26]</td>
</tr>
<tr>
<td>3, 4</td>
<td>(20, 24]</td>
</tr>
<tr>
<td>2</td>
<td>(15, 20]</td>
</tr>
<tr>
<td>1</td>
<td>(-∞, 15]</td>
</tr>
</tbody>
</table>
Problem Formulation

Video packet size > T slots x bits/MCS

T slots with robust MCS are not enough!

-> Higher MCS, Packet scheduling based on priority

SNR: $\gamma_1$

SNR: $\gamma_2$

SNR: $\gamma_K$

MCS: $1 \leq m \leq M$

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Problem Formulation

Utility: \( u^k_j \) \( k \) receiving frame \( j \) at client \( k \) given that all frames it depends on are received.

Goal: Maximize the total utility received by all clients subject to the total slot constraint.

MCS: \( 1 \leq m \leq M \)
I/P-frame Scheduling

Goal: Maximize the utility for P-frames subject to the slot constraint \( t \)

\[
\max \sum_{j=0}^{G} \sum_{k=1}^{K} z_j^k u_j^k s.t \sum_{m} \left[ \sum_{j} \frac{x_j^m L_j}{R_m} \right] \leq t
\]
I/P-frame Scheduling

• Define optimal utility: \( U_P(j,m,t) \) with the P-frame \( P_l, l = 0, 1, \ldots, j \) with MCS up to \( m \) and at most \( t \) slots

\[
U_P(j,m,t) = \max_{0 \leq i \leq j} \left[ U_P(i,m-1,t-\tau_{i+1,j,m}) + \sum_{l=i+1}^{j} \sum_{k \in S_m} u_l^k \right]
\]

\[
U_P(i,m-1,t-\tau_{i+1,j,m}) + \sum_{l=i+1}^{j} \sum_{k \in S_m} u_l^k
\]
B-frame Scheduling

Goal:
Selects a subset of B-frames and MCS $m$ with resource constraint $T - t$
B-frame Scheduling

• Algorithm:

\[
\text{for all } m^*(t) \leq m \leq M \\
\text{find the max. } b_j \\
\rightarrow U_B(m, T - t) = \sum_{b=1}^{b_j} \sum_{k \in S_m} u_b^k
\]

MCS \( m \), T-t slots

Same priority
Joint I/B/P-frame Scheduling

• Optimal total utility

\[ U^* = \max_t U_P^*(t) + U_B^*(T - t) \]

- Utility of I/P-frames
- Utility of B-frames
Implementation

• MuVi is implemented on PicoChip WiMAX testbed
• Operating on 2.6GHz, 10MHz channel width
• Gateway solution (Click-module)
MuVi

1. Have SNR feedback from clients
2. Packet value aware
3. Utility maximization
4. MCS selection
PSNR

- MuVi provides differentiated service
- MuVi improves avg. PSNR by 13, 7dB
Client Mobility

SNR (dB)

PSNR per frame (dB)

0  100  200  300  400  500  600 (frame number)

MuVi

Adaptive
Demo

Naïve scheme  MuVi
## Related Work

<table>
<thead>
<tr>
<th>Medusa*</th>
<th>MuVi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet value awareness</td>
<td></td>
</tr>
<tr>
<td>Asynchronous, WiFi (media is shared)</td>
<td>Synchronous OFDMA system</td>
</tr>
<tr>
<td>No radio resource allocation, Heuristic based rate adaptation</td>
<td>Optimal resource allocation algorithm and PHY rate selection</td>
</tr>
<tr>
<td>Client’s reception reports, Retransmission</td>
<td>No reception reports, No retransmission</td>
</tr>
<tr>
<td>Client modification</td>
<td>No client modification</td>
</tr>
</tbody>
</table>

* Scalable WiFi Media Delivery through Adaptive Broadcasts, NSDI 2010

Jongwon Yoon / MuVi / MobiCom 2012
Conclusion

• **Optimal resource allocation** and **MCS selection** can improve the overall quality of video across multiple clients.

• **Gateway solution**, minimum change (sending feedback to GW) in WiMAX BS.

• Implementation is compatible with off-the-shelf clients (no client modification).

• Applicable to other OFDMA-based systems, LTE and LTE-Advanced.
Thank You!

• Questions?