VoIP via IEEE 802.11 “VoWLAN”
EETS 8313: Internet Telephony
Sami Alshuwair

Agenda

Evolution of Enterprise Telephony
Why Deploy VoIP over Wireless LAN
VoWLAN Market Trends
VoIP Challenges and Solution
VoWLAN Challenges and Solution
WLAN System Architectures Considerations
VoWLAN Alternatives
Recommendations
Evolution of Enterprise Telephony
From circuit-switched to packet-switched
Traditionally private branch exchange (PBX)
– Analog/digital phones, proprietary
Internet Protocol PBX began a new era
– Converge voice/data, IP-based enterprise network
Session Initiation Protocol (SIP) emerges
VoIP extends coverage to include WLANs
– SIP-based, VoWLAN phones provide comm.
Fixed mobile convergence solution emerging
– Seamless handoff between mobile cellular and Wi-Fi networks

Why Deploy VoWLAN?
Clearly understand your needs
Reduce mobile cellular minutes
– VoWLAN conversations are “free” calls
Improve in-building voice coverage
– Deploy more access points to improve coverage
Integrate mobile & enterprise telephony systems
When cellular phones are not an option
– VoWLAN signals use 2.4 GHz or 5 GHz bands
Provide wireless foundation for unified comm.
– Voice, video, IM, all over common IP network
VoWLAN Market Trends

Growing becoming pervasive

WLAN phone market reach $3.7B by 2009

Integrate enterprise Telephony + mobility

Vendors integrate their voice solutions

Vendor consolidation

IEEE 802.11 tech. improving

Mobile cellular tech. improving

How VoWLAN Solutions Can Reduce Cost and Improve Productivity

Dual-mode “Smart Phones”

Enterprise:
– Market forces employees to be more productive

Healthcare:
– Critical to reach the right person immediate

Warehouse/retail:
– Effective customer services

Cisco ROI Model Assumption:
Six-year period
1000 users; 40% mobile users
US tariff rates
Deploy Cisco Unifies wireless Solution
Cisco Dual Mode net price $290
VoIP Protocol Stack Header Overhead

Codec Information

<table>
<thead>
<tr>
<th>Codec &amp; Bit Rate (Kbps)</th>
<th>Codec Sample Size (Bytes)</th>
<th>Codec Sample Interval (ms)</th>
<th>Mean Opinion Score (MOS)</th>
<th>Voice Payload Size (Bytes)</th>
<th>Voice Payload Size Per Bit (ms)</th>
<th>Packets Per Second (PPS)</th>
<th>Bandwidth MP or FRF.12 (Kbps)</th>
<th>Bandwidth w/ RTP MP or FRF.12 (Kbps)</th>
<th>Bandwidth Ethernet (Kbps)</th>
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<tbody>
<tr>
<td>G.711 (64)</td>
<td>80</td>
<td>10</td>
<td>4.1</td>
<td>160</td>
<td>20 ms</td>
<td>50</td>
<td>82.8 Kbps</td>
<td>47.6 Kbps</td>
<td>97.2 Kbps</td>
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<tr>
<td>G.728 (8)</td>
<td>10</td>
<td>10</td>
<td>3.92</td>
<td>20</td>
<td>20 ms</td>
<td>50</td>
<td>26.8 Kbps</td>
<td>13.4 Kbps</td>
<td>26.8 Kbps</td>
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<td>G.723.1 (6.3)</td>
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<td>30</td>
<td>3.9</td>
<td>24</td>
<td>30 ms</td>
<td>34</td>
<td>19.9 Kbps</td>
<td>11.9 Kbps</td>
<td>24.9 Kbps</td>
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<tr>
<td>G.726 (12.2)</td>
<td>20</td>
<td>5</td>
<td>3.85</td>
<td>80</td>
<td>20 ms</td>
<td>50</td>
<td>50.8 Kbps</td>
<td>25.4 Kbps</td>
<td>55.8 Kbps</td>
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<tr>
<td>G.728 (12.4)</td>
<td>25</td>
<td>5</td>
<td>3.81</td>
<td>60</td>
<td>30 ms</td>
<td>34</td>
<td>42.8 Kbps</td>
<td>21.4 Kbps</td>
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<tr>
<td>G.728 (16)</td>
<td>10</td>
<td>5</td>
<td>3.61</td>
<td>60</td>
<td>30 ms</td>
<td>34</td>
<td>28.5 Kbps</td>
<td>15.2 Kbps</td>
<td>31.5 Kbps</td>
</tr>
</tbody>
</table>

VoIP Bandwidth Calculation per Call

For example, the required bandwidth for a G.729 call (8 Kbps codec bit rate) with cRTP, MP and the default 20 bytes of voice payload is:

– Codec bit rate = codec sample size / codec sample interval

– Total packet size (bytes) = (MP header of 6 bytes) + (compressed IP/UDP/RTP header of 2 bytes) + (voice payload of 20 bytes) = 28 bytes

– Total packet size (bits) = (28 bytes) * 8 bits per byte = 224 bits

– Voice payload size = 20 bytes (default voice payload) * 8 bits per byte = 160 bits

– PPS = (8 Kbps codec bit rate) / (160 bits) = 50 pps

– Bandwidth per call = voice packet size (224 bits) * 50 pps = 11.2 Kbps
VoIP Challenges and Solutions

Bandwidth Management:
- Challenge: loaded network/SW with adv. encoding
- Solution: load balancing, call admiss. control

Packet Loss:
- Challenge: RTP: packet loss < 3%
- Solution: Packet loss concealment & redund. algor.

Latency:
- Challenge: One way latency “G.113” <= 150 mSec
- Solution: 802.11e/WMM + wired QoS mechanism

Jitter:
- Challenge: Packet arrival time <= 30 mSec
- Solution: Jitter butter, 802.11e/WMM + wired QoS

802.11 WLAN “de facto” Standards

<table>
<thead>
<tr>
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<tr>
<td>IEEE 802.11a</td>
<td>5 GHz</td>
<td>OFDM</td>
<td>CSMA/CA</td>
<td>23 Mbit/s</td>
<td>54 Mbps</td>
<td>- Cordless phone</td>
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<td></td>
<td>- Amateur Radio</td>
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<td></td>
<td>- Aeronautical Radio</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>- Navigation</td>
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<td>IEEE 802.11b</td>
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<td>DSSS, CCK</td>
<td>CSMA/CA</td>
<td>4.3 Mbit/s</td>
<td>11 Mbps</td>
<td>- MW Oven</td>
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<td></td>
<td></td>
<td></td>
<td>- Bluetooth Device</td>
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<td></td>
<td></td>
<td>- Amateur Radio</td>
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<tr>
<td>IEEE 802.11g</td>
<td>2.4 GHz</td>
<td>OFDM, CCK</td>
<td>CSMA/CA</td>
<td>19 Mbit/s</td>
<td>54 Mbps</td>
<td>- Same as 802.11b</td>
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<tr>
<td>IEEE 802.11n</td>
<td>2.4 GHz &amp; 5 GHz</td>
<td>OFDM, CCK</td>
<td>CSMA/CA</td>
<td>74 Mbit/s</td>
<td>248 Mbps</td>
<td>- Same as 802.11b/11a</td>
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</tbody>
</table>
**802.11 Medium Access**

MAC Frame Types:
- Data
- Control: RTS, CTS & ACK
- Management: Beacon

Distrib. Coord. Func. (DCF)
- Uses a CSMA/CA algorithm
- Senses the medium first
- If it is idle for DIFS amount of time, the frame transmitted
- Otherwise a backoff time B is randomly in the interval \([0, CW]\)
- Has no priority “best effort”

DCF Method Signal Flow

SIFS = Short Interframe Space. 16us for .11a and 10us for .11b/g
DIFS = DCF Interframe Space = SIFS + 2 x Slot Time
PIFS = PCF Interframe Space = SIFS + Slot Time
Slot Time = 20us for .11b & 9us for .11a; .11g is 9us when all STA high-speed otherwise 20us
Backoff = Random * Slot Time

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**802.11 Medium Access Cont.**

Point Coordination Function (PCF)
- Contention-free frame transfer
- Single Point Coordinator (PC) controls access to the medium. AP acts as PC.
- PC transmits beacon packet when medium is free for PIFS time period. PCF has higher priority than DCF (PIFS < DIFS)
- PCF not used b/c not ideal for real-time traffic:
  - Unachieved performance when traffic load increas.
  - Polling schemes prolong the delay in WLAN

PCF Method Signal Flow

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IEEE 802.11e “QoS” Overview

Hybrid Coordination Function (HCF) combines polled and CSMA/CA channel access

Enhanced DCF Channel Access (EDCA)
– Contention based
– DiffServ-Service like
– Traffic can be classified into 8 different classes
– Each station has 4 Access Categories (AC)

IEEE 802.11e “QoS” Overview Cont.

• HCF Controlled Channel Access (HCCA)
  – “InServ-service like”
  – Specify time interval for STA “TDM-service like”
  – Can start polling period at any time

Automatic Power Save Delivery (APSD)
– Reduces power consumption 50% to 80% in active mode.
VoWLAN Security

Wired Equivalent Privacy (WEP)
- 40 bit – 128 bits key
- Authentication easy to break

802.11i:
- 802.1x: “authentication”
  Varies; vendors preference
- TKIP known as WPA
- CCMP known as WPA2
  Increased overhead
  More processing time/delay
- Hard to implement in inter-domain handover

TKIP = Temporal Key Integrity Protocol
WPA = WiFi Protected Access
CCMP = Counter Mode with Cipher Block Chaining
Message Authentication Code Protocol
PMK = Pairwise Master Key
PTK= Pairwise Transient Key

VoWLAN Security Cont. VLANs:

802.1Q Wired Network w/VLANs

AP Channel:
SSID “Data” = VLAN 1
SSID “Voice” = VLAN 2
SSID “Visitor” = VLAN 3

SSID = Service Set ID, PEAP = Protected Extensible Authentication Protocol, AES= Advanced Encryption Standard, LEAP= Lightweight Extensible Authentication Protocol
VoWLAN Handover/Roaming

WLAN AP covers 50m² to 300m² → freq. handover < 50ms recommended, but >200ms packet lost
Layer 2 “V” handover: from AP to AP w/same IP
Layer 3 “H” handover: from AP to AP w/new IP
  – SIP or MIP used to resume voice session
With 802.1x & .11i association takes 300-500ms
  – Include scan. joining new ch, authen. & associat.
  – Passive scan during active VoIP to reduce scan time
  – Establish secure key introd. delay “four handshake”
802.11r fast handover: cache context “neighbor graph”
VoWALN Fast Secure Roaming Layer 3 “Vertical”-Different IP Subnet

1. Client associates with AP and receives an IP address, optionally using WPA (802.1x) or VPN for security
2. Control “B” creates client database: MAC & IP, security context & association, QoS, etc.
3. Client roams to new subnet or roams out of radio coverage and returns
4. Client associate with new AP & controller. Client database copied to new controller
5. New controller recognizes roaming event and provides client with the same initial IP address

GRE = Generic Routing Encapsulation is a tunneling protocol

VoWALN Capacity

What is the max. number of voice call AP can support?
– Ask your vendor

Transmission rate “throughput”

Voice packet payload length depended on encoding

Capacity enhancement solutions:
– Enhanced air access MAC “HCF”
– Virtual cells “Meru Network propriety”
– Header compression
– Frame aggregation
VoWALN Capacity Cont.

Throughput Effect:

80.11b is around 6Mbps & 802.11a/g around 26/17Mbps

VoIP capacity can not be estimated based on raw data throughput:
– Assuming 10Kb/s voice source, theoretical capacity of 802.11b is 11Mbps/10Kbps =1100 → 550 two-way VoIP sessions.
– In practice only a few VoIP users can be supported in 802.11b!
  – Low payload to overhead ratio for short VoIP packets and inherent inefficiency in 802.11 MAC

VoWALN Capacity Cont.

Packet Interval & Vocoder Effect:

Many vendor select 30ms

Voice call increase w/packet interval increase

VoWLAN 802.11a 5x than VoWLAN 802.11b

Larger packetization interval → more end-to-end delay

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VoWALN Capacity Enhancement

**No over-the-air QoS**

```
Channel Access with Today's 802.11 AP

<table>
<thead>
<tr>
<th>Channel ID</th>
<th>AP</th>
</tr>
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<tr>
<td>1</td>
<td>5.36</td>
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<tr>
<td>2</td>
<td>5.38</td>
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<tr>
<td>3</td>
<td>5.4</td>
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<tr>
<td>4</td>
<td>5.42</td>
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<td>5</td>
<td>5.44</td>
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<tr>
<td>6</td>
<td>5.46</td>
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<td>7</td>
<td>5.48</td>
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<td>8</td>
<td>5.5</td>
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<td>9</td>
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<td>10</td>
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<tr>
<td>11</td>
<td>5.56</td>
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</tbody>
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**Over-the-air QoS**

```
Channel Access with Meru AP for QoS

<table>
<thead>
<tr>
<th>Channel ID</th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.36</td>
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<tr>
<td>2</td>
<td>5.38</td>
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<td>5.52</td>
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<td>10</td>
<td>5.54</td>
</tr>
<tr>
<td>11</td>
<td>5.56</td>
</tr>
</tbody>
</table>
```

HCF “802.11e” doesn’t reduce overhead rather improves air traffic control “QoS”; contention loss is reduced and jitter is predictable/low

Reduce AP spacing: data

Further AP spacing: voice

802.11n/abg virtual cells

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VoWALN Capacity Enhancement

**Timing Overhead of single Voice Frame over 802.11b**

<table>
<thead>
<tr>
<th>Data component</th>
<th>Time (us)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCF Last Frame Spec. EIFS</td>
<td>55</td>
</tr>
<tr>
<td>Frame Aggregation: Multicast, Multiplexing “M-M”</td>
<td>97</td>
</tr>
<tr>
<td>Voice Frame (187b)</td>
<td>14.85</td>
</tr>
<tr>
<td>RTP/UDP aggregation</td>
<td>30.1</td>
</tr>
<tr>
<td>MAC Protocol Duration</td>
<td>20.6</td>
</tr>
<tr>
<td>MAC Frame Check Sequence</td>
<td>2.0</td>
</tr>
<tr>
<td>Frame from Source Spec. (221b)</td>
<td>69</td>
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<tr>
<td>RTP/UDP aggregation for M-M</td>
<td>97</td>
</tr>
<tr>
<td>RTP/UDP aggregation for L2 &amp; L1</td>
<td>3.5</td>
</tr>
<tr>
<td>Total</td>
<td>130.4</td>
</tr>
</tbody>
</table>

Bulk overhead lies on L2 & L1

Header compression for IP layer and above would be insignificant

Inter-Call Frame Aggregation: Multicast, Multiplexing “M-M”

Frame Aggregation into RTP Frame by Voice Source

- Capacity 80%, 90% higher than VoIP
- Security & Delay (collision & PSM)

Packet delay increases

Frame Aggregation “Intra-Call”

Requires changes in the MAC layer implement. of the interface queue
### VoWLAN Challenges and Solutions

**Location Tracking**
- Challenge: meet E911 and E112 requirements
- Solution: WLAN appliance, GSM/CDMA tracking

**Handset Battery Life**
- Challenge: improve talk/standby time to 4+/100+
- Solution: U-ASPD, propriety

**Coverage & Capacity**
- Challenge: Pervasive coverage, no dropped call, etc.
- Solution: HCF, propriety, frame aggregation

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### VoWLAN Challenges and Solutions Cont.

**Roaming**
- Challenge: Maintain connection/quality <50 ms
- Solution: 802.11r, propriety, 802.11k/.11v (future)

**Security**
- Challenge: avoid eavesdropping, maintain access control
- Solution: WAP2 (wireless) + VLAN (wired), 802.1x
WLAN System Architectures Consideration

Centralized versus distributed

Definition

– Centralized (C) – controller-based data forwarding
– Distributed (D) – AP-based forwarding

Impact on wired network

– C – may switch packets twice
– D – switch packets only once

Impact on WLAN controller

– C – controller touches packets from every AP
– D – AP – touches packets from associated stations

Impact on VoWLAN jitter/latency

– C – controller processes every VoWLAN call/packet
– D – AP processes packets for associated stations

Other factors

– Emergence of 802.11n
  802.11n will increase traffic by 5x
VoWLAN Alternatives; Pros and Cons

Mobile Cellular Phones

– Example: Nokia E60, iPhone, etc.
– Pro: Widely available, good outdoor coverage
– Con: Costly, limited in building coverage, not integrated with enterprise telephony system (FMC)

Cordless PBX Handsets

– Example: Avaya TransTalk 9040, Philips 5111
– Pro: Excellent range, good voice quality, no WLAN security issues
– Con: Requires an additional wireless network, no high-speed data, limited capacity

Recommendations

Determine the need for VoWLAN
Make sure that WLAN coverage is sufficient
Verify WLAN is ready for VoWLAN
Ensure VoWLAN compatibility with enterprise WLAN
Gain experience with single-mode phones before introducing dual-mode “smart phones”
References

[10] Shiao-Li Tsao, “Research Challenges and Perspectives of Voice over Wireless LAN,” Dept. of Computer Science and Information Engineering, National Chiao Tung University, Hanchu, Taiwan, R.O.C., 2005
[15] The enterprise is ready for wireless VoIP. Is wireless VoIP ready for the enterprise, Meru Networks, 2005
[16] Fulfilling the promise of 802.11n in the Enterprise without compromise, Meru Networks, 2007

Frame Aggregation “Intra-Call”

Legacy Burst

Intra-Call

Preamble + PLCP headers + SIFS will be saved
Some overhead will be induced to identify each MPDU