FEC in EPON
Technical Proposal

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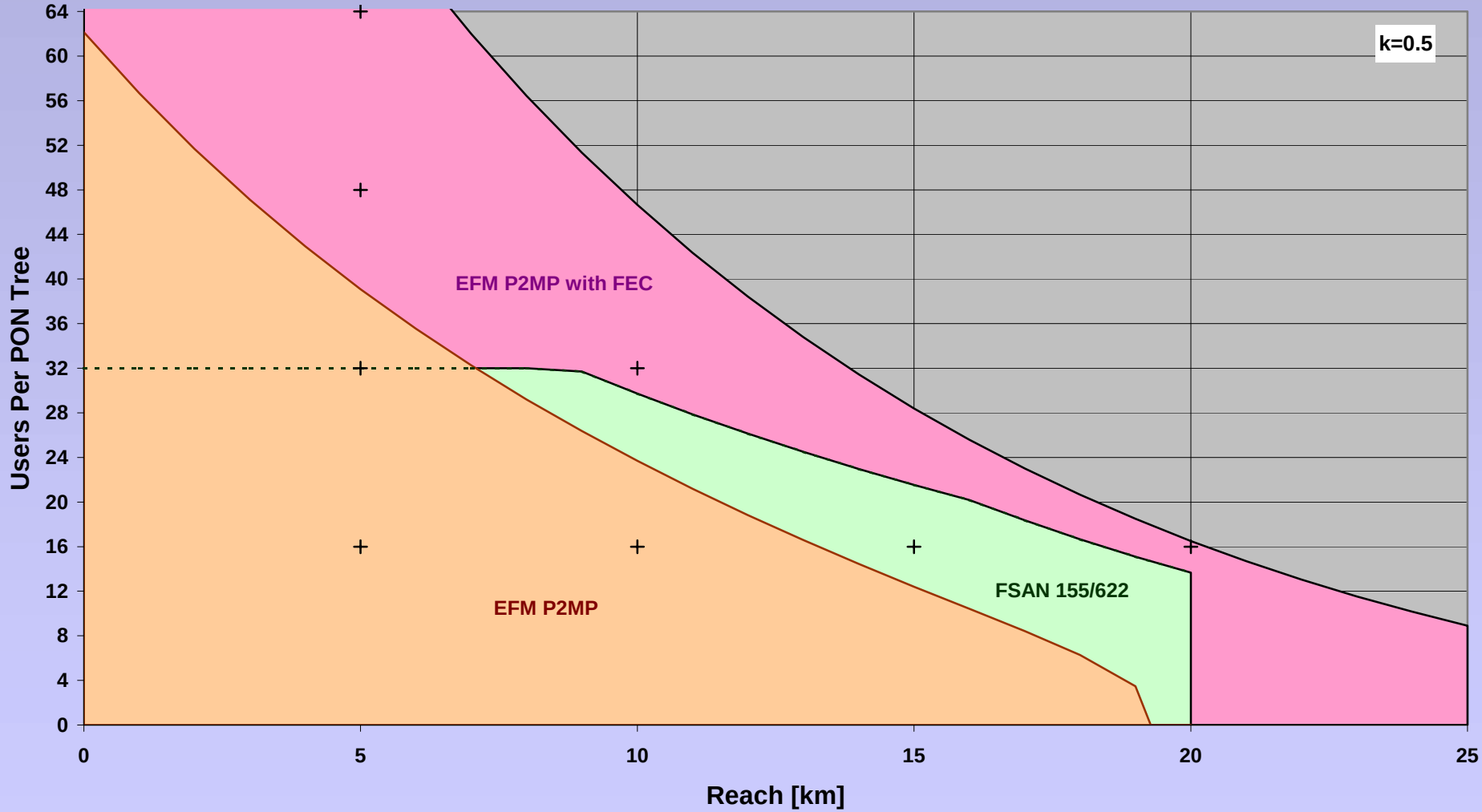
Scope

- Sales pitch
- Frame format
- Frame synchronization algorithm and state machines
- Mean time to false packet acceptance

Motivation

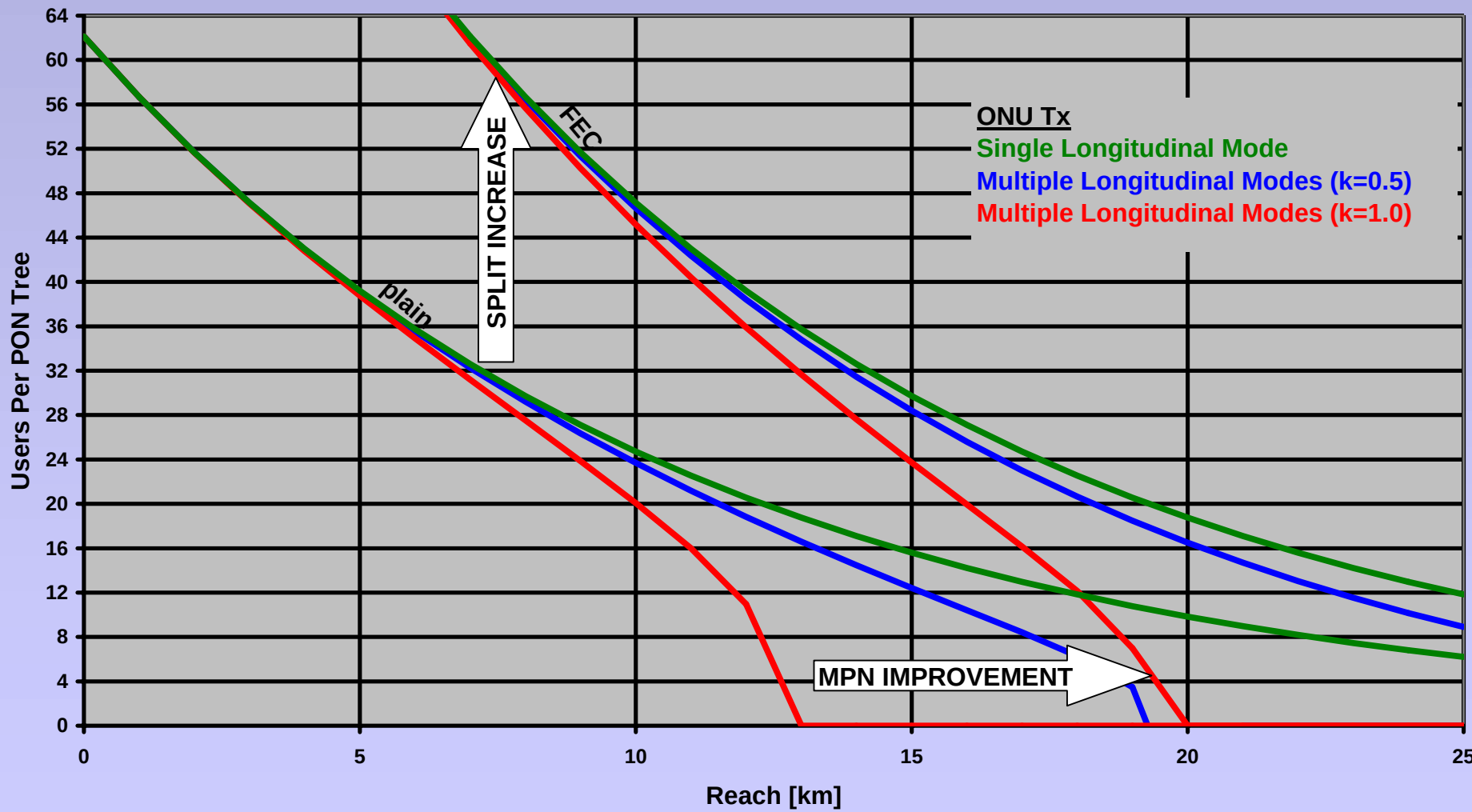
- **Higher line rate in EFM PON causes split deficiency vs. APON**
  - Shuts out FTTH market
- **FEC is the cost effective method to meet reach/split targets maintaining low-cost optics**
  - Increase splits – when power limited
  - Increase distance – when MPN-limited
- **Improve Business Case**

Competitive With FSAN



What is the Gain?

P2MP PMD Proposal



FEC Compatibility

- **Compatibility with legacy Ethernet format**
  - Network shared by FEC and non-FEC devices
  - FEC coding only for devices requiring it
  - Stream of an FEC coded data should be understood by current non FEC devices without undue errors
- **Ability to add FEC functionality externally**

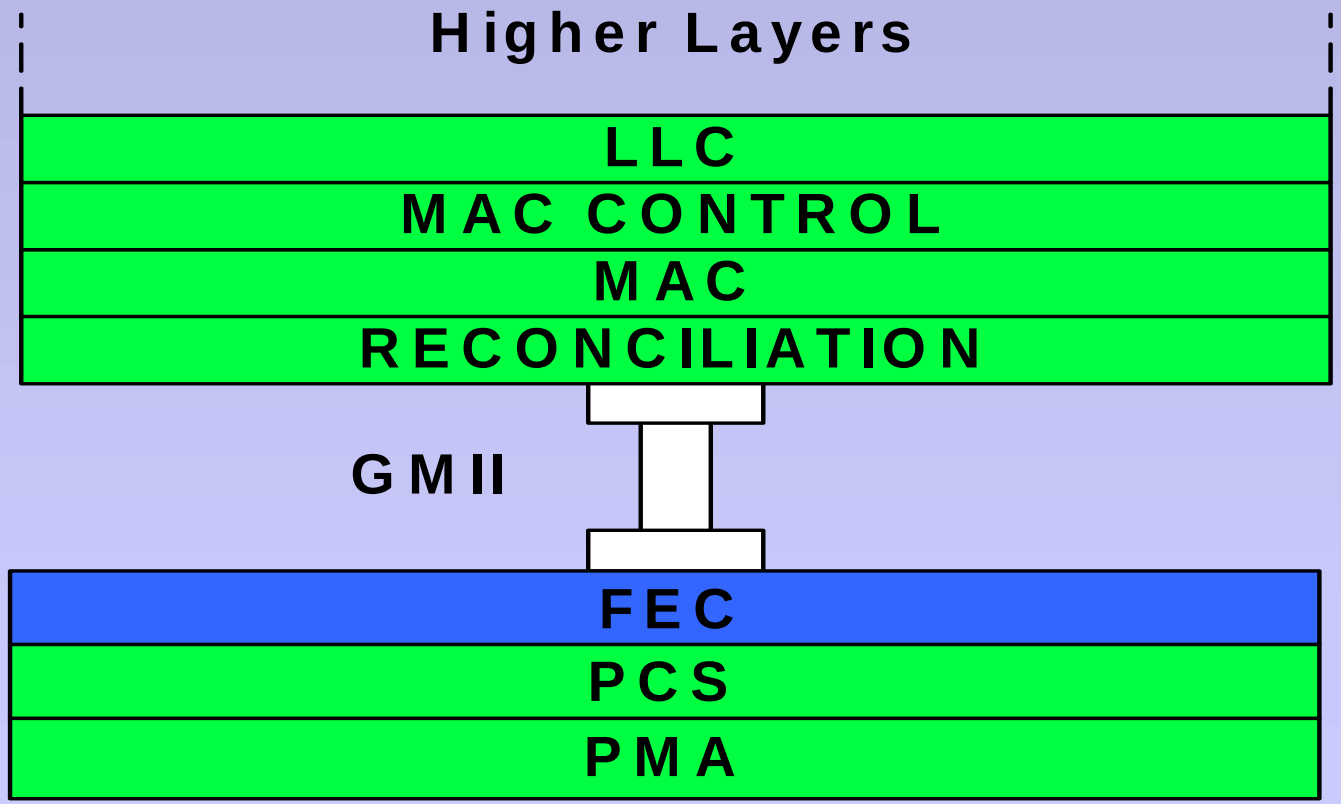
- **Optional and transparent use of FEC**

Basic Principles of Operation

- **Maintaining the frame structure**
  - Parity check bytes added at the end of the frame
- **FEC is coded before the 8B/10B code**

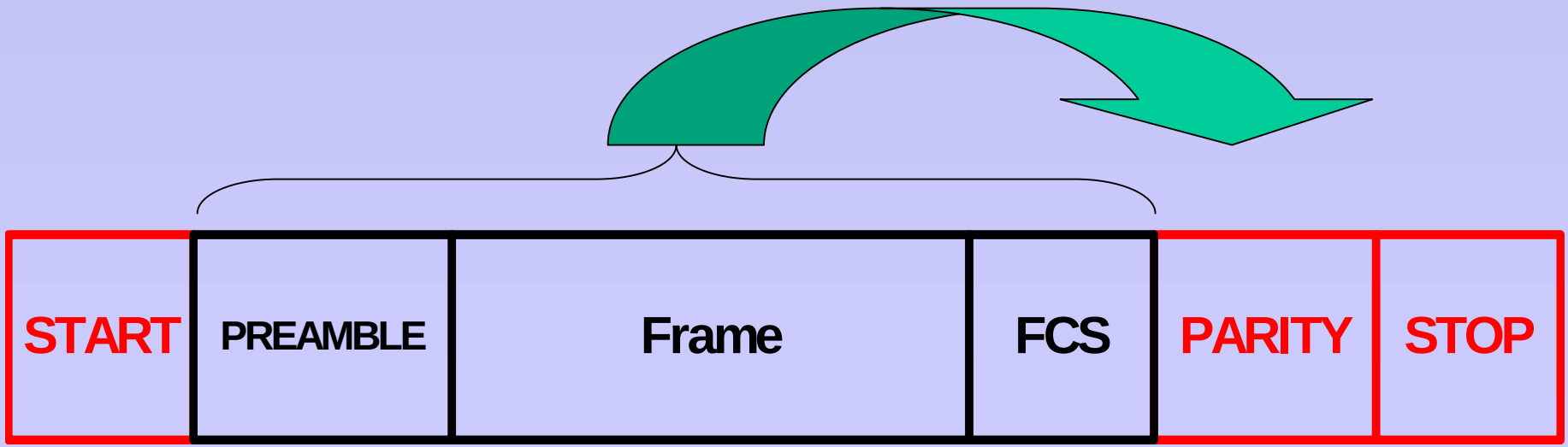
- **Legacy devices observe a normal Ethernet frame**
  - False_Carrier_detect mode of PCS Rx when parity bytes received (RX_ER is asserted)

FEC Layering in P2MP Ethernet



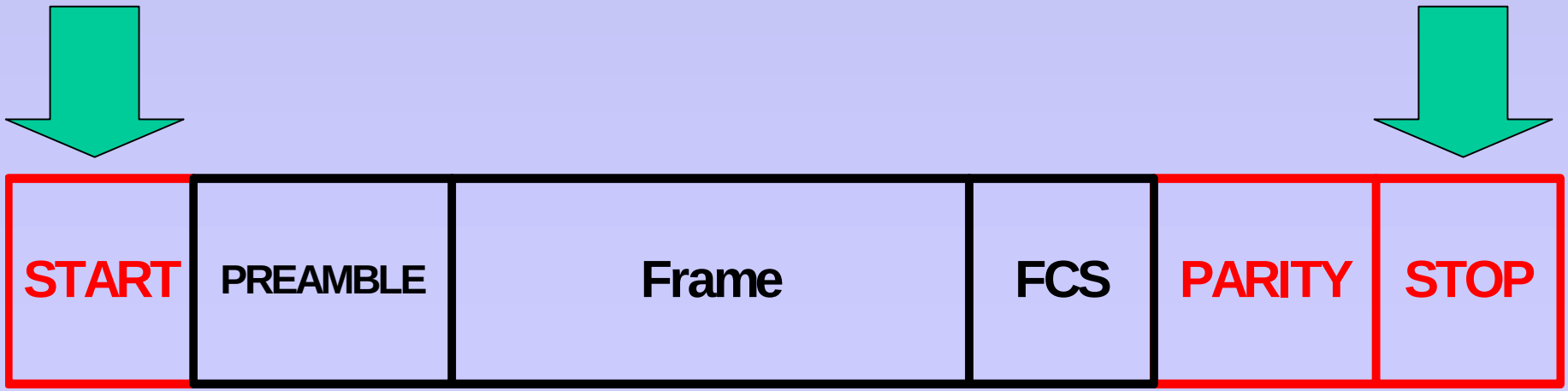
Encoding

- Parity check bytes added at the end of the packet
- All of the packet is encoded including preamble, address and FCS
- Shortened last frame – virtual zero padding
- Idles not protected



Frame Markers

- Special start and stop symbols added
- Symbols are immune to high noise
- Symbols are actually sequences detectable with a correlator
- 60 bit long for noise immunity



Protection Sequence Selection

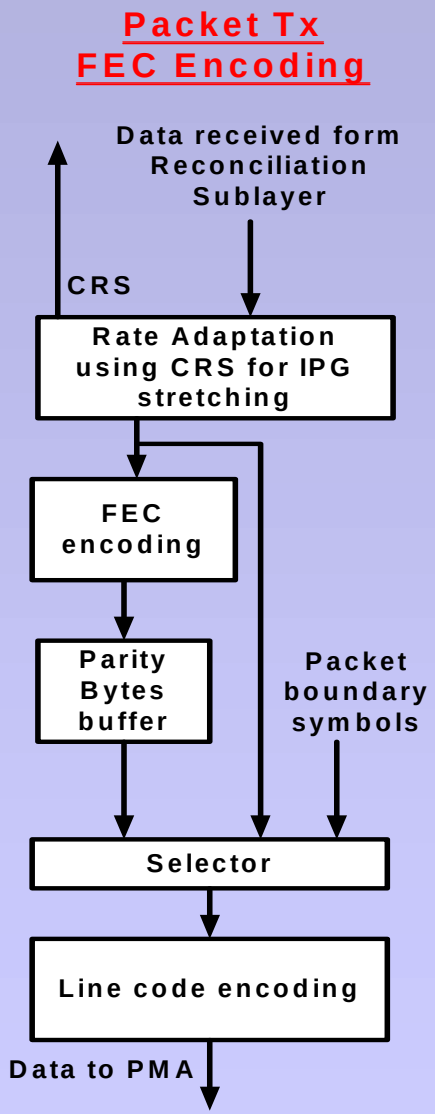
- **Sequence is long enough to be detected with very high probability**
- **Sequence can flow through non-FEC PCS transparently**

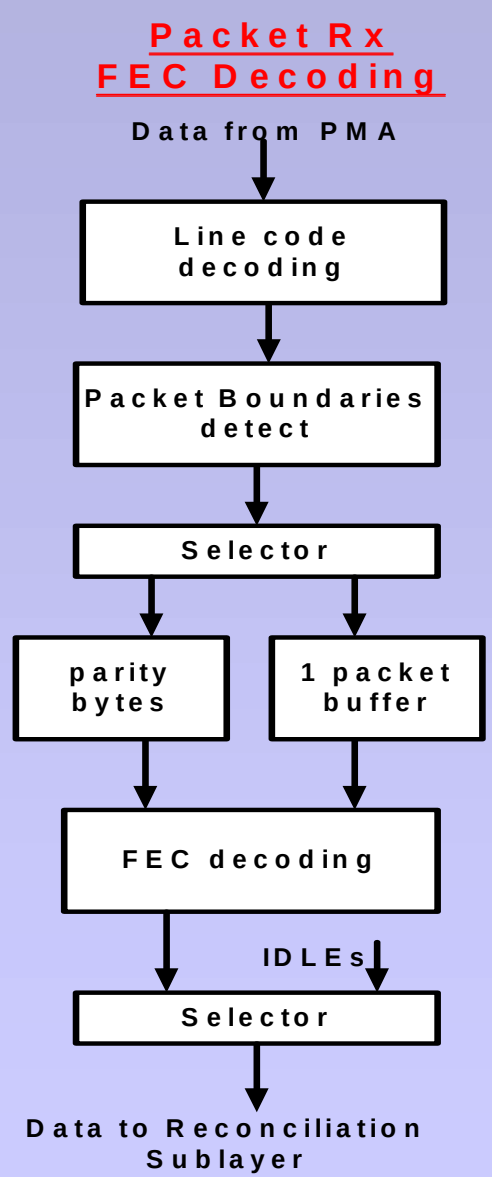
- **Examples**
  - /K28.5/ - comma is in the idle word and is duplicated many times – remains the same
  - /S_fec/ - Start_of_Packet - ex: /R/R/K28.5/D5.6/S/
  - /T_fec/ - End_of_Packet - ex: /T/R/K28.5/D21.2/T/R/

FEC Rate Adaptation

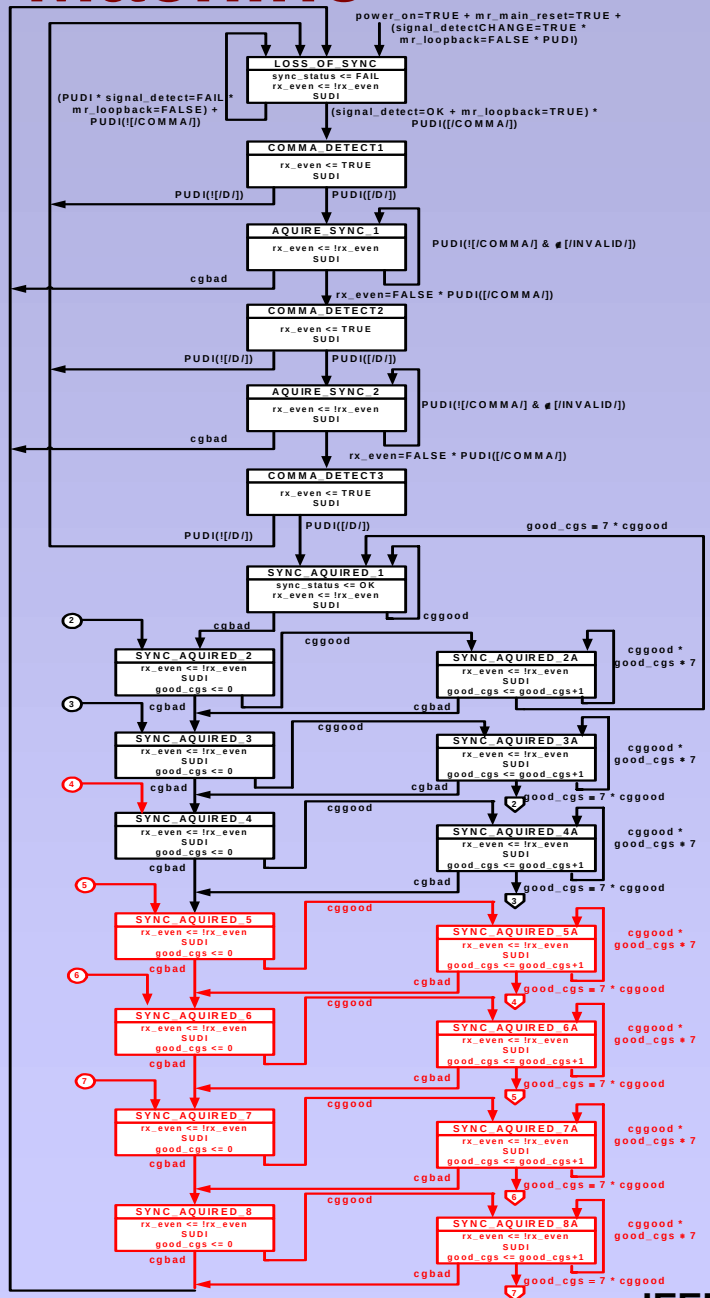
- **Additional idles inserted in FEC packet reception instead of additional data**
- **In transmission rate adaptation can be achieved in 2 ways**
  - Open loop - IPG stretching adapting MAC rate
  - Close loop – exporting a signal from PHY to the reconciliation layer
    - CRS or COL lines existing in half duplex mode

Data Flow for FEC Sublayer





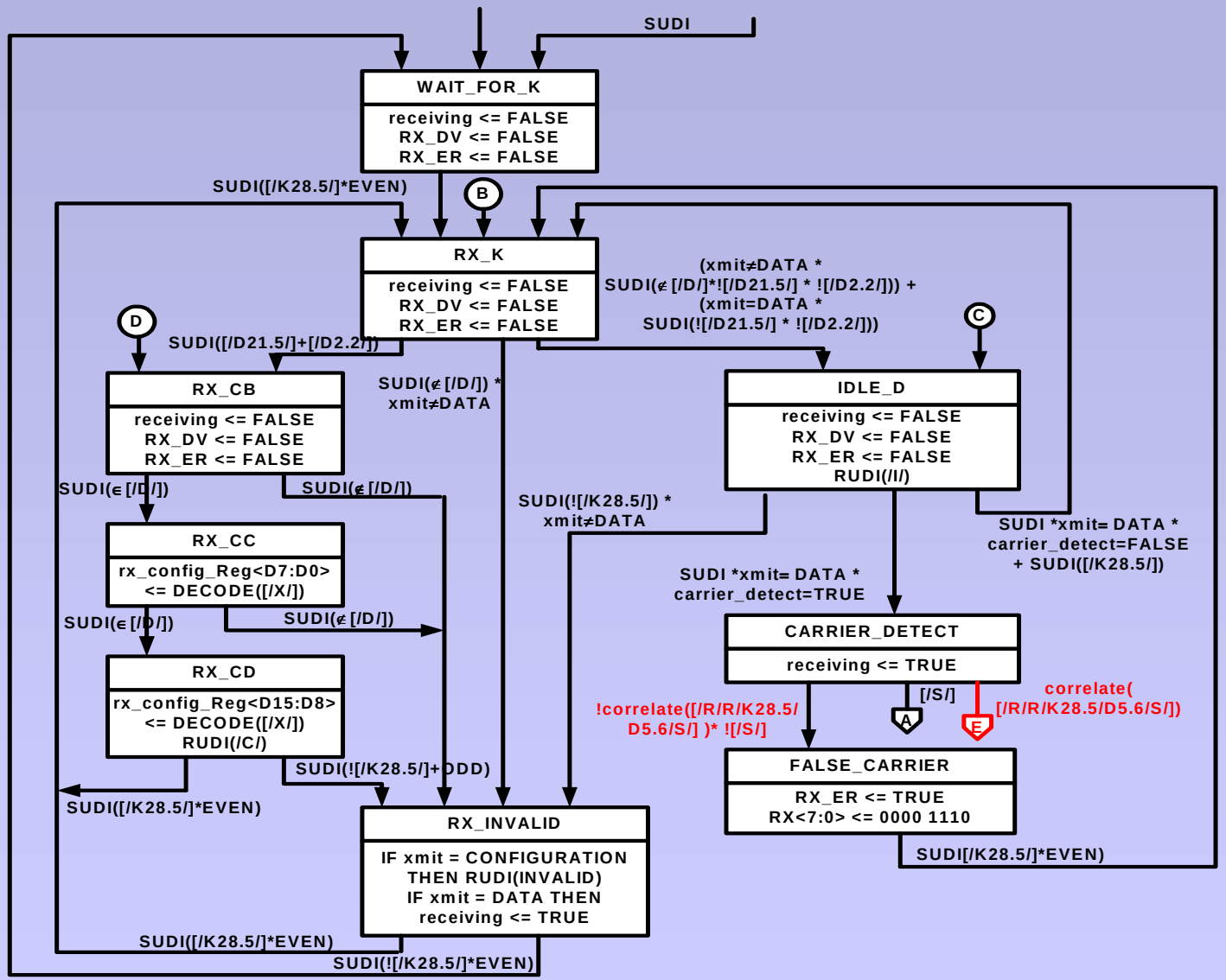
Rx Sync State Machine



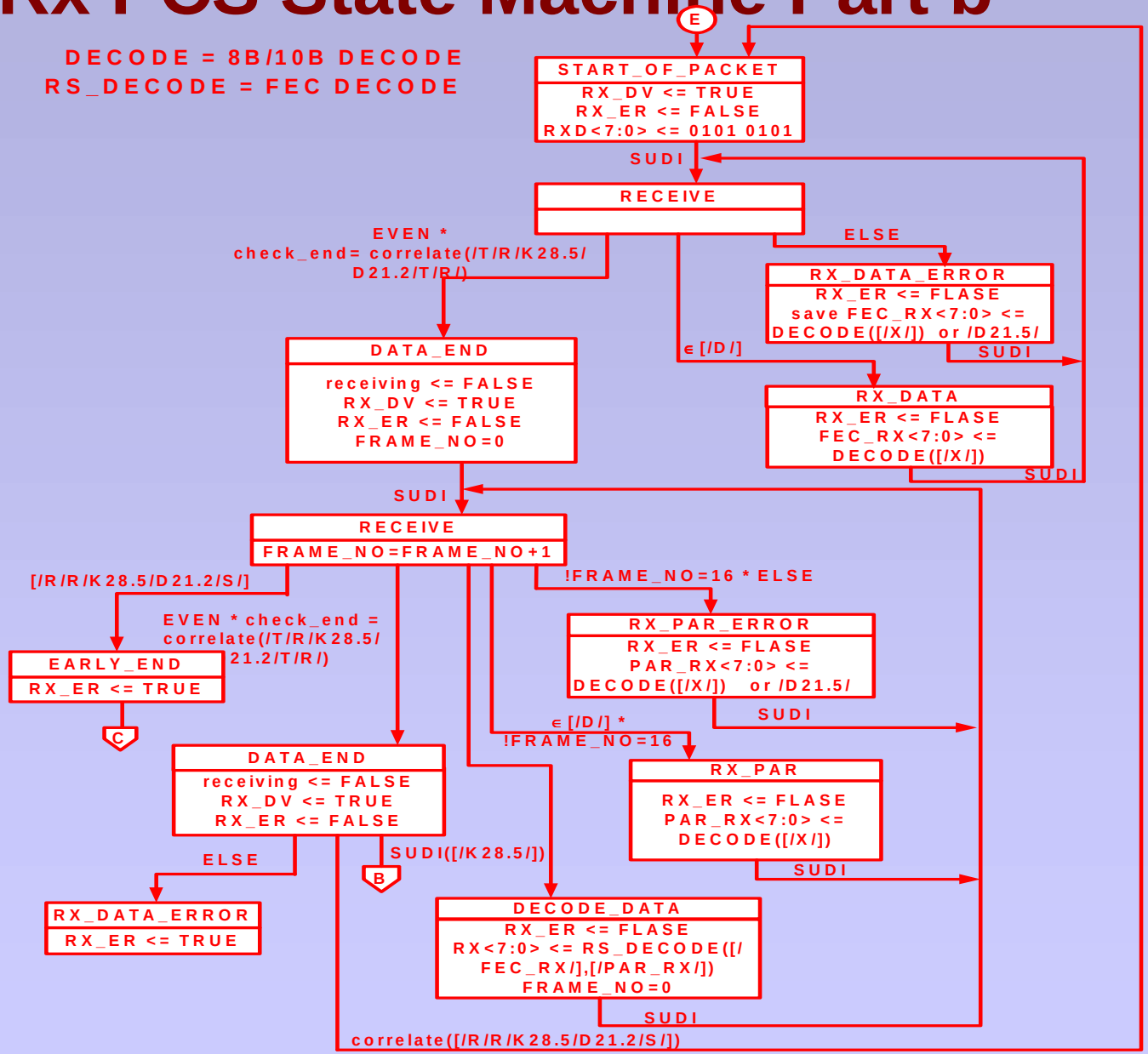
Probability for Lock Errors

- Acquisition is performed following 3 commas detection. Acquisition error probability is reduced from 3e-11 to 3e-3
- De-acquisition – following 3 sequential bad words – reduced from (1e-11)^3 to (1e-3)^3 – once every 1sec
- 7 step state machines reduce the probability to (1e-3)^7 – one in every 31,700 years

FEC Rx PCS State Machine Part a



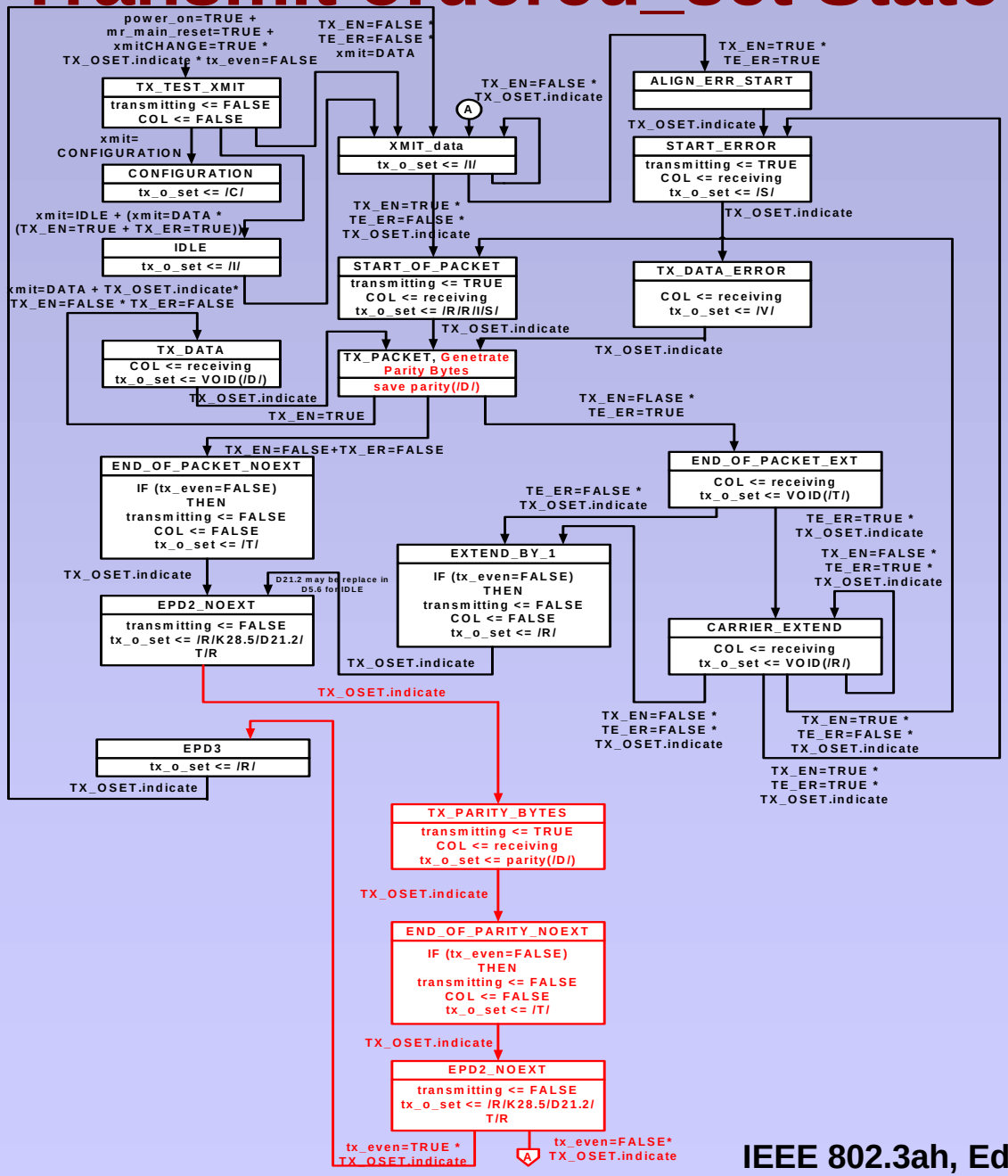
FEC Rx PCS State Machine Part b



PCS RX State Machine

- Only Frame boundary detection is added to current PCS Rx State Machine
- FEC detection is independent and performed above the current PCS Rx State Machine

FEC PCS Transmit ordered_set State Machine



Mean Time to False Packet Acceptance

- Bit error probability before FEC is Pe=1e-4
- Bit error probability After FEC is Pcu=1e-12
- The probability for an FCS error in Ethernet:

$$P_{UD} = \frac{1500}{255} \cdot \frac{P_{CU}}{10} \cdot \left(\frac{1}{2}\right)^{32} = 1.4e-22$$

- Most code-words are not 17 bytes distant The number of 17 bytes neighbors:

$$R_{17} = \frac{\binom{17}{9} \cdot A_{17}}{\binom{255}{9} \cdot (256)^9} = \frac{\binom{17}{9} \cdot \left[\binom{255}{17} \cdot 255\right]}{\binom{255}{9} \cdot (256)^9} \approx 6 \cdot 1e-8$$

Mean Time to False Packet Acceptance – Cont’

- Total probability of undetected errors for Ethernet with FEC – 1e-29
- For 1GE this means an error in 4e16 years

Miss detect in Start & Stop Markers

- **Length of correlation sequence – 6 bytes that are 60 bits – detected with bit correlators**
- **Probability of miss-detect from IDLE pattern**
  - The minimal distance of a sequence from an IDLE pattern is 15 bits –

$$P_{ce} < \binom{15}{7} P_b^7 \approx 1e-24$$

- **Probability of miss-detect from IDLE pattern**
  - The nearest data sequence is 6 bits distant -

$$P_{ce} < \frac{320}{\left(2^8\right)^6} \cdot \binom{6}{3} P_b^3 \approx 2e-23$$

Conclusion

- FEC framing compatible with legacy Ethernet introduced
- Layering proposed above PCS with PCS extensions
- Frame format uses IPG for code words
- Low probability of error propagation shown
- 60 bit patterns used as markers
- Two minimally intrusive schemes for MAC integration shown