How can we enable ubiquitous mobile video services?

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The Trend

• Mobile traffic is growing, mostly video
• Continuum of screen sizes exist
• Not just linear TV: social, interactive TV
• BUT, Wireless capacity still limited

Video Will be 66% of Global Mobile Data Traffic by 2014

Laptops and Smartphones Driving Growth

*Source: Cisco Visual Networking Index
Multiple Video Content Delivery Methods

### Multiple Content Sources
- **Home** (Slingbox)
- **Internet** (Hulu, Joost, Netflix, Blockbuster)
- **Broadcast Networks**
- **IPTV, cable, telecom carrier**

### Multiple Networks
- **WiFi Hotspot**
- **Broadband wireless** (3G, LTE, WiMax)
- **Broadcast** (Terrestrial, Sat.)

### Multiple Devices
- **Car**

### Mobile content delivery methods:
- Streaming: unicast, broadcast
- Download: kiosk, STB, over-the-air

### New usage models
- Video conferencing, video share
- Video twitter, video blogging
- Live video broadcasting, video upload

### Key criteria:
- Quality
- Latency
- Throughput
- Capacity
- Scalability
- Cost
The Challenge

Compression efficiency has improved \(~2-3x\) every 10 years

Spectral Efficiency has improved by \(~2x\) every 5 years

Video characteristics not yet exploited in wireless networks

## Capacity Analysis

<table>
<thead>
<tr>
<th></th>
<th>WiMAX</th>
<th>3GPP LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplexing mode</td>
<td>TDD, DL:UL=1:1</td>
<td>FDD</td>
</tr>
<tr>
<td>OFDMA symbol bandwidths</td>
<td>20 MHz (TDD), 80 MHz (TDD)</td>
<td>2x10 MHz (FDD), 2x40 MHz (FDD)</td>
</tr>
<tr>
<td>Subcarrier spacing</td>
<td>10.9375 kHz</td>
<td>15 kHz (unicast), 7.5 kHz (MBSFN)</td>
</tr>
<tr>
<td>OFDMA usable data subcarriers per 10 MHz bandwidth</td>
<td>768 (DL/UL 802.16m) 720 (DL 802.16e) 560 (UL 802.16e)</td>
<td>600 (unicast) 1200 (MBSFN)</td>
</tr>
<tr>
<td>OFDMA useful symbol duration</td>
<td>91.43 usec</td>
<td>66.7 usec (unicast) 133.3 usec (MBSFN)</td>
</tr>
<tr>
<td>Cyclic prefix (CP) length</td>
<td>1/16 of a symbol</td>
<td>4.6 usec (unicast) 33.3 usec (MBSFN)</td>
</tr>
<tr>
<td>OFDMA symbol duration w/ CP</td>
<td>97.1 usec</td>
<td>71.6 usec (unicast) 166.7 usec (MBSFN)</td>
</tr>
<tr>
<td>Frame duration</td>
<td>5 msec</td>
<td>10 msec (Sub-frame duration is 1 msec.)</td>
</tr>
<tr>
<td>Number of OFDMA symbols in frame</td>
<td>51</td>
<td>14 per sub-frame (unicast) 6 per sub-frame (MBSFN)</td>
</tr>
<tr>
<td>Number of usable OFDMA symbols in a sub-frame for data</td>
<td>50 (if DL:UL=1:1, 25 DL, 25 UL symbols)</td>
<td>12 (unicast) 6 (MBSFN)</td>
</tr>
<tr>
<td>MBS/MBMS control overhead</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>DL unicast control overhead</td>
<td>11.2% (802.16m) 24.1% (802.16e)</td>
<td>17%</td>
</tr>
<tr>
<td>UL unicast control overhead</td>
<td>9.23% (802.16m) 16.7% (802.16e)</td>
<td>9%</td>
</tr>
</tbody>
</table>
## The Limits - Unicast

<table>
<thead>
<tr>
<th>Technology</th>
<th>Unicast Video Users/Sector for R = 384 kbps</th>
<th>Unicast Video Users/Sector for R = 768 kbps</th>
<th>Unicast Video Users/Sector for R = 1.536 Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>3GPP Rel. 10 (LTE Adv.) 4x2 MU-MIMO 2x10 MHz FDD</td>
<td>10</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>WiMAX Rel. 2.0 (802.16m) 4x2 MU-MIMO 20 MHz TDD 1:1</td>
<td>11</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>3GPP Rel. 10 (LTE Adv.) 4x2 MU-MIMO 2x40 MHz FDD</td>
<td>42</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>WiMAX Rel. 2.0 (802.16m) 4x2 MU-MIMO 80 MHz TDD 1:1</td>
<td>44</td>
<td>22</td>
<td>11</td>
</tr>
</tbody>
</table>
Potential research vectors

**PHY/MAC SP**
- MU-MIMO
- Interference Alignment
- Advanced FEC
- Advanced receivers

**Signal Processing**
- [leverage Moore’s Law]

**Het. Networks**
- [more spectrum]

**Net. Arch.**
- [reduce distance]

**Video Aware SP**
- JSCC
- A-FEC
- UEP
- SVC
- Distortion Aware
- Resource Allocation
- Video pre- and Post- processing

**Existing Spectrum**
- Broadcast
- Cellular
- WiFi & WPAN

**New Spectrum**
- TVWS
- Cog. Radios

**System Opt.**
- Network coding
- Coop. error recovery
- Peer-to-peer
- Distortion aware
- Routing

**Macro**
- Micro
- Femto
- Cooperative
- Multi-hop
- Mesh
Wireless Network Components

**Content Cloud**

- Hulu
- Netflix
- SlingMedia
- CBS
- CNN
- ESPN

- Compress
- ‘Snack-size’
- Side-info.

**Portal, Proxy Server**

- Move Networks
- Ortiva Wireless

- Transcoding
- Adaptive streaming
- Opt. transport
- Ad insertion
- Fast channel switch

**Routers, Network servers**

- Cisco (Medianet)

- Prioritized routing
- Admission control
- VQE measure, management

**Base-Station, AP**

- Ericsson, Huawei

- Enhanced capacity (LTE/WiMax)
- Unicast
- MBS/MBMS
- Ex: LTE+SVC testbed

**Client**

- Apple, RIM

- Encode
- Decode
- Broadcast
- HD capable
- HDMI
- SW/Apps
Wireless Network Components

- Video Content Generators
- Portal, Proxy Server
- End-to-end opt
- Broadcast
- Cellular
- Broadband

★ = Video-aware processing element
Future Wireless Network

Video Content Generators

Portal, Proxy Server

Router

End-to-end opt

Cooperative Access Networks

Broadcast

Macro

Micro

WiFi AP Femto

Storage

Distributed, P2P Storage

★ = Video-aware processing element

Cooperative and Interconnected Clients

Intel Confidential
Adding Video Awareness to Clients

SoC
- Transport & Network Layer
- Video Encode/Decode
- Quality Evaluation
- Image Improvement
- Scaling
- Capture
- Display

VAE

Wireless Module
- Host I/O
- MAC
- Baseband
- Analog RF
- Radio Manager

Jointly manage Radio & Video Quality of Experience
Manage power consumption
Communicate with Network
Adding Video Awareness to Clients

Codec settings
Scalable options
Error Concealment
High-level Overview of H.264 SVC

- 3 dimensions of scalability (all or a subset may be present in a bitstream)
- Temporal Scalability
- Spatial Scalability
- Quality Scalability
  - Coarse Grained (CGS)
  - Medium Grained (MGS)
H.264 SVC SNR Scalability Example

- Medium Grain Scalability (MGS) enables extraction of multiple bit rates
- Bitstreams with multiple quality layers enable fast rate adaptation, cross-layer optimization opportunities
Given $\text{SNR}$ and $\mathbf{H}$

$[\text{MIMO Alamouti STC}]$

$$\text{PER} \propto f\left(\frac{\text{SNR}}{2}, \|\mathbf{H}\|_F, R\right)$$

$$D_{\text{max}} \propto f(D(R), EC)$$

[measured or tables]

**Example R-D Curve**

**Client Optimization**

$$MCS_{\text{SELECTED}} = \arg\min_{MCS} D(R) \ast (1 - \text{PER}) + D_{\text{max}} \ast \text{PER}$$

**Client Recommended MCS and Codec Rate**
WiFi LLS Performance

Goodput-maximizing link adaptation (variable PER)
WiFi LLS Performance

Goodput-maximizing link adaptation (target PER=1%)
WiFi LLS Performance

Distortion-minimizing link adaptation

PSNR (dB) vs. Average Received SNR (dB)

- 802.11n MCS Modes with BICM-CC and 2x2 Alamouti STC
- 802.11n MCS Modes with BICM-CC and 2x2 MIMO SM-MMSE
WiFi LLS Performance

- **PSNR (dB)**
  - Optimal MCS: STC-16QAM rate 1/2
- **Goodput (bps/Hz)**
  - Optimal MCS: STC-16QAM rate 3/4

SNR = 13 dB

Graph showing the relationship between PSNR and Goodput at different MCS rates.
WiFi: Impact of ARQ & Rate Scaling

PSNR Comparison with ARQ + Rate Scaling

- Goodput-maximizing link adaptation
- Distortion-minimizing link adaptation
- Baseline scheme w/o rate matching

Peak SNR (dB)

Average Received SNR (dB)
What’s New w/ ‘JSCC’? Why Now?

Ecosystem (‘Perfect storm?’)
- Powerful devices, larger screens, good graphics
- Higher capacity wireless networks [good enough]
- IPTV and accepted social video usage models

Technology
- Running into limits in wireless network improvements
- Good scalable video compression (H.264 SVC)
  - Enables distributed management of video transport
- Improved video quality understanding (visual perception quality metrics)
- Greater meta-data creation for video content (linking linear TV w/ internet)...can help improve transport?
- Improved video processing, more memory in mobile devices
- 3D, stereoscopic video
Conclusions

• Video content could dominate future traffic
  • Demand could be there if network capacity allows it

• Video characteristics not yet fully exploited
  • What information is useful / needed?
  • How to make information broadly accessible (in real-time)?
  • How to best use this information in a wireless network?
  • What is the benefit / gain?

• Cooperation at many levels needed
  • Content, transport, access, cellular, broadcast, etc.

• Intel issuing RFP for ‘Video Aware Wireless Networks’
  • Device Optimizations for Video Communications
  • End-to-End Video Transmission Optimizations
  • Novel System and Network Architectures for Video Delivery
Thanks!

Questions?