EPoC Upstream FEC Efficiency

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Overview

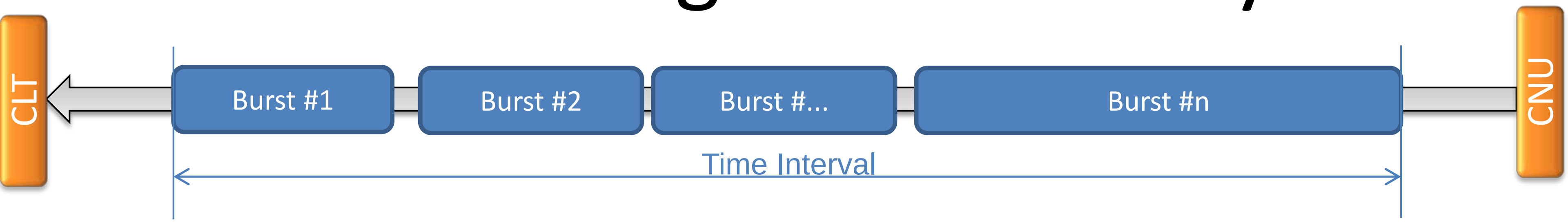
- The efficiency of the downstream EPoC FDD is easy to understand.
- In the downstream, the continuous PHY should have a single FEC codeword size with no shortening so the FEC efficiency is the FEC code rate.
- In the burst upstream, the efficiency of the FEC is complicated by burst terminations that don't match the codeword size.
- This presentation explores the burst efficiency and more importantly the overall system efficiency related to the FEC codeword size.
- Full size codewords, shortened codewords, and multiple FEC codeword sizes will be considered.

FEC Codeword Size Overview

Code	Rate	Information size (bits)	Codeword size (bits)	Parity size (bits)	SNR @BER=1e-8 (1024QAM)
10G-EPON RS	0.878	1792	2040	248	N/A
Short LDPC	0.750	840	1120	280	28.8 dB
Medium LDPC	0.848	5040	5940	900	29.1 dB
Long LDPC	0.889	14400	16200	1800	29.7 dB

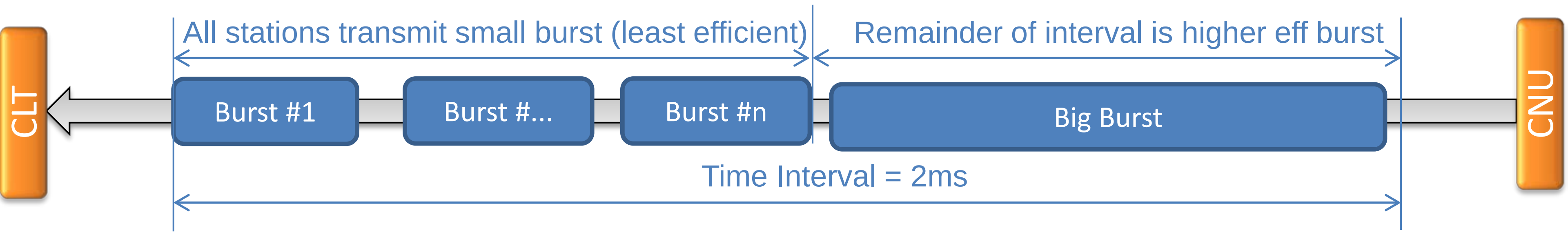
- 10G-EPON used a single FEC codeword size with full codewords only.
- The same FEC is used in the upstream and downstream direction.
- For the EPoC downstream, a single long FEC codeword with no shortening is attractive. High performance and low overhead. (Something similar to the Long LDPC in the table above)
- For EPoC upstream, multiple LDPC code sizes are possible for the upstream.
- The proposed code sizes above will be used for this analysis.

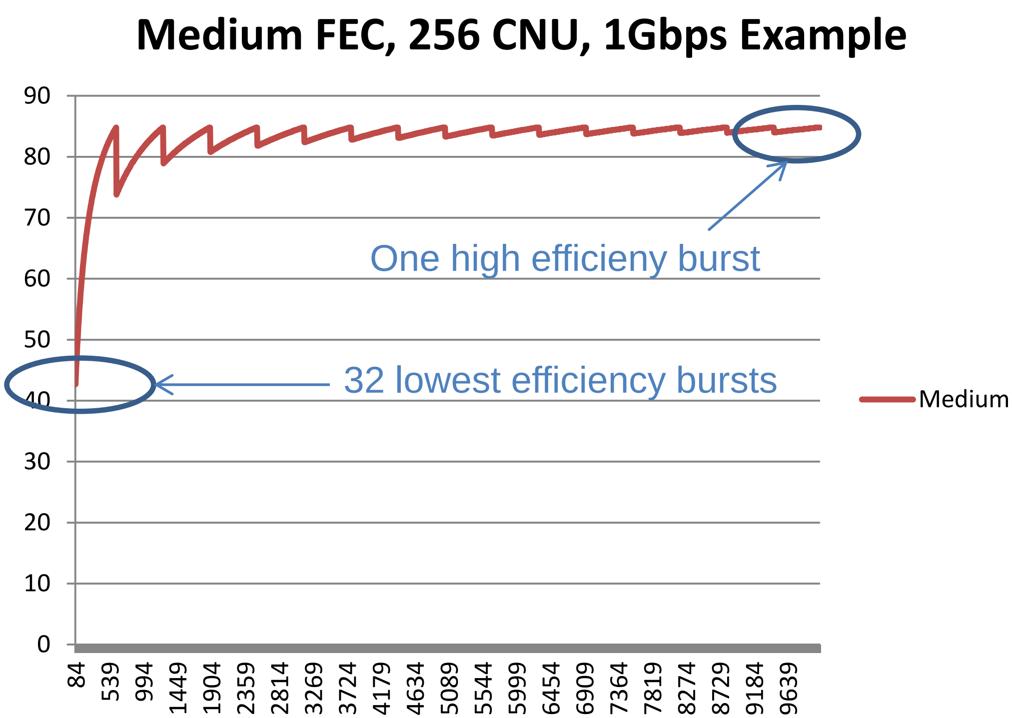
Calculating FEC Efficiency



- Burst Efficiency
  - Burst sizes that are not aligned to a FEC codeword size cause a loss in burst efficiency.
  - The efficiency for burst sizes from 84 Bytes to 10K Bytes will be considered
  - Burst efficiency is a good starting point but overall system efficiency is more important.
- System Efficiency
  - Assuming all bursts are maximum size is too optimistic.
  - Assuming all bursts are minimum size is too pessimistic.
  - The efficiency of the FEC on a burst interface can be estimated by the understanding the number of bursts over a time period.
  - A scenario with a lowest efficiency burst (small) from every CNU and the remainder of the time interval filled with long burst(s) is a practical worst case.
  - The efficiency will be calculated for 32, 64, 128, and 256 CNU systems and for upstream bandwidths of 250Mbps, 500Mbps, and 1000Mbps.
  - A time interval of 2ms will be used for the analysis. (i.e. Every CNU will transmit every 2ms)

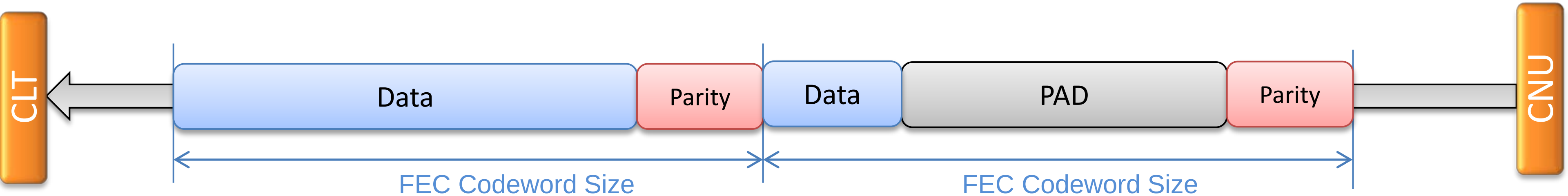
Going from Burst Efficiency to Worst Case System Efficiency





- Calculate total number of bits in cycle. (2ms@1Gbps=2000000 bits.)
- Calculate bits in lowest efficiency bursts (256 Bursts*84 byte payload*42% eff) [Assume everyone sends one]
- Subtract low efficiency bursts from total number of bits.
- If bits leftover is a positive number, then add one large burst with leftover data.
- Calculate efficiency from total payload over payload+parity for cycle.
- NOTE: Same size bursts improves performance and fewer bursts improve performance.

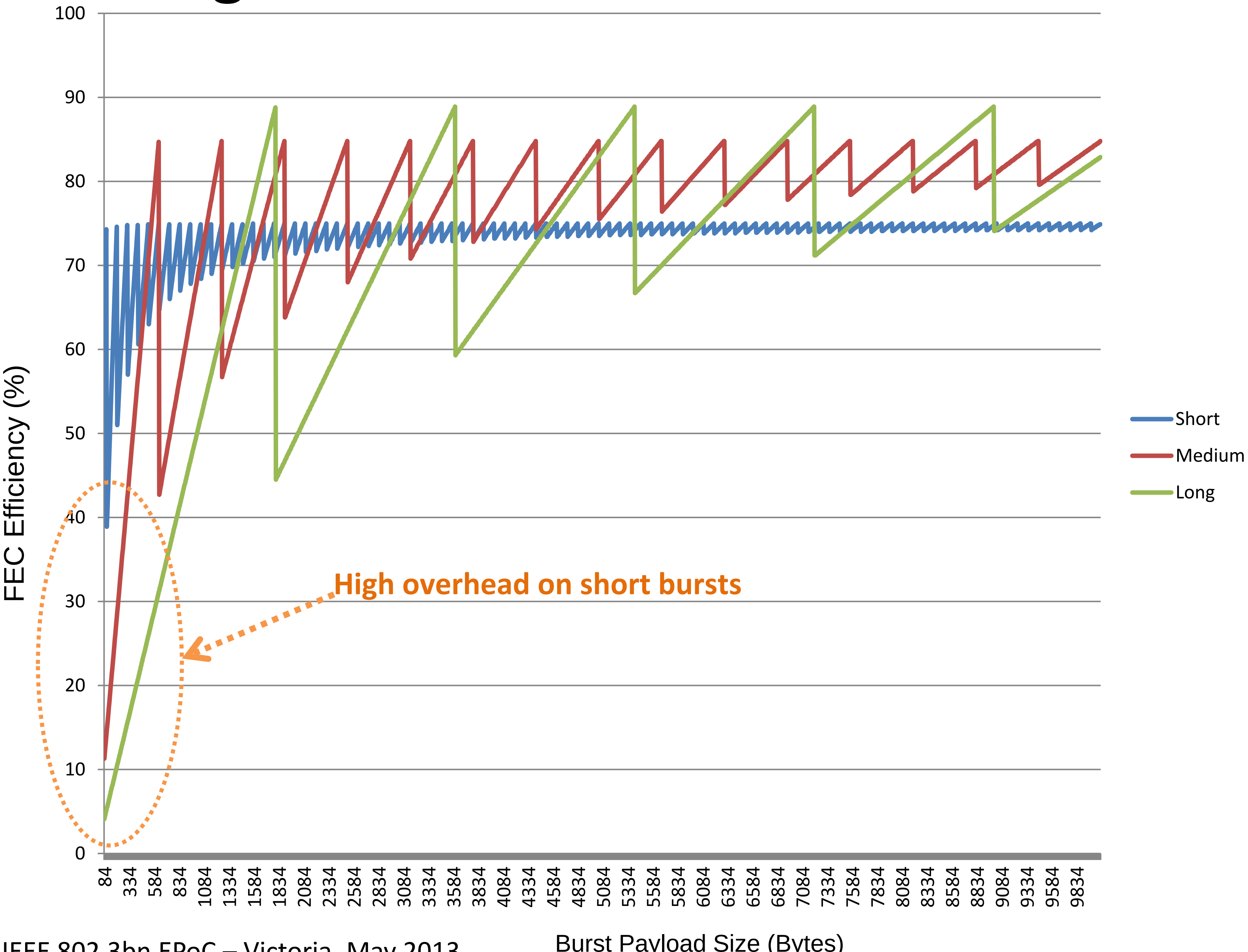
Single Full Size Codeword



- Bursts are extended in length to be even multiples of the FEC codeword size.
- Allows for the simplest and lowest cost decoder.
- This method was used for 10G-EPON upstream.

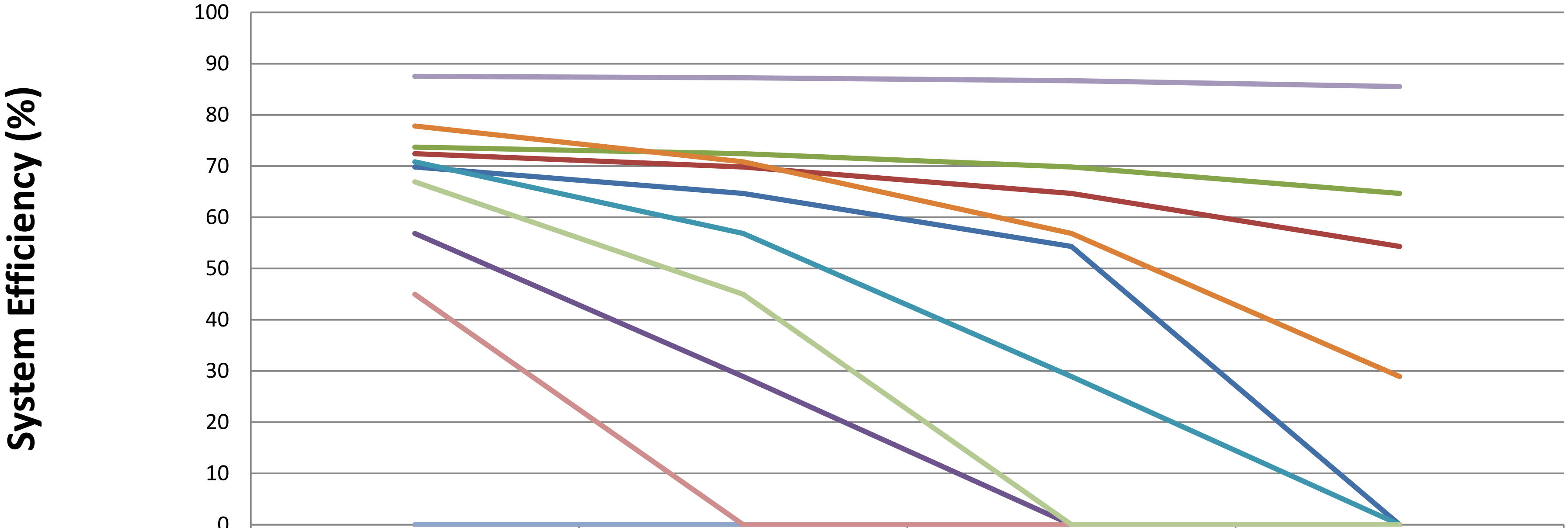
Will a single full size codeword work for EPoC?

Single Full Size Codeword Burst Efficiency



Single Full Size Codeword System Efficiency

System FEC Efficiency based on CNUs and Data Rate



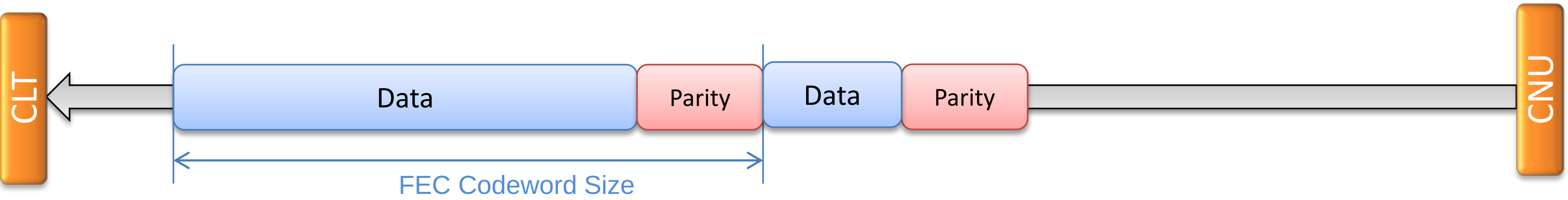
	32	64	128	256 CNUs
Short(250Mbps)	69.8288	64.6576	54.3152	0
Short(500Mbps)	72.4144	69.8288	64.6576	54.3152
Short(1Gbps)	73.7072	72.4144	69.8288	64.6576
Medium(250Mbps)	56.8632	28.9264	0	0
Medium(500Mbps)	70.8316	56.8632	28.9264	0
Medium(1Gbps)	77.8158	70.8316	56.8632	28.92645
Long(250Mbps)	0	0	0	0
Long(500Mbps)	44.9646	0	0	0
Long(1Gbps)	66.9323	44.9646	0	0
10G-EPON	87.51484	87.22968	86.659365	85.51873

Single Full Size Codeword Summary

- 10G EPON has good efficiency because of high data rate.
- The lower data rates of EPoC cause significant waste if full size codewords are used on short bursts.
- In large CNU systems, polling or small bursts on most of CNUs have no capacity or negative capacity for normal data. (0's in the table)
- None of the codeword sizes allow for a 250Mbps upstream with 256 users.
- Short Codeword size has the best performance but efficiency of 50-70% is still low.
- For EPoC upstream data rates and user counts, shortened last code words must be considered.

Fixed size codewords perform poorly with EPoC Upstream Data Rates

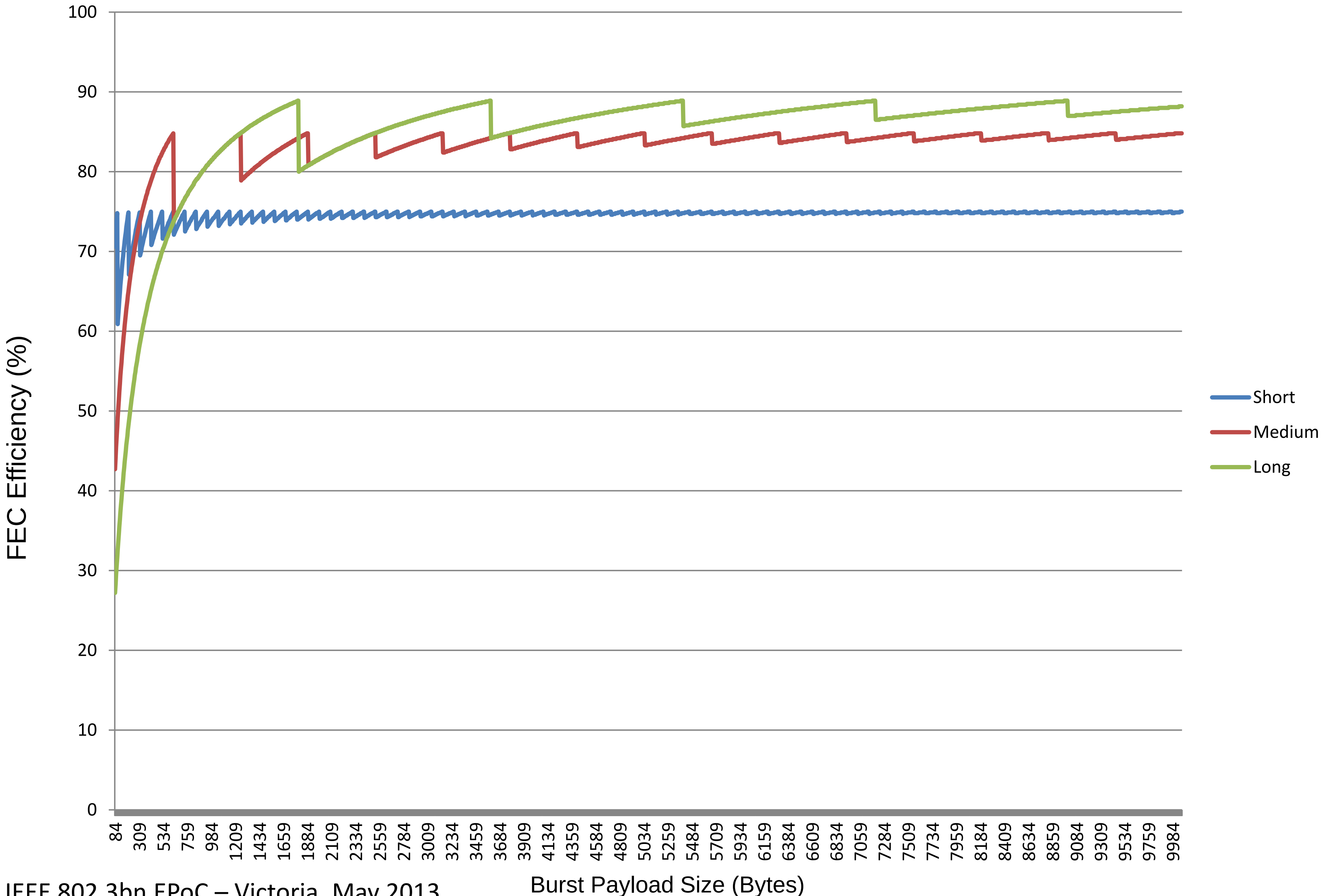
Shortened Last Codeword



- FEC codewords at the end of bursts do not send padding.
- Codewords are padded with zeros at transmitter and receiver for calculation of parity.
- Full size parity is transmitted after a truncated FEC codeword.
- Decoder must handle higher decoding rate for shortened codewords. The codeword rate is increased.

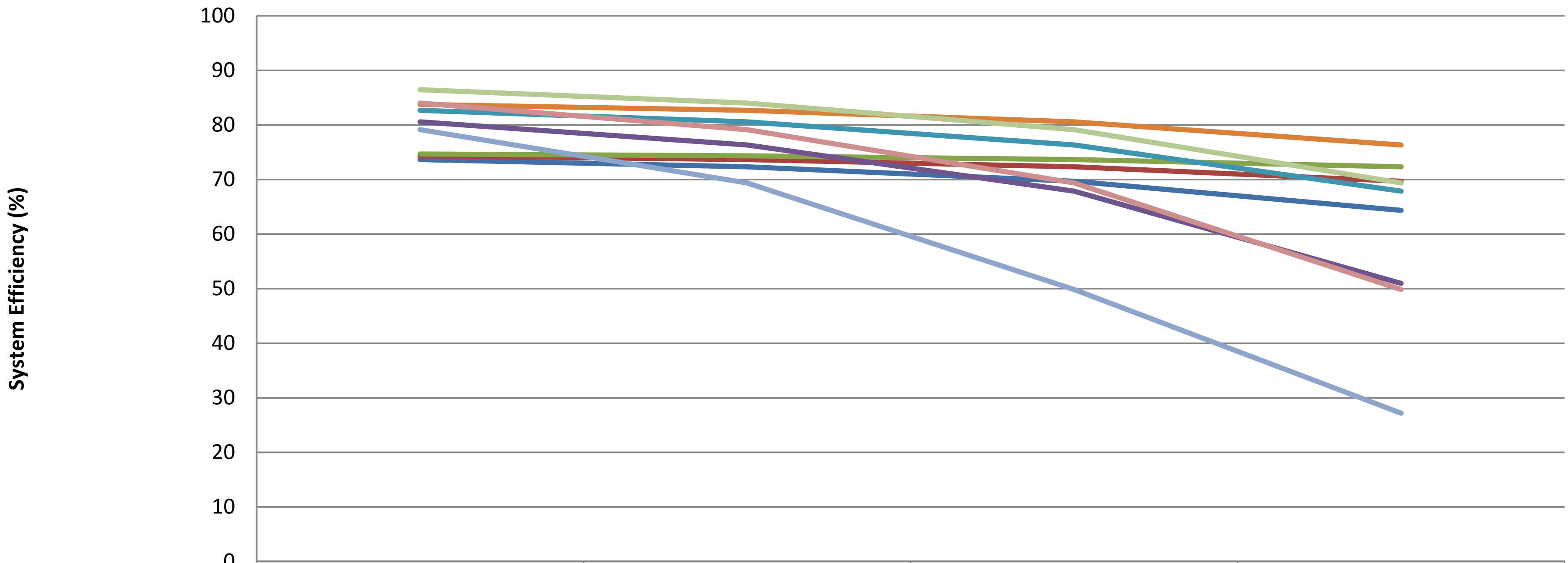
Will a single codeword size with shortening work for EPoC?

Single Shortened Codeword Size Burst Efficiency



Single Shortened Codeword System Efficiency

System FEC Efficiency based on CNUs and Data Rate



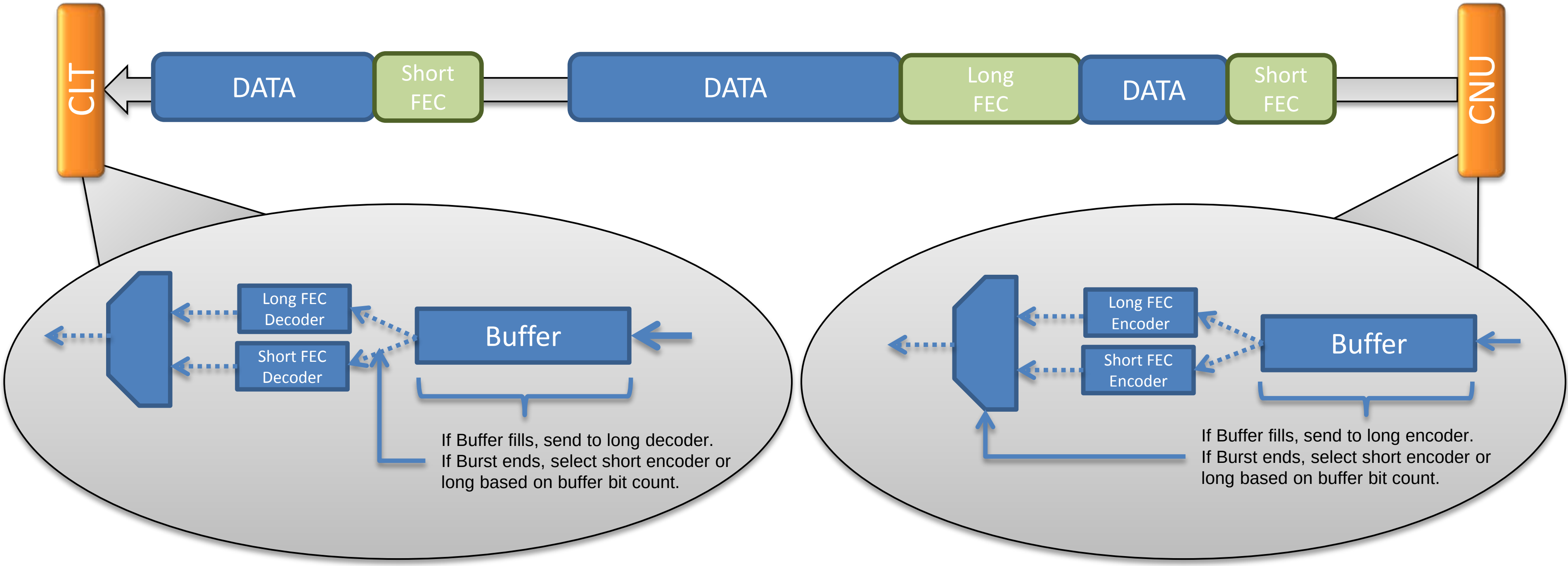
	32	64	128	256 CNUs
Short(250Mbps)	73.6688	72.3376	69.6752	64.3504
Short(500Mbps)	74.3344	73.6688	72.3376	69.6752
Short(1Gbps)	74.6672	74.3344	73.6688	72.3376
Medium(250Mbps)	80.5692	76.3384	67.8768	50.9538
Medium(500Mbps)	82.6846	80.5692	76.3384	67.8769
Medium(1Gbps)	83.7423	82.6846	80.5692	76.33845
Long(250Mbps)	79.136	69.3722	49.8444	27.18446602
Long(500Mbps)	84.018	79.1361	69.3722	49.8444
Long(1Gbps)	86.459	84.01805	79.1361	69.3722

Shortened Last Codeword Summary

- Shortened last codeword improves performance for all codeword sizes.
- The Long FEC looks good with a small number of CNUs but is not usable for a large number of CNUs.
- Medium FEC is the best performance in most scenarios but it is only 51% efficient with 256 CNUs and 250Mbps.
- The Small FEC has the most consistent performance but overall efficiency is between 64%-75%.
- The short FEC has low efficiency on long bursts while the long FEC has low efficiency on short bursts.

Shortened Last Codeword is an improvement but it isn't good enough.

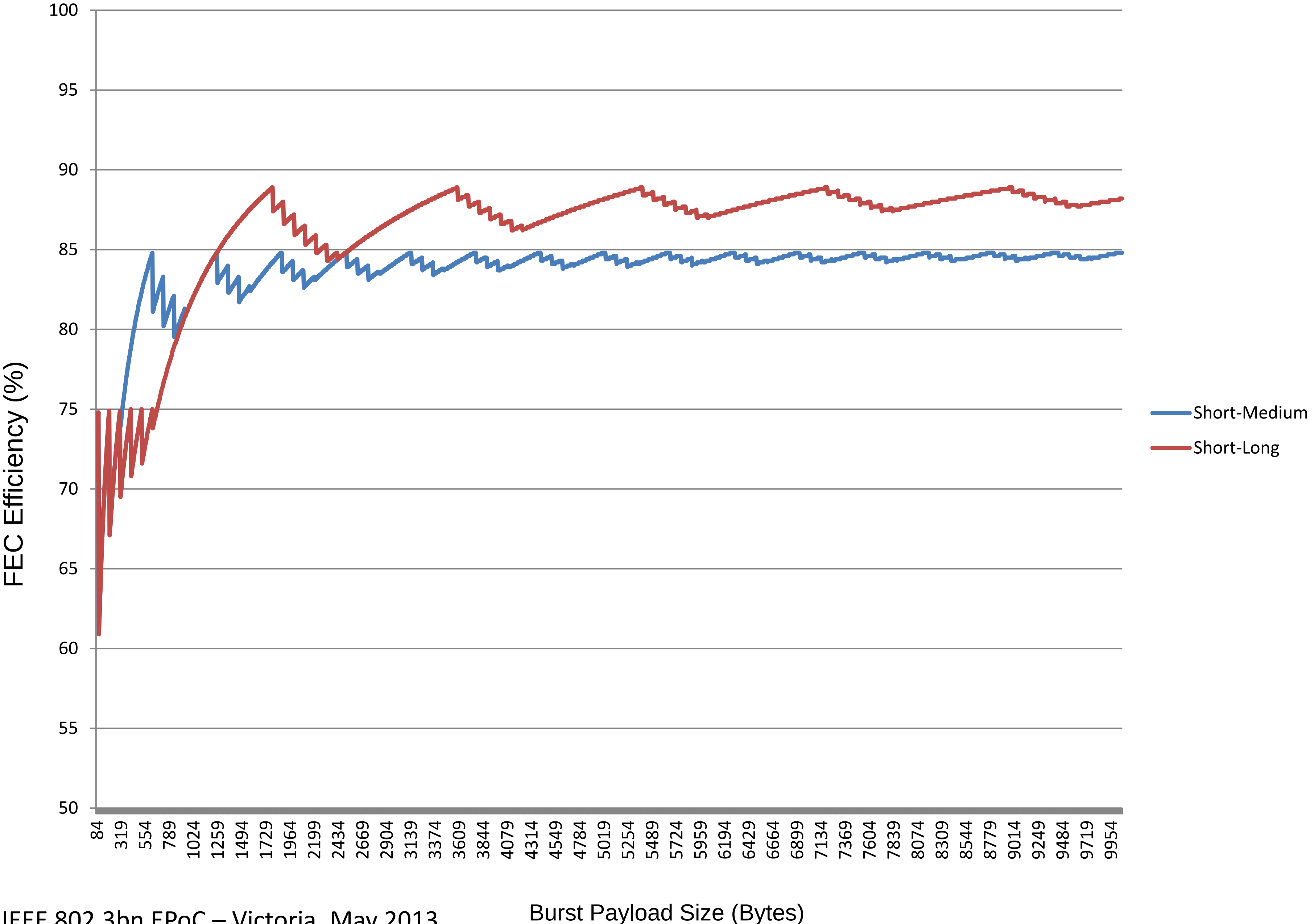
Two FEC or not two FEC



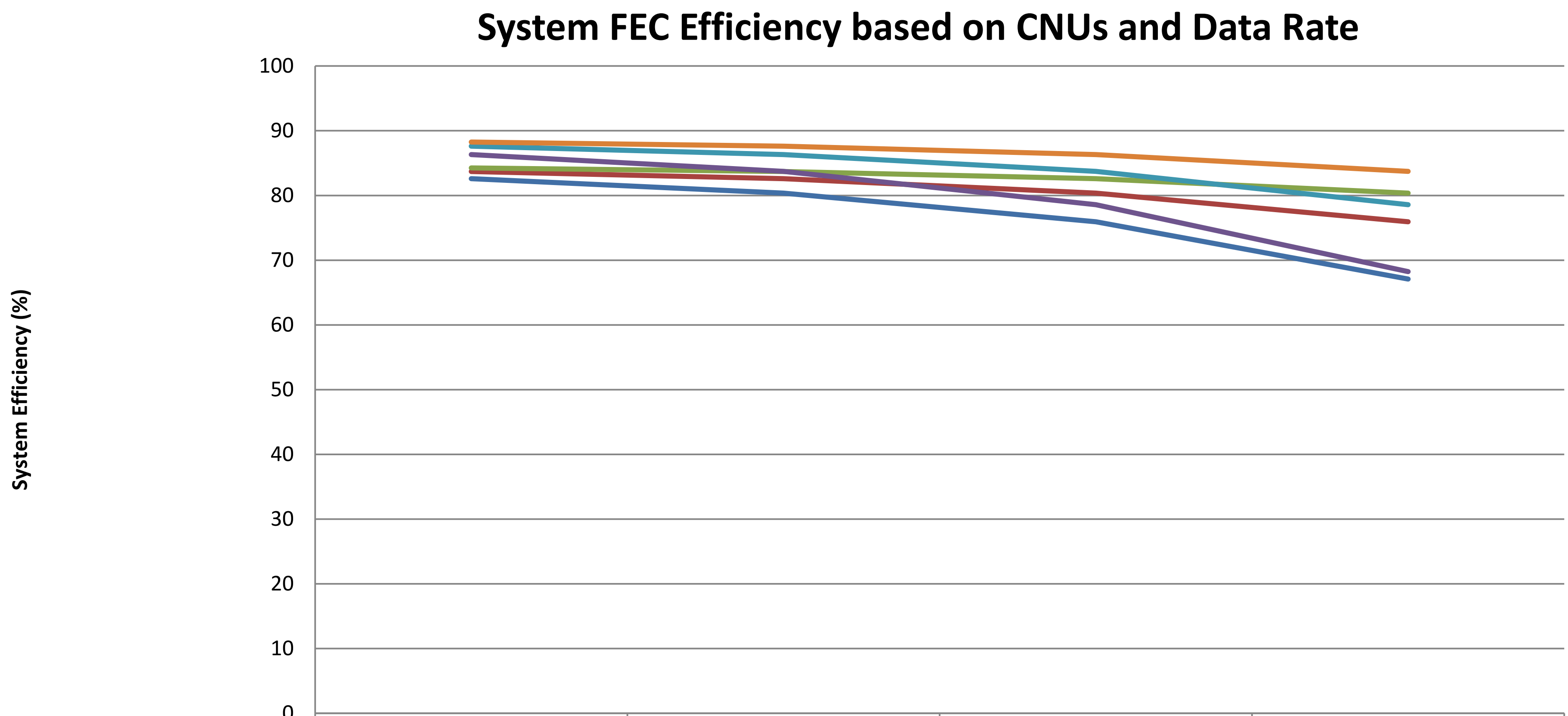
- Using multiple FECs can reduce the parity required for small bursts or odd size end of bursts.
- Short or Long FEC codeword will be determined by size of data block at end of burst.
- End of burst will be determined by the data detector in the transmitter.
- End of burst will be determined by the end of burst marker on the receiver.
- Shortening and/or multiple FEC code word sizes could use the same methodology.

Shortened Last Codeword or Multiple FECs are feasible

Two Codeword Sizes Burst Efficiency



Two Codeword Sizes System Efficiency



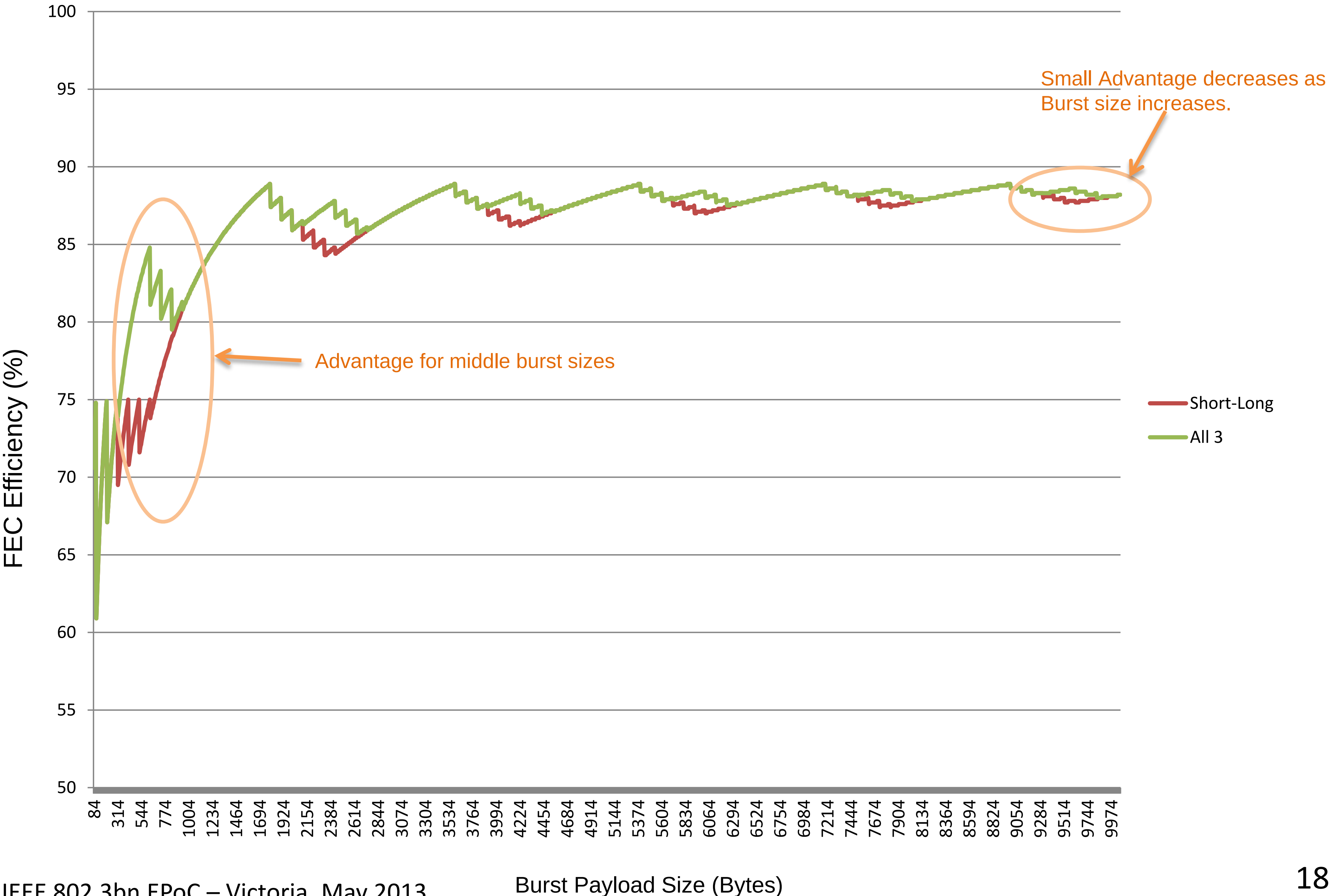
	32	64	128	256 CNUs
Short-Medium(250Mbps)	82.5856	80.3714	75.9428	67.0856
Short-Medium(500Mbps)	83.6928	82.5857	80.3714	75.9428
Short-Medium(1Gbps)	84.2464	83.69285	82.5857	80.3714
Short-Long(250Mbps)	86.3162	83.7324	78.5648	68.2298
Short-Long(500Mbps)	87.6081	86.3162	83.7324	78.5649
Short-Long(1Gbps)	88.25405	87.6081	86.3162	83.73245

Two Codeword Sizes Summary

- The Short-Long combination out performs the Short-Medium codeword size in all load scenarios.
- The Short-Long combination out performs (68%-88%) the Short only codeword size (64%-75%) in all scenarios.
- The complexity of 2 codeword sizes is likely worth a 4% to 12% performance gain.

If Two Codeword size are good, three must be great.

Two vs Three Codeword Size Burst Efficiency

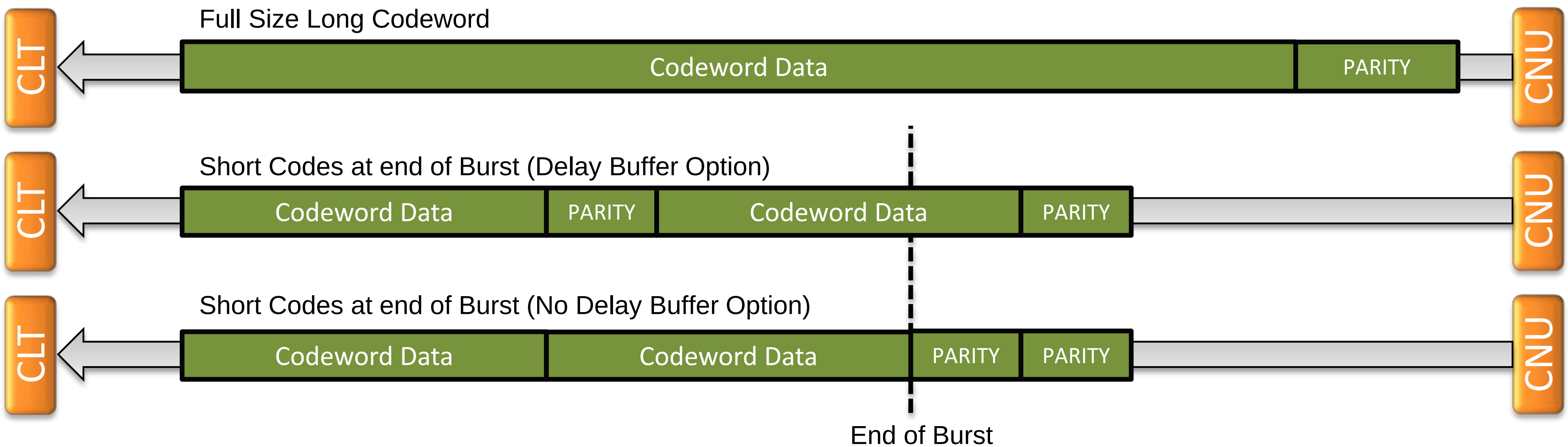


Two vs Three Codeword Sizes Summary

- Using all three codeword sizes improves the burst efficiency for certain burst sizes but does not improve the burst efficiency for short and long bursts.
- Since the System efficiency calculation uses worst case efficiency of the small bursts and fills the remaining with big bursts, there is no improvement in the numbers.
- The better efficiency of “All 3” for 500 Byte to 1000 Byte bursts is not a realistic gain in a loaded system.
- Small bursts will be stay small but medium size bursts will increase in size as efficiency decreases and delay increases.

Three Codeword sizes adds little value over Two.

Two FEC Delay Implications



- Transmit Delay
  - A transmit buffer or additional delay is not required to use the short FEC.
  - Parity can be inserted after each codeword block or at the end of the codeword data.
  - The choice of long and short code at the end of the burst is not known until the last data and end of burst has occurred.
  - By inserting all of the short codeword parity at the end of the burst, there is no need to delay the codeword data until the end of a long codeword.
  - The no delay buffer option does require multiple FEC encoders (short and long) along with storage of the short code parity.
- Receive Delay
  - FEC decoding can't start until the end of parity has been received. There is no delay difference between a single long code and multiple short codes.

FEC Efficiency Summary

- EPoC data rates don’t allow the full size codewords used in 10G EPON.
- FEC Codeword shortening is required based on the proposed codeword sizes.
- Two Codeword sizes is feasible by detecting the end of burst on the transmitter and receiver.
- The Short and Long Codeword sizes shows near optimal efficiency.
- The gain for adding three codeword sizes seems minimal.