Comparison of Physical layers between HSMT and IEEE 802.3dm

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General Comparison

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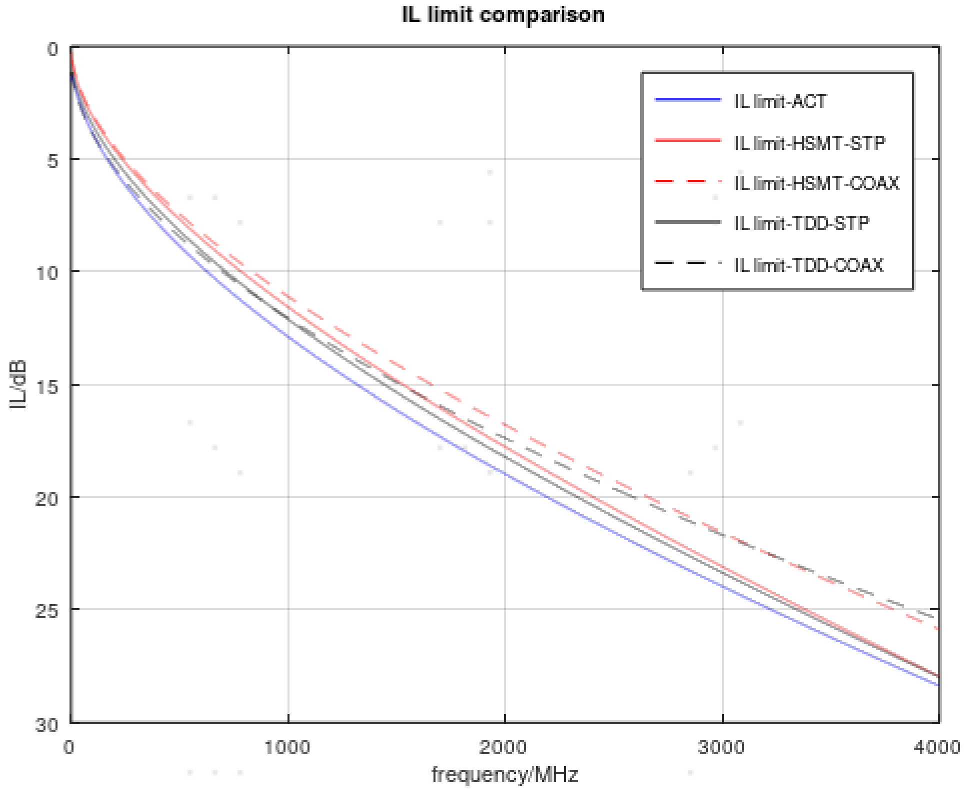
- HSMT supports more speed grades and has different rate targets from 802.3dm.
- Since HSMT specifies the line rate, the net rate is about 85% of the line rate due to overhead.
- We can focus on the following speed grades when comparing with IEEE 802.3dm.

Speed Grade	Net rate*	Modulation	Speed in 802.3dm	Modulation
DL 2 (3.2Gbps)	2.72Gbps	NRZ	2.5Gbps	PAM2
DL 4 (6.4Gbps)	5.44Gbps	NRZ	5Gbps	PAM2
DL 4a (6.4Gbps)	5.44Gbps	PAM4	5Gbps	PAM2
DL 6 (12.8Gbps)	10.88Gbps	PAM4	10Gbps	PAM4

**Net rate is assumed to be 85% of Line rate for simplicity*

- At similar rates, HSMT and 802.3dm adopt the same modulation schemes. Particularly at net rates of 5.x Gbps, HSMT provides both NRZ and PAM4 options, while 802.3dm had a lengthy debate over whether to use PAM2 or PAM4.

Insertion loss



- In IEEE 802.3dm, despite extensive discussions, the IL limit has not yet been determined
  - ✓ The IL limit proposed by ACT is (*Reference*: [IL Limit Proposal]):

    Insertion loss(f) ≤ -0.0015 + 0.001325*f + 0.3645*√f + 1.1785/ √f (dB)

  - ✓ The IL limit proposed by TDD is (*Reference*:[802.3dm Cable Channel IL and RL limits]):

    STP CnC IL Limit $IL = 0.322 \cdot \sqrt{f} + 0.0019 \cdot f + \frac{1}{\sqrt{f}}$

    Coax CnC IL Limit $IL = 0.3 + 0.345 \cdot \sqrt{f} + 0.000825 \cdot f + \frac{0.48}{\sqrt{f}}$

- HSMT has separate IL limits for STP and Coax as follows:

$$STP_{IL} < 0.0024 \times f + 0.29 \times \sqrt{f}$$

$$Coax_{IL} < (-1.3 + 0.0115 \times f + 2 \times \sqrt{f} + 3.79/\sqrt{f}) \times 0.15$$

- IL is limited by a lot of factors, including: length, frequency, cable type, aging, number of inline connectors and temperature.
- A point of contention in IEEE 802.3dm is whether to define different IL limits for STP and COAX, primarily because the two different cables have different characteristics.
- A single IL limit proposed by ACT in dm on the other hand, allows the flexible usage of cables in the market, and allows for longer cable length.

RS-FEC

- The use of RS-FEC involves a tradeoff between latency and error correction capability. The comparison of RS-FEC for HSMT, TDD scheme in dm and ACT scheme in dm is as follows:

	Data Rate	Line Rate	N	K	m	Correctable FEC errors	Coding Gain	FEC Delay
TDD	100Mbps	3Gbps	130	124	8	**3**	**3.7**	365ns
	2.5Gbps	3Gbps	130	122	8	**4**	**4.3**	371ns
	5Gbps	6Gbps	130	122	8	**4**	**4.3**	185ns
	10Gbps	12Gbps	130	122	8	**4**	**4.5**	93ns
ACT	100Mbps	117Mbps	50	46	6	**2**	**3.2**	2821ns
	2.5Gbps	2.812Gbps	360	326	10	**17**	**6.5**	1404ns
	5Gbps	5.625Gbps	360	326	10	**17**	**6.5**	702ns
	10Gbps	11.25Gbps	360	326	10	**17**	**6.8**	351ns
HSMT	85Mbps	100Mbps	73	69	8	**2**	**3.6**	6240ns
	2.72Gbps	3.2Gbps	384	354	9	**15**	**6.7**	1167ns
	5.44Gbps	6.4Gbps	384	354	9	**15**	**6.7**	584ns
	10.88Gbps	12.8Gbps	384	354	9	**15**	**6.7**	292ns

**The data for TDD and ACT are from Error Probability and RS-FEC Coding Gain and Comparison of ACT and TDD Propagation Delay*

RS-FEC and Propagation delay

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- In general, the RS-FEC proposed for ACT in dm and HSMT have very similar capabilities. The differences are:
  - ✓ In upstream, HSMT has clearly higher FEC delay compared to ACT in dm. In the meanwhile, HSMT offers even higher coding gain than ACT in dm.
  - ✓ In downstream, HSMT has slightly less FEC delay than ACT in dm, but correspondingly, it can also correct slightly fewer errors than ACT.
- When considering total propagation delay, this presentation takes Quiet_Period_Delay, Referesh_Header_Delay and FEC_Delay into account as per *Comparison of ACT and TDD Propagation Delay*.

FEC_Delay	← Inherent FEC encoding and decoding delay
+ Quiet_Period_Delay	← No data is transmitted during Quiet Period
+ Refresh_Header_Delay	← No data is transmitted during Refresh Header
+ ~~Implementation_Sepcific_Delay~~	← Every implementation can have different delay
~~+ Cable_Propagation_Delay~~	← Propagation delay over the link segment
= Total_Delay	← The total delay over the link

Propagation delay

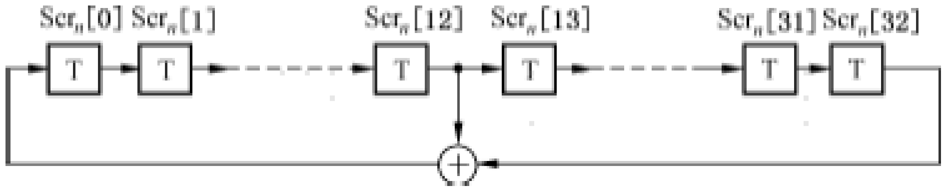
	Data Rate	Line Rate	Quiet Period	Refresh Period	FEC Delay	Total Delay
TDD	100Mbps	3Gbps	9040ns	160ns	365ns	**9565ns**
	2.5Gbps	3Gbps	773ns	160ns	371ns	**1304ns**
	5Gbps	6Gbps	773ns	160ns	185ns	**1118ns**
	10Gbps	12Gbps	773ns	160ns	93ns	**1026ns**
ACT	100Mbps	117Mbps	0	0	2821ns	**2821ns**
	2.5Gbps	2.812Gbps	0	0	1404ns	**1404ns**
	5Gbps	5.625Gbps	0	0	702ns	**702ns**
	10Gbps	11.25Gbps	0	0	351ns	**351ns**
HSMT	85Mbps	100Mbps	0	0	6240ns	**6240ns**
	2.72Gbps	3.2Gbps	0	0	1167ns	**1167ns**
	5.44Gbps	6.4Gbps	0	0	584ns	**584ns**
	10.88Gbps	12.8Gbps	0	0	292ns	**292ns**

- In upstream, HSMT exhibits significantly greater delay than ACT, yet it still has considerably lower total delay than TDD.
- In downstream, HSMT has the shortest delay among the three schemes.

Scrambling

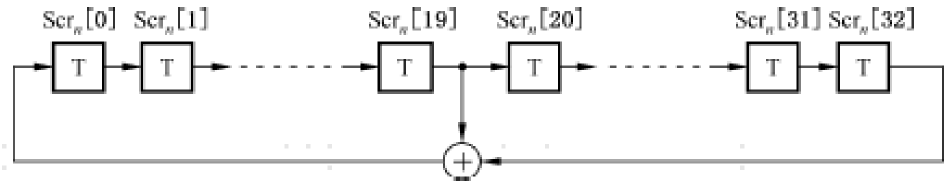
HSMT Downstream and ACT Upstream:

Scrambler generator polynomial: $x^{33} + x^{13} + 1$



HSMT Upstream and ACT Downstream:

Scrambler generator polynomial: $x^{33} + x^{20} + 1$



- Both HSMT and the ACT in dm (Also TDD in dm) employ the same scrambling polynomial to generate scrambling codes for scrambling.
- The only difference is that the specific polynomials used for uplink and downlink are opposite between the two schemes, which essentially has no performance difference.

Modulation and Line coding

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In upstream, ACT uses DME and HSMT uses NRZ + 8B/10B

- ACT with DME
  - ✓ DME helps with synchronization
  - ✓ beneficial for AC coupling circuit
  - ✓ DME is DC balanced, so avoid baseline wander (BLW) issue
- HSMT with NRZ+8B/10B
  - ✓ NRZ is simple, but has less immunity to BLW
  - ✓ 8B/10B has bounded disparity (disparity range [-2,2]) and is DC balanced, so also alleviate BLW issue
  - ✓ In terms of AC coupling circuits and PoC, 8B/10B encoding is less effective than DME.
- **Both ACT in dm and HSMT recognize the seriousness of the BLW issue and adopt different approaches to address it.**

In downstream, HSMT adopts 9B/10B

- Similar to 8B/10B, 9B/10B also provides bounded disparity (disparity range [-4, 4]) and DC balance. Therefore, it also alleviates BLW issue.

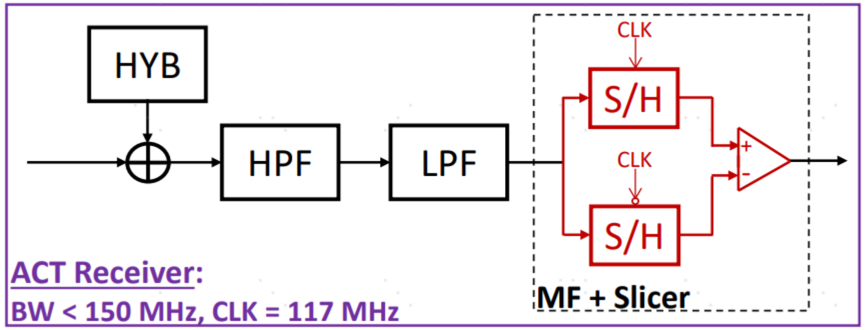
Other differences in physical layer

- **ACT (and also TDD) in dm supports an optional Precoder function, but HSMT does not support**
  - ✓ Precoder is optional in dm and ch. It is used to alleviate burst errors caused by DFE.
  - ✓ In some scenarios, a precoder can transform a burst of consecutive errors into two independent errors, one at each end.
  - ✓ A precoder does not always provide positive gain.

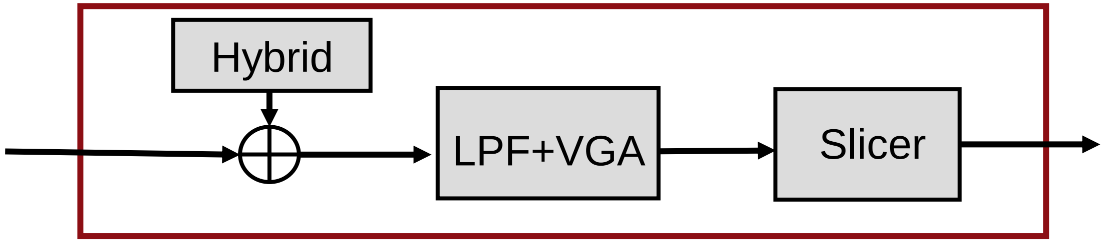
- **For both UL and DL, HSMT further supports retransmission mechanism to further increase the robustness**
  - ✓ Retransmission can target single or multiple PLDB packets.
  - ✓ When the receiving node fails to correctly receive one or more PLDBs, it can initiate a physical layer retransmission message to the transmitting node, requesting retransmission.
  - ✓ With one retransmission, HSMT can achieve end-to-end low-latency transmission within 20 microseconds.

Possible implementation for upstream receiver

- In IEEE 802.3dm, many contributions have presented potential implementation schemes for the ACT solution. An example is shown below (*Ref: Hossein Sedarat - IEEE 802.3dm - Analog-Based ACT Receiver*):



- For HSMT, in upstream direction, the implementation can be quite similar, and the main difference is ACT uses DME and HSMT uses NRZ.
- A possible implementation for HSMT is shown below



- For both cases, no need for echo canceller and equalization!

Conclusion

- For physical layer processing, when compared to ACT in dm, the main differences of HSMT lie in using retransmission, not using a precoder, using different RS-FEC coding, not applying DME to the uplink, and additionally using 8B/10B or 9B/10B.
- Some of these differences represent different approaches to solving the same problem, such as the use of DME and 8B/10B.
- Despite the differences, HSMT and ACT in dm also have many similarities, such as similar RS-FEC error correction capability, identical scrambling codes, similar interleaving schemes, and most importantly, both being essentially ACT solutions.
- Without considering implementation-specific delays, ACT and HSMT generally demonstrate better latency performance than TDD in the vast majority of cases.
- ACT solution leads to simple upstream receiver design, which needs no echo-canceller and no equalization.

Thank You!