SpaceFibre

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  - Physical

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SpaceFibre Requirements

- Compatible with SpaceWire
  - At the packet and network levels
- High speed
  - 2 Gbits/s now (2.5 Gbit/s signalling)
  - 5 Gbits/s planned (6.5 Gbits/s signalling)
- Very high speed
  - Multiple lanes e.g. 4 lanes 8 Gbits/s
- Flight quality components
- Fibre and copper implementations
- 100 m optical fibre
- 5 m copper
- Low mass cable

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SpaceFibre Requirements

- FDIR
  - Fault detection
    - Parity/disparity
    - CRC
  - Fault isolation
    - Galvanic isolation
    - Data framing – time containment
    - Virtual channels – bandwidth containment
  - Fault recovery
    - Link level retry
    - Graceful degradation on lane failure
    - Babbling idiot protection
    - Error reporting

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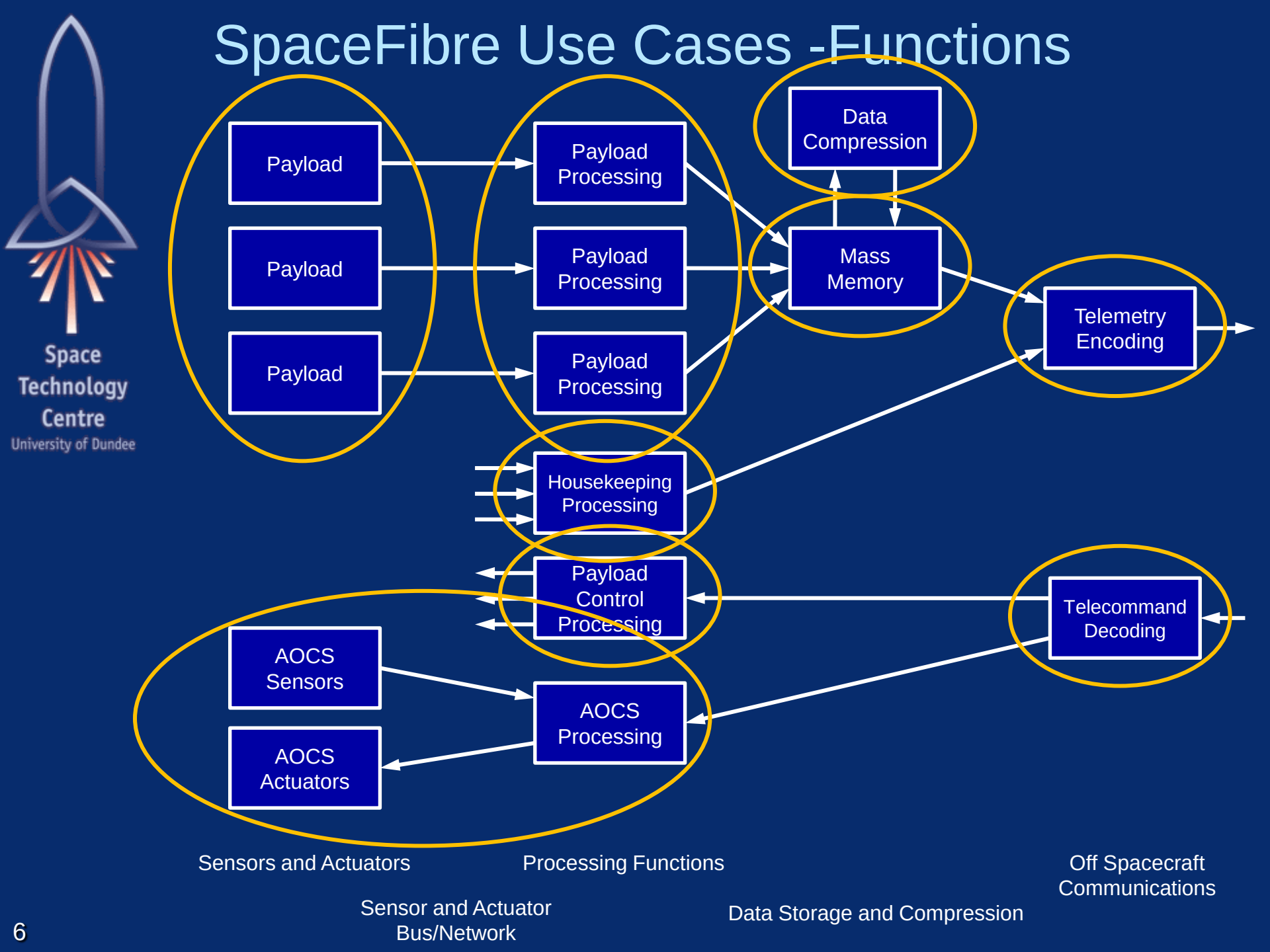
SpaceFibre Requirements

- Support SOIS services
  - Packet delivery
  - Memory access
  - Synchronisation / Time distribution
  - Device discovery
  - Test
- Quality of Service
  - Best Effort
  - Assured
  - Resource Reserved
  - Guaranteed

SpaceFibre Use Cases -Functions



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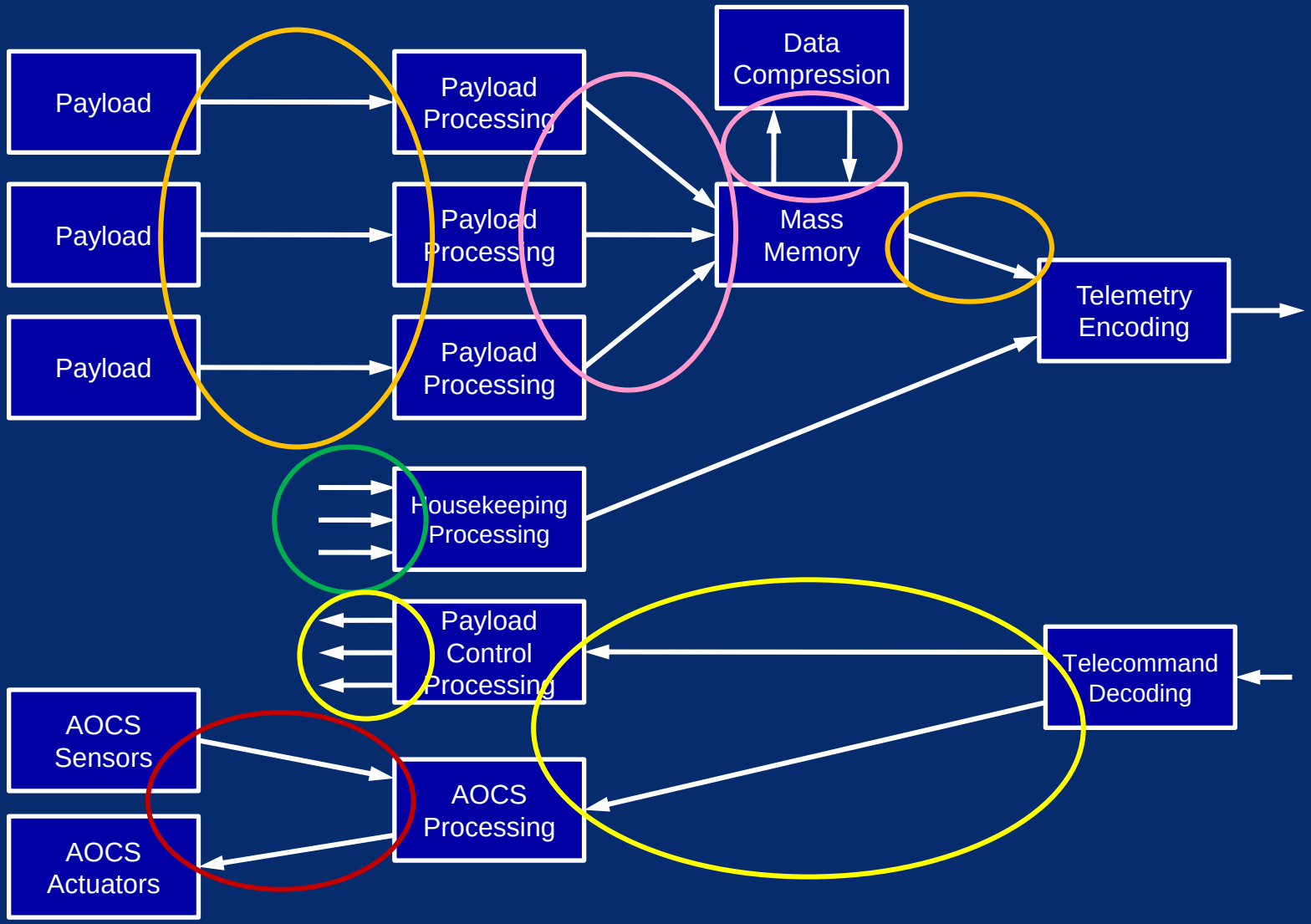
SpaceFibre Use Cases - Networks



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SpaceFibre Use Cases

- Instrument data to mass-memory
  - Point-to-point or virtual circuit
- Instrument data to processor
  - Point-to-point or virtual circuit
- Mass-memory modules
  - Network, controlled deterministically
- Multiprocessor
  - Network, asynchronous
- Mass-memory to telemetry downlink
  - Point-to-point
- Housekeeping data gathering
  - Network/bus, single master

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SpaceFibre Use Cases

- Telecommand to control processor
  - Point-to-point or bus
- Payload control
  - Bus, discrete signals
- AOCS/GNC
  - Deterministic bus, discrete signals
- Time distribution
  - Time-codes, bus, separate wires
- Synchronisation / Signalling
  - Time-codes, bus, separate wires

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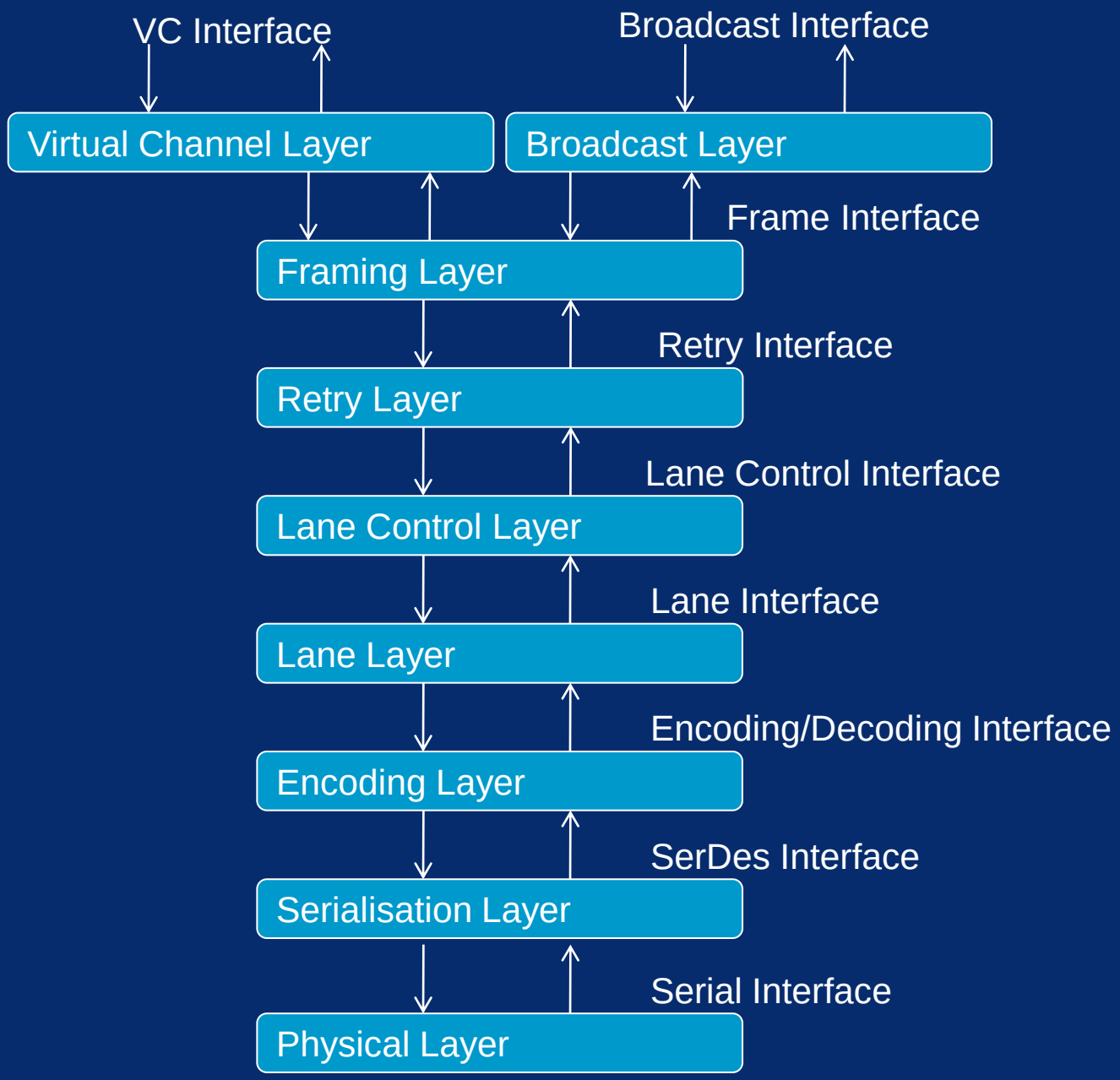
SpaceFibre

- Target SpaceFibre capabilities to the space application
  - Very high-speed
  - Point-to-point
  - Virtual Networks
  - Virtual circuits
  - Low latency signalling
- FDIR
- QoS

SpaceFibre Overview



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SpaceFibre Layers

- **Virtual Channel:**
  - Quality of service and flow control
- **Broadcast:**
  - broadcasts short messages across network
- **Framing:**
  - Frames information to be sent over link
  - Scrambles SpaceWire packet data
- **Retry:**
  - Recovers from transient and persistent errors

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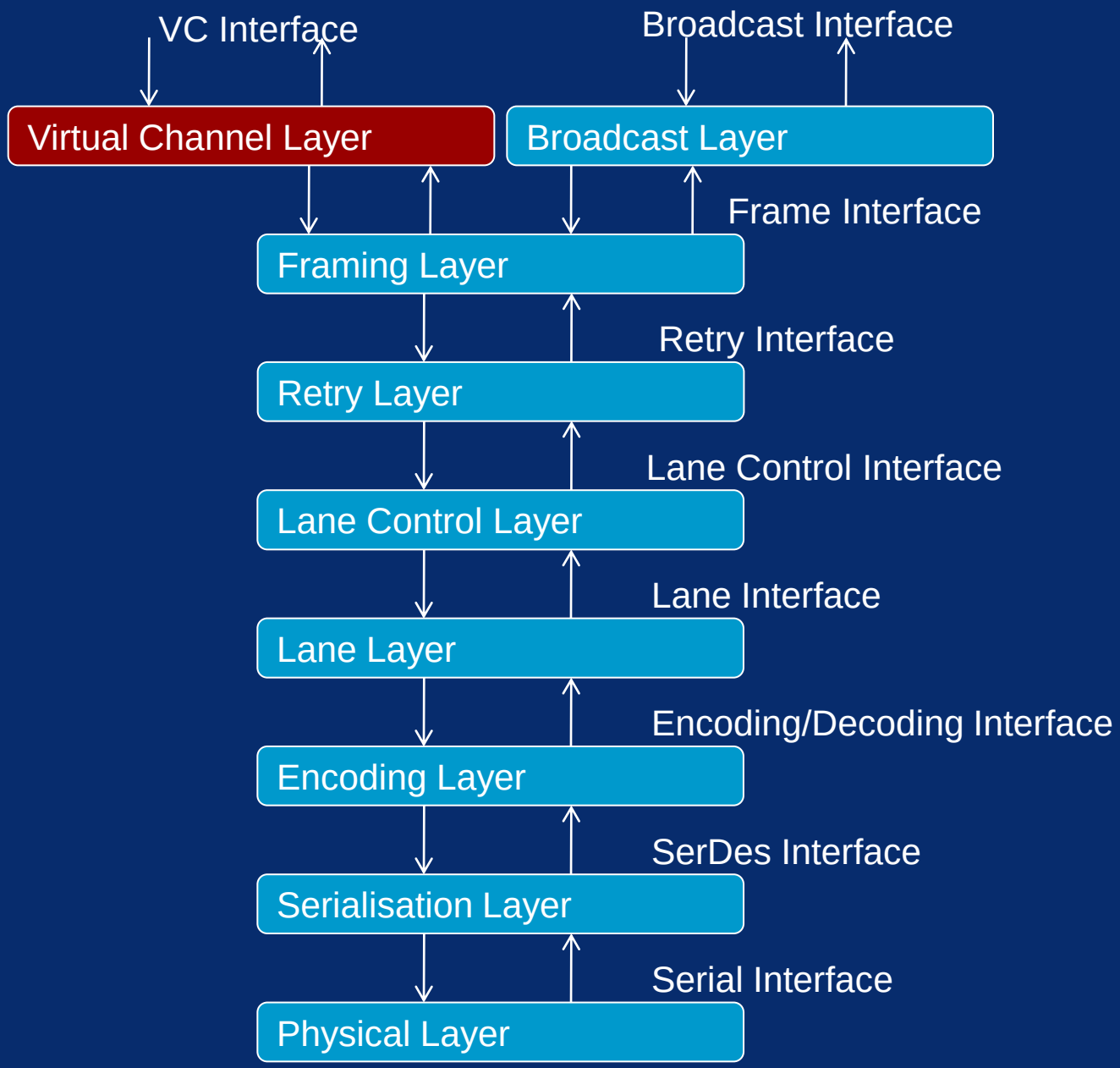
SpaceFibre Layers

- **Lane Control:**
  - Runs several SpaceFibre lanes in parallel
  - Provides higher data throughput and redundancy with graceful degradation
- **Lane:**
  - Lane initialisation, error detection and re-initialisation
- **Encoding/Decoding:**
  - Encodes data into symbols for transmission
- **Serialisation:**
  - Serialises SpaceFibre symbols
- **Physical:**
  - Fibre optic or copper medium.

SpaceFibre Virtual Channel Layer



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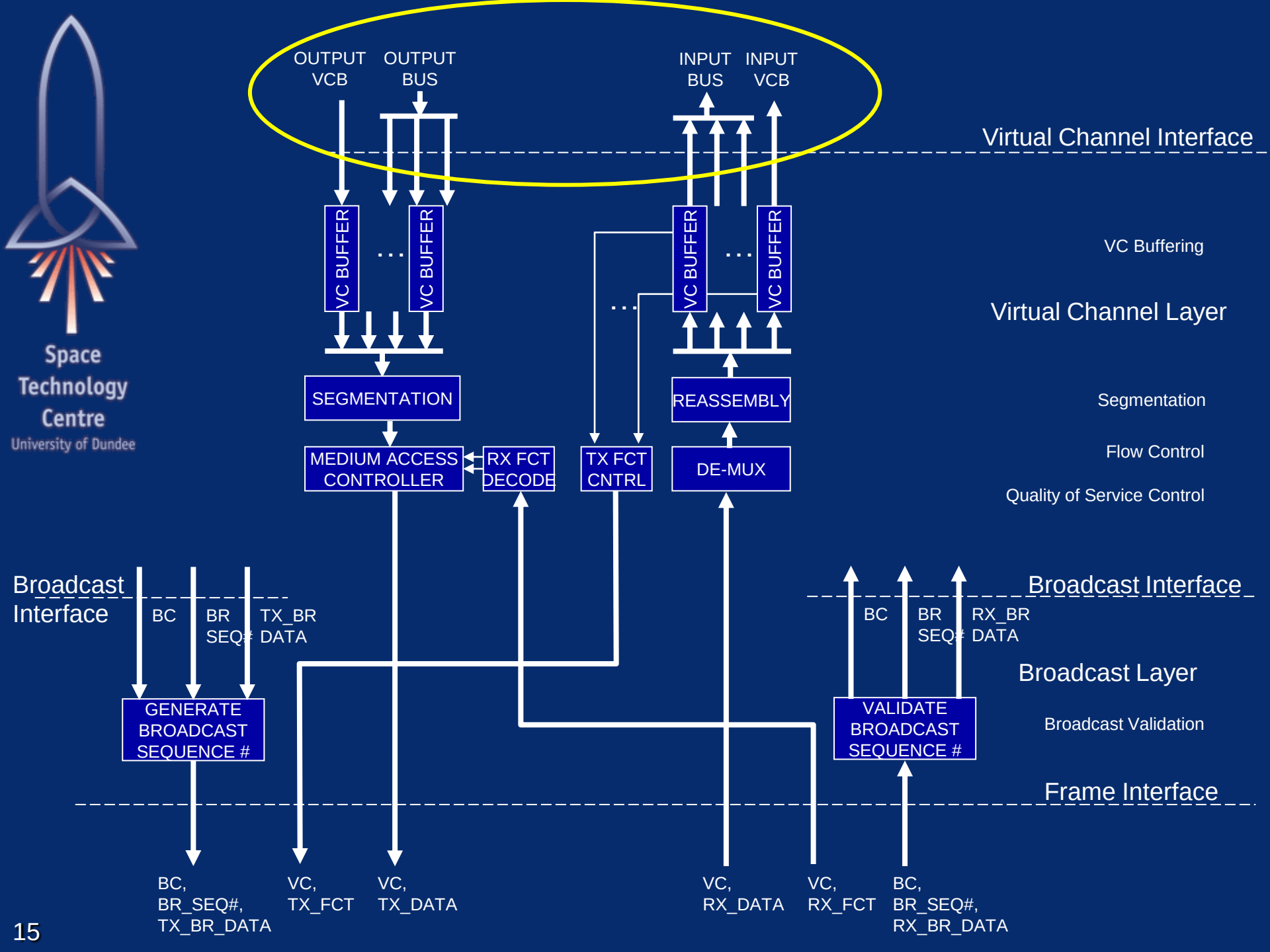

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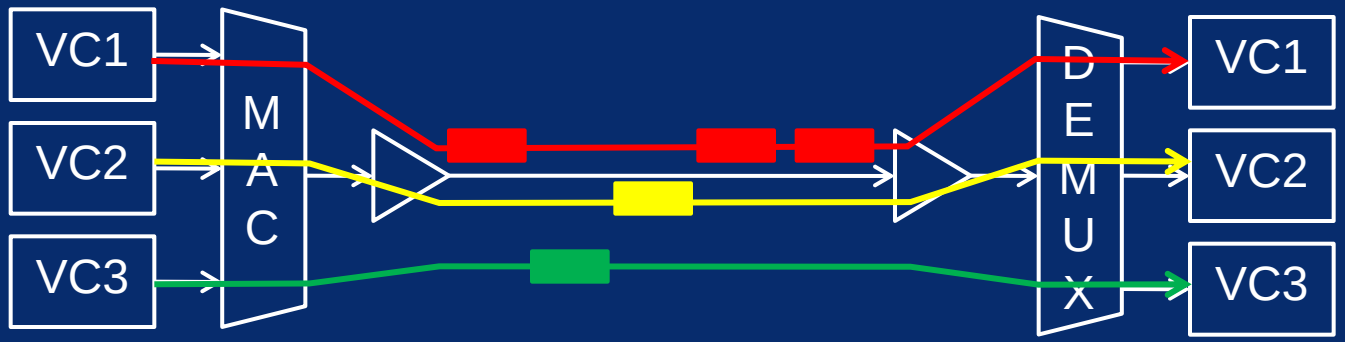
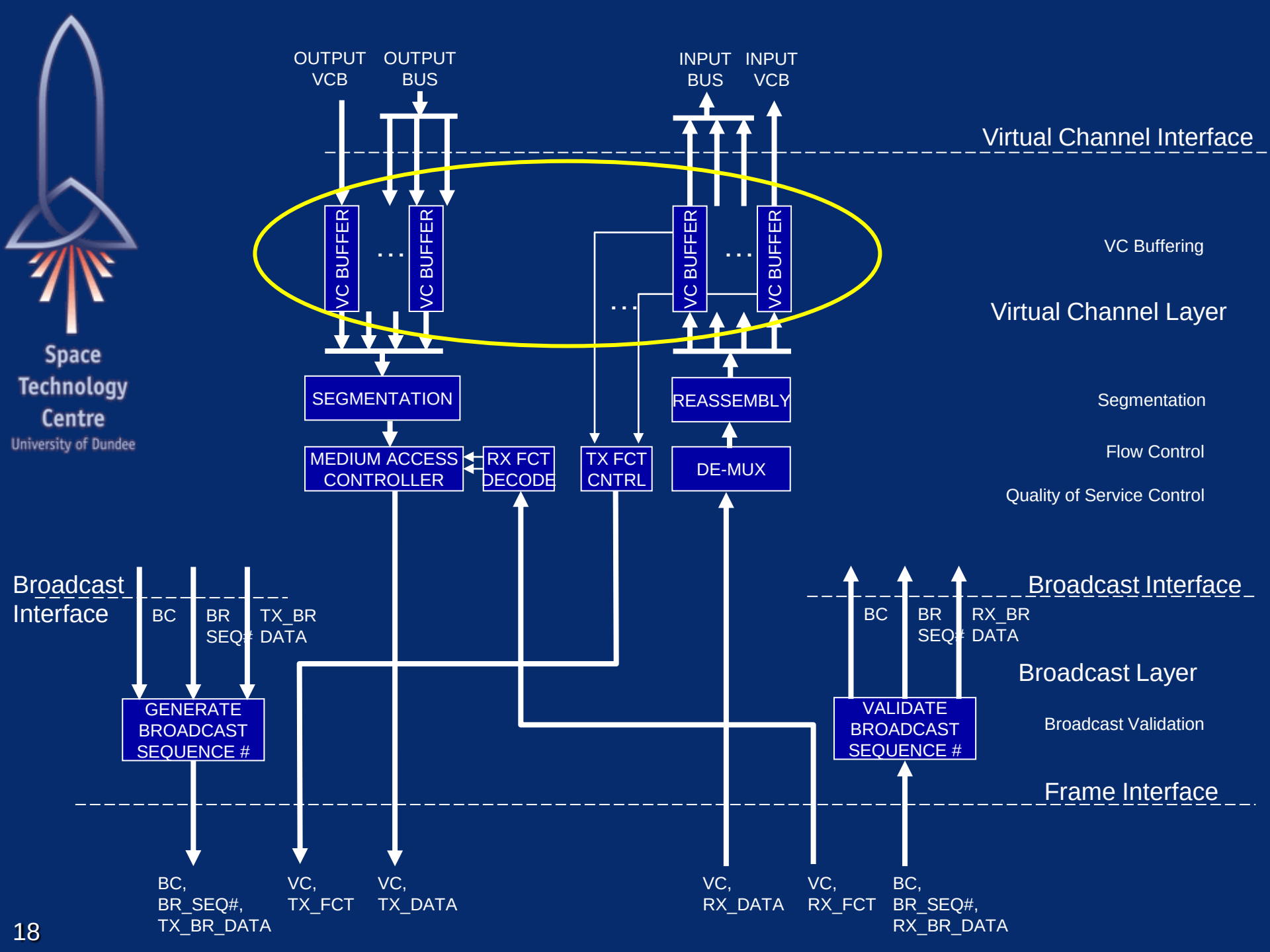
SpaceFibre Virtual Channels

- Virtual Channel Interface
  - Used to send and receive SpaceWire packets
  - Comprises a number of virtual channel buffers
    - Output VCBs for sending SpaceWire packets
    - Input VCBs for receiving SpaceWire packets
    - Conceptual FIFO type interface
    - Accepts SpaceWire N-Chars (data + EOP/EEP)
  - Application
    - Loads packet information sequentially into VCB
    - Addressing and routing is identical to SpaceWire

Virtual Channels



- VC sends when
  - Source VC buffer has data to send
  - Destination VC buffer has space in buffer
  - QoS for VC results in highest precedence
- A SpW packet flowing through one VC does not block another packet flowing through another VC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OUTPUT VCB
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INPUT BUS
INPUT VCB
Virtual Channel Interface
VC BUFFER
VC BUFFER
VC BUFFER
VC BUFFER
VC Buffering
Virtual Channel Layer
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REASSEMBLY
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TX FCT CNTRL
DE-MUX
Flow Control
Quality of Service Control
Broadcast Interface
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BR SEQ#
TX_BR DATA
BC
BR SEQ#
RX_BR DATA
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Broadcast Layer
GENERATE BROADCAST SEQUENCE #
VALIDATE BROADCAST SEQUENCE #
Broadcast Validation
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VC, TX_FCT
VC, TX_DATA
VC, RX_DATA
VC, RX_FCT
BC, BR_SEQ#, RX_BR_DATA

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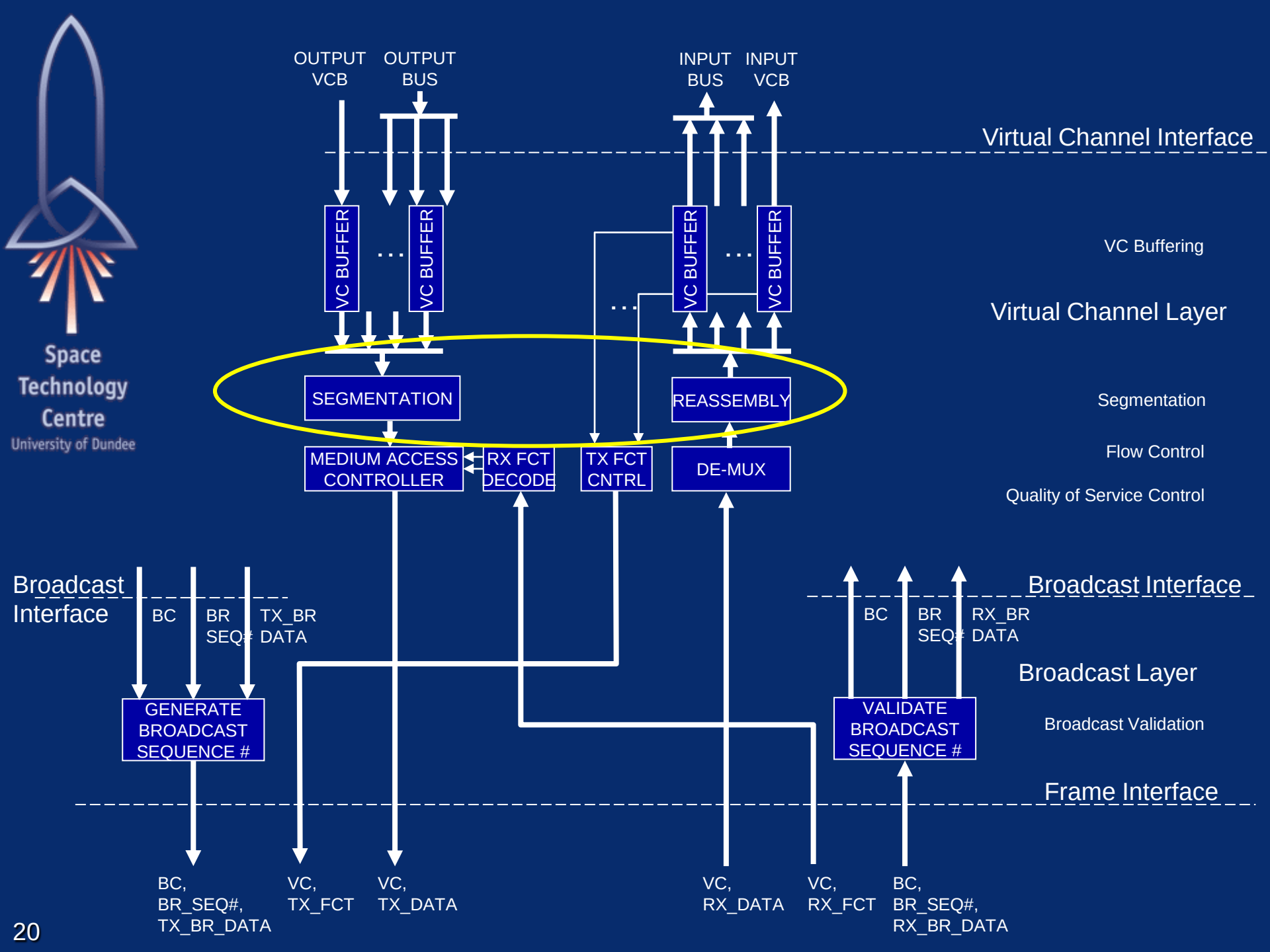
SpaceFibre Virtual Channels

- Virtual channel buffering
  - VCBs buffer SpaceWire packets
  - Output VCB
    - Buffers data before it is sent
  - Output VCB must contain
    - A full frame of data (256 N-Chars)
    - Or an EOP / EEP
    - Before it is put forward for arbitration and sending
  - Inputs VCBs
    - Holds at least one full data frame
    - Application can read data at its leisure
      - Without affecting the network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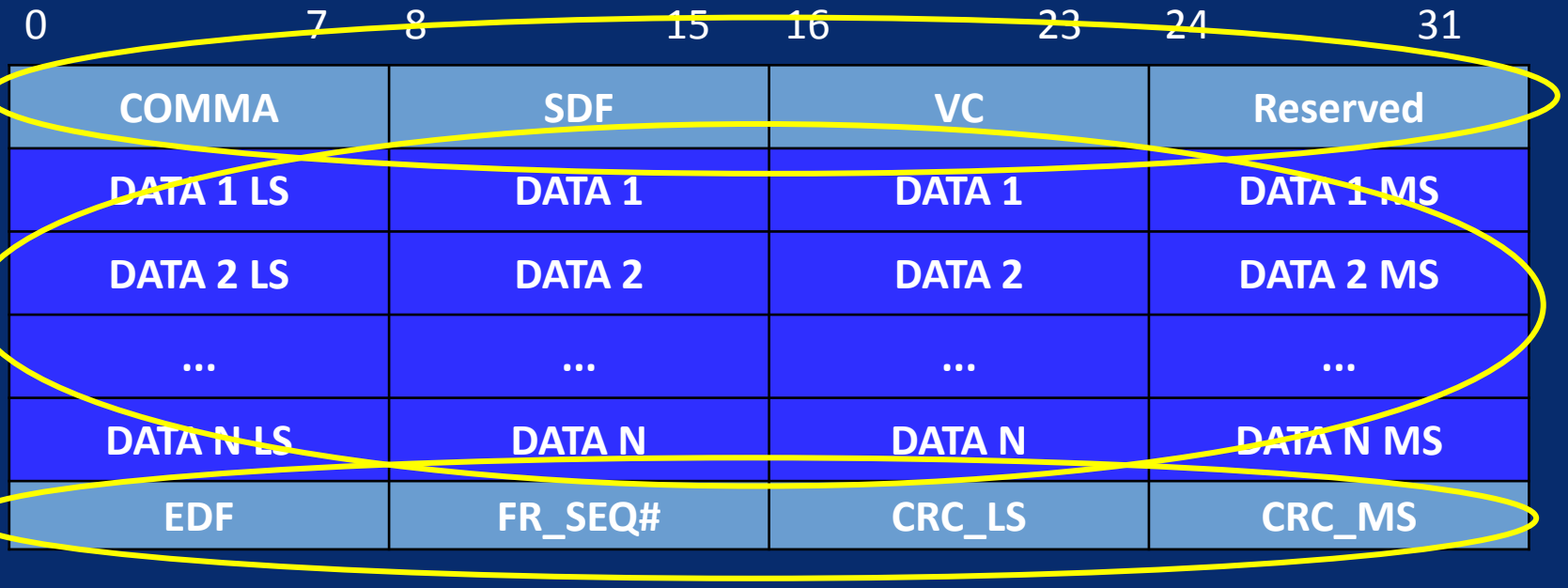
SpaceFibre Virtual Channels

- Segmentation
  - Splits SpaceWire packet stream into data frames
  - Each frame contains a chunk of data
    - Up to 256 N-Chars
  - Room for frame indicated by FCT
  - Framing permits
    - Additional FDIR information
      - CRC
      - Sequence number
    - Isolates any errors, containing them in frame
    - Supports retry for robust communication
  - Allows QoS to be implemented efficiently

SpaceFibre Data Frame



0 – 7	8 – 15	16 – 23	24 – 31
COMMA	SDF	VC	Reserved
DATA 1 LS	DATA 1	DATA 1	DATA 1 MS
DATA 2 LS	DATA 2	DATA 2	DATA 2 MS
…	…	…	…
DATA N LS	DATA N	DATA N	DATA N MS
EDF	FR_SEQ#	CRC_LS	CRC_MS

- 32-bit oriented, control words and data words
- Start Data Frame
  - Virtual Channel Number
- Data field contains up to 256 N-Chars
  - From one or more SpaceWire packets
- End Data Frame
  - Frame sequence Number, CRC

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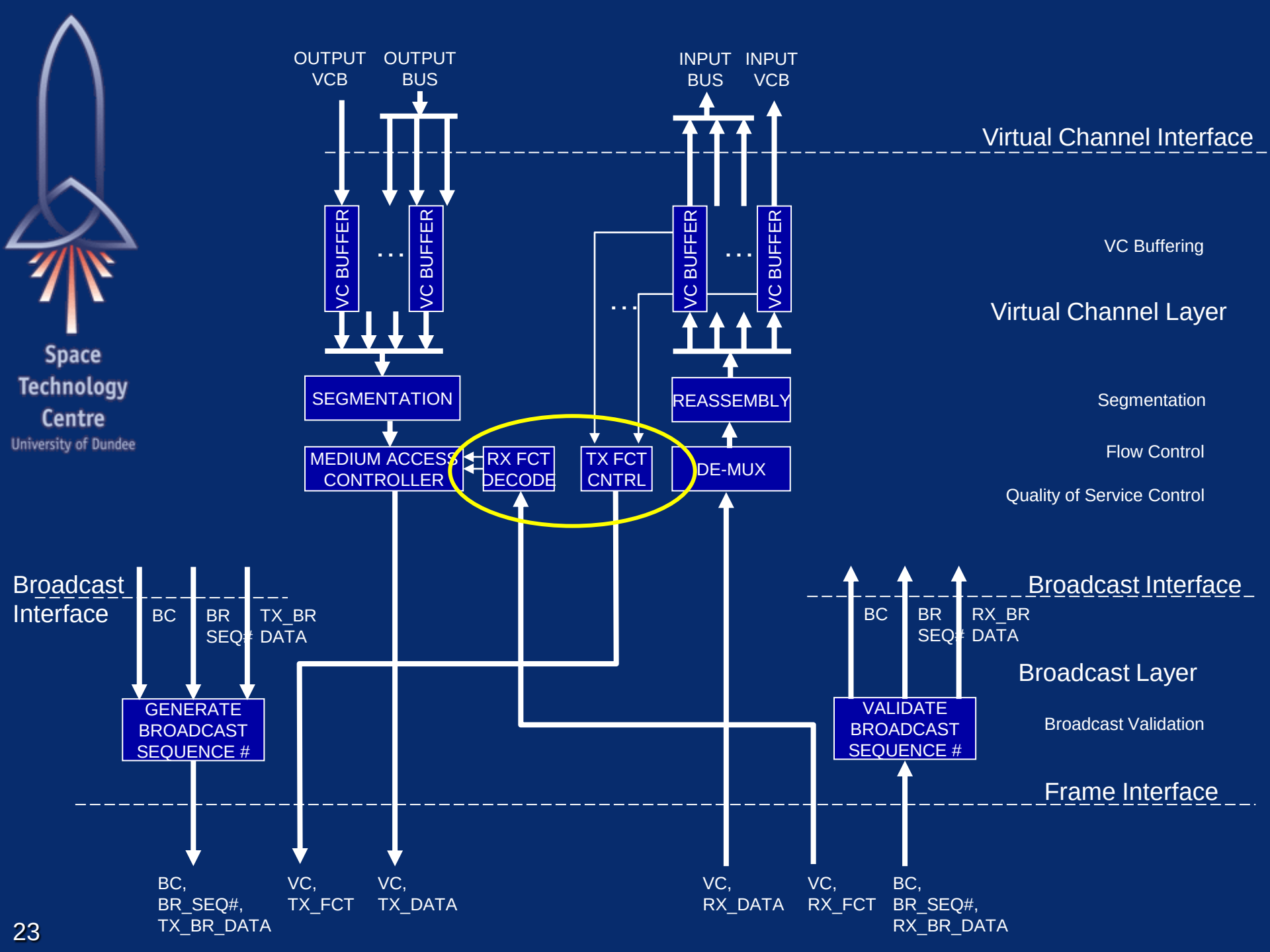
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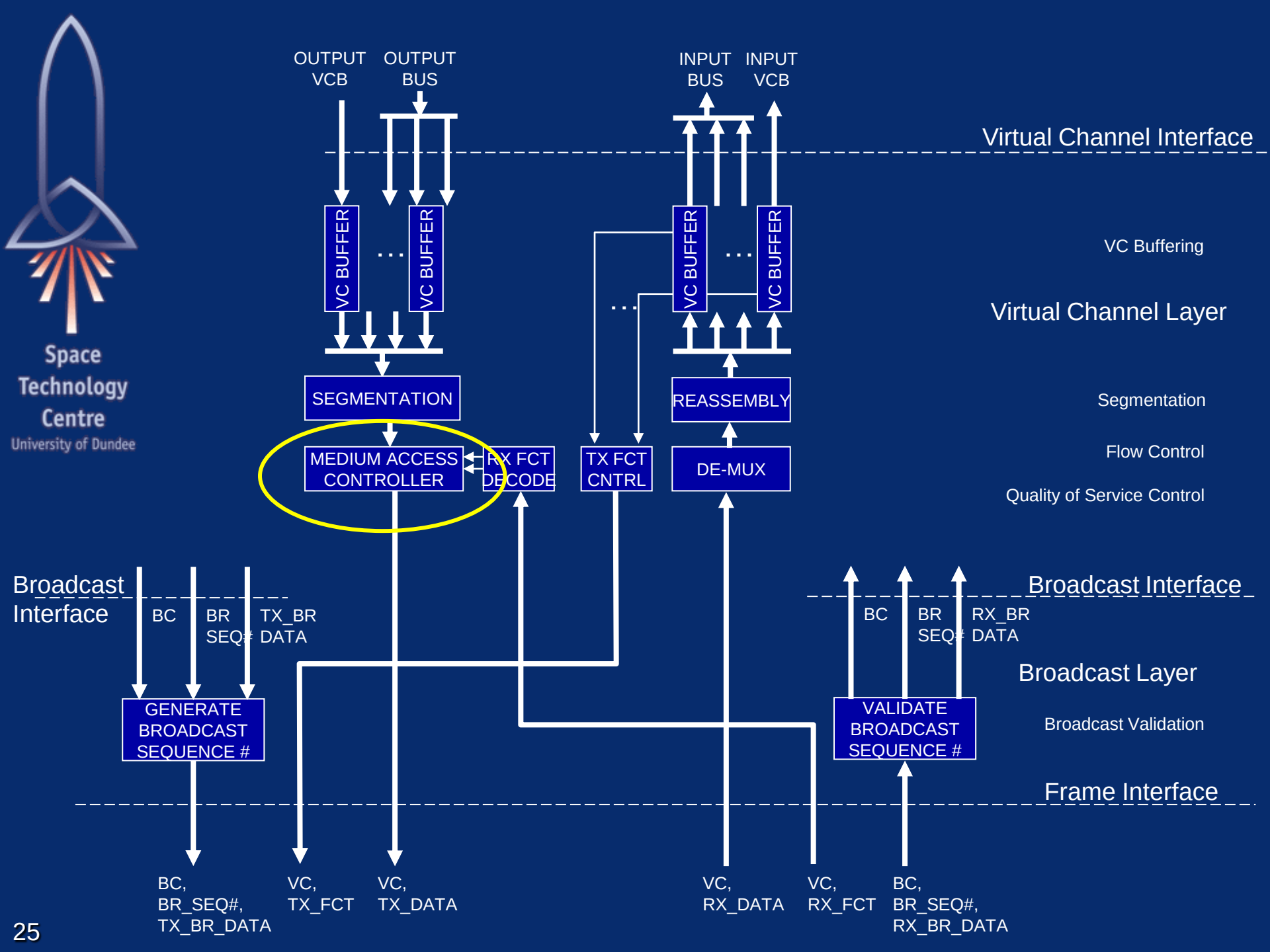
SpaceFibre Virtual Channels

- Flow Control
  - Makes sure there is room in input VCB at far end of the link
  - Before sending a data frame
  - Avoids blocking
  - FCT exchanged for 256 N-Chars (full frame)
  - FCT sent when input buffer has room for another full data frame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SpaceFibre Virtual Channels

- Medium Access Controller
  - Determines what output VCB to send next frame from
  - Depends on:
    - Which output VCBs have data to send
    - Which input VCBs at other end of link have room
    - Arbitration or QoS policy in force for each virtual channel

SpaceFibre Virtual Channels

- Quality of service
  - Fair arbitration
    - Each virtual channel has equal opportunity to use link
  - Priority
    - Virtual channel with highest priority goes first
  - Bandwidth reserved
    - Virtual channel with allocated bandwidth and recent low utilisation goes next
  - Scheduled
    - Time-slots defined by broadcast messages
    - Virtual channels allocated to specific time-slots
    - In allocated time-slot, virtual channel allowed to send

Simulation Results

- Bandwidth allocation
  - One virtual channel
  - Multiple virtual channels
    - All link bandwidth allocated
    - Some link bandwidth not allocated
    - Some non allocated bandwidth is used by one channel with excess of throughput
  - Source data burst
- Priority
  - Impact on bandwidth allocated
- Scheduling
  - Impact on latency and jitter

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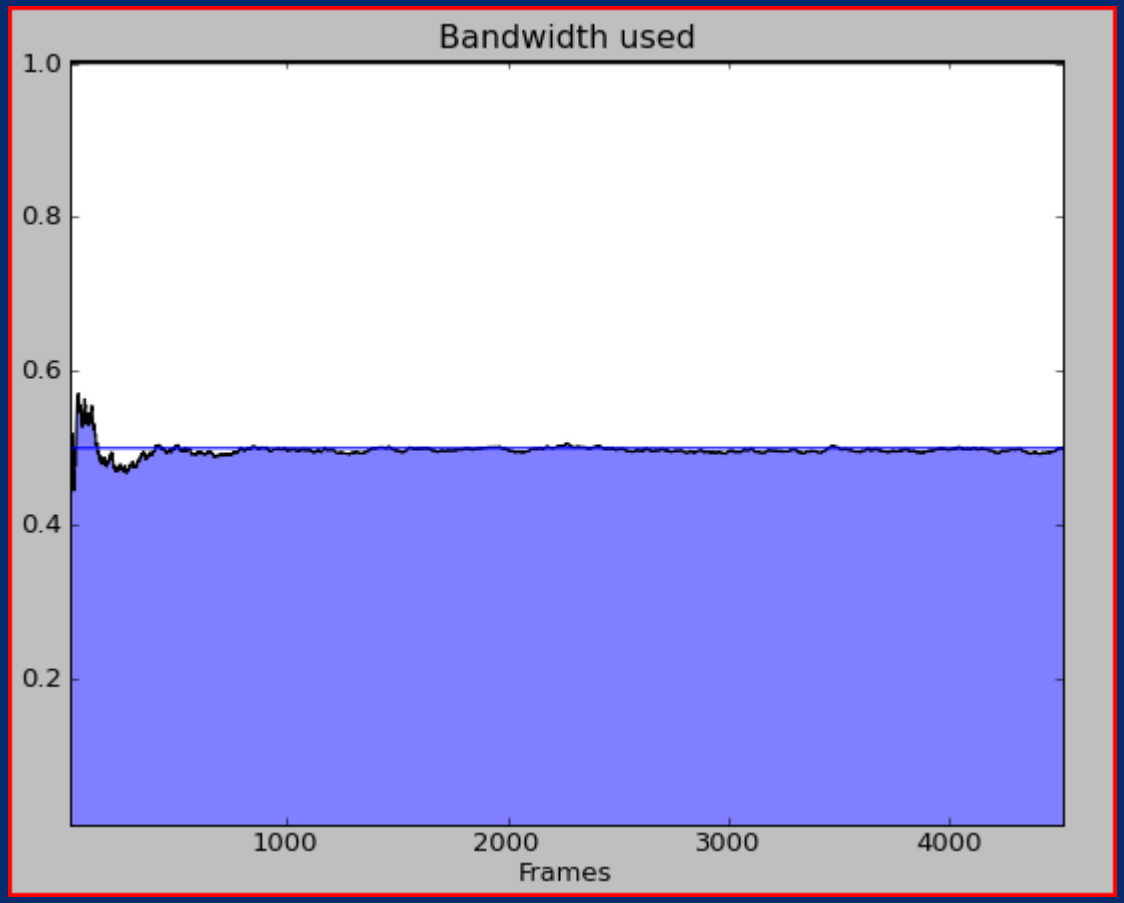
Simulation Results

- One virtual channel that uses half bandwidth



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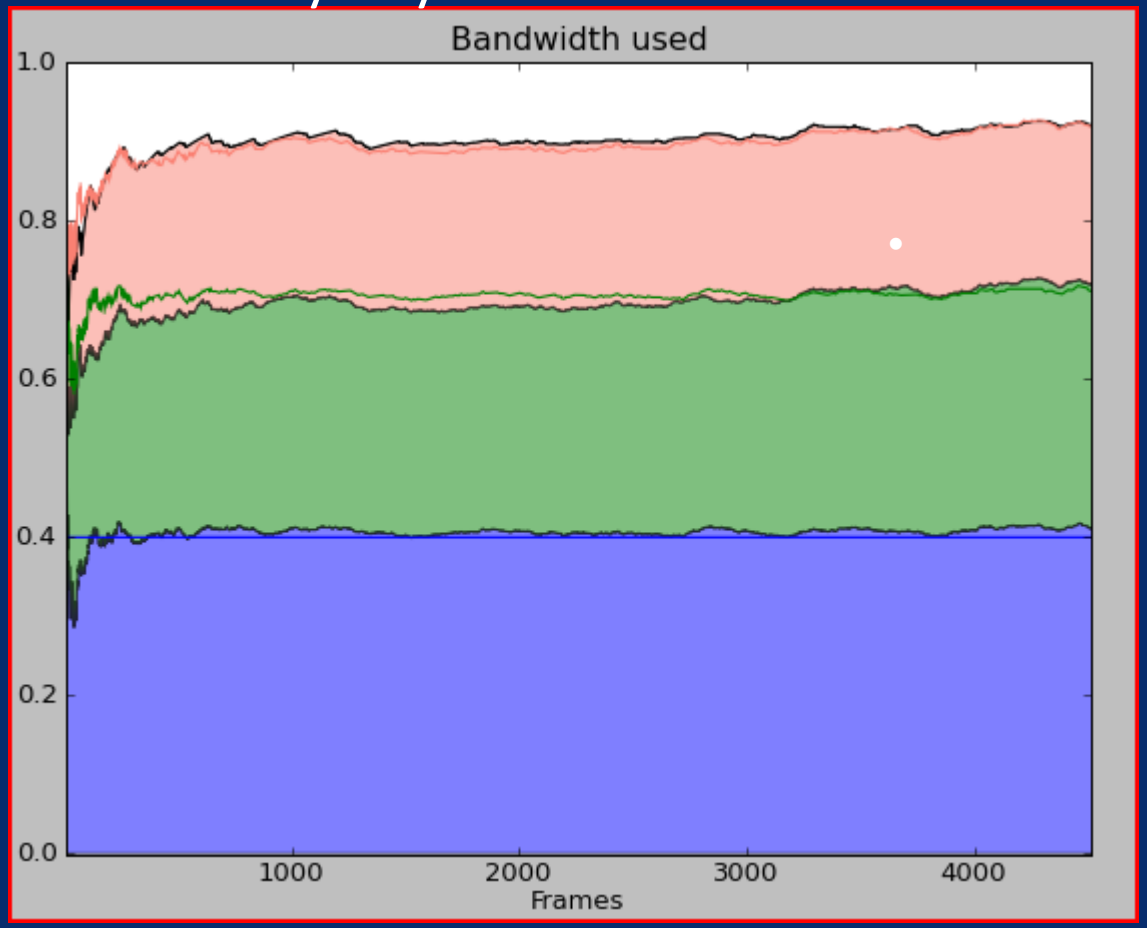
Simulation Results

- Three virtual channels
- Throughput equal to allocated bandwidth
- 10% of available bandwidth not allocated and is not used by any channel



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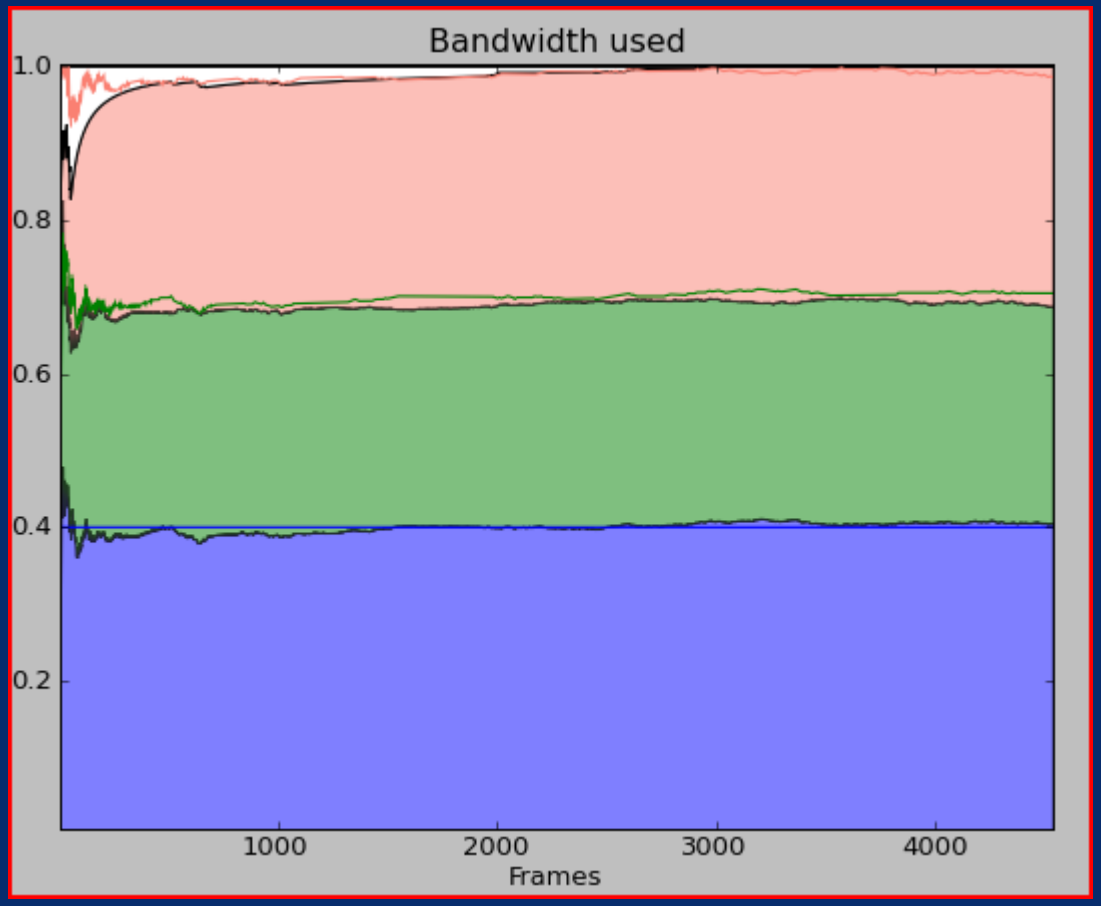
Simulation Results

- Three virtual channels
- Throughput equal to allocated bandwidth
- 100% of bandwidth allocated



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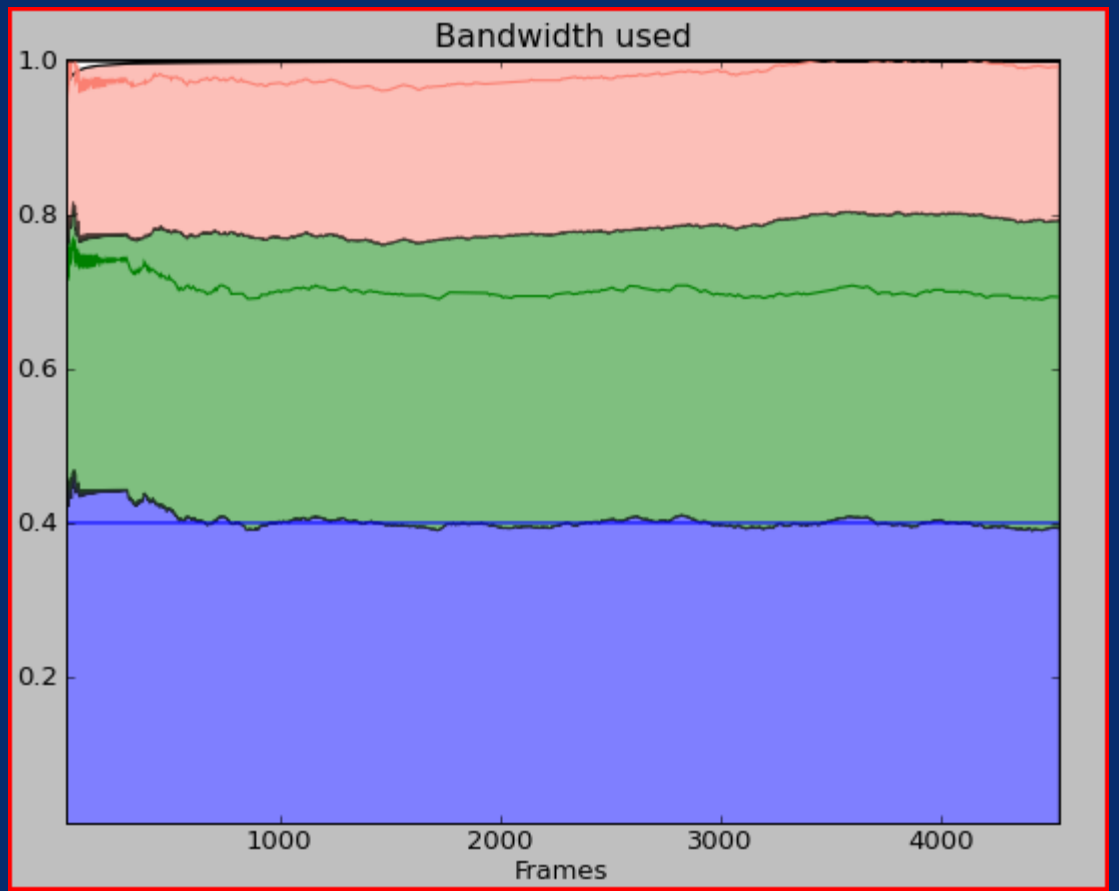
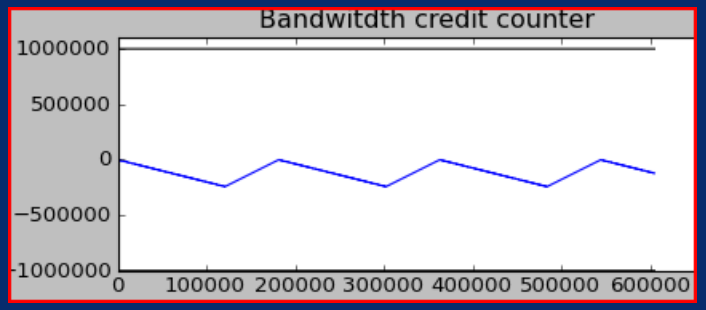
Simulation Results

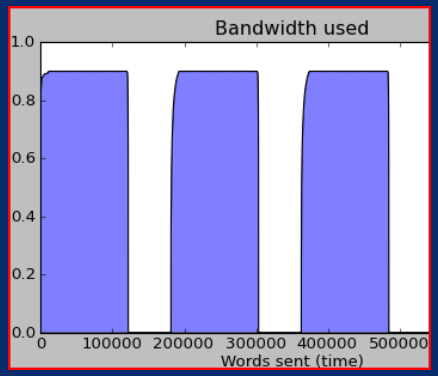
- Three virtual channels
- Throughput equal to allocated bandwidth
  - Except for green channel
  - Green channel has more data to send than allocated
  - Uses the non-allocated bandwidth



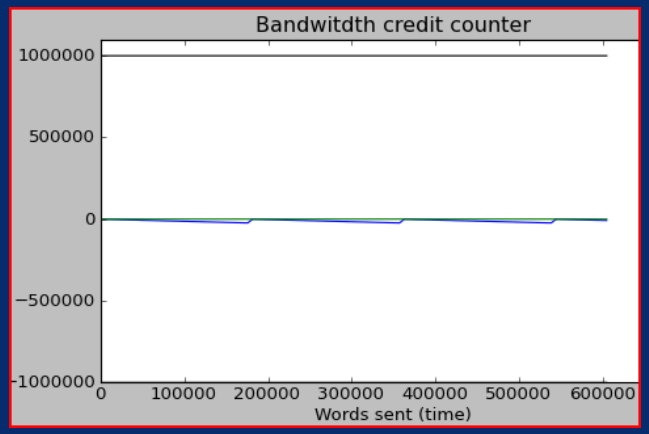
Source data burst

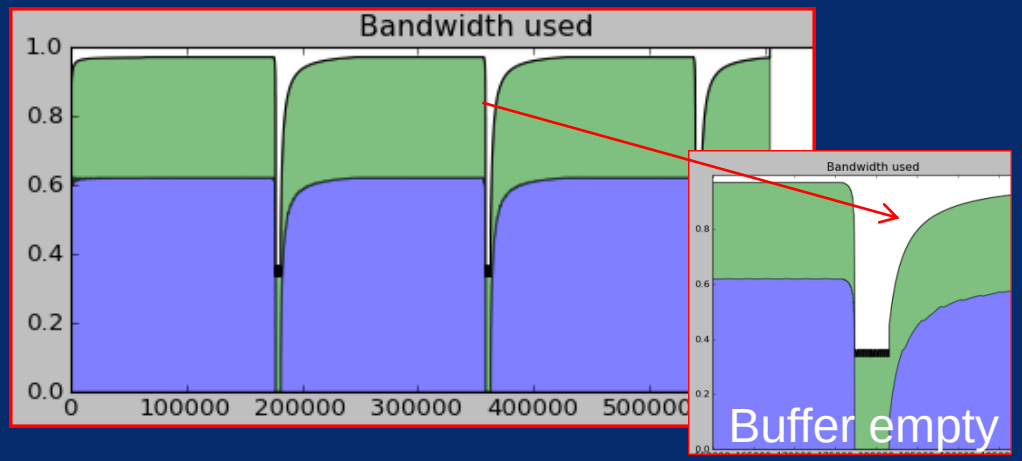
- Single bursty source channel
  - Use in average 60% of the link





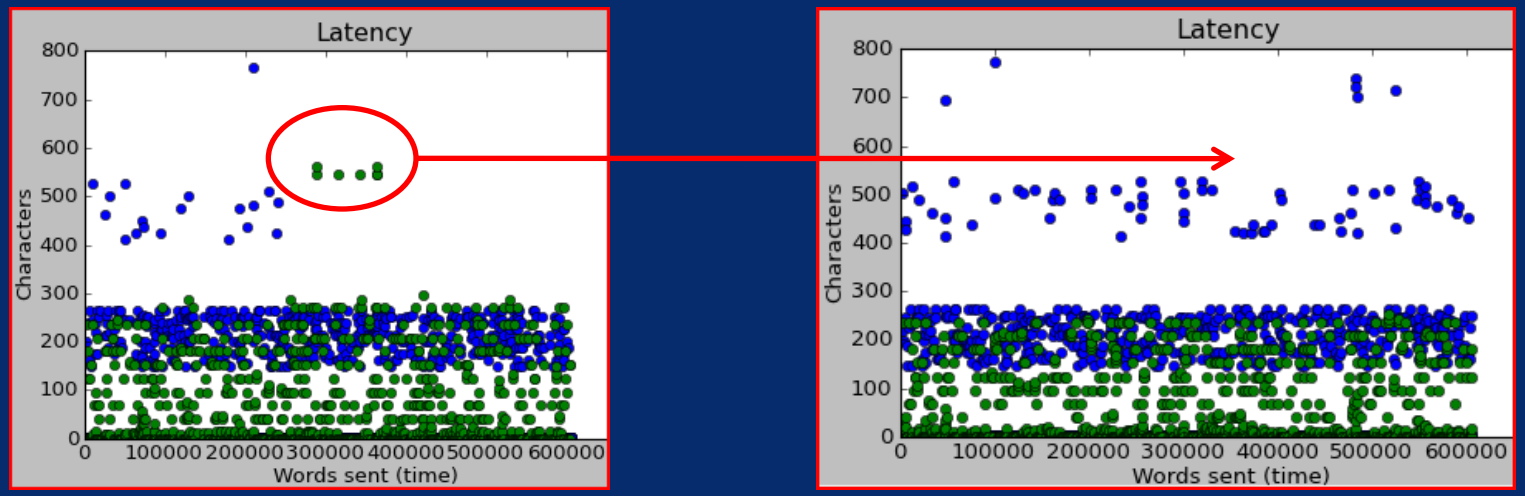
- Bursty source channel and a constant source channel
  - Blue source packets are buffered to guarantee the bandwidth for the green channel





Priority

- Priority reduces the latency and jitter of a channel



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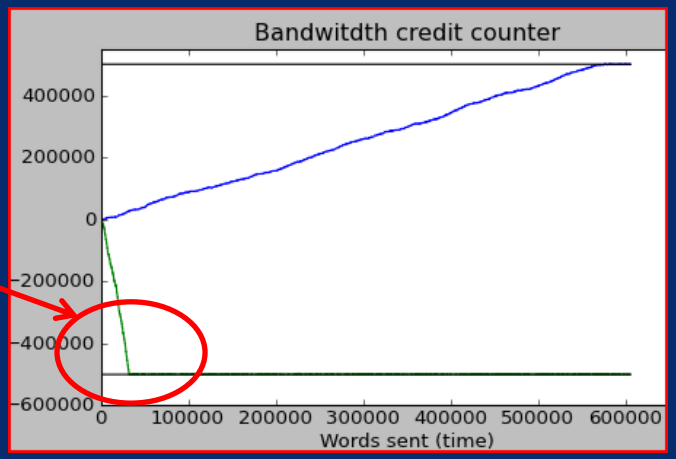
Priority

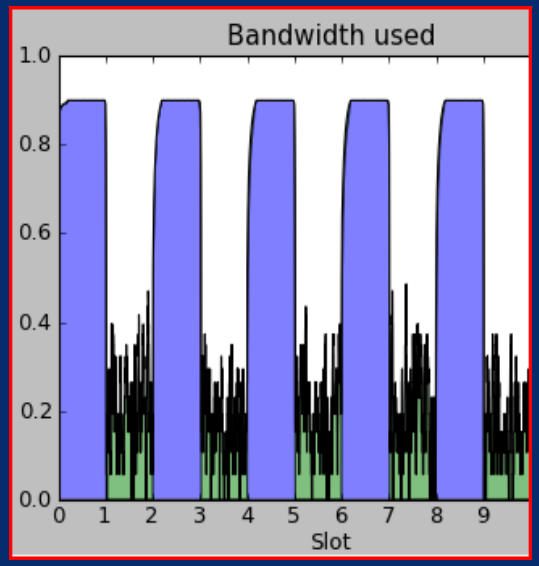
- The bandwidth used by a priority channel can be higher than allocated.
  - But the anomaly is notified to the user

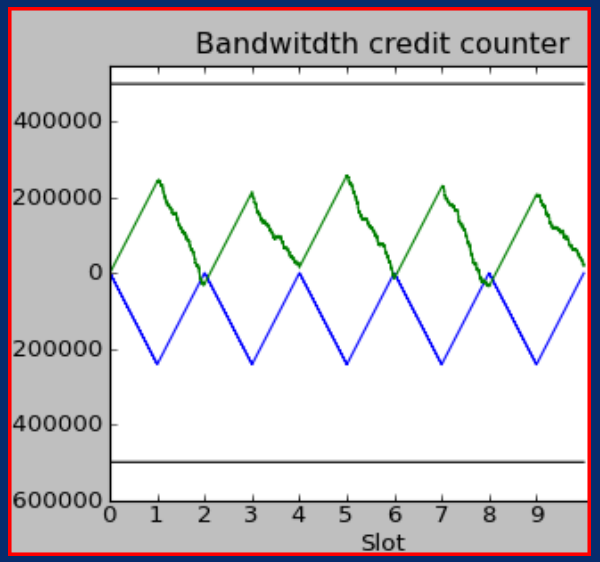
Unexpected use of bandwidth detected



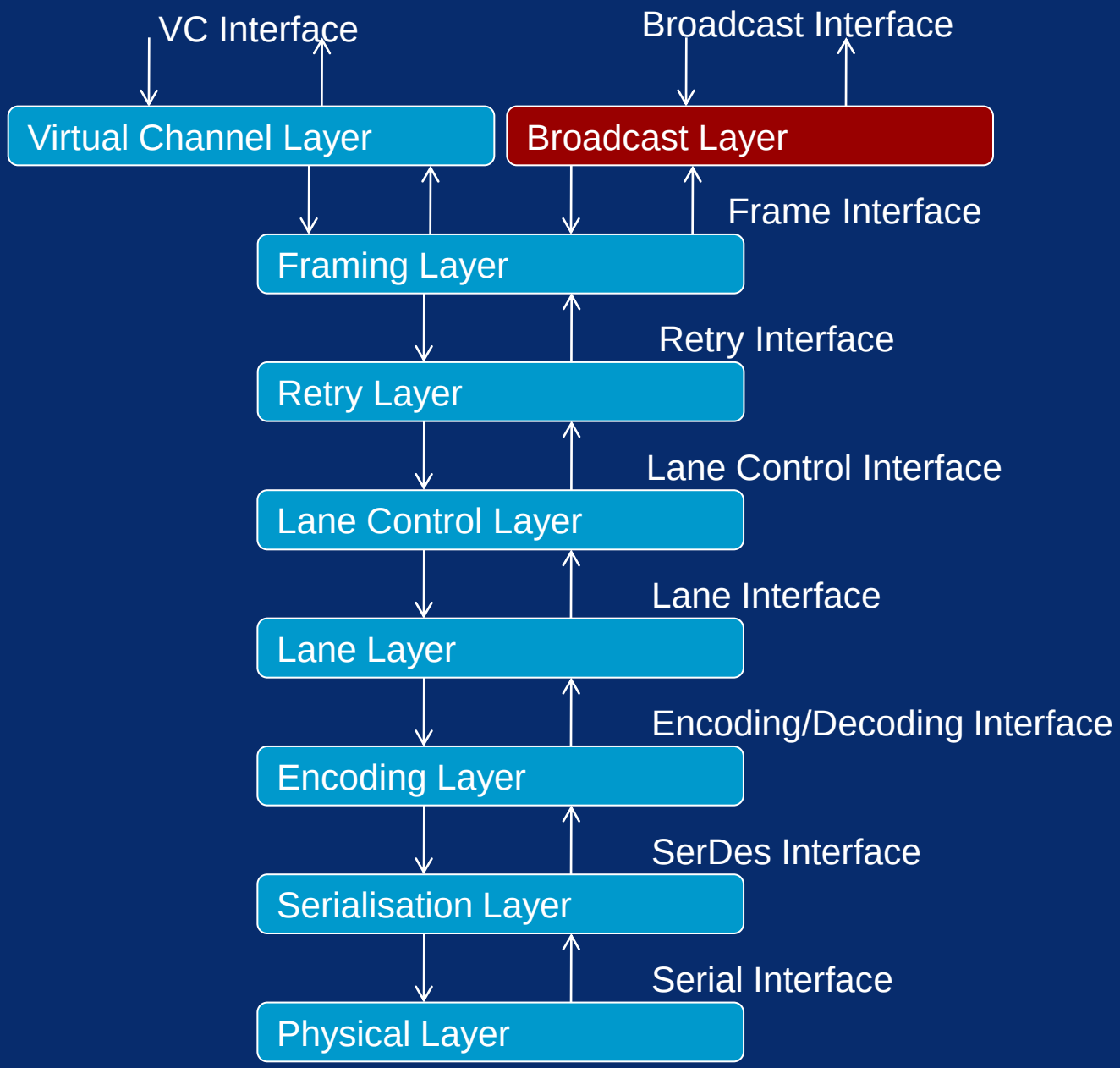
Scheduling

- If the data source is synchronized with the channel schedule the latency and jitter is minimum.





SpaceFibre Broadcast Layer



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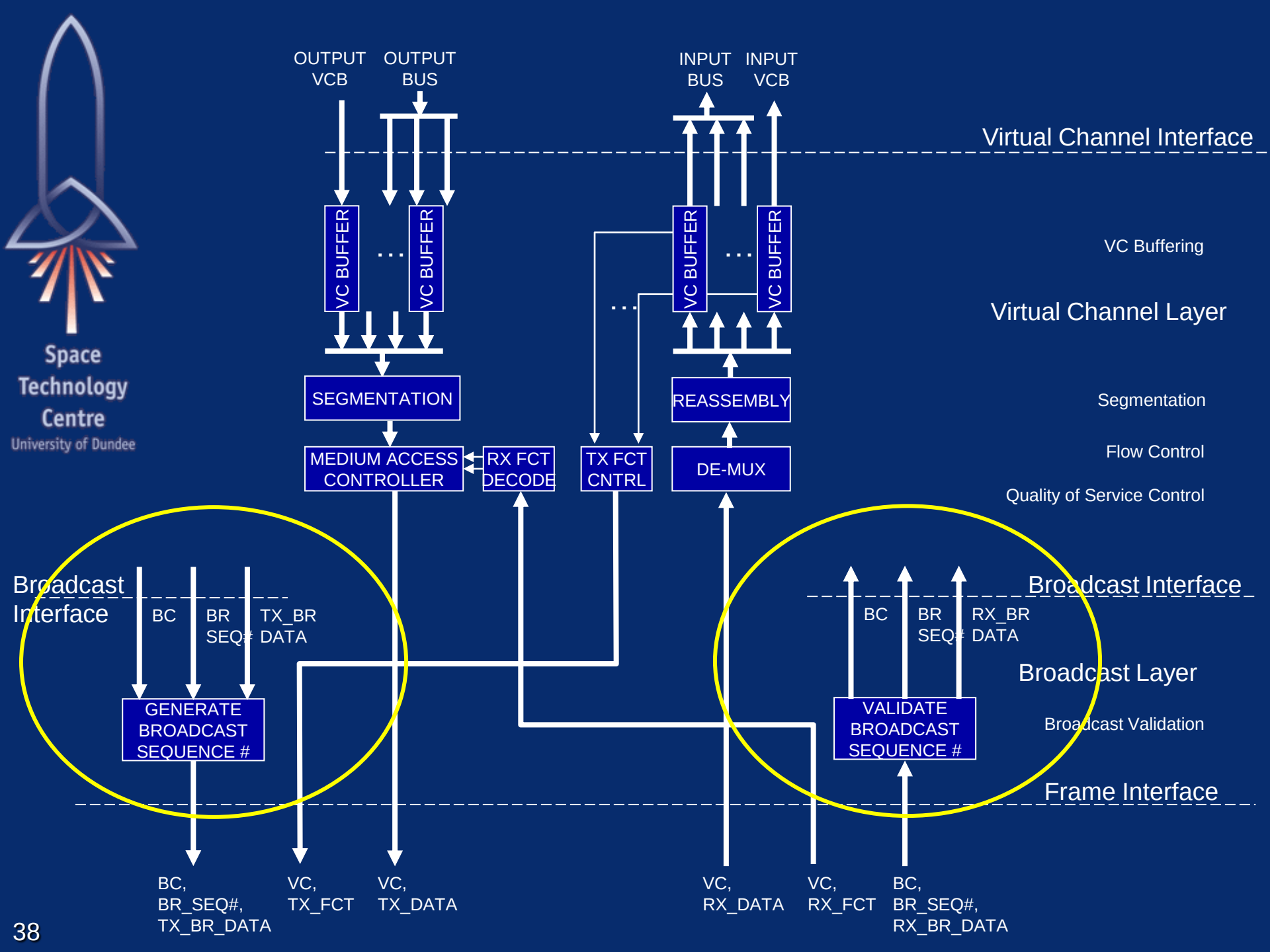
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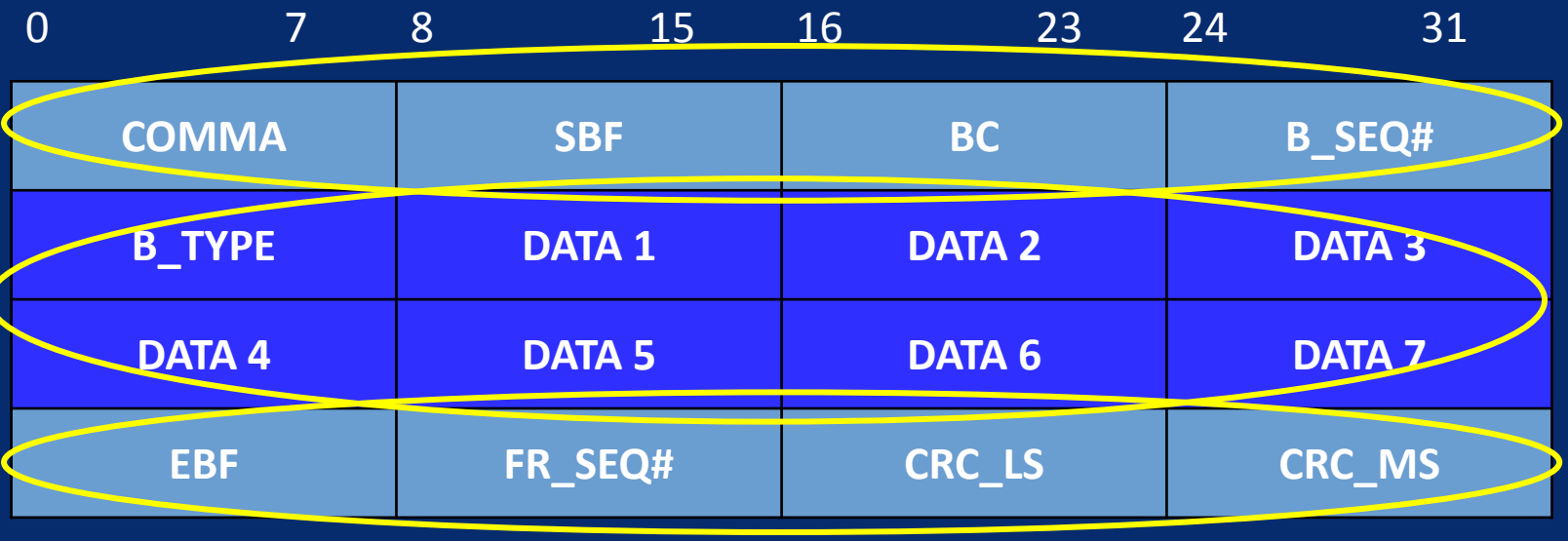
SpaceFibre Broadcast Channels

- Broadcast Channel Interface
  - Use to broadcast short messages across the network and to receive those messages
  - Can be used for many functions
    - Time distribution
    - Synchronisation
    - Network management
    - Event signalling
  - Broadcast interface is a set of registers
    - Broadcast channel
    - Broadcast sequence number
    - Message type
    - Message data

SpaceFibre Broadcast Frame



- Start Broadcast Frame
  - Broadcast Channel, Broadcast Sequence Number
- Message field contains
  - Broadcast message type
  - Broadcast message data
- End Data Frame
  - Frame sequence number, CRC

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SpaceFibre Broadcast Channels

- Broadcast mechanism
  - Operates like SpaceWire time-codes
- Broadcast sequence number
  - Used to support broadcast
  - Incremented for each broadcast message sent
  - Like SpaceWire time-code
- Broadcast channel
  - Each broadcast channel runs its own set of broadcast sequence numbers
  - Enables 256 independent broadcast channels

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SpaceFibre Broadcast Channels

- Broadcast channels split into three types:
  - Network management broadcast channels (0-31)
    - 0-7: Time synchronisation
      - 0-3 Time distribution
      - 4-7 Synchronisation
    - 8-31: Network control,
      - Configuration, control, and FDIR of a SpaceFibre network
  - Node broadcast channels (32-253)
    - Each broadcast channel associated with the node
    - With logical address of the same value as the broadcast channel number
  - Reserved broadcast channels (254, 255)

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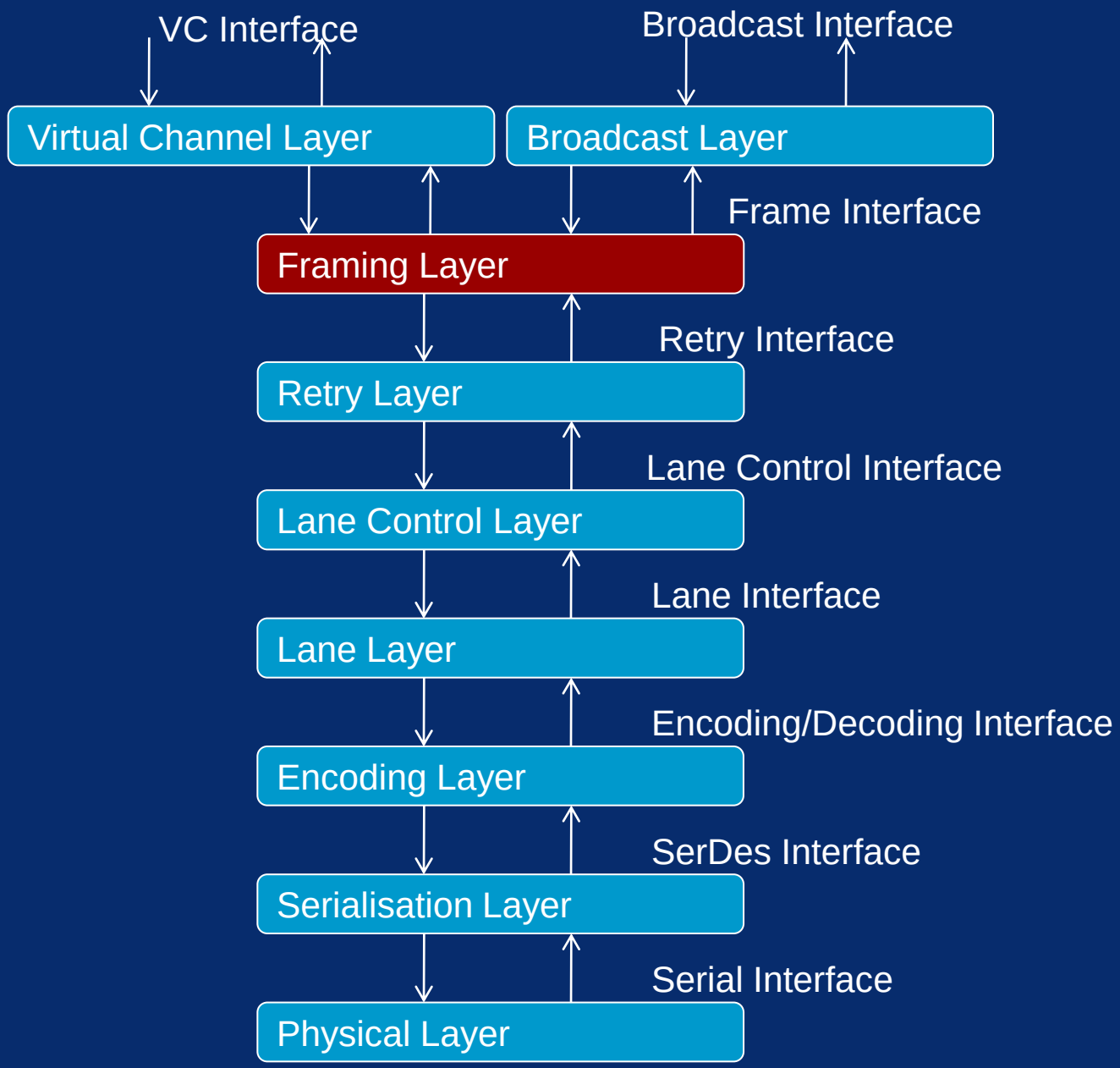
SpaceFibre Broadcast Channels

- Broadcast type
  - Defines sematics of broadcast message
  - E.g. “Time” type
    - Data field contains seven bytes of system time
- Subscription
  - User application can subscribe to particular
    - Broadcast channels
    - Broadcast message types
  - Only receive notification of messages they subscribe to

SpaceFibre Framing Layer



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SpaceFibre Data Frame

0 7	8 15	16 23	24 31
COMMA	SDF	VC	Reserved
DATA 1 LS	DATA 1	DATA 1	DATA 1 MS
DATA 2 LS	DATA 2	DATA 2	DATA 2 MS
…	…	…	…
DATA N LS	DATA N	DATA N	DATA N MS
EDF	FR_SEQ#	CRC_LS	CRC_MS

- 32-bit oriented, control words and data words
- Start Data Frame
  - Virtual Channel Number
- Data field contains N-Chars
  - From one or more SpaceWire packets
- End Data Frame
  - Frame sequence Number, CRC

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SpaceFibre Data Frames

- Data field can contain
  - SpaceWire data characters
  - SpaceWire EOP
  - SpaceWire EEP
  - SpaceWire Null
    - Only used to fill out a word
    - After EOP/EEP

Example Data Frame Content

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EOP, EEP, Null Coding

- Must be able to differentiate
  - EOP, EEP, Null
  - From Data characters
- Use K-codes
  - EOP K28.0
  - EEP K28.2
  - Null K28.6
- None of these contain comma
  - Since they can occur anywhere in a word
  - Comma must only occur in LS symbol position
- Data values of these K-codes
  - Used in scrambling, CRC
  - K-code value not replace when scrambling

Data Scrambling

- Spread the spectrum of data / idle frames
- By convolution
  - with a broad spectrum signal
  - i.e. a noise or random number source
- Convolution in frequency domain is multiplication in time domain.
- Multiplication of a bit sequence can be done by XOR

Data Scrambling

- Bit wise multiplication (XOR) of data with a sequence of random numbers produced from a scrambling polynomial
- The scrambling polynomial is

  $G(x) = X^{16} + X^5 + X^4 + X^3 + 1$
- Seed for scrambler is 0xffff
- Re-seeded at the start of every new data or idle frame
- Data field of data frames and idle frames scrambled prior to transmission

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De-Scrambling

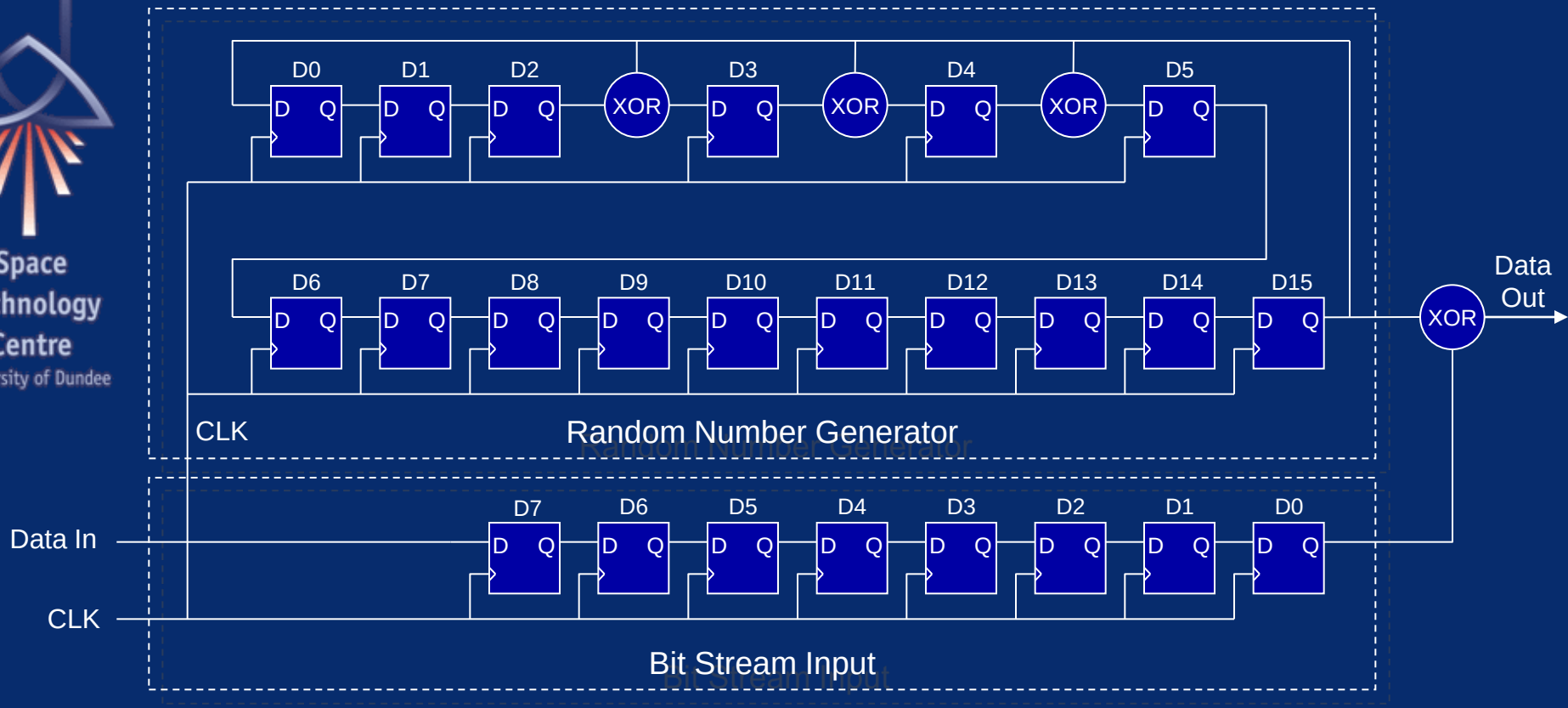
- De-convolve known “noise” from received signal
- De-convolution in frequency domain is division in time domain
- Multiplication and division give the same result in bit-wise boolean algebra

0 represents -1, 1 represents +1

-1 x -1 = +1	-1 / -1 = +1	0 XOR 0 = 1
-1 x +1 = -1	-1 / +1 = -1	0 XOR 1 = 0
+1 x -1 = -1	+1 / -1 = -1	0 XOR 1 = 0
+1 x +1 = +1	+1 / +1 = +1	1 XOR 1 = 1

- Therefore XOR the incoming bit stream with the scrambling polynomial to recover data

Scrambler/De-Scrambler



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SpaceFibre Broadcast Frame

0 7	8 15	16 23	24 31
COMMA	SBF	BC	B_SEQ#
B_TYPE	DATA 1	DATA 2	DATA 3
DATA 4	DATA 5	DATA 6	DATA 7
EBF	FR_SEQ#	CRC_LS	CRC_MS

- Start Broadcast Frame
  - Broadcast Channel, Broadcast Sequence Number
- Message field contains
  - Broadcast message type
  - Broadcast message data
- End Data Frame
  - Frame sequence number, CRC

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SpaceFibre Idle Frame

0 7	8 15	16 23	24 31
COMMA	SIF	FR_SEQ#	RESERVED
SEED LS	SEED	SEED	SEED MS
PRBS 1 LS	PRBS 1	PRBS 1	PRBS 1 MS
PRBS 2 LS	PRBS 2	PRBS 2	PRBS 2 MS
…	…	…	…
PRBS N LS	PRBS N	PRBS N	PRBS N MS

- Start Idle Frame
  - Frame Sequence Number
- Data field contains
  - Seed for pseudo-random sequence
  - Pseudo-random bit sequence
- No End of Frame
  - Ended by the start of next data or broadcast frame

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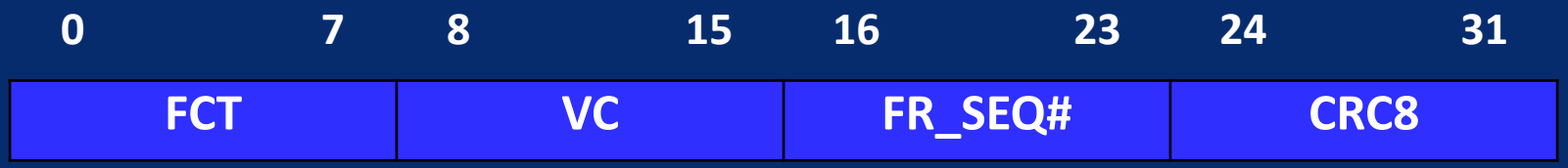
SpaceFibre FCT Control Word



- FCT
  - FCT identifier symbol (K23.7)
- Virtual Channel
  - Virtual channel number
  - FCT is for this virtual channel
- FR_SEQ#
  - Frame sequence number
  - So missing/erroneous FCTs can be recovered
- CRC8
  - For integrity checking of FCT

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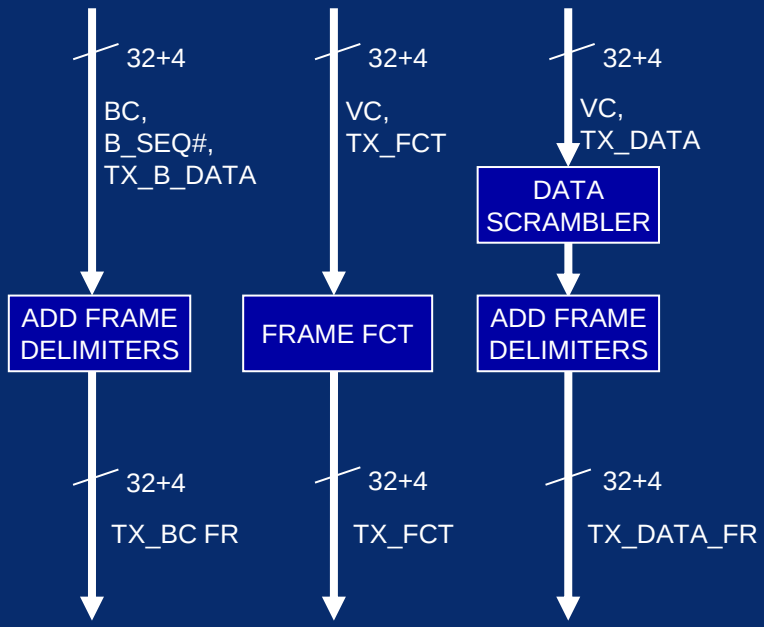
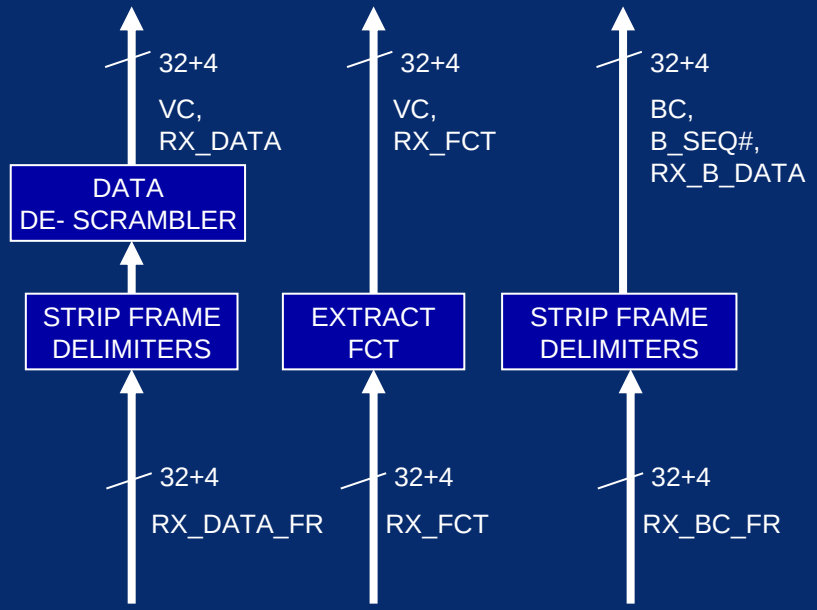
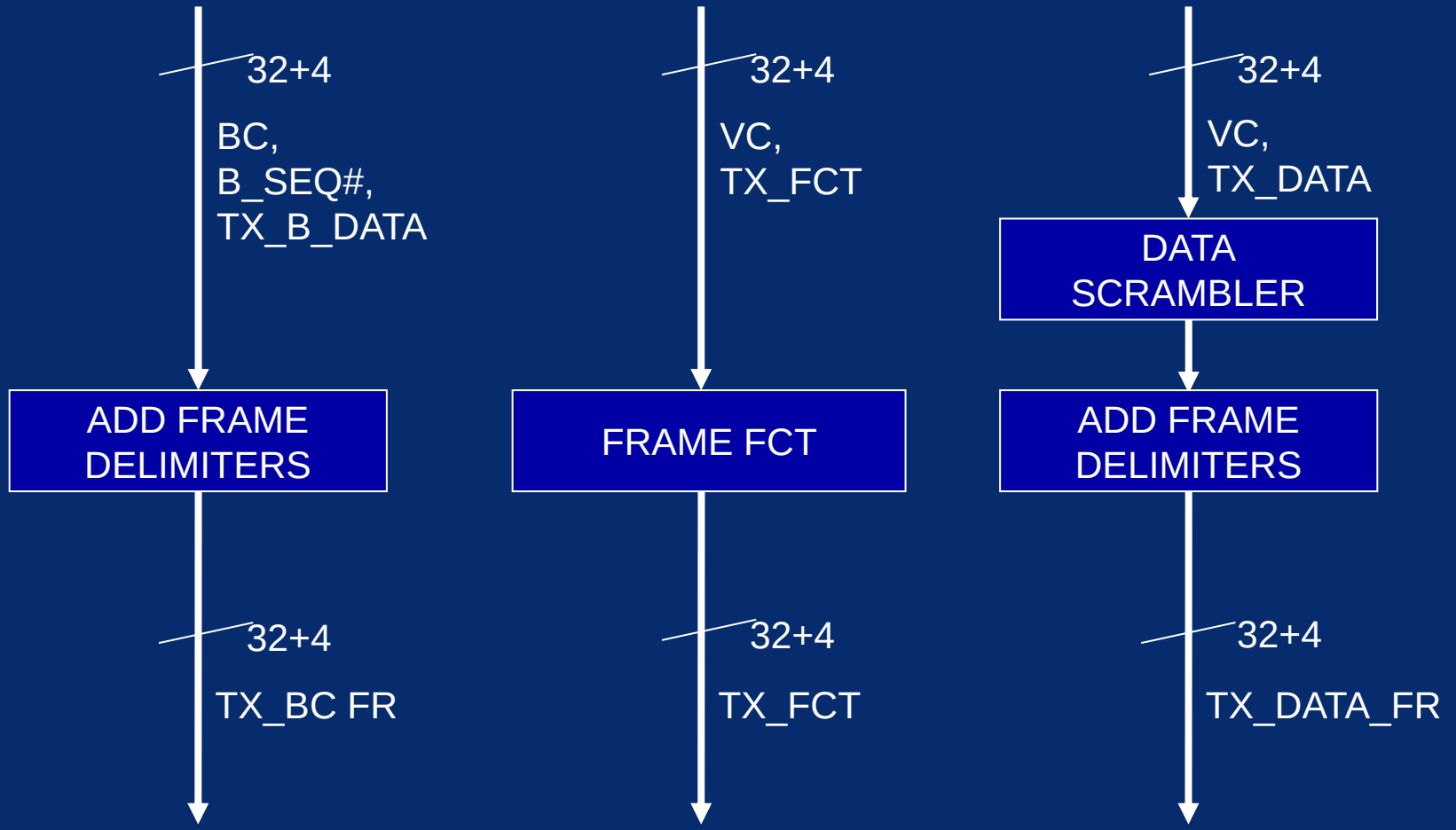
Framing Layer

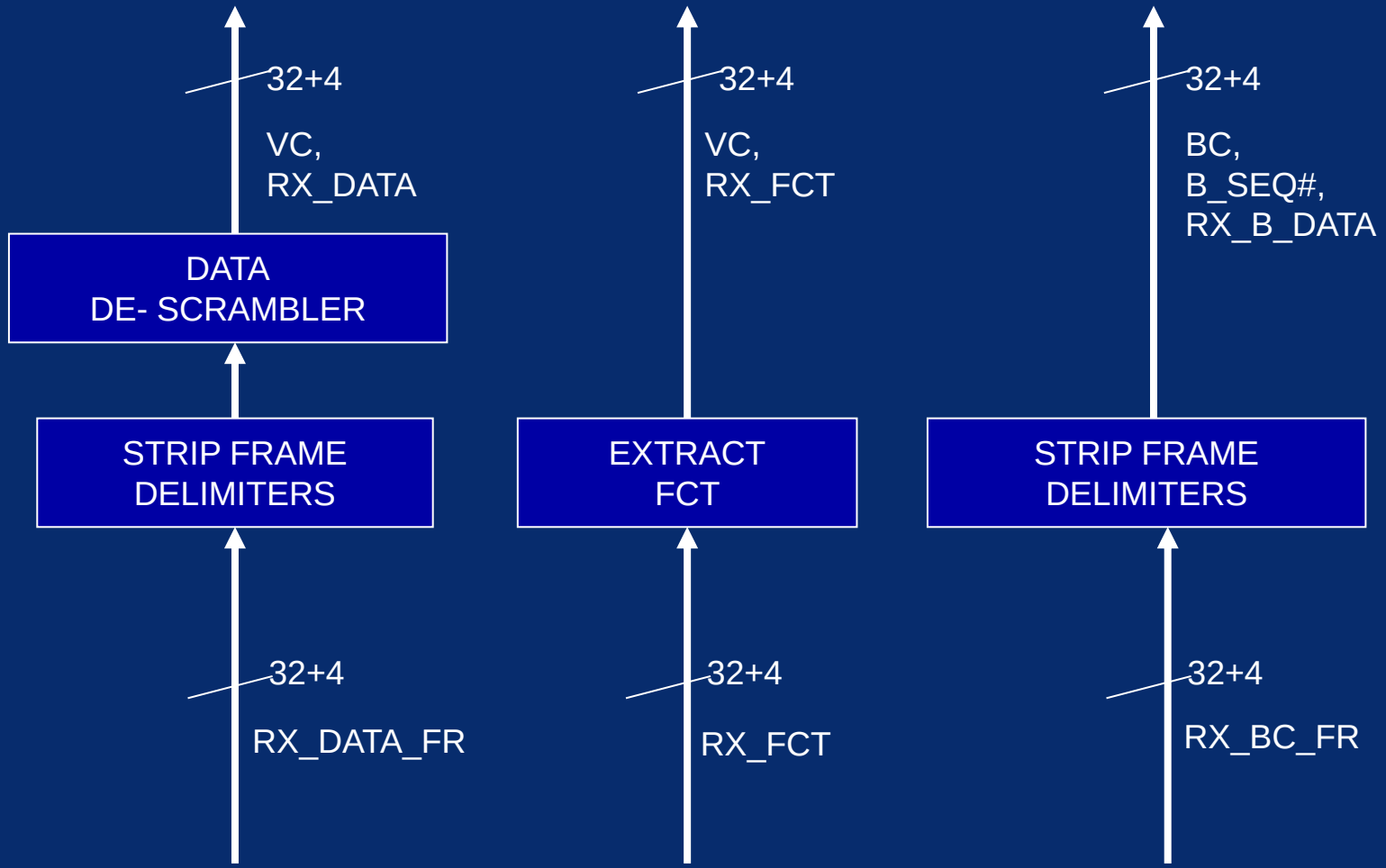




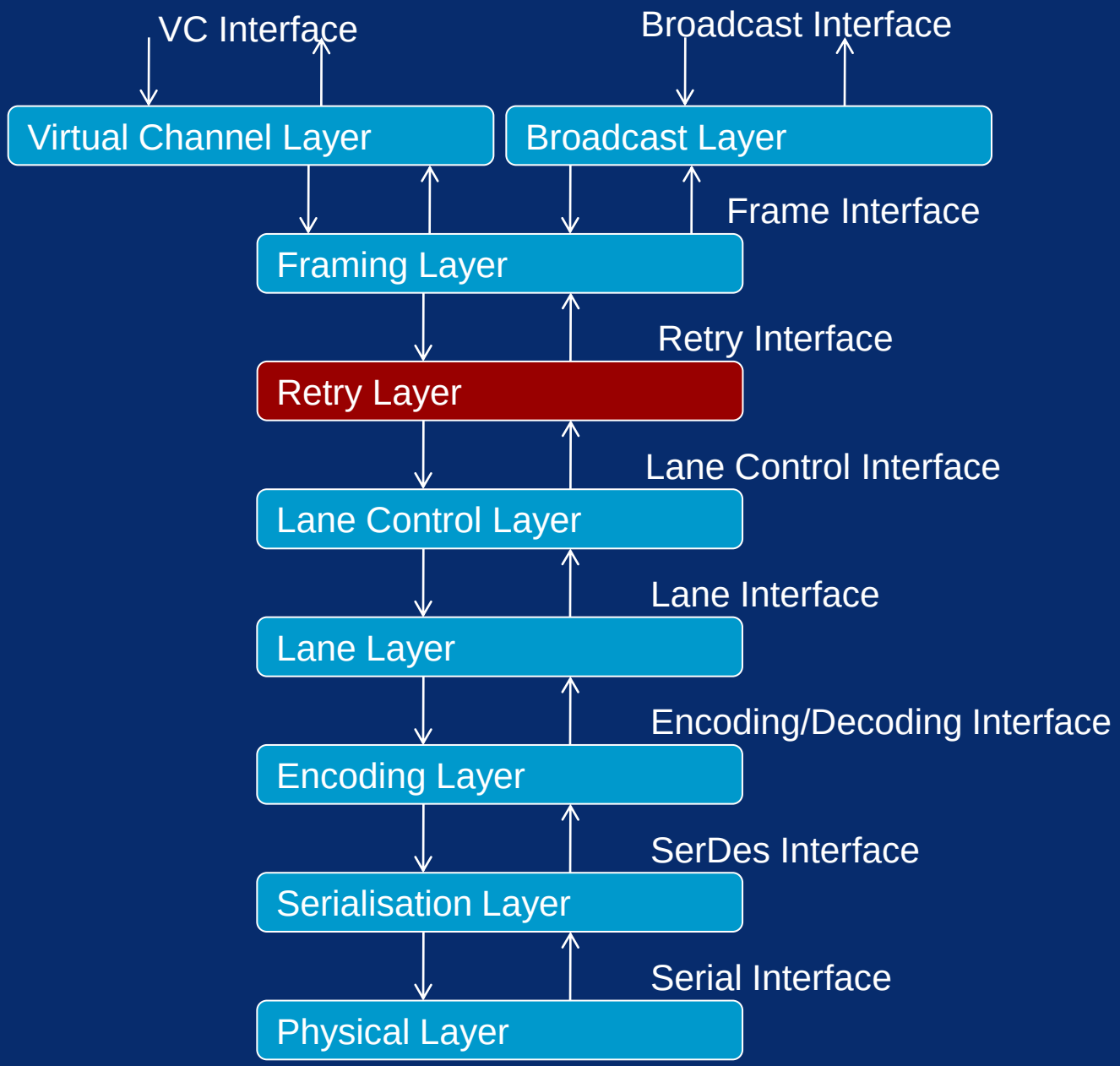
Transmit Framing



Receive De-Framing



SpaceFibre Retry Layer



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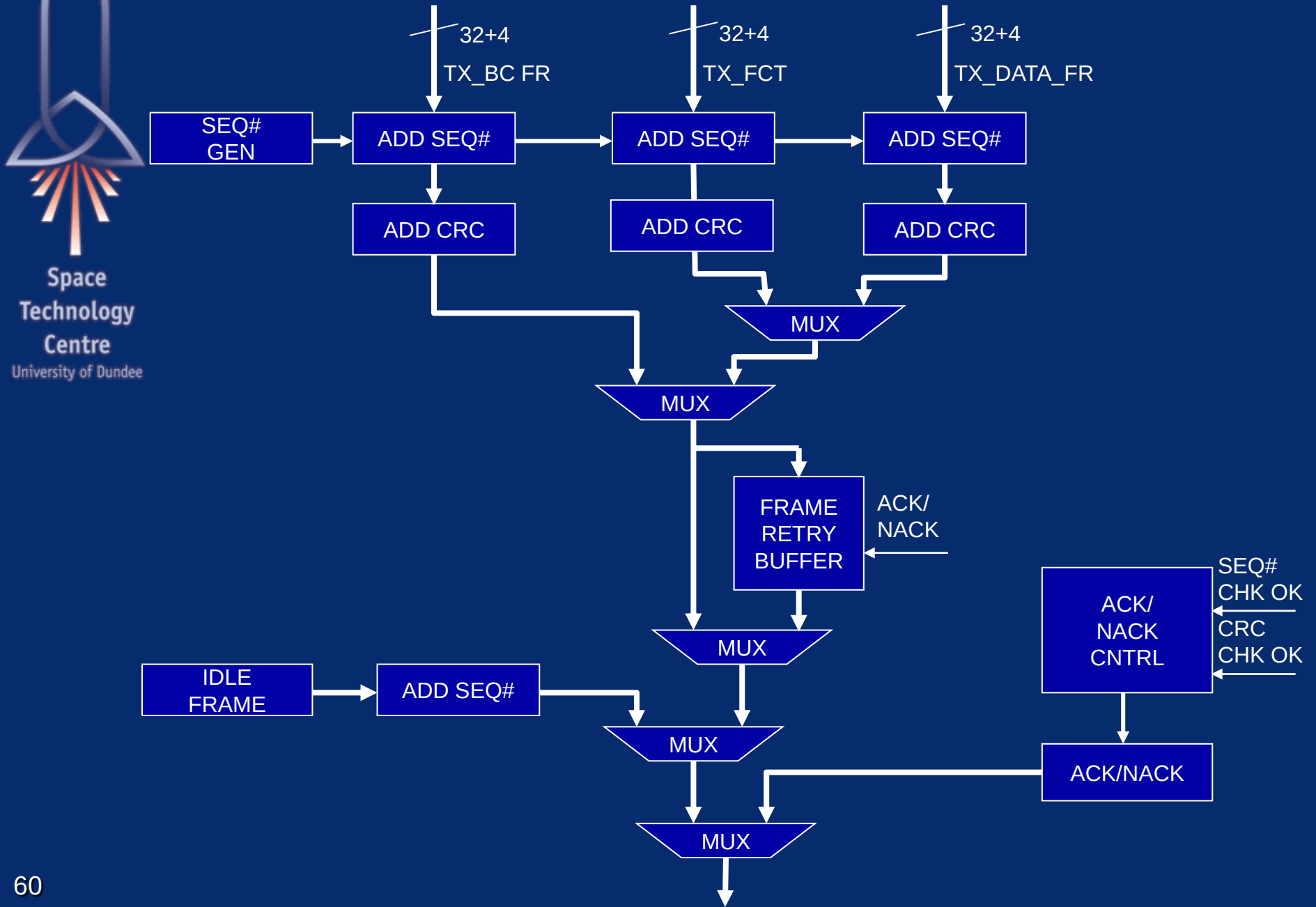
SpaceFibre Retry Layer - Transmit



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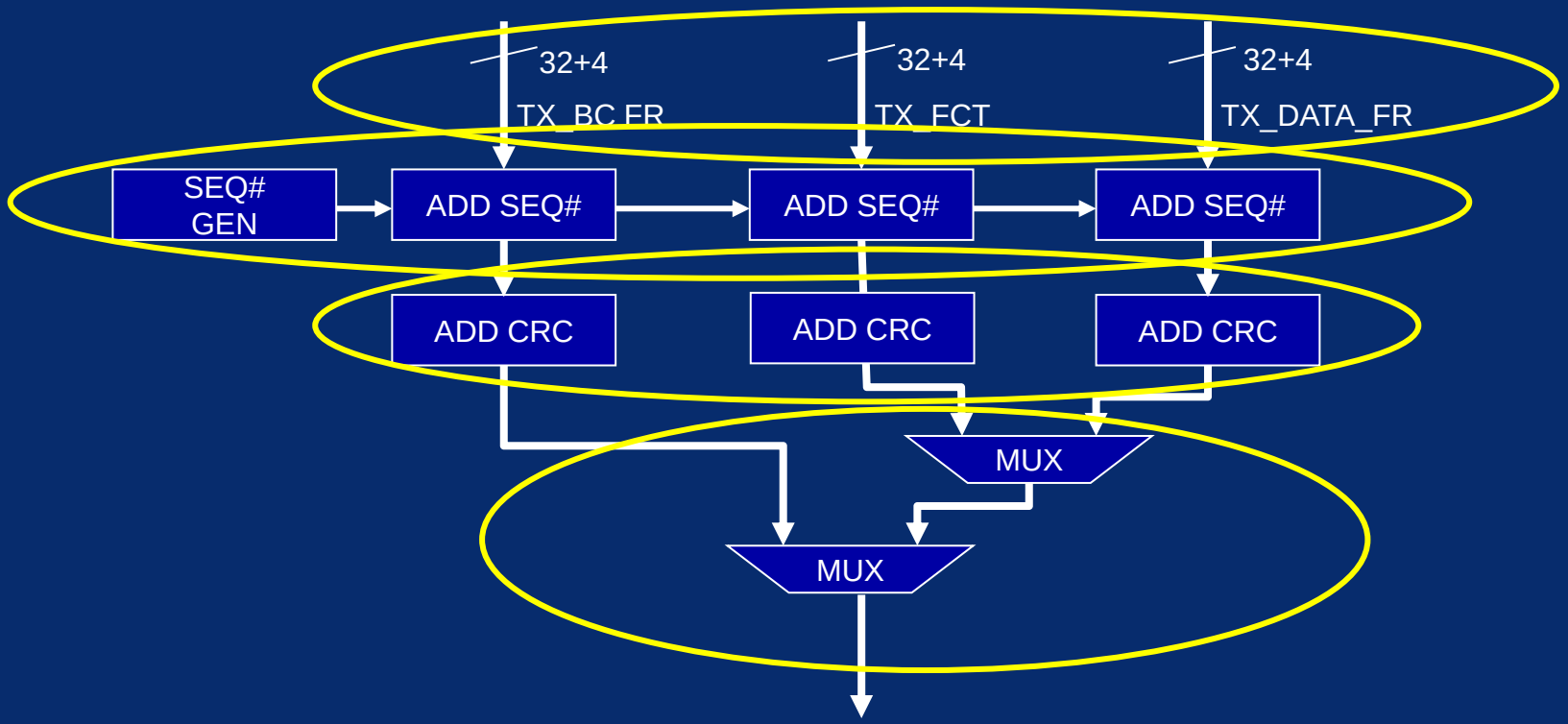
SpaceFibre Retry Layer - Transmit



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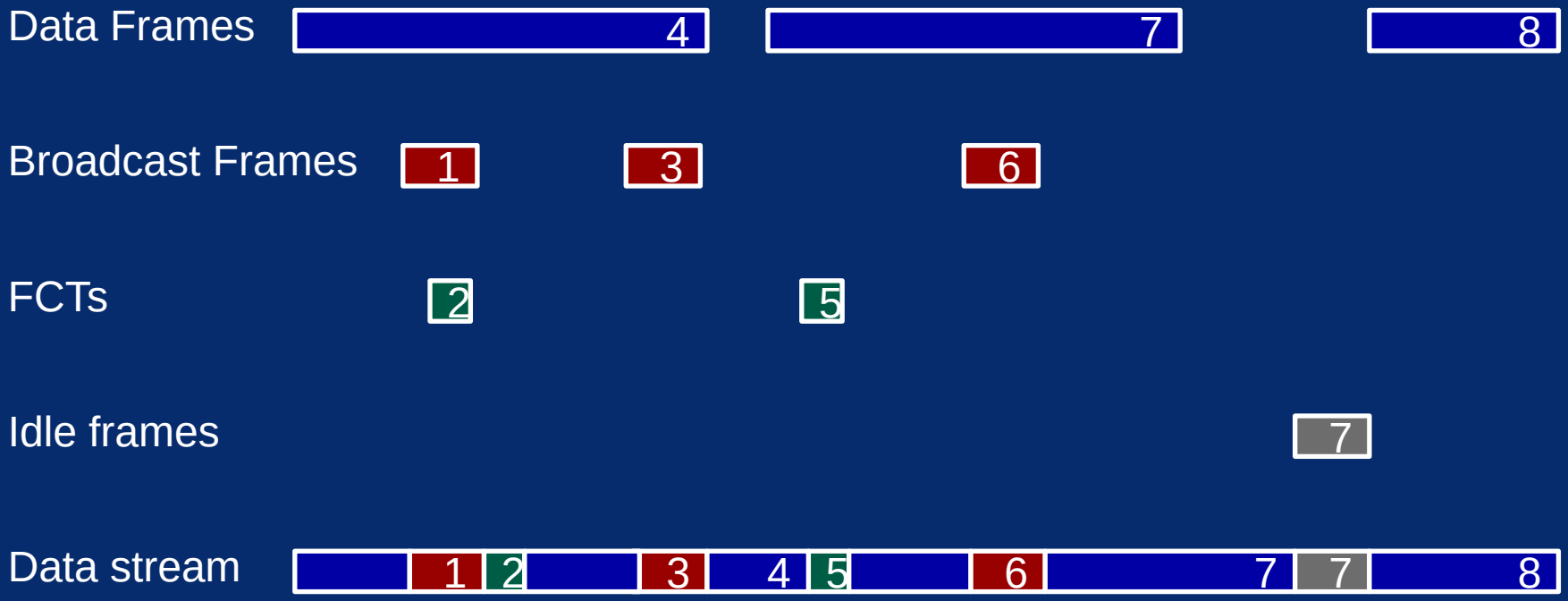
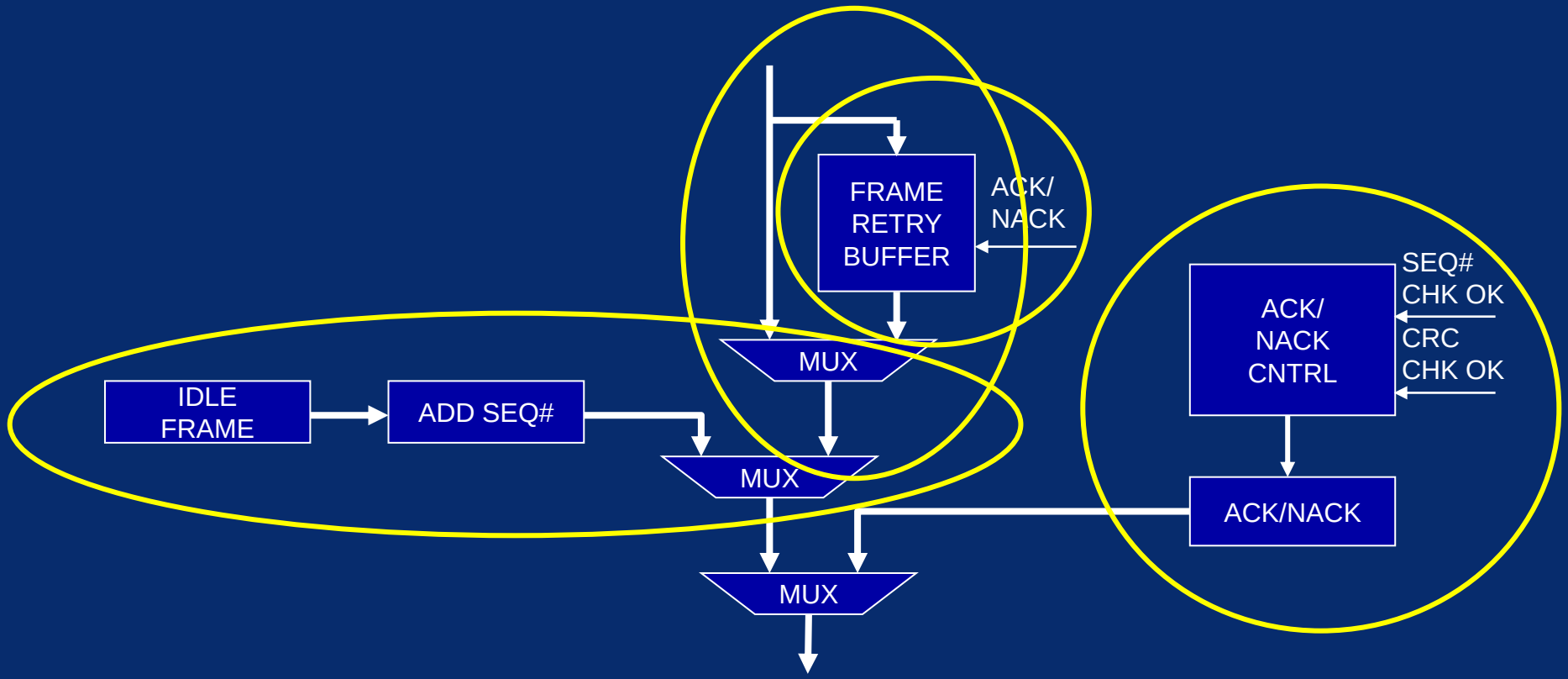
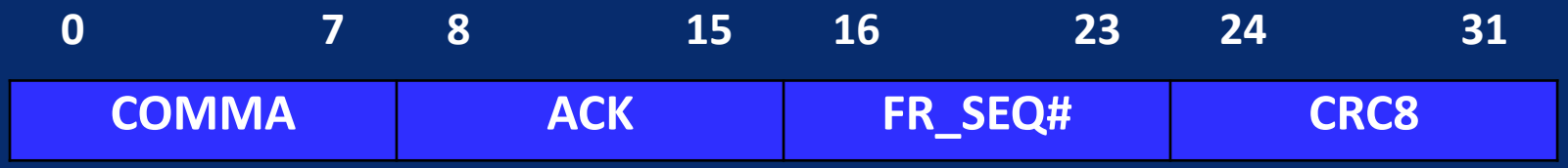
Multiplexing of Frames and FCTs



SpaceFibre Retry Layer - Transmit



ACK Control Word

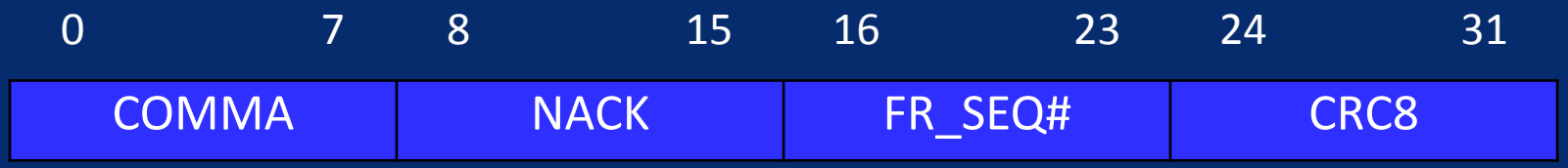


- COMMA
  - Identifies this as a control word
- ACK
  - Identifies control word as an ACK
- FR_SEQ#
  - Frame sequence number
  - Of last correctly receive frame/FCT
- CRC8
  - For integrity checking of ACK

ACK

- Send ACK
  - Whenever a data frame, FCT, or broadcast frame
    - Received without error and in correct order
  - ACK contains frame sequence number
    - Of the last correctly receive frame
- Received ACK
  - Check for errors using CRC8
  - If error, discard ACK
    - Another ACK will be sent when the next frame/FCT is received
  - If no error, ACK ok
    - Remove all frames/FCTs in retry buffer
    - With frame sequence number less than or equal to that of the ACK

NACK Control Word

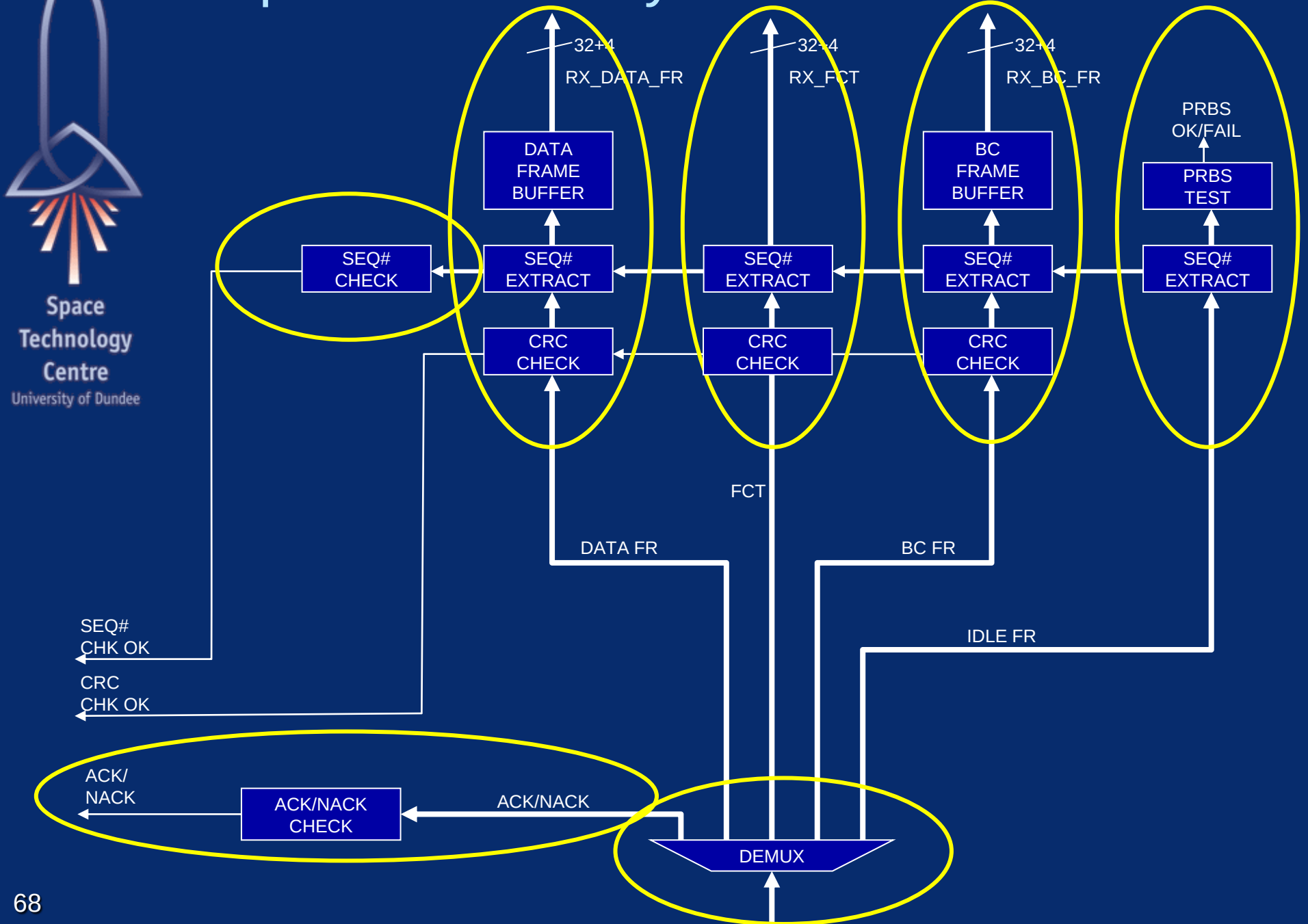


- COMMA
  - Identifies this as a control word
- NACK
  - Identifies control word as an NACK
- FR_SEQ#
  - Frame sequence number
  - Of last correctly receive frame/FCT
- CRC8
  - For integrity checking of ACK

NACK

- Send NACK
  - Whenever a data frame, FCT, or broadcast frame
    - Received with error or in wrong order
  - NACK contains frame sequence number
    - Of the last correctly receive frame
- Received NACK
  - Check for errors using CRC8
  - If error, discard NACK
    - Another NACK will be sent when the next frame/FCT is received
  - If no error, NACK ok
    - Resend all frames/FCTs in retry buffer
    - With frame sequence number greater than that of the NACK

SpaceFibre Retry - Receive



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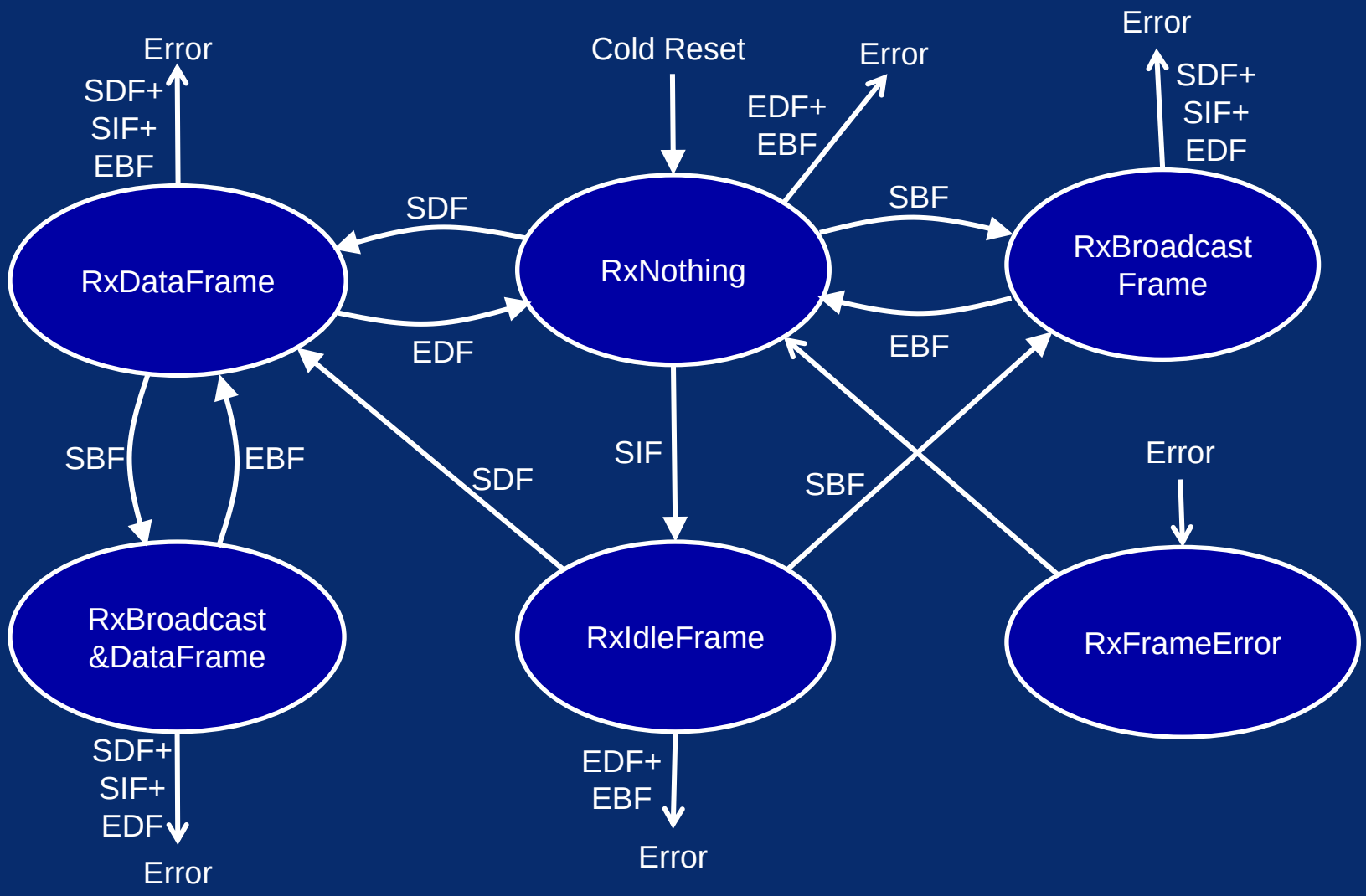
What Frame does a data word belong to?



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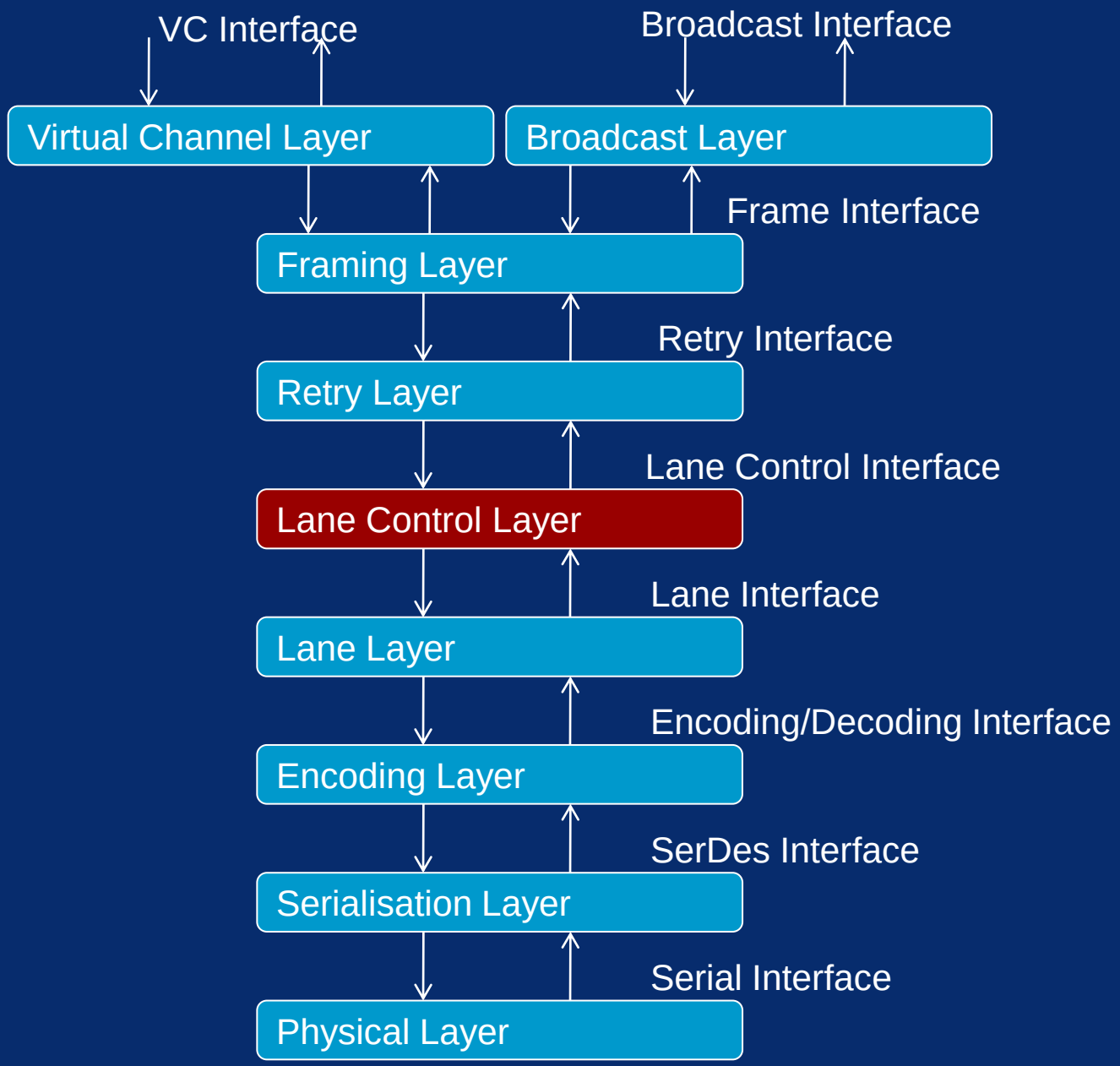
Link Layer Retry

- Small amount of memory required
  - To support many sources and virtual channels
- Rapid recovery from
  - Transient and persistent errors
- Signals permanent error
  - To network manager
  - Using broadcast frame
- Isolates effects of faults to where they occur
  - Minimises the effect on the system

SpaceFibre Lane Control Layer



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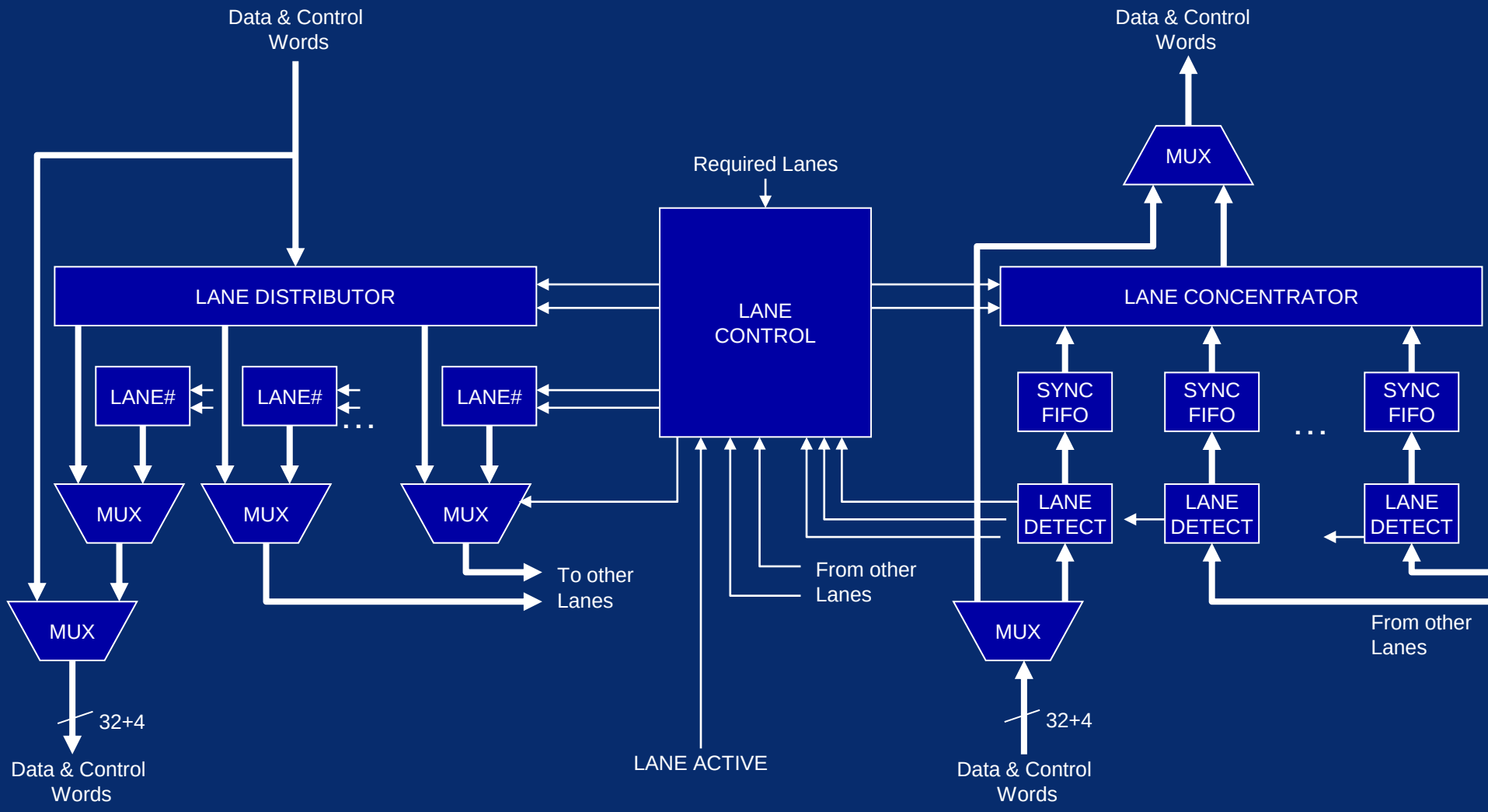
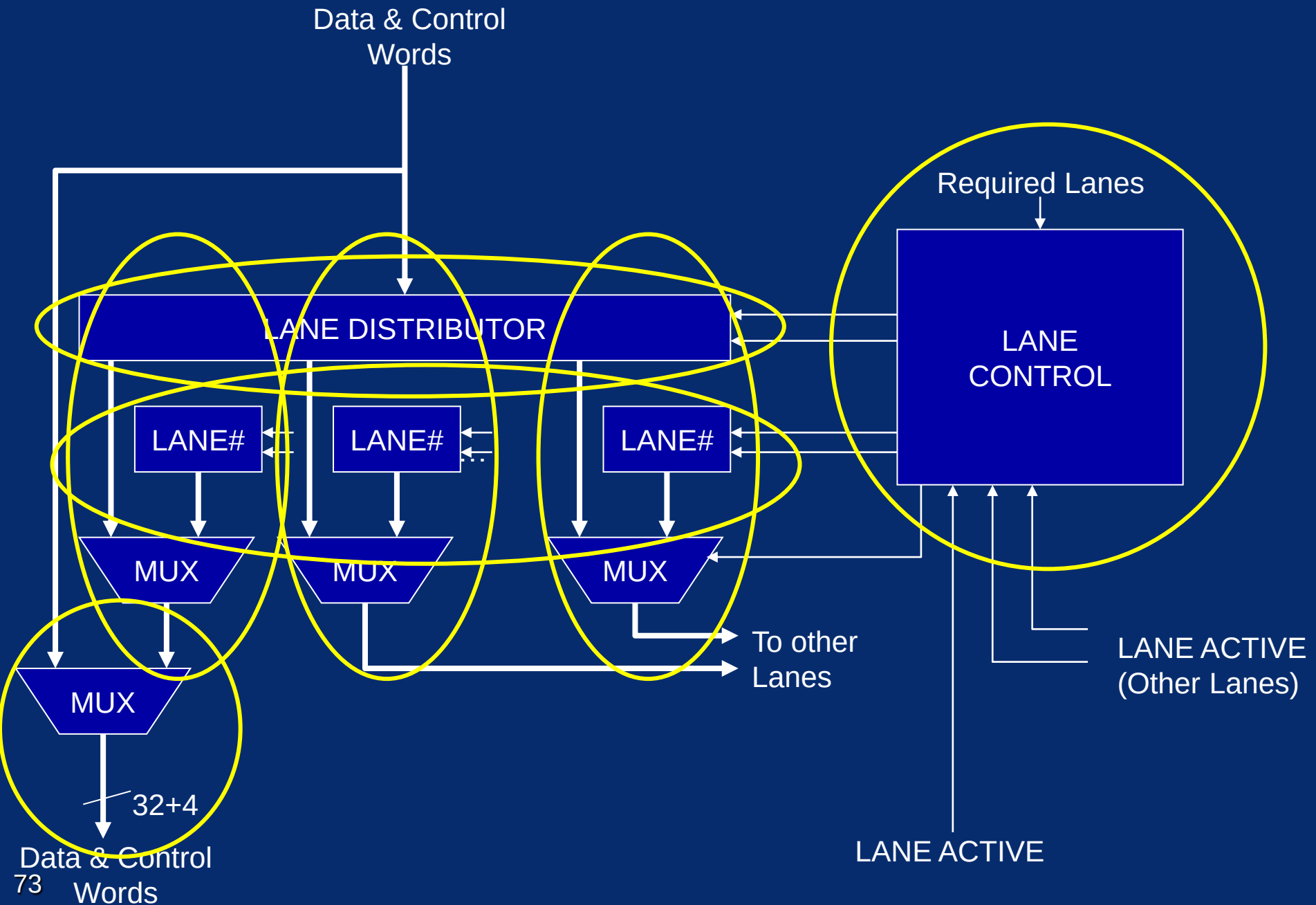
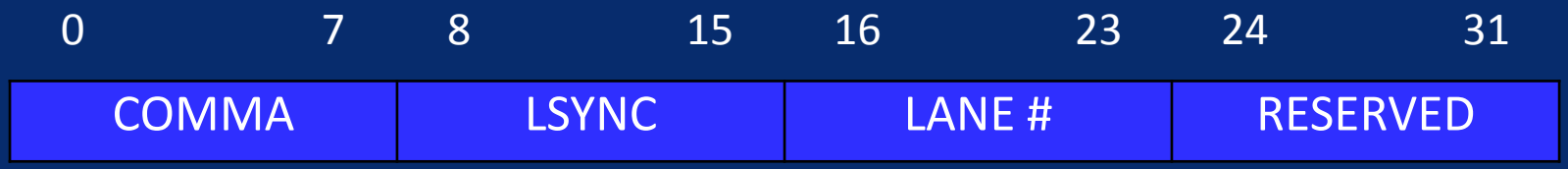
Lane Control Layer



Lane Control Layer

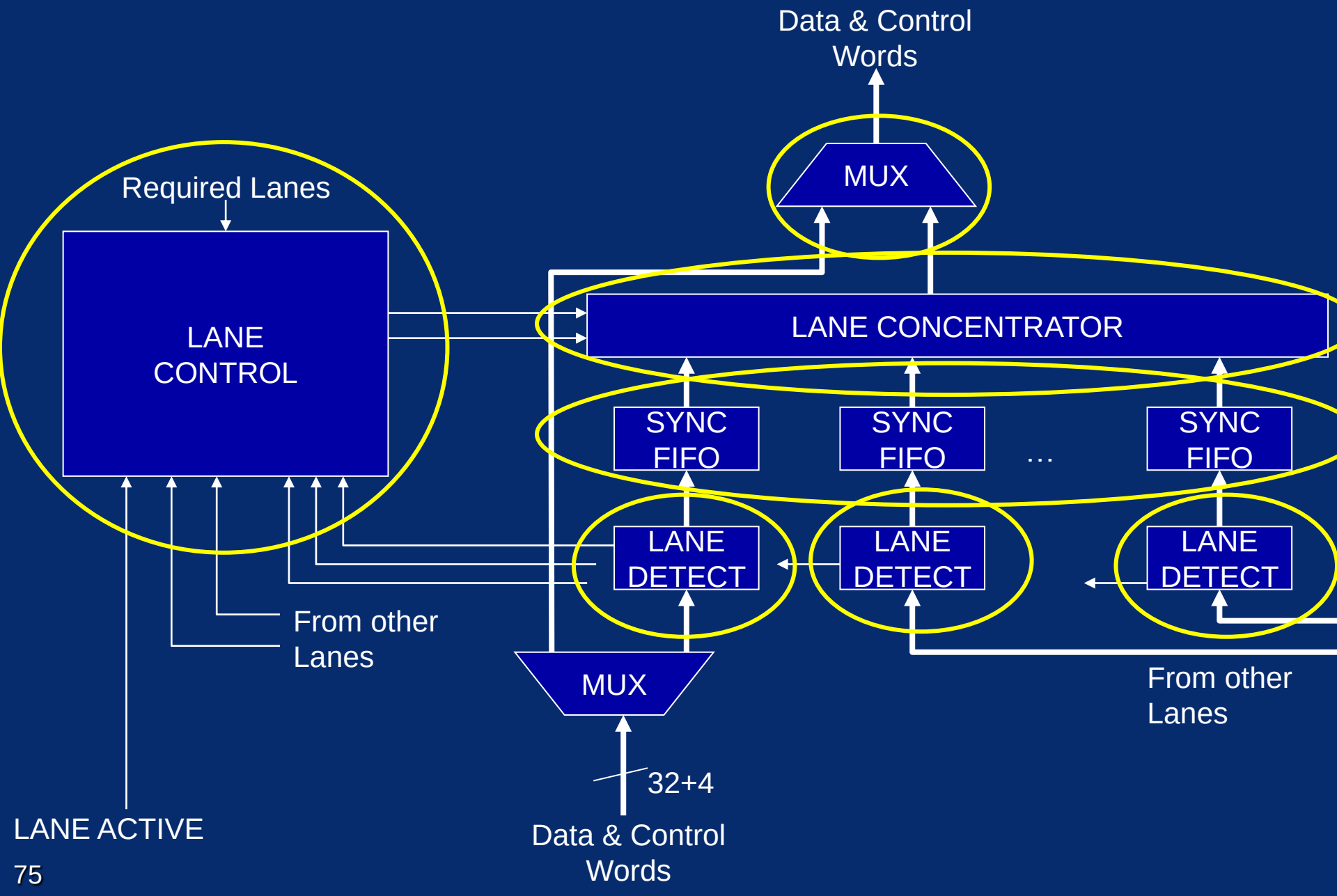


Lane Sync Control Word

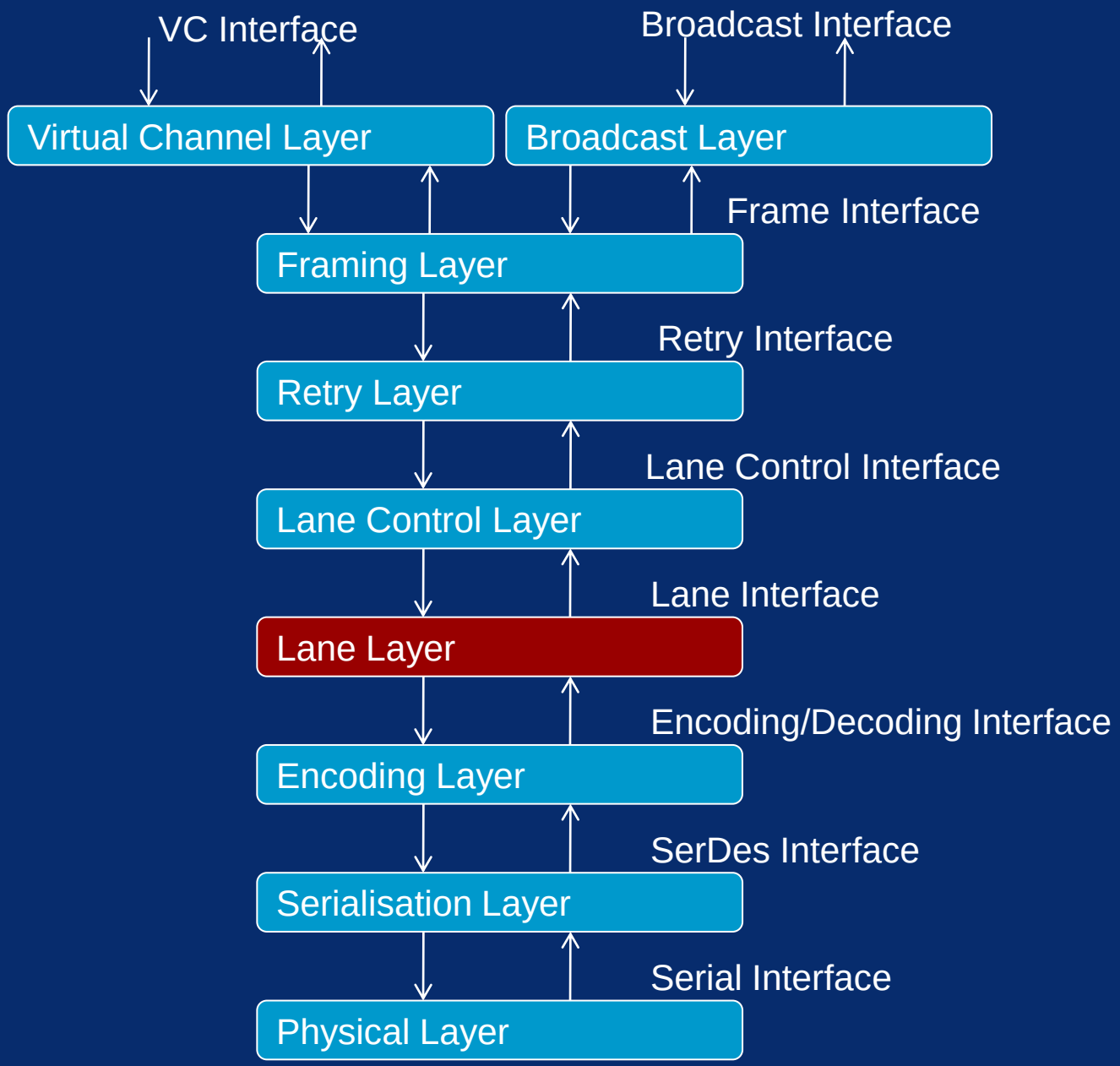


- COMMA
  - Identifies this as a control word
- LSYNC
  - Identifies control word as a Lane Sync control word
- LANE#
  - Lane number
  - 1 to 10 lanes
  - 0, implies lane not being used
- Reserved

Lane Control Layer



SpaceFibre Encoding Layer



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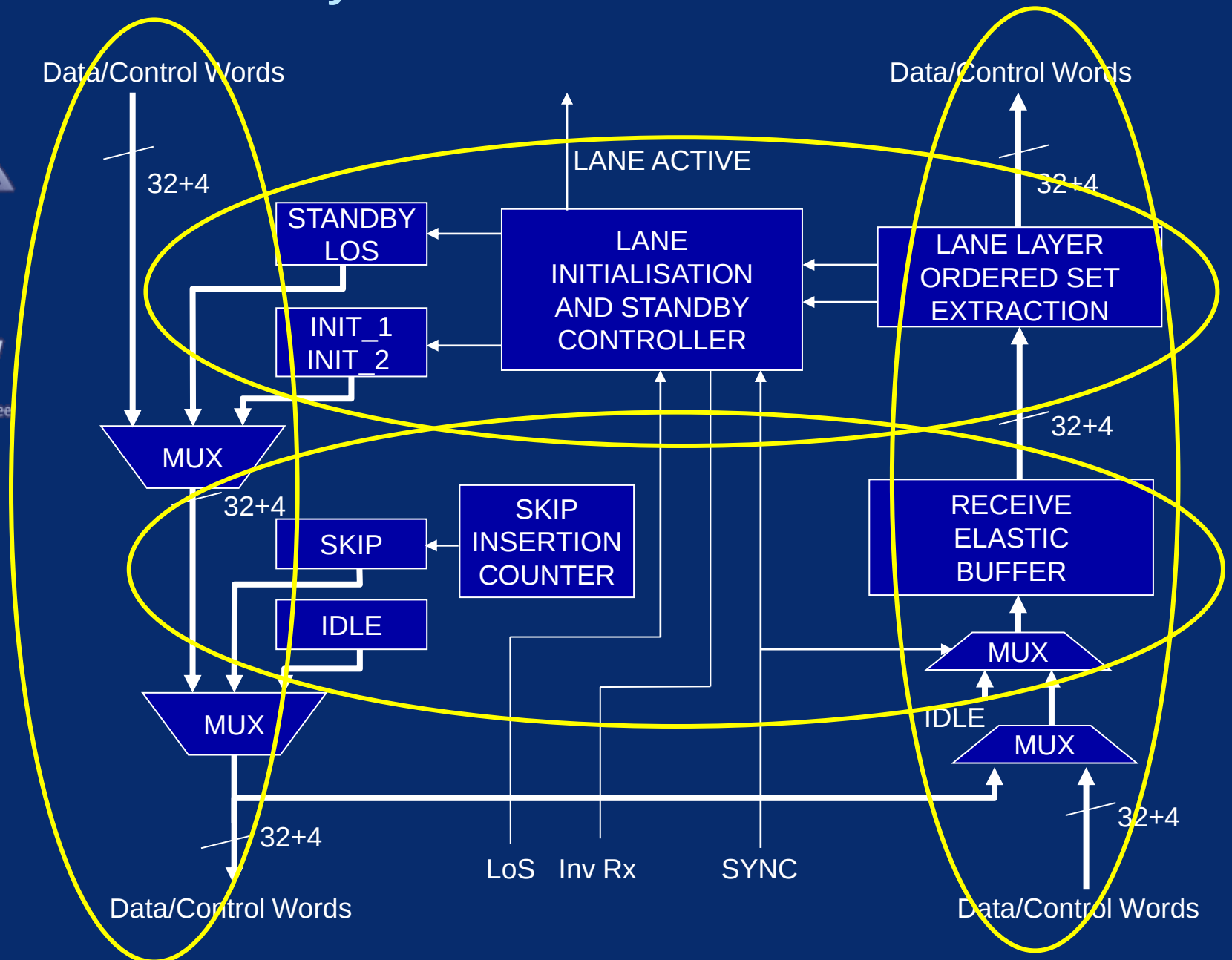
Lane Layer



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Lane Control-Words

- SKIP
  - Supports receive elastic buffer
  - Set every 5000 words
- IDLE
  - Sent when nothing else to send
- INIT1
  - Used for initialisation handshake
- INIT2
  - Used for initialisation handshake
- STANDBY
  - Sent to indicate about to go into Standby mode
- LOS
  - Sent to indicate receiver lost signal

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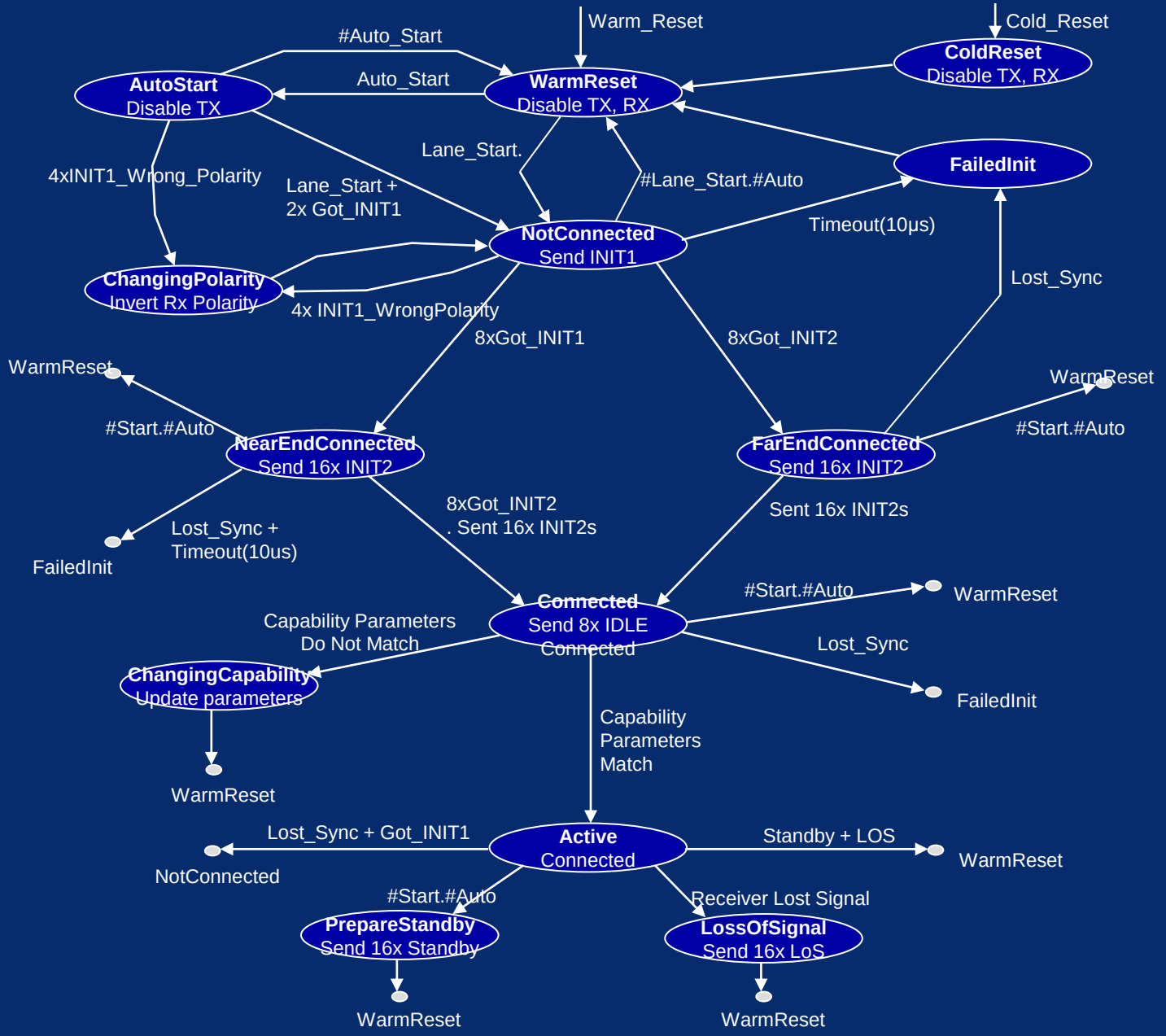
Precedence of frames and control words

- SKIP, highest precedence
- LoS
- Standby
- LSYNC
- ACK/NACK
- Broadcast frame
- FCT
- Data frame
- Idle frame
- IDLE, lowest precedence.

Lane Initialisation State Machine



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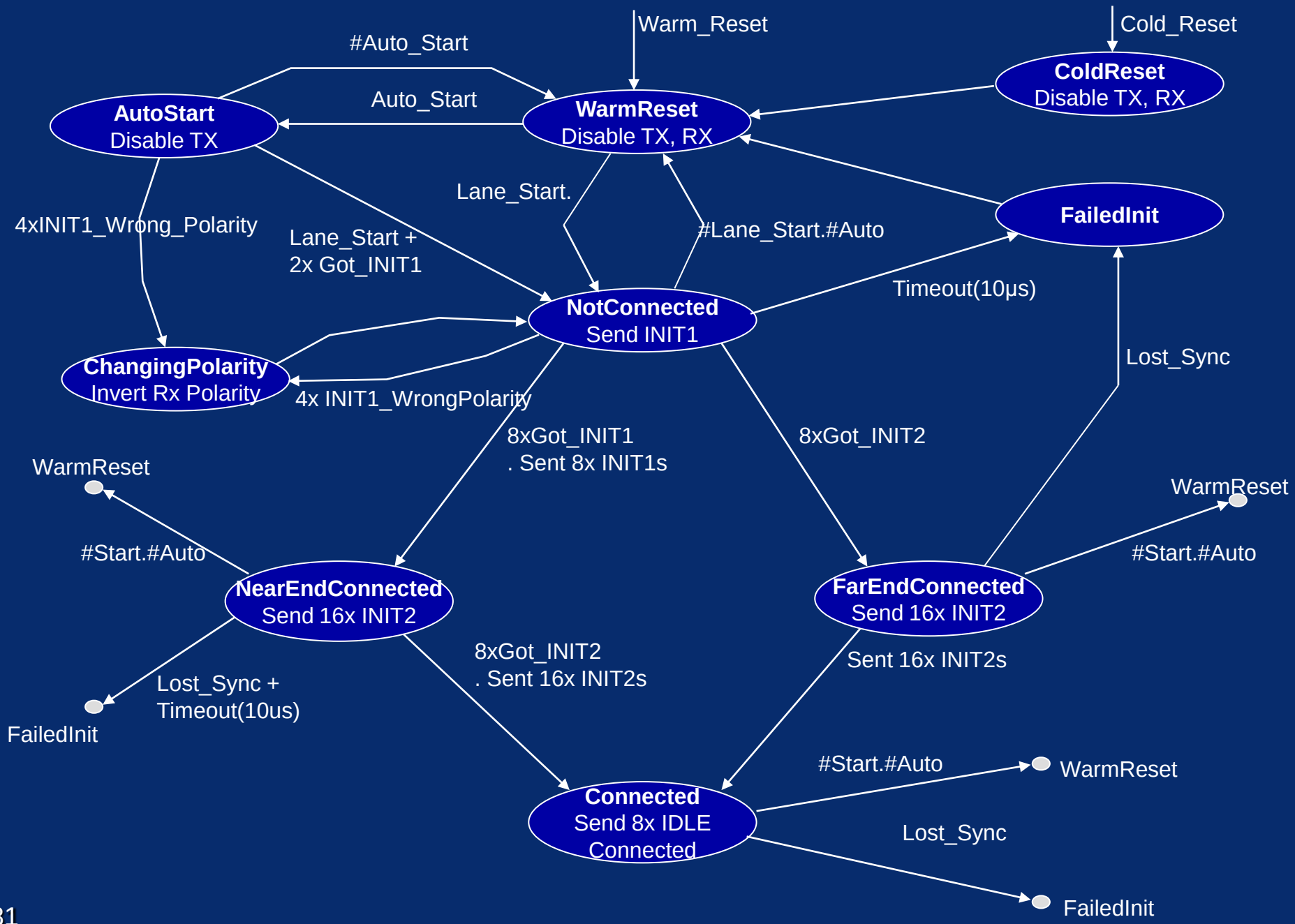
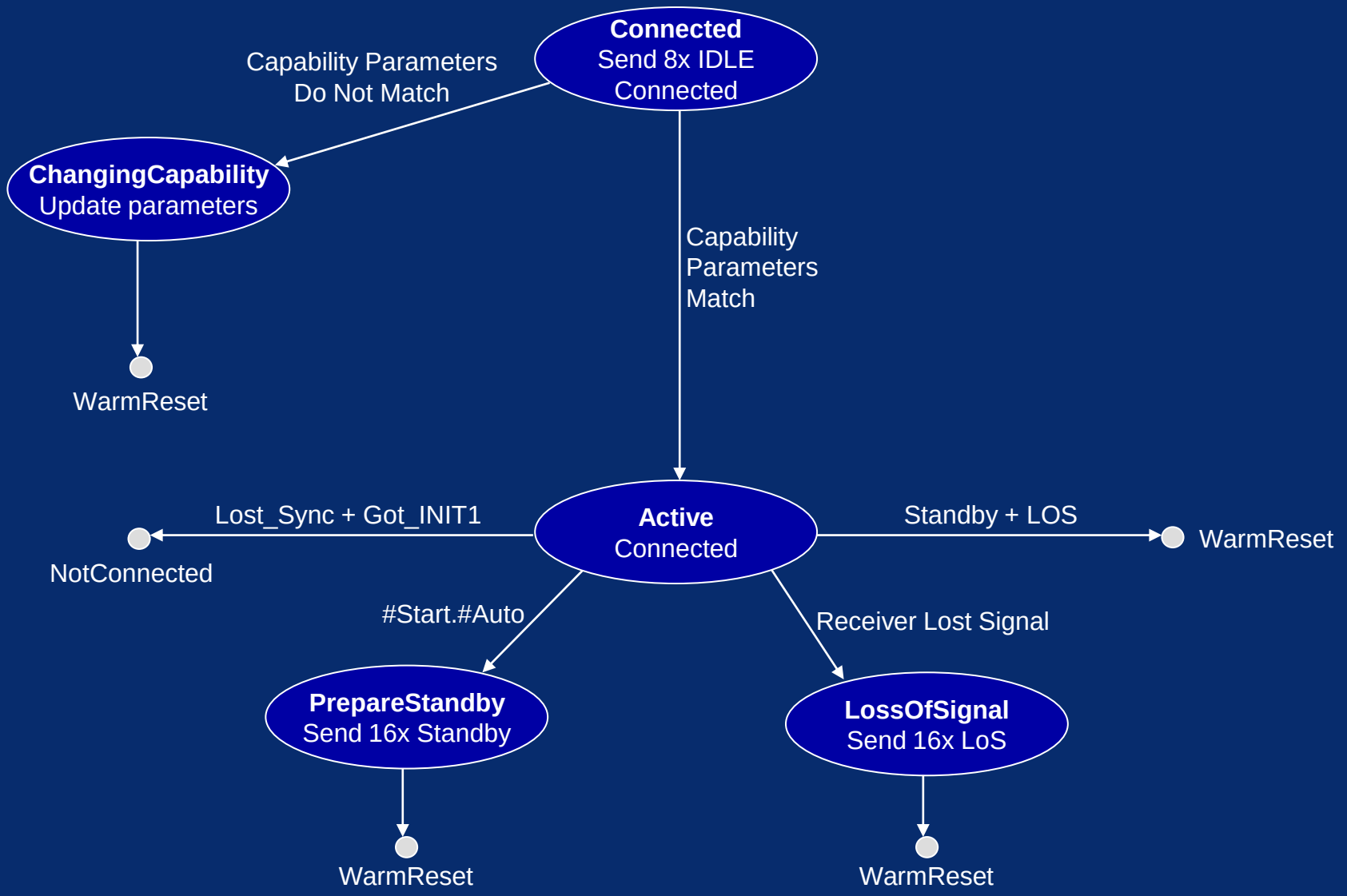
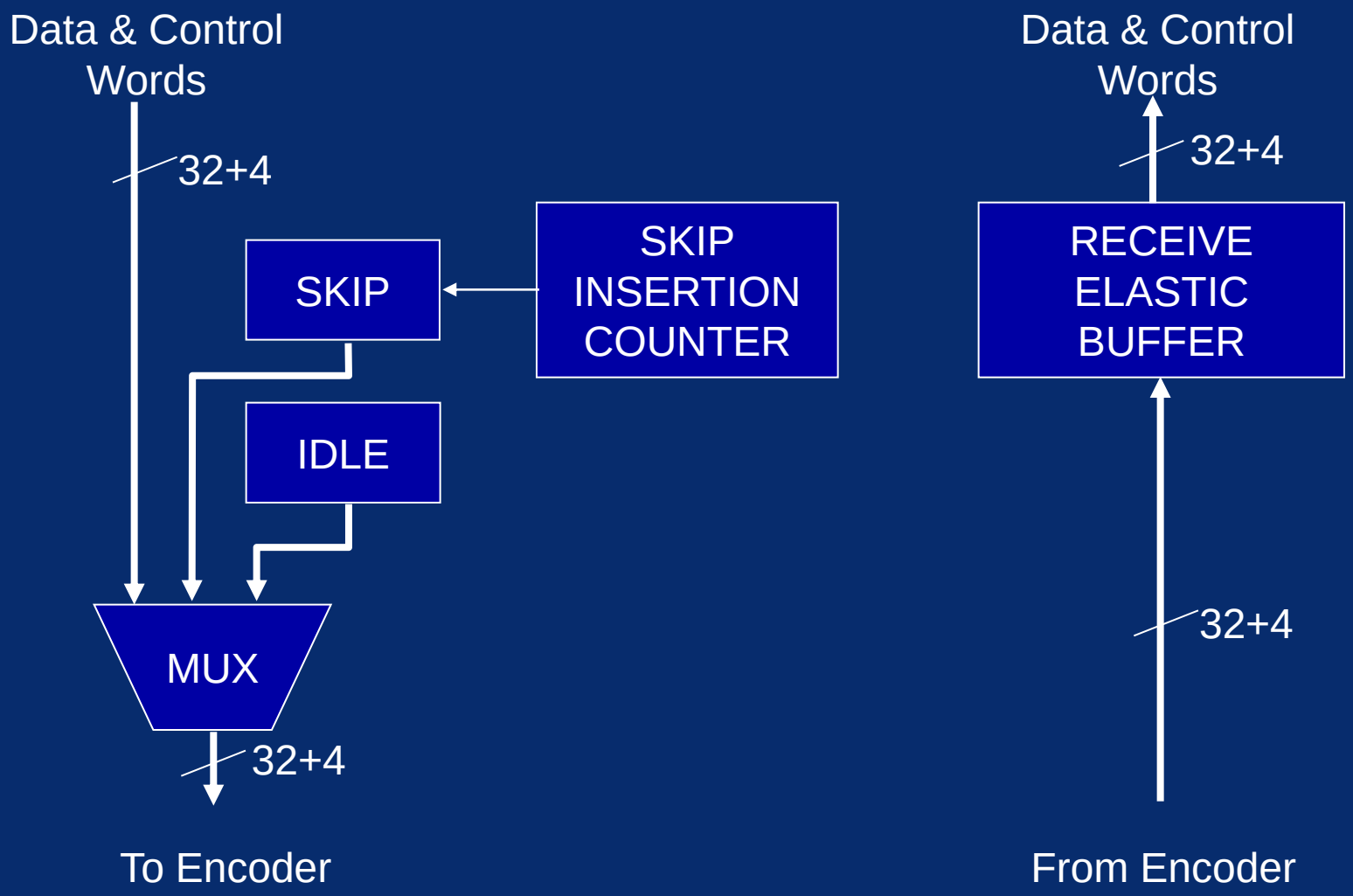
Lane Initialisation State Machine



Lane Initialisation State Machine



Data Rate Adjustment



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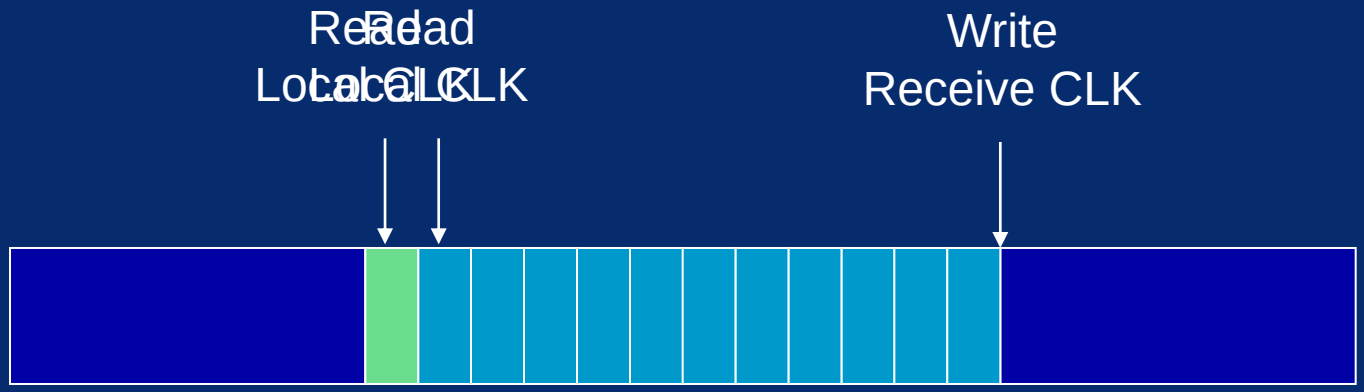
Receive Elastic Buffer

- Receive clock and system clock will be at slightly different frequencies
- Receive elastic buffer makes up for these differences



Nominal condition buffer half-full

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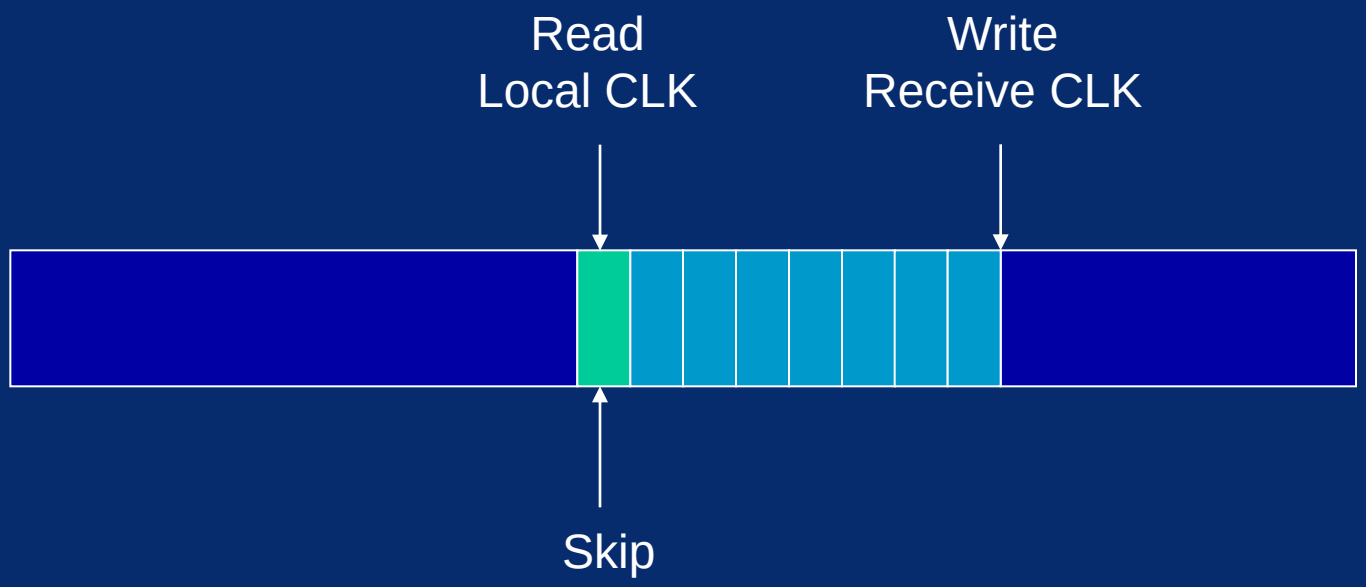
Receive Elastic Buffer

- When buffer less than half full
- Local CLK is faster than Receive CLK
- Skip characters are read but read pointer not incremented (once only)
- Effect is to add Skips to the buffer



Buffer less than half full (emptying)

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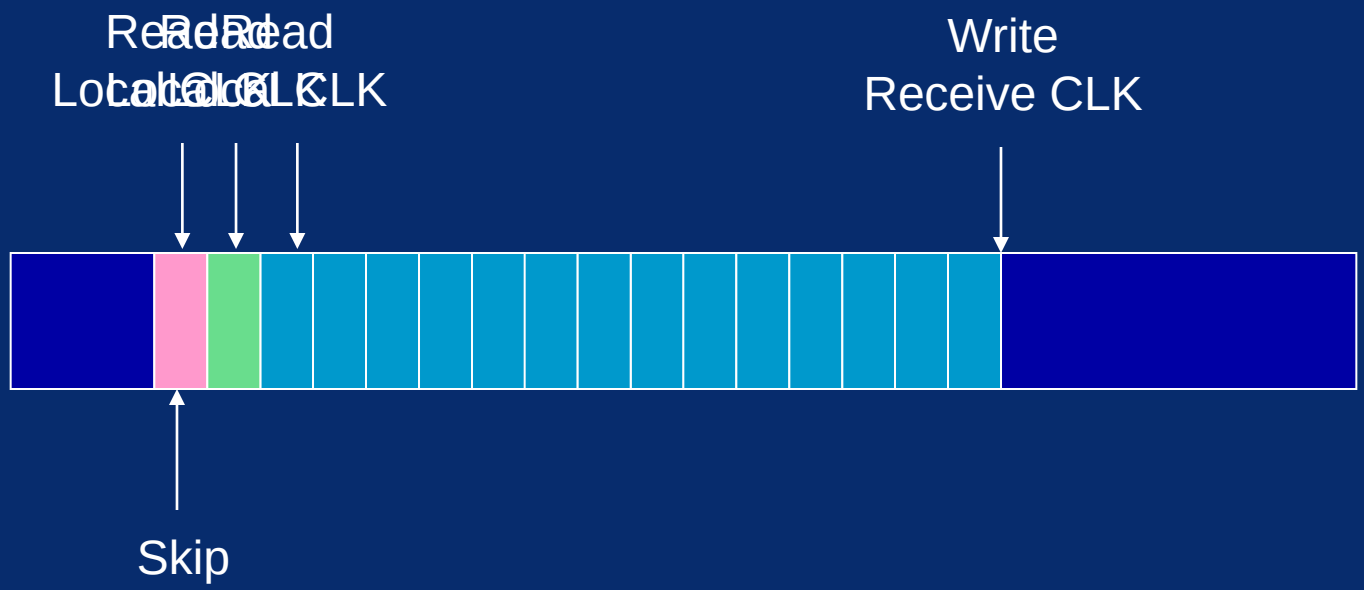
Receive Elastic Buffer

- When buffer more than half full
- Local CLK is slower than Receive CLK
- Skip characters are skipped: read pointer incremented past them
- Effect is to remove skips from buffer



Buffer more than half full (filling up)

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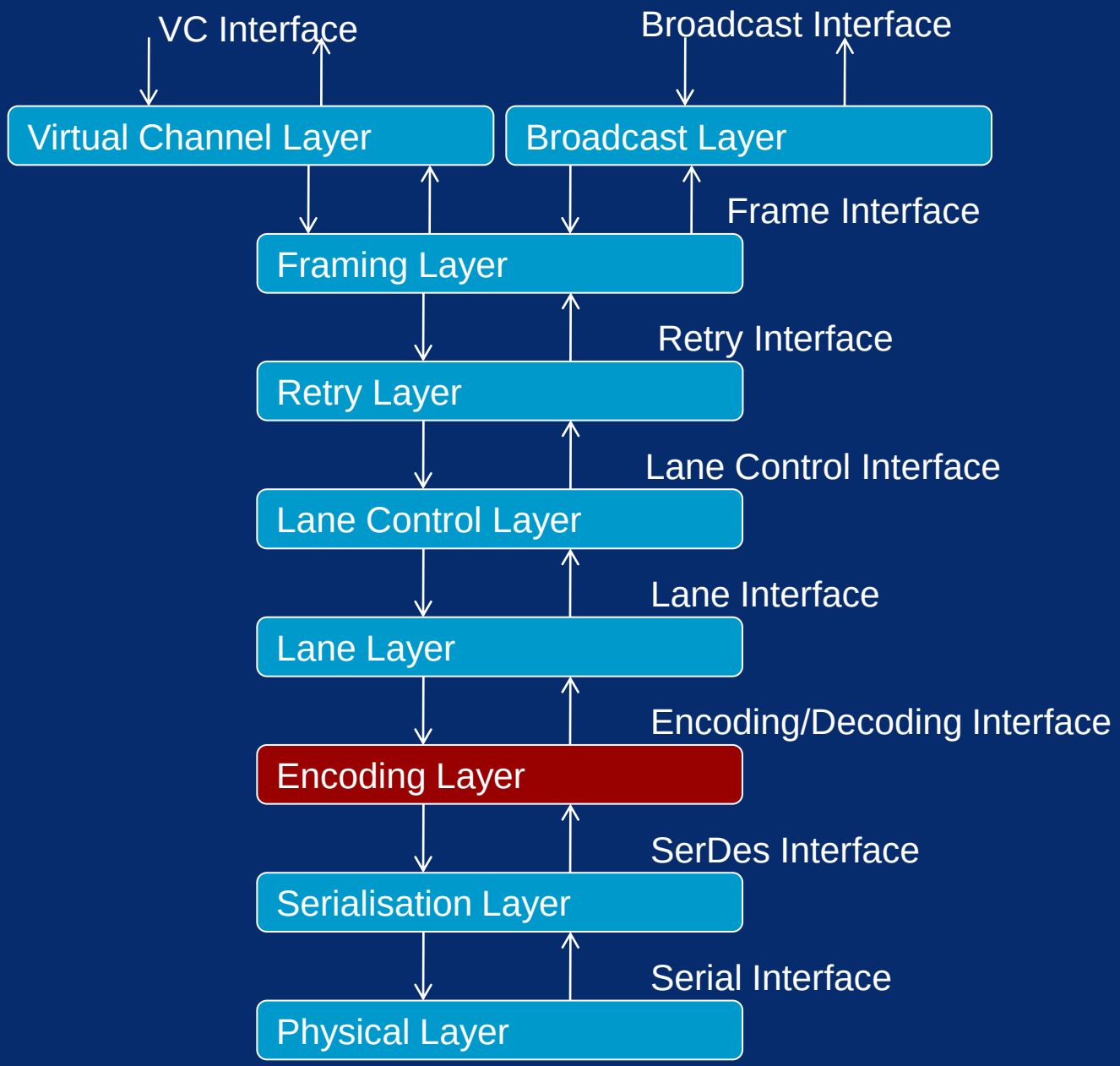
Receive Elastic Buffer

- Must ensure that there are sufficient Skips in the data stream
- So that they can be removed if necessary
- Frequency of Skips depends on:
  - Size of elastic buffer
  - Maximum frequency difference between
    - Local CLK: System clock at this end of link
    - Receive CLK: System clock at other end of link
    - One skip every 5000 data or control words

SpaceFibre Encoding Layer



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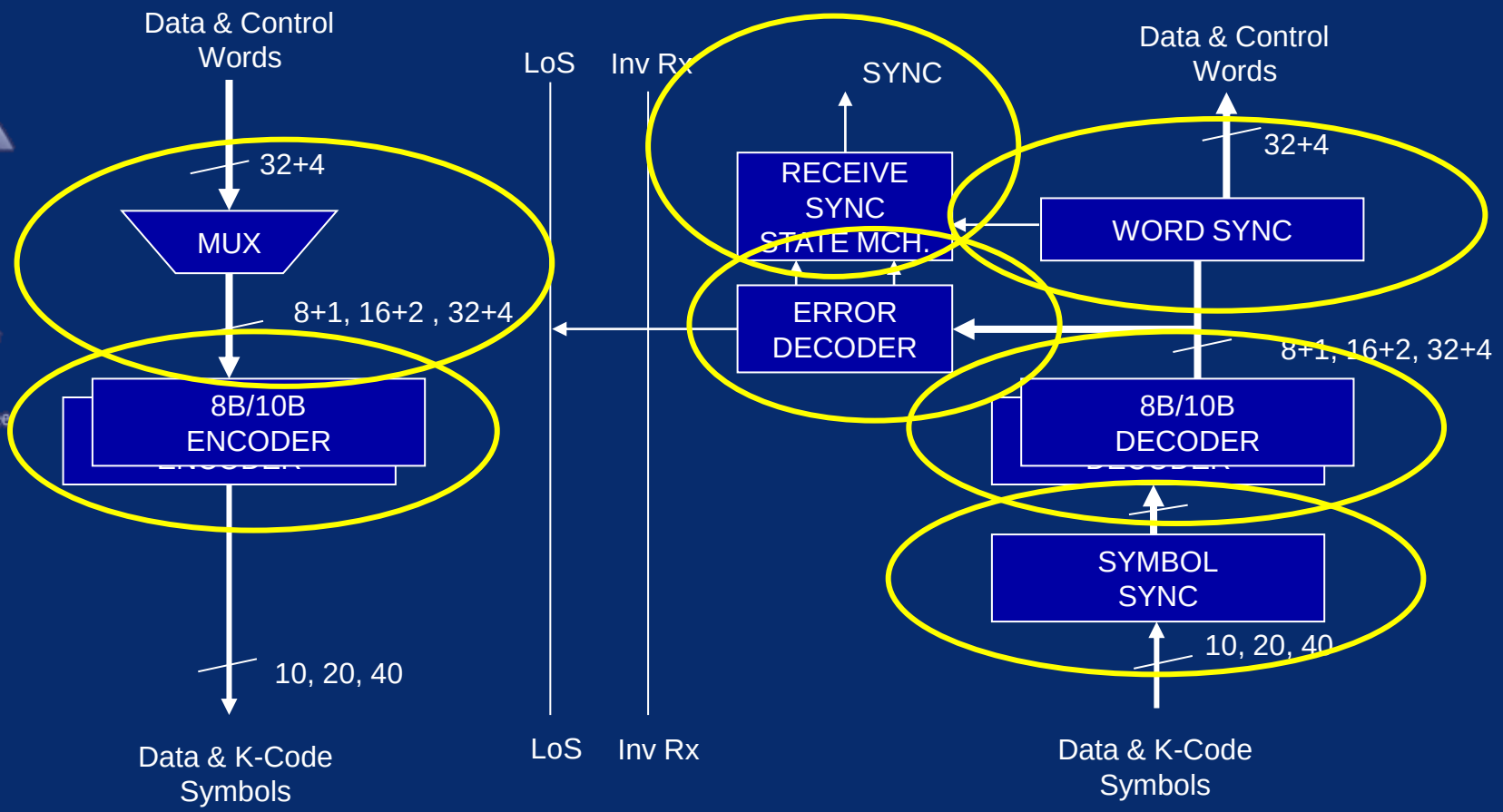
SpaceFibre Encoding Layer



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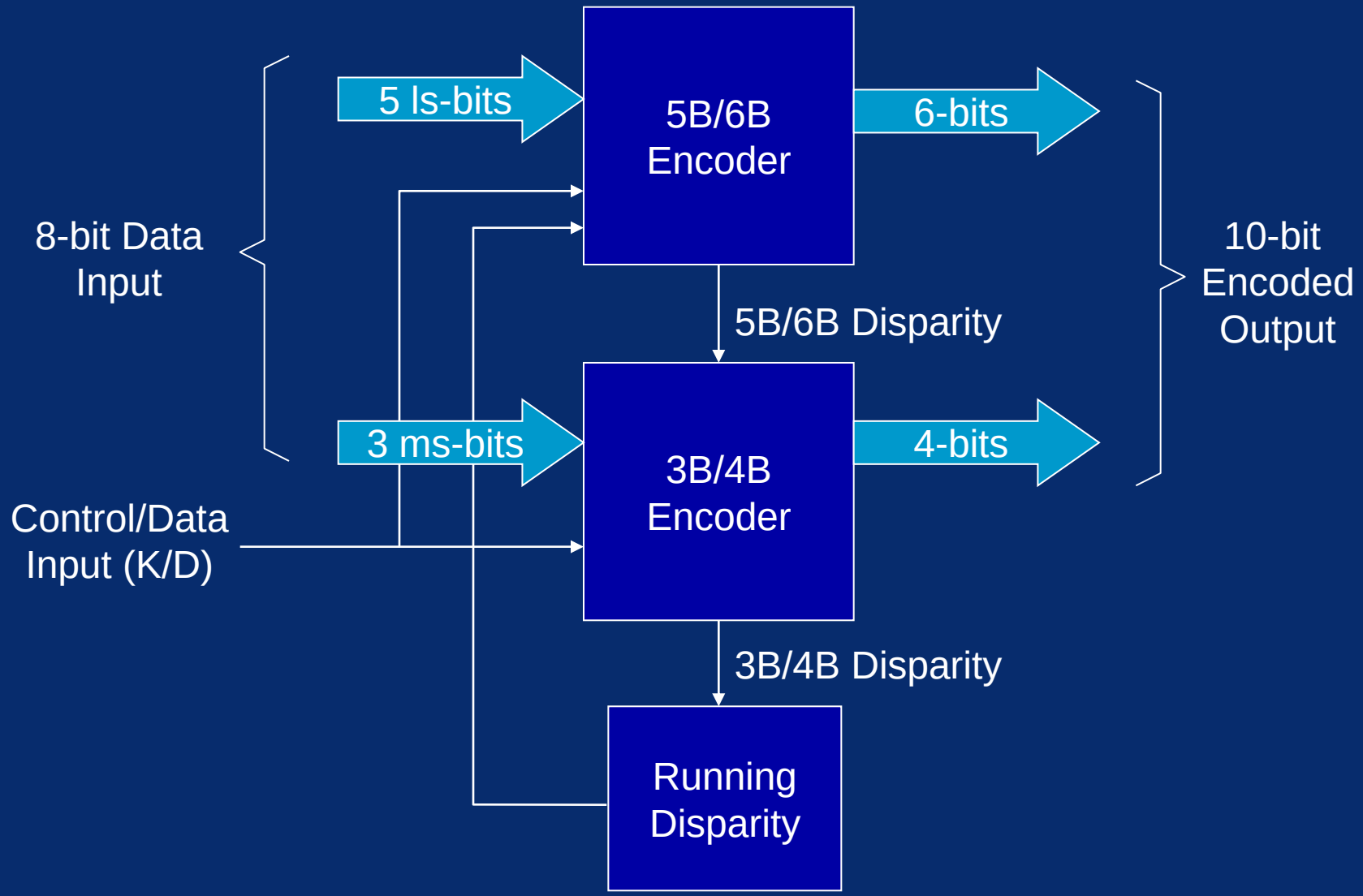
8B/10B Coding

- Zero DC bias:
  - same number of ones and zeros
- 10-bit symbols representing
  - 8-bit data codes
  - Some control codes, K-codes
  - Codes use
    - 5 ones and 5 zeros
    - 4 ones and 6 zeros
    - 6 ones and 4 zeros
  - Characters with different number of 1s and 0s have two possible codes to preserve DC bias

8B/10B Coding

- Ensures sufficient bit transitions for clock recovery
  - No more than 5 consecutive ones or zeros
- All characters encoded with 10-bits giving constant bit and character rates, simplifying transmitter and receiver
- Unused codes can be used to detect link errors

8B/10B Encoder



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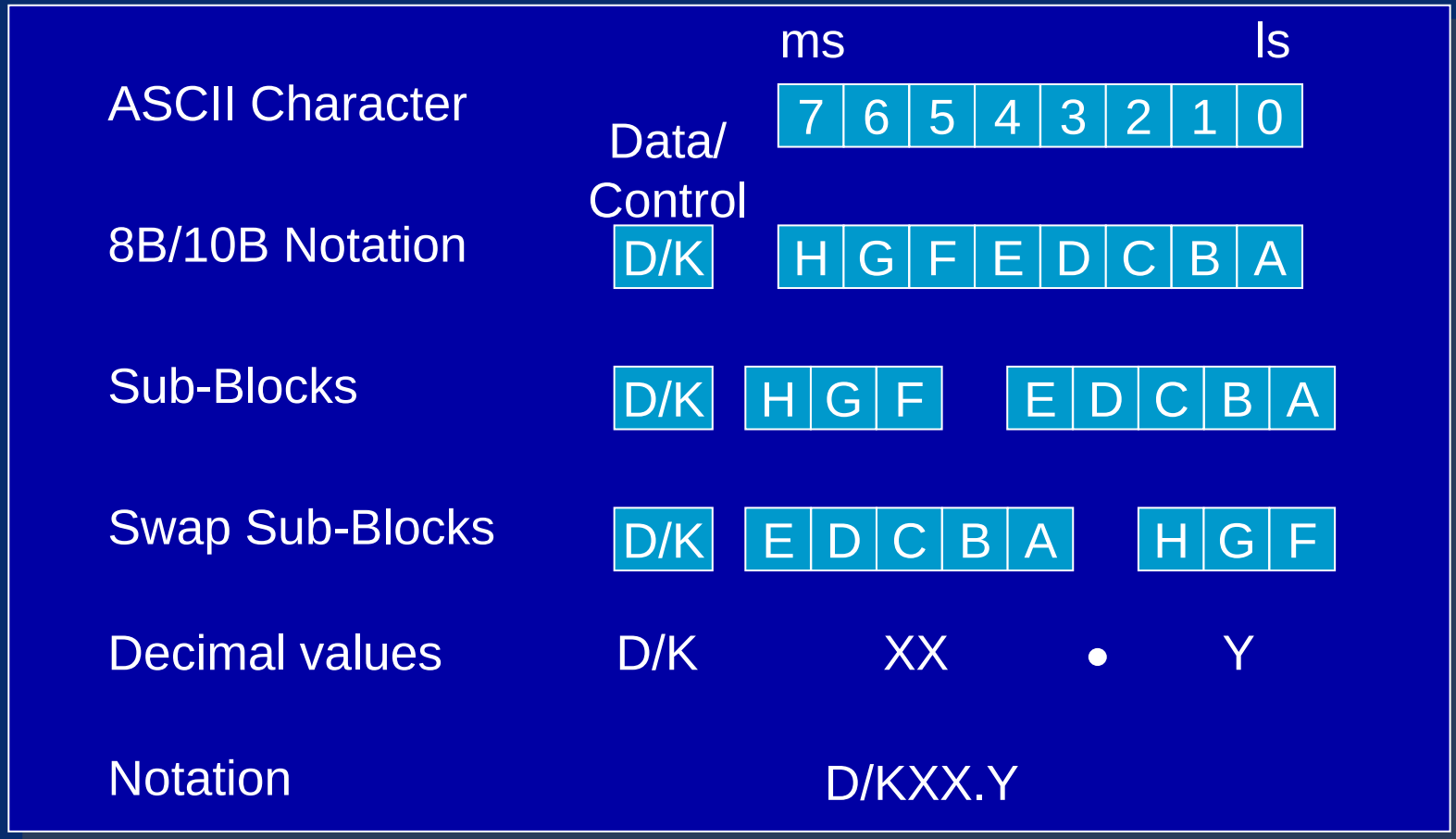
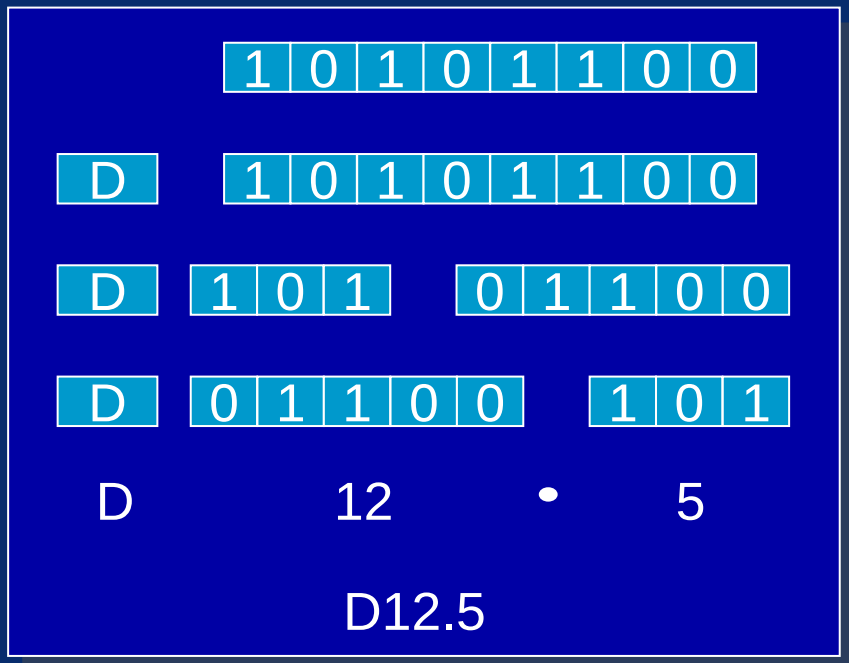
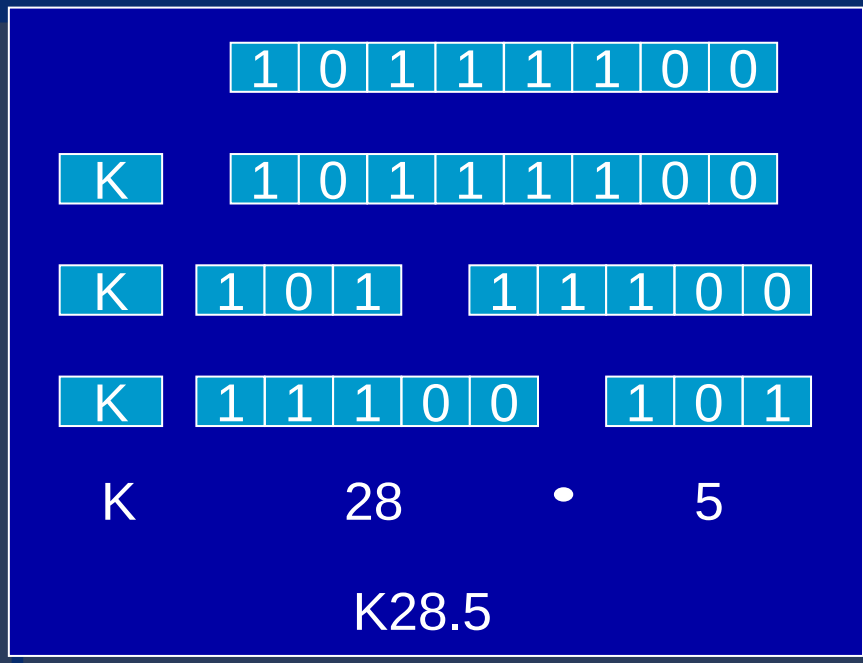
8B/10B Notation



8B/10B Notation Examples





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Part of 5B/6B Encoding Table

Input		Output	
Data Input	**Data bits 43210 (EDCBA)**	**Current Running Disparity -ve abcdei**	**Current Running Disparity +ve abcdei**
D00.y	00000	100111	011000
D01.y	00001	011101	100010
D02.y	00010	101101	010010
D03.y	00011	110001	
D04.y	00100	110101	001010
D05.y	00101	101001	
D06.y	00110	011001	
D07.y	00111	111000	000111
D08.y	01000	111001	000110
D09.y	01001	100101	
D10.y	01010	010101	

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3B/4B Encoding

Input		Output	
Data Input	**Data bits 765 (HGF)**	**3B/4B Disparity -ve fghj**	**3B/4B Disparity +ve fghj**
D/Kxx.0	000	1011	0100
Dxx.1	001	1001	
Kxx.1	001	0110	1001
Dxx.2	010	0101	
Kxx.2	010	1010	0101
D/Kxx.3	011	1100	0011
D/Kxx.4	100	1101	0010
Dxx.5	101	1010	
Kxx.5	101	0101	1010
Dxx.6	110	0110	
Kxx.6	110	1001	0110
Dxx.7	111	1110/0111	0001/1000
Kxx.7	111	0111	1000

8B/10B Control (K) Codes

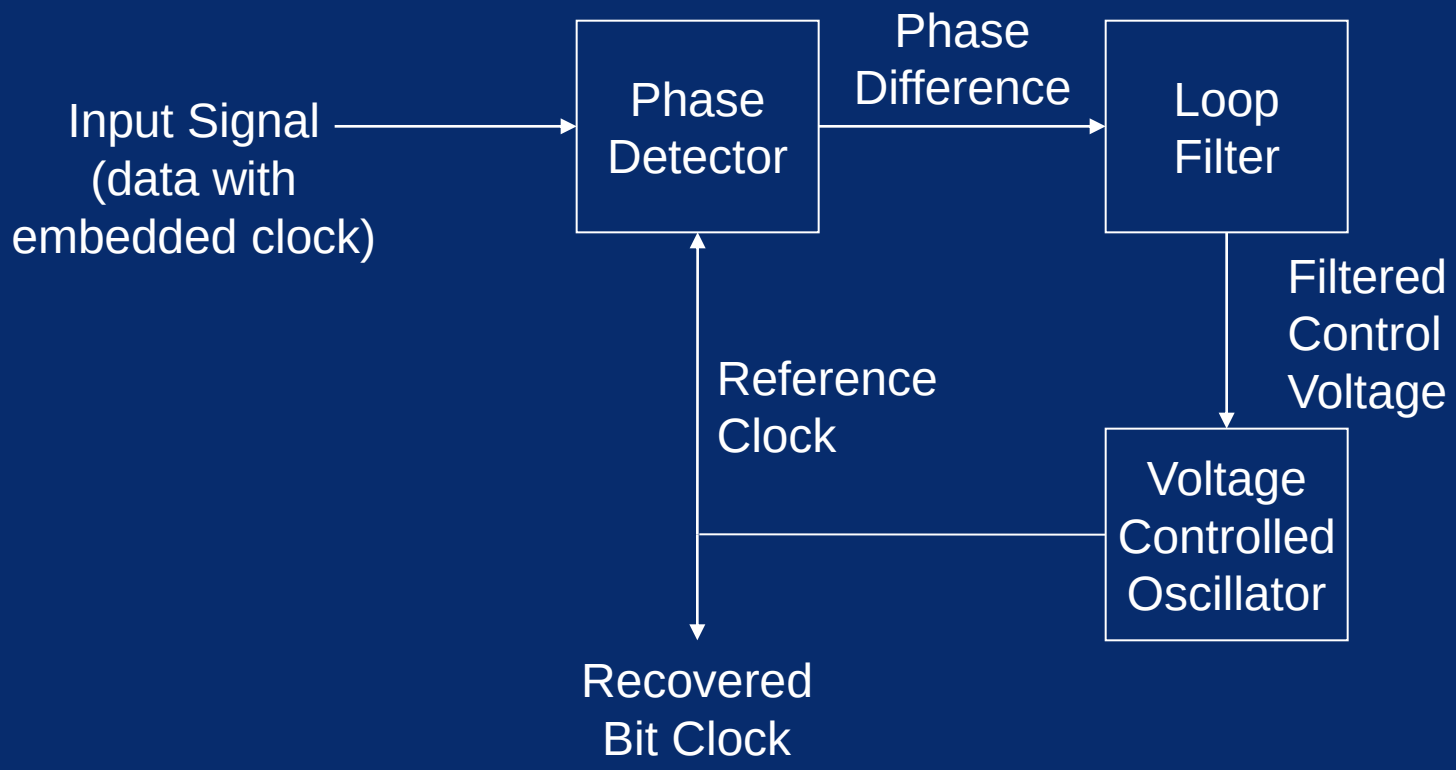
Input	Output	
Special Character Name	Current Running Disparity -ve	Current Running Disparity +ve
K28.0	001111 0100	110000 1011
K28.1	001111 1001	110000 0110
K28.2	001111 0101	110000 1010
K28.3	001111 0011	110000 1100
K28.4	001111 0010	110000 1101
K28.5	001111 1010	110000 0101
K28.6	001111 0110	110000 1001
K28.7	001111 1000	110000 0111
K23.7	111010 1000	000101 0111
K27.7	110110 1000	001001 0111
K29.7	101110 1000	010001 0111
K30.7	011110 1000	100001 0111

SpaceFibre Synchronisation

- Bit synchronisation
  - Extracting bits from receiver output
- Symbol synchronisation
  - Extracting symbols from the bit stream
- Word synchronisation
  - Extracting words from the symbol stream
- Lane synchronisation
  - Combining words from several lanes into data stream
- Frame synchronisation
  - Data frames
  - Broadcast frames
  - Idle frames

Bit Synchronisation

- Receive Clock Recovery



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Symbol synchronisation

- 8B/10B Comma Pattern
  - Three control codes contain a unique 7-bit pattern
  - 0011111 or 1100000
  - Does not occur in data codes
  - Cannot be produced by combining any data code or other control code
  - Pattern is known as the comma pattern
  - Widely used for character synchronisation

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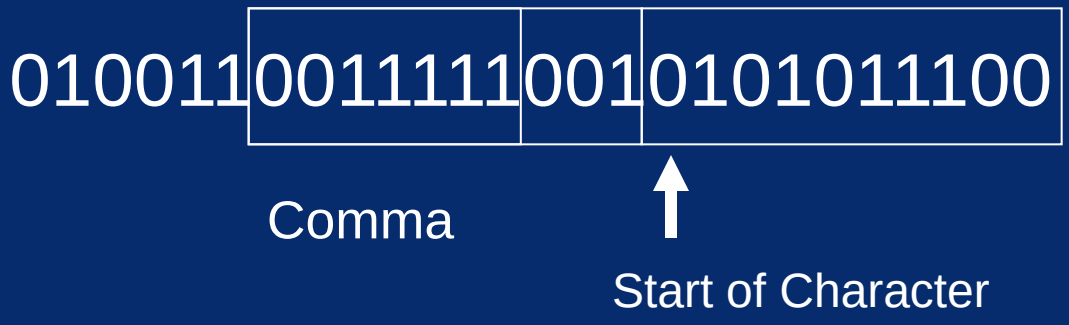
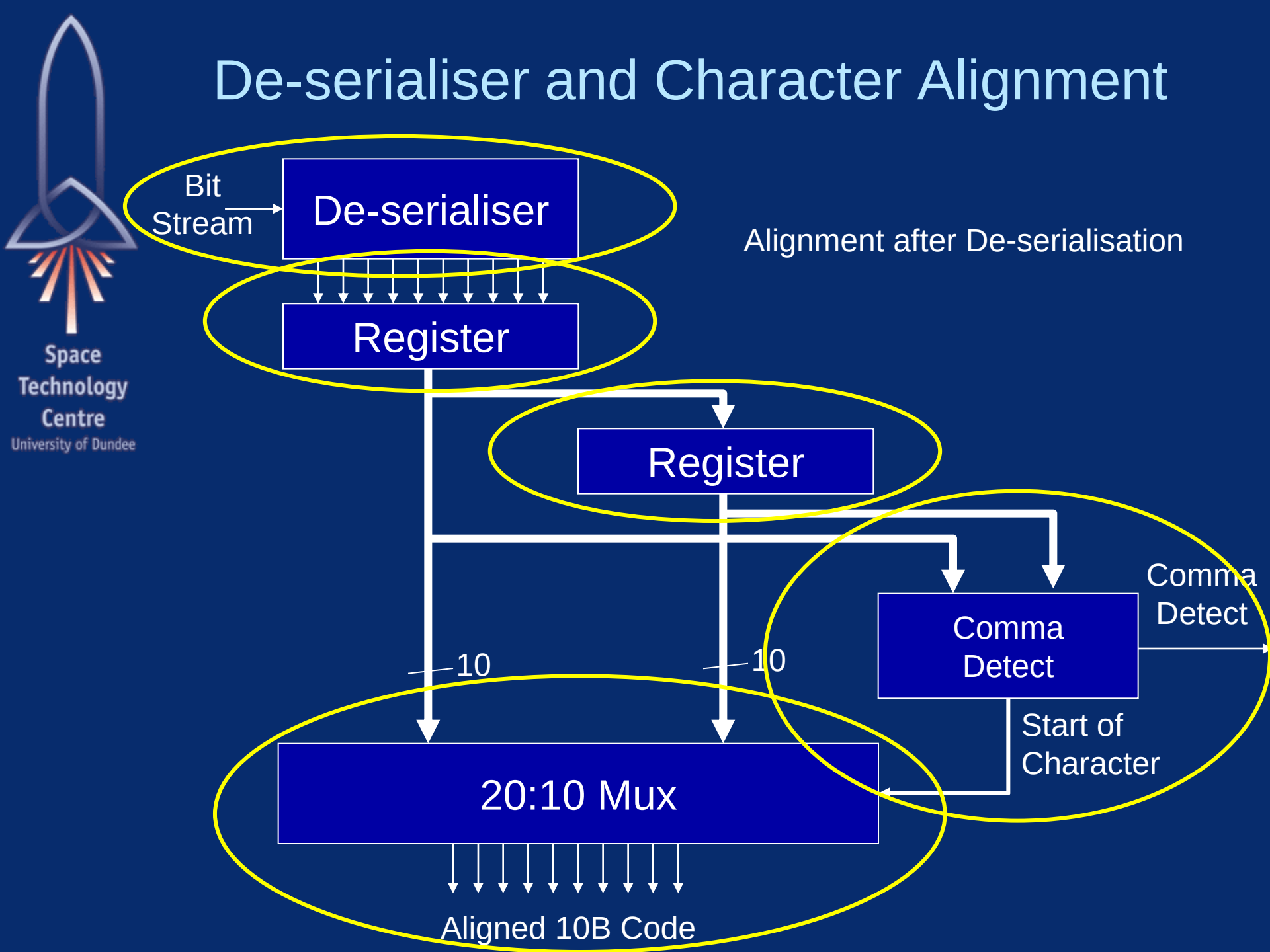
Symbol synchronisation

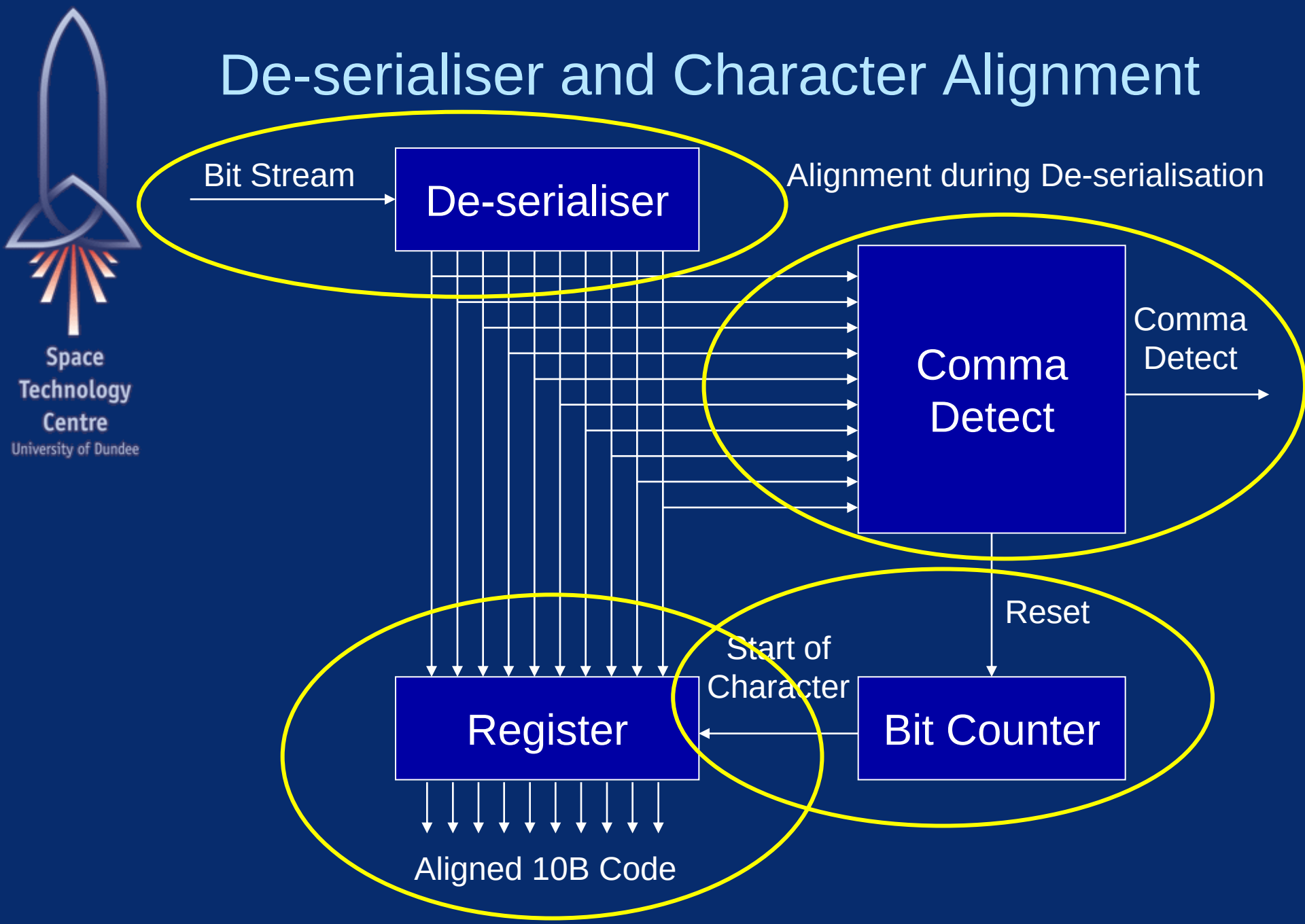
- Commas
  - Used to detect the character boundaries in the serial bit stream
  - Contain unique seven bit sequences
- Plus Comma
  - 0011111
- Negative Comma
  - 1100000
- Example



De-serialiser and Character Alignment



De-serialiser and Character Alignment



Receive Synchronisation State Machine

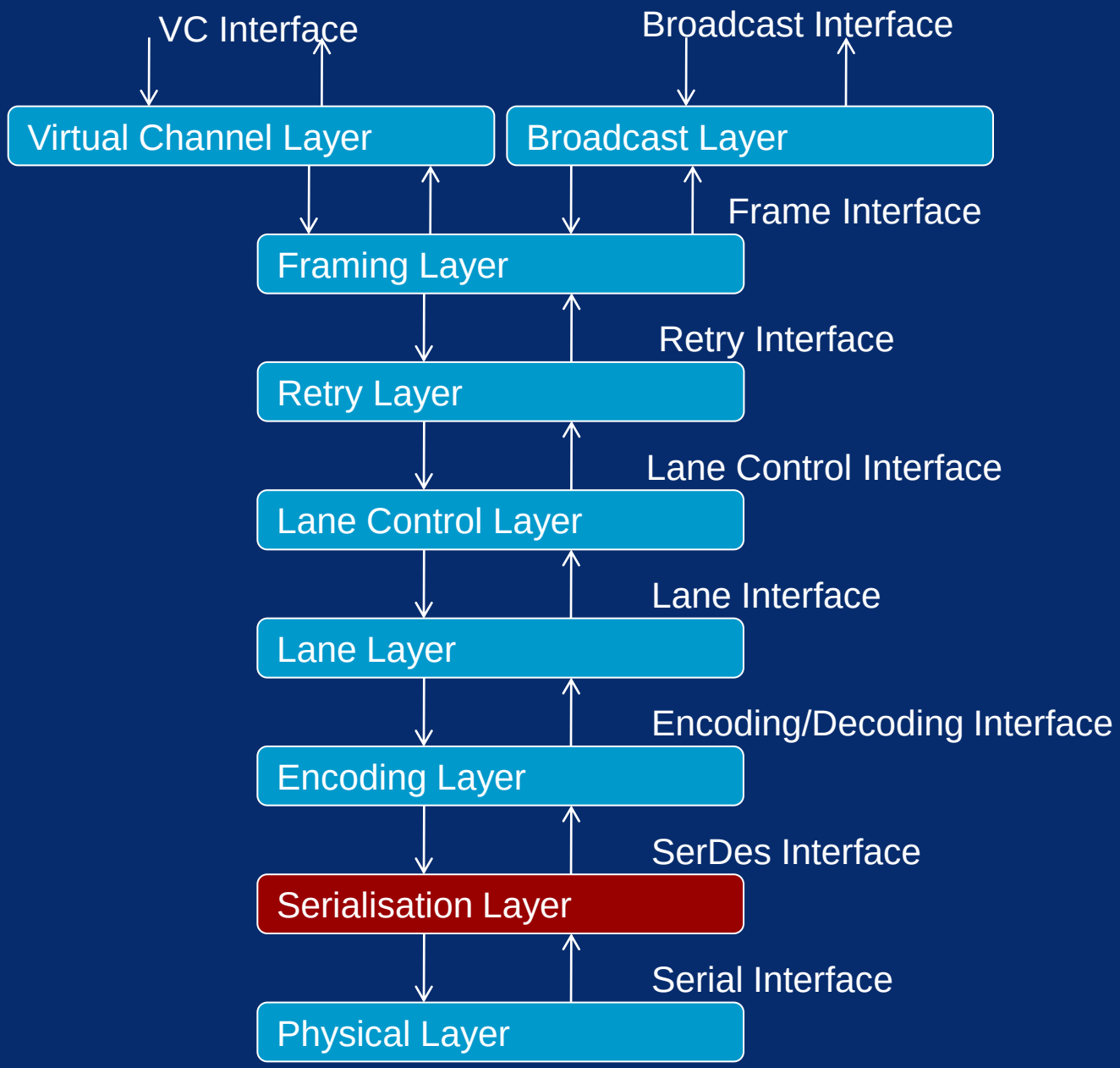
RX error = disparity or invalid symbol error

Word realignment = word synchronisation lost (i.e. comma in position other than LS byte)

Word Synchronisation

- Comma is least significant symbol in word
  - Synchronise word accordingly
- INIT1 and INIT2 start with commas
- Ensures symbol and word synchronisation
  - During initialisation
  - After error, during re-initialisation
- Comma used at start of frames
  - Helps to ensure synchronisation
  - Immediately prior to data transfer

SpaceFibre Serialisation Layer



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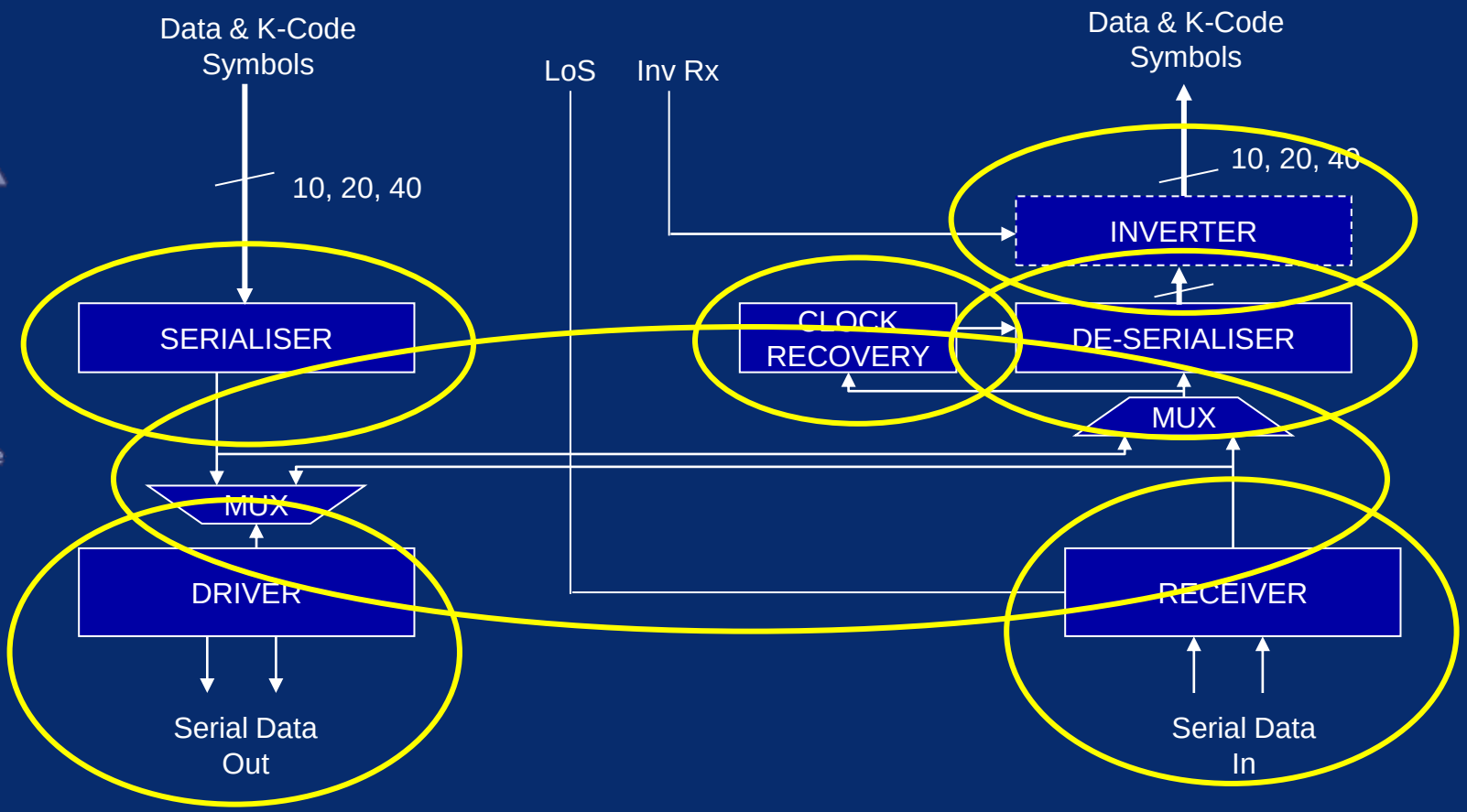
SpaceFibre Serialisation Layer



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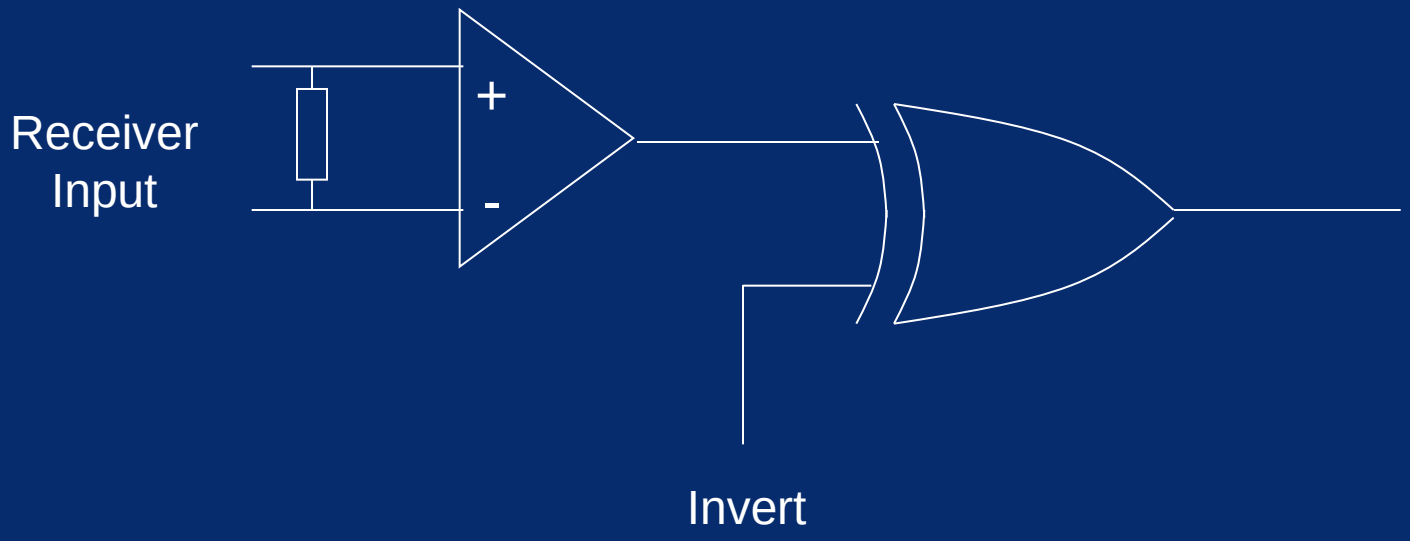
Polarity Inversion

- Changing receive polarity
  - To simplify high-speed PCB layout
    - And improve signal integrity
  - Include change of polarity on receiver input
  - Detect polarity
  - Swap polarity if required



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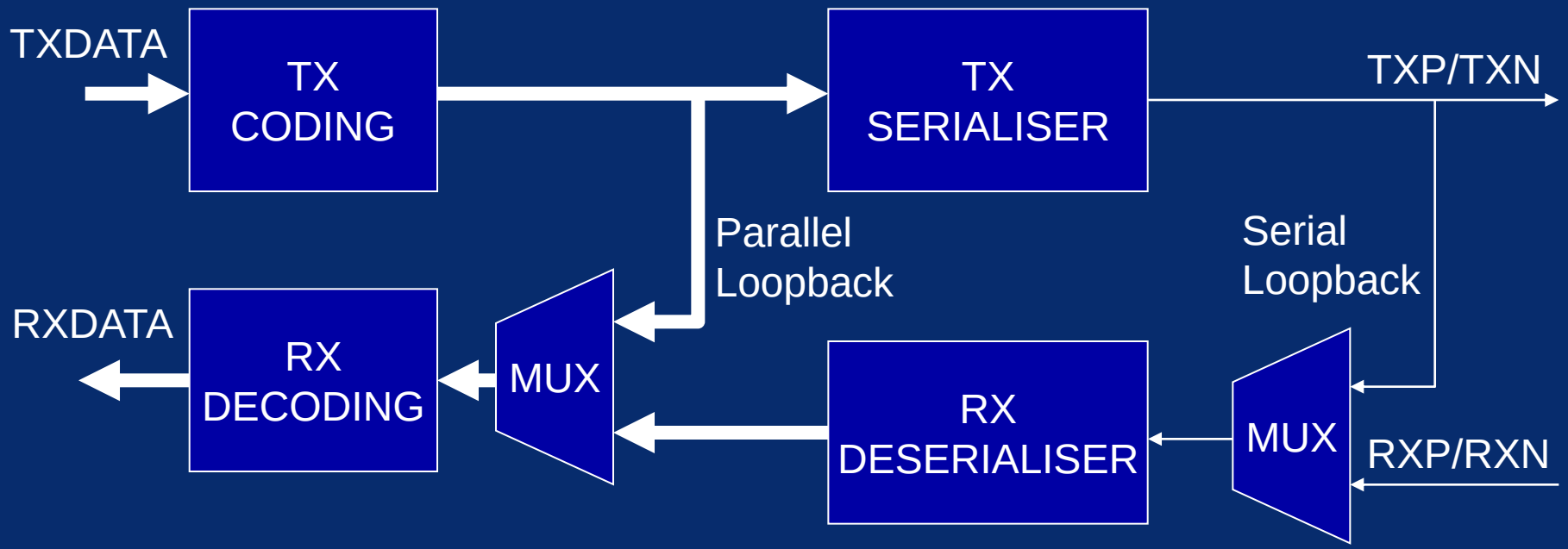
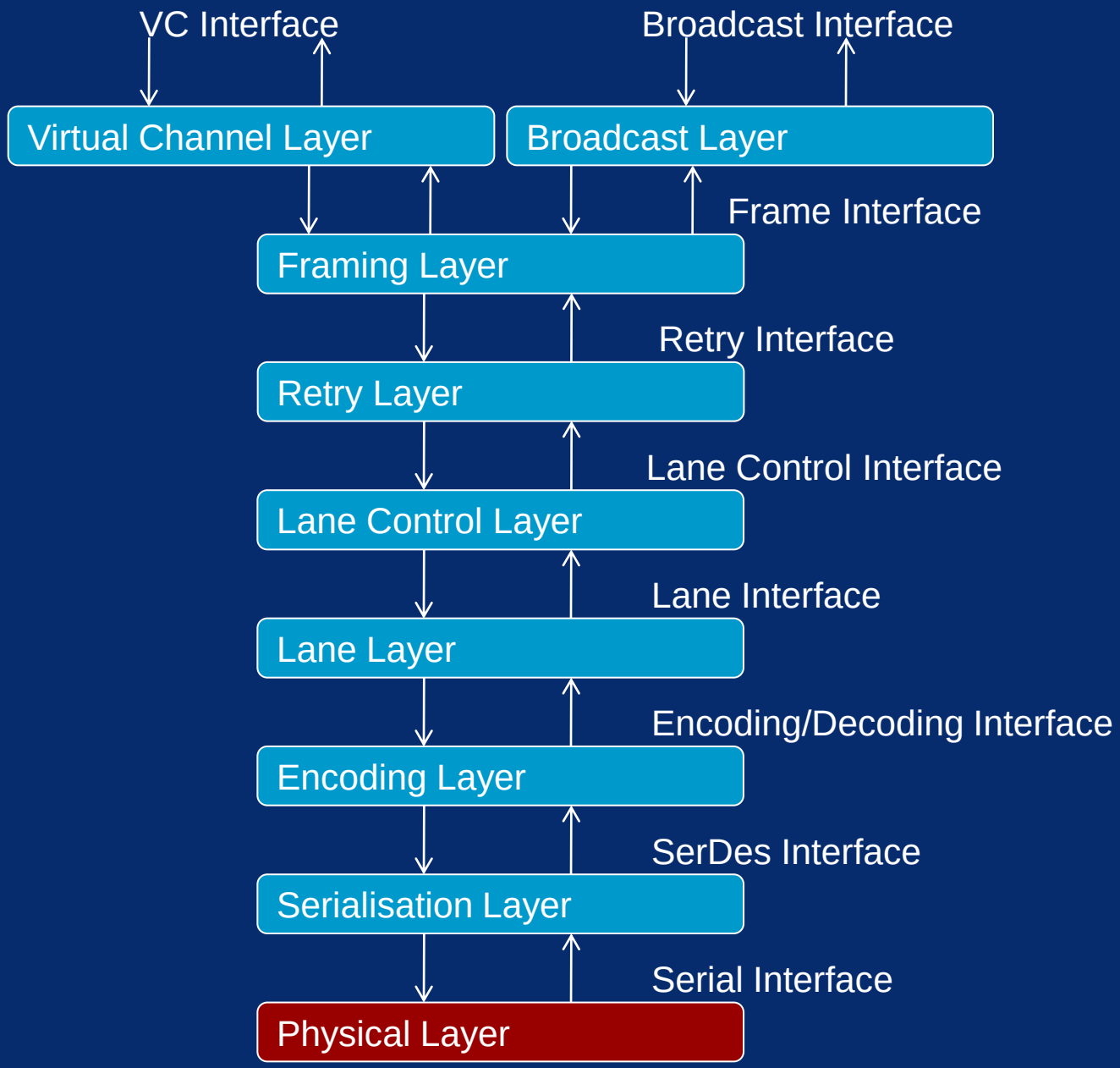
Loopback

- Normal operation
- Internal parallel loopback
- Internal serial loopback



SpaceFibre Physical Layer



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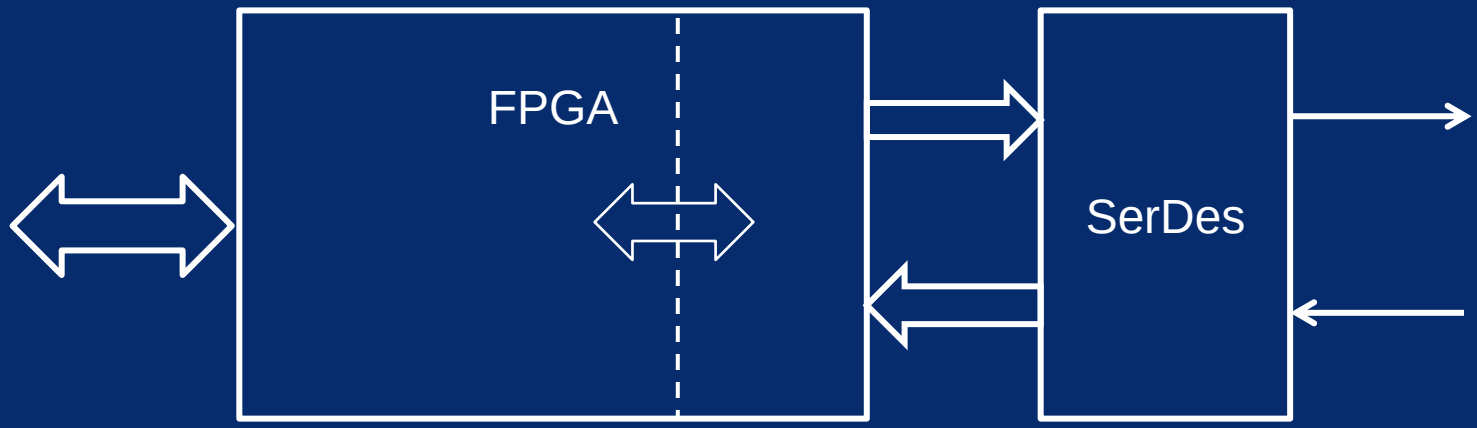
Physical Layer

- Required characteristics specified
  - Drivers/Receivers
  - Line
  - Cable
  - Connectors
- Different physical layers
  - Copper
    - CML
    - LVDS up to 1 Gbit/s operation
  - Fibre
    - Optical fibre
    - 100 m or more

Spaceflight Implementation

- How can we implement this today
  - For flight applications
  - Avoiding several years of chip development and qualification effort?
- Difficult bit is the SerDes
  - Runs at high speed
  - Requires analogue phase-locked loop
- Solution: use existing radiation tolerant SerDes and FPGA
- Possibly Xilinx if the MGTs are radiation tolerant?

Flight Implementation



Application Logic

Encoding

Link Control

Lane Control

Retry

Framing

Virtual Channels

Broadcast Channel

Serialisation

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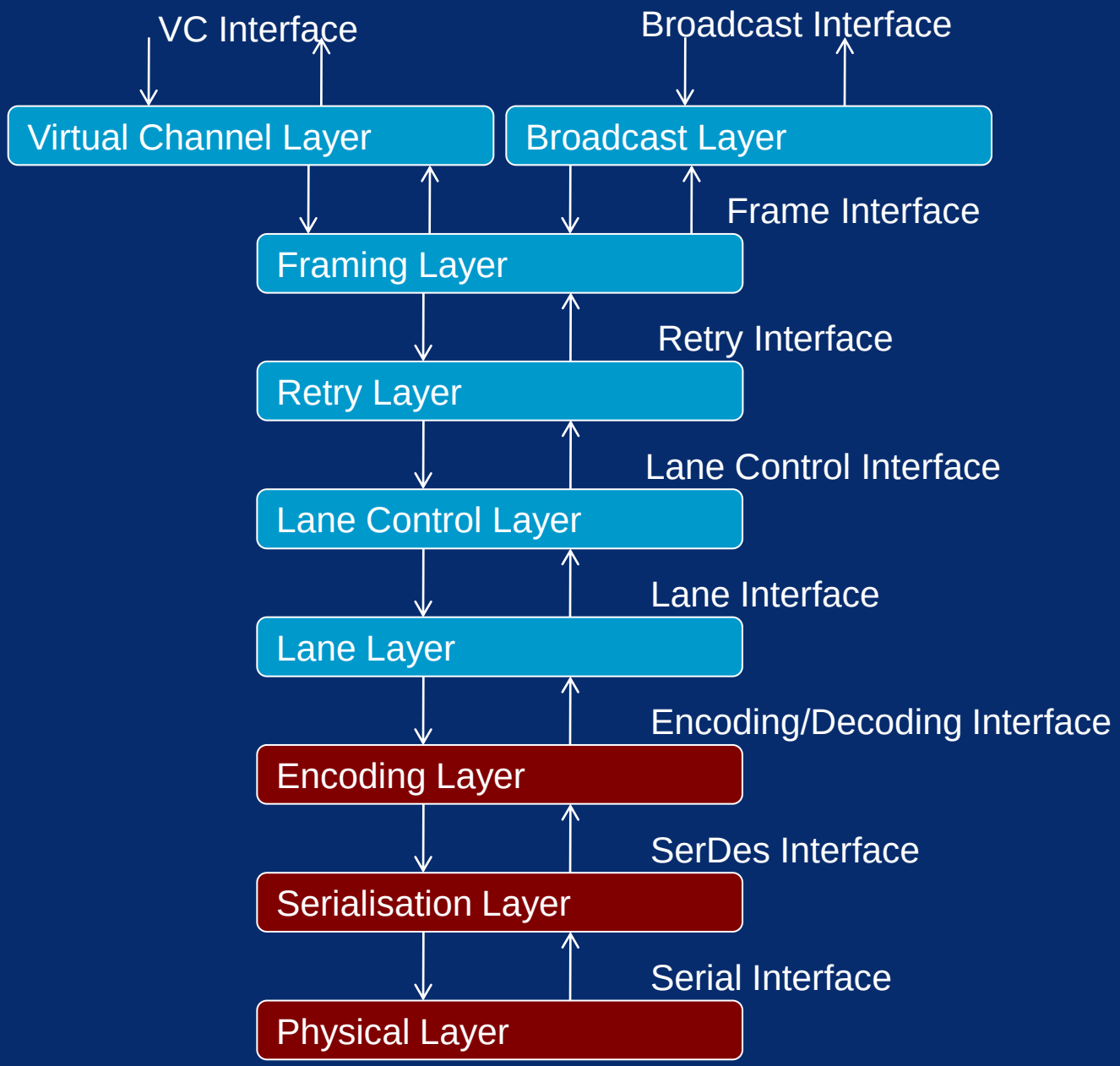
TLK2711-SP

- TLK2711-SP
  - Radiation tolerant SerDes
  - Includes 8B/10B encoder/decoder
  - Runs at 2.5 Gbits/s
    - 2 Gbit/s actual data rate
  - Combined with a radiation tolerant FPGA
  - Can be used to implement radiation tolerant SpaceFibre interface
- Problem: incompatible with draft SpaceFibre standard!
- SpaceFibre specification modified to be able to use this device
- Also possible to use other SerDes devices

SpaceFibre and TLK2711-SP



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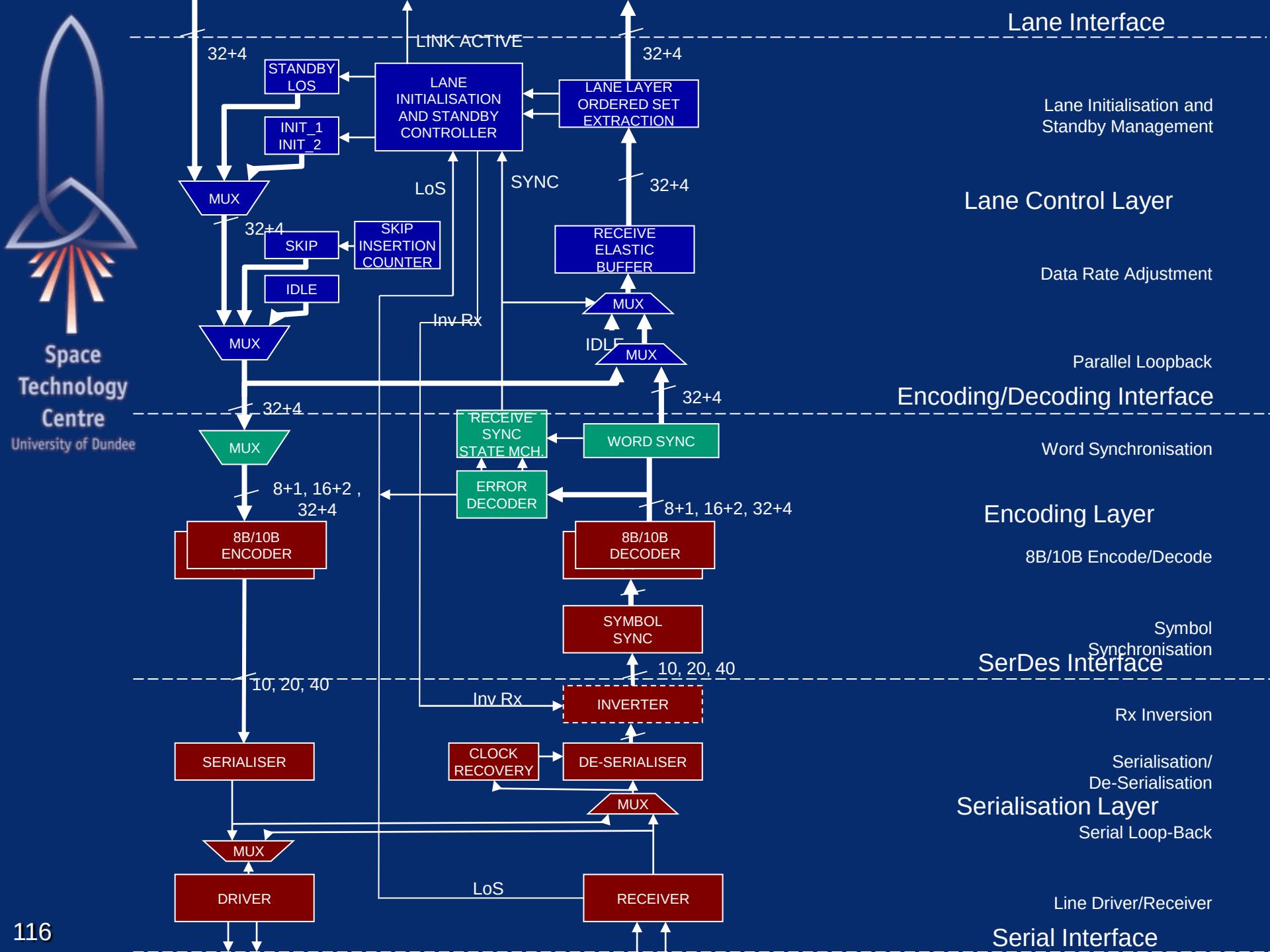

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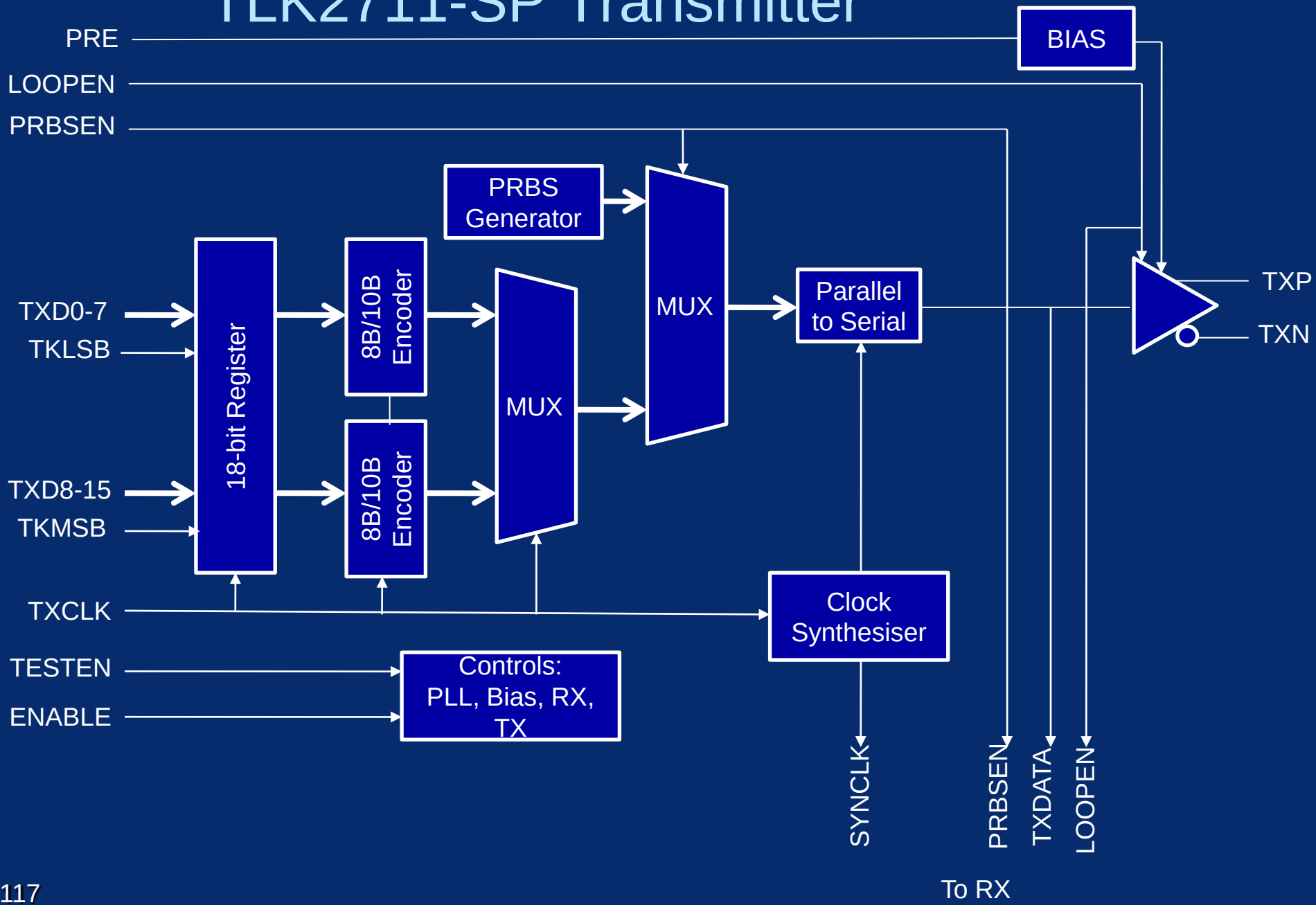
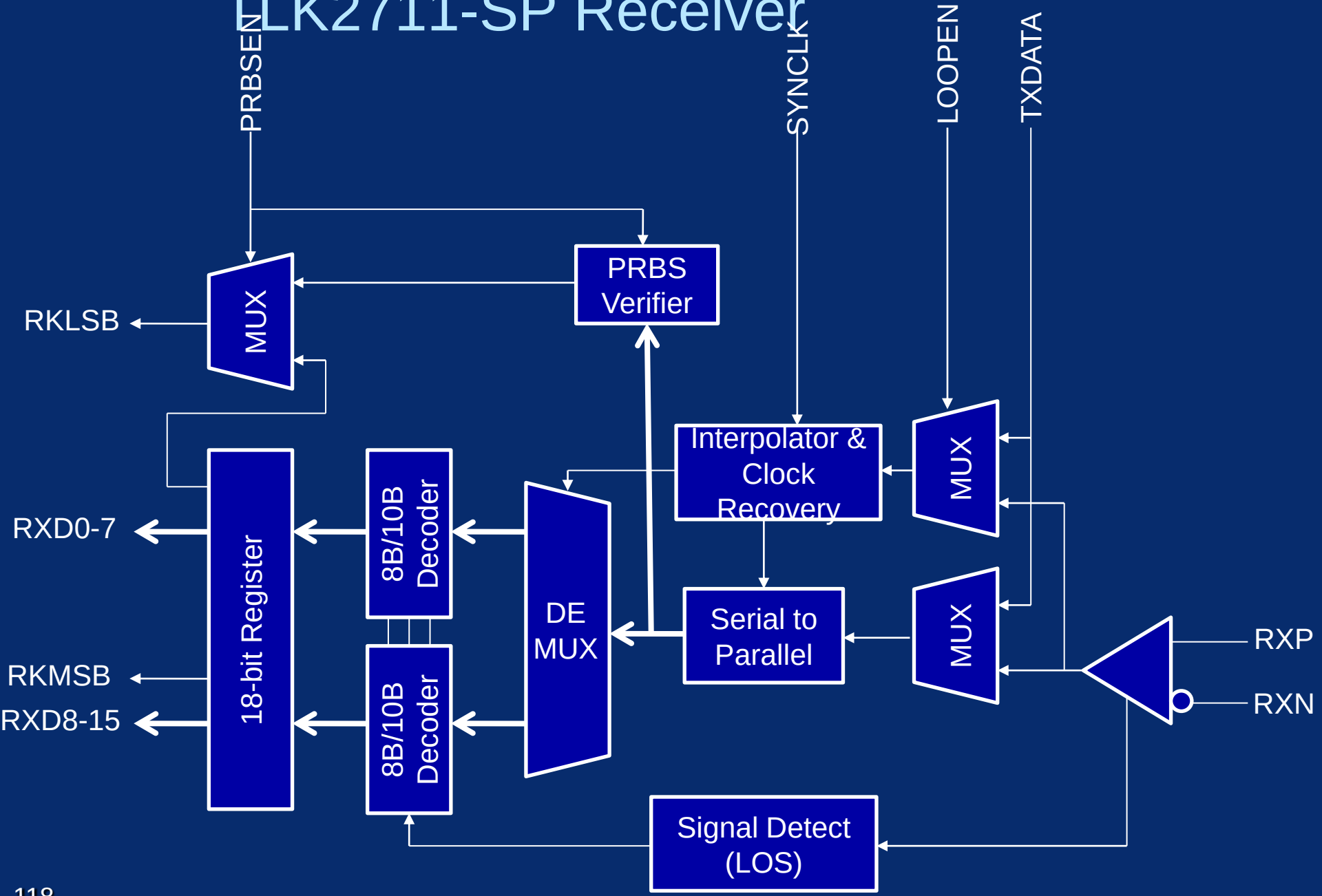
TLK2711-SP Transmitter



TLK2711-SP Receiver



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TLK2711 Compatibility with SpaceFibre

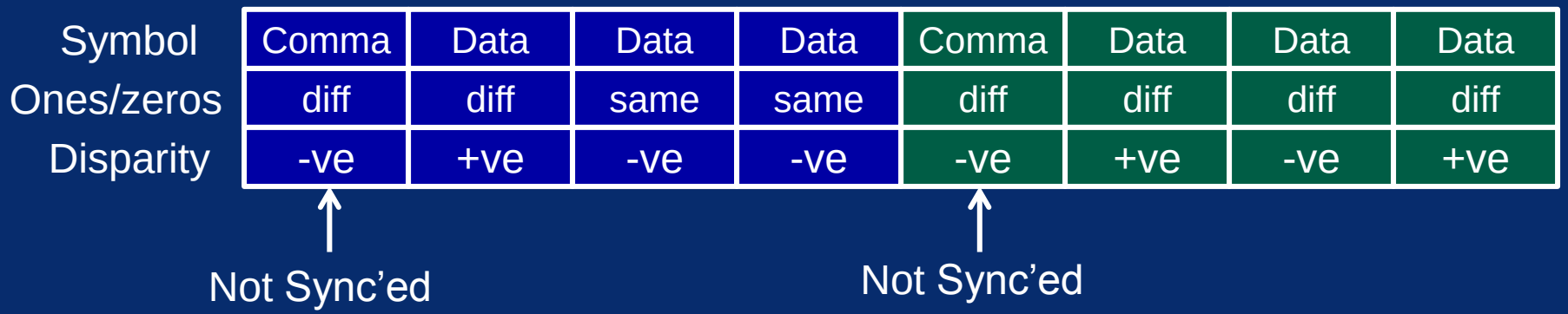
- Bit stream inversion
  - TLK2711 does not support bit inversion
  - Bit inversion is useful to help PCB layout
  - SpaceFibre makes bit inversion mandatory for new devices
  - But permits legacy devices like TLK2711 to not implement bit inversion
- Detecting inversion
  - INIT1 and IDLE control words have valid bitwise inverse symbols
  - Can then detect if direct or inverse INIT1's being received
  - If inverse, change polarity of receiver

TLK2711 Compatibility with SpaceFibre

- Bit synchronisation
  - Bit and symbol synchronisation performed inside TLK2711
  - Status information not provide
  - Impact on receive synchronisation state machine
  - Now uses reception of valid symbols to indicate bit and symbol synchronisation

TLK2711 Compatibility with SpaceFibre

- Symbol synchronisation
  - Does not support symbol synchronisation on negative disparity commas
  - Link might never synchronise, depending on data being sent



TLK2711 Compatibility with SpaceFibre

- Solution to Symbol Synchronisation
  - During initialisation
    - Use pairs of control words both starting with comma
    - Comma has +ve or –ve disparity
    - First control word has only symbols with same number of 1s and 0s after the comma

Symbol	Comma	Data	Data	Data	Comma	Data	Data	Data
Ones/zeros	diff	same	same	same	diff	?	?	?
Disparity	-ve	+ve	+ve	+ve	+ve	-ve	?	?

Not Sync'ed

Sync'ed

TLK2711 Compatibility with SpaceFibre

- Solution to Symbol Synchronisation
  - During initialisation
    - Polarity is not known
    - INIT1 and IDLE control words have valid bitwise inverse symbols
    - These bitwise inverse symbols are chosen to also have same number of 1s and 0s
    - So if bit stream is inverted can still synchronise

TLK2711 Compatibility with SpaceFibre

- Parallel loopback
  - Not implemented in TLK2711
  - It does provide serial loopback
  - SpaceFibre makes parallel loopback optional
  - Serial loopback is mandatory

TLK2711 Compatibility with SpaceFibre

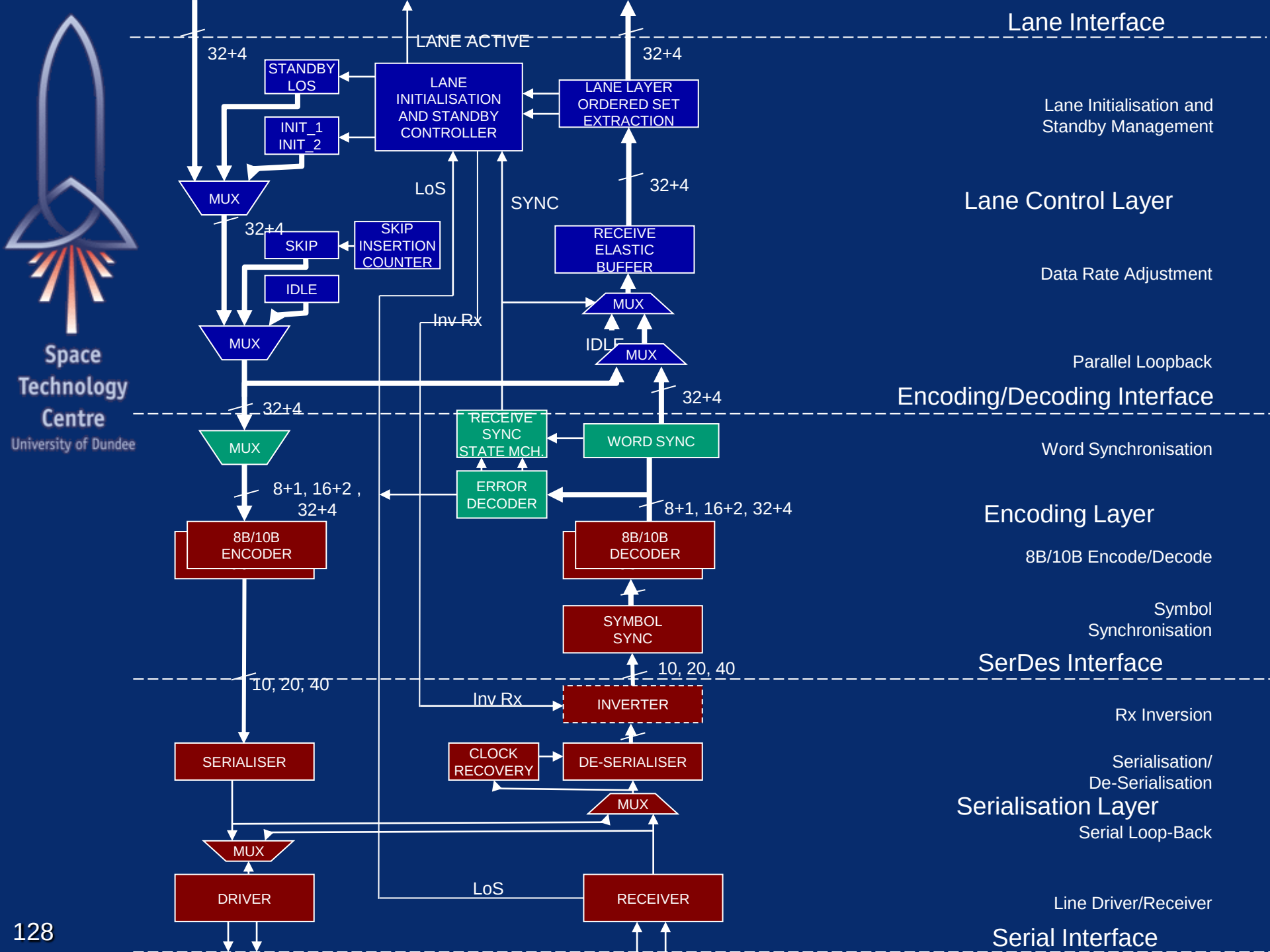
- Interface
  - Interface to TLK2711 is 16-bits data + 2 D/K bits
    - i.e. two symbols wide
  - SpaceWire uses control and data words
    - Four symbols wide
    - 32-bits + 4 D/K bits
  - Need to be multiplexed over TLK2711 interface
  - SpaceFibre specification permits 8+1, 16+2, or 32+4 wide interfaces to be used

TLK2711 Compatibility with SpaceFibre

- Error indication
  - TLK2711 indicates error detected by receiver by output of a K0.0 code
  - Which is not a valid K-code
  - Decoder needed to decode this K-code into an error signal

TLK2711 Compatibility with SpaceFibre

- Line drivers and receivers
  - TLK2711 uses Voltage Mode Logic (VML)
  - SpaceFibre specifies Current Mode Logic (CML)
    - To improve conducted emissions
  - Can translate from VML to CML using resistor network



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Revised SpaceFibre Architecture

- Interface to lower layers
  - Compatible with different serialiser/de-serialiser devices
  - May be necessary to adapt specific device to this common interface
- Encoding/decoding interface
  - Transfer control and data words
  - Encoding
    - 8B/10B encoding into groups of four symbols
  - Decoding
    - Symbol synchronisation
    - 8B/10B decoding
    - Word synchronisation to from control and data words

Conclusions - SpaceFibre Requirements

- Compatible with SpaceWire
  - At the packet and network levels ✓
- High speed
  - 2 Gbits/s now (2.5 Gbit/s signalling)
  - 5 Gbits/s planned (6.5 Gbits/s signalling) ✓
- Very high speed
  - Multiple lanes e.g. 4 lanes 8 Gbits/s ✓
- Flight quality components ✓
- Fibre and copper implementations ✓
- 100 m optical fibre ✓
- 5m copper ✓ TBC
- Low mass cable ✓

Conclusions - SpaceFibre Requirements

- FDIR
  - Fault detection ✓
    - Parity/disparity
    - CRC
  - Fault isolation ✓
    - Galvanic isolation
    - Data framing – time containment
    - Virtual channels – bandwidth containment
  - Fault recovery ✓
    - Link level retry
    - Graceful degradation on lane failure
    - Babbling idiot protection
    - Error reporting

Conclusions - SpaceFibre Requirements

- Support SOIS services
  - Packet delivery ✓
  - Memory access ✓
  - Synchronisation / Time distribution ✓
  - Device discovery TBC
  - Test TBC
- Quality of Service
  - Best Effort ✓
  - Assured ✓
  - Resource Reserved ✓
  - Guaranteed ✓

SpaceFibre Benefits

- Sends and receives SpaceWire packets
- Virtual channels
  - Multiplexes SpaceWire packets over link
  - Overcomes SpaceWire router blocking problem
- Broadcast messages
  - Provides low latency messaging
  - Based on an extension of the SpaceWire time-code mechanism
- Coherent quality of service mechanisms
  - Bandwidth sharing for payload data-handling applications
  - Deterministic data delivery for command and control applications

Benefits

- FDIR support including
  - Galvanic isolation
  - Fault detection with disparity, CRC, sequence #
  - Fault isolation to prevent fault propagation
  - Fault recovery to provide rapid recovery from transient faults
- Lanes
  - For higher throughput with graceful degradation
  - Hot and cold redundancy support
- QoS in the CODEC
  - Providing inherent robustness against a range of system errors, like babbling idiots

Schedule

- Currently simulating in software and OPNET
- Presentation December 2011
  - SpaceWire Working Group meeting
- Draft ECSS standard end January 2012
  - Available for Working Group members
- Initial review feedback by March 2012
- Update to draft standard by May 2012
- ECSS standardisation process starts

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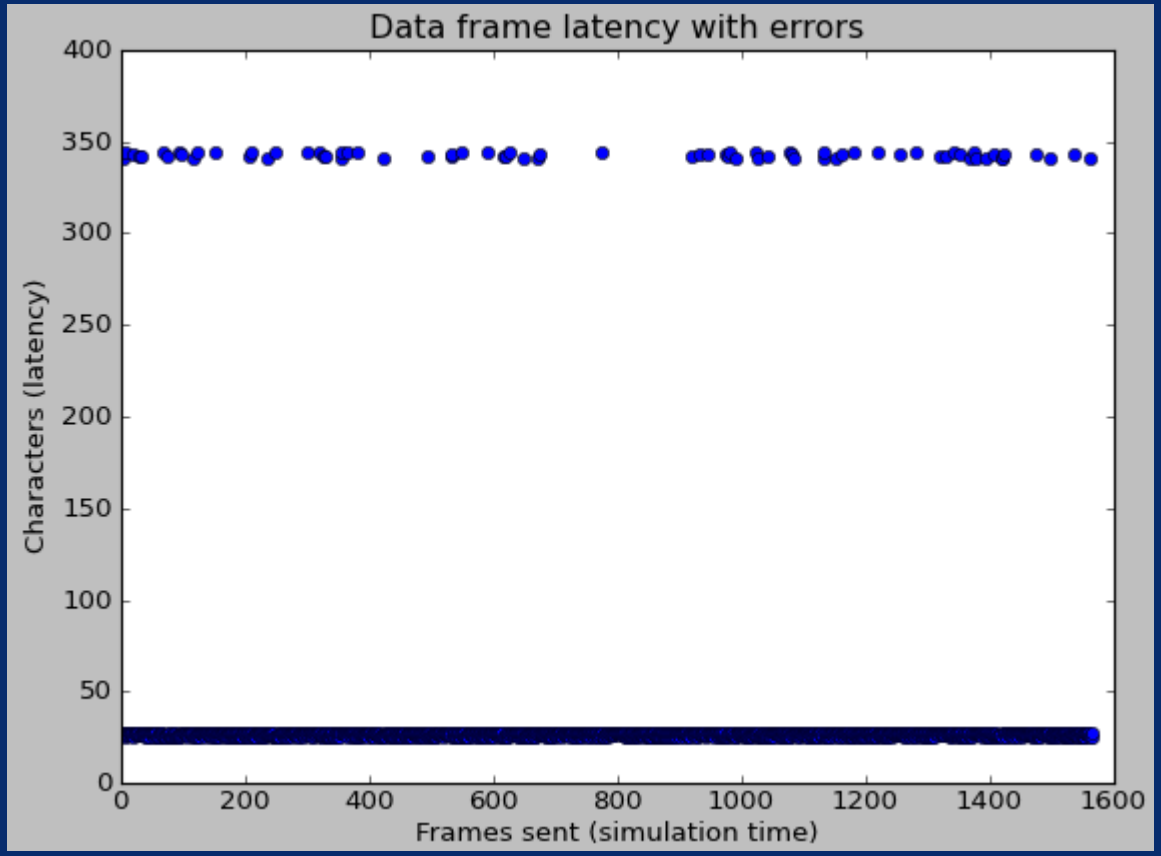
Data frame latency when errors occur

- The additional latency is basically the retransmission time of the frame with error (256 characters, around 1µs) plus the double of the transmission delay (say 8-10m, i.e. 2*20 character delay = 2*80ns).



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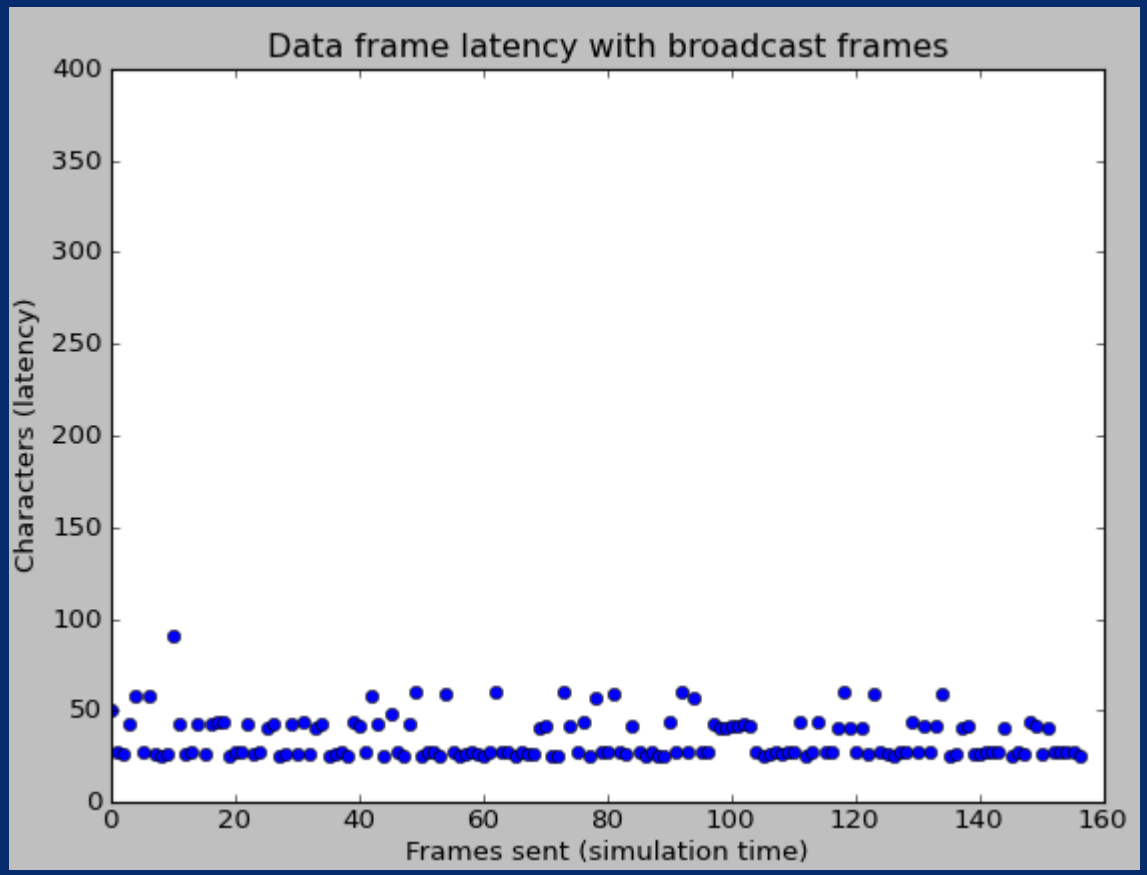
Data frame latency with broadcast frames

- The data frame latency may be affected by one or more broadcast frames that may be inserted within the data frame transmission.



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Broadcast frame latency

- The broadcast frame latency depends on:
  - The transmission time and line delay
  - Jitter introduced by other broadcast frames being sent.