Improving VoIP Call Capacity over IEEE 802.11 Networks

Yeonsik Jeong, Sandeep Kakumanu, Cheng-Lin Tsao, and Raghupathy Sivakumar

GNAN Research Group
Georgia Institute of Technology
Outline

- Call Capacity Study
  - Simulations/Experimentation/Analysis
- Solution Basis
- Algorithms
- Performance Evaluation
- Conclusion
Call Capacity Study: Simulation

- **Network Conditions**
  - IEEE 802.11b network with 11 Mbps link

- **Codec Spec of G.711**
  - Frame interval: 10 ms → Frame rate: 100
  - Frame size: 80 bytes
  - Data rate: 64 Kbps

- **Expected number of VoIP calls**
  - 85 calls

- **Actual number of VoIP calls in ns-2 simulation**
  - 5 calls in ideal condition
Call Capacity Study: Experimentation

Testbed Diagram

- Internet
- wan.org
- DNS Server / WAN Emulator
- DHCP
- ece.org
- ns.wan.org
- gnan.org
- router.ece.org
- router.gnan.org
- client1-6.gnan.org
- 802.11b
- proxy.ece.org
- sphone.ece.org
- client.ece.org
- proxy.gnan.org
- sip:siva@ece.org
- sip:ysjeong@gnan.org
- 10.10.10.1/24
- 10.10.10.2/24
- 10.10.20.1/24
- 10.10.20.2/24
- 10.10.40.1/24
- 10.10.40.2/24
- 10.10.40.3/24
- 10.10.40.11-16/24
- 10.10.30.1/24
- 10.10.30.2/24
- 10.10.40.1/24
- 10.10.40.11-16/24
Call Capacity Study: Experimentation

- Call Setup
  - One real VoIP call via Kphone and SIP Express Router
  - A number of emulated calls via Iperf
    - Bidirectional CBR/UDP traffic
    - Frame size: 92 bytes (considering 12 byte RTP header)
    - Data rate: 73.6 Kbps
  - Actual number of VoIP calls in testbed experimentation
    - 5 calls
Call Capacity Study: Analysis

- Terminology (also used as a Metric)
  - Maximum Frame Rate (MFR)
    - Captures the frame rate that can be expected at each layer $L$
  - Minimum Required Transmission Delay (mRTD)
    - Gives time taken to transmit the PDU at the corresponding layer
  - Maximum Number of VoIP Calls (MNVC)

\[
MNVC(L) = \left\lfloor \frac{\text{MFR}(L)}{2k} \right\rfloor = \left\lfloor \frac{1}{2k \cdot \text{mRTD}(L)} \right\rfloor, \quad k \text{ is frame rate of codec}
\]
Call Capacity Study: Analysis

- Application Layer Capacity
  - Ideal throughput

\[
\text{MFR}(\text{APP}) = \frac{R}{8D}, \quad R \text{ is transmission rate and } D \text{ is frame size}
\]

\[
\text{MNVC}(\text{APP}) = \left\lfloor \frac{\text{MFR}(\text{APP})}{2k} \right\rfloor = \left\lfloor \frac{11 \times 10^6}{2 \times 100 \times 8 \times 80} \right\rfloor = 85
\]

The potential MNVC at the application layer is 85 calls
Call Capacity Study: Analysis

- Impact of Transport and Network Layers
  - Add protocol headers to the frame

\[
mRTD(RTP) = MFR(APP)^{-1} + T(RTP) \\
mRTD(UDP) = mRTD(RTP) + T(UDP) \\
mRTD(IP) = mRTD(UDP) + T(IP) \\
T(L) = \frac{8 \cdot H(L)}{R}
\]

\[
mRTD(RTP) = 58.2 \mu s + 8.7 \mu s = 66.9 \mu s \\
mRTD(UDP) = 66.9 \mu s + 5.8 \mu s = 72.7 \mu s \\
mRTD(IP) = 72.7 \mu s + 14.5 \mu s = 87.2 \mu s
\]

\[
MNVC(IP) = \left\lfloor \frac{1}{2k \cdot mRTD(IP)} \right\rfloor = \left\lfloor \frac{1}{2 \times 100 \times 87.2 \times 10^{-6}} \right\rfloor = 57
\]

The potential MNVC at the network layer, taking into account all the overheads of RTP, UDP, and IP headers, is 57 calls.
Call Capacity Study: Analysis

- Impact of MAC Layer
  - Adds considerable overhead to the frame including MAC header, MAC backoff time, MAC ACK, and inter-transmission times (DIFS and SIFS)

\[
mRTD(MAC) = mRTD(IP) + T(MAC) + T_{DIFS} + T_{BO} + T_{SIFS} + T_{ACK} \\
= 87.2\,\mu s + 24.8\,\mu s + 50\,\mu s + 310\,\mu s + 10\,\mu s + 304\,\mu s \\
= 786\,\mu s
\]

\[
MNVC(MAC) = \left[ \frac{1}{2k \cdot mRTD(MAC)} \right] = \left[ \frac{1}{2 \times 100 \times 786 \times 10^{-6}} \right] = 6
\]

The potential MNVC at the MAC layer, taking into account all the overheads of the higher layers, DIFS, SIFS, backoff delay, and ACK, is 6 calls
Call Capacity Study: Analysis

- Impact of Physical Layer
  - Adds long preamble known as PLCP header transmitted at the basic rate (1 Mbps)

\[
\text{mRTD(PHY)} = \text{mRTD(MAC)} + T_{PHY} \\
= 786\mu s + 192\mu s \\
= 978\mu s
\]

\[
\text{MNVC(PHY)} = \frac{1}{2k \cdot \text{mRTD(PHY)}} = \frac{1}{2 \times 100 \times 978 \times 10^{-6}} = 5
\]

The potential MNVC at the PHY layer, taking into account all the overheads of the higher layers and PLCP header, is 5 calls.
Solution Basis

- Final Equation for MNVC of Physical Layer

\[
MNVC = \frac{1}{2k \left( T_{DIFS} + T_{BO} + T_{SIFS} + T_{ACK} + T_{PHY} + \frac{8 \left( D + \sum_{l_{=RTP}}^{MAC} H(L) \right)}{R} \right)}
\]

- Five Schemes Possible to Improve MNVC
  - ACK Aggregation (AA): results in the reduction of \( T_{ACK} \)
  - Frame Aggregation (FA): decreases \( k \)
  - Link Adaptation (LA): can control \( R \)
  - Time Saving (TS): reduces \( T_{DIFS} \)
  - Header Compression (HC): reduces \( \sum H(L) \)
Solution Basis

- Impact of Each Scheme on Performance Improvement

<table>
<thead>
<tr>
<th>AA</th>
<th>FA</th>
<th>LA</th>
<th>TS</th>
<th>HC</th>
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<tr>
<td># of ACK</td>
<td>MNVC</td>
<td>k (s)</td>
<td>MNVC</td>
<td>R (Mbps)</td>
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<tr>
<td>0</td>
<td>8.3</td>
<td>25</td>
<td>17.9</td>
<td>2</td>
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<td>7.1</td>
<td>1.25</td>
<td>2.9</td>
<td>11</td>
</tr>
</tbody>
</table>

- Proposed Solutions
  - ACK Aggregation (AA)
  - Frame Aggregation (FA)
  - Link Adaptation (LA)
ACK Aggregation (AA)

- **Motivation and Description**
  - AA refers to sending a single ACK for a block of $n$ frames
  - **Adaptive AA** algorithm uses variable block size based on the received block ACK information
    - Increases the block size upon receiving a block ACK with all successes
    - Decreases the block size on receiving a block ACK with even a single frame loss

![Graph showing Maximum Frame Rate vs. Delay Budget (ms)](image)
Frame Aggregation (FA)

- Motivation and Description
  - FA refers to fusing multiple frames destined to the same end user into a single large frame
  - **Enhanced piggybacking** aggregates frames only when required
    - To improve the performance of upstream flow, a client maintains a variable which holds the number of aggregated frames in the previously received frame from the AP
Link Adaptation (LA)

- Motivation and Description
  - LA refers to changing the transmission rate for the data frames
  - SARF (Size-aware Auto Rate Fallback) algorithm is based on ARF, but it considers channel condition as well as the frame size
    - If a small frame is in error then there is a high probability of error for a large frame as well, and when a large frame is successful, there is also a high probability of success for a small frame
Performance Evaluation

- **ns-2 Simulation**
  - VoIP traffic
    - Bi-directional CBR/UDP traffic with a frame size of 92 bytes
  - Background traffic
    - Bi-directional CBR/UDP traffic with a frame size of 1472 bytes
  - Number of wireless nodes
    - Single in AA and LA, multiple in FA
  - Loss rate threshold: 2 %

- **Metrics**
  - Maximum Frame Rate (MFR)
    - A fine grained metric for small improvement in AA and LA
  - Maximum Number of VoIP Calls (MNVC)
    - A metric for improvement of one call or more in FA
Performance Evaluation

- ACK Aggregation (AA)
  - Erroneous channels with BER of $10^{-5}$ and $10^{-4}$

The Adaptive AA follows the envelope of two graphs with different fixed block sizes and gives the best performance.
Performance Evaluation

- Frame Aggregation (FA)
  - Erroneous channel with a BER of $10^{-5}$

The FA gives 18 calls without any background traffic and 7 calls with a background traffic of 3 Mbps for a delay budget of 60 ms.
Performance Evaluation

- Link Adaptation (LA)
  - Erroneous channel with varying SNR condition

The SARF shows similar performance to ARF in MFR but better performance in QoS metric as the number of frames sent at wrong rate.
Conclusion

- **Summary**
  - Analyze the reasons of the inferior performance of VoIP over IEEE 802.11 networks
  - Setup an experimental testbed to verify the analysis
  - Propose three algorithms at the MAC layer and show the performance improvement

- **Ongoing Work for Software Implementation**
  - Implement the FA into Linux 2.6.11 kernel in the real testbed
  - Show the performance improvement of 17 calls

GNAN Research Group, Georgia Tech
http://www.ece.gatech.edu/research/GNAN