무선LAN 기술개발 동향 및 서비스 전망

2004. 02

홍승억
Contents

- Part1 : Introduction
- Part2 : Current Trends on IEEE 802.11 WLAN Standardization
- Part3 : Wireless LAN Service and/or Application Aspects
Part 1: Introduction
IEEE 802 LAN/MAN SC’s Standardization WGs related to Wireless Communications

- IEEE 802.11: Wireless LAN
- IEEE 802.15: Wireless PAN
  - Bluetooth-based WPAN (802.15.1), co-existence (802.15.2), UWB (802.15.3/3a), sensor networks (802.15.4/4a)
- IEEE 802.16: Wireless MAN, (Fixed) BWA (Broadband Wireless Access)
- IEEE 802.18: RR-TAG (Radio Regulatory Technical Advisory Group)
- IEEE 802.20: MBWA (Mobile BWA)
Wireless Standards in IEEE 802 LMSC

<table>
<thead>
<tr>
<th>Standard</th>
<th>Range (meters)</th>
<th>Peak Data Rate (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.15.1</td>
<td>1</td>
<td>1M, 10M, 100M, 1G</td>
</tr>
<tr>
<td>802.15.3 (UWB)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>802.20</td>
<td>1k</td>
<td></td>
</tr>
<tr>
<td>802.11b</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>802.11a/g</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>802.16(a) (BWA)</td>
<td>1k</td>
<td></td>
</tr>
</tbody>
</table>

Current Bit-rate < 100 Mbps
## Comparative Table of IEEE 802 Wireless Group

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>802.11</th>
<th>802.15</th>
<th>802.16</th>
<th>802.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. Bands</td>
<td>Unlicensed</td>
<td>Unlicensed</td>
<td>Licensed Unlicensed</td>
<td>Licensed</td>
</tr>
<tr>
<td>Range (Typical Cell-size)</td>
<td>Local Area</td>
<td>Personal Space</td>
<td>Metropolitan Area Access</td>
<td>Metropolitan Area Access</td>
</tr>
<tr>
<td>Mobility Support</td>
<td>Portability Local Roaming</td>
<td>Personal Space Connector Avoidance</td>
<td>Fixed (Mobile)</td>
<td>Vehicular speed mobility Inter-Metro roaming</td>
</tr>
<tr>
<td>Station Power</td>
<td>Battery</td>
<td>Battery</td>
<td>Mains</td>
<td>Battery</td>
</tr>
<tr>
<td>LOS/NLOS</td>
<td>NLOS</td>
<td>NLOS</td>
<td>LOS (10-66GHz) NLOS (2-11GHz)</td>
<td>NLOS</td>
</tr>
</tbody>
</table>
Part 2: Current Trends on IEEE 802.11 WLAN Standardization
Contents

- Introduction to IEEE 802.11
- Overview of IEEE 802.11 technologies
- Finalized and Finalizing IEEE 802.11 Standards
- Emerging IEEE 802.11 Standards
- Other Related Standards
- Conclusion
History

- 1970s: ALOHA
- 1972: Slotted ALOHA
- 1975: Carrier Sense Multiple Access (CSMA)
  - Non-persistent
  - p-persistent
- CSMA/CD: Ethernet (1976)
IEEE 802.11 Standards

- Layers 1 and 2

- 1 MAC and Multiple PHYs

1. MAC (common)
   - 2.4GHz 2.4GHz
   - 1 & 2Mbps
   - 5GHz

   - 802.11b CCK
     - 5.5 & 11 Mbps
   - 802.11g ERP-X
     - 1 ~ 54 Mbps
   - 802.11a OFDM
     - 6 ~ 54 Mbps

IEEE 802.11’s scope

Applications
TCP/UDP
IP
LLC
MAC
PHY

Took Off
Available since 2003. 7
Available since 2002

2004/2/9, Seungeok Hong – 11
IEEE 802.11 Wireless LAN Standardization

- 802.11 Working Group formed in 1991
  - Individual membership
  - Published the 1st spec. in 1997

- Within IEEE 802 LAN/MAN Standards Committee
  - 802.1D/G/Q/etc., 802.2 LLC, 802.3 CSMA/CD, 802.15 WPAN

- All IEEE 802.x MAC has the same MAC SAP!!!
  - Between 802.x MAC and 802.2 LLC
  - Between 802.x MACs via 802.1D bridge
802.11: Liaisons with Standards Organizations and Industry Bodies

- IEEE 802.11
- IEEE 802.15 Wireless Personal Area Networks
- Bluetooth
- IEEE 1394 & 1394 TA
- 5GIAG
- Cable Labs
- OFDM Forum
- ETSI – BRAN HIPERLAN
- Japan MMAC/PC
- IEEE 802.16 Wireless Broadband
- Europe
- 2004/2/9, Seungeok Hong – 13
Overview of IEEE 802.11 Technologies
Infrastructure(IS) Mode

- An Access Point(AP) and multiple Stations(STAs)
  - AP works as a bridge between wired and wireless.
  - Every transmission is between AP and STA(s).
  - BSS, ESS

- **Ad-hoc mode**
  - IBSS
IEEE 802.11 PHY

- The EM Spectrum allocation

Freq.:
- 1 KHz
- 1 MHz
- 1 GHz
- 1 THz
- 1 PHz
- 1 EHertz

Infrared
- Visible
- UV
- X-rays
- Gamma-rays

Freq.:
- 30 KHz
- 300 KHz
- 3 MHz
- 30 MHz
- 300 MHz
- 3 GHz
- 30 GHz

LF
- (AM radio)
- MF

MF
- (SW radio)
- HF

HF
- (FM radio, TV)
- VHF

VHF
- (Cellular, TV)
- UHF

UHF
- SHF

ISM
- Cordless phone
- Old WLAN

IEEE 802.11(b)
- Bluetooth
- Microwave Oven

IEEE 802.11a
- HiperLAN2

U-NII & Other bands
- Cordless phone
- Old WLAN

IEEE 802.11(b)
- Bluetooth
- Microwave Oven

IEEE 802.11a
- HiperLAN2
5GHz대 주파수의 개요

5.150~5.725GHz대역에서 위성통신, 레이다, 방송중계용에 사용하고 있는 주파수를 WRC-2003 결과에 따라 국내에서 무선랜 및 FWA 분배 검토중

국내주파수 분배현황

<table>
<thead>
<tr>
<th>주파수</th>
<th>위성통신 (ICO, 글로벌스타 위성지구막)</th>
<th>기상용,군용 레이다</th>
<th>항공기레이다 무선항행 무선표정 (2차)</th>
<th>기상용,군용 레이다 TV방송중계</th>
<th>ISM (ITS,WLAN) TV방송중계</th>
</tr>
</thead>
<tbody>
<tr>
<td>실내WLAN</td>
<td>실내 외WLAN FWA</td>
<td>실외WLAN</td>
<td>실외WLAN</td>
<td>ISM</td>
<td></td>
</tr>
</tbody>
</table>

※TV 방송중계(5.650~5.925GHz)
WRC-2003 국제 분배 결과

### 결의 1
이동업무 (RLAN)를 1차 업무로 분배

<table>
<thead>
<tr>
<th>대역 (MHz)</th>
<th>출력 (max. EIRP)</th>
<th>범위</th>
<th>제한 규정</th>
<th>공유방안</th>
</tr>
</thead>
<tbody>
<tr>
<td>5150~5250</td>
<td>200mW (10mW/MHz or 0.25mW/25kHz)</td>
<td>실내</td>
<td>MSS 위성수신기 보호 (ITU-R S.1426 권고)</td>
<td>실내, 출력 제한</td>
</tr>
<tr>
<td>5250~5350</td>
<td>200mW (10mW/MHz) or 1W (50mW/MHz)</td>
<td>실내</td>
<td>EESS 보호 (ITU-R F.1613, SA.1166, SA.1632, M.1652 권고)</td>
<td>안테나 마스크, 공유기술 적용</td>
</tr>
<tr>
<td>5470~5725</td>
<td>1W (50mW/MHz) or 250mW (공중선전력)</td>
<td>실외</td>
<td>무선표정보호 (ITU-R M.1653 권고)</td>
<td>공유기술 적용</td>
</tr>
</tbody>
</table>

### 결의 2
고정업무 (FWA)를 추가 업무 (제 3지역 한국포함 12개국)로 분배

<table>
<thead>
<tr>
<th>대역 (MHz)</th>
<th>출력 (max. EIRP)</th>
<th>범위</th>
<th>제한 규정</th>
<th>비 고</th>
</tr>
</thead>
<tbody>
<tr>
<td>5250~5350</td>
<td>2W (BS10/UT15dBi 안테나 이득포함)</td>
<td>실외</td>
<td>EESS, SRS 보호 (ITU-R M.1613 권고)</td>
<td>일본, 한국포함 12개국</td>
</tr>
</tbody>
</table>

※ 결의 3 : 5460~5570MHz대역에 지구탐사 및 5350~5570MHz대역에 우주연구 1차업무 추가분배
결의 4 : 5350~5650MHz대역에 무선표정보업무를 1차업무로 상향 조정

* E.I.R.P (Effective Isotropic Radiated Power) : 공중선전력 + 안테나이득
각국별 활용현황

<table>
<thead>
<tr>
<th>도메인</th>
<th>주파수대</th>
<th>국가</th>
<th>주경로</th>
</tr>
</thead>
<tbody>
<tr>
<td>및범위</td>
<td>5.150~5.250GHz</td>
<td>한국</td>
<td>검토중</td>
</tr>
<tr>
<td>BMAS</td>
<td>5.350~5.470GHz</td>
<td>한국</td>
<td>검토중</td>
</tr>
<tr>
<td>ISM</td>
<td>5.725~5.825GHz</td>
<td>한국</td>
<td>검토중</td>
</tr>
<tr>
<td>유럽</td>
<td>455MHz</td>
<td>유럽</td>
<td>비면허</td>
</tr>
<tr>
<td>Hiperlan II</td>
<td>300MHz</td>
<td>미국</td>
<td>비면허</td>
</tr>
<tr>
<td>U-NII</td>
<td>455MHz</td>
<td>일본</td>
<td>비면허</td>
</tr>
</tbody>
</table>

- 유럽은 Hiperlan II 융용으로 주파수 455MHz(5.15~5.35, 5.47~5.725GHz) 할당
- 미국은 300MHz(5.15~5.35, 5.725~5.825GHz)을 비허가 대역으로 할당(1997)
- 일본은 5.15~5.25GHz BMAS용으로 할당(2000.3), 5.25~5.35GHz FWA 추진 검토

* BMAS(Broadband Mobile Access System) : 일본의 고속무선접속 서비스
  UNII (Unlicensed National Information Infrastructure ) : 미국의 초고속무선망용 비면허주파수 대역
What’s Next with IEEE 802.11?

- Does it provide Secure Communication?
  - No!!! Many securities holes in 802.11 → 802.11i
- Is Wireless Ethernet sufficient for you?
  - No!!! Emerging A/V wireless applications → 802.11e
- Is 11Mbps PHY rate at 2.4GHz enough?
  - No!!! The faster, the better → 802.11g → Complete project!!!
- Can We live with Bluetooth or other 2.4GHz wireless techs?
  - No!!! Not easy, Looking for solutions about the co-existence problem → 802.15.2
Finalizing or Finalized Standardization Efforts
TGe for QoS

- Enhance the current 802.11 MAC to expand support for applications with QoS requirements, and in the capabilities and efficiency of the protocol
- Modifying both DCF and PCF to make Hybrid Coordination Function (HCF)
  - New channel access mechanism (EDCA, HCCA)
- Added feature
  - Prioritization/parameterized QoS support (TXOP, AIFS, CWmin/max)
  - Burst transmission (Group ACK)
  - Direct Link

- Status
  - LB#59 on 802.11e/D5.0 passed
    - Aug. 23, 2003
  - LB#63 on 802.11e/D6.0 (?)
  - First-generation 802.11e products was available last year (2003)!
    - Partially or full draft spec.
TGf for Inter-Access Point Protocol (IAPP)

- To enable communications among APs from different vendors to form an infrastructure (called Distribution System)
  - Eg.) to support hand-off smoothly
- A recommended practice using UDP/IP, TCP/IP, RADIUS, ...
- Status
  - Sponsor ballot process is finalizing (802.11f/D6.0)
  - Complete project. (Jul. 2003)
TGg for Extended Rate PHY (ERP)

- To support over 20 Mbps at 2.4 GHz band
- Combination of 802.11b CCK & 802.11a OFDM (@2.4 GHz)
  - Optionally, DSSS-OFDM & ER-PBCC-22/33
- Co-existence with 802.11b
  - Protection scheme
- Low throughput because co-existence with 802.11b STAs
  - Packet bursting : 802.11e draft

- Status
  - Sponsor ballot finalized (802.11g/D8.2)
  - Complete project
    - Approved in Jul. 2003
  - Some products based on standard spec available already !!!
T Gh for Spectrum Management

- Spectrum Managed IEEE 802.11a
- Defining Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC)
- To handle European regulation, which requires DFS and TPC at 5GHz
  - Can be useful for smart spectrum management

- Status
  - Sponsor ballot on going
  - 802.11h/D3.11
  - Sep., 2003 passed!!!
  - Further work in IEEE 802.18
TGi for Security

- Enhance the current 802.11 MAC to provide improvements in security
  - Addressing known security problems
- New encryption and key management
  - TKIP (Wi-Fi WPA 1.0)
  - CCMP (Wi-Fi WPA 2.0 ?)
  - 4-way hand-shake key negotiation
  - PSK for Ad-hoc
- Status
  - LB#62 on 802.11i/D7.0 passed (Nov., 2003)
IEEE 802.11 표준화 개요

- IEEE 802.11 Wireless LAN
  - 802.11b: Supports 11 Mbps at 2.4 GHz
  - 802.11a: Supports 54 Mbps at 5GHz with OFDM
  - 802.11e: Enhancement of QoS.
  - 802.11d: Beacon
  - 802.11f: Inter AP Protocol
  - 802.11g: Supports 54 Mbps at 2.4 GHz with OFDM
  - 802.11h: Adoption of TPC and DFS to avoid Interference
  - 802.11i: Enhancement of Security
  - 802.11 5GSG: Harmonization of 5GHz Range
  - 902.11 WNG: Wireless LAN Next Generation
Emerging and Other Standardization Efforts
TGj for 4.9 ~ 5 GHz Operation in Japan

- To enhance the current 802.11 MAC and 802.11a PHY to additionally operate in newly available Japanese 4.9 GHz
- To obtain Japanese regulatory approval
  - Channel numbering for 4.9 GHz
  - Optional 5 & 10 MHz channels

- Status
  - Initial meeting in Jan. 2003
  - Proposed draft D1.0 in March 2003
  - D1.2 in Nov. 2003
  - LB #64 on 802.11j/D1.2 (?)
TGk for Radio Resource Management

- To define Radio Resource Measurement enhancements to provide interfaces to higher layers for network measurements
- Original standard has a basic set of radio resource measurements for internal use
  - Make them available to external entities for, e.g., roaming, coexistence, and others

- Status
  - Initial meeting in Jan. 2003
  - 802.11k/D0.9 : Dec. 2003
TGm for Maintenance

- To correct technical errors and so on coming from the integration of multiple amendments
- Activity in parallel with 802.11 editor
  - 802.11-1999 (2003 edition) will be generated by 802.11 editor by combining 802.11-1999, .11a, .11b, and .11d
- Status
  - Started in Mar. 2003
TGN (Old High Throughput Study Group (HTSG))

- To improve the 802.11 standard to provide higher throughput, i.e., 100 Mbps
- Enhance both OFDM PHY and MAC
  - Make the current MAC more efficient
  - Add MIMO, channel bonding, etc. to PHY

- Status
  - Will work as a TG beginning in May
  - Officially, becoming a TG in Sept.
WLAN Next Generation Standing Committee (WNG SG)

- Investigating the globalization and harmonization of WLANs and revisions to the 802.11 standard
  - Jointly with ETSI and MMAC
  - Refinement to the existing IEEE 802.11 standard
  - A never-ending activity, different from TGs

- Past and current discussion topics:
  - Both TGk and HTSG spun off from WNG SG
  - Inter-working with 3G, smart antenna, UWB, VoIP, multi-hop, fast handoff...
Current Technological Issues of Real World

- Efficient hot-spot planning
- QoS
- Seamless roaming/hand-off
- Security
- High-speed mobility issues

⇒ Adopted Application Areas: VoIP, Audio/Video Streaming, Video Conferencing, Ubiquitous Computing, etc.
Upcoming TGs and SGs in IEEE 802.11 (1)

- **TGP**: Wireless Access for the Vehicular Environment (WAVE SG)
  - DSRC application
  - Vehicle-to-roadside, vehicle-to-vehicle communication
  - Delay/Doppler spread immunity increasing algorithms/techniques

- **TGr**: Fast Roaming
  - Seamless roaming techniques

- **TGs**: ESS Mesh Networking
  - New WDS usage model
  - Hybrid(ad-hoc + infra) network forming techniques(?)
Upcoming TGs and SGs in IEEE 802.11 (2)

- **WIEN SG**: Wireless InterWorking with External Networks
  - Ex.) 3GPP/3GPP2, etc.

- **WNM SG**: Wireless Network Management

- **WPP SG**: Wireless Performance Prediction Study
Related Other Standards Activity

- IEEE 802.15.x ➔ WPAN, UWB
- IEEE 802.16 ➔ (M)BWA
- IEEE 802.20 ➔ MBWA
  - 802.20 + 802.16 ➔ Cellular(3G ~ ??)
  - 802.20 + 802.16 + 802.11 ➔ pure IP based Ubiquitous communication(?) (both data and voice, toward 4G)
- Test and Research for inter-operability or co-existence with standards activity above
  - Seamless mobility
  - QoS provisioning
  - Security
Conclusion

- Introduced the IEEE 802.11 WLAN technology and standard

- Reviewed the current standardization trends within the IEEE 802.11 Working Group
Part 3 : Wireless LAN Service and/or Application Aspects : New Issues and Attempt of IEEE 802.11 WLAN
Contents

• Introduction

• Interworking with Other network
  – Converging technologies for AAA function
  – Heterogeneous (seamless) handoff

• In-building or outdoor usage
  – Hot-spot, Hot-zone
  – Cellular model
  – Vehicle communication

• Usage of Home Networking
  – Audio/Video transmission
  – Coverage extension and Rate adaptation techniques
3 main segments of WLAN market

- Residential/SOHO
- Enterprise mobile WLAN network
- Cellular off-load network
3 main segments of WLAN market: An Integrated Network
Interworking with Other networking
Interworking with Other Network (1)

- WLAN + Cellular interoperability
  - 3GPP + WLAN
  - 3GPP2 + WLAN

- Converging Service Architecture
  - Tight coupling
  - Loose coupling
  - No coupling

- Issues
  - Security: Authentication/Authorization, Billing
  - Handoff

→ Integrated AAA (functional, logical/physical)
Interworking with Other Network (2)

Loose coupling

Tight coupling
Handoff Issues

- Vertical (Inter-network(technology), heterogeneous)
- Horizontal (Intra-network(technology), homogeneous)
- Seamless handoff
  - L2 handoff → intra-tech handoff
  - L3 handoff: most delay source
    - IETF MobileIP and variants
    - Requirement of optimizing algorithm: routing, caching, etc.
WLAN for In-Building or Outdoor
WLAN for Hot-spot or Hot-zone

- Cell design
  - Load balancing algorithm
  - Capacity increasing problem

- RF Frequency Planning for Enterprise or Outdoor Deployment
  - Consideration of co-channel & adjacent channel interference
    - Dense AP installation: similar to micro-cellular RF networks
    - IEEE 802.11 b/g/a: Independent frequencies
      - 5.1 ~ 5.3 GHz: 8
      - 2.4 GHz band: 3 (4?)
Cell Planning Example (1)

7 frequency, Reuse = 1

3 frequency, Reuse = 1
Cell Planning Example (2)

- C = 7 (7 frequency)
  - \( R_u = R_{cell} \times \sqrt{3 \times C} = 4.48 \times R_{cell} \)
- C = 3 (3 frequency)
  - \( R_u = R_{cell} \times \sqrt{3 \times C} = 3.00 \times R_{cell} \)

- C: cluster size, which is the number of frequencies used in the reuse pattern
- \( R_u \): the reuse radius of the cell cluster
- \( R_{cell} \): the radius of coverage of a single cell
Cell Planning Example (3)

- Distance > AP’s cell radius
  - \( RF \) propagation loss \( \propto R^3 \) or \( R^4 \)
  - Free space propagation loss \( \propto R^2 \)

- Interference reduction
  - \( C = 7 \): 19.5 dB to 26.1 dB (allows 36 to 54 Mbps OFDM)
  - \( C = 3 \): 14.3 dB to 19.1 dB (allows 22 Mbps to 36 Mbps)
Cell Capacity Increasing Purpose

*Smart antenna + Power control*

- Sectorizations + space-time signal processing + beam-forming + other adaptive signal processing techniques
- Sectored antenna (current) $\rightarrow$ array adaptive antenna ((near) future)
- Adopting to Enterprise and outdoor: very careful placement & alignment cell sector
- Power control: IEEE 802.11 is not introduced.
  - On-going study: IEEE 802.11h (*finished*) + IEEE 802.11k + IEEE 802.11n + WPP SG + fast-roaming SG
Outdoor Usage

- DSRC
- Vehicle-to-Roadside communication
  - IEEE 802.11a-RA (Road Aside)
- Vehicle-to-Vehicle communication

➢ **WAVE SG.**

MAC and PHY Enhancement need
WLAN for Home Networking
WLAN for Home Networking

• A/V streaming and transmission (QoS)
  – Transmission between A/V consumer electronics
    • HD monitor – HD set-top or other various media source device
    • Relationship to UWB
  – VoIP

• Coverage extension and Reduced shadowing region
  – ESS mesh networking (TGs ?)
  – Dual-band concurrent operable AP
    • Throughput enhancement + range extension
Multimedia over IP

- Other Applications requiring QoS capabilities over WLAN
  - Distribution audio
    - Net radio, MP3 music, etc.
  - Distribution video
    - Streaming video, DVD, HDTV, etc.
  - Easy BW planning: Improvements of the quality of video codecs (e.g. MPEG-4)
    - DVD quality $\rightarrow \sim 1$ Mbps
### Home Capacity Analysis (1)

**No HD case**

<table>
<thead>
<tr>
<th>Service</th>
<th>Rate Upstream (Mbps)</th>
<th>Rate Downstream</th>
<th>Number of Channels</th>
<th>Total Rate Upstream</th>
<th>Total Rate Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPEG DVD-TV</td>
<td>0.5</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>Toll Quality Voice</td>
<td>0.064</td>
<td>0.064</td>
<td>2</td>
<td>0.128</td>
<td>0.128</td>
</tr>
<tr>
<td>Streaming Media</td>
<td>0.01875</td>
<td>0.3</td>
<td>2</td>
<td>0.0375</td>
<td>0.6</td>
</tr>
<tr>
<td>ABR Web Service</td>
<td>0.0965</td>
<td>0.386</td>
<td>1</td>
<td>0.0965</td>
<td>0.386</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>1.262</td>
<td>17.114</td>
</tr>
</tbody>
</table>
# Home Capacity Analysis (2)

## HD usage case (not introduced MPEG-4)

<table>
<thead>
<tr>
<th>Service</th>
<th>Rate Upstream (Mbps)</th>
<th>Rate Downstream</th>
<th>Number of Channels</th>
<th>Total Rate Upstream</th>
<th>Total Rate Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD-TV</td>
<td>1.5625</td>
<td>25</td>
<td>2</td>
<td>3.125</td>
<td>50</td>
</tr>
<tr>
<td>Toll Quality Voice</td>
<td>0.064</td>
<td>0.064</td>
<td>4</td>
<td>0.256</td>
<td>0.256</td>
</tr>
<tr>
<td>Streaming Media</td>
<td>0.01875</td>
<td>0.3</td>
<td>1</td>
<td>0.01875</td>
<td>0.3</td>
</tr>
<tr>
<td>ABR Web Service</td>
<td>0.0965</td>
<td>0.386</td>
<td>2</td>
<td>0.193</td>
<td>0.772</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3.59275</strong></td>
<td></td>
<td></td>
<td><strong>51.328</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Need efficient MAC(HCF) for optimized BW control & more compression technologies !!!*

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Not enough 802.11a/g
Home Capacity Analysis (3)

- VoIP
  - Do not require a significant amount of bandwidth
  - Removing other 2.4GHz, 5.2/5.8GHz interference source
  - New market creation
Application of Repeater/Small mesh AP for Residential/SOHO Coverage (1)

- Most critical issues
  - Cell coverage
  - Throughput

- Low-cost method
  - Using repeater (can be used to implement small mesh residential network) : WDS

- Related TGs and SGs in IEEE 802.11
  - TGn, TGk, TGi, fast-roaming SG, WPP SG, ESS mesh SG
Application of Repeater/Small mesh AP for Residential/SOHO Coverage (2)

Examples
Application of Repeater/Small mesh AP for Residential/SOHO Coverage (3)

- Multi-hop connectivity
  - Pros. : coverage extension, capacity increasing
  - Cons. : additive delay introduce by routing delay, retransmission between APs and others
    - Excessive round-trip delay ➔ Provision problematic environment for VoIP and Video conferencing

- 2 cases for residential mesh network
  - Single-freq. mode
    - Not dual-mode and only supporting single freq.
    - AP-AP & AP-clients ➔ single freq. operation
  - Dual-freq. mode
    - Simultaneous 2 freq. supporting, 2 separate wireless link supporting
Application of Repeater/Small mesh AP for Residential/SOHO Coverage (4)

**Single-freq. mode**
- Backward compatible
- Highly inefficient: overlapping coverage areas
  - High interference environment
  - Worst case throughput: reduced factor = 1/(N+1). N = # of repeater/mesh APs (WDS reducing factor)

**Dual-freq. mode**
- All APs support 2 freq. simultaneously.
  - Example)
    - AP-to-AP backbone(?) comm.: 5GHz 802.11a
    - AP-to-client comm.: 2.4GHz 802.11b/g
  - Interference limiting effect!!!
Application of Repeater/Small mesh AP for Residential/SOHO Coverage (5)

Examples of Dual-frequency configuration

Cable/DSL MODEM

5.XGhz inter-AP backhaul

AP A

AP B

Subscriber coverage area A
Freq. : 2.4GHz Ch. #1

Subscriber coverage area B
Freq. : 2.4GHz Ch. #5
감사합니다 !!!!