OFDM-based 802.16.3 sub-11 GHz BWA Air Interface Physical Layer proposal

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Purpose:
To present an OFDM based PHY proposal for 802.16.3 TG3

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OFDM-based PHY Initial Proposal for 802.16.3 PHY

Naftali Chayat and Tal Kaitz

BreezeCOM
Why OFDM?

• Multipath robustness
• Incorporated in data-oriented standards
  – 802.11a: WLAN
  – HIPERLAN/2: WLAN with QoS
• Incorporated in broadcast standards
• Facilitates smart antenna techniques in multipath environment
• Enables fast parallel polling
Guard Interval and FFT Interval

After multipath

FFT interval

2+16 μsec =18 μsec
FFT size tradeoffs

• GI is dictated by multipath duration
• Short FFT advantages
  – Shorter training sequences
  – Lower payload size granularity
  – Phase noise tolerance
• Long FFT advantages
  – Lower GI overhead and pilot symbol overhead
  – Steeper spectrum falloff
  – Facilitates OFDMA
Throughput vs. FFT size

• 64 pt FFT mode
  – 48 data subcarriers, 4 pilot subcarriers

• 256 pt FFT mode (optional gear shift)
  – 208 data subcarriers, 8 pilot subcarriers
    • Faster spectral falloff is utilized to increase the fraction used.

• 16 pt Guard Interval in all modes (4 us @ 3.5 MHz)
  – Once the 64 pt FFT is used only in a small part of the packet, the incentive to decrease the GI reduces

• The 256 subcarrier mode provides
  – 27% rate improvement with 16 pt GI,
  – 18% rate improvement with 8 pt GI

• 1024 mode buys additional 6% or 3%, respectively
Which FFT size to use? Both!

- 64 pt FFT is used in HIPERLAN and 802.11a
- Many proposals sympathize with longer FFT, mainly 256
  - Couple of proposals go higher- 512, 2048
- Pure 256 and beyond is not efficient due to preamble size
  - Unless radically new preambles designed
- Solution – a FFT size switchover
FFT size switchover solution

- Start with FFT size 64 preamble
  - similar to 802.11a and HIPERLAN/2
- Transmit the PHY header at FFT size 64
  - The receiver uses the header for refining the carrier tracking loop frequency estimate
- Send short sequence to retrain loops
- Transmit payloads at FFT size 256
Time-frequency view
Modulation Constellations

- Use square QAM constellations only
  - Metrics extracted from I or Q separately
    - Significant implementation simplification
    - Not possible for 8PSK, 32QAM, 128QAM
      - ECC rate compensates for excess bits
- BPSK+4/16/64 QAM on downlink
  - 256 QAM optional
- BPSK+4/16 QAM on uplink
  - 64,256 QAM optional
Multipath effect on subcarriers

- Each subcarrier is scaled according to the channel, but they still do not interfere with each other
Error Correction Coding

• Convolutional code shall be used as a baseline mandatory mode.
  – K=7, R=1/2, 2/3, 3/4; terminated tail
    • Optional R=7/8
• Interleaver is needed to avoid adjacent faded bits
• Turbo Codes shall be used as an option with FFT-256 mode
  – One BTC block per one OFDM symbol
    • Possibly per integer number of OFDM symbols
  – BTC parameters chosen per constellation+rate
# Modulation, ECC and Data Rates

3.5 MHz wide channels, 52 subcarriers, 12.5% guard interval

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Coding rate</th>
<th>Data Rate</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>R=1/2</td>
<td>1.33 Mbit/s</td>
<td>-94</td>
</tr>
<tr>
<td>BPSK</td>
<td>R=3/4</td>
<td>2.00 Mbit/s</td>
<td>-93</td>
</tr>
<tr>
<td>QPSK</td>
<td>R=1/2</td>
<td>2.67 Mbit/s</td>
<td>-91</td>
</tr>
<tr>
<td>QPSK</td>
<td>R=3/4</td>
<td>4.00 Mbit/s</td>
<td>-87</td>
</tr>
<tr>
<td>16QAM</td>
<td>R=1/2</td>
<td>5.33 Mbit/s</td>
<td>-86</td>
</tr>
<tr>
<td>16QAM</td>
<td>R=3/4</td>
<td>8.00 Mbit/s</td>
<td>-82</td>
</tr>
<tr>
<td>64QAM</td>
<td>R=2/3</td>
<td>10.67 Mbit/s</td>
<td>-78</td>
</tr>
<tr>
<td>64QAM</td>
<td>R=3/4</td>
<td>12.00 Mbit/s</td>
<td>-77</td>
</tr>
<tr>
<td>256QAM</td>
<td>R=2/3</td>
<td>14.22 Mbit/s</td>
<td>-73</td>
</tr>
<tr>
<td>256QAM</td>
<td>R=3/4</td>
<td>16.00 Mbit/s</td>
<td>-71</td>
</tr>
</tbody>
</table>

Sensitivity assumes NF=6 dB and 4 dB implementation loss
# Data Rates with 256pt FFT

3.5 MHz wide channels, 216 subcarriers, 3.1% guard interval

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<tr>
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<th>Data Rate</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>R=1/2</td>
<td>1.62 Mbit/s</td>
<td>-94</td>
</tr>
<tr>
<td>BPSK</td>
<td>R=3/4</td>
<td>2.44 Mbit/s</td>
<td>-93</td>
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<tr>
<td>QPSK</td>
<td>R=1/2</td>
<td>3.25 Mbit/s</td>
<td>-91</td>
</tr>
<tr>
<td>QPSK</td>
<td>R=3/4</td>
<td>4.87 Mbit/s</td>
<td>-87</td>
</tr>
<tr>
<td>16QAM</td>
<td>R=1/2</td>
<td>6.50 Mbit/s</td>
<td>-86</td>
</tr>
<tr>
<td>16QAM</td>
<td>R=3/4</td>
<td>9.75 Mbit/s</td>
<td>-82</td>
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<tr>
<td>64QAM</td>
<td>R=2/3</td>
<td>13.00 Mbit/s</td>
<td>-78</td>
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<tr>
<td>64QAM</td>
<td>R=3/4</td>
<td>14.62 Mbit/s</td>
<td>-77</td>
</tr>
<tr>
<td>256QAM</td>
<td>R=2/3</td>
<td>17.33 Mbit/s</td>
<td>-73</td>
</tr>
<tr>
<td>256QAM</td>
<td>R=3/4</td>
<td>19.50 Mbit/s</td>
<td>-71</td>
</tr>
</tbody>
</table>

Sensitivity assumes NF=6 dB and 4 dB implementation loss
Subcarrier based parallel polling

- Fourier Transform allows simultaneous detection of multiple subcarriers sent by multiple users
  - Extreme case of OFDMA combined with On-Off Keying with 1 subcarrier per user.
- CDMA-like, but preserves orthogonality
- Concentrates power, allows higher SNR
- Permute frequencies in each superframe to avoid prolonged fades
Subcarrier based polling

Frame 1

Frame 2

Frame 3
Preamble Structures

• The preamble is used to estimate
  – Antenna diversity selection and AGC convergence
  – Coarse, then fine frequency offset
  – Coarse, then fine timing offset
  – Channel response

• More prior knowledge allows shorter preambles
  – Gain preadjusted by transmit power control
  – Coarse frequency offset known from prior transmissions
  – Timing preadjusted by ranging and timing advance
Preamble for Initial Acquisition

Signal detection
AGC convergence
Diversity selection
Coarse freq. offset estimate

Fine timing acquisition
Fine freq. offset estimation
Channel estimation

RATE and LENGTH
Received at 1.33 Mbit/s

DATA is received at RATE indicated in the SIGNAL field

DATA is received at RATE set by the MAC
Preamble for Re-Acquisition

Fine training sequence
SIGNAL
DATA1
DATA2

Fine timing acquisition
Fine freq. offset estimation
Channel estimation

Received at 1.33 Mbit/s
DATA is received at RATE indicated in the SIGNAL field

DATA is received at RATE set by the MAC
Optional Advanced Techniques

• OFDMA
  – The OFDM preserves orthogonality between transmissions of different users
  – Allows survival at higher path loss

• Space-Time coding
  – The decoupling between equalization and coding plays important role in making those techniques practical
  – New preambles need to be designed for training of response from multiple antennas
Peak2Avg Problem- How bad?

- Worst case peaks are $kN$ times the average
  - $N$ is the number of subcarriers
  - $k$ is constellation dependent, about 2-4 dB
  - 20 dB for $N=52$, 26 dB for $N=216$

- Central Limit Theorem (sum of many small contributions) $\Rightarrow$ amplitude is Rayleigh

- Worst peak in a typical packet is +10 dB

- Some clipping can be tolerated!!
  - OFDM spreads clips over subcarriers
  - Error Correction Coding improves robustness

- Typical PA backoff – 7-9 dB
  - Depends on constellation and on regulatory masks
BRZE’s OFDM proposal Summary

• Parameters draw on 802.11a+HIPERLAN/2 standards
  – Available technology
• Improved performance modes
  – Longer FFTs, improved ECCs
• Fast Parallel Polling for fast demand discovery
• Ready for advanced antenna and multiaccess techniques