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SpaceWire and SOIS Services

Steve Parkes
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- SpaceWire Mapping to SOIS
  - Important features of SpaceWire
  - Work done by CCSDS TCONS and UoD
    - Inputs from NASA GSFC
      - Jane Marquart
      - Greg Menke
      - Rick Schnurr

SOIS Mapping

- Packet Service
- Memory Service
- Time Service
- Test Service
- Device Discovery Service

SOIS Mapping - Simple

- Packet Service -> SpaceWire Packets
- Memory Service -> RMAP
- Time Service -> Time-codes + RMAP
- Test Service -> RMAP
- Device Discovery Service -> ?

Maybe not so simple

- Limitations of a SpaceWire network
- Wormhole routing
  - No packet buffering
- Means packets block access to links while being transmitted
  - Large packets result in long blockage time
  - Smaller packets can be interleaved
- Limited priority mechanism in SpaceWire
- Means small packets may be blocked by other small packets for substantial periods of time
- Problem made worse when there are several routers to be traversed

QoS: Quality of Service

- Having some control over when information will be delivered over a network
- Bandwidth – how much information you can transfer without upsetting other users of the network
- Latency – how long it takes for a packet to cross the network
- Determinism – knowing when a packet will arrive within small finite time limits

SpaceWire QoS

- There isn’t any
- Except limited priority implemented in some routers
- SpW-10X has two levels of priority
  - using logical addresses
  - to map different levels of priority

Priority

- Arbitration in Router
  - Fair arbitration
  - Priority based
- SpaceWire header contains address only
- Assign priority to logical addresses
  - For example
  - Addresses 32 and 33 may address same destination
  - 32 low priority
  - 33 high priority
- Priority handled in the routers

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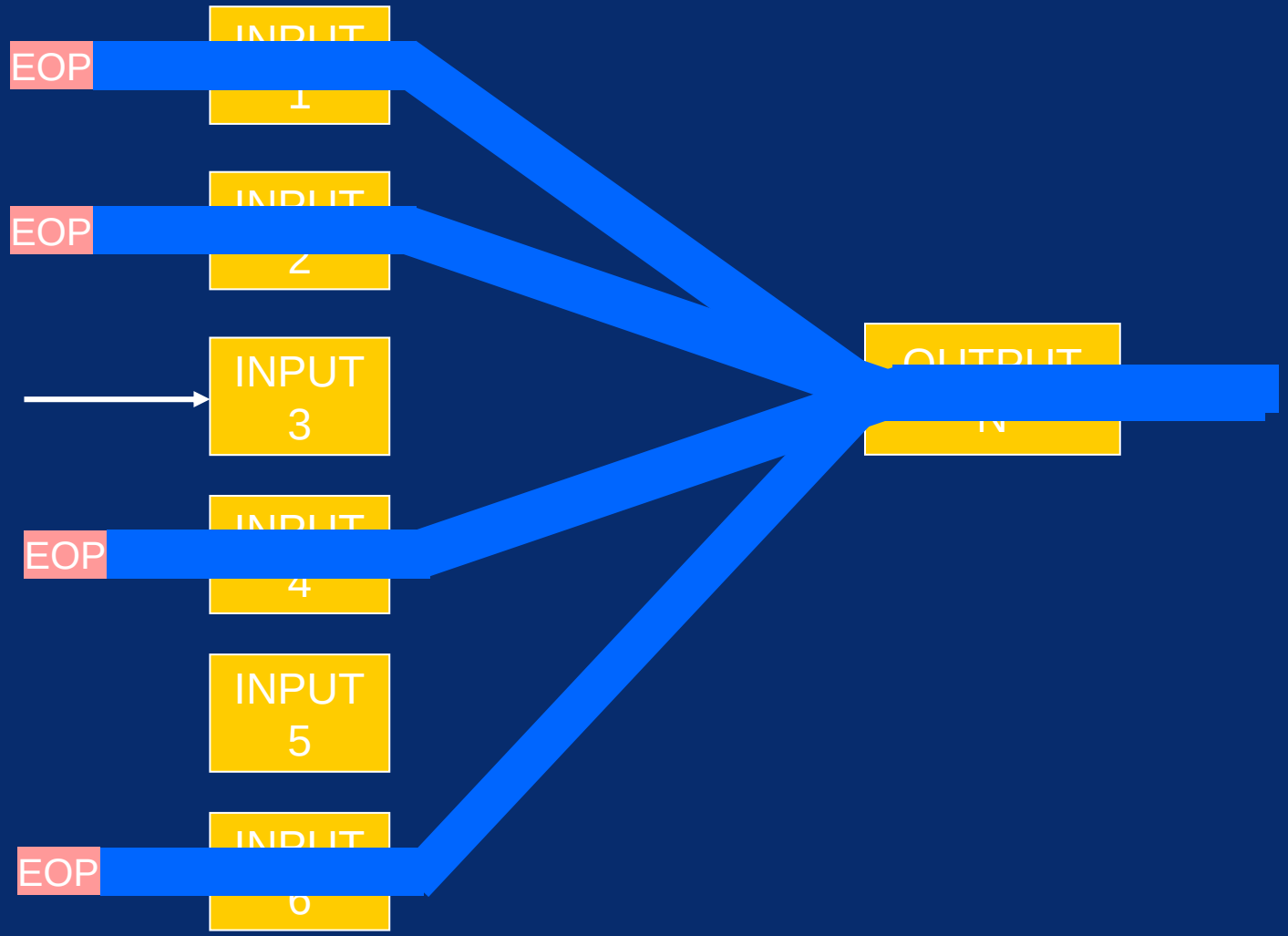
Arbitration



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Priority

	Address	Priority	Port 0	Port 1	Port 2	Port 3	Port 4
Configuration	0	0	1	0	0	0	0
Path Addressing	1	0	0	1	0	0	0
	2	0	0	0	1	0	0
	…						
Logical Addressing	32	0	0	1	0	0	0
	33	1	0	1	0	0	0
	34	0	0	0	0	0	1
	…						
Reserved	255	0	0	0	0	0	0

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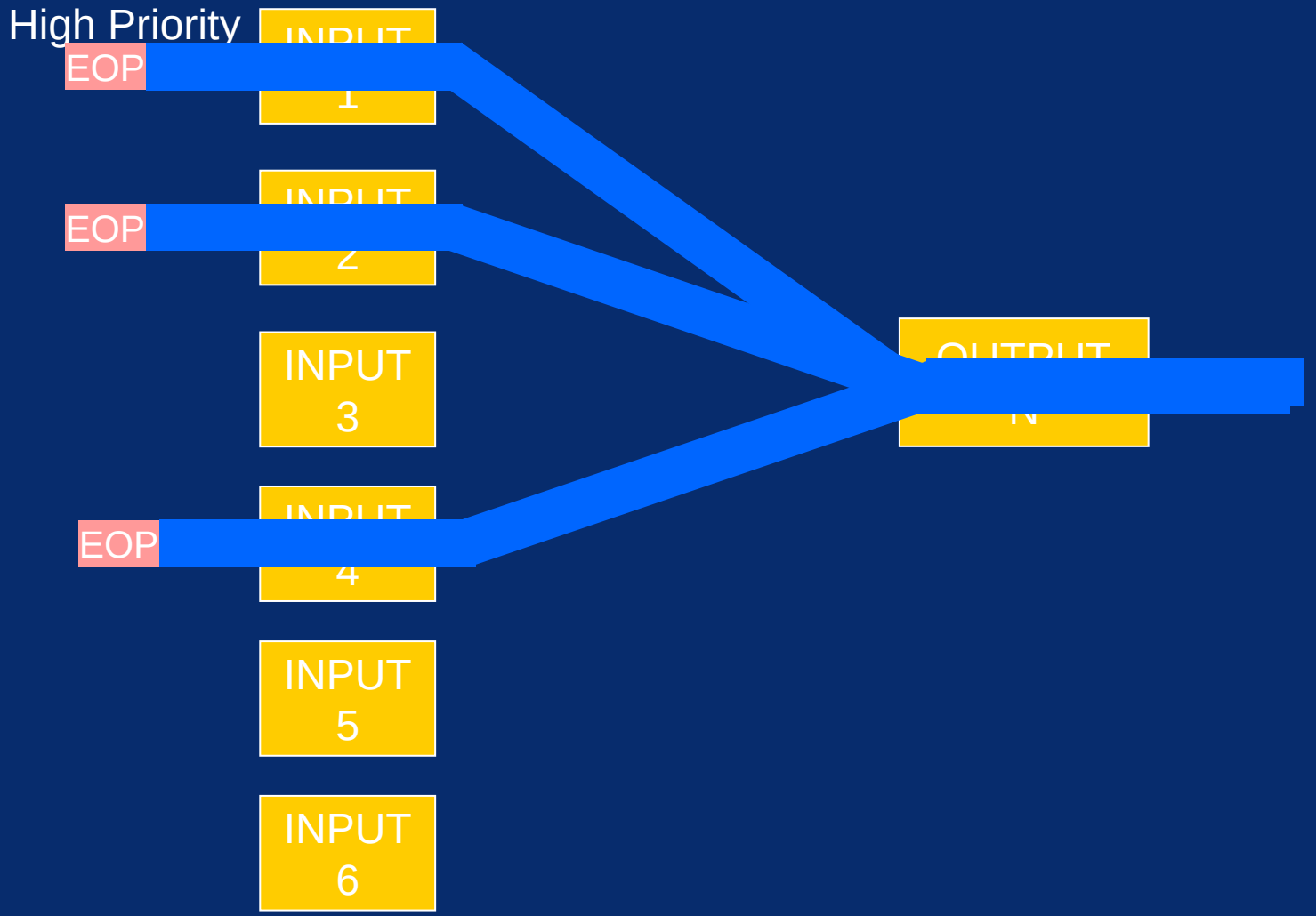
Arbitration with Priority



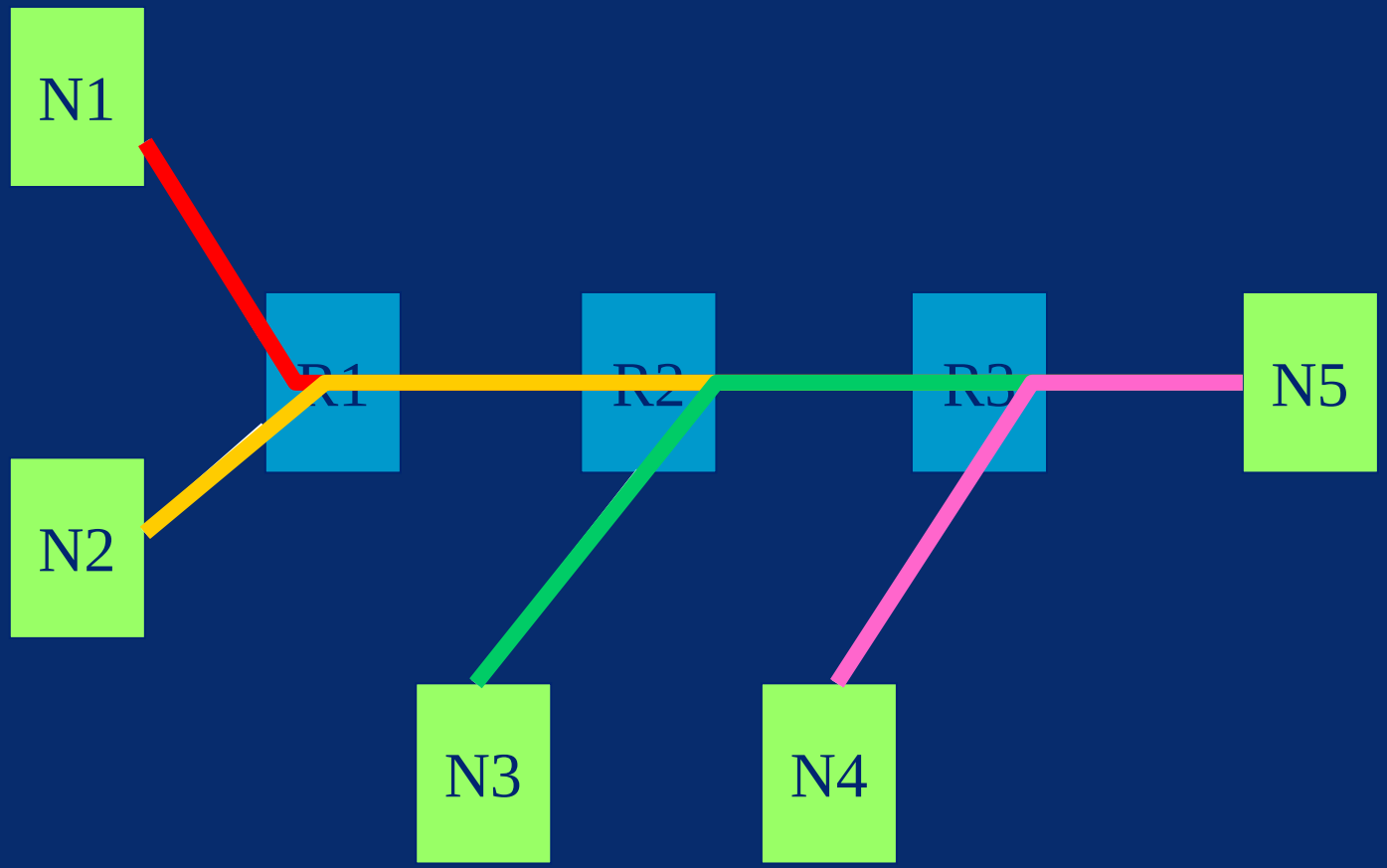
SpaceWire Address and Priority

- SpaceWire address byte is 8-bits
  - Giving 256 addresses (ignoring path addresses for simplicity)
- Could reserve e.g. 3-bits for priority
  - Giving just 32 addresses each with 8 priority levels
- This mapping is up to the router designer
  - SpW-10X has 2 priority levels
  - Nominally for control and data

QoS and Media Access

- QoS requires media access control.
- Simple view
  - Provide priority access to packets entering the network
- Problem
  - Limited priority support when passing through the network
  - So a packet that enters the network with high priority
  - May be blocked by other low priority packets already in transit through the network

Blocking in Network



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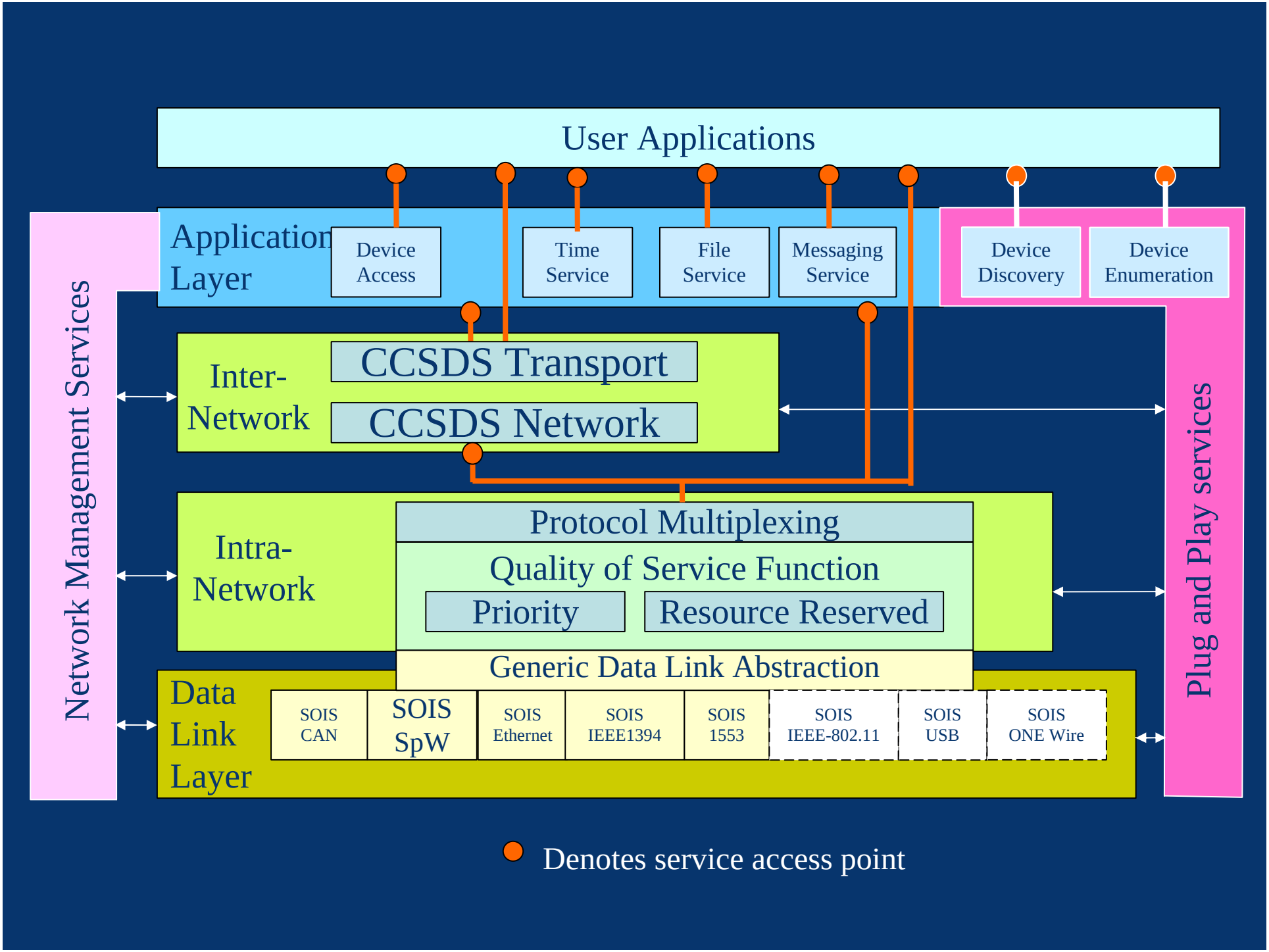
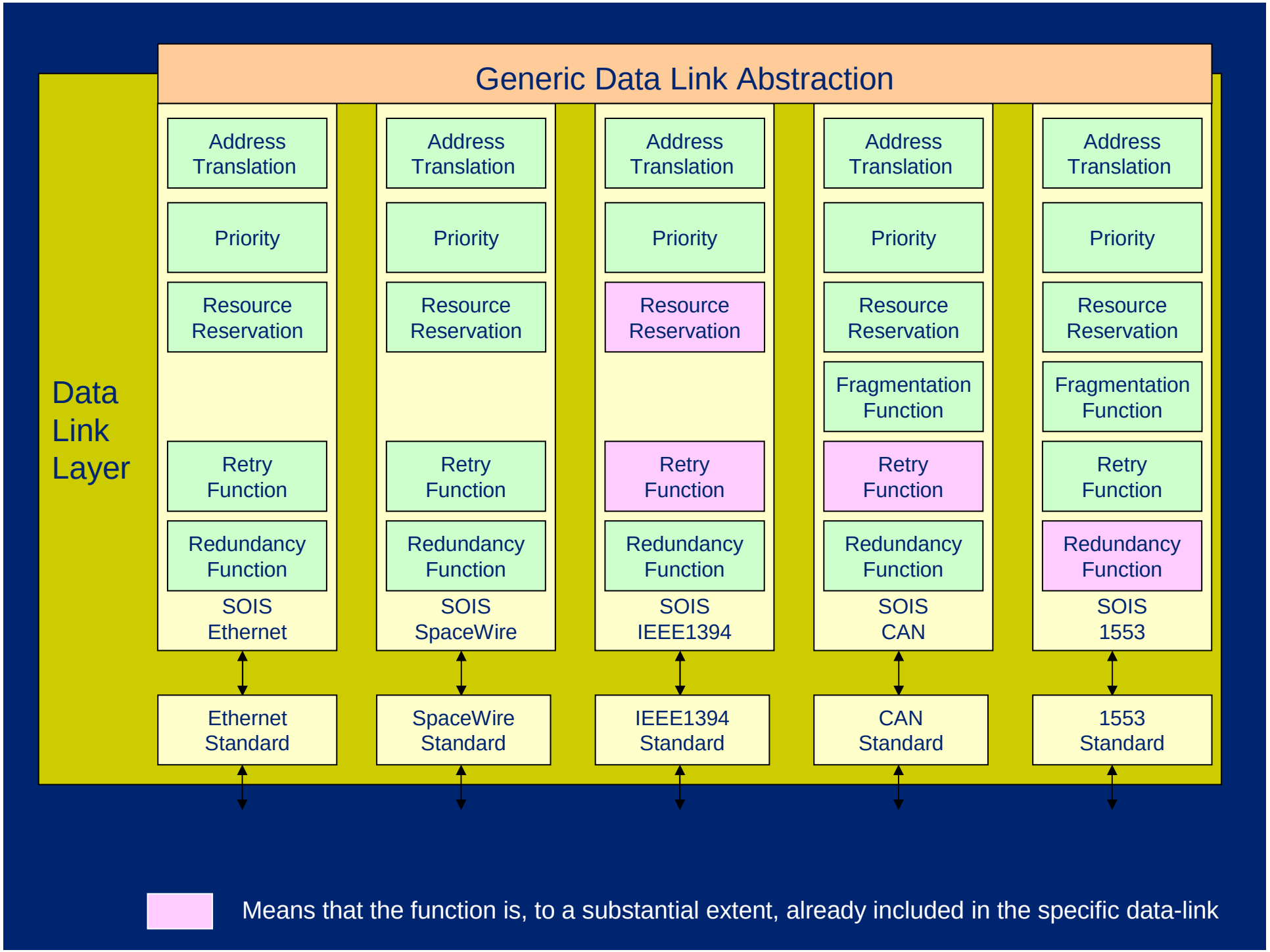
SOIS TCONS

- TCONS – Time Critical Onboard Network Services
- OBL – Onboard Bus and LAN


User Applications
Application Layer
Device Access
Time Service
File Service
Messaging Service
Device Discovery
Device Enumeration
Network Management Services
Inter-Network
CCSDS Transport
CCSDS Network
Intra-Network
Protocol Multiplexing
Quality of Service Function
Priority
Resource Reserved
Generic Data Link Abstraction
Data Link Layer
SOIS CAN
SOIS SpW
SOIS Ethernet
SOIS IEEE1394
SOIS 1553
SOIS IEEE-802.11
SOIS USB
SOIS ONE Wire
Plug and Play services
Denotes service access point


Generic Data Link Abstraction
Data Link Layer
Address Translation
Priority
Resource Reservation
Fragmentation Function
Retry Function
Redundancy Function
SOIS Ethernet
SOIS SpaceWire
SOIS IEEE1394
SOIS CAN
SOIS 1553
Ethernet Standard
SpaceWire Standard
IEEE1394 Standard
CAN Standard
1553 Standard
Means that the function is, to a substantial extent, already included in the specific data-link

TCONS Aims

- Common networking services
- Across several underlying buses/sub-networks ✗
- Carry multiple network/transport/application protocols ✔
- Time critical services ✔
- Consistent quality of service paradigm ✔

TCONS – Intra-Network

- Multiplexing of higher level protocols
  - May be mapped to SpaceWire Protocol ID
  - Or have a carried-protocol ID field
- Quality of service
  - QoS tag used to specify what class of traffic a PDU is
  - QoS tag defines how PDU will be treated
  - as it passes through the onboard network
- Quality of service examples
  - Priority
  - Bandwidth reservation
  - Scheduled delivery

OBL Aims

- Define the functions needed to implement TCONS
- On each bus/sub-network
- Generic data link abstraction
- Specific definitions for specific buses/sub-networks
  - SpaceWire
  - Ethernet
  - Mil-Std 1553
  - IEEE1394
  - CAN

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SpaceWire Mapping

Redundancy

- Redundancy models:
  - equivalent data links
  - provide alternative paths
  - from a source end-point to a destination end-point
  - on a single sub-network.
- Equivalent data links may be used in one of three ways:
  - Sending data over both paths at the same time.
  - Sending over the prime link and then if there is a failure using the redundant link (Often used for MIL-STD-1553 bus).
  - Sending over either link, then if failure of one link all traffic goes over the remaining link.

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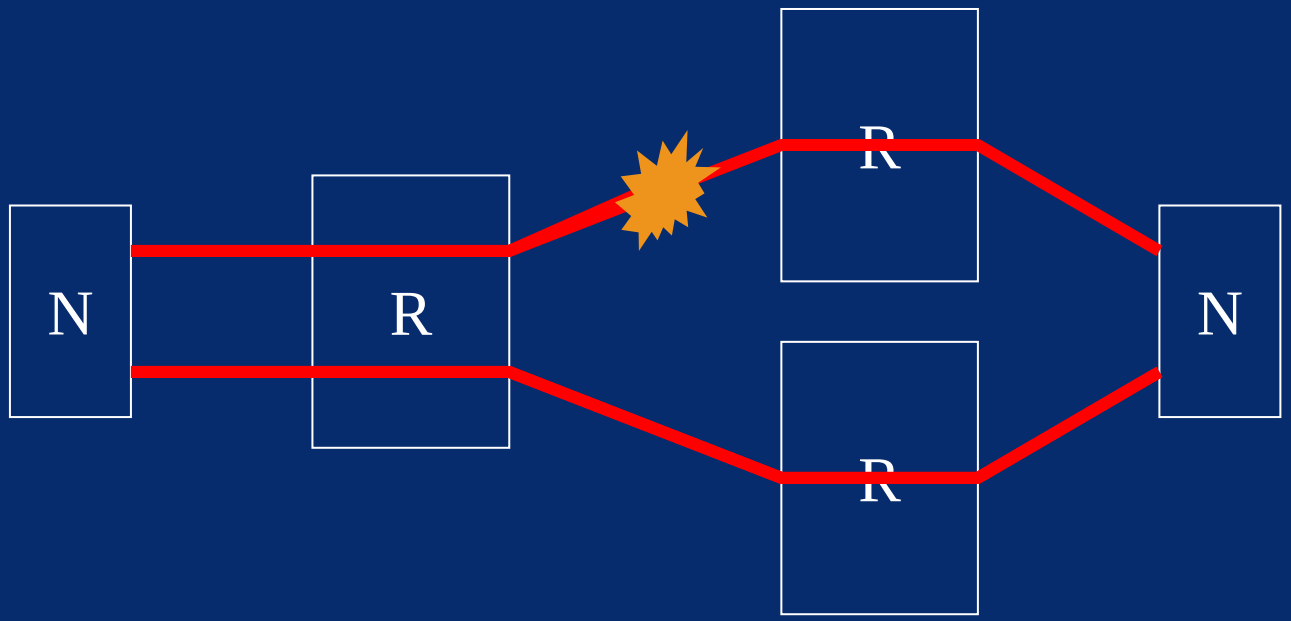
Both paths at same time



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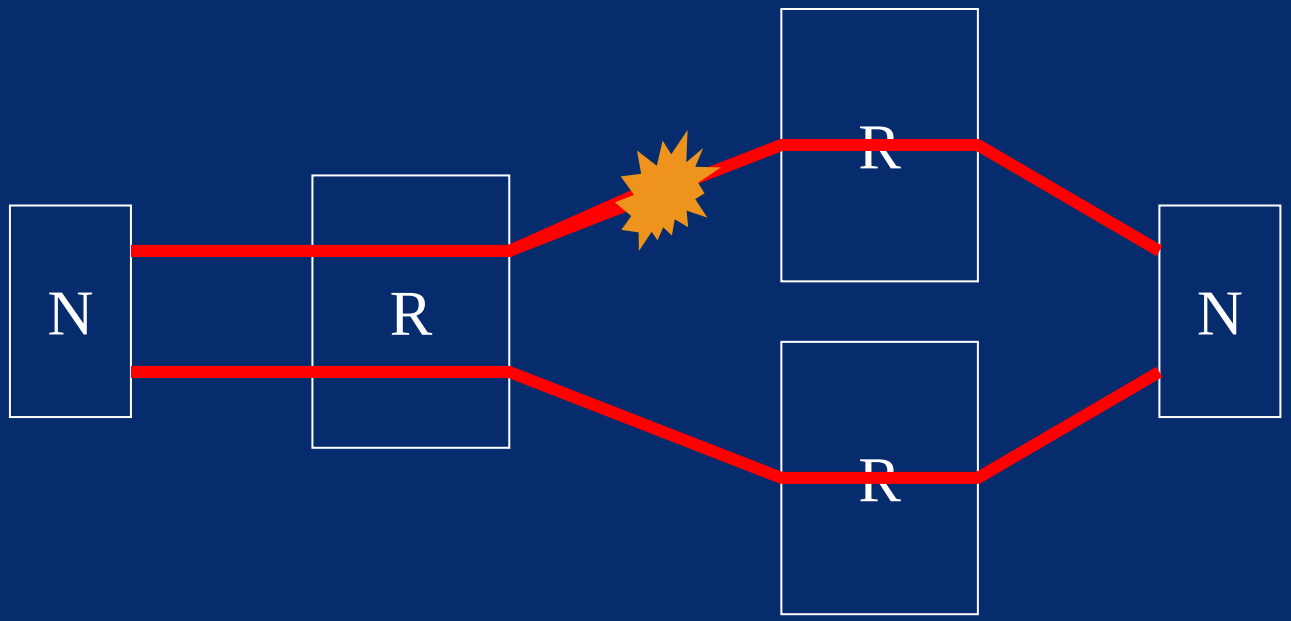
One path then alternative



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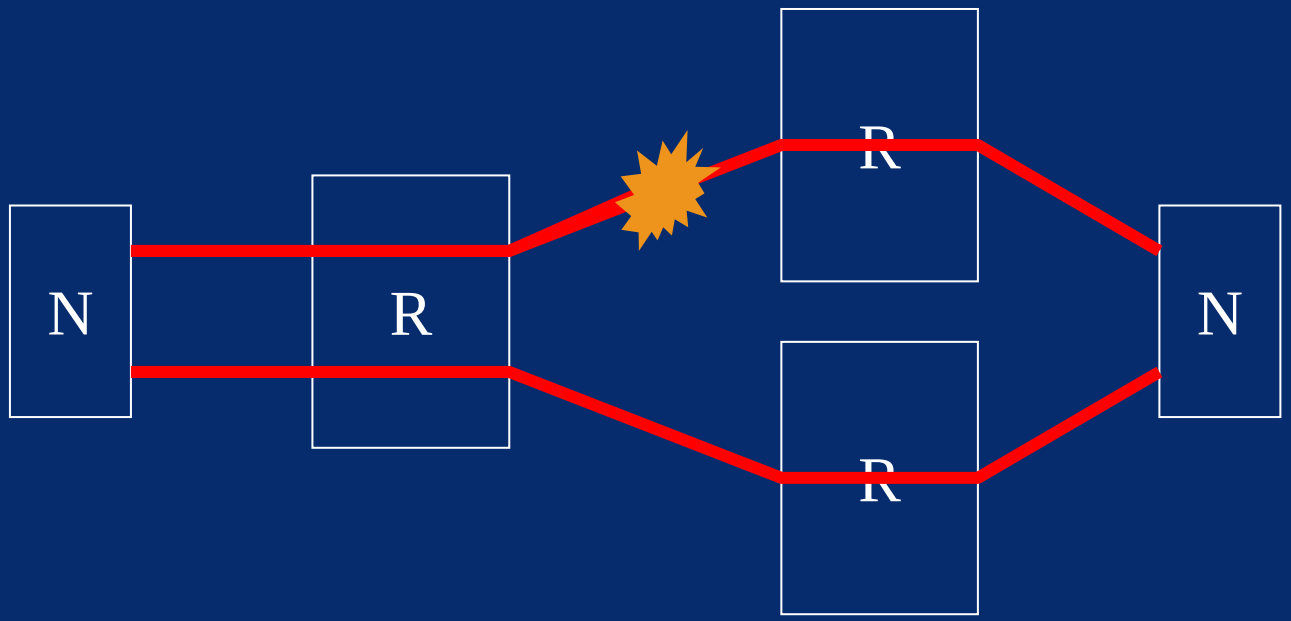
Either path then remaining path



Redundancy

- Autonomous switching between equivalent data links supported.
- Controlled using management parameters associated with a traffic class.
- System management policy might dictate a uniform redundancy policy which applications must use.

Retry

- Retry function provides mechanism for
  - Resending PDUs
  - Not received correctly at the other end of the data link.
- When the source sends a PDU it starts a timer.
- When PDU arrives at the destination an acknowledgement is returned to the source.
- If source does not receive acknowledgement before timer times-out
- Then PDU is assumed not to have arrived at the destination
- Source resends the PDU.

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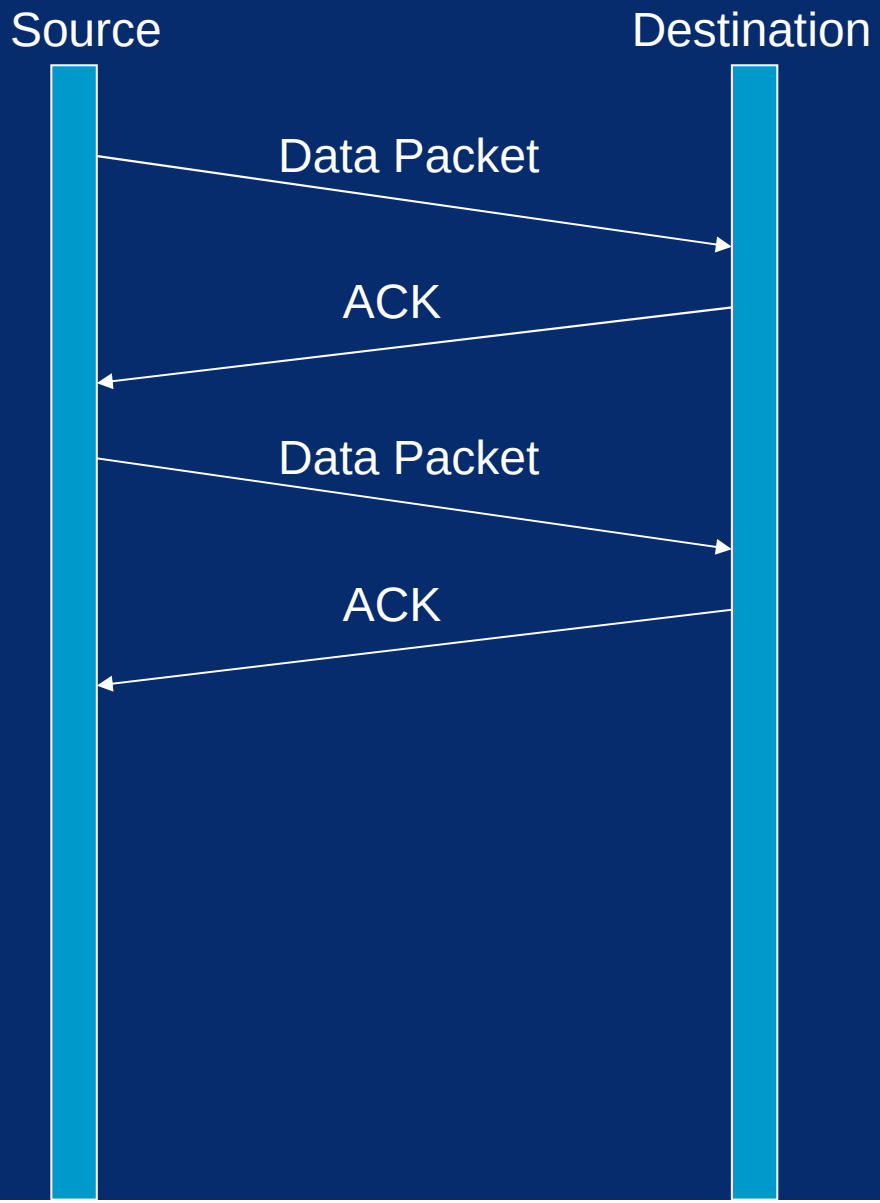
Normal Operation



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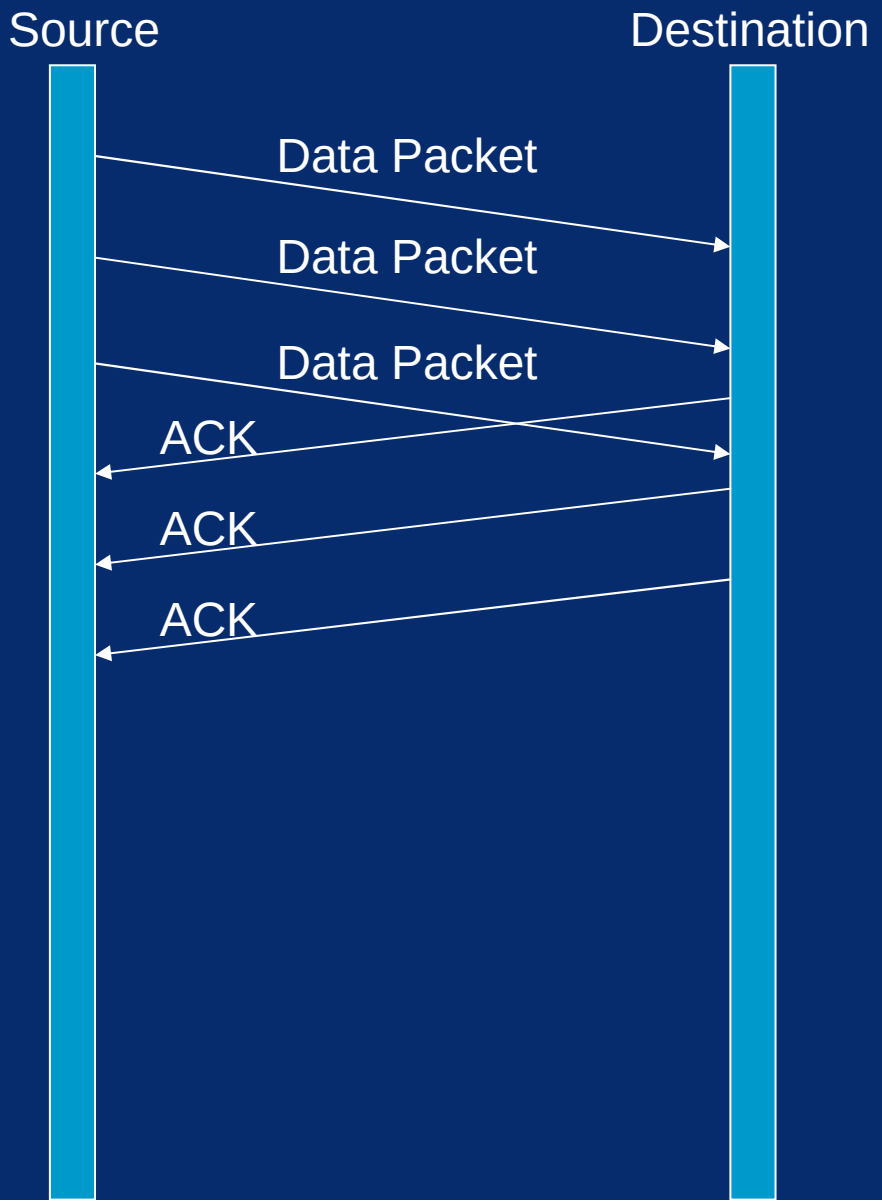
Normal Operation



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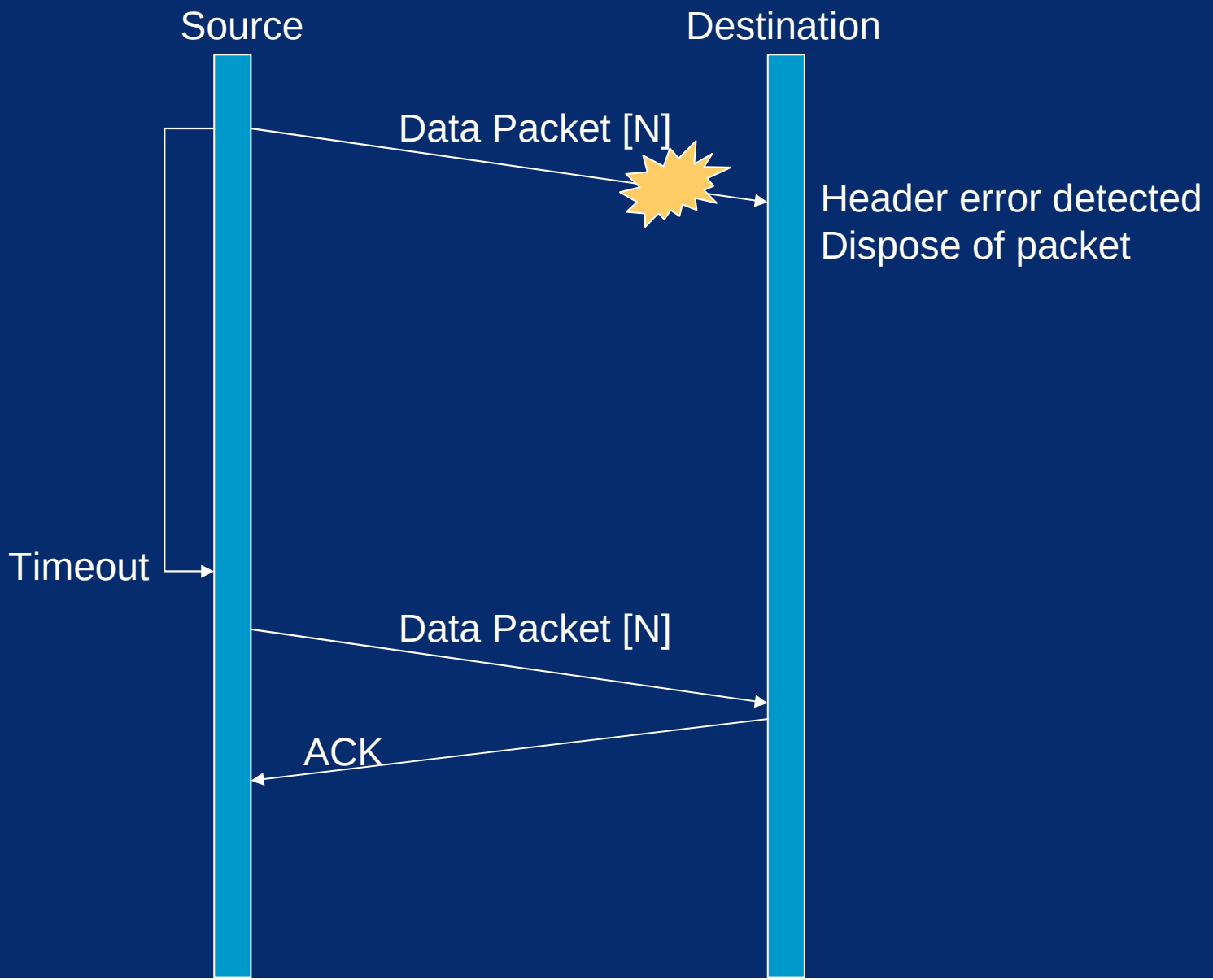
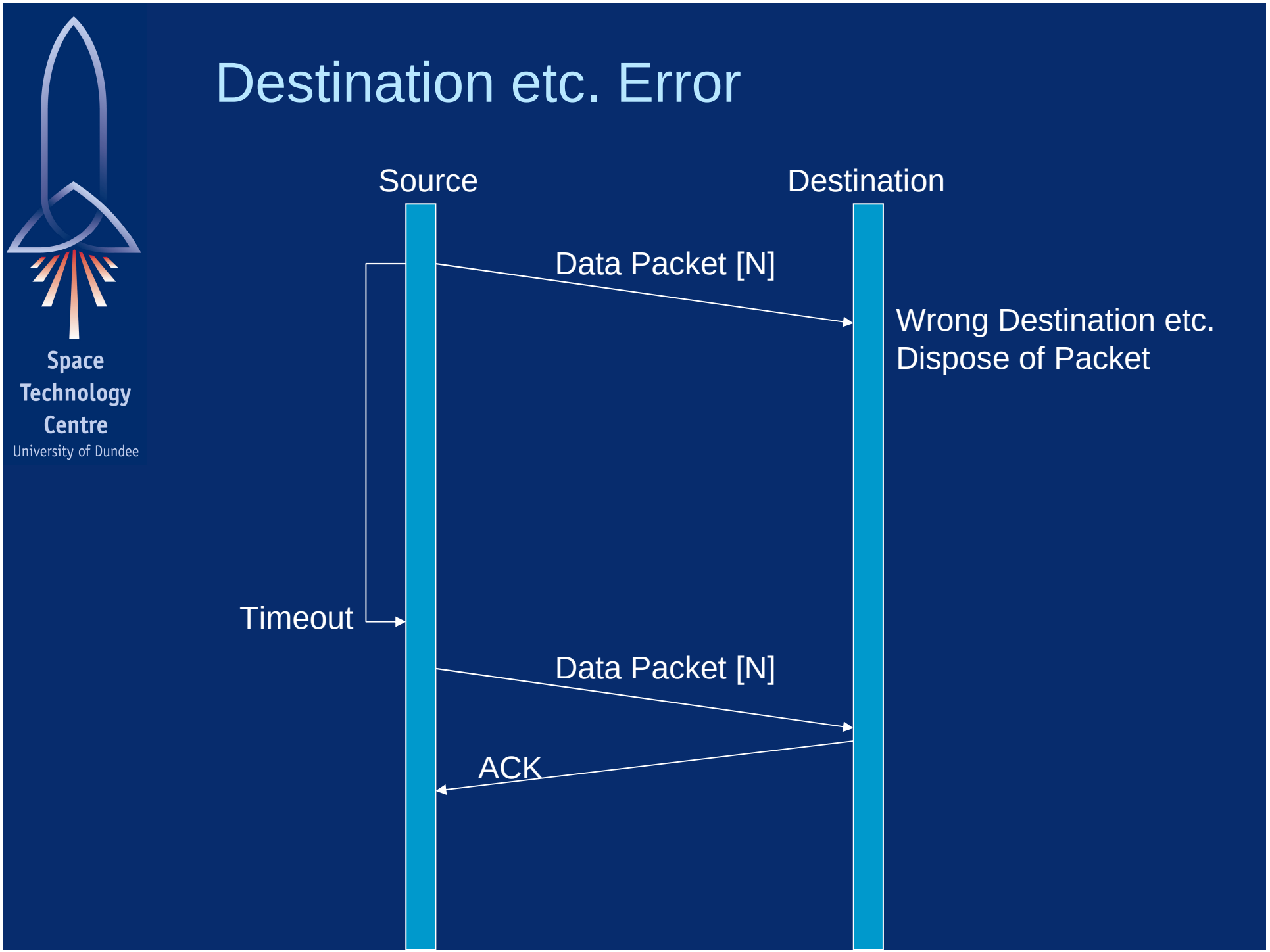
Header Error

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Destination etc. Error
Source
Destination
Data Packet [N]
Wrong Destination etc.
Dispose of Packet
Timeout
Data Packet [N]
ACK

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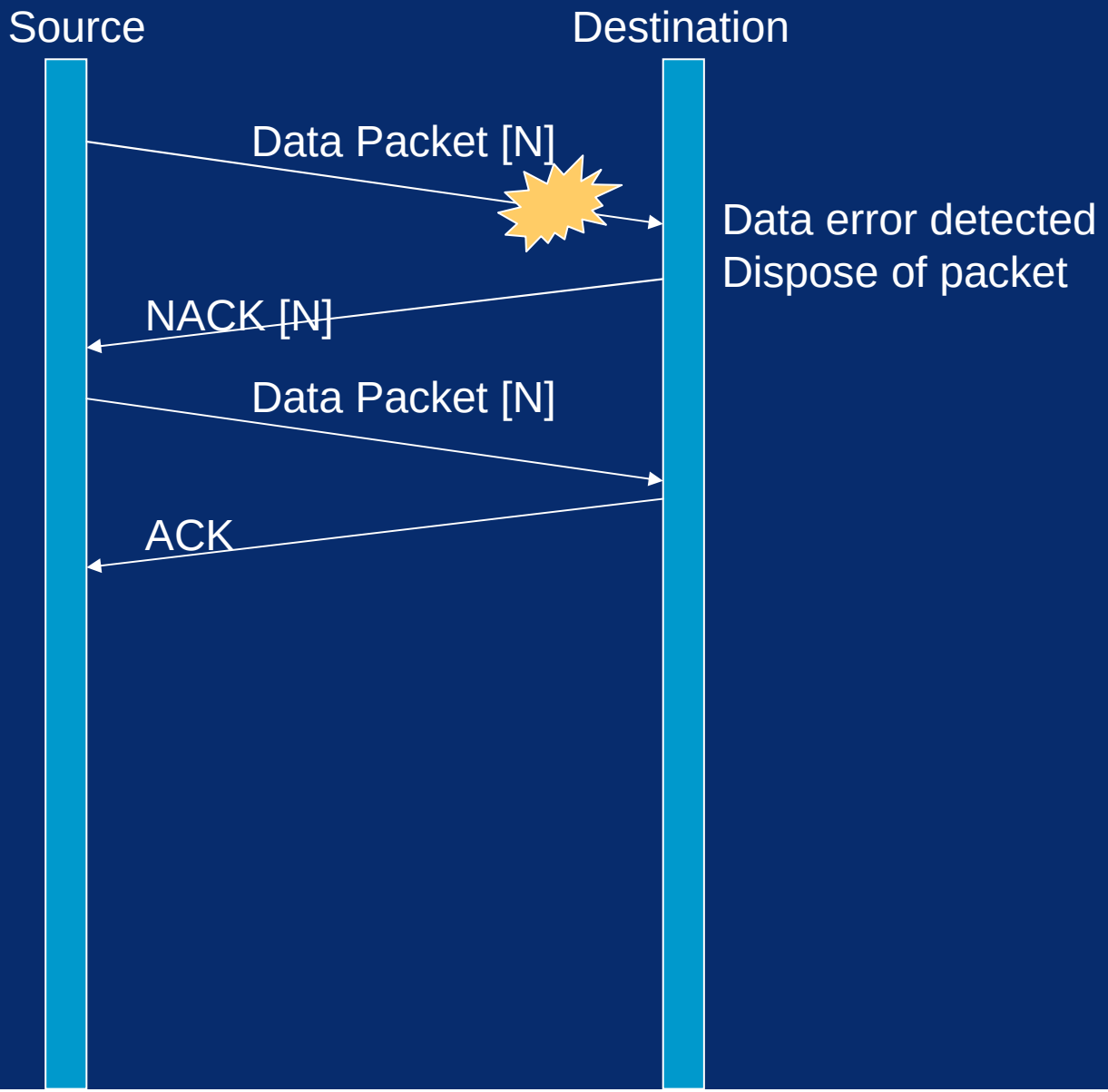
Data Error



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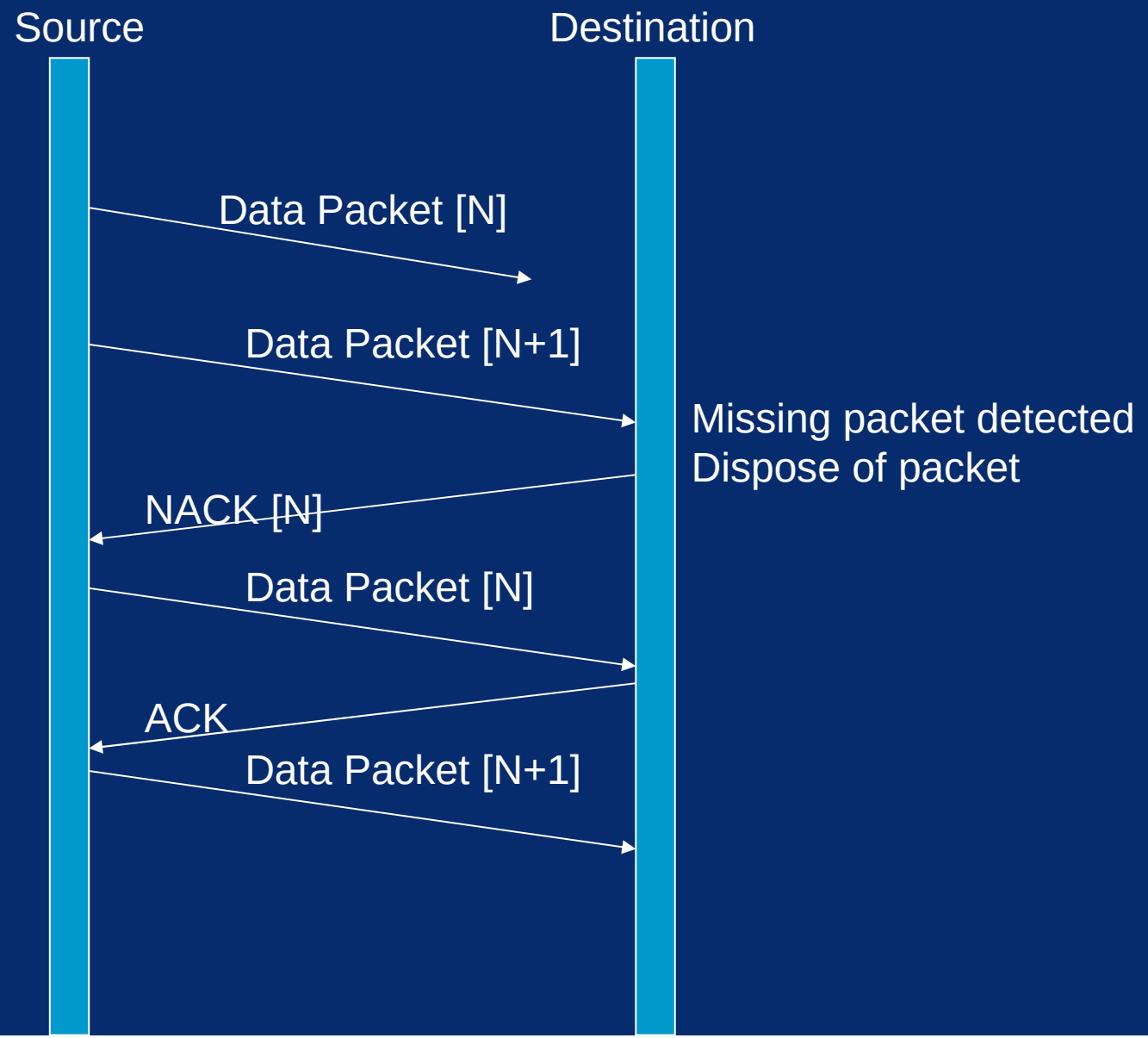
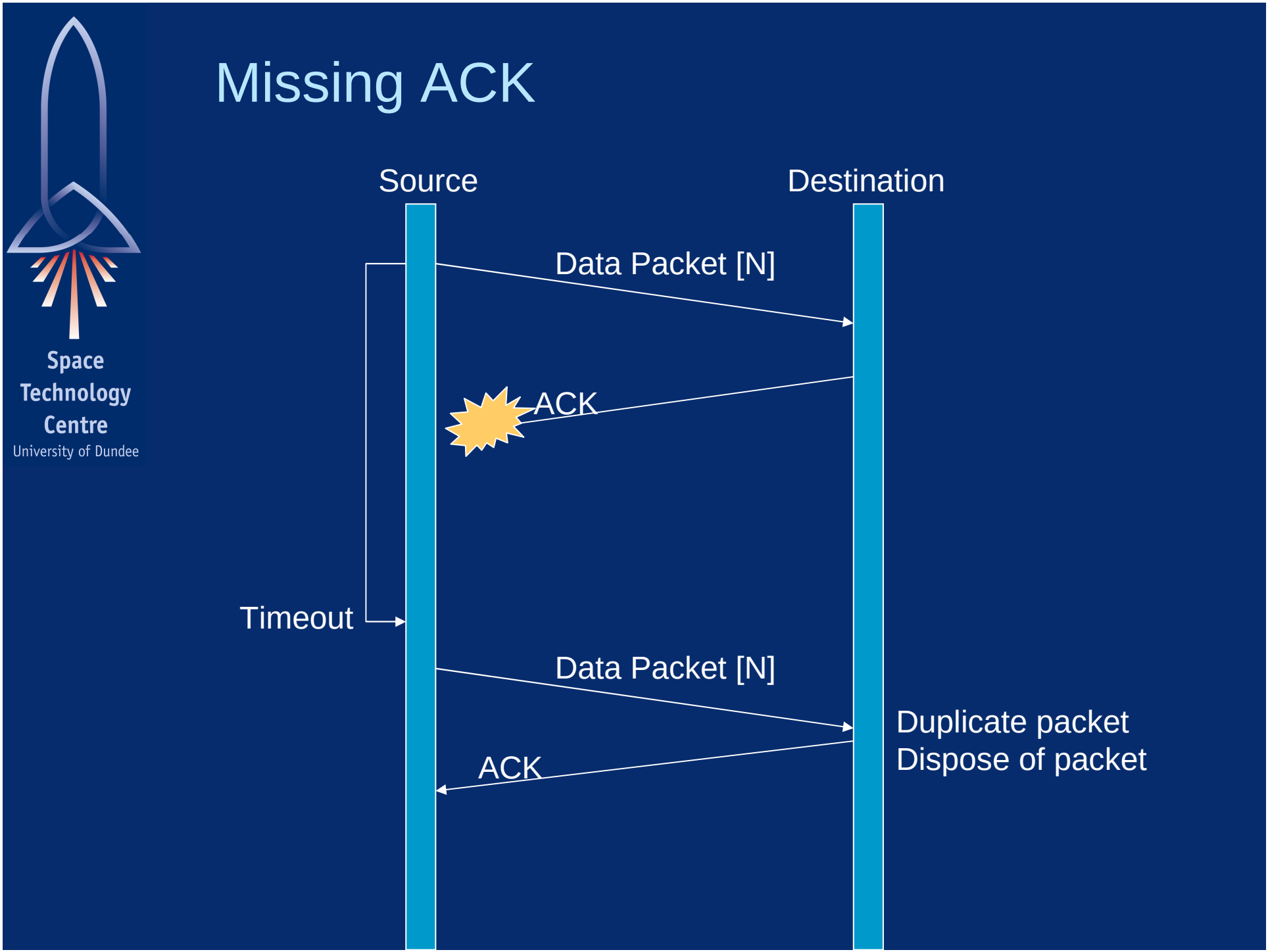
Sequence Error




Missing ACK
Source
Destination
Data Packet [N]
ACK
Timeout
Data Packet [N]
Duplicate packet
Dispose of packet
ACK
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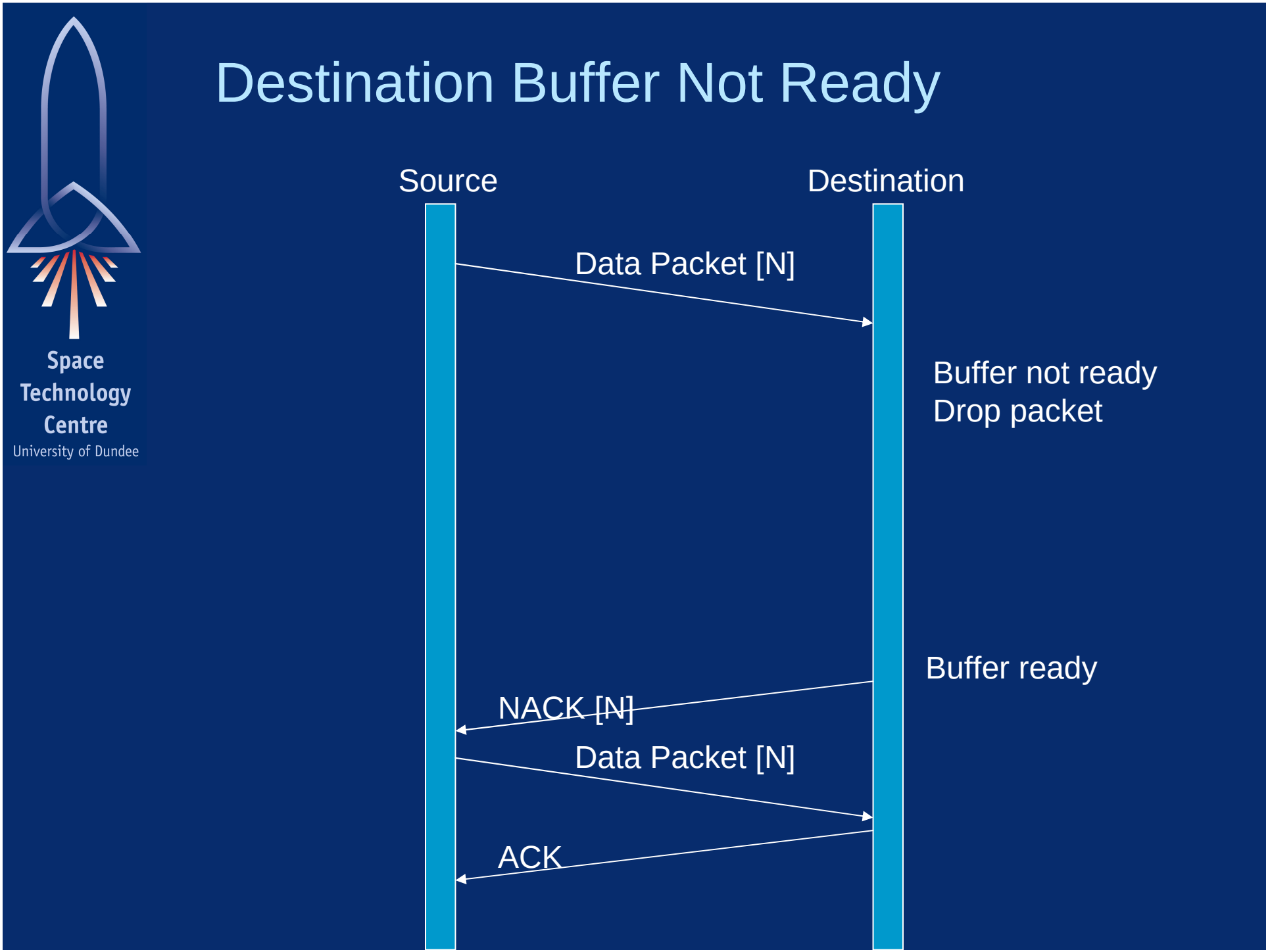
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Destination Buffer Not Ready
Source
Destination
Data Packet [N]
Buffer not ready
Drop packet
Buffer ready
NACK [N]
Data Packet [N]
ACK

Redundancy Management

- In source
  - Address translation tables
  - Determine prime and redundant paths
- Parameter determines which is active path
- Network management can set active path parameter at any time
- Automatic redundancy switching enabled by management parameter

Automated redundancy switching

- When automatic redundancy switching enabled
- If retry count reaches prime limit
  - Switch to redundant path
- If retry count reaches redundant limit
  - Stop sending
  - Inform network management

Address Translation

- Address translation translates between network address and SpW address space.
- SOIS will support two classes of SpW
  - Non-route through SpW
    - IP source and destination addresses are mapped onto SpW address space
    - Knowledge of the original IP address is lost,
  - Route through SpW
    - Original IP source and destination address is either transmitted
    - Or mapped in a recoverable way to the SpW address space.

Address Resolution

SOIS Logical Address	SpaceWire Logical Address	Prime SpaceWire Path Address	Redundant SpaceWire Path Address
0100h	34h	01 04 02h	02 04 02h
0120h	39h	01 06 05 02h	02 03 05 02h
0122h	54h (low priority)	01 04 03h	02 04 03h
0122h	55h (high priority)	01 04 03h	02 04 03h

- Could also have redundant SpaceWire logical addresses

Quality of Service

- QoS is ability to provide predictable, differentiated communication services
- Characterised in terms of features relevant to a communications service
  - Reliability
  - Transmission rate
  - Effective bandwidth
  - Latency
  - Error rate

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TCONS QoS Model

- Three levels to TCONS QoS Model:
  a) Priority
  b) Resource reserved / non-reserved
  c) Try once / retry

TCONS QoS Model

- Result in four service types
- Best Effort: Non-reserved, try once
- Assured: Non-reserved, retry
- Reserved: Resource reserved, try once
- Guaranteed: Resource reserved, retry

- Each of these service types also has several priority levels
  - Priority for non-reserved types is global
  - Priority for reserved types is within a channel

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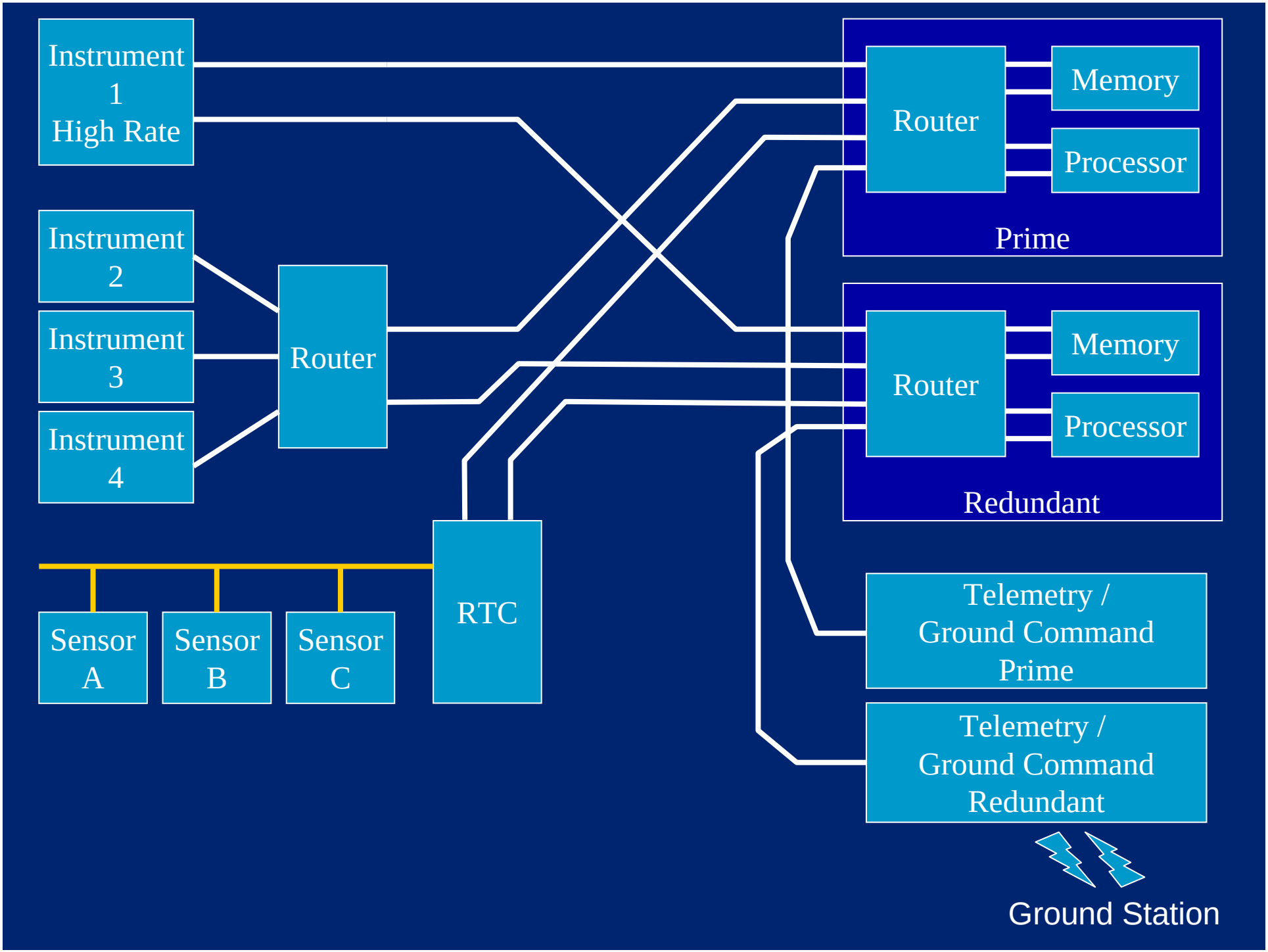
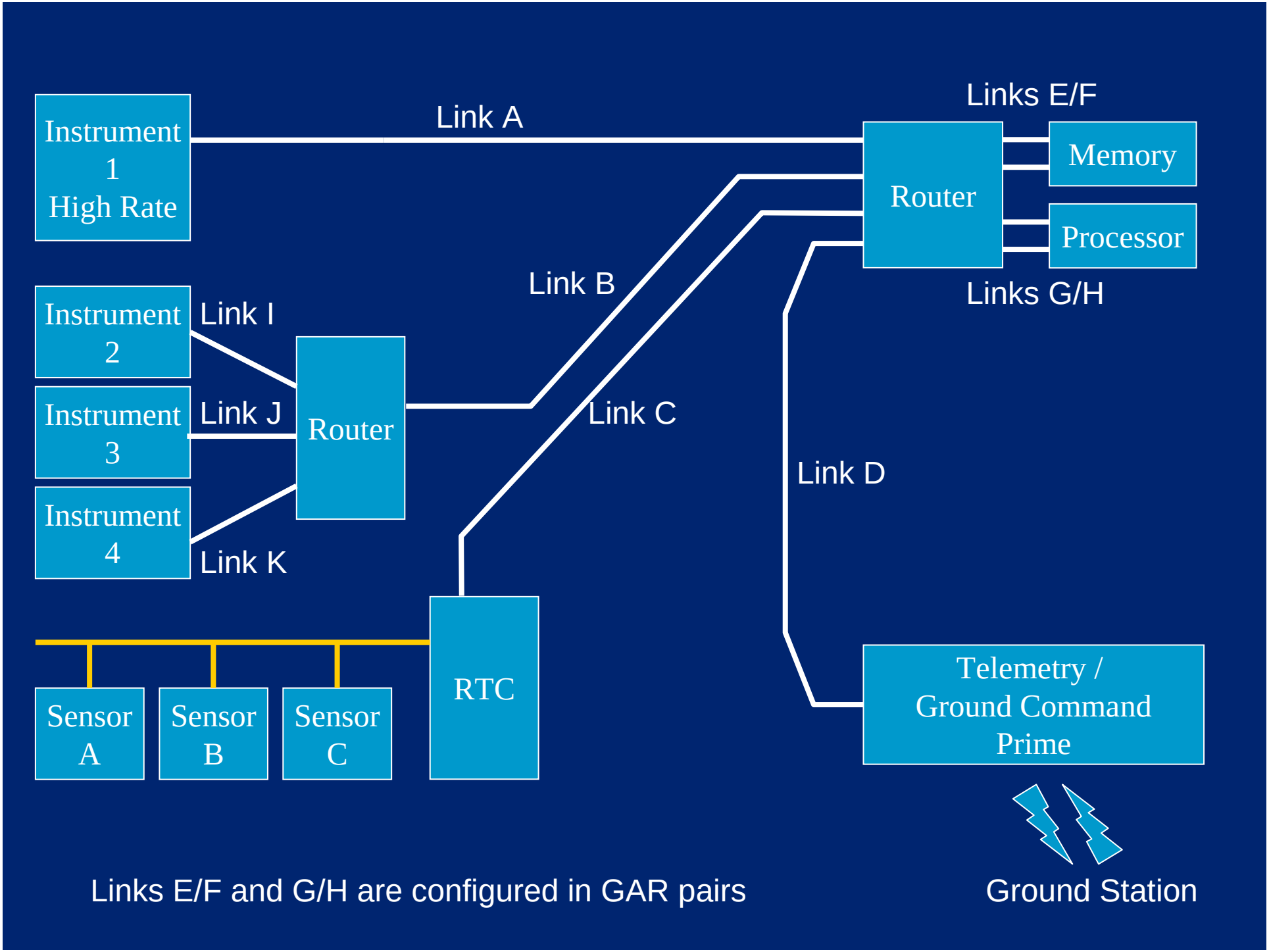
TCONS QoS Mechanisms

- Traffic Class
  - A traffic class is a category of traffic on a sub-network distinguished by its quality of service.
- Channel
  - A reservation of resources between source and destination
  - Specifies
    - Source
    - Destination(s)
    - Usage of reserved resources
    - E.g. percentage bandwidth of communications link

Table 3-1 Traffic Class Summary		
Traffic Class	**Service Interface Parameters**	**Managed Parameters**
Best Effort	Priority	None
Assured	Priority, Receipt notification (on/off)	Redundancy on/off Retry on Retry attempts
Reserved	Priority, Channel number	For each channel: Bandwidth allocation / schedule slot id Redundancy off Retry off
Guaranteed	Priority, Receipt notification (on/off), Channel number	For each channel: Bandwidth allocation / schedule slot id Redundancy on/off Retry on Retry attempts


Instrument 1 High Rate
Instrument 2
Instrument 3
Instrument 4
Router
Sensor A
Sensor B
Sensor C
RTC
Router
Memory
Processor
Prime
Router
Memory
Processor
Redundant
Telemetry / Ground Command Prime
Telemetry / Ground Command Redundant
Ground Station


Instrument 1 High Rate
Link A
Links E/F
Router
Memory
Processor
Links G/H
Instrument 2
Link I
Instrument 3
Link J
Instrument 4
Link K
Router
Link B
Link C
Link D
RTC
Sensor A
Sensor B
Sensor C
Telemetry / Ground Command Prime
Ground Station
Links E/F and G/H are configured in GAR pairs

Links are Critical Resources

- Multiple data paths share some links
- Routers are non-blocking
- So if the output link is not blocked the inputs will not be blocked
- Routers are not critical resources

Table 3-1 Utilisation of resources (links)		
Link	Left to right / up	Right to left/ down
A	Not shared	Processor commands and ground commands
B	Instruments 2, 3, 4	Processor commands and ground commands
C	RTC	Processor commands and ground commands
D	Telecommands	Data from memory for down link
E/F	Instruments 1, 2, 3, 4 and RTC Processor commands and ground commands	Date from memory for down link
G/H	Data from instruments or memory for processing	Processor commands Processed data
I	Not shared	Processor commands and ground commands
J	Not shared	Processor commands and ground commands
K	Not shared	Processor commands and ground commands

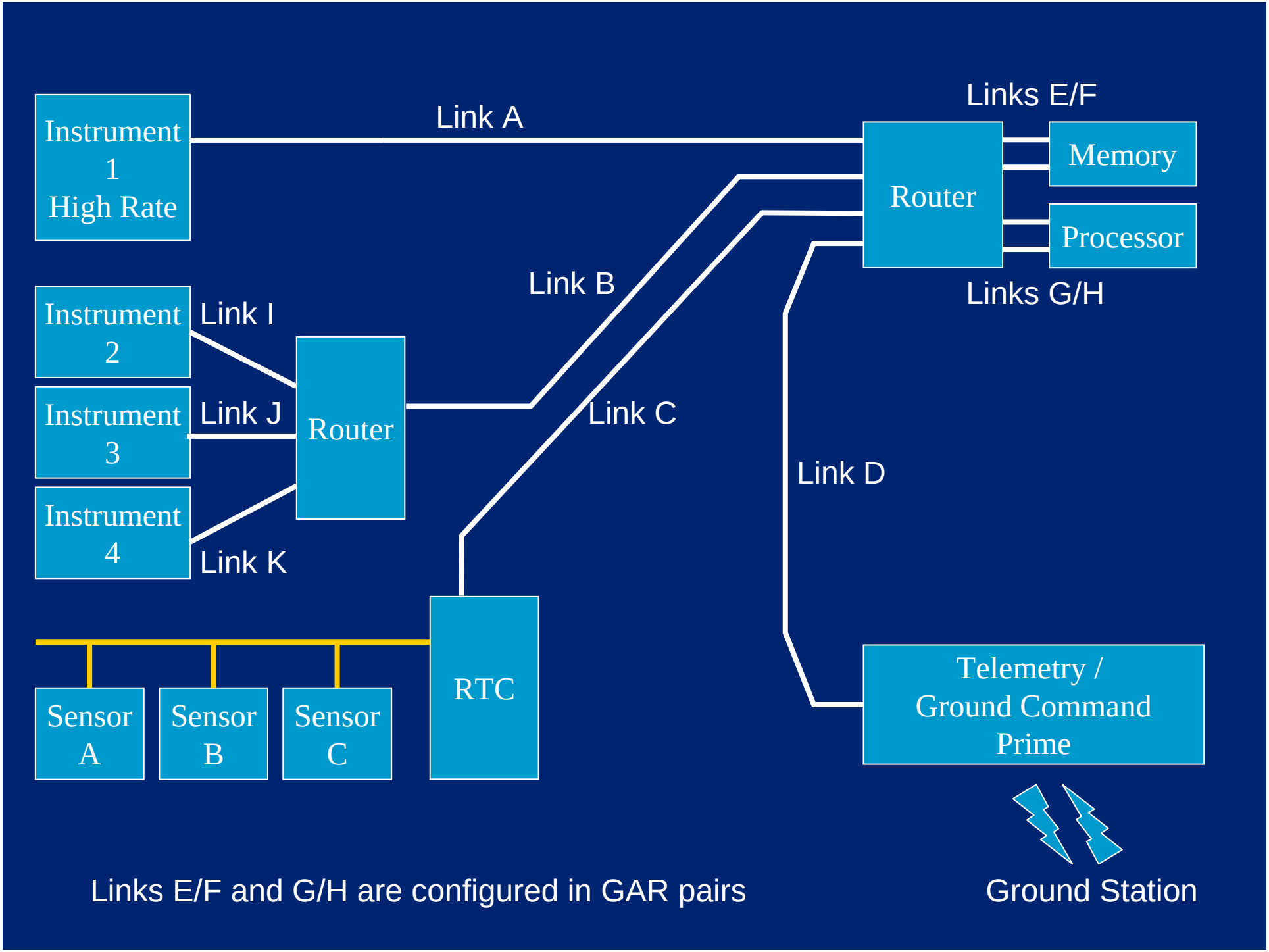

Instrument 1 High Rate
Link A
Links E/F
Router
Memory
Processor
Links G/H
Instrument 2
Link I
Instrument 3
Link J
Instrument 4
Link K
Router
Link B
Link C
Link D
RTC
Sensor A
Sensor B
Sensor C
Telemetry / Ground Command Prime
Ground Station
Links E/F and G/H are configured in GAR pairs

Table 3-2 Channel allocations			
Channel No.	Traffic	Links used L to R / Up	Links used R to L / Down
1	Instrument 1 to memory	A, E/F	
2	Instrument 2 to memory	I, B, E/F	
3	Instrument 3 to memory	J, B, E/F	
4	Instrument 4 to processor for processing	K, B, G/H	
5	RTC sensor data to memory	C, E/F	
6	Processor to memory – processed data	E/F	g/h
7	Memory to telemetry		e/f, d
8	Processor commands to any other unit	E/F	g/h, a, b, c, i, j, k
9	Ground commands to any other unit	D, E/F, G/H	a, b, c, i, j, k

Scheduling

- Delivery of PDUs according to a predefined schedule.
- May be used
  - to support deterministic data delivery
  - to reserve bus/sub-network bandwidth
- Scheduling function splits up the bandwidth on a bus/sub-network using time division multiplexing.
- A number of equal duration time-slots are used.

Time-slots

- Means of dividing network bandwidth between channels
- Equal divisions of time
  - during which a discrete set of communications can take place
- Time-slots distributed by SpaceWire time-codes
- 64 time-code values
- 64 time-slots for minor cycle or epoch
- Used to separate time-slots in a scheduled system
- Used to measuring and allocating bandwidth usage in a bandwidth reserved system

Scheduled System

- When a time-code arrives
- Any node that has a channel scheduled to communicate in that time-slot
- Can send a packet
- Or several short packets
- Or one packet and allow time for a retry

Scheduling

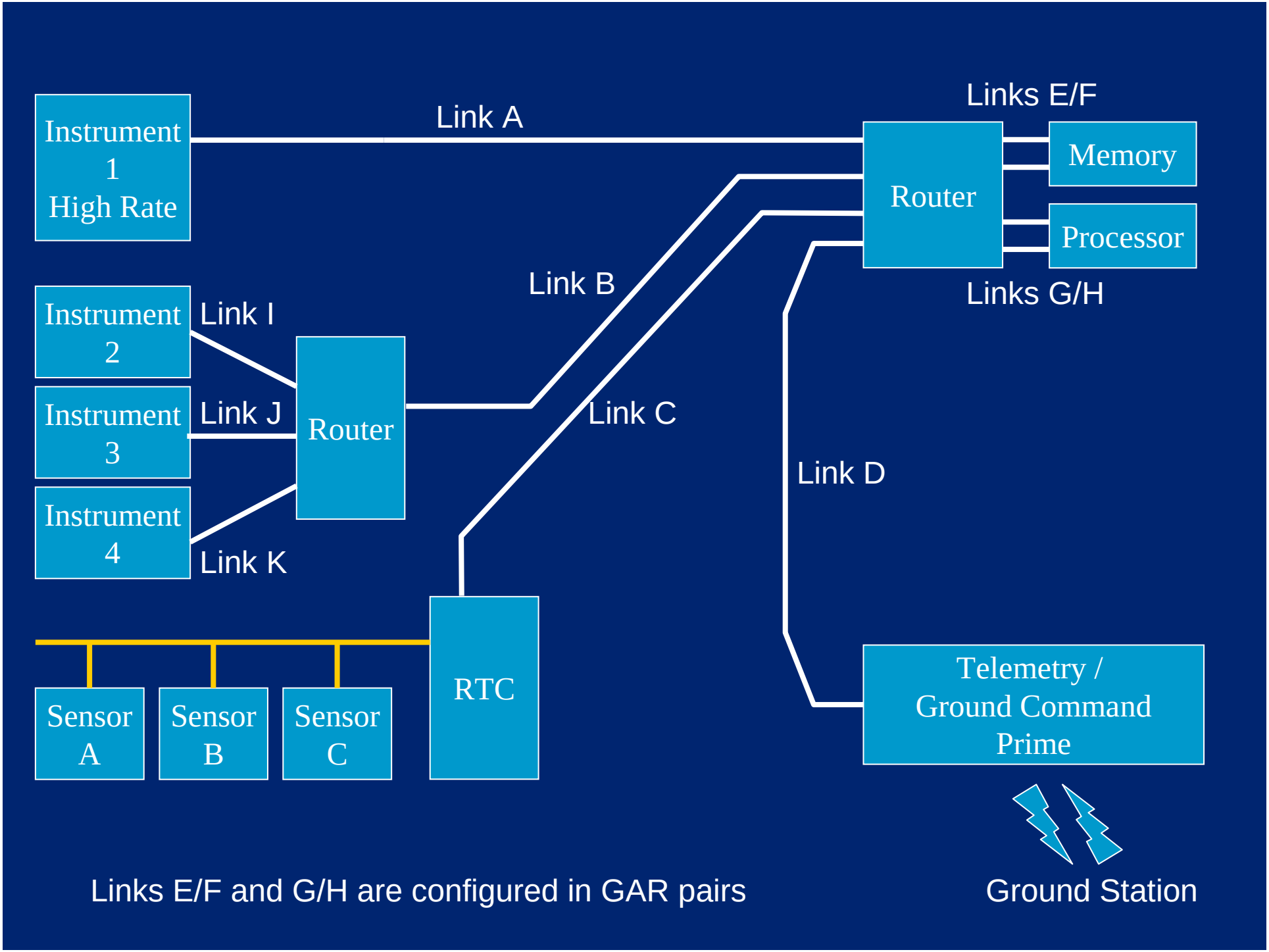
- Knowledge about the communication schedule held in each end-point
- So that they know when (i.e. in which time-slot) they are allowed to transmit data.

Scheduling on SpaceWire

- Channels assigned to time-slots
- So that there is no conflicting resources
- Assignment of channels to time-slots is a schedule table

Slot Allocation in a Scheduled System

	Slot 0	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8	…	Slot 63
Channel 1	A, E/F	A, E/F	A, E/F	A, E/F	A, E/F	A, E/F	A, E/F	A, E/F			A, E/F
Channel 2	I, B, E/F				I, B, E/F						
Channel 3		J, B, E/F									
Channel 4			K, B, G/H								
Channel 5				C, E/F							
Channel 6						g/h, E/F					
Channel 7	e/f, d	e/f, d	e/f, d	e/f, d	e/f, d	e/f, d	e/f, d	e/f, d			e/f, d
Channel 8							E/F, g/h, a,b,c,I,j,k				
Channel 9								D,E/F,G/H a,b,c,i,j,k			D,E/F,G/H a,b,c,i,j,k


Instrument 1 High Rate
Link A
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Links G/H
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Link J
Instrument 4
Link K
Router
Link B
Link C
Link D
RTC
Sensor A
Sensor B
Sensor C
Telemetry / Ground Command Prime
Ground Station
Links E/F and G/H are configured in GAR pairs

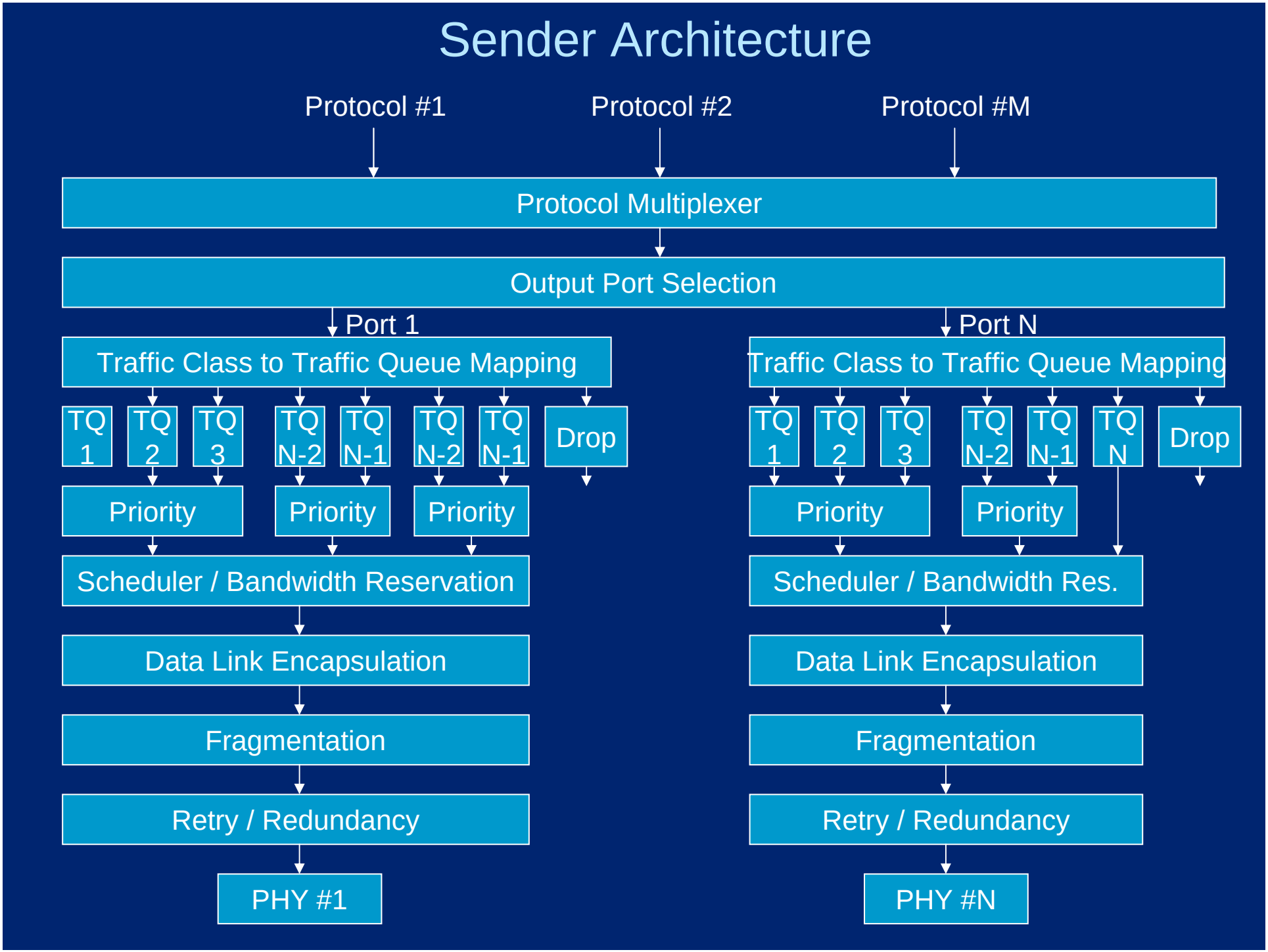
Bandwidth Reservation

- A simple extension of the time-slot concept
- Channels assigned percentage of each link bandwidth
- Percentage utilisation of any specific link must not exceed 100%
- Source keeps track of amount of data sent over each channel
- Channel utilisation
  - Calculated at end of each time-slot
  - In terms of percentage used of Bandwidth for that channel
- When source has several possible packets to send
- It sends the one that is to travel through the channel with lowest channel utilisation
- Source shall not send packet if the channel has 100% utilisation

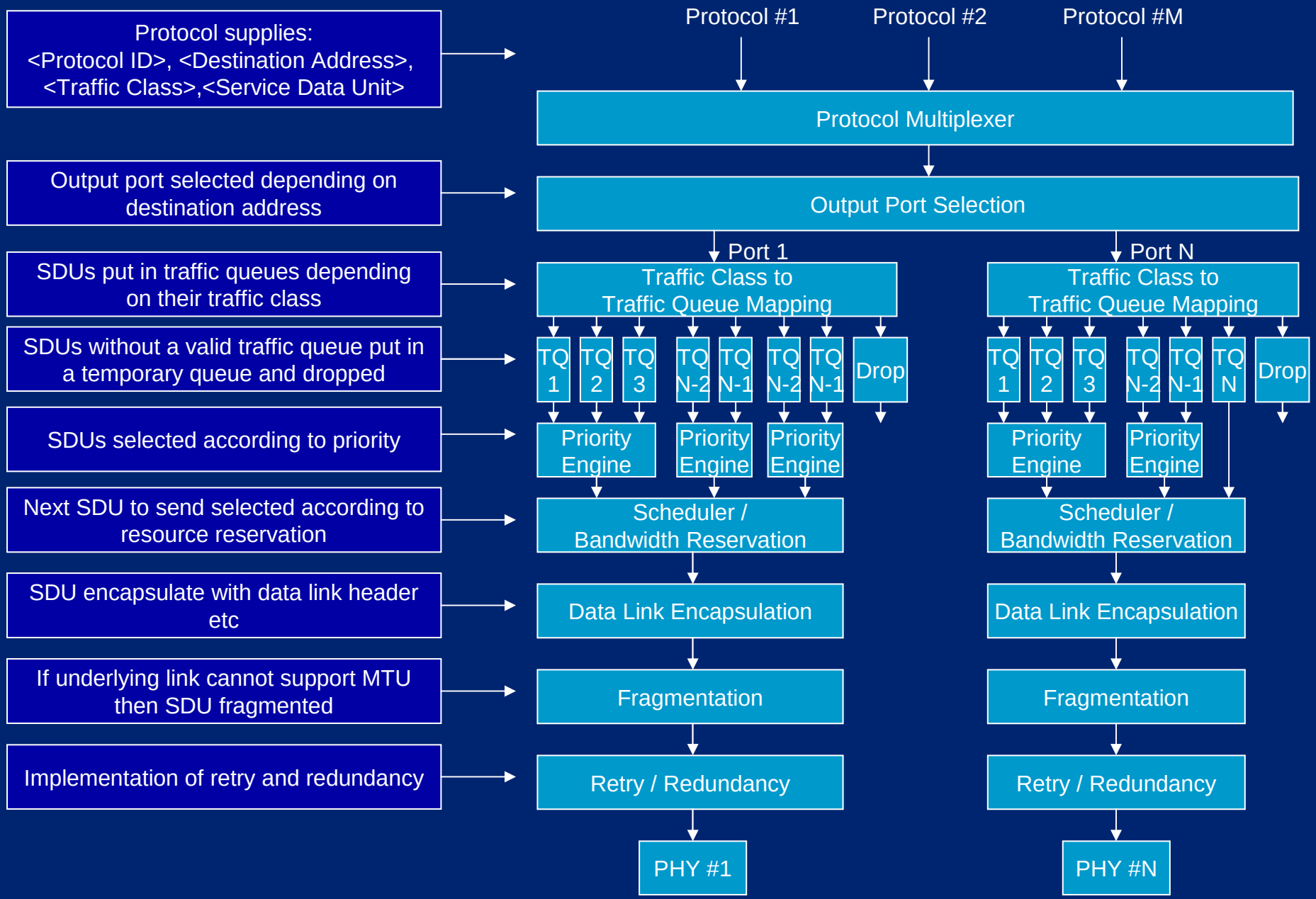
Table 3-3 Channel bandwidth reservation			
Channel No.	Traffic	Resources	Reserved Bandwidth
1	Instrument 1 to memory	A, E/F	100%
2	Instrument 2 to memory	I, B, E/F	25%
3	Instrument 3 to memory	J, B, E/F	12.5%
4	Instrument 4 to processor for processing	K, B, G/H	12.5%
5	RTC sensor data to memory	C, E/F	12.5%
6	Processor to memory – processed data	E/F, g/h	12.5%
7	Memory to telemetry	e/f, d	100%
8	Processor commands to any other unit	E/F, g/h, a, b, c, i, j, k	12.5%
9	Ground commands to any other unit	D, E/F, G/H, g/h, a, b, c, i, j, k	12.5%

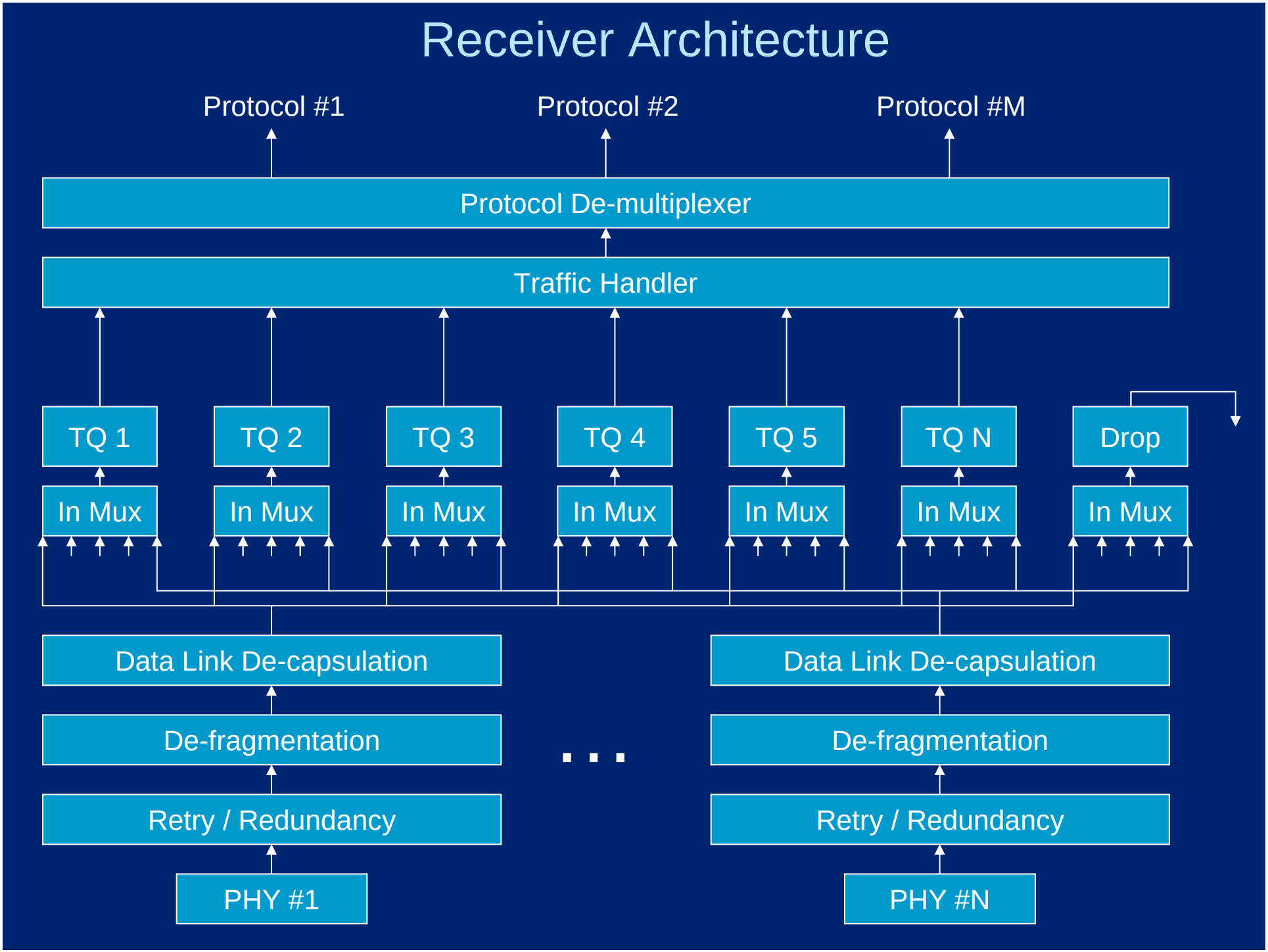
Interface architecture

- Following architectures were derived by
- Greg Menke (NASA GSFC)
- From work of TCONS

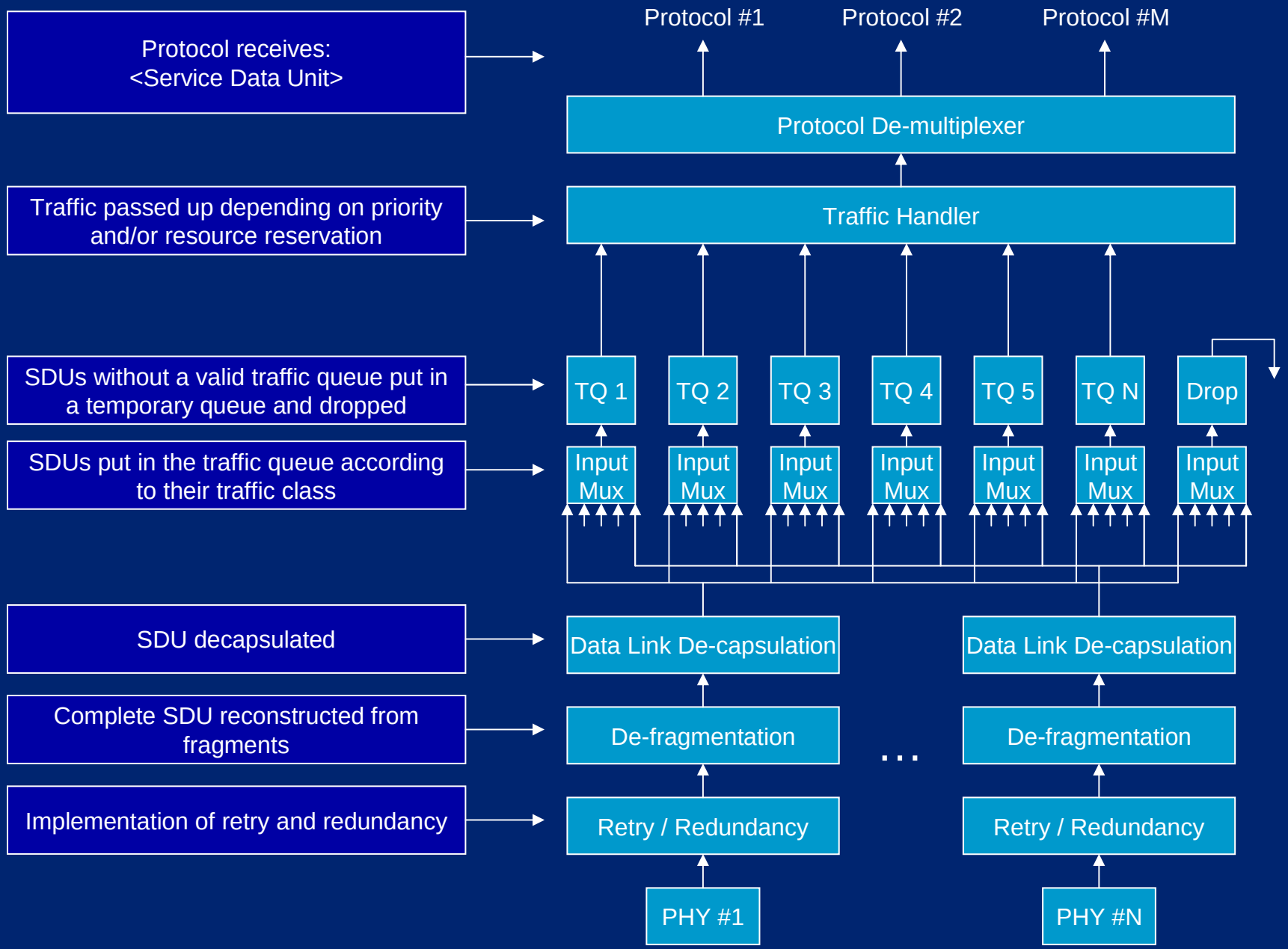

Sender Architecture
Protocol #1
Protocol #2
Protocol #M
Protocol Multiplexer
Output Port Selection
Port 1
Port N
Traffic Class to Traffic Queue Mapping
Traffic Class to Traffic Queue Mapping
TQ 1
TQ 2
TQ 3
TQ N-2
TQ N-1
TQ N-2
TQ N-1
Drop
TQ 1
TQ 2
TQ 3
TQ N-2
TQ N-1
TQ N
Drop
Priority
Priority
Priority
Priority
Priority
Scheduler / Bandwidth Reservation
Scheduler / Bandwidth Res.
Data Link Encapsulation
Data Link Encapsulation
Fragmentation
Fragmentation
Retry / Redundancy
Retry / Redundancy
PHY #1
PHY #N

Sender Architecture




Receiver Architecture
Protocol #1
Protocol #2
Protocol #M
Protocol De-multiplexer
Traffic Handler
TQ 1
TQ 2
TQ 3
TQ 4
TQ 5
TQ N
Drop
In Mux
In Mux
In Mux
In Mux
In Mux
In Mux
In Mux
Data Link De-capsulation
Data Link De-capsulation
De-fragmentation
De-fragmentation
Retry / Redundancy
Retry / Redundancy
PHY #1
PHY #N

Receiver Architecture



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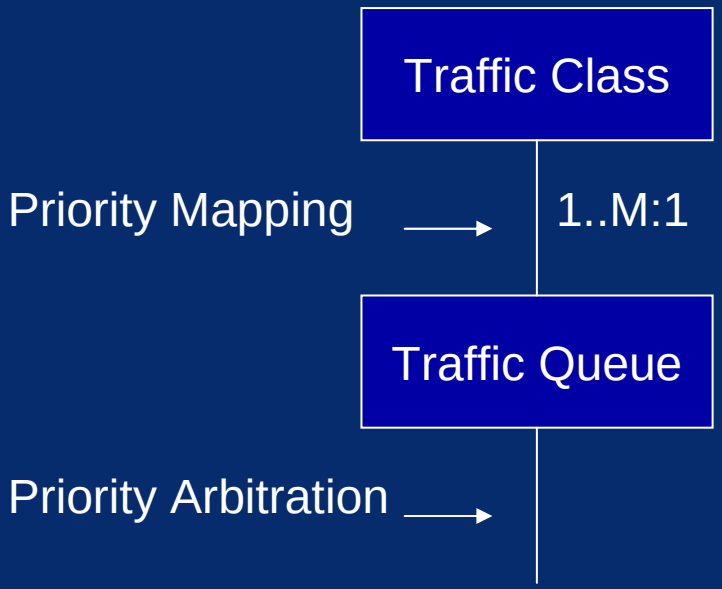
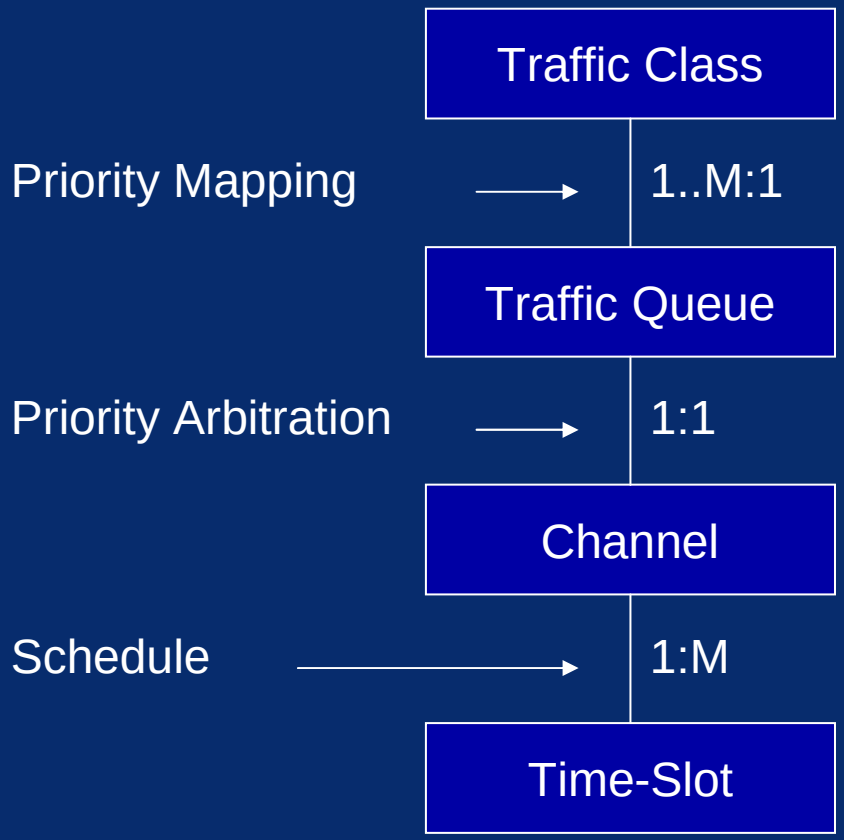
Priority in an Asynchronous System



1:1 means a one to one mapping
1:M means a one to many mapping
1..M:1 means a one to one or many to one mapping

Resource Reservation in a Scheduled System



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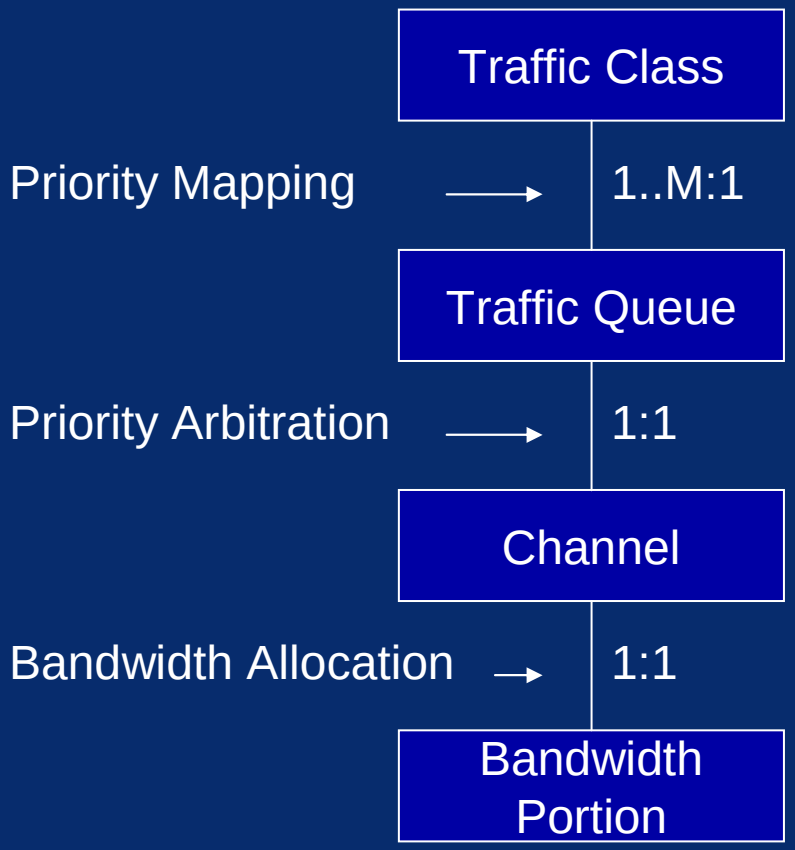
Resource Reservation in an Asynchronous System



1:1 means a one to one mapping
1:M means a one to many mapping
1..M:1 means a one to one or many to one mapping

Conclusions

- Architecture that provides:
  - Uniform interface for communicating over various underlying buses
    - Scheduled
    - Asynchronous
  - Comprehensive QoS for onboard applications
    - Priority
    - Reserved / non-reserved
    - Retry / try once
  - Can be implemented in many different ways
    - E.g. Merging many traffic classes into single traffic queue for simple unit
    - E.g. Multiple traffic queues to support required QoS
    - E.g. Buffered or un-buffered operation
  - Can make use of features of underlying buses
    - E.g. retry mechanism of IEEE1394
    - E.g. group adaptive routing of SpaceWire
  - Missing functions will be defined in a common way

Conclusions

- Presented initial mapping of SpaceWire to CCSDS SOIS
- Based on TCONS architecture (April 2006)
- QoS concepts now adopted by CCSDS SOIS
  - Best Effort
  - Assured
  - Resource Reserved
  - Guaranteed Delivery
- Initial definition of SpaceWire mapping of:
  - Packet delivery service
- Other services need to be considered
- Consistent QoS is very important
- Software interoperability also very important
  - NASA GSFC have defined API