Measurement-Based Analysis of the Performance of several Wireless Technologies

R. Cosma\textsuperscript{a}, A. Cabellos-Aparicio\textsuperscript{b}, J. Domenech-Benlloch\textsuperscript{c}, J. Gimenez-Guzman\textsuperscript{c}, J. Martinez-Bauset\textsuperscript{c}, M. Cristian\textsuperscript{a}, A. Fuentetaja\textsuperscript{d}, A. López\textsuperscript{b}, J. Domingo-Pascual\textsuperscript{b}, J. Quemada\textsuperscript{d}

a. Technical University of Cluj-Napoca, Romania
b. Universitat Politècnica de Catalunya, Barcelona, Spain
c. Universidad Politècnica de Valencia, Spain
d. Universidad Politécnica de Madrid, Spain

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Agenda

I. Introduction
II. Layer 3 Parameters
III. Measurement Methodology
IV. Experimental Results
V. Conclusions and Future Work
I. Introduction

• Events with major implications for the Internet:
  ◦ The advent of broadband connections (DSL, Cable Modems, Wireless Access)
  ◦ The rapid evolution of Wireless Technologies

• The current paradigm shift:
  ◦ High Bandwidth
  ◦ Low Delay
  ◦ Extended Area of Service
  ◦ Mobility
Present Solutions

- IEEE 802.11 (WiFi)
  - Reduced costs
  - Maximum theoretical debits of 54 Mbps (.g)
  - Short-range coverage / low mobility

- UMTS / HSDPA
  - 3G Technology: Mobility issues have been solved
  - Standards that enhance the Data Rates

- IEEE 802.16 (WiMAX)
  - New Infrastructure
  - Mobility support in 802.16e
  - Economical benefits
II. Layer 3 Parameters

- Standard metrics for the performance of Internet data delivery services:
  - One-way Delay (OWD)
  - Interpacket Delay Variation (IPDV)
  - Packet Loss Ratio (PLR)

- Relevance:
  - Performance of Transport Layer protocols
  - Performance of Interactive/Real-time applications
  - Insights on the dynamics and effectiveness of Layer 2 protocols/implementations.
III. Measurement Methodology

1. Deployment and configuration of the test-bed scenario
2. Clock Synchronization
3. Generating the Probe Traffic
4. Capture of Test Traffic at the relevant nodes
5. Extraction of Layer 3 Metrics from the capture files
The Network Time Protocol
- Hierarchy-based Architecture (Stratum Levels)
- Time source differentiation algorithms
- Information combining (agreement) algorithms

NTP Dedicated Network
- Separate Network Interfaces
- Stratum 1 Servers
- GPS-based Time Source
- High accuracy
Test traffic - Isabel

- Why did we use a videoconferencing application?
  - Simultaneous traffic generation for all the clients
  - UDP advantages
  - Different nature of Audio and Video flows

- Isabel:
  - High modularity
  - Appropriate logical topology
Test traffic - Isabel

- Each client sends its data to the \textit{flowserver}.
- Flow multiplexing takes place at the \textit{flowserver}.

Interactive Terminals

Access Network

Flowserver

Physical Topology

Logical Topology
Traffic Capture - Wireshark

- Requirements:
  - Timestamping
  - Capture file format

- Wireshark:
  - Platform-independent operation
  - Advanced GUI
  - PCAP file format
Layer 3 Metrics Extraction

- Implementation:
  - Perl programming language
  - Net::Pcap wrapper

- Functionality:
  - Synchronization checking
  - RTP flows listing
  - Packet matching algorithm for metric extraction
IV. Experimental Results

- **Structure:**
  - Statistical descriptors of central tendency and variability: min, max, mean, median, standard deviation
  - Histogram and CDF plots for OWD/IPDV
  - Variation of metrics with respect to packet size

- **Objectives:**
  - Empirical evaluation of link performances
  - Influence of Layers 1 & 2
  - Link behavior when subject to CBR/VBR traffic
## Test traffic overview

<table>
<thead>
<tr>
<th>Link/SSRC</th>
<th>Flow</th>
<th>Packets</th>
<th>Flow size (Mbytes)</th>
<th>Throughput (kbps)</th>
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<tbody>
<tr>
<td>Ethernet (2800)</td>
<td>Up</td>
<td>Audio</td>
<td>32261</td>
<td>9.04</td>
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<td></td>
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<td>Video</td>
<td>22805</td>
<td>16.38</td>
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<td>UMTS (2799)</td>
<td>Up</td>
<td>Audio</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
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<td>19117</td>
<td>13.29</td>
</tr>
<tr>
<td>WiFi (2798)</td>
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<td>Audio</td>
<td>32864</td>
<td>9.21</td>
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<tr>
<td></td>
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<td>Video</td>
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<td>14.37</td>
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<tr>
<td>WiMAX (2797)</td>
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<td>Audio</td>
<td>22429</td>
<td>6.28</td>
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<tr>
<td></td>
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<td>Video</td>
<td>21005</td>
<td>15.08</td>
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Results - WiFi

• Statistical parameters

<table>
<thead>
<tr>
<th>Metric</th>
<th>Max</th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
<th>Dev</th>
<th>PLR</th>
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</thead>
<tbody>
<tr>
<td>Video Up</td>
<td>OWD</td>
<td>20.373</td>
<td>4.677</td>
<td>1.003</td>
<td>0.550</td>
<td>7.128</td>
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<td>1.443</td>
<td>0.400</td>
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<td>0.587</td>
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<td>0</td>
<td>0.015</td>
<td>-2.039</td>
<td>1.488</td>
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<tr>
<td>Video Down</td>
<td>OWD</td>
<td>2.849</td>
<td>1.278</td>
<td>0.895</td>
<td>0.516</td>
<td>2.072</td>
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<tr>
<td></td>
<td>IPDV</td>
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<td>0</td>
<td>0.059</td>
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<td>0.602</td>
<td>0.511</td>
<td>1.616</td>
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<td></td>
<td>IPDV</td>
<td>0.607</td>
<td>0</td>
<td>0.018</td>
<td>-1.571</td>
<td>1.406</td>
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</tbody>
</table>

• Maximum OWD values due to ARQ mechanism
• Well-centered IPDV distributions
• Uplink / Downlink asymmetry due to channel access mechanism
Results – WiFi Uplink

- Metrics variation with packet size:
  - OWD: unaffected
  - IPDV: increased values for packet sizes > 400 bytes
**Results - WiMAX**

- **Statistical parameters**

<table>
<thead>
<tr>
<th>Metric (ms)</th>
<th>Max</th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
<th>Dev</th>
<th>PLR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Video</strong></td>
<td></td>
<td></td>
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<tr>
<td>Up</td>
<td>OWD</td>
<td>275.118</td>
<td>150.672</td>
<td>134.998</td>
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<td>35.005</td>
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<tr>
<td><strong>Audio</strong></td>
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<tr>
<td>Up</td>
<td>OWD</td>
<td>244.949</td>
<td>107.593</td>
<td>81.300</td>
<td>42.960</td>
<td>67.957</td>
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<tr>
<td></td>
<td>IPDV</td>
<td>39.185</td>
<td>400 µs</td>
<td>4.616</td>
<td>-62.378</td>
<td>27.819</td>
</tr>
<tr>
<td><strong>Video</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down</td>
<td>OWD</td>
<td>158.730</td>
<td>78.567</td>
<td>67.192</td>
<td>55.251</td>
<td>34.513</td>
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<tr>
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<td>10.160</td>
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<td>0.570</td>
<td>-22.082</td>
<td>9.540</td>
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<tr>
<td><strong>Audio</strong></td>
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<tr>
<td>Down</td>
<td>OWD</td>
<td>104.967</td>
<td>68.058</td>
<td>62.121</td>
<td>54.322</td>
<td>23.135</td>
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<td>IPDV</td>
<td>8.691</td>
<td>0</td>
<td>0.275</td>
<td>-16.799</td>
<td>8.514</td>
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</tbody>
</table>

- **Asymmetries:**
  - Uplink / Downlink – different power amplifier gains for MS and BS
  - Audio (CBR) / Video (VBR)

- **High Packet Loss Ratios:**
  - Experimental MS equipment at Valencia
Results – WiMAX Uplink

• Optimal packet length: ~500 bytes.
• Discrete nature of IPDV distribution:
  ◦ Frame size: 5ms
  ◦ TDD
  ◦ ARQ mechanism
• Multiple retransmissions
Results – WiMAX Downlink

- IPDV unstable with small packet sizes
- Discrete nature of IPDV
- Less frame retransmissions than Uplink
Results – UMTS/HSDPA

- Statistical parameters

<table>
<thead>
<tr>
<th>Metric (ms)</th>
<th>Max</th>
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<th>Median</th>
<th>Min</th>
<th>Dev</th>
<th>PLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video Up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OWD</td>
<td>258.251</td>
<td>153.877</td>
<td>95.385</td>
<td>75.903</td>
<td>103.481</td>
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<tr>
<td>IPDV</td>
<td>27.792</td>
<td>-0.258</td>
<td>1.058</td>
<td>-66.573</td>
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<tr>
<td>Video Down</td>
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<td>0.242%</td>
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<td>OWD</td>
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<td>50.047</td>
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<tr>
<td>IPDV</td>
<td>11.751</td>
<td>0</td>
<td>1.825</td>
<td>-22.244</td>
<td>15.349</td>
<td></td>
</tr>
</tbody>
</table>

- Special setup imposed by the maximum *uplink* bandwidth
- High maximum values due to congestion in the provider’s network
- IPDV distributions better than WiMAX
- Efficient ARQ mechanisms
Results – UMTS Uplink

- Metric variation with packet size:
  - OWD stable
  - IPDV less stable, increasing

- Discrete IPDV nature:
  - Link temporization at RLC layer
  - Loss recovery in integer number of TTIs
Results – UMTS Downlink

- Lower OWD values
- IPDV and OWD stable with packet size
- HSDPA effects on IPDV discretization:
  - TTI limited to one radio frame
  - Reduced radio frame duration
V. Conclusions

- Simple methodology for extracting Layer 3 Metrics for heterogeneous networks
- WiFi:
  - Good stability of metrics in respect to packet size
  - Extreme values caused by ARQ mechanism
  - Uplink / Downlink asymmetry due to the radio channel disputing algorithm
- WiMAX:
  - High PLR – experimental equipment
  - Uplink / Downlink asymmetry
  - IPDV discretization due to ARQ mechanisms
- UMTS / HSDPA:
  - Efficient retransmission schemes
  - HSDPA effects on Downlink metrics
- Better values for metrics associated with CBR (Audio) traffic
V. Conclusions

<table>
<thead>
<tr>
<th></th>
<th>WiFi</th>
<th>WiMAX</th>
<th>UMTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>OWD</td>
<td>Green</td>
<td>Orange</td>
<td>Red</td>
</tr>
<tr>
<td>IPDV</td>
<td>Green</td>
<td>Red</td>
<td>Orange</td>
</tr>
<tr>
<td>PLR</td>
<td>Green</td>
<td>Orange</td>
<td>Green</td>
</tr>
<tr>
<td>Throughput</td>
<td>Green</td>
<td>Orange</td>
<td>Green</td>
</tr>
<tr>
<td>Range/Mobility</td>
<td>Red</td>
<td>Orange</td>
<td>Green</td>
</tr>
</tbody>
</table>

- **Best**
- **Medium**
- **Worst**
V. Future Work

- Development of a system for *fingerprinting* wireless links:
  - Based on the nature of OWD & IPDV distributions
  - Network Layer could infer the access link w/o employing cross-layering techniques
- Extending the Perl application:
  - Real-time mode
  - Capture and processing of traffic other than RTP over UDP