IEEE802.11n Standardization: Introduction and Status October-2005

ENSEIRB ’05

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Overview

Introduction to IEEE standardization
Introduction to IEEE802.11n objectives
Current status of standardization & future
Presentation of TGnSync proposition
Presentation of WWiSE proposition
Comparison TGnSync / WWiSE
Q & A
Introduction to IEEE802.11 standardization
IEEE standardization process

Initiation of a Study Group (SG)

Definition of the PAR (« project authorization request »)

Initiation of the Working Group (WG)

Definition of the Draft Standard (75%)

Letter Ballot Phase

Approve Draft Standard

Publish approved Standard
Practical Aspects

&

Who is participating to IEEE Standardization?
La normalisation IEEE

La normalisation IEEE: Voir le site « 802wirelessworld.com » pour 802.11
La participation / droit de vote pour individus (pas l’entreprise // ETRI)
Réunions tous les 2 mois, par exemple 2005:
  - janvier: Monterey, USA
  - mars: Atlanta, USA
  - mai: Cairns, Australia
  - juillet: San Francisco, USA
  - septembre: Anaheim, USA
  - novembre: Vancouver, Canada
  - janvier 2006: Big Island, Hawaii
  - + F2F meetings

Participants: En générale des PhD en communication numériques / MAC
Souvent très expérimenté
A la fois des directeurs de recherche et des chercheurs
Majorité: Chercheur des entreprises privées
Quelques universitaires (plutôt américain)

Déroulement à l’IEEE: 1) Mise en place d’un « study group »
2) Definition d’un PAR (Project Authorization Request)
3) Definition du « Draft Standard »
4) Letter Ballot phase

Motivation / entreprises: Discussion
### Active Working Groups and Study Groups

- **802.1** Higher Layer LAN Protocols Working Group
- **802.3** Ethernet Working Group
- **802.11** Wireless LAN Working Group
- **802.15** Wireless Personal Area Network (WPAN) Working Group
- **802.16** Broadband Wireless Access Working Group
- **802.17** Resilient Packet Ring Working Group
- **802.18** Radio Regulatory TAG
- **802.19** Coexistence TAG
- **802.20** Mobile Broadband Wireless Access (MBWA) Working Group
- **802.21** Media Independent Handoff Working Group
- **802.22** Wireless Regional Area Networks
- **Link Security** Executive Committee Study Group is now part of 802.1

### Inactive Working Groups and Study Groups

- **802.2** Logical Link Control Working Group
- **802.5** Token Ring Working Group
- **802.12** Demand Priority Working Group

### Disbanded Working Groups and Study Groups

- **802.4** Token Bus Working Group
- **802.6** Metropolitan Area Network Working Group
- **802.7** Broadband TAG
- **802.8** Fiber Optic TAG
- **802.9** Isochronous LAN Working Group
- **802.10** Security Working Group
- **802.14** Cable Modem Working Group (Temporarily housed off-site)
- **QOS/FC** Executive Committee Study Group
IEEE802.11: Topics

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<th>Available Bandwidth per Channel</th>
<th>Frequency Band</th>
</tr>
</thead>
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<tr>
<td>IEEE802.11</td>
<td>up to 2 Mbps</td>
<td>1 MHz (FHSS), 22 MHz (DSSS)</td>
<td>2.400 - 2.483 GHz</td>
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<td>IEEE802.11a</td>
<td>up to 54 Mbps</td>
<td>20 MHz (16.7 MHz used)</td>
<td>5.18 - 5.32 GHz</td>
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<td>up to 11 Mbps</td>
<td>22 MHz</td>
<td>2.400 - 2.483 GHz</td>
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<tr>
<td>IEEE802.11g</td>
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<td>22 MHz (to be defined)</td>
<td>2.400 - 2.483 GHz</td>
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<td>IEEE802.11d</td>
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<td>Regulatory issues for 2.4 GHz</td>
<td></td>
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<td>IEEE802.11f</td>
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<td>IEEE802.11REVma</td>
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<td>IEEE802.11n</td>
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<td>High Throughput Management</td>
<td>20MHz and 40MHz</td>
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<tr>
<td>IEEE802.11p</td>
<td>Wireless Access for Vehicular Environment</td>
<td>2.4GHz &amp; 5GHz band</td>
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<td>Mesh Networking</td>
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<td>IEEE802.11t</td>
<td>Recommended Practice Wireless Perform.</td>
<td>2.4GHz &amp; 5GHz band</td>
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<td>IEEE802.11u</td>
<td>Interworking with External Networks</td>
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<td>IEEE802.11v</td>
<td>Wireless Network Management</td>
<td>2.4GHz &amp; 5GHz band</td>
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<tr>
<td>IEEE802.11 ADS SG</td>
<td>Advanced Security</td>
<td>2.4GHz &amp; 5GHz band</td>
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<tr>
<td>IEEE802.11 ADF SG</td>
<td>Access Point Functionality</td>
<td>2.4GHz &amp; 5GHz band</td>
<td></td>
</tr>
</tbody>
</table>
Introduction to IEEE802.11n objectives
IEEE802.11n scope and status (1/3)

Scope: high throughput WLANs

PAR (Project Authorization Request) objective: “Define modifications to both 802.11 PHY and MAC so that a maximum throughput of at least 100Mbps at the MAC SAP is enabled”

Functional Requirements for IEEE802.11n:

“100Mbps must be demonstrated in a 20MHz bandwidth”
“Backward compatibility with 802.11a”
“Backward compatibility with 802.11g if 2.4GHz band considered”

Motorola gives inputs beyond PAR

PAR sees MIMO as technology for throughput increase
(implicitly at short range)

Motorola wants to exploit MIMO for range extension: low/medium-rate & long-distance
IEEE802.11n scope and status (2/3)

Status of 802.11n

Issue of Call For Proposals requires approval of Functional Requirements, Comparison Criteria and Usage Models documents, which is expected at the May session (publication of standard: beginning of 2006?)

Main focus on PHY enhancement: proposal of multiple antenna techniques (Space-Time Block Codes, Spatial Division Multiplexing, etc.) and advanced coding techniques (LDPC, Turbo-Codes)

MAC enhancements: extended-range modes, low-power modes, etc.

Main differences between WWiSE / TGnSync

Closed loop / open loop approach

Beamforming / STBC

Definition of LDPC codes
**IEEE802.11n scope and status (3/3)**

**Increase PHY performance**

Given PAR and Functional requirements ("100Mbps in 20MHz bandwidth") multiple antenna techniques are required to increase the peak data rate with good coverage (add advanced coding schemes?)

Which multiple antennas techniques should be used?

How many antennas can be considered?

How does “100Mbps at the MAC SAP” translate in terms of PHY data rate requirements (⇐ depends on MAC efficiency ⇐ depends on MAC amendment)?

**Increase MAC SAP goodput:**

SAP = Service Advertisement Protocol, goodput = measurement of actual data successfully transmitted

How high can the throughput be with an enhanced PHY and 802.11 or 802.11e MACs?

How can this efficiency be increased with backward compatibility constraints?
Introduction to IEEE802.11n:

Overview over an OFDM (MIMO) System
A typical OFDM/MIMO system: IST-BroadWay

Scrambler
FEC encoding
Interleaving
Mapping
Frequency domain spreading (for CC, K=5)

Pilots / zeros insertion & IFFT
Guard Interval (CP-OFDM) or Pseudo-Random-Postfix (PRP-OFDM) insertion for low-complexity CIR tracking in mobility context

DAC / low-pass filtering / digital I/Q modulator

5GHz / 60GHz up-conversion (55GHz fixed frequency osc. for low phase-noise)
Introduction to IEEE802.11n objectives:

Overview on MIMO techniques
Candidate technologies (1/4)

Multiple antenna techniques (1/3)

Space-Time Block Codes (STBC) to benefit from transmit spatial diversity (with Maximum Ratio Combining)

Suitable for increasing communication reliability/range or overall cell throughput, but they are not optimal for high peak data rates

Spatial Division Multiplexing (SDM, MIMO)

Data rate multiplied by number of transmit antennas but transmit diversity not exploited and potentially high decoding complexity \((N_r \geq N_t)\)
Multiple antenna techniques (2/3)

Hybrid schemes: increase data rate and exploit transmit diversity for higher robustness/good range

Combining SDM and STBC is a good tradeoff + possibility to handle asymmetrical antenna configurations (e.g. 4x2)

Transmit diversity exploited with partial CSI at the TX: select subcarrier/antenna subset based on SNR, capacity...

- SDM combined with STBCs (Open Loop OL)

- SDM combined with TS (Closed-Loop CL)
Candidate technologies (3/4)

Multiple antenna techniques (3/3): SVD based beamforming

\[ y(t) = H \cdot x(t) \]
\[ = U \cdot \Sigma \cdot V^H \cdot x(t) \]
\[ U^H \cdot y(t) = \Sigma \cdot V^H \cdot x(t) \]
\[ y'(t) = x'(t) \]

Beamforming and diversity gain at both receiver and transmitter

Singular Value decomposition:
For a square matrix A, the square roots of the eigenvalues of \( A^H A \)
where \( ^H \) is the conjugate transpose, are called singular values

1st path, \( \alpha_1 = 1 \)
2nd path, \( \alpha_2 = 0.6 \)
Candidate technologies (4/4)

** Modifications to modulator/mapping **

Consider higher order constellations to increase spectral efficiency, e.g. 256QAM 3/4 ⇒ 72Mbps

Increase the number of subcarriers: increase peak data rate (keep same cyclic prefix length) or increase robustness to IBI (increase also cyclic prefix length)?

Consider advanced OFDM modulators e.g. PRP-OFDM modulator for low complexity robustness to mobility (see advanced PHY, IP)

** Advanced coding schemes **

Turbo-Codes or LDPCs: might be required to decrease SNR requirements. Possibility to push IP on advanced coding schemes from Motorola Labs (Joe Nowak)
Presentation of TGnSync key features
TGnSync members

OEM / System Vendors
- Cisco
- C-Cation (New)
- Interdigital (New)
- Mitsubishi Electric
- Nortel
- Panasonic
- Samsung
- Sanyo
- Sharp
- Sony
- Toshiba
- Wavebreaker/ATcrc
- Wavion

Semi-Conductor Vendors
- Agere
- Atheros
- Intel
- Marvell
- Philips
- Qualcomm

Academia
- Infocomm
- Tohoku University
- Univ of Victoria
- Polytech Inst. of NY (New)
Scalable PHY Architecture

**Mandatory**
- Open Loop SDM
- Conv. Coding
- RX assisted Rate Control
- 2 Spatial Streams
- Low Cost & Robust
- Regulatory Constraints
  - 20 MHz
  - ≤ 140 Mbps

**Optional**
- Closed Loop TX BF
- LDPC
- 4 Spatial Streams
- Throughput Enhancement
- Robustness Enhancement
- ≤ 630 Mbps

- ≤ 243 Mbps

Motorola Proprietary Information, IEEE802.11n
MOTOROLA and the Stylized M Logo are registered in the US Patent & Trademark Office. All other product or service names are the property of their respective owners. © Motorola, Inc. 2005
PHY Summary of TGn Sync Proposal

Mandatory Features:
- 1 or 2 Spatial Streams
- 20MHz and 40MHz* channelization
- 1/2, 2/3, 3/4, and 7/8 channel coding rates
- RX assisted Rate Control
- Optimized Interleaver for 20 & 40MHz
- 400ns & 800ns Guard Interval
- Full & seamless interoperability with a/b/g

Optional Features:
- Transmit Beamforming
- Low Density Parity Check (LDPC) Coding
  - Completed merger process with LDPC partial proposals
- Support for 3 or 4 spatial streams

NEW

140Mbps in 20MHz
243Mbps in 40MHz

NEW
PHY Summary

Mandatory Rate of 140Mbps in 20MHz:
- 2 Spatial Streams
- 7/8th rate coding
- 400ns Guard Interval
- RX assisted Rate Control

Low Cost & Robust Throughput Enhancement:
- Scalable to 243 Mbps in 40MHz

Optional Robustness/Throughput Enhancements:
- LDPC Coding
- Transmit Beamforming
- Scalable to 630Mbps with 4 spatial streams in 40MHz
Scalable MAC Architecture

BASELINE MAC
- Robust Aggregation
- QoS Support (802.11e)
- Rx assisted link adapt.

LEGACY INTEROP.
- Long NAV
- Pairwise Spoofing
- Single-Ended Spoofing

ADDITIONAL EFFICIENCY
- Header Compression
- Multi-Receiver Aggregation
- Bi-Directional Data Flow
- BA Enhancements

CHANNEL MANAGEMENT
- 20/40 MHz Modes

Robust & Scalable MAC Architecture
Explanations

(Long) NAV

NAV: When the data frame is transmitted all the other nodes hearing the data frame adjust their Network Allocation Vector (NAV), which is used for virtual carrier sense at the MAC layer.

Long NAV: When a STA has a TXOP, it may set a long NAV to protect multiple PPDUs using a single protection MAC layer protection exchange, e.g., RTS/CTS.

Spoofing

Spoofing is the use of the legacy RATE and LENGTH fields to keep the legacy STA off the air for a desired period of time

```
L-STF    L-LTF  L-SIG  HT-SIG  HT STF  HT LTF  ...  HT LTF  Data
```

→ Legacy RATE and LENGTH fields
   => Packet Length in OFDM Symbols

Pairwise Spoofing: Protection of pairs of PPDUs sent between an initiator and a single responder

Single-ended Spoofing: Protection of aggregate and any responses using legacy PLCP spoofing at the initiator only, Can be used to protect multiple responses
MAC Summary of TGn Sync Proposal

Mandatory Features:
- MAC level aggregation
- RX assisted link adaptation
- QoS support (802.11e)
- MAC header compression
- Block ACK compression
- Legacy compatible protection
- 20/40 MHz channel management

Optional Features:
- Bi-directional data flow
- MIMO RX Power management
Presentation of WWiSE key features
Expanded membership

Airgo Networks
Broadcom
Buffalo
Conexant
ETRI
France Telecom
Hughes Network Systems
ITRI
Motorola

Nokia
NTT
Ralink
Realtek
STMicroelectronics
Texas Instruments
TrellisWare
Winbond
PHY features

Mandatory modes:
- 2 transmitters, 20 MHz, open-loop using SDM
- Rates 54, 81, 108, 121.5, 135 Mbps
- Evolution to OFDM format, raising data rate to 135 Mbps

10 MHz channelization supported (optional)
- All 20 MHz modes have a ½-data rate 10 MHz counterpart

Optional 40 MHz counterparts of all 20 MHz modes
- Every mode offered in 20 MHz is also offered in 40 MHz
- 40 MHz channels have regulatory problems and are prohibited in major domains.
  - To provide a unified worldwide 11n experience, it makes the most sense to have
    40 MHz be optional

Optional extensions to 3 and 4 transmit antennas
Optional space-time block codes for longer range
- All space-time block codes are now optional

Optional LDPC code
EXTENDED beacon / Sig-Field for long-range modes
Preamble structure for Interoperability

Interoperability Legacy / 11n:

Transmit Antennas

<p>| | | | | | | | | |</p>
<table>
<thead>
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<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS_{eunit}</td>
<td>GI2</td>
<td>LS_{eunit}</td>
<td>GI</td>
<td>SIG-MM</td>
<td>SS_{evec}</td>
<td>GI2</td>
<td>LS_{evec}</td>
<td>GI</td>
</tr>
<tr>
<td>SS_{eunit} (400 ns cs)</td>
<td>GI2</td>
<td>LS_{eunit} (1000 ns cs)</td>
<td>GI</td>
<td>SIG-MM (1000 ns cs)</td>
<td>SS_{evec} (400 ns cs)</td>
<td>GI2</td>
<td>LS_{evec} (1600 ns cs)</td>
<td>GI</td>
</tr>
<tr>
<td>SS_{eunit} (200 ns cs)</td>
<td>GI2</td>
<td>LS_{eunit} (1000 ns cs)</td>
<td>GI</td>
<td>SIG-MM (1000 ns cs)</td>
<td>SS_{evec} (200 ns cs)</td>
<td>GI2</td>
<td>LS_{evec} (1000 ns cs)</td>
<td>GI</td>
</tr>
<tr>
<td>SS_{eunit} (600 ns cs)</td>
<td>GI2</td>
<td>LS_{eunit} (200 ns cs)</td>
<td>GI</td>
<td>SIG-MM (200 ns cs)</td>
<td>SS_{evec} (600 ns cs)</td>
<td>GI2</td>
<td>LS_{evec} (1700 ns cs)</td>
<td>GI</td>
</tr>
</tbody>
</table>

Short sequence  Long sequence  Signal  Short sequence  Long sequence  Signal  Signal  Long sequence

10 x 0.8 = 8µs  1.6 + 2 x 3.2 = 8µs  4µs  10 x 0.8 = 8µs  1.6 + 2 x 3.2 = 8µs  4µs  4µs  1.6 + 2 x 3.2 = 8µs

Idea:
Tell legacy devices to remain silent during 11n transmission
Optional mode data rates, multiple spatial streams

20 MHz:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Rate ½, 16-QAM</th>
<th>Rate ¾, 16-QAM</th>
<th>Rate 2/3, 64-QAM</th>
<th>Rate ¾, 64-QAM</th>
<th>Rate 5/6, 64-QAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Tx, 20 MHz</td>
<td>81</td>
<td>121.5</td>
<td>162</td>
<td>182.25</td>
<td>202.5</td>
</tr>
<tr>
<td>4 Tx, 20 MHz</td>
<td>108</td>
<td>162</td>
<td>216</td>
<td>243</td>
<td>270</td>
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40 MHz:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Rate ½, 16-QAM</th>
<th>Rate ¾, 16-QAM</th>
<th>Rate 2/3, 64-QAM</th>
<th>Rate ¾, 64-QAM</th>
<th>Rate 5/6, 64-QAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Tx, 40 MHz</td>
<td>108</td>
<td>162</td>
<td>216</td>
<td>243</td>
<td>270</td>
</tr>
<tr>
<td>3 Tx, 40 MHz</td>
<td>162</td>
<td>243</td>
<td>324</td>
<td>364.5</td>
<td>405</td>
</tr>
<tr>
<td>4 Tx, 40 MHz</td>
<td>216</td>
<td>364</td>
<td>432</td>
<td>486</td>
<td>540</td>
</tr>
</tbody>
</table>
Optional mode data rates, single spatial stream

2x1, 20 MHz:

<table>
<thead>
<tr>
<th>PHY rate, Mbps</th>
<th>Code rate</th>
<th>Constellation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.75</td>
<td>1/2</td>
<td>BPSK</td>
</tr>
<tr>
<td>10.125</td>
<td>3/4</td>
<td>BPSK</td>
</tr>
<tr>
<td>13.5</td>
<td>1/2</td>
<td>QPSK</td>
</tr>
<tr>
<td>20.25</td>
<td>3/4</td>
<td>QPSK</td>
</tr>
<tr>
<td>27</td>
<td>1/2</td>
<td>16-QAM</td>
</tr>
<tr>
<td>40.5</td>
<td>3/4</td>
<td>16-QAM</td>
</tr>
<tr>
<td>54</td>
<td>2/3</td>
<td>64-QAM</td>
</tr>
<tr>
<td>60.75</td>
<td>3/4</td>
<td>64-QAM</td>
</tr>
<tr>
<td>67.5</td>
<td>5/6</td>
<td>64-QAM</td>
</tr>
</tbody>
</table>

1x1, 40 MHz; 2x1, 40 MHz

<table>
<thead>
<tr>
<th>PHY rate, Mbps</th>
<th>Code rate</th>
<th>Constellation</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.5</td>
<td>1/2</td>
<td>BPSK</td>
</tr>
<tr>
<td>20.25</td>
<td>3/4</td>
<td>BPSK</td>
</tr>
<tr>
<td>27</td>
<td>1/2</td>
<td>QPSK</td>
</tr>
<tr>
<td>41</td>
<td>3/4</td>
<td>QPSK</td>
</tr>
<tr>
<td>54</td>
<td>1/2</td>
<td>16-QAM</td>
</tr>
<tr>
<td>81</td>
<td>3/4</td>
<td>16-QAM</td>
</tr>
<tr>
<td>108</td>
<td>2/3</td>
<td>64-QAM</td>
</tr>
<tr>
<td>121.5</td>
<td>3/4</td>
<td>64-QAM</td>
</tr>
<tr>
<td>135</td>
<td>5/6</td>
<td>64-QAM</td>
</tr>
</tbody>
</table>
Long range protection for EDCA (Enhanced Distributed Channel Access) / HCCA (HCF controlled channel access)

General idea of extended beacon / SIG-field:
MAC features

Three 802.11e EDCA/HCCA MAC enhancements:
- HTP burst, aggregation, extended Block Ack
  Challenge reduce overhead, approach taken: get rid of the IFS and use MAC header compression
  Note: Block Ack mandatory

MSDU (MAC Layer) Aggregation
- Regroup PDUs for same receiver address
- Removes significant MAC overhead

**Increased maximum PSDU length, to 8191 octets**
- Issue: cannot change TX power and PHY mode

**HTP Burst (High Throughput)**
- Multiple Receiver Address allowed within the burst
- Can change PHY parameters since we deal with multiple destinations (not TX power)
- Block Ack Request and Block Ack frames allowed within burst

**Enhanced Block Ack**
- Introduce possibility not to ACK a Block Ack REQ: do not interrupt HTB bursts

**Rate & mode recommendation**
- It is of critical importance that this information is advisory and does not mandate Tx behavior
  - Rate selection algorithms do not need to be redesigned
  - There is no need for an elaborate protocol to decide when information is stale
  - The transmitter (e.g., AP) may in many situations have more information about overall network conditions than the receiver, should be able to override receiver request
  - Facilitates low power operation
    - E.g., in receiver that is at the edge of its capabilities at the higher data rate

**Channel state information exchange:**
- General purpose mechanism, built on already existing mechanisms in 802.11h
- Sufficient precision for current and future purposes
Comparison TGnSync vs WWiSE
## WWiSE and TGn Sync PHY proposals

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<thead>
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<th>WWISE proposal</th>
<th>TGnSync Proposal</th>
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<tbody>
<tr>
<td><strong>Mandatory</strong></td>
<td></td>
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<tr>
<td>• 20MHz bandwidth (135Mbps)</td>
<td>• 20MHz (140Mbps) and 40MHz (243Mbps) bandwidths</td>
</tr>
<tr>
<td>• 2Tx, 2 spatial streams</td>
<td>• 2Tx, 2 spatial streams</td>
</tr>
<tr>
<td>• Open-loop SDM</td>
<td>• Open loop SDM</td>
</tr>
<tr>
<td>• Coding Rates: 1/2, 2/3, 3/4, and 5/6</td>
<td>• Coding Rates: 1/2, 2/3, 3/4, and 7/8</td>
</tr>
<tr>
<td>• 54 data tones</td>
<td>• Guard interval: 400ns and 800ns</td>
</tr>
<tr>
<td></td>
<td>• 48 data tones in 20MHz bandwidth</td>
</tr>
<tr>
<td></td>
<td>• 108 data tones in 40MHz bandwidth</td>
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<table>
<thead>
<tr>
<th>Optional</th>
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<tr>
<td>• 3 or 4Tx in 20MHz bandwidth</td>
<td>• SDM with 3 or 4 spatial streams</td>
</tr>
<tr>
<td>• STBC</td>
<td>• Orthogonal spatial spreading</td>
</tr>
<tr>
<td>• Hybrid SDM/STBC schemes for asymmetrical configurations</td>
<td>• Transmit beamforming</td>
</tr>
<tr>
<td>• 40MHz bandwidth (1 to 4Tx)</td>
<td>• LDPC codes</td>
</tr>
<tr>
<td>• 108 data tones in 40MHz bandwidth</td>
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<tr>
<td>• LDPC codes</td>
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<th>PL/CP</th>
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<tbody>
<tr>
<td>• Cyclic shift on both STS and LTS</td>
<td>• HT-specific preamble based on tone subsets</td>
</tr>
</tbody>
</table>
Environment/Device/App target
References

03-05-0886-07-000n-wwise-proposal-ht-spec.doc
11-04-0889-04-000n-tgnsync-proposal-technical-specification.doc

WWiSE WEB-Site:
http://www.wwise.org/

TGnSync WEB-Site:
http://www.tgnsync.org/home
Q & A