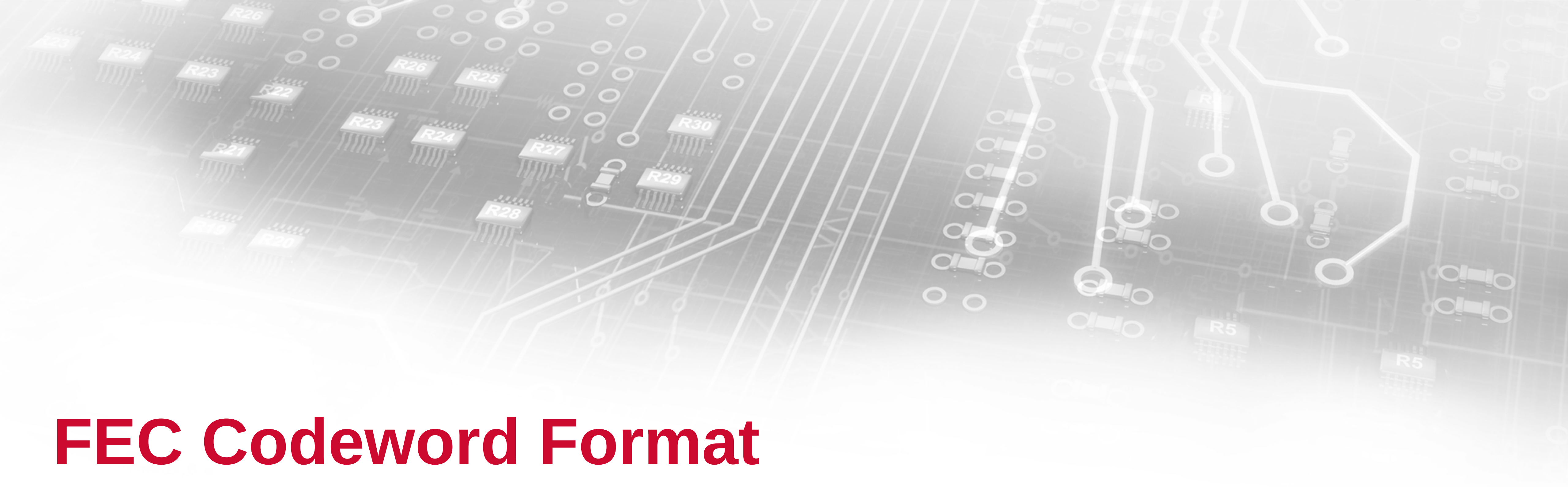


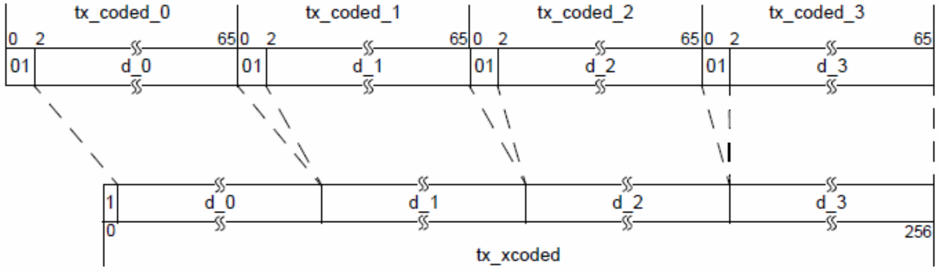
FEC Codeword Format and Alignment Mechanism

Glen Kramer

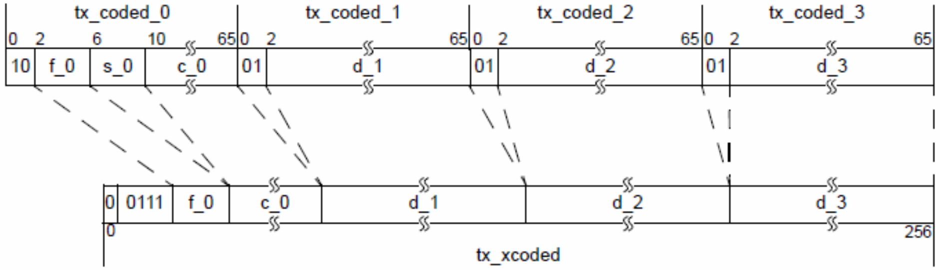
Broadcom

256b/257b Line Coding

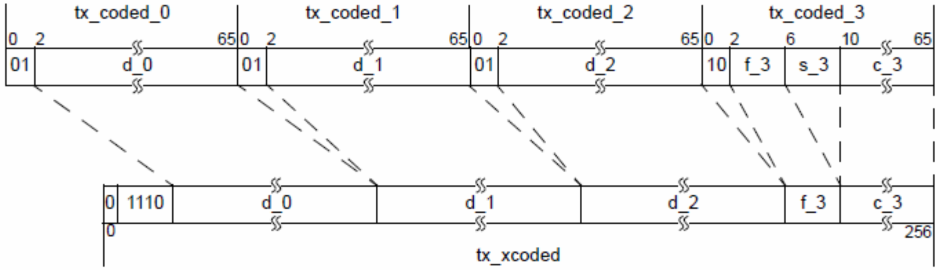
- Specified in 802.3, Clause 91 for 100GBASE-R
- Transcodes four 64b/66b blocks into one 256b/257b block
  - Throughput gain of 2.72% or 680 Mbps per lane
- The downstream LDPC Codeword accepted in Orlando (LDPC[18493,15677]) already assumes 256b/257b encoding
  - **Payload:** 61 block x 257 bits = 15677 bits (entire 257b blocks are protected)
  - **Parity:** 11 blocks x 256 bits = 2816 bits (only 256 bits per block are used to carry parity)
  - **Total CW size:** 15677 bits + 2816 bits = 18493 bits or 61 + 11 = 72 blocks



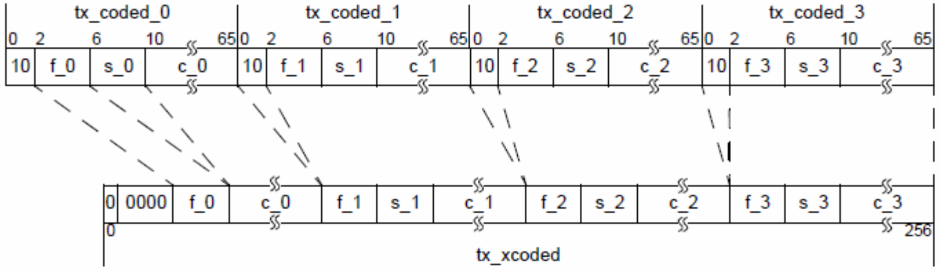
Example 1: All data blocks



Example 2: Control block followed by three data blocks



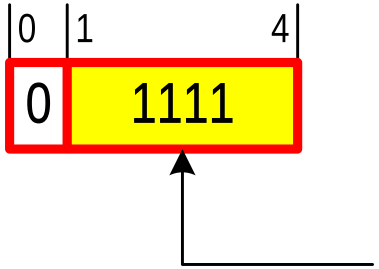
Example 3: Three data blocks followed by a control block



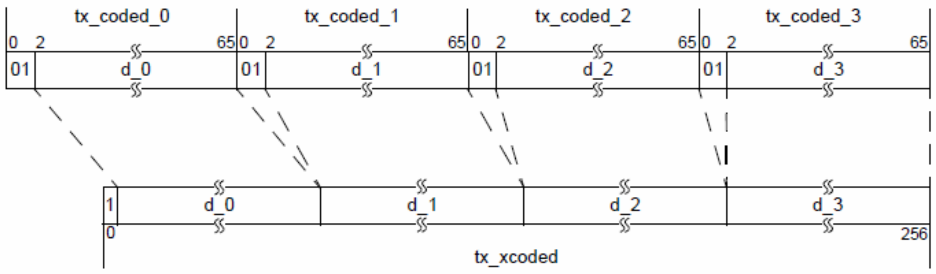
Example 4: All control blocks

Parity Delineation

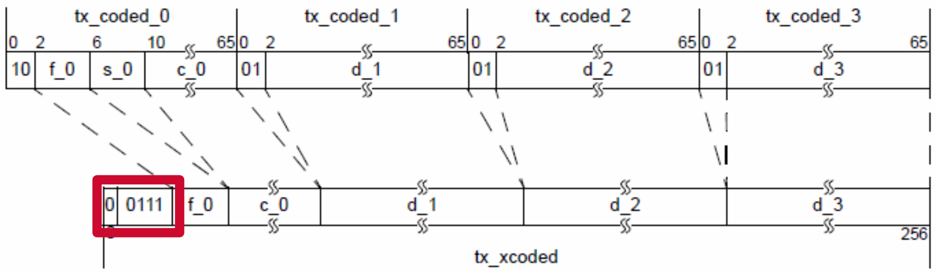
- In .3av we have defined special 64b/66b sync headers for parity
  - SH = 01: Data
  - SH = 10: Control
  - SH = 00, 11: Parity
- In 256b/257b, sync headers are collapsed to a single bit (1:All data, 0:Control+[Data])
- However, one control code-point is available to mark the parity



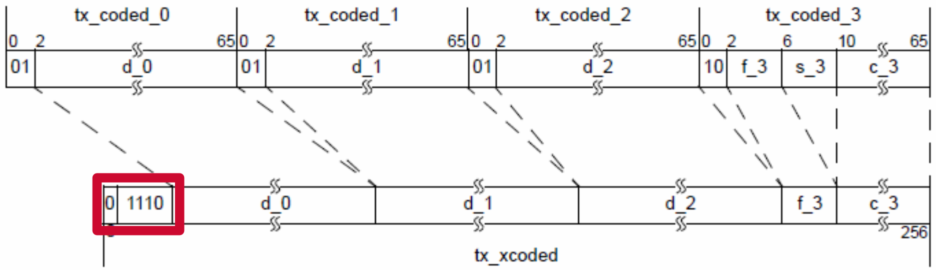
Code-point 1111$_b$ is not used in regular control blocks.
This code-point can mark the beginning of Parity section of FEC Codeword



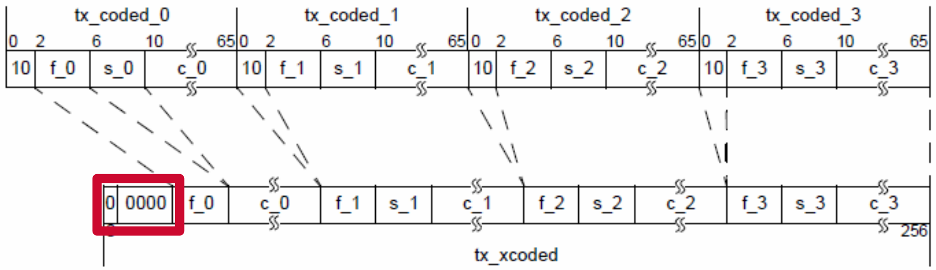
Example 1: All data blocks



Example 2: Control block followed by three data blocks



Example 3: Three data blocks followed by a control block



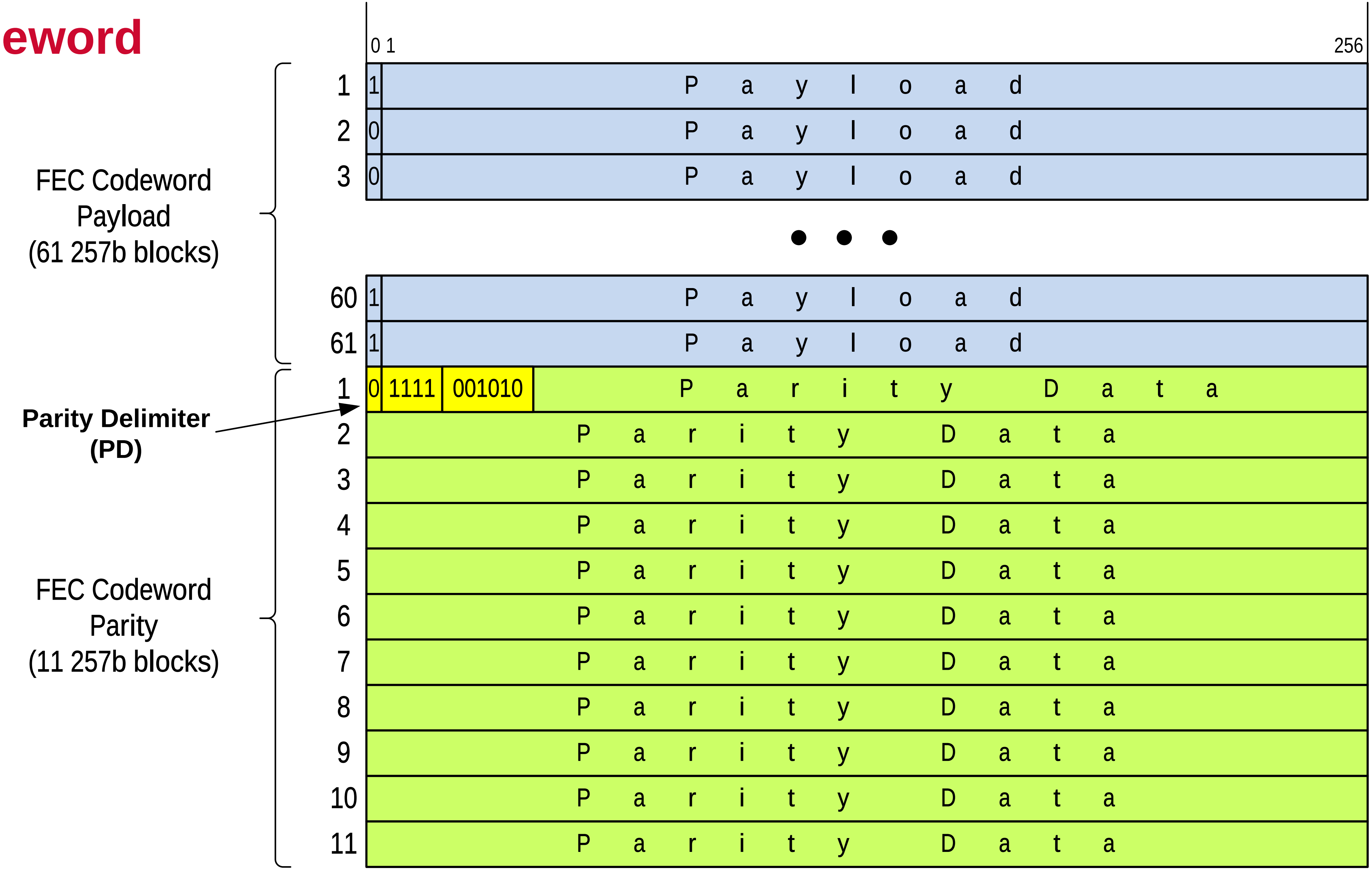
Example 4: All control blocks

Parity Delineation

- For the receiver to align to the FEC codewords, it is enough to only mark the first parity block with a special **Parity Delimiter (PD)**.
- The PD should start with the special code-point 0-1111 plus 6 additional bits to make it as close to balanced code as possible (i.e., 5 zeroes, 6 ones)
  - 011-1100-1010$_b$ (or **0x3ca**) ← Wow! A divine sign!!! Go ahead, argue with this proposal (🌩)
- If we use the code-point to mark the first parity block, then in this block we only have 257-11=246 bits available for the actual parity value.
- Subsequent 10 parity blocks are used to carry parity entirely, i.e., all 257 bits of each block.
- The total size of parity is 246 + 10×257 = 2816 as planned.

FEC Codeword Format

- FEC protects the entire 257b payload block



0 1 256

FEC Codeword Payload (61 257b blocks)

1 1 Payload
2 0 Payload
3 0 Payload
● ● ●
60 1 Payload
61 1 Payload

Parity Delimiter (PD)

FEC Codeword Parity (11 257b blocks)

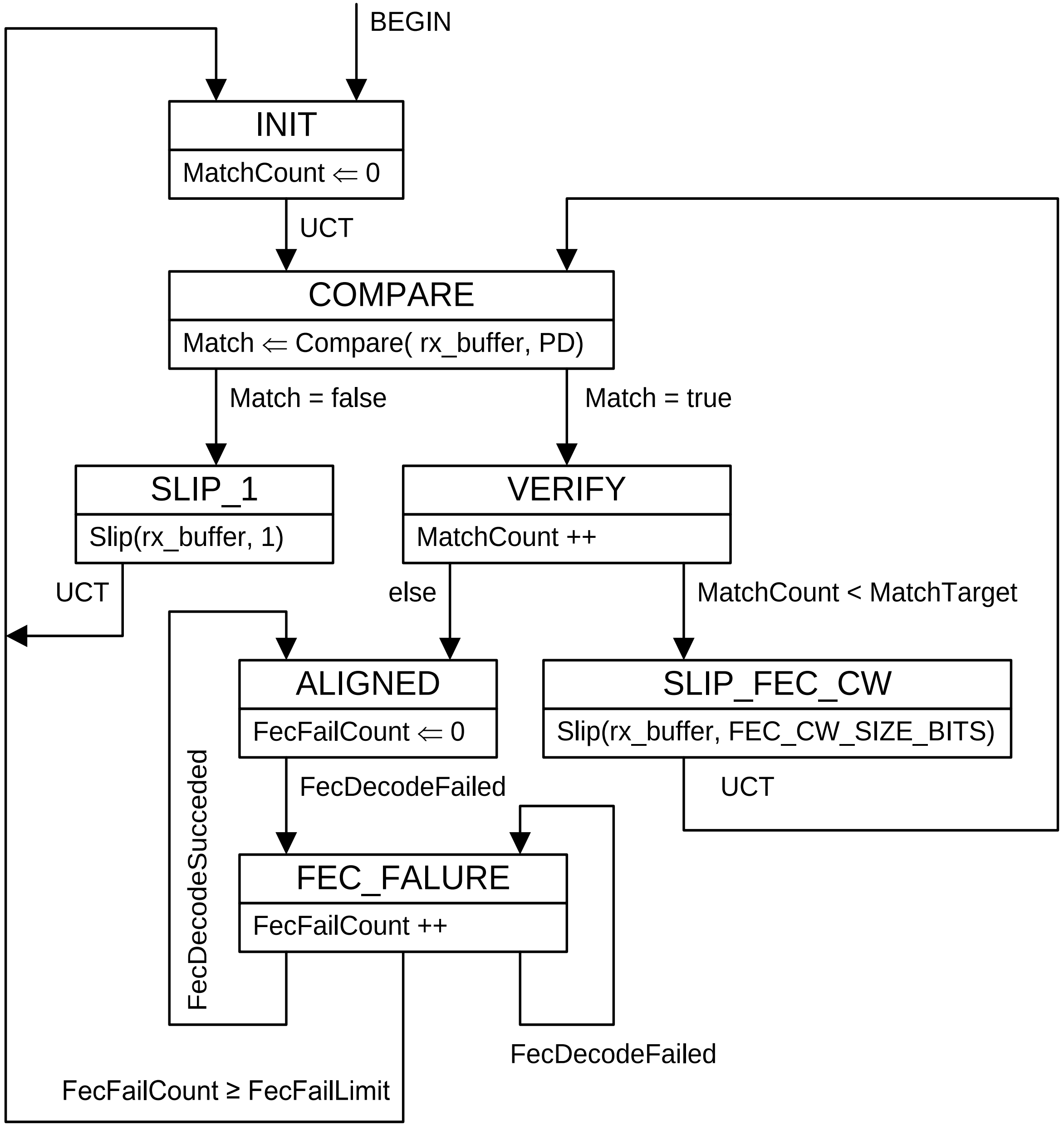
1 0 1111 001010 Parity Data
2 Parity Data
3 Parity Data
4 Parity Data
5 Parity Data
6 Parity Data
7 Parity Data
8 Parity Data
9 Parity Data
10 Parity Data
11 Parity Data

ONU FEC alignment mechanism

- Downstream never needs to shorten the codewords. Every codeword has a fixed size of 72 257b blocks (payload + parity)
- After reboot, the ONU needs to align to FEC codewords
  - Direct step from bit alignment to FEC CW alignment
  - There is no 257b block alignment in between. (257b blocks are not alignable; requires additional alignment markers)

To do the alignment, the ONU does the following:

1. Hunt for PD (11-bits) in the received bit stream
   a) If PD is not matched, *MatchCount = 0*, slip incoming stream by 1 bit, go to (1).
   b) If PD is matched, *MatchCount* ++, slip incoming stream by one full FEC codeword (18504 bits), go to (1)
2. When *MatchCount* reaches a *MatchTarget* threshold (5?), declare the alignment
3. If FEC decoder consistently indicates decoding failure for *FecFailLimit* (3?) consecutive FEC CWs, set *MatchCount = 0*, go to 1 to realign.



Reliability of Alignment Mechanism

- The alignment SD will often pursue false leads before stumbling on the true delimiter. That is OK and expected.
- Because the alignment mechanism relies on the feedback from the FEC Decoder, probability of a wrong alignment is 0. The ONU will get aligned eventually. The question is how long that would take?

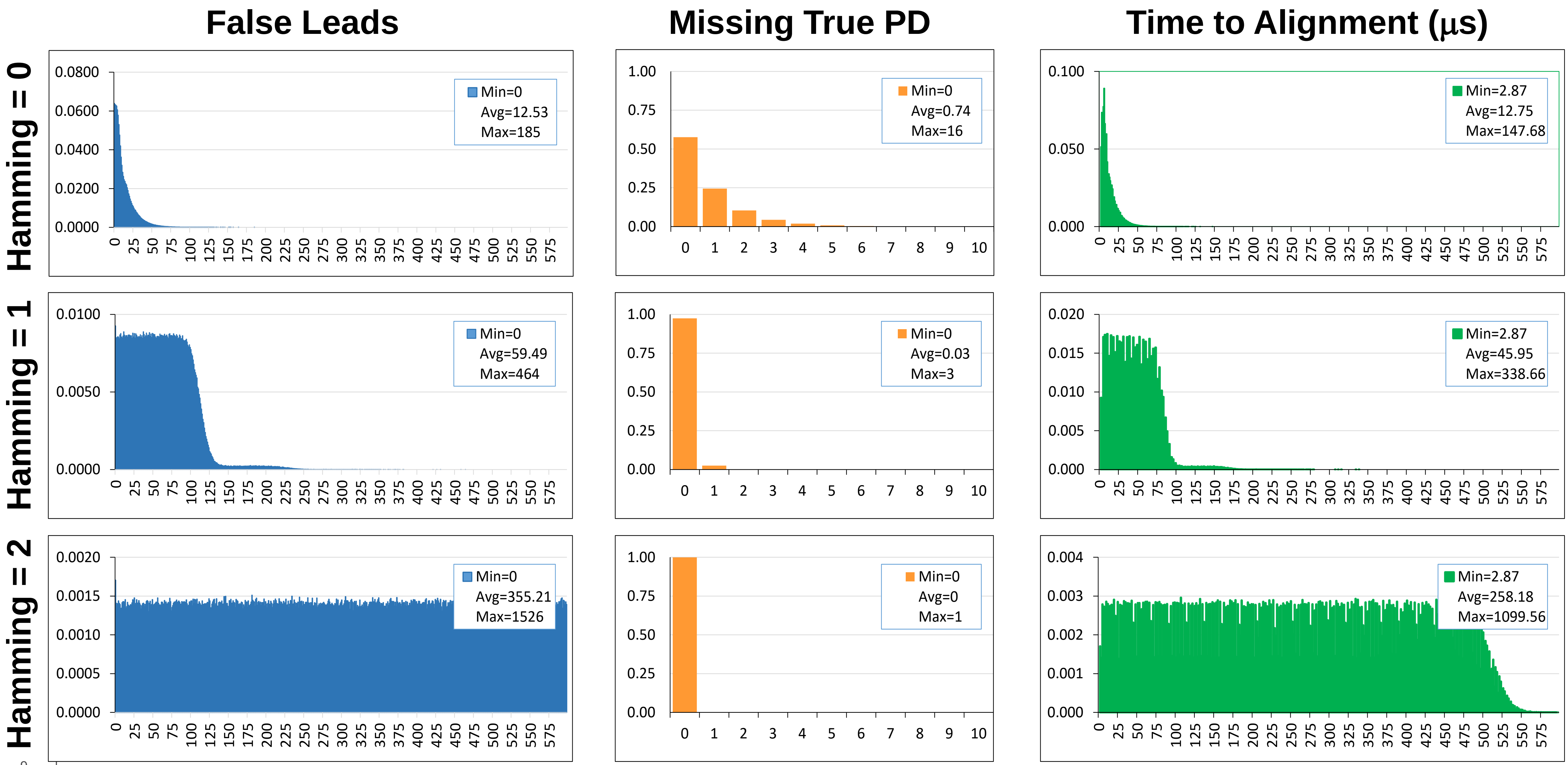
- The efficiency of FEC alignment depends on the choice of
  - *PD matching Hamming threshold*
  - *MatchTarget*
  - *FecFailLimit*

- We should find the best combination of these values to minimize the alignment time

Simulation study

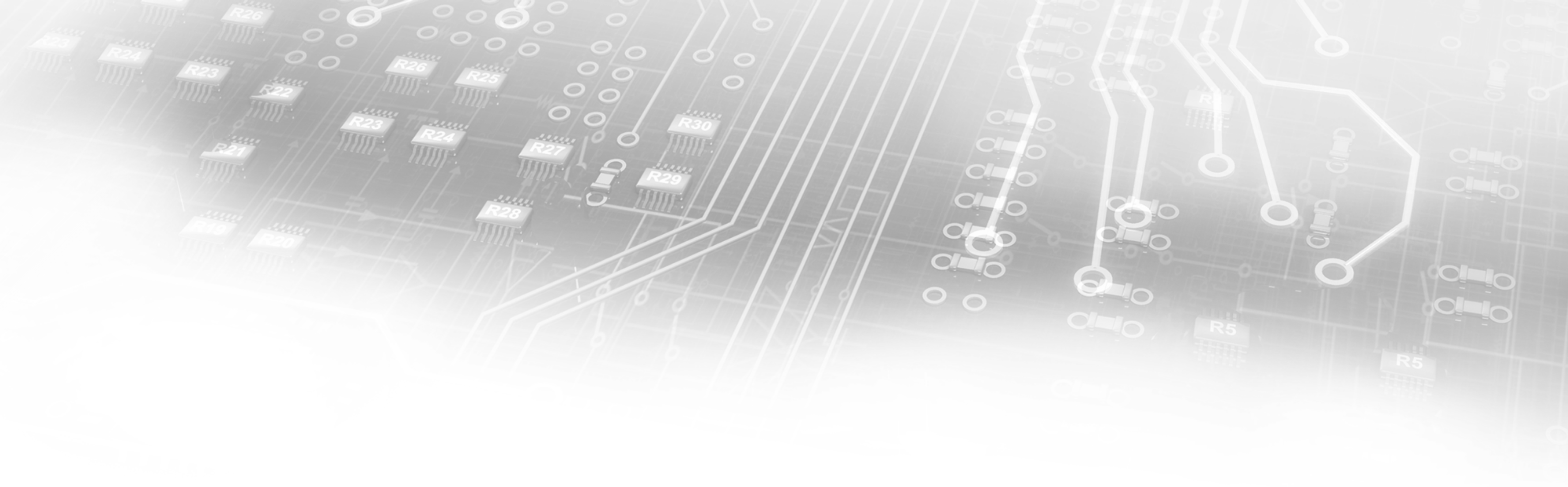
- 1 million alignment attempts for each configuration
- Input BER = 0.01
- Match Target = 5 (i.e., need to match five delimiters in a row to declare alignment)
- *Hamming threshold* = {0, 1, 2}
- *MatchTarget = 5* (i.e., need to match five delimiters in a row to declare alignment)
- *FecFailLimit = 3*
  - Time to detect loss of alignment (persistent FEC decode failure) = 10μs (this includes Rx time for 3 FEC CWs and FEC decoder delay)
  - This parameter was not relevant as alignment to a wrong position was not observed in the simulation

Simulation Results for varying match hamming threshold



Conclusion

- If we hunt for a PD with H=2, the Alignment algorithm will pursue many more false leads. But the true PD position is never missed (in 1M tries, anyway).
- If we hunt for a PD with H=0, the algorithm will pursue very few false leads. But in about 42% of tests, the true delimiter will be missed the first time. Sometimes the true PD position may be missed multiple times (max observed in 1 M tests is 16 times)
- However the main metrics for the performance of the alignment algorithm is the total time it takes an ONU to align. Simulations show that using H=0 provides by far the shortest alignment time.
  - Average: 12 75µs
  - Maximum: 147.68µs
- Considering the typical interval between Discovery GATEs of 1 second, the alignment time (in any configuration) consumes a negligible fraction of the overall ONU Discovery and Registration time.



Backup

Hamming Distance Threshold

- When we hunt for the PD in the input stream, we should allow a match with some Hamming distance (H = 0? 1? 2?)
- Probability of a random block (not PD) looking like PD

$$\text{if H} = 2, \qquad P(falsePD) = \frac{\binom{11}{2} + \binom{11}{1} + 1}{2^{11}} = 0.0327$$

$$\text{if H} = 1, \qquad P(falsePD) = \frac{\binom{11}{1} + 1}{2^{11}} = 0.00586$$

$$\text{if H} = 0, \qquad P(falsePD) = \frac{1}{2^{11}} = 0.000488$$

Expected Number of Matches

- Expected number of false PDs matchings in one FEC CW (continuous scan):

$$\text{if H} = 2, \qquad F = 18504 \times 0.0327 = 605$$

$$\text{if H} = 1, \qquad F = 18504 \times 0.00586 = 108$$

$$\text{if H} = 0, \qquad F = 18504 \times 0.000488 = 9$$

- On average, the comparator will encounter half the expected number of false PDs.
- For each false PD, the comparator will usually try one more position exactly 18504 bits away, before resuming the hunt.

Average Time to Align

- The average time before arriving to the true PD position is therefore $740ns \times F/2$

$$\text{if H} = 2,\ Time = 223\,\mu s$$

$$\text{if H} = 1,\ Time = 40\,\mu s$$

$$\text{if H} = 0,\ Time = 3.3\,\mu s$$

Missing True PD

- Once the scanner arrived to the proper PD position, what is the probability of missing it?
- To declare alignment, the comparator needs to match the PDs with Hamming Distance H exactly 18504 bits apart M times (M = 5?)
- Probability of alignment failure = probability that at least one of the comparisons will not match, i.e., at least one out of M PDs will have more than H errors.

$$P(PDmatch) = \sum_{h=0}^{H} \binom{11}{h} BER^{h} \times (1 - BER)^{11-h}$$

- Probability of mismatch of 1 or more PD out of M:

$$P(PDmismatch) = 1 - P(PDmatch)^{M}$$

Probabilities of missing true PD

H	Prob. of matching a single true PD **P(PDmatch)**	Prob. of mismatching at least one PD out of M **P(PDmismatch), M=**		
		3	**4**	**5**
0	0.895338254	0.282269	0.357388	0.424645
1	0.994820283	0.015459	0.020558	0.025632
2	0.999844627	0.000466	0.000621	0.000777