2nd Generation OFDM for 802.16.3

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Dr. Robert M. Ward Jr. Voice: (858) 513-4326
SciCom, Inc Fax: (858) 513-4326
13863 Millards Ranch Lane E-mail: drbmward@IEEE.org
Poway, Ca. 92064

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Purpose:
This presentation is for initial phy proposals for 802.16.3 TG3

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2ND GENERATION OFDM PROPOSAL

FOR 802.16.3

IEEE 802.16.3c-00/38

November 2000

Bob Ward
SciCom
SUMMARIZING KEY BWA REQUIREMENTS

• Physical Channel requirements (Ref 1)
  – 2 to 11 Ghz Frequency Range
  – Bidirectional communications
  – Operate in multipath
  – Support up to 50 km ranges
  – Operate in multicell/sector topology
  – Low BER

• Service requirements (Ref 1)
  – Capacity
    • Up to 10 Mbps per user
    • Aggregate data rate to support multiple users simultaneously
    • Scalable growth
  – Integrated transport
    • Voice, video, data
    • Commensurate levels of QOS
  – Multiple Access capable
    • Point to Multiple Point operation
    • Easy method of service grant
PHY LAYER PROPOSAL SUMMARY

- **OFDM modulation basis**
  - Waveform inherently designed to mitigate multipath (Ref 2, 3)
  - Integrated processing facilitates low BER

- **Concatenated FEC**
  - Supports longer ranges
  - Supports low BER operation

- **Multilayer Framing link protocol**
  - Flexible to efficiently match bursty and non bursty traffic

- **Downlink / Uplink**
  - OFDM is efficient for both downlink (to users) and uplink (from users)

- **Spectrum allocation**
  - TDD for uplink / downlink separation
  - Scalable for different channel bandwidth needs
**SIGNAL PROCESSING OVERVIEW**

- **Framing layer**
  - Multiplex data via frame structures
  - Framing also supports use of different OFDM modes for range flexibility

- **Reed Solomon**
  - This outer code is concatenated with inner coding for greater range of operation
  - Selectable length to effectively match frame lengths and OFDM modes

- **Use a combined coded modulation method**
  - TCM or turbo code

- **QAM Modes**
  - Increased number of modes for greater flexibility: \(2^M, M = 1, 2, 4, 5, 6, 7\)

- **OFDM**
  - Longer symbols for more rugged and efficient operation needed by BWA application
  - Key parameters made selectable for greatest flexibility
    - Guard length
    - Pilot operation
    - Active Number of subcarriers
    - Preamble
Utilize a framing structure to enhance multiple access and capacity

- **Super Frame Layer**
  - Composed of $N_{\text{frames}}$ to match requirements at Mac/Phy layer

- **Frame Layer**
  - Composed of $N_{\text{segments}}$ to:
    - Frame preamble for coarse synchronization
    - QAM mode can be selected for each segment
    - Assign uplink/downlink segments to match traffic load (TDD operation)

- **Segment Layer**
  - Composed of $N_{\text{OFDM\_symbols}}$
    - Preamble for improved synchronization of segment
    - OFDM symbols as minimum time resolution of user assignment
REED SOLOMON OUTER CODING

• Standard Reed Solomon code parameters
  – Galois Field: $2^8$

  – Selectable Lengths to effectively match OFDM frames/symbols:
    • RS(n,k), $n \leq 256$, $k \leq 16$

  – Generator Polynomial
    $$g(x) = \prod_{i=m}^{n+2j} (x + \alpha^i)$$

  – Field Primitive: $x^8 + x^4 + x^3 + x^2 + 1$

• Performance
  – Capable of satisfying decoding rates needed to meet system data rates with reasonable complexity
  – Decoding latency low
BASE THE INNER CODING STRUCTURE ON A COMBINED CODED MODULATION METHOD

- Basic trellis coding modulation demonstrates the potential
  - Code constellations to use subsets
  - Decision regions within subsets are enlarged, thereby improving decision performance

- Simple Example for 64 QAM/OFDM
  - A parser divides \( n \) bits into \( m + k \) bits
  - \( k \) bits are encoded into \( k+1 \) bits, the coded \( k+1 \) bits select a QAM subset
  - The uncoded \( m \) bits select the constellation point within the selected QAM subset
  - Coding gain achieved since
    - Decision on subset protected by convolutional decoding
    - QAM decoding error rate within each subset is reduced since minimum distance between points is doubled
  - Specifics for 64 QAM, 4 bytes mapped to 36 bits
    - 24 bits not encoded: protected by outer coding and OFDM structure
    - 8 bits encoded to 12 bits with \( 2R(1/2,2/3P) \) (note 2/3 puncturing \( \Rightarrow \) 3 bits out for every two in)

\[
\begin{align*}
\text{Parse} & \quad n \quad \text{bits} \\
N = m+k & \quad k \quad \text{bits} \\
\quad k+1 \quad \text{bits} & \quad m \quad \text{bits} \\
\text{Convolutional Encoder Rate} & = \frac{k}{k+1} \\
2^N\text{-QAM Mapper} & \quad \text{Signal select from subset} \\
\text{QAM subset Select} & \\
1,0 & \quad \text{I,Q}
\end{align*}
\]
MULTIPLE QAM MODES ADD FLEXIBILITY

• Added Modes of 32 and 128 QAM
  – Feasibility of up to 64 QAM demonstrated in 802.11a, DVB-T implementations
  – Also recommended is 802.11a’s BPSK, QPSK, 16 and 64 QAM modes

• Advantages of multiple modes
  – Larger constellations for increased spectral efficiency
  – Smaller constellations for greater range, more robustness
  – Increased flexibility to traffic allocation

• 32/128 constellations are standard configurations in DVB systems
  – Eliminates corner points of square constellations
  – Provides 5 and 7 bits per subcarrier respectively (4 and 6 bits for 16 and 64 QAM respectively)
  – Do not suffer same acquisition penalties in OFDM as incurred with single carrier QAM systems due to less corner energy
UNCODED BER PERFORMANCE

- More regular increase in power per QAM mode
  - 32 QAM mode splits the 6db additional power requirement to use 64 over 16 QAM
  - For approximately 3 db more power, 128 QAM relative to 64 QAM increases capacity by 17% (7/6)
COMPARING CONSTELLATION PEAK TO AVERAGE POWERS

- 32 and 128 QAM constellations also stand out as having smaller PARs relative to the next smaller constellation

<table>
<thead>
<tr>
<th>M</th>
<th>Peak Power</th>
<th>P_{avg}</th>
<th>PAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>18</td>
<td>10</td>
<td>2.553</td>
</tr>
<tr>
<td>32</td>
<td>34</td>
<td>20</td>
<td>2.304</td>
</tr>
<tr>
<td>64</td>
<td>98</td>
<td>42</td>
<td>3.680</td>
</tr>
<tr>
<td>128</td>
<td>170</td>
<td>82</td>
<td>3.166</td>
</tr>
</tbody>
</table>
OFDM STRUCTURE

• Selectable parameters
  – Selectable FFT length 64, 256, 512, (1024)
    • Greater lengths offer more ruggedness, spectral rollof efficiency
  – Selectable Guard length up to 25% of FFT length
    • Match multipath requirements
    • Guard Intervals relative to active part of symbol: 1/32, 1/16, 1/8, 1/4
  – Select OFDM parameters relative to needs within framing layer
    • For example match QAM mode
  – Selectable pilot on/off operation. If off, use alternatively
    • Distributed preambles
    • Decision feedback methodology to lessen need for pilots
  – Selectable active number of subcarriers
    • Avoid frequency selective interference/multipath
    • Can be used to support channelization design
FLEXIBLE DATA CAPACITY

• **OFDM system**
  – Larger constellations offer greater spectral efficiency to boost rates
  – Larger 512 FFT size can be used to support higher rates
  – Capacity is easily calculated (as exemplified for 802.11a’s 64 QAM mode with coding with 54 Mbps capability)

\[
\text{bps} := \frac{M \cdot N_{\text{ASC}} \cdot R_{\text{code}}}{T_{\text{Symb}}} \quad \text{bps} = 5.4 \leftrightarrow 10^7
\]

  for 64 QAM, 6 bits per subcarrier
  \[M = 6\]

  Number of active subcarriers
  \[N_{\text{ASC}} = 48\]

  Coding rate
  \[R_{\text{code}}\]

  OFDM symbol duration
  \[T_{\text{Symb}}\]

• **Concatenated Coding with selectable rates**
  – Punctured convolutional coding to optimize rate
  – Selectable Reed Solomon parameters to optimize rate

• **System Structure**
  – Multilayer structure can also be used to tailor user/system rates
  – FDMA & FDD/TDD methods
SUMMARY OF ADVANTAGES

• Improved system capacity
  – Mode flexibility allows tuning to deployment needs
  – Increased number of QAM modes provides greater spectral efficiencies
  – Framing uses modal operation efficiently
  – Longer packet capabilities

• Performance
  – Increased range
    • Concatenated TCM scheme improves link margins
  – Good synchronization
    • Distributed preambles
  – Reduced Overhead
    • Selectable guard times, pilot on/off, selectable active subcarriers
    • Framing used to minimize preamble overhead
  – Greater OFDM ruggedness
    • More subcarriers (frequency selective impairments more easily combatted)
    • Selectable subcarriers (avoidance, aids analog filtering)
    • Guard times tunable to multipath environment
  – Longer Packets supported
    • Overall architecture more resilient to channel imperfections
# EVALUATION

<table>
<thead>
<tr>
<th>Item</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Meets Systems Requirements</td>
<td>Yes. OFDM based proposal for bi-directional communications in 2 – 11 Ghz with capabilities to support system capacity and reliability needs.</td>
</tr>
<tr>
<td>2. Channel Spectrum efficiency</td>
<td>Very Efficient. OFDM technology with underlying multimode QAM supports higher spectrum efficiency. Concatenated RS-convolutional coding with selectable coding rates to afford best match to channel needs.</td>
</tr>
<tr>
<td>3. Simplicity of implementation</td>
<td>Moderately simple. Utilizes proven technologies in current implementations. Also, inherent mode flexibility allows tailoring implementation to meet specific cost/performance criteria.</td>
</tr>
<tr>
<td>4. Spectrum Resource Flexibility</td>
<td>Uses spectrum flexibly. Supports TDD/FDD, Hybrid channel access methodologies.</td>
</tr>
<tr>
<td>5. System Service flexibility</td>
<td>Flexibility is good. OFDM subcarriers can support logical assignment of services.</td>
</tr>
<tr>
<td>7. Reference System Gain</td>
<td>Allows optimization of System Gain as OFDM technology supports frequency selective gain and via coding technique.</td>
</tr>
<tr>
<td>8. Robustness to Interference</td>
<td>Moderate. Reducing QAM mode for longer range diminishes interference outside immediate cell.</td>
</tr>
<tr>
<td>9. Robustness to Channel Impairments</td>
<td>OFDM is inherently designed to mitigate multipath. Preamble can be designed to support antenna diversity.</td>
</tr>
<tr>
<td>10. Robustness to radio impairments</td>
<td>Linearity is required due to use of higher order constellations. OFDM provides an integrating gain for synchronization.</td>
</tr>
<tr>
<td>11. Support of advanced antenna techniques</td>
<td>Not specifically addressed by this proposal. However, does not prohibit.</td>
</tr>
</tbody>
</table>

IEEE 802.16.3c-00/38
REFERENCES

• 802.16.3-00/02r3, Functional Requirements for the 802.16.3 Interoperability Standard
• 802.16.3c-00/16, Selection Criteria pertinent to Modulation, Equalization, Coding for the for 2-11 GHz Fixed Broadband Wireless Systems, Robert M. Ward, Jr
• 802.16.3c-00/13, Modulation and Equalization Criteria for 2-11 GHz Fixed Broadband Wireless Systems, David Falconer and Sirikiat Lek Ariyavisitakul