QoS Challenges for Wireless Broadband: WLAN, Wireless Ad Hoc and WiMAX

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Talk Outline

- QoS Challenges for Wireless Video Networking
- Airtime Fairness Design for WLAN Infrastructure Camera Networks
- Information Broadcasting for Distributed WLAN Ad-Hoc Camera Networks
- Joint Scheduling and Resource Allocation for Video Multicast over WiMAX
- Conclusion
End-to-End QoS Video Networking over Wireless

Best-effort packet network
- limited bit-rate
- variable throughput
- variable loss
- variable delay

Wireless error sources
- radio noise and interference
- attenuation
- dispersion
- multi-path interference

Video Server

Internet

Receiving & Transmitting End Clients

last/first mile
Video Coding Evolution

video – most bandwidth consuming media

Microsoft Windows Media Player, Apple Quicktime, and RealSystems Real Player
Adapting to Wireless Heterogeneous Networks

- **Microsoft**: fast streaming technology
- **RealSystems**: G2 SureStream technology
- **Adaptive Encoding Rate**
- **Rate Transcoding**
- **Scalable Video Coding**
  - H.264 based (MPEG4 AVC scalable extension, HHI 2007)
  - Temporal, Spatial, and SNR scalability
H.264 Scalable Video

How Many Layers Are Enough?

- B0(QCIF@7.5) 67.66 Kbps
- B0+E1(QCIF@15.0) 101.77 Kbps
- B0+E1+E2(CIF@15.0) 187.19 Kbps
- B0+E1+E2+E3(CIF@15.0) 346.92 Kbps
- B0+E1+E2+E3+E4(CIF@30.0) 522.77 Kbps
Moving Toward All-IP Wireless Broadband

Cellular

1G  2G  3G

Wireless MAN (WiMAX)

802.16d  802.16e

Wireless LAN (Wi-Fi)

802.11a/b/g  802.11n

Wireline

V.90  ADSL  FTTH

4G Wireless Broadband (WiMAX & LTE)

- OFDM/OFDMA
- MIMO Antenna
- New Spectrum
- Flexible All-IP Core

[Alamouti, 2007]
Perfect Synergy of WLAN/ Wi-Fi and WiMAX

Are they ready for Multimedia Networking?
Ad-Hoc & Infrastructure Modes of 802.11 WLAN

(a) Ad-Hoc Mode
(independent basic service set, IBSS)

(b) Infrastructure Mode
(basic service set, BSS)
CSMA/CA MAC Access

A backoff scheme (combined with interframe spacing, IFS) for multiple access contention.

\[ \text{backoff} = \text{rand}[0; CW - 1] \times \text{slot time} = \text{rand}[0; CW_{\text{min}} \times 2^n - 1] \times \text{slot time} \]
Link/ Rate Adaptation in Multirate 802.11 WLAN

- IEEE 802.11 support multiple transmission rates, depending on the underlying channel condition, e.g., 802.11b: 11, 5.5, 2, 1 Mbps
- Techniques for link/rate adaptation:
  - AutoRate Fallback (ARF): consecutive failure/success
  - Receiver-based AutoRate (RBAR): RTS/CTS carrying
  - MiSer: a table-look-up for optimal rate-power combination
  - Goodput Rate Selection: ratio of the expected delivered data payload to the expected transmission time
Service Differentiation in 802.11 WLAN

- Varying DIFS and Backoff Time

  high\_priority: \( \text{backoff\_time} = \frac{1}{2} \text{rand}[0; CW_{\text{min}} \times 2^n] \times \text{slot\_time} \)

  low\_priority: \( \text{backoff\_time} = \frac{1}{2} CW \times 2^n \times \text{slot\_time} + \frac{1}{2} \text{rand}[0; CW_{\text{min}} \times 2^n] \times \text{slot\_time} \)

- Limiting Maximum Frame Length: fragmentation

- Varying Initial Contention Window Size: \( CW_{\text{min}} \)

- **802.11e**: Enhanced Distributed Coordination Access

<table>
<thead>
<tr>
<th>Access Categories</th>
<th>AC_VO</th>
<th>AC_VI</th>
<th>AC_BE</th>
<th>AC_BK</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIFS number</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>( CW_{\text{min}} )</td>
<td>7</td>
<td>15</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>( CW_{\text{max}} )</td>
<td>15</td>
<td>31</td>
<td>1023</td>
<td>1023</td>
</tr>
</tbody>
</table>
Centralized Scheduler & Resource Allocator of WiMAX

QoS Queues: each connection has a queue, packets of the same connection will be put into the same queue.

Packet/Connection Scheduler: decide which packet/connection and how many packets of this connection to be transmitted.

Radio Resource Allocator: decide which subchannel frequencies and modulation & coding (MCS) for those scheduled packets.
A WiMAX TDD Frame

- Partial Usage SubChannels (PUSC) for users with high velocity (low SNR)
- Band Adaptive Modulation & Coding (AMC) Subchannels for users with low velocity (high SNR)

Subscribers’ Scheduling and radio Resource Allocation mechanisms are not specified in WiMAX standard
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Serving Multiple Video Streams in A WLAN

- In wireless **home entertainment**
- In video **surveillance**
- In **search and rescue** (military usage)
The throughput of all hosts transmitting at the higher rate is degraded [Heusse03]

10x11M → 1x2M + 9x11M
Call for a “distributed” control algorithm for airtime fairness that combines slow APP layer and fast MAC/PHY layer control loops.
The Distributed Cross Layer Congestion Control (CLC)

- PLR > 5% ➔ Go lower rate
- PLR < 3% for 3 sec ➔ Go higher rate
  And within Max Throughput

Fair share of airtime \( x (1 - \text{FER}) \)

\[
G^i_e \approx \frac{1}{N} \cdot G^i_{\text{MAX}} \cdot (1 - p^j)
\]

Higher data rate ➔ Smaller contention window

\[
r^i \cdot CW^i_{\text{min}} = r^j \cdot CW^j_{\text{min}} = \text{const. \ } \forall i, j
\]
Experimental Evaluation

- Family of algorithms of increasing complexity
  - Simulation (ns2)
  - Real implementation
    - Axis 207w 802.11b/g cameras
    - Siemens AP2630 802.11b/g
  - Throughput, packet loss, PSNR in various dynamic scenarios with 4-10 cameras/sources
    - MPEG-4 video (100-800 Kbps)
  - Packet sniffing and statistics from custom Airopeek extension
ns2 Simulation
Performance

Three Rates in 6 STAs:
(11 11 5.5 5.5 2 2)
Video: 100-800 Kbps

(a) 11 Mbps STA Throughput
(b) 2 Mbps STA Throughput
(c) 11 Mbps STA PLR
(d) 2 Mbps STA PLR
Real Implementation: Test 7 Cameras

CLC Off

Corresponds to different link conditions

CLC On

Goodput proportional to link condition of each camera

FAIRNESS

One bad link brings down goodput of all cameras

QUALITY

~ 0% Packet Loss Rate

PLR unacceptable for video streaming

Real Implementation:
Test 7 Cameras
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Distributed Wireless Ad Hoc Camera Networks

- More than 600,000 video camera deployed in London
- One human operator: 6-10 camera, 1-2 hours vigilance span
- Apply *intelligence* (a predefined set of rules) strategically to an array of networked video cameras, for security surveillance and health care monitoring
Tracking Across Distributed Camera Networks (DCNs)

Overlapping Field of View

Non-Overlapping Field of View
One-Hop or Multi-Hop Broadcasting

Broadcast Storm Problem
Application to Vehicular Ad-Hoc Networks (VANETs)

Vehicle-to-Infrastructure Communication

Vehicle-to-Vehicle Communication

emergency or location aware video
Modeling Backoff Mechanism using 802.11

- When broadcasting, no RTS/CTS, no ACK, no retransmission, no exponential backoff, and a fixed contention window, \( W = CW \).

\[
p\{b(t) = k\} = p\{b(t-1) = k+1\} + \frac{p\{b(t-1) = 0\}}{W}, \quad k < W - 1
\]

\[
p\{b(t) = W - 1\} = \frac{1}{W} p\{b(t-1) = 0\}, \quad k = W - 1
\]

\[
\lim_{t \to \infty} p\{b(t) = k\} = p_k = \frac{2(W - k)}{W(W + 1)}, \quad p_0 = \frac{2}{W + 1} \text{ (transmission prob)}
\]
Modeling the Dynamics of Multiple Nodes

In case of “\(n\)” competing nodes and “\(n_t\)” transmitting nodes (assume they are independent)

- **no transmission**: \(p_x(n) = p\{n_t = 0\} = (1 - p_0)^n\)
- **at least one transmission**: \(p_t(n) = p\{n_t \geq 1\} = 1 - (1 - p_0)^n\)
- **exactly one transmission**: \(p_s(n) = p\{n_t = 1\} = np_0(1 - p_0)^{n-1}\)
- **node collision**: \(p_c(n) = p\{n_t \geq 2\} = 1 - p_s(n) - p_x(n)\)
Metrics for Performance Evaluation

- **Packet Delivery Ratio (PDR)**

\[
PDR = \frac{\text{Average Number of Packets Successfully Delivered}}{\text{Average Number of Packets Delivered}} = \frac{p\{n_t = 1\}}{\sum_{i=1}^{n} i \cdot p\{n_t = i\}}
\]

\[
= \frac{\binom{n}{1} \cdot p_0 \cdot (1 - p_0)^{n-1}}{n \cdot p_0} = \frac{n \cdot p_0 \cdot (1 - p_0)^{n-1}}{n \cdot p_0} = (1 - p_0)^{n-1}
\]

- **Normalized Throughput S’ (assume \(T_s = T_c = T_\sigma \cdot \sigma\))**

\[
S' = \frac{L_{avg}}{C \cdot T_{avg}} = \frac{1}{C} S, \quad (S = \text{throughput}, \ C = \text{channel capacity})
\]

where \(T_{avg} = p\{n_t = 0\} \cdot \sigma + p\{n_t = 1\} \cdot T_s + p\{n_t > 1\} \cdot T_c\)

and \(L_{avg} = p\{n_t = 1\} \cdot L_{\text{payload \_bytes}} \cdot 8\)
Throughput Maximization

- Optimal contention window size, $W^*$ [Bianchi, 2003]

Let $\frac{dS'}{dp_0} = 0 \Rightarrow (1 - p_0)^n - T_\sigma \{np_0 - [1 - (1 - p_0)]\} = 0$

Assume $W \gg n > 1$, then $(1 - p_0)^n \approx 1 - np_0 + \frac{n(n-1)}{2} p_0^2$

$p^*_0 \approx \frac{1}{n} \sqrt{\frac{2}{T_\sigma}} \Rightarrow W^* \approx n\sqrt{2T_\sigma}$ ← (average packet duration in slots)

- Based on IEEE STD 802.11-2007, content window size $W$ is hardwired in PHY layer, even though specified in 802.11e MAC and many wireless QoS solutions.

- Reliably estimating the number of competing nodes, $n$, is another challenging issue.
Adjust Transmission Prob. With Fixed Contention Window?

- If channel idle probability is high, then deliver more.
  - $\text{Pidle} \uparrow \Rightarrow P_0(n) \uparrow$
  - $P_0(n)$: transmission probability of individual node
- If channel idle probability is low, then deliver less.
  - $\text{Pidle} \downarrow \Rightarrow P_0(n) \downarrow$
- iPro (Idle Probability based broadcasting)
  - $P_0(n) = \text{Pidle} \times p_0$

$$\tilde{P}_{idle}(t) = \left(1 - \frac{\Delta t}{T_0}\right) \cdot \tilde{P}_{idle}(t - \Delta t) + \frac{\Delta t}{T_0} \cdot b, \quad \text{where} \quad b = \begin{cases} 0, & \text{if channel busy.} \\ 1, & \text{if channel idle.} \end{cases}$$
**iPro Scheme**

Periodically update channel idle probability $\tilde{P}_{idle}$

On Backoff timer expires:

- Generate a random number $p_r$ over $[0,1]$
- if $p_r < \tilde{P}_{idle}$ transmit the packet
- else entering re-backoff
Single Hop Simulations

- Network topology: 50x50 m²
- Transmission Range: 100 m
- Carrier Sense Range: 250 m
- Data rate: 1Mbps (802.11b), capture effect is disabled.
Multi-Hop Simulations

- Network topology: 500x500 m²
- Transmission Range: 100 m
- Carrier Sense Range: 250 m
- Data rate: 1Mbps (802.11b), (hidden node problems).

![Graphs showing Total Packets Sent and Received in 5 seconds](image-url)
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An End-to-End Scalable IPTV WiMAX Multicasting

CQI: channel quality indicator
MCS: modulation and coding scheme
CID: connection id
MBS: multicast and broadcast service

Video Layer ➔ Multicast group ➔ WiMAX Connection
MBS Zone with Multi-BSs
Mapping SVC Layers in an MBS Zone

- **$VB^1$**
- **$VB^4$**
- **$VE_1^1$**
- **$VE_2^2$**
- **$VB^2$**
- **$VB^5$**
- **$VE_1^2$**
- **$VE_1^3$**
- **$VE_2^4$**
- **$VB^3$**
- **$VE_1^4$**
- **$VE_1^5$**
- **$VE_2^5$**

$VB^v$: base layer of video $v$

$VE_{1,v}$: enhancement layer of video $v$, layer $i$
# MCS Selections in WiMAX

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Coding Rate</th>
<th>Required Receiver SNR (dB)</th>
<th>Normalized OFDMA Slot Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>1/2</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>8</td>
<td>1.5</td>
</tr>
<tr>
<td>16-QAM</td>
<td>1/2</td>
<td>10.5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>64-QAM</td>
<td>1/2</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2/3</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
<td>20</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Opportunistic Multicasting Scheduling

- For a given set of subscribers
  - Schedule a subset of subscribers in every transmission opportunity
  - Channel quality (CQI) as criteria
  - Adaptive (MCS) as tools
- Take advantage of
  - Temporal channel quality fluctuation
  - User diversity
- Result in
  - Higher throughput (lower resource consumption)
  - Higher total system utility
max min (effective, bottleneck) frame receiving \( \bar{Q}_i^k, \forall i \in U \)

\[
\bar{Q}_i^k = \begin{cases} 
(1 - \frac{1}{t_c}) \times \bar{Q}_i^{k-1} + \frac{1}{t_c} \times I(m^{k-1}, q_i^{k-1}), & k > 1 \\
1, & k = 1.
\end{cases}
\]

Adapting MCS subject to minimize slot consumptions

\[
K^b = \begin{cases} 
N \times \min_{i \in U} \left\{ \bar{Q}_i^{(b-1)N} \right\} \times fm, & b > 1; \\
\left\lfloor \frac{N}{2} \right\rfloor, & b = 1.
\end{cases}
\]

\[
r^b = \frac{K^b}{N}, \quad S^k = \left[ \frac{R}{c(m^k)} \right], \quad m^k \in M
\]

\[
m^k = \arg \max_{m \in M} \left\{ c(m) \times I(m, q_i^k) : i = \arg \min_{i \in U} \left\{ \bar{Q}_i^k \right\} \right\}.
\]
Enhancement Layers
Subset Selections

- Maximize total system utility functions
  - Corresponding to (QoE) quality gain of each layer
  - Imply to maximize utility gain per unit of resource
- Jointly consider scheduling and resource allocation

Subject to
- System-wide gain
- Available resource
- Layer dependency

$$\begin{align*}
\max & \sum_v \sum_l u_{v,l} \cdot |N_{v,l}| \\
\text{subject to} & \sum_v \sum_l S_{v,l}(N_v) \leq B
\end{align*}$$

$$G_{v,l}(i) = \overline{Q}_{i,v,l} \cdot \left\{ j : \overline{Q}_{j,v,l} \geq \overline{Q}_{i,v,l}, j \in N_v \right\}$$

$$G_{v,l} = u_{v,l} \cdot \min \left\{ \overline{Q}_{v,l} \right\} \cdot |N_{v,l}(m_{v,l}^k)|$$

- Have to iterate resource allocation and scheduling
Simulation Setup

- IEEE 802.16e OFDMA PUSC mode
- COST 231 propagation loss model
- ITU Vehicular A power delay profile
- Mobile stations are uniformly distributed in the cell
Application Setup

- Pre-allocate 1/4 of total channel for multicast
- 3 videos with subscribers \{100, 80, 40\}
- 4 layers each with utility \{0.5, 0.25, 0.15, 0.1\}
- 250 Kbps each layer
- 200 frame FEC block size (about 1 sec)

Schemes to compare:

1) Proposed (adaptive $r$);
2) fixed FEC at $r=0.9$;
3) fixed FEC at $r=0.5$;
4) non-opportunistic scheme (NOMS)
Overall Performance

- Based layers can be received as long as enough FEC protection.
Conclusion

- Future internet = content + service + management (interactive, ubiquitous, personalized, secure, aware)
- Video networking and IPTV are killer applications for the next generation wireless broadband
- Current wireless broadband standards are not ready for large scale practical video dissemination
- Three QoS top-down design examples (MediaNets)
  - Understand better the application & data
  - Decide which layers (time and spatial granularity) can be improved
  - Cross layers can be even more effective