BCPM
Implementation details
Jan Boer, Lucent Technologies

See the notes pages for an explanation of the slides

Contents

• Transmitter
  – 10 Mbit/s modulation scheme
• Receiver structure / complexity
• Implementation / performance trade-off
• Preamble / training
  – interoperability / coexistence
Basic receiver structure

- RF and IF stages
- Complete Mixer
- A/D
- Correlator
- Synchronization and Timing
- Find I,Q peak, determine position, polarity
- pos, pol I,Q
- Decode position, polarity
- 1,2,5,8,10 Mbit/s

8 Mbit/s after the correlator

- Corr I
- Corr Q
- Q pos. I pos. data (bytes)
- 2 3 4 5 6 7 8 9 10
- TXD . . . 0 0 1 1 0 0 0 1 1 0 0 0 0 1 0 0 1 0 0 1 . . .
- 001 000 (21h) 01 100 110 (99h) 01
- G pos. I pos. I,Q phase change

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10 Mbit/s after the correlator

<table>
<thead>
<tr>
<th>Data (bytes)</th>
<th>I pos.</th>
<th>Q pos.</th>
<th>I/Q phase change</th>
</tr>
</thead>
<tbody>
<tr>
<td>000 000 01</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>011 110 01</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>001 001 01</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>010 110 01</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

8 and 10 Mbit/s compared

- **Eb/N0**
  - detection problem is the same (QPSK and 1 out of 8 positions)
    - **Eb/N0** = 6dB for both 8 and 10 Mbit/s

- **SNR**
  - At 10 Mbit/s 11/9 more (0.87dB) than 8 Mbit/s
  - Effect on link budget minimal, because also 11/9 more energy is send at the transmitter (Barker sequences shifted into each other)
Performance at multipath channel

- Delayspread in combination with Barker sidelobs reduce the performance
- With basic receiver delayspread up to 30-40 ns can be handled
- Dramatic improvement by treating sidelobs and the channel with MLSE techniques
- MLSE receiver structure is not complex due to Barker correlation properties
**Channel Matched Filter**

- CMF is the complex conjugate of the channel impulse response $c(t)$

$$c(t) \rightarrow c^*(t)$$

Output of CMF is the impulse response of the transmitted signal by the convolution of the channel and the CMF:

$$[c(t) \ast c^*(t)]$$

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**Simple example**

- Two ray channel impulse response

$$c(t) \rightarrow (1) \rightarrow (2) \rightarrow (1)$$

$$c(t) \ast c^*(t)$$
Benefits of the application of the CMF

- Concentrates energy, improving SNR
- Gives (anti-)symmetric impulse response
- Gives optimal sample timing

Tentative Symbol Estimator

- With knowledge of channel the TSE removes cross rail interference i.e. crosstalk of I component on the Q component and vice versa and estimates the 4 most likely positions combinations for I and Q
- Crossrail interference is caused by the channel (echoes) and the CMF (convolution of the two)
- Interference is known
- Interference of I on Q and Q on I is symmetrical because of the antisymmetrical impulse response of the channel and the CMF and is defined by the imaginary part of $c(t) \ast c^*(t)$
Crossrail example

Tx: $q(t)$

$c(t) \ast c^*(t)$

Because of knowledge of the channel crossrail terms (imag. part of $c(t) \ast c^*(t)$) are known (bias terms)

Bias terms are calculated during training (8 values for 8 positions)

Biasterms

$c(t) \ast c^*(t)$

only imaginary term contribute to bias terms
TSE procedure

- For all possible positions of I (from 0 to 7) and Q (also from 0 to 7) calculate:
  - maximum determines polarity of I and Q
    - \( b^+ (I+Q) \) + +
    - \( b^- (I+Q) \) - -
    - \( -b^+ (I-Q) \) + -
    - \( -b^- (I-Q) \) - +

- Select 4 maxima out of 64 (to be evaluated in the Mode Sifter (trellis))

Example of TSE calculation

Position evaluation

<table>
<thead>
<tr>
<th>I position</th>
<th>Q position</th>
<th>b</th>
<th>( b^+ (I+Q) )</th>
<th>( b^- (I+Q) )</th>
<th>( b^+ (I-Q) )</th>
<th>( b^- (I-Q) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>-4</td>
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<tr>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>-4</td>
</tr>
</tbody>
</table>
**TSE Implementation**

- **Low complexity:**
  - in evaluation block 64 *4*2 additions during a symbol period (1 microsecond)
  - optimal implementation choices can reduce this number
  - selection of 4 maximum values out of 64
The Mode Sifter

- Reduced state trellis structure sifting the tentatively retained modes (maxima of TSE)
- Calculates path metric taking ISI and sidelobs into account
- Trellis path determines final estimate
  - path depth of 4 is sufficient

Trellis structure
Metric calculation

- Iteration process

\[ \Lambda'(i^{(m)}(0)) = V(i^{(m)}(0)) \]
\[ \Lambda'(i^{(m)}(k + 1)) = \Lambda'(i^{(m)}(k)) + V(i^{(m)}(k + 1)) - G(i^{(m)}(k + 1), i^{(m)}(k)) \]

where \( V \) is the metric as calculated in the TSE
\( G \) is the ISI term

- At each step (symbol) the addition of the two terms have to be performed for 16 possible paths

The ISI term

\[ G(i(k + 1), i(k)) = \hat{a}(k) \hat{a}(k + 1) L_r(i(k + 1) - \hat{i}(k)) + \hat{b}(k) \hat{b}(k + 1) L_r(11 + \hat{i}(k + 1) - \hat{i}(k)) + \hat{a}(k) \hat{b}(k + 1) L_r(11 + \hat{i}(k + 1) - \hat{i}(k)) - \hat{b}(k) \hat{a}(k + 1) L_r(11 + \hat{i}(k + 1) - \hat{i}(k)) \]

where:
\( \hat{a}(k) = \) sign of the real part of symbol \( i(k) \): \( \{1, -1\} \)
\( \hat{b}(k) = \) sign of the imaginary part of symbol \( i(k) \): \( \{1, -1\} \)
\( \hat{\lambda}_r(k) = \) position of the real part of symbol \( i(k) \): \( \{1, 2, 3, 4, 5, 6, 7, 8\} \)
\( \hat{\lambda}_i(k) = \) position of the imaginary part of symbol \( i(k) \): \( \{1, 2, 3, 4, 5, 6, 7, 8\} \)
\( \hat{n}(k) = (\hat{a}(k), \hat{b}(k), \hat{\lambda}_r(k), \hat{\lambda}_i(k)) \)
\( L_r(k) = \) real part of autocorrelation function of basic received signal (Barker-code + channel)
\( L_i(k) = \) imaginary part of autocorrelation function of basic received signal (Barker-code + channel)
Complexity of Modesifter

• Metric calculation
  – 16 * 5 additions per symbol
• Path maintenance
  – basic digital techniques can be applied
• Because the reduced trellis structure (4X4) the Modesifter has, compared to other blocks, a rather low complexity in terms of gates

Performance/complexity trade-off

• Basic receiver
  – no CMF, TSE or MS
  – gate count 20-30 Kgates
  – will work in a (simple) office environment
    • up to 30-40 ns delayspread for 8 and 10Mbit/s
    • fall back to 1,2 or 5 Mbit/s
Performance/complexity trade-off

• Basic receiver with CMF
  – gatecount 35-45 Kgates
  – works in office environments and most other environments at 5 Mbit/s fallback
  – delayspread
    • 5 Mbit/s  275-350 nsec
    • 8 Mbit/s  55-90 nsec
    • 10 Mbit/s  50-80 nsec

• receiver with CMF, TSE and MS
  – gatecount about 60 Kgates
  – works in office, retail and industrial environments
  – delayspread
    • 5 Mbit/s  355-400 nsec
    • 8 Mbit/s  235-265 nsec
    • 10 Mbit/s  130-220 nsec
Preamble and training

• Training (above standard 1 Mbit/s)
  – 8 or 16 symbols for CMF
  – calculation for Bias and ISI terms
    • during processing of 1Mbit/s SFD (16 symbols)

• Optional short preamble is proposed
  – draft text doc 98-10r
  – March presentation 98-99

Interoperability / Coexistence

• Interoperability
  – short preamble Tx - short preamble Rx
  – long preamble Tx - long preamble Rx
  – long preamble Tx - short preamble Rx

• Coexistence
  – all Proposed DS Phy’s

• BUT..
Coexistence with FH

• Symbol Technologies showed that coexistence with Frequency hoppers can be achieved by adding a FH signal preceding the preamble.
• Lucent proposes to incorporate the optional extension into the BCPM proposal.

Conclusions

• BCPM is not complex
• Implementation of a MLSE structure is not complex for BCPM
  – CMF, TSE and MS described
  – Doubles gate count compared to 2 Mbit/s DS
• Implementation (gate count) / performance trade-off
• Coexistence/interoperability with current DS and FH standard