IEEE 802.3ah

FEC Framing in EFM

Lior Khermosh – Passave

Supporting:

lior.khermosh@passave.com
Scope

- FEC for EFM
- Merging FEC with Ethernet packet format in a transparent way
  - Defining layering with FEC
  - Defining FEC packet format
Motivation

- FEC as the cost effective method to meet reach/split targets using low-cost optics:
  - Split limit case - improve link budget
  - Distance limit case - extend MPN-limited uplink reach
- Using RS (255,239) octet based code
- Additional ~4dB gain
Compatibility

- Need to support and fit in with current Ethernet devices
- Compatibility with data format
  - Stream of an FEC coded data should be understood by current non FEC Ethernet devices and not cause them errors
- Ability to add FEC functionality externally
- Optional and transparent use of FEC
Adding FEC to the Ethernet layers

Higher Layers

LLC
MAC CONTROL
MAC RECONCILIATION

GMII

FEC PCS sublayer (optional & transparent)

PCS
PMA
Basic Principles of Operation

- Keeping the packet structure
  - Parity check bytes should be added at the end of the packet - IPG stretching
- Using systematic code – visible data bytes
- FEC is coded before the 8B/10B code

Non FEC devices observes a regular Ethernet packet
  - Detecting False_Carrier_detect at parity bytes time (RX_ER is asserted)
Ethernet FEC Packet Format

- All of the packet is encoded including preamble, address and FCS
- Parity check bytes added at the end of the packet
- Shortened last frame – virtually zero padded
- Additional delay of a packet size – up to 12usec
  Net Round trip delay is 100usec for 10Km
- Special 10B code words are not FEC coded – using a sequence of symbols to add immunity

<table>
<thead>
<tr>
<th>Start Symbols</th>
<th>Preamble</th>
<th>SFD</th>
<th>Header</th>
<th>Data: 46-1500 byte</th>
<th>FCS</th>
<th>Stop Symbols</th>
<th>parity bytes</th>
<th>Stop Symbols</th>
<th>IPG</th>
</tr>
</thead>
</table>

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Protecting Special 10B words

- Special 10B words are used for packet start, packet stop and comma detection.
- Extend the words to a sequence and protect with correlation of sequence.
- Should be transparent to FEC disabled state machine (Also assigned as False_carrier_detect).

- /K28.5/ - comma is in the idle word and is duplicated many times - remains the same.
FEC Layering Mechanism

- For the reconciliation layer – IPG stretching
- Additional Idles inserted in reception
- IPG stretching in transmission can be achieved in 2 ways
  - Open loop – Adapting MAC rate as in 10G
  - Close loop – Exporting a signal to the Reconciliation layer
    - Use of something like the CRS or COL lines of half duplex mode
Data Flow for FEC Sublayer

**FEC Decoding**

- Data from PMA
  - 8/10 decoding
    - data arbitrator
      - RS decoding
        - 1 packet buffer
          - Data to Reconciliation Sublayer

**FEC Encoding**

- Data received form Reconciliation Sublayer
  - CRS
    - Rate Adaptation using CRS for IPG stretching
      - RS encoding
        - data wrapper
          - 8/10 encoding
            - Data to PMA
Effect of FEC Data on non FEC devices

- Compatibility of data stream is relevant for receiving only
- For non-FEC devices the Packet is transparent
- During Parity check bytes and start & stop sequences, RX_ER is asserted - Transmitted as False_carrier_detect mode
- The False_carrier_detect mode is ignored by Reconciliation Layer
Compatibility with Current devices

- FEC may be added after non-FEC devices using an FEC component which:
  - On transmission
    - Detects the packet boundaries
    - Encode FEC and add parity bytes at the end of the packet
    - Has a adaptation FIFO – uses pause flow control to enable/disable data from current device
  - On reception
    - Decodes FEC
    - Pad Idles
FEC Rate Efficiency

- 16 Parity check bytes are added for each 255 bytes
- Additional bytes: \(2 \cdot t \cdot \left\lfloor \frac{64}{k} \right\rfloor\) to \(2 \cdot t \cdot \left\lfloor \frac{1518}{k} \right\rfloor\)
- FEC can overwrite current IPG
- Can achieve better efficiency by using \(t=2,4\) code for short packets
parity length and percentage overhead for fixed t=8 code

packet length [bytes]

parity length [bytes]

percentage loss [%]
parity length and percentage overhead for variable length code t=8,4,2
Conclusion

- Combining FEC with the Ethernet packet
- Need to support current Ethernet devices
- Optional and transparent use of FEC
- Parity check bytes at the end of the Ethernet packet
- IPG stretching mode
Appendix

- State machine of current PCS
- FEC data stream through current PCS RX. state machine
- FEC data stream through FEC PCS RX. state machine
- FEC Rx state machine
PCS Rx State Diagram
# PCS signaling for Non FEC device with FEC coded data

<table>
<thead>
<tr>
<th>Comments</th>
<th>10B stream</th>
<th>Carrier Detect</th>
<th>Receiving</th>
<th>RX_DV</th>
<th>RX_ER</th>
<th>RXD&lt;7:0&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IDLEs</strong></td>
<td>/IDLE/</td>
<td>FALSE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>RUDI(/I/)</td>
</tr>
<tr>
<td><strong>Special Packet start</strong></td>
<td>/R/R/</td>
<td>TRUE</td>
<td>TRUE</td>
<td>FALSE</td>
<td>TRUE</td>
<td>0000 1110</td>
</tr>
<tr>
<td></td>
<td>/K28.5/D21.2/</td>
<td>FALSE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>RUDI(/I/)</td>
</tr>
<tr>
<td><strong>Packet Start</strong></td>
<td>/S/</td>
<td>TRUE</td>
<td>TRUE</td>
<td>TRUE</td>
<td>FALSE</td>
<td>0101 0101</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>/D/D/</td>
<td>(All error states as before)</td>
<td>FALSE</td>
<td>FALSE</td>
<td>DECODE[/x/]</td>
<td></td>
</tr>
<tr>
<td><strong>Packet End</strong></td>
<td>/T/R/K28.5/</td>
<td>FALSE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>FALSE</td>
<td></td>
</tr>
<tr>
<td><strong>Special Packet end</strong></td>
<td>/D21.2/</td>
<td>FALSE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>FALSE</td>
<td>RUDI(/I/)</td>
</tr>
<tr>
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<td>TRUE</td>
<td>TRUE</td>
<td>FALSE</td>
<td>TRUE</td>
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</tr>
<tr>
<td><strong>FEC parity</strong></td>
<td>/D/D/</td>
<td>TRUE</td>
<td>TRUE</td>
<td>FALSE</td>
<td>TRUE</td>
<td>0000 1110</td>
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<td>/R/R/K28.5/D21.2/S/</td>
<td>TRUE</td>
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Rx. State-Machine – FEC Sublayer

DECODE = 8B/10B DECODE
RS_DECODE = FEC DECODE

START_OF_PACKET
RX_DV <= TRUE
RX_ER <= FALSE
RXD<7:0> <= 0101 0101

RECEIVE
RX_ER <= FALSE
FEC_RX<7:0> <= DECODE([/X/]) or /D21.5/
RX_DATA
receiving <= FALSE
RX_DV <= TRUE
RX_ER <= FALSE
FRAME_NO=0

RECEIVE
RX_DATA_ERROR
RX_ER <= FALSE
PAR_RX<7:0> <= DECODE([/X/]) or /D21.5/
RX_PAR
receiving <= FALSE
RX_DV <= TRUE
RX_ER <= FALSE
DATA_END

FRAME_NO=1

FRAME_NO=FRAME_NO+1

RX_PAR_ERROR
RX_ER <= FALSE
PAR_RX<7:0> <= DECODE([/X/]) or /D21.5/
RX_PAR
receiving <= FALSE
RX_DV <= TRUE
RX_ER <= FALSE
DATA_END

FRAME_NO=16

FRAME_NO=FRAME_NO+1

RX_DATA_ERROR
RX_ER <= FALSE
RX<7:0> <= RS_DECODE([/FEC_RX/],[/PAR_RX/])

EARLY_END
RX_ER <= TRUE

EEVEN * check_end = /[R/K28.5/D21.2/T/R/]
DATA_END
receiving <= FALSE
RX_DV <= TRUE
RX_ER <= FALSE

ELSE
RX_ER <= TRUE
EARLY_END

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