Lower complexity architectures for implementing 10GBT XTalk cancellers and equalizers FIRs

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Overview

- Background
- Lower complexity alternatives
- DFT FIR implementation
Background

- The bulk of the 1G and 10G computation is in the Finite Impulse Response (FIR) filters:
  - Echo cancellers (4), NEXT cancellers (12), FEXT cancellers (12) and Equalizers (4)
- For a direct form implementation of an FIR, the number of operations is proportional to:
  - The update rate (i.e. sampling rate)
  - Number of coefficients (i.e. time span)
- The complexity of the direct form implementation is roughly proportional to the square of the sampling rate
- For long FIRs, there are lower complexity alternatives
Lower Complexity FIR Alternatives

- Autoregressive Moving Average (ARMA) models of FIRs
  - Replace FIR with more compact FIR/IIR model
  - See e.g. “Stable Pole-Zero Modeling of Long FIR Filters with Application to MMSE-DFE”, N. Al-Dhahir, A. Sayed and J. Cioffi, IEEE Trans on Comm, pp 508-513, May 97

- Multi-rate filters
  - See e.g. “Multirate Systems and Filter Banks”, P.P. Vaidyanathan

- Domain transformation
  - E.g. DFT
FIR implementation in DFT domain

- FIR Filtering can be implemented in the DFT domain with DFT multiplication
  - Initialization: DFT of FIR coefficients, $H = T(h)$
  - DFT of data block, $X = T(x)$
  - Multiplication of DFT data and DFT of FIR, $Y = H \times X$
  - IDFT of product, $\text{invT}(Y)$
- Overlap-and-add or Overlap-and-save are used to correct for edge effects

\[
x \rightarrow \quad h \quad \rightarrow \quad y = \text{conv}(h, x)
\]

\[
h \quad \rightarrow \quad T \quad \rightarrow \quad X = T(x) \quad \rightarrow \quad y = \text{invT}(Y)
\]

\[
H = T(h) \quad \rightarrow \quad Y = T_F(H, X) \quad \rightarrow \quad \text{invT}
\]
FIR lengths for 1G and 10G

- The FIR lengths below are from a survey of tutorials, white papers and data sheets from 802.3 participants, PHY vendors, etc.
- The estimates for 10G are based on choosing the average reported 1G FIR lengths and increasing them by the relative sampling clock increase (800MHz/125MHz)
- The sizes of the filters and the assumed sampling clock rate are illustrative and not specific recommendations that we are making

<table>
<thead>
<tr>
<th></th>
<th>Echo</th>
<th>NEXT</th>
<th>FEXT</th>
<th>FF DFE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>max</td>
<td>min</td>
<td>max</td>
</tr>
<tr>
<td>1G FIR length (surveys)</td>
<td>40</td>
<td>120</td>
<td>20</td>
<td>75</td>
</tr>
<tr>
<td>10G FIR length (estimates)</td>
<td>500</td>
<td>300</td>
<td>100</td>
<td>80</td>
</tr>
</tbody>
</table>
## FIR savings from DFT FIR implementation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ECHO</th>
<th>NEXT</th>
<th>FEXT</th>
<th>FF EQ</th>
<th>Total FIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIR length</td>
<td>500</td>
<td>300</td>
<td>100</td>
<td>80</td>
<td>7120</td>
</tr>
<tr>
<td>BlockSize or net samples</td>
<td>524</td>
<td>724</td>
<td>156</td>
<td>176</td>
<td></td>
</tr>
<tr>
<td>FFTsize</td>
<td>1024</td>
<td>1024</td>
<td>256</td>
<td>256</td>
<td></td>
</tr>
<tr>
<td>log2N</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Real operations/sample for FIR</td>
<td>500</td>
<td>300</td>
<td>100</td>
<td>80</td>
<td>7120</td>
</tr>
<tr>
<td>Total operations/block for DFT FIR</td>
<td>22528</td>
<td>22528</td>
<td>4608</td>
<td>4608</td>
<td></td>
</tr>
<tr>
<td>Real operations/sample for FFT</td>
<td>43</td>
<td>31</td>
<td>30</td>
<td>26</td>
<td>1005</td>
</tr>
<tr>
<td>Approx Savings</td>
<td>91%</td>
<td>90%</td>
<td>70%</td>
<td>67%</td>
<td>86%</td>
</tr>
<tr>
<td>Gain</td>
<td>11x</td>
<td>10x</td>
<td>3x</td>
<td>3x</td>
<td>7x</td>
</tr>
</tbody>
</table>

### New Issues
- Block processing Latency
- Increased memory
- Increased precision
Conclusion

- The bulk of 1G/10G computation is FIR filters

- Direct form FIR implementation results in high complexity as many have pointed out repeatedly in the email reflector

- Alternative lower complexity solutions are available that provide Mult/ADD gains of up to 10x (i.e. 90% savings)