SpaceWire-RT

Steve Parkes, Albert Ferrer-Florit
Space Technology Centre,
University of Dundee

Space Technology Centre
University of Dundee

Contents: Concepts

- Background
- Communications Model
- Protocol Stack
- Service Interfaces
- Operation of SpaceWire Protocol Stack
- Asynchronous and Scheduled Systems
- Quality of Service
- Channels

Concepts: Architecture (1)

- User Application Interface
- Segmentation
- Address Translation
- Error Detection
- Redundancy
- Priority

- Asynchronous Retry
- Asynchronous Flow Control
- Asynchronous Encapsulation

Concepts: Architecture (2)

- Scheduling
- Shared Resources
- Scheduled Retry
- Scheduled Flow Control
- Time-Slot Timing
- Scheduled Encapsulation

- Network Management

Space Technology Centre
University of Dundee

Current Specification Background

- Requirements agreed by SpW Working Group
  - Feb 2008
- Requirements from CCSDS SOIS
  - QoS
    - Best Effort,
    - Assured,
    - Resource-Reserved,
    - Guaranteed
  - Services
    - Memory Access,
    - Packet Transfer,
    - Plug and Play
    - Also Time-Distribution and Test

Space Technology Centre
University of Dundee

Current Specification Background

- Extensive prototyping to confirm concepts and ease of implementation
- Specification Draft 2.0
  - Reviewed by ESA and SciSys
  - ~80 RIDs addressed
  - Updated document distributed to ESA/SciSys
  - No further comments
- Resulting Draft 2.1 specification distributed to SpW Working Group
- Some corrections/clarifications been added
- Will be re-issued as draft 2.2 following this meeting

WARNING

The current document is an early draft of the proposed standard and is for discussion purposes only. It will change after prototyping work has been completed. Applicable documents may also change.

DO NOT USE THIS DOCUMENT TO DESIGN DEVICES OR SYSTEMS!

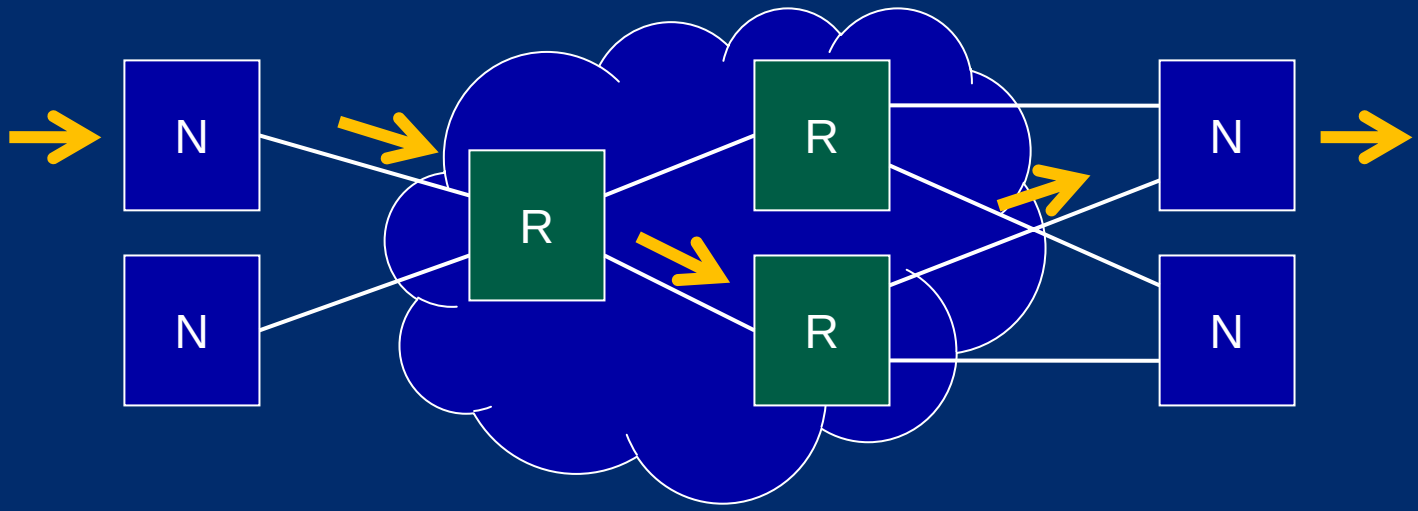
Space Technology Centre
University of Dundee

SpaceWire Paradigm

- Point to point links
- Stream service
  - I.e. Inputs and outputs are FIFOs
- No quality of service control
- No reservation of memory at destination
- Link level flow control
  - used to prevent FIFO overflow

Space Technology Centre
University of Dundee

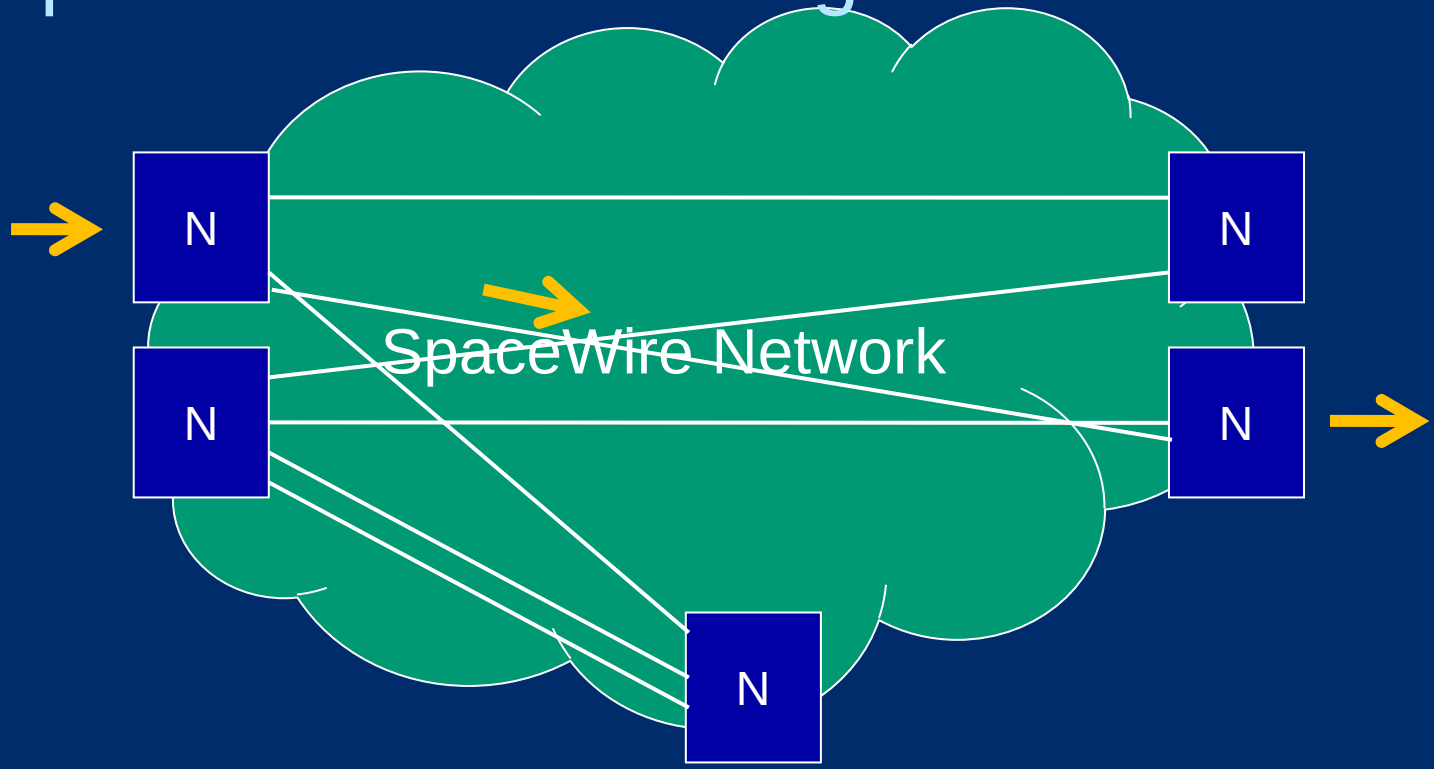
SpaceWire Paradigm



- Networks route data from source to destination
- Interface to network is same as that for point to point links
- Destination address added to each packet

Space Technology Centre
University of Dundee

SpaceWire-RT Paradigm



- Conceptual (virtual) point to point links
- Stream service
- Any SpaceWire packet over SpW-RT
- Adds QoS to SpaceWire paradigm
- Does not provide management of memory

Space Technology Centre
University of Dundee

SpaceWire RMAP

- Remote Memory Access Protocol
- RMAP service runs over SpaceWire
- Means of reading and writing to memory
  - Of a remote node
  - Over SpaceWire network
- Supports
  - Device configuration, control & monitoring
  - Transfer of data from instrument to memory etc
- Mechanism for managing access to memory in remote node

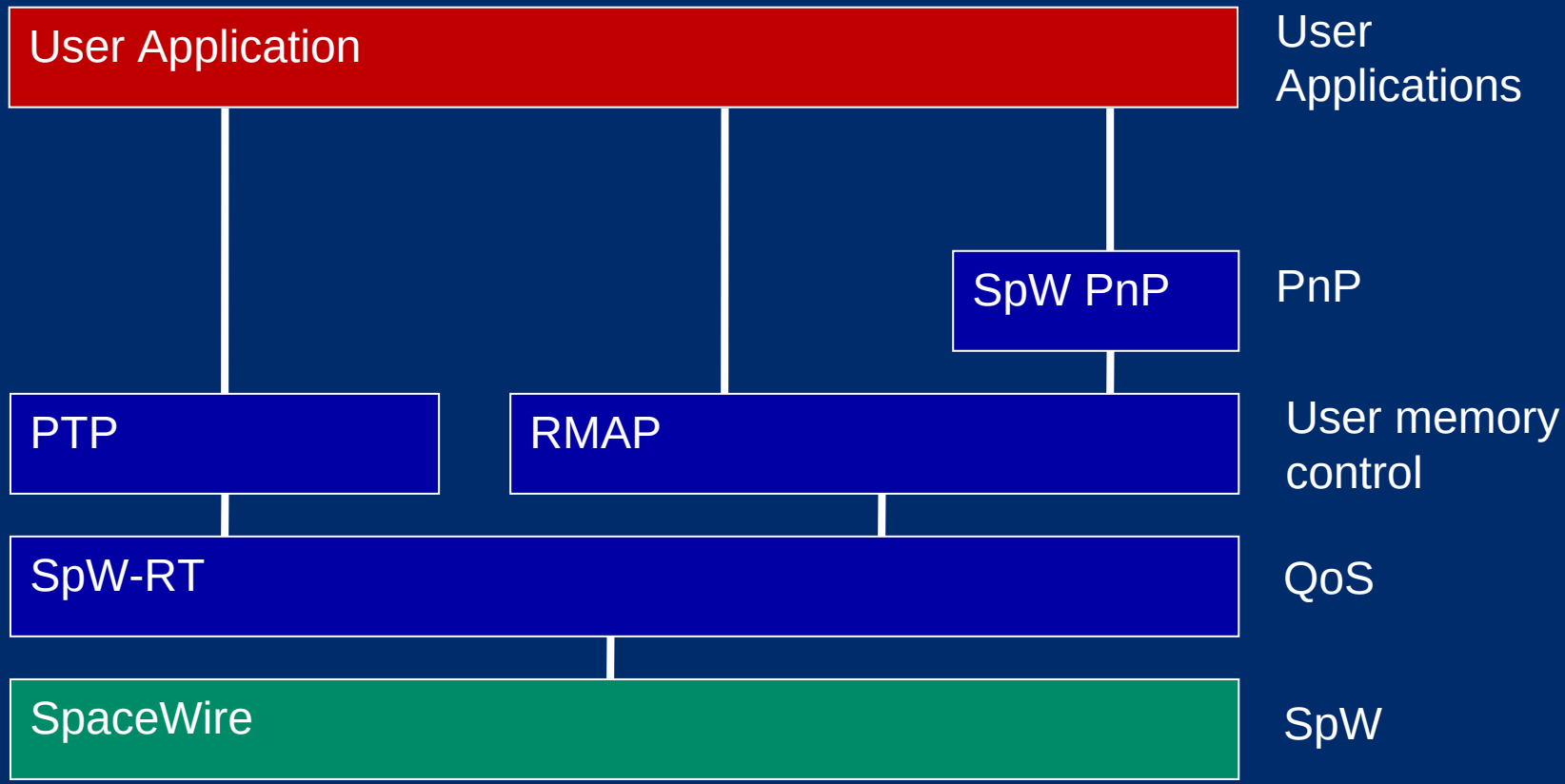
Space Technology Centre
University of Dundee

SpaceWire-PnP

- SpaceWire Plug and Play
- Mechanisms for:
  - Consistent configuration of nodes and routers
  - Discovering presence of nodes on a network
- Designed to use RMAP protocol
  - To reduce additional hardware needed

Space Technology Centre
University of Dundee

SpaceWire Protocol Stack

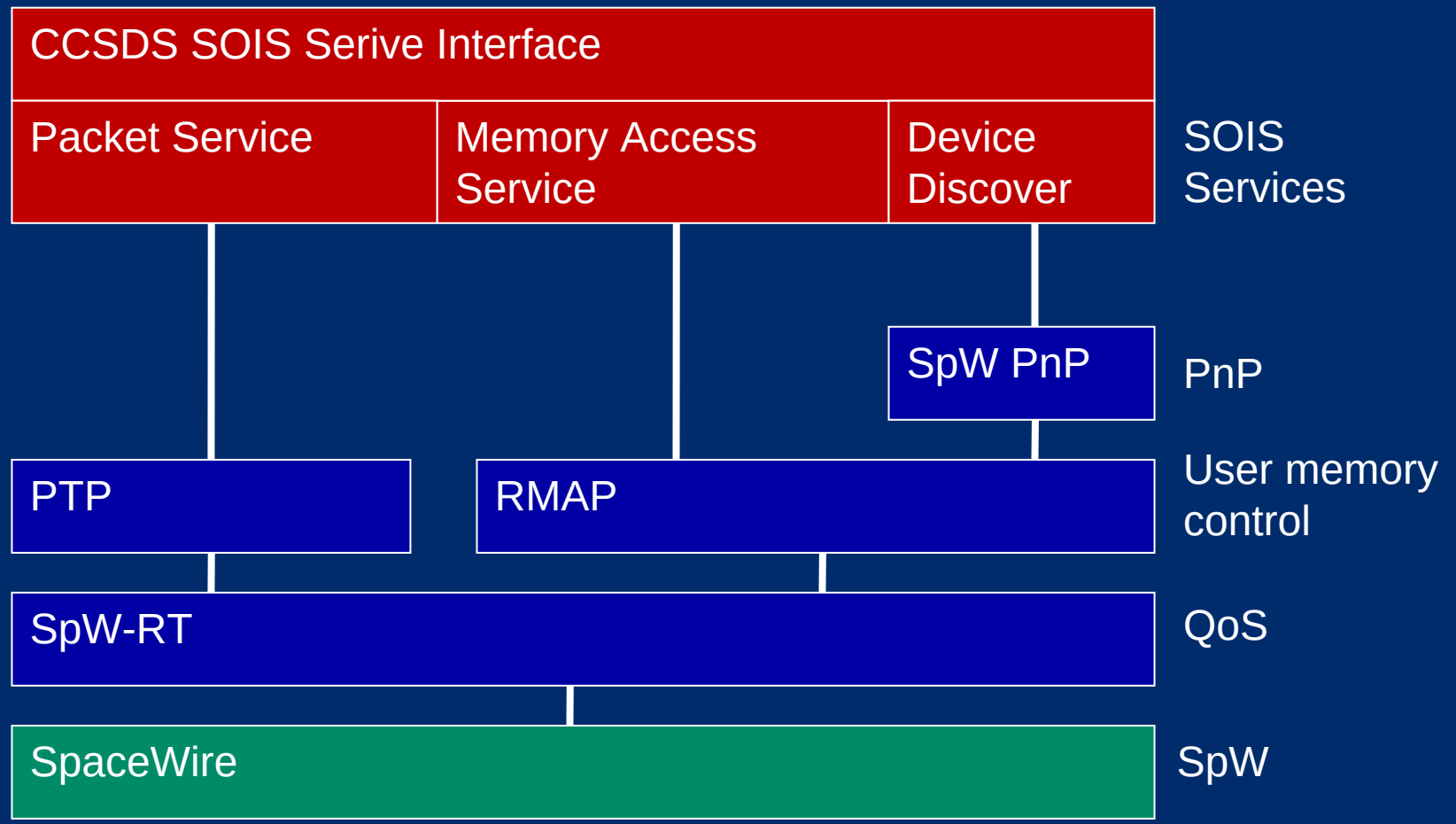


Space Technology Centre
University of Dundee

User Memory Control

- RMAP
  - An end to end application for SpaceWire
  - Reads, writes and RMWs to remote memory
  - Provides management of memory
  - E.g. Write command
    - When write command arrives at destination
    - Have to get authorisation
    - Before writing to user memory
- SpW Packet Transfer Protocol
  - Another end to end application for SpaceWire
  - Transfers user packets across SpaceWire network
  - Provides management of memory
    - I.e. Flow control
    - Check user buffer ready for packet before sending it.

CCSDS SOIS – SpaceWire Protocol Stack



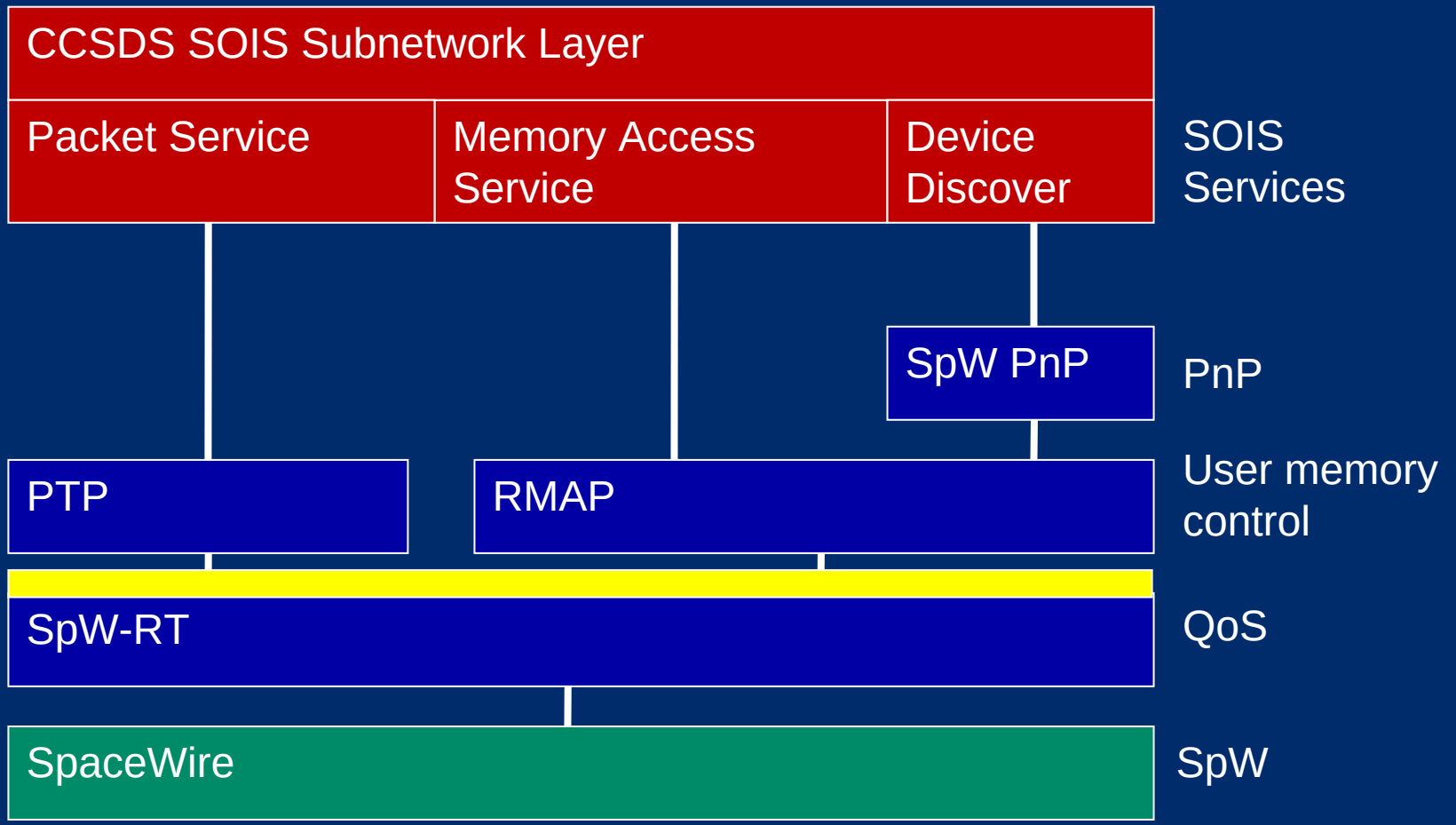
Space Technology Centre
University of Dundee

Space Technology Centre
University of Dundee

SOIS Services

- Memory Access Service
  - Reads and writes to “user” memory
  - Requires management of “user” memory
  - Various QoS requirements
  - “User” memory considered part of sub-network
- Packet Delivery Service
  - Delivers packets from source to destination
  - Requires management of packet buffers
  - Various QoS requirements
- Device Discovery Service
  - Discovers (new) devices on the network
- Synchronisation Service
- Test Service

SpaceWire-RT Service Interface



Space Technology Centre
University of Dundee

Space Technology Centre
University of Dundee

SpaceWire-RT Service Interface

- Send_Data.request
  - Requests to send a Service Data Unit (SDU)
    - From source node where request is made
    - To destination node on SpaceWire network
- Parameters:
  - channel,
  - source address,
  - destination address,
  - cargo.

SpaceWire-RT Service Interface

- Receive_Data.indication
  - Indicates SpaceWire-RT packet received
  - Passes SDU it carried to SpaceWire-RT user;
- Parameters:
  - channel,
  - source address,
  - destination address,
  - cargo.

Space Technology Centre
University of Dundee

SpaceWire-RT Service Interface

- Notify_Delivered.indication
  - Indicates SDU was safely delivered to destination
  - Over a channel providing assured or guaranteed service
- Parameters:
  - channel,
  - source address,
  - destination address,
  - SDU_ID
    - need to make sure this is known by the user application

Space Technology Centre
University of Dundee

SpaceWire-RT Service Interface

- Notify_Error.indication
  - Indicates problem delivering the SDU
  - Over channel that provided assured or guaranteed service
- Parameters:
  - channel,
  - source address,
  - destination address,
  - SDU_ID,
  - error metadata.

Space Technology Centre
University of Dundee

SpaceWire-RT Service Interface

- Open.request
  - Opens a channel
- Parameters:
  - source,
  - destination,
  - channel,
  - configuration information.

SpaceWire-RT Service Interface

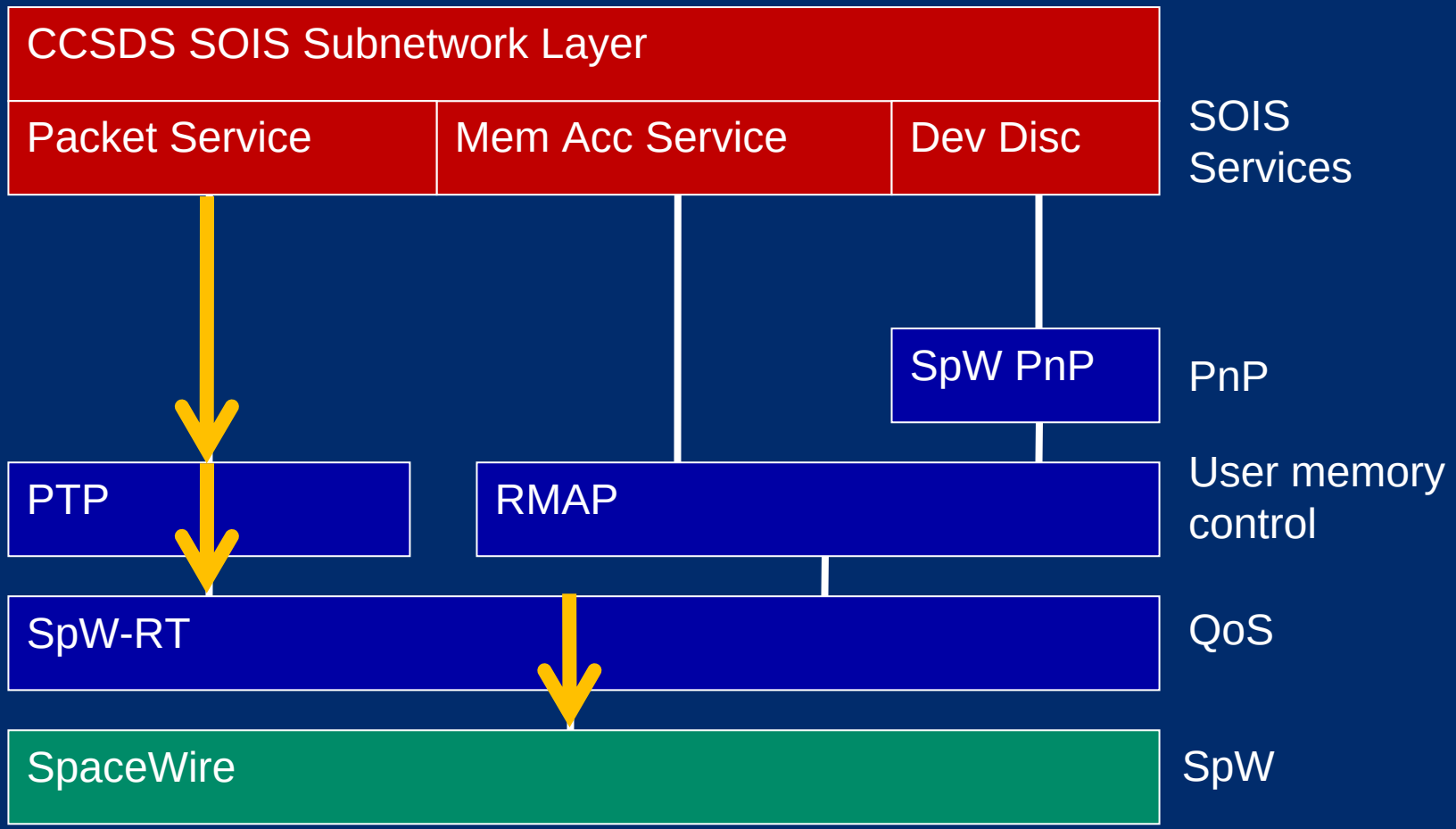
- Close.request
  - Closes a channel
- Parameters:
  - source,
  - destination,
  - channel.

SpaceWire-RT Service Interface

- Redundancy_Invocation.indication
  - Indicates that one or more retries or redundancy switching were invoked for a channel.
- Parameters
  - channel,
  - reliability metadata

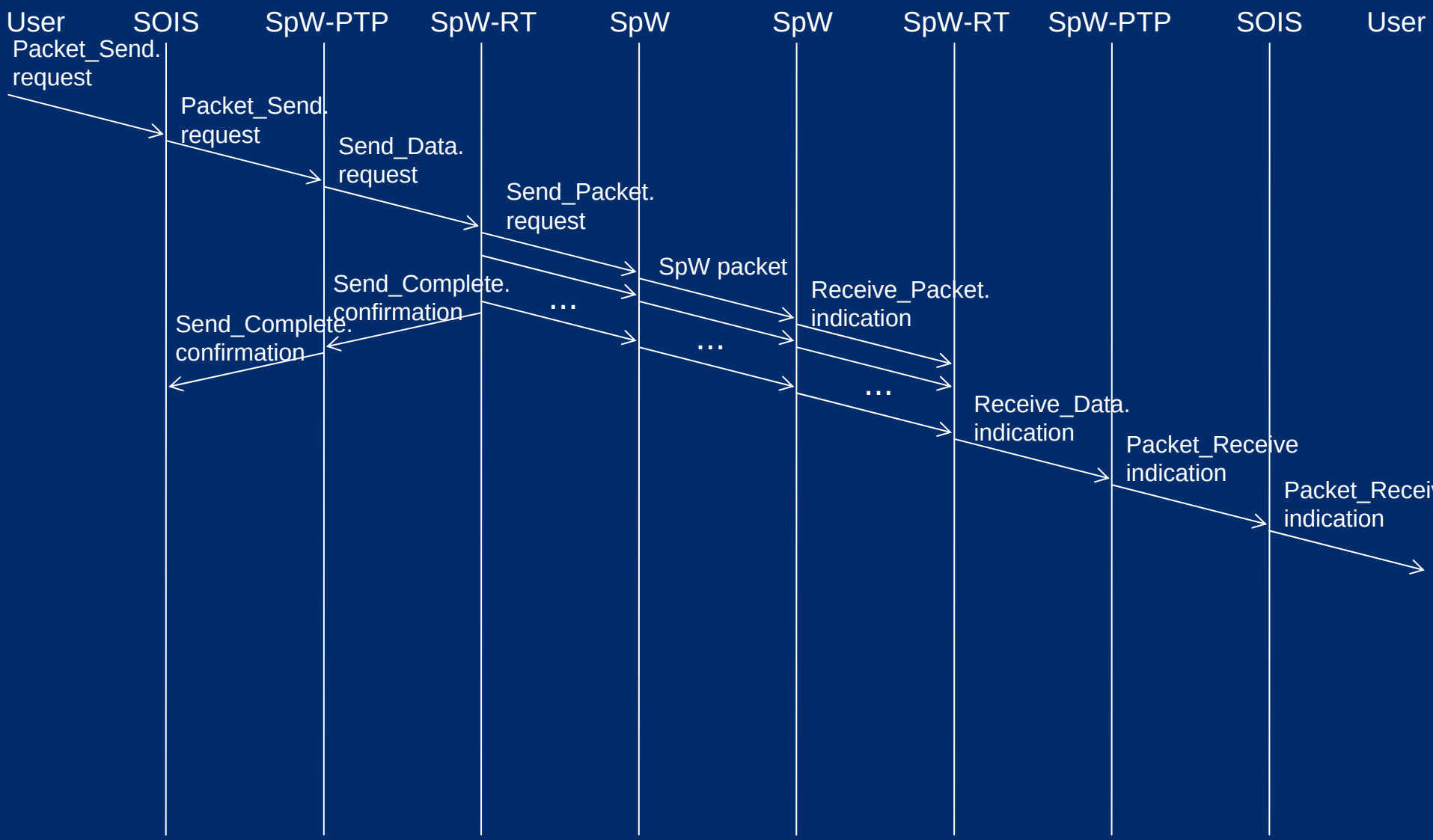
Protocol Stack and Service Interface Example

- Example
  - Packet Transfer

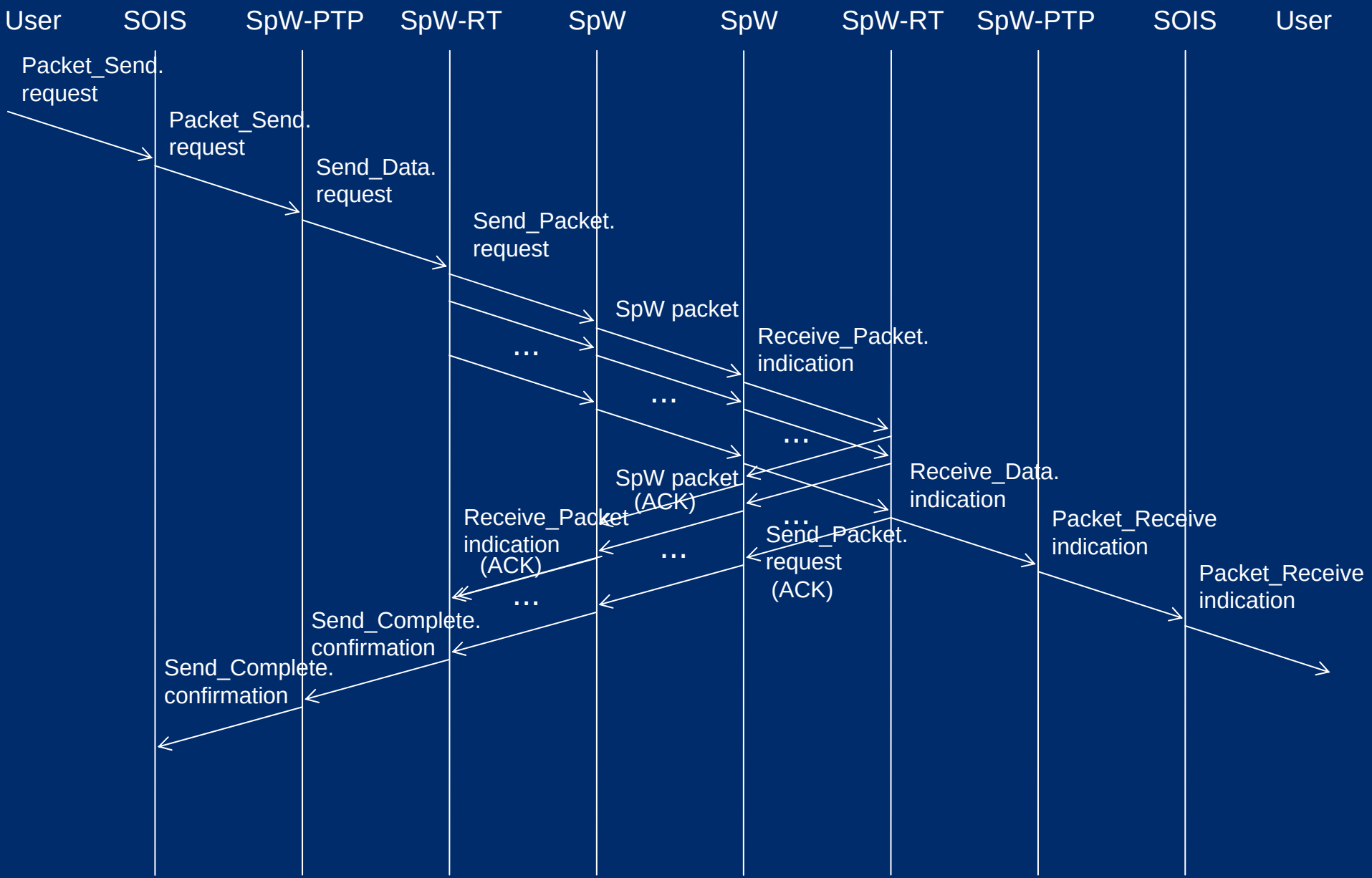


Space Technology Centre
University of Dundee

Packet Transfer – Best Effort QoS



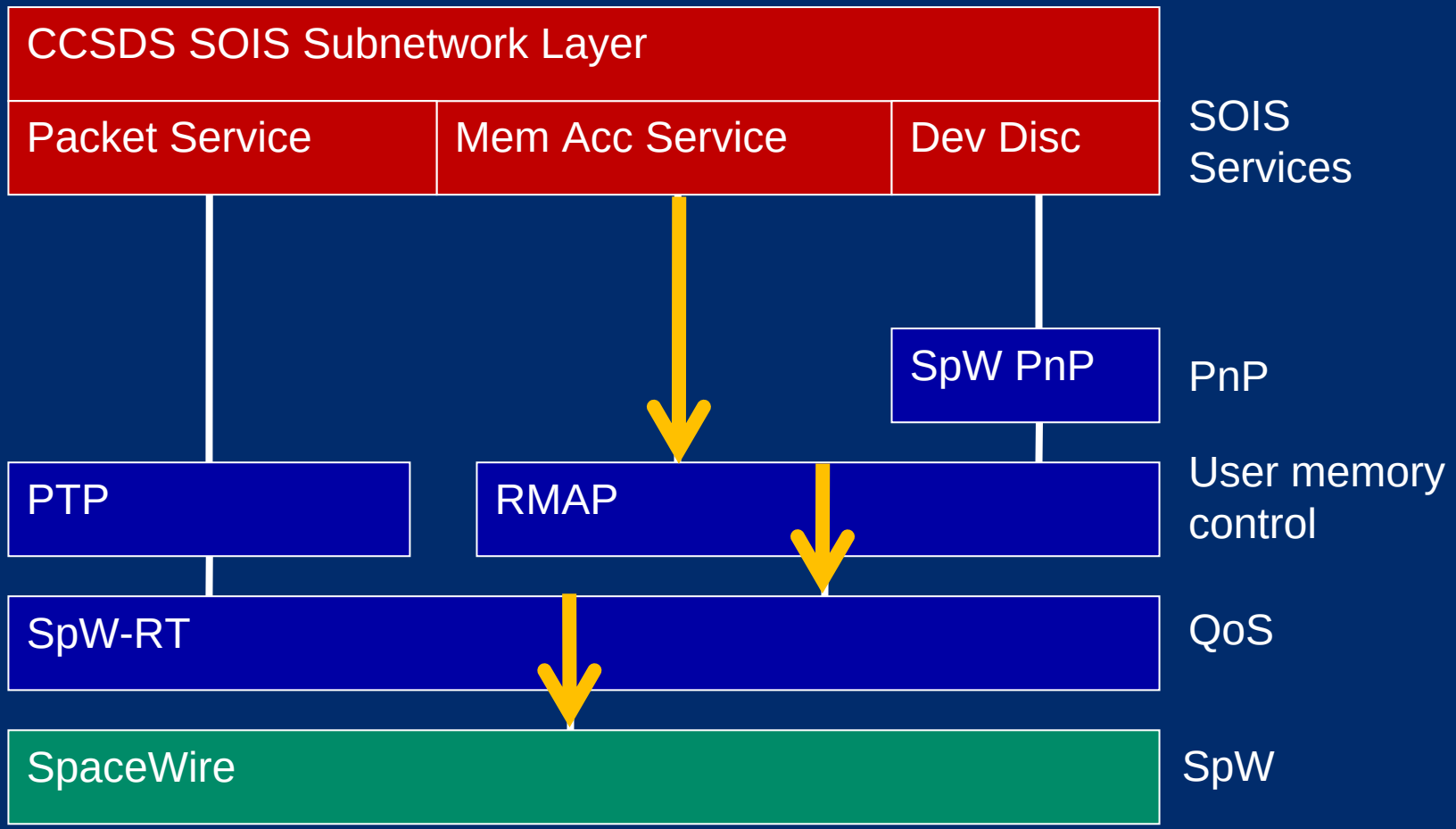
Packet Transfer – Assured QoS



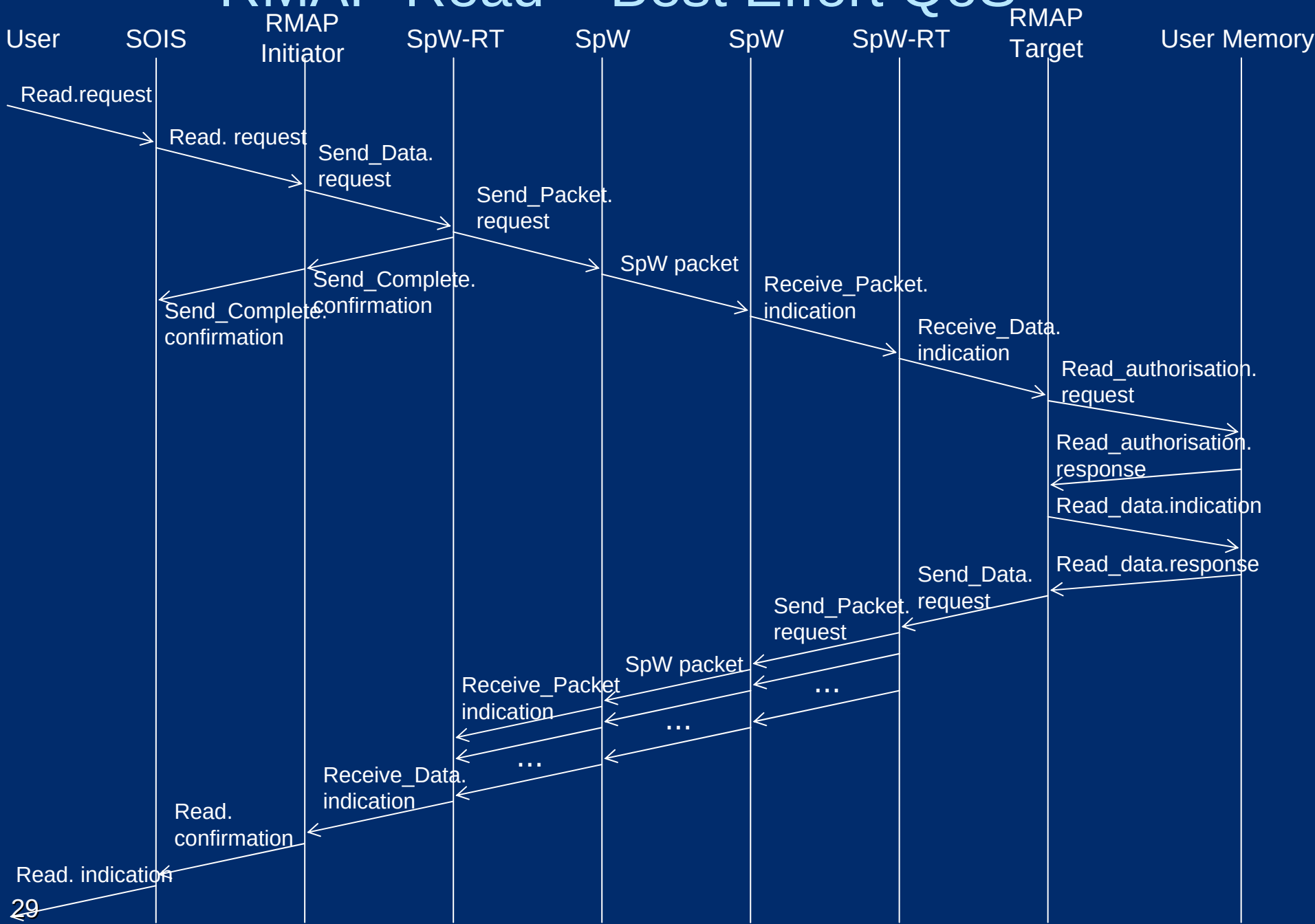
Space Technology Centre
University of Dundee

Protocol Stack and Service Interface Example

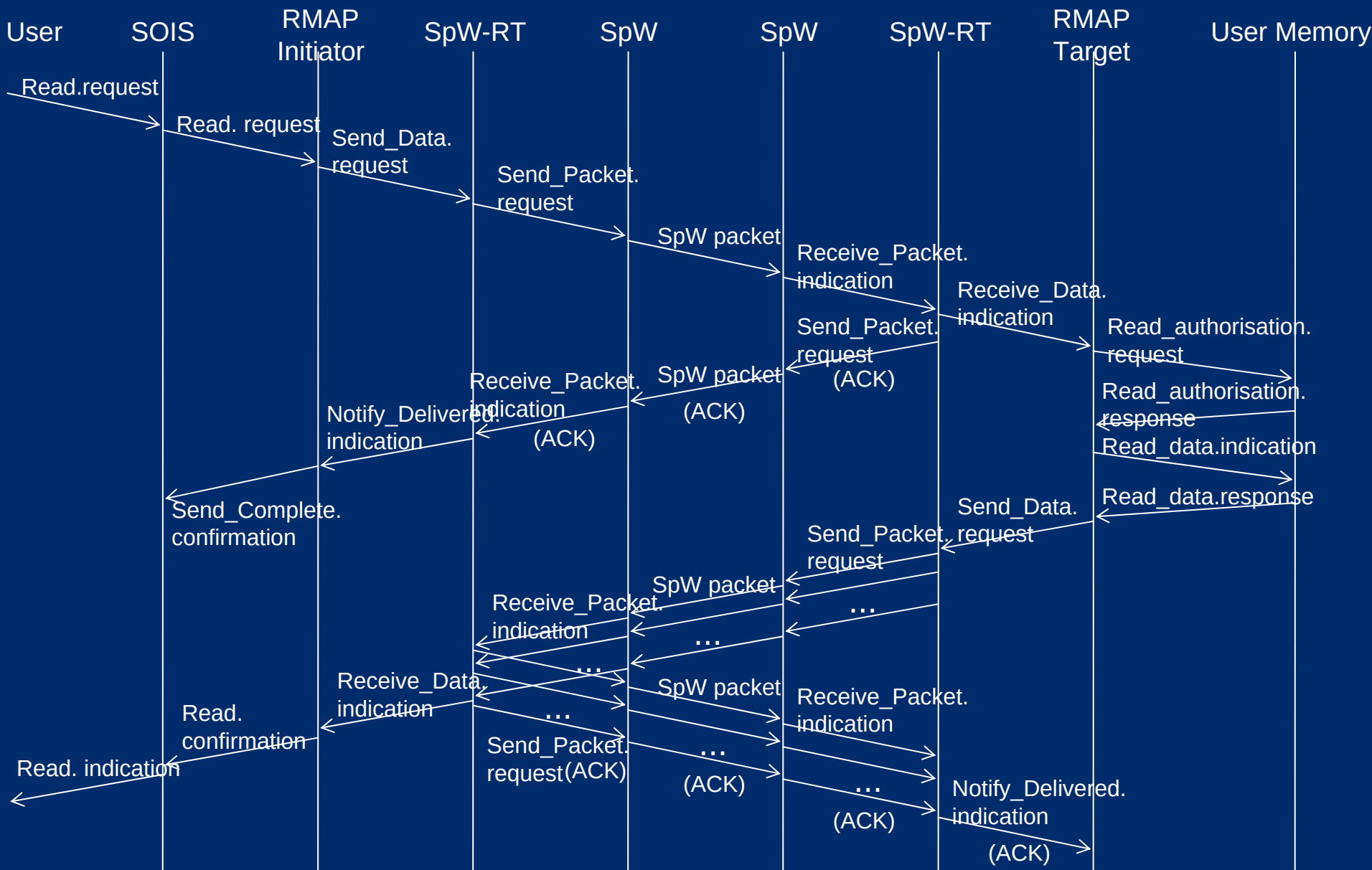
- Example
  - Memory Read



RMAP Read – Best Effort QoS



RMAP Read – Assured QoS



Space Technology Centre
University of Dundee

SpaceWire-RT Qualities of Service

- Basic
  - Does not ensure delivery (no retry)
  - May deliver duplicate or out of sequence data PDUs
  - Not timely (no time constraints)
- Best Effort
  - Similar to Basic QoS
  - Does not deliver duplicate or out of sequence data PDUs
- Assured
  - Reliable (retries in event of error)
  - Not timely

SpaceWire-RT Qualities of Service

- Resource Reserved
  - Does not ensure delivery (no retry)
  - When a DP is delivered it is delivered on time
    - Deterministic
- Guaranteed
  - Reliable (retries in event of error)
  - Timely (delivers on time)
    - Deterministic

Asynchronous and Scheduled Systems

- Two types of system supported:
- Asynchronous
  - Sending information is asynchronous
  - Priority used to provide timeliness
  - Basic, Best Effort and Assured QoS only
- Scheduled
  - Network bandwidth split up using time-slots
  - Each source channel assigned one or time-slots
    - When it is allowed to send data
  - Provides deterministic delivery
  - Support all QoS classes

Schedule using Time-slots

	Time-slot										
Channel	0	1	2	3	4	5	6	7	8	…	63
41/70/1											
52/70/1											
53/70/1											
54/70/1											
60/60/1											
80/70/1											
80/54/1											

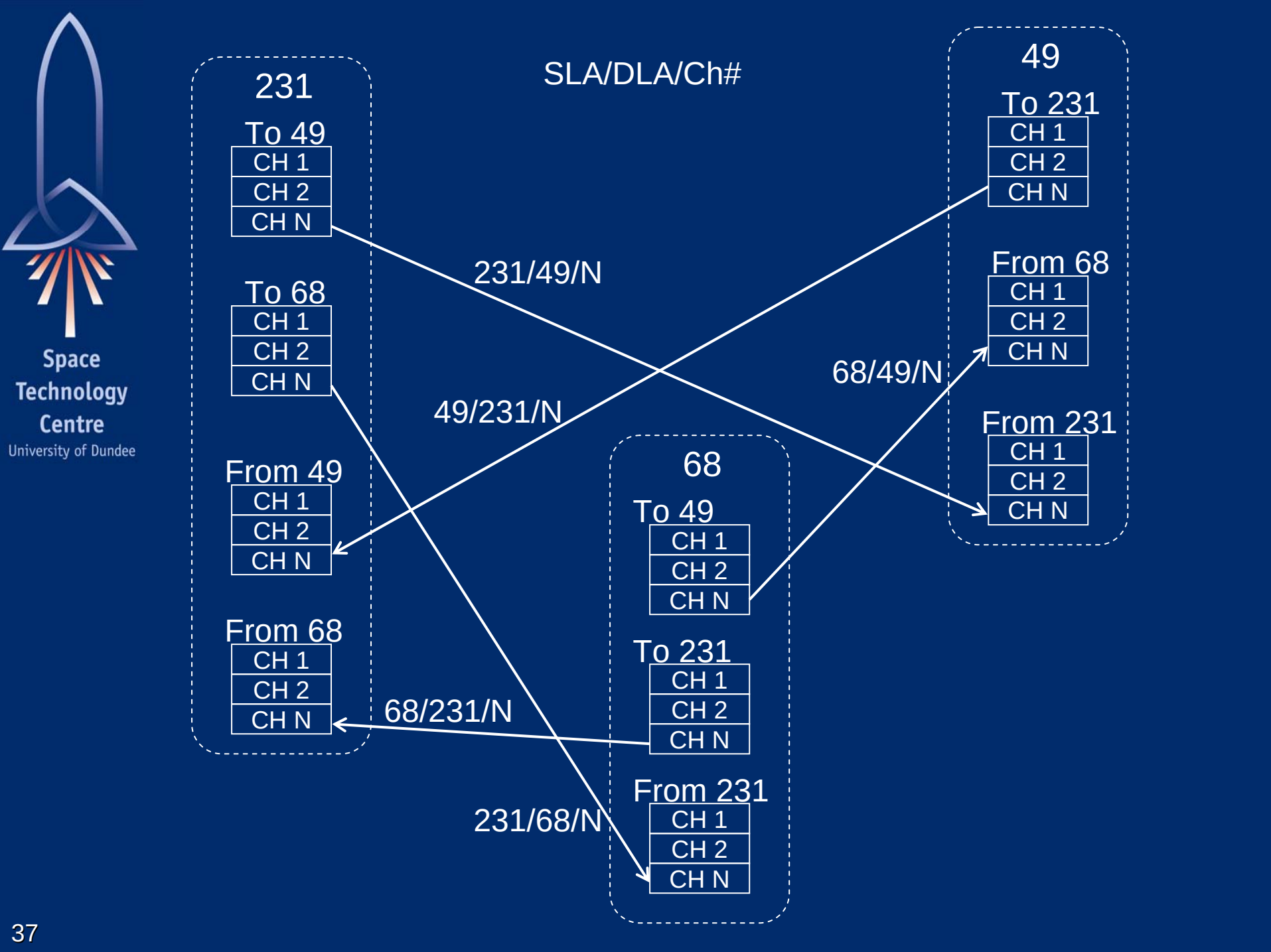
Source / Destination / Channel Number

QoS in Scheduled Network

- Guaranteed
- Resource-reserved
- Allocated
  - Basic
  - Best Effort
  - Assured
- Opportunistic
  - Basic
  - Best Effort
  - Assured

Channels

- Channel = virtual point to point link
- Channel is:
  - Set of network resources
  - Connects SpW-RT user in source
  - To SpW-RT user in destination
  - Uni-directional
- Includes:
  - Source channel buffer (like a FIFO)
  - SpaceWire links over which data PDUs travel
  - Destination channel buffer (like a FIFO)
- Channel specified by
  - Source / destination / channel number
  - E.g. 231 / 82 / 3


Space Technology Centre
University of Dundee
SLA/DLA/Ch#
231
To 49
CH 1
CH 2
CH N
To 68
CH 1
CH 2
CH N
From 49
CH 1
CH 2
CH N
From 68
CH 1
CH 2
CH N
231/49/N
49/231/N
68/231/N
231/68/N
49
To 231
CH 1
CH 2
CH N
From 68
CH 1
CH 2
CH N
From 231
CH 1
CH 2
CH N
68/49/N
68
To 49
CH 1
CH 2
CH N
To 231
CH 1
CH 2
CH N
From 231
CH 1
CH 2
CH N

Space Technology Centre
University of Dundee

Architecture

Architecture

- User interface
  - Interface to users of SpaceWire-RT
- Segmentation
  - Chops SDUs into chunks to send in Data PDUs (DPs)
  - Ensures that a large SDU does not hog the SpW network
- End to end flow control
  - Check destination buffer ready before sending packet
  - Ensures that DPs accepted immediately by destination to prevent blocking

Architecture

- Retry
  - Resends DPs that are lost or arrive with errors
  - Uses acknowledgement to confirm receipt
- Error detection
  - CRC used in DP header and cargo
  - Error detection used for retry and redundancy switching
- Redundancy
  - Alternative paths through SpaceWire network
  - Retry N times then switch to redundant path
  - Simultaneous retry for critical applications

Architecture

- Address translation
  - SpW logical addresses used to identify nodes
  - Translates from logical address to path or logical address
  - Includes prime/redundant path addresses
- PDU Encapsulation
  - Wraps data PDUs with necessary header information
  - Encodes ACKs, BFCTs, etc

Architecture

- Resource reservation
  - Asynchronous network:
    - Priority
  - Scheduled network:
    - Time-codes sent periodically (e.g. 100 µs)
    - Divide time into time-slots
    - One source can send in any one time-slot
      - Avoids conflicting use of network resources
    - Or several sources can send if they do not use the same network resources – i.e. links

Space Technology Centre
University of Dundee

User Application Interface

- QoS layer for SpaceWire
- Any SpaceWire application can run over RT
- SpW-RT uses same conceptual model as SpaceWire
- User interface is via source and destination channel buffers
  - User writes information into a source buffer
  - SpaceWire-RT transfers this information across the SpaceWire network
  - User reads information from destination buffer

User Application Interface

- User interface in source:
  - Source
    - logical address of source node
  - Destination
    - logical address of destination node
  - Channel number
    - Specific channel between source and destination
    - Defines QoS
  - Cargo
    - Information that is to be sent
  - Separator
    - Distinguishes one user data entity from next

User Application Interface

- User interface in destination:
  - Indication
    - New piece of user information has started to arrive
  - Source
    - logical address of source node
  - Destination
    - logical address of destination node
  - Channel number
    - Specific channel between source and destination
    - Defines QoS
  - Cargo
    - Information that has been received
  - Separator
    - Distinguishes one user data entity from next

Segmentation

- Segmentation allows multiple, large, user data entities to be transferred at the same time - interleaving
- Each SpW-RT data PDU can carry up to 256 bytes of user information
- Large user data entities have to be slit up into 256 byte segments
- Split into one or more data PDUs containing 256 bytes user information
- Followed by zero or one data PDUs containing fewer than 256 bytes user information

Address Translation

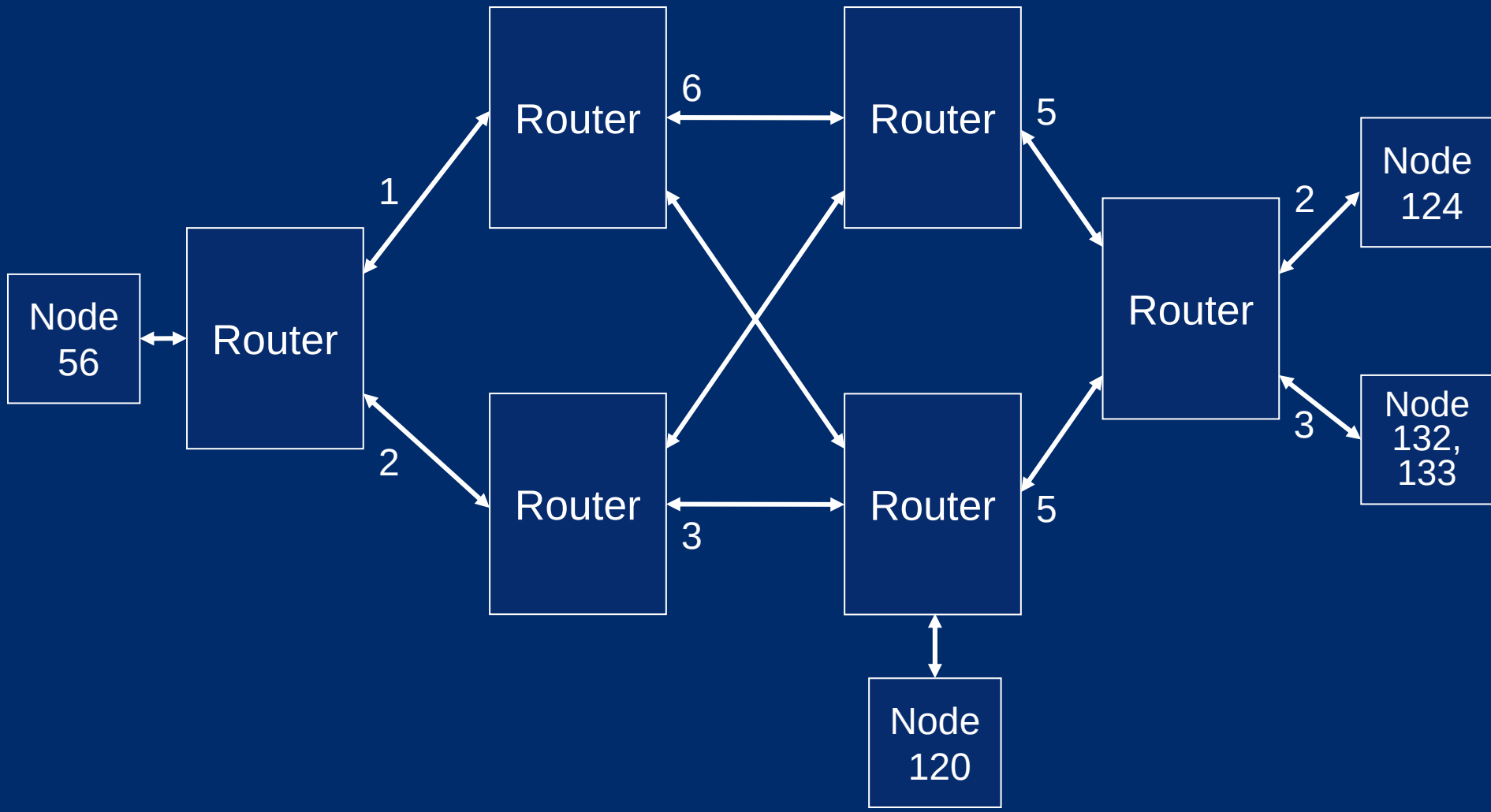
- Nodes identified using SpaceWire logical addresses.
  - A unit can have more than one SpaceWire logical address
  - Only one node can have a specific logical address
- Up to 223 logical addresses
  - Sufficient for most spacecraft applications
- Routing can be done with path and/or logical addressing
- Node identification done with logical addresses

Address Translation

- Address translation
  - From node identity logical address
  - To path/logical address for routing
- Type of address used for routing depends on redundancy approach

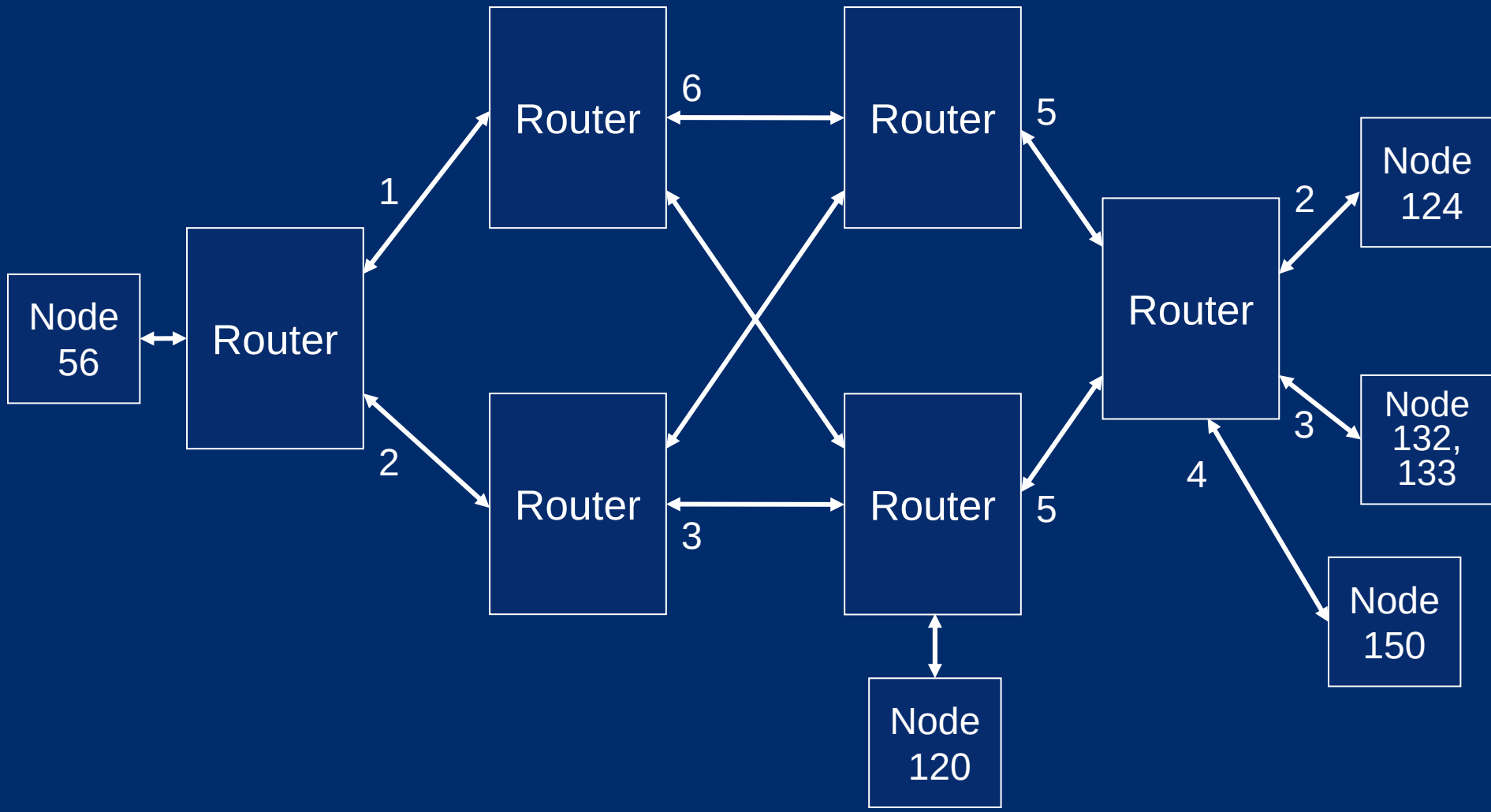
Address Translation

SpaceWire Logical Address	Priority	Prime SpaceWire Address	Redundant SpaceWire Address
120	-	120	120
124	-	1, 6, 5, 2, 124	2, 3, 5, 2, 124


Node 56
Router
1
2
Router
Router
6
3
Router
Router
5
5
Router
2
3
Node 124
Node 132, 133
Node 120

Address Translation

SpaceWire Logical Address	Priority	Prime SpaceWire Address	Redundant SpaceWire Address
120	-	120	120
124	-	1, 6, 5, 2, 124	2, 3, 5, 2, 124
132	low	132	132
132	high	133	133
150	-	1, 150	2, 150


Node 56
Router
1
2
Router
Router
6
3
Router
Router
5
5
Router
2
3
4
Node 124
Node 132, 133
Node 150
Node 120

Space Technology Centre
University of Dundee

Address translation

- Address tables for reply etc
  - Accessed via SLA, DLA, Ch#
  - Held in each node
  - May require updating if network changes
- Multiple network configuration regimes may be incorporated in the table
  - To allow rapid re-organisation of channel paths
  - Depending on network state

Error Detection

- Needed to
  - Prevent delivery of incorrect data
  - Initiate retry
  - Initiate redundancy switching

Error Detection

- Six types of error
  - Packet header error
    - Discard
  - Packet delivered to wrong destination
    - Discard
  - Packet received with data error
    - Discard
  - Missing packet or out of sequence packet
    - Valid for Basic QoS
  - Duplicated packet
    - Valid for Basic QoS
  - SpaceWire EEP
    - Discard

Error Detection

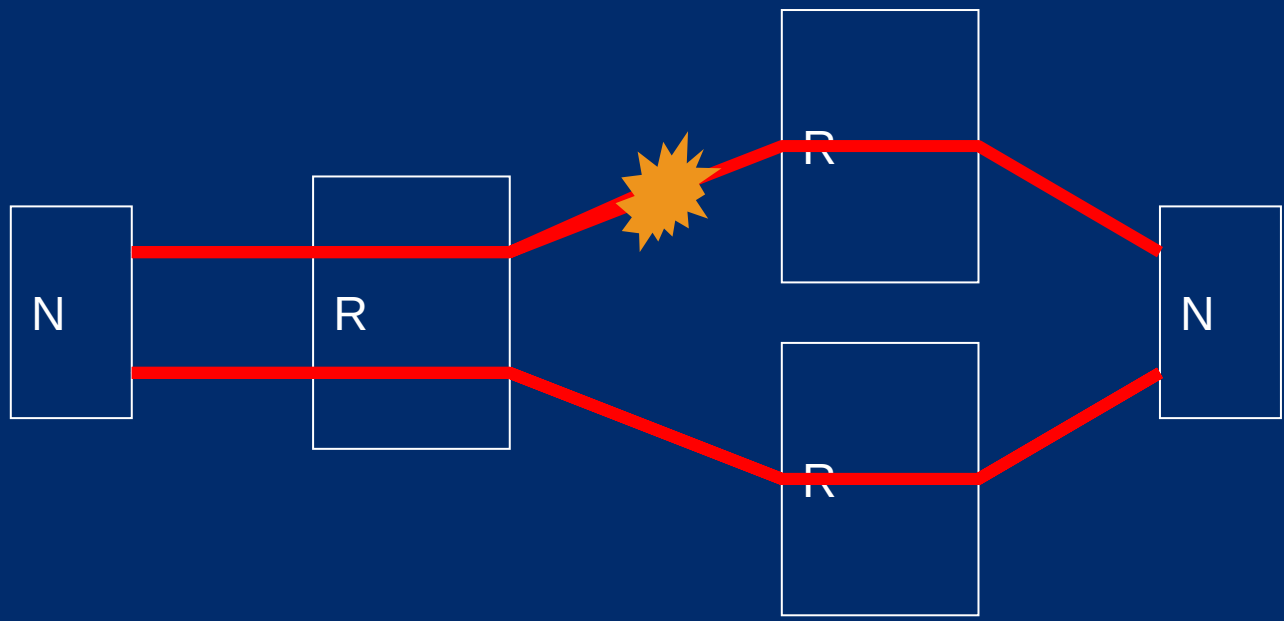
- Several more types of error to be considered
  - Babbling node
  - Time-code errors
  - Etc

Redundancy

- Redundancy model:
  - Alternative paths from source node to destination node
- Managed and autonomous redundancy switching
- Redundancy supported in three ways:
  - Send over both paths simultaneously
  - Send over prime path then if failure send over redundant path
  - Send over either path then if failure send over remaining path

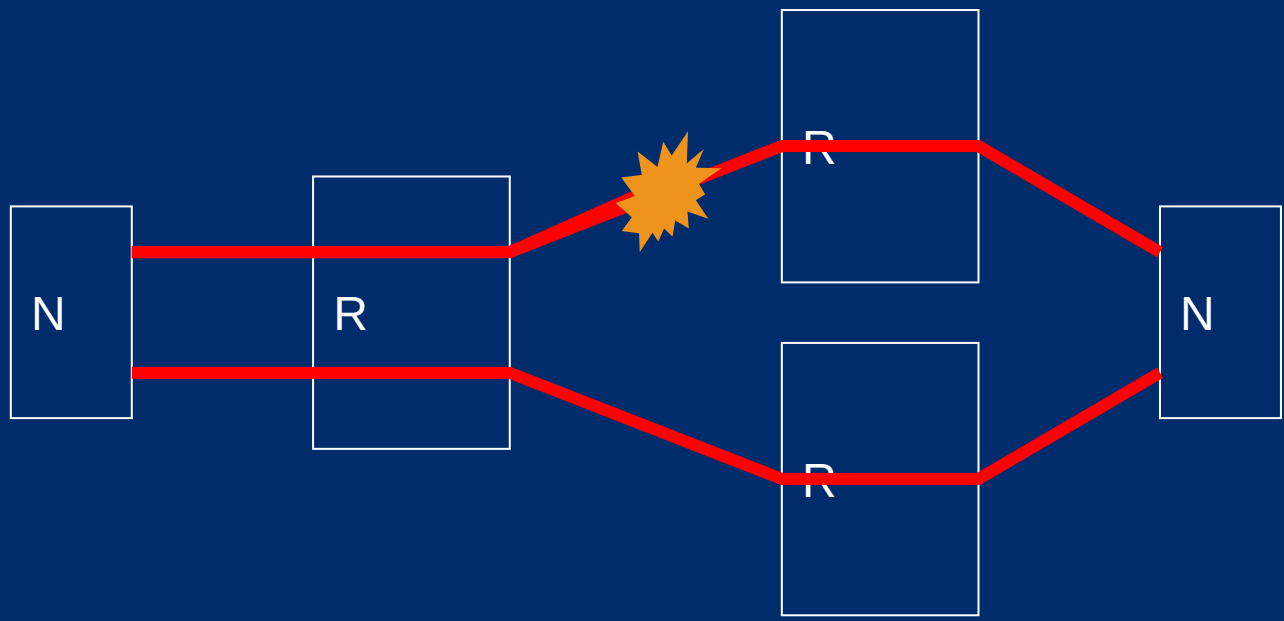
Space Technology Centre
University of Dundee

Both paths at same time



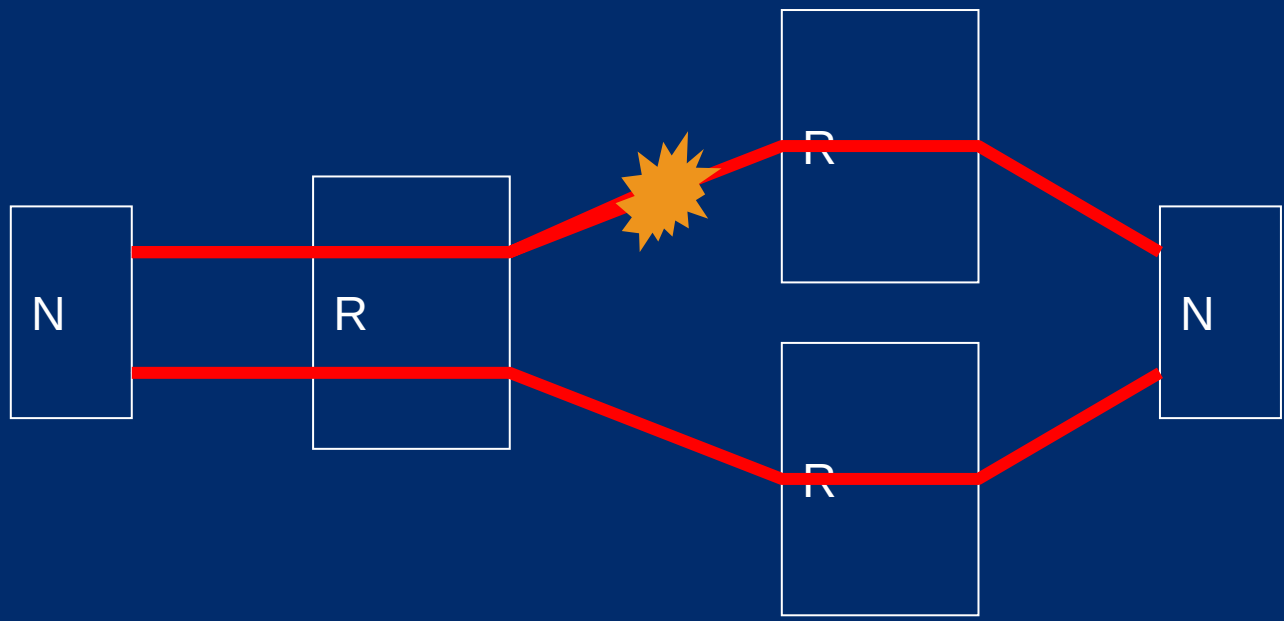
Space Technology Centre
University of Dundee

One path then alternative



Space Technology Centre
University of Dundee

Either path then remaining path



Redundancy

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

Redundancy Parameters

- Simultaneous retry on/off
- Number of attempts on prime path (Np)
- Autonomous reconfiguration enabled/disabled
- Number of attempts on redundant path (Nr)
- Number of attempts on other alternative paths when appropriate (Na)

Example

- Try once on prime path & report failure
  - Simultaneous retry = off
  - Number attempts on prime path = 1
  - Autonomous reconfiguration = disabled
  - Number attempts on redundant path = 0

Example

- Try three times on prime path & report failure
  - Simultaneous retry = off
  - Number attempts on prime path = 3
  - Autonomous reconfiguration = disabled
  - Number attempts on redundant path = 0

Example

- Try twice on prime path, twice on redundant path & report failure
  - Simultaneous retry = off
  - Number attempts on prime path = 2
  - Autonomous reconfiguration = enabled
  - Number attempts on redundant path = 2

Example

- Try twice simultaneously on prime and on redundant paths & report failure
  - Simultaneous retry = on
  - Number attempts on prime path = 2
  - Autonomous reconfiguration = disabled
  - Number attempts on redundant path = 2

Priority

- Priority is applicable for
  - Basic
  - Best Effort
  - Assured
- Priority given by channel number
  - Channel number 1 highest priority
  - Channel number 2 next
  - Etc

Table 3-3 Example Channel Numbering for Priority Arbitration

Destination	Channel Number SLA / DLA / Channel	Priority
49	88/49/1	High
49	88/49/2	Medium
49	88/49/3	Low
62	88/62/1	High
62	88/62/2	Medium
62	88/62/3	Low
75	88/75/1	High
75	88/75/2	Medium
75	88/75/3	Low
112	88/112/1	High
112	88/112/2	Medium
112	88/112/3	Low

Space Technology Centre
University of Dundee

Asynchronous Network Functions

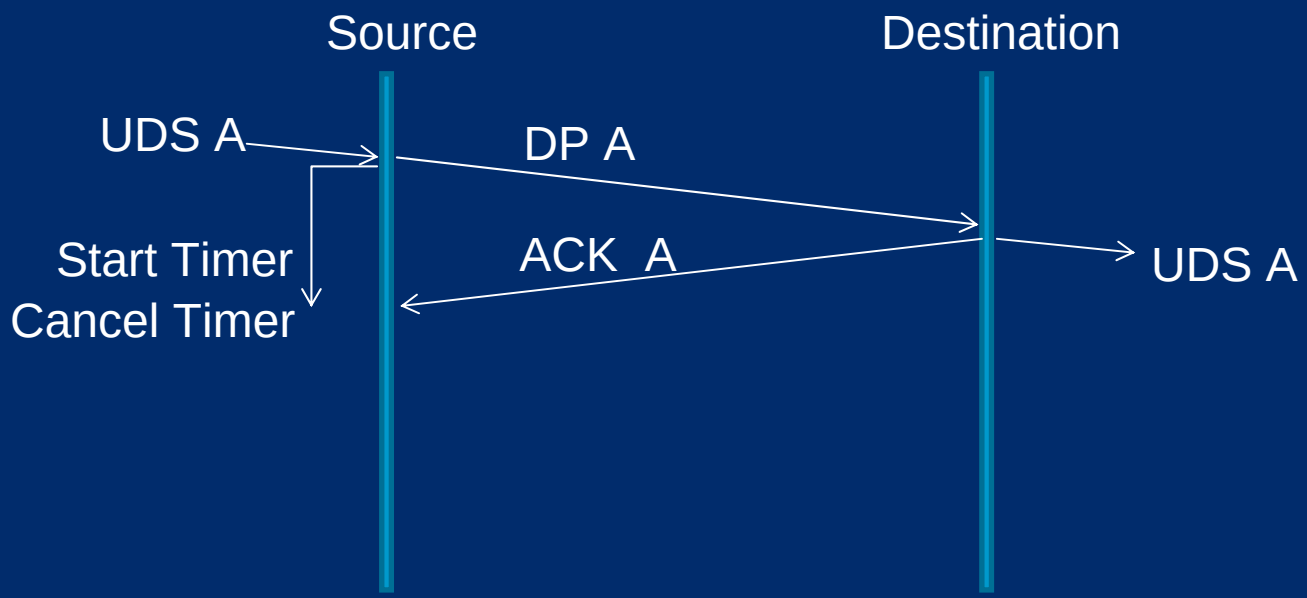
Retry, Flow-Control, Encapsulation

Retry

- Retry function necessary for reliability
  - In conjunction with redundancy
- Resends any segment
  - that goes missing
  - or that arrives in error
- Means that applications do not have to worry about this
- Delivery is ensured
- Simplifies application development
- Efficient implementation
- Flexible

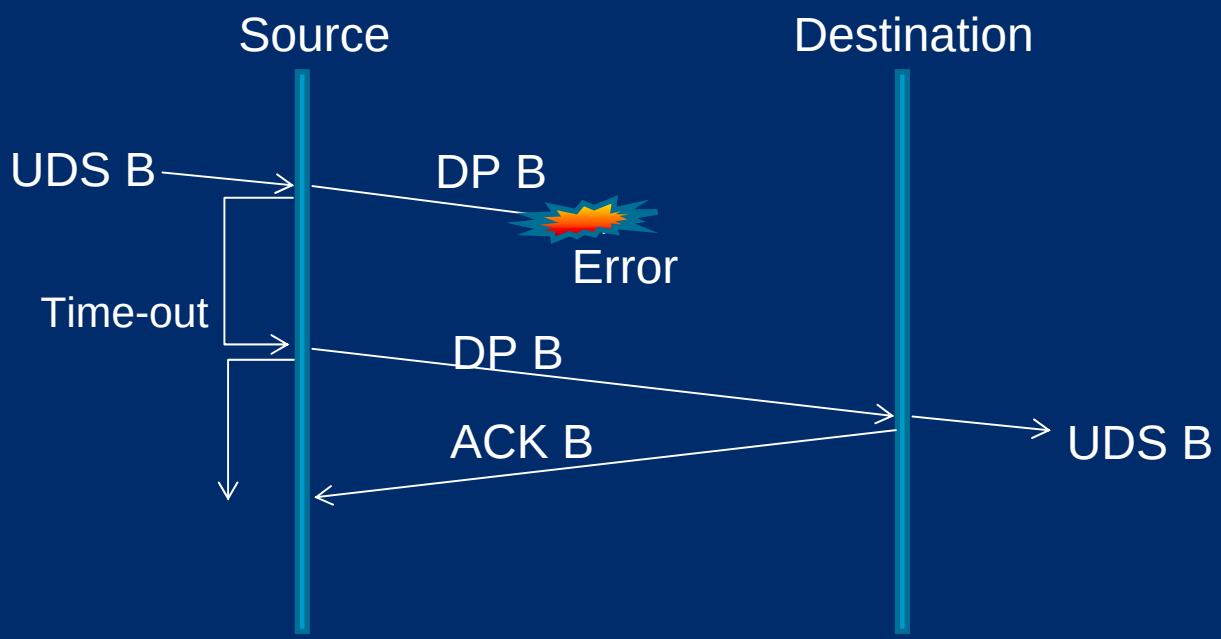
Space Technology Centre
University of Dundee

Retry: Normal Operation



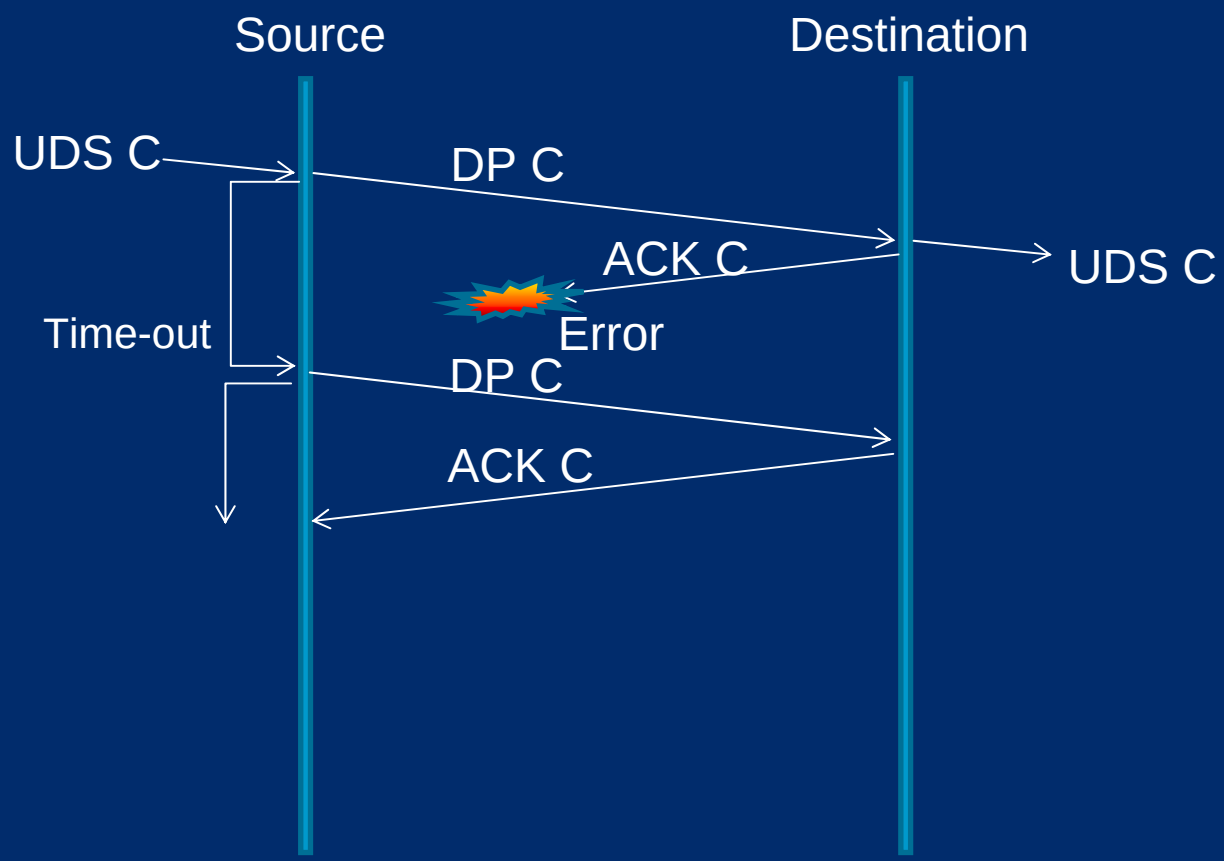
Space Technology Centre
University of Dundee

Retry: Data PDU Lost



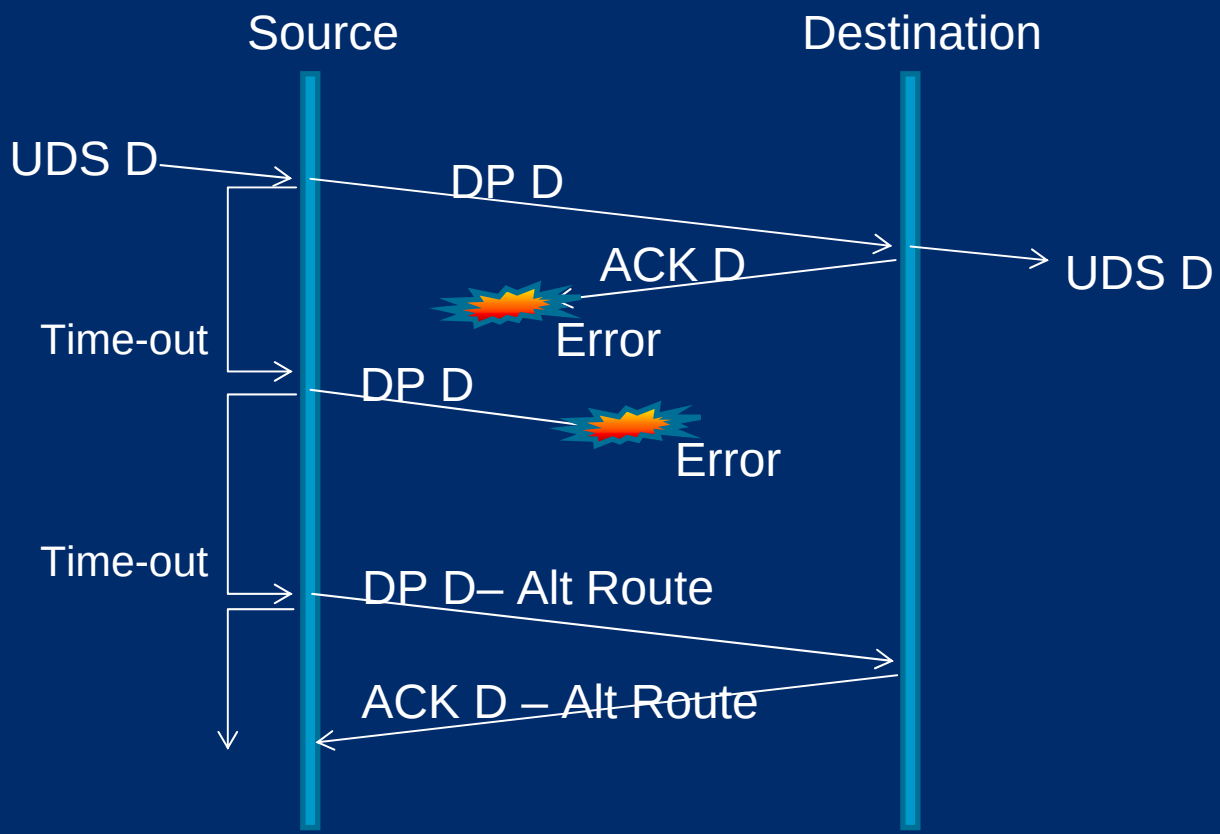
Space Technology Centre
University of Dundee

Retry: Missing ACK



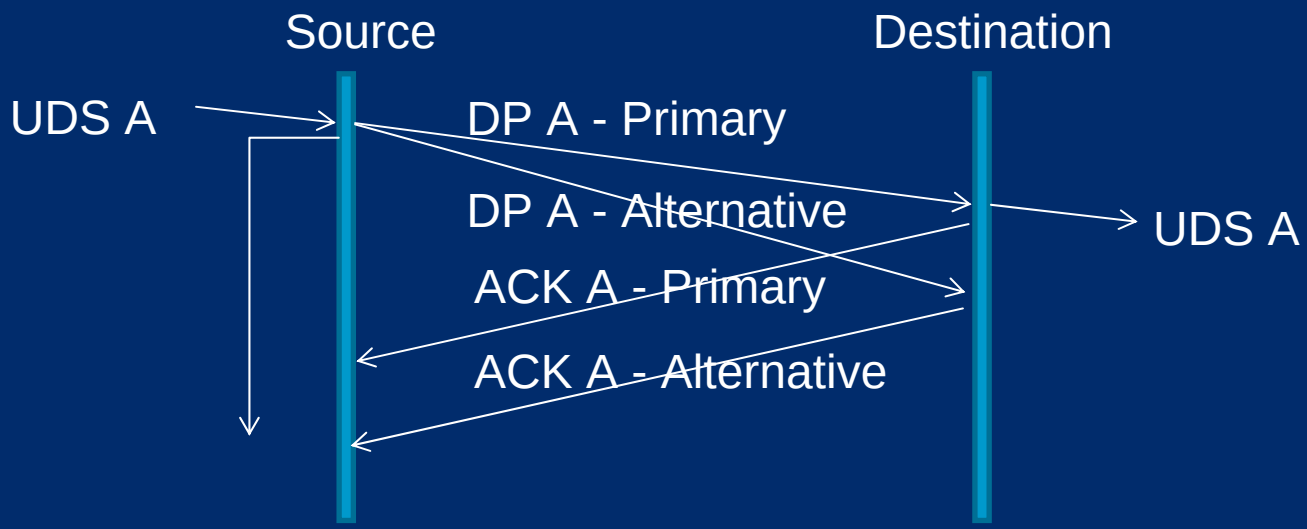
Space Technology Centre
University of Dundee

Retry: Failed Link – Try Alternative Path



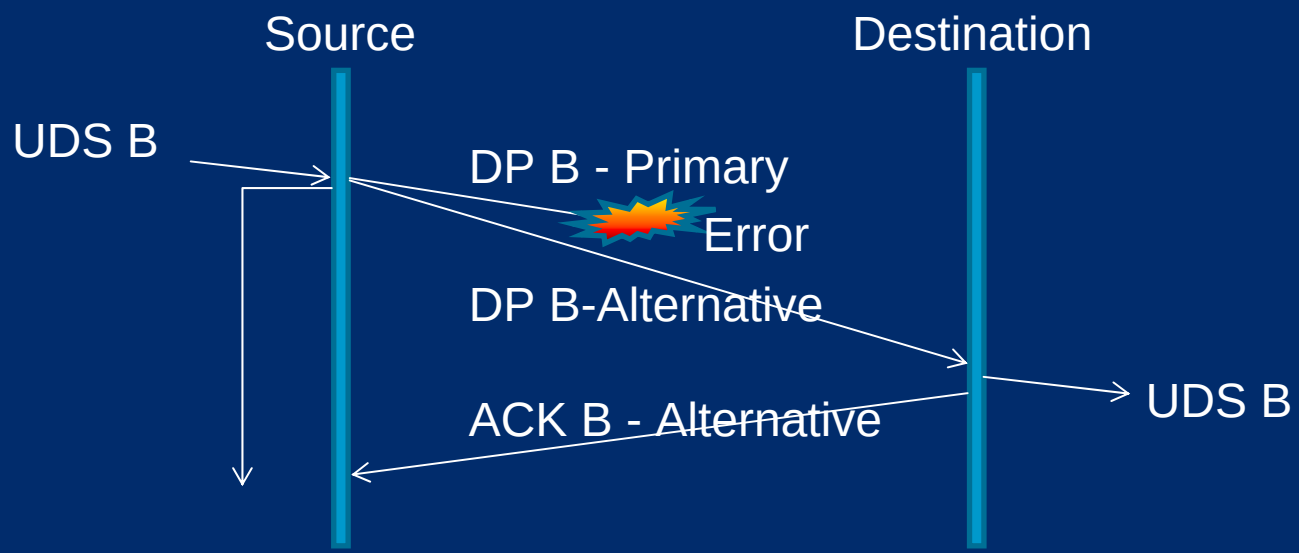
Space Technology Centre
University of Dundee

Simultaneous Retry: Normal Operation



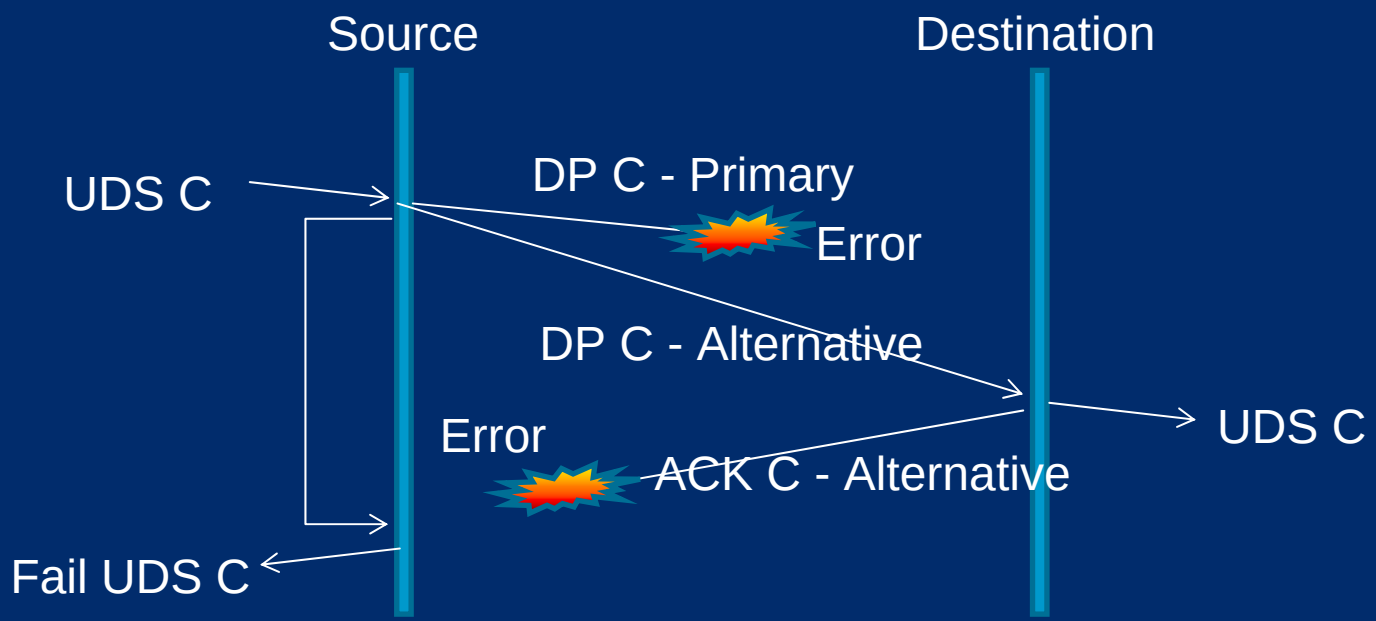
Space Technology Centre
University of Dundee

Simultaneous Retry: Data PDU Lost



Space Technology Centre
University of Dundee

Simultaneous Retry: Lost ACK



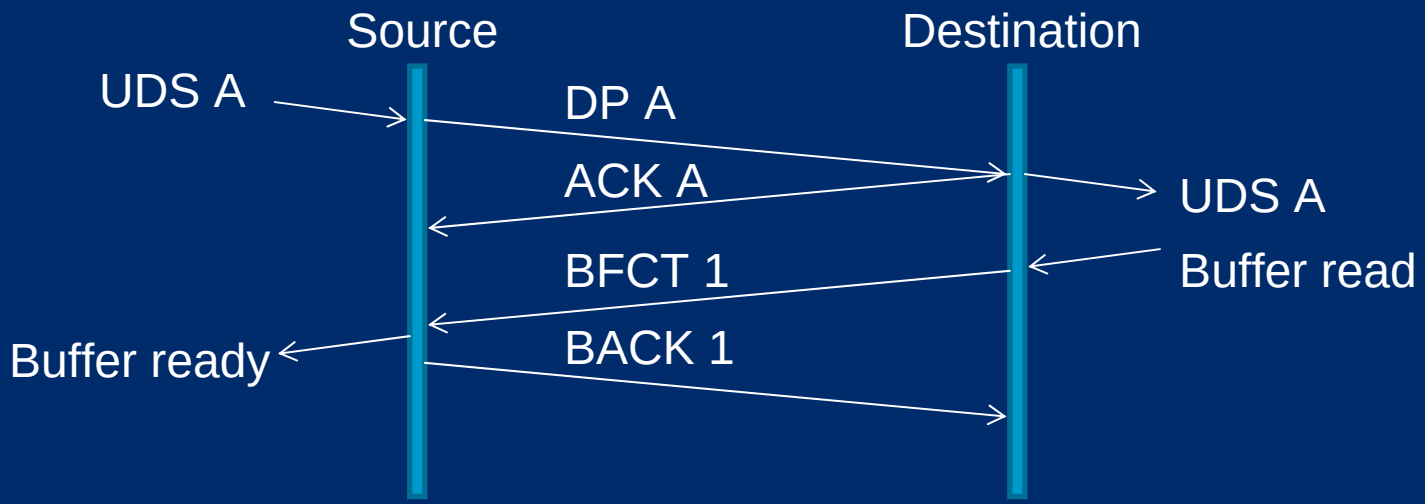
Space Technology Centre
University of Dundee

End to End Flow Control

- Why do we need flow control?
  - SpaceWire uses worm hole routing
  - A blockage at a destination
  - Can cause disruption through network
- Two options
  - Throw away packets if no room in destination buffer
    - Wastes system bandwidth
    - Hinders timeliness
  - Use flow control

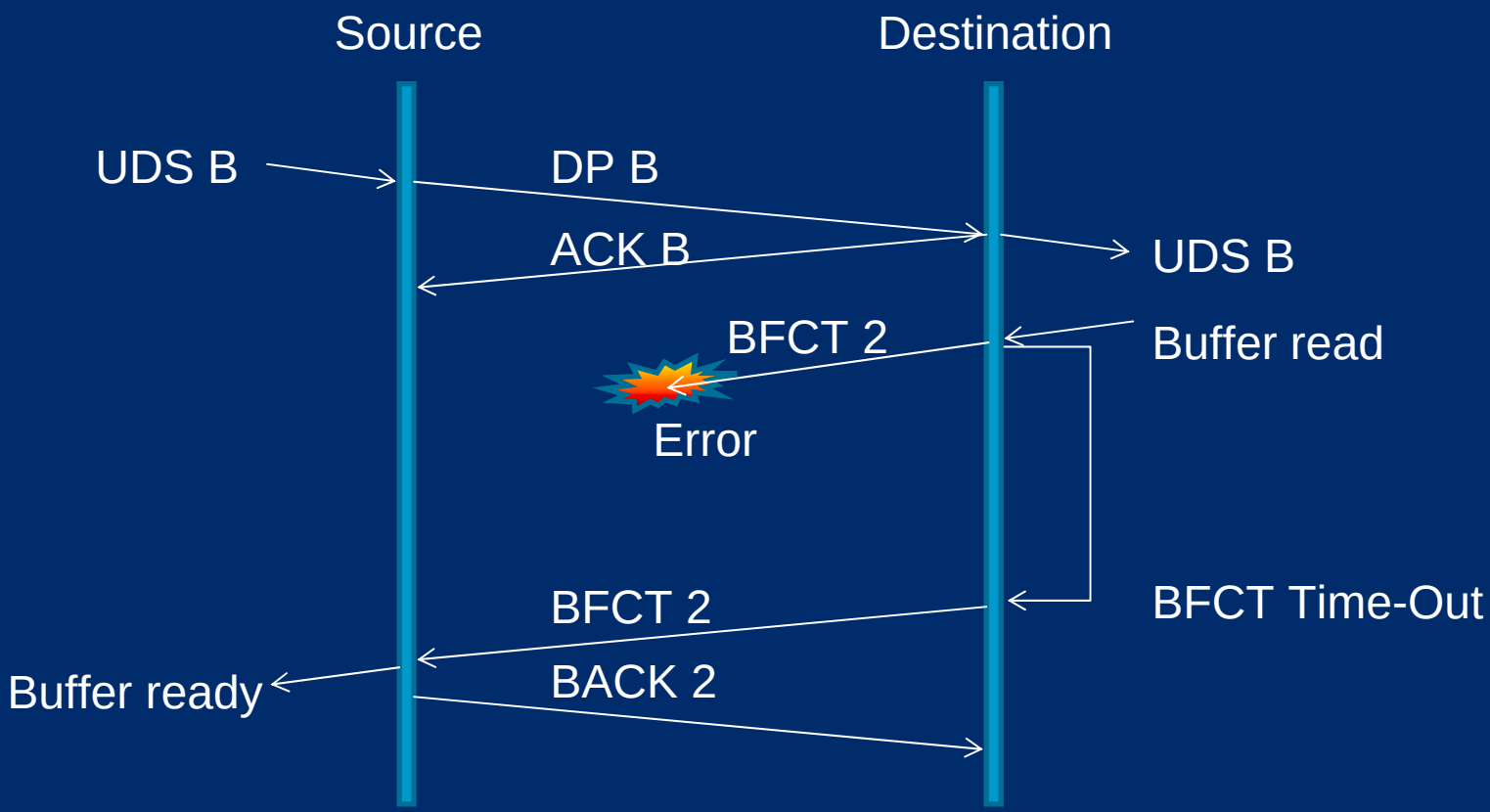
Space Technology Centre
University of Dundee

Flow-Control: Normal Operation



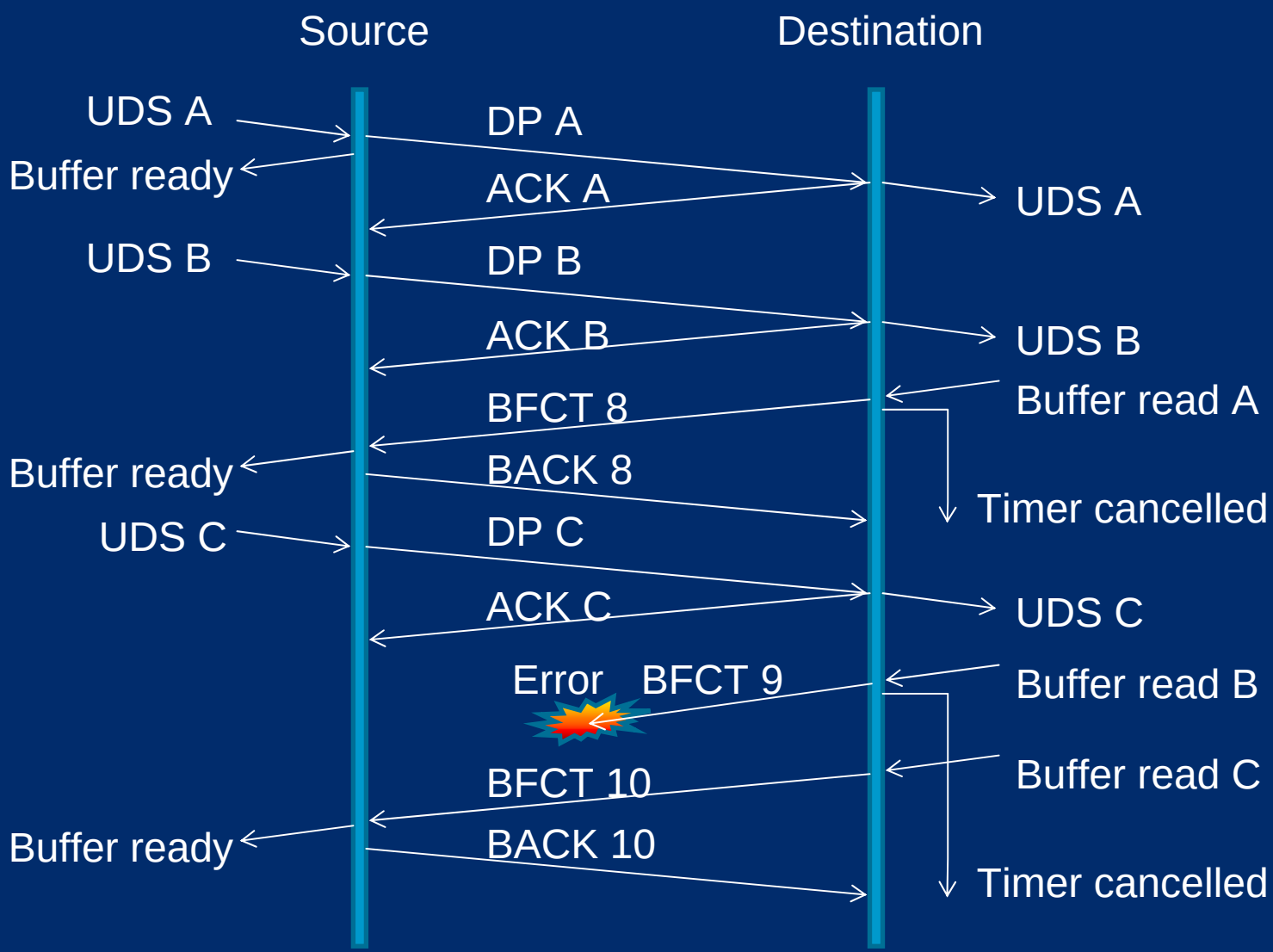
Space Technology Centre
University of Dundee

Flow-Control: BFCT Lost



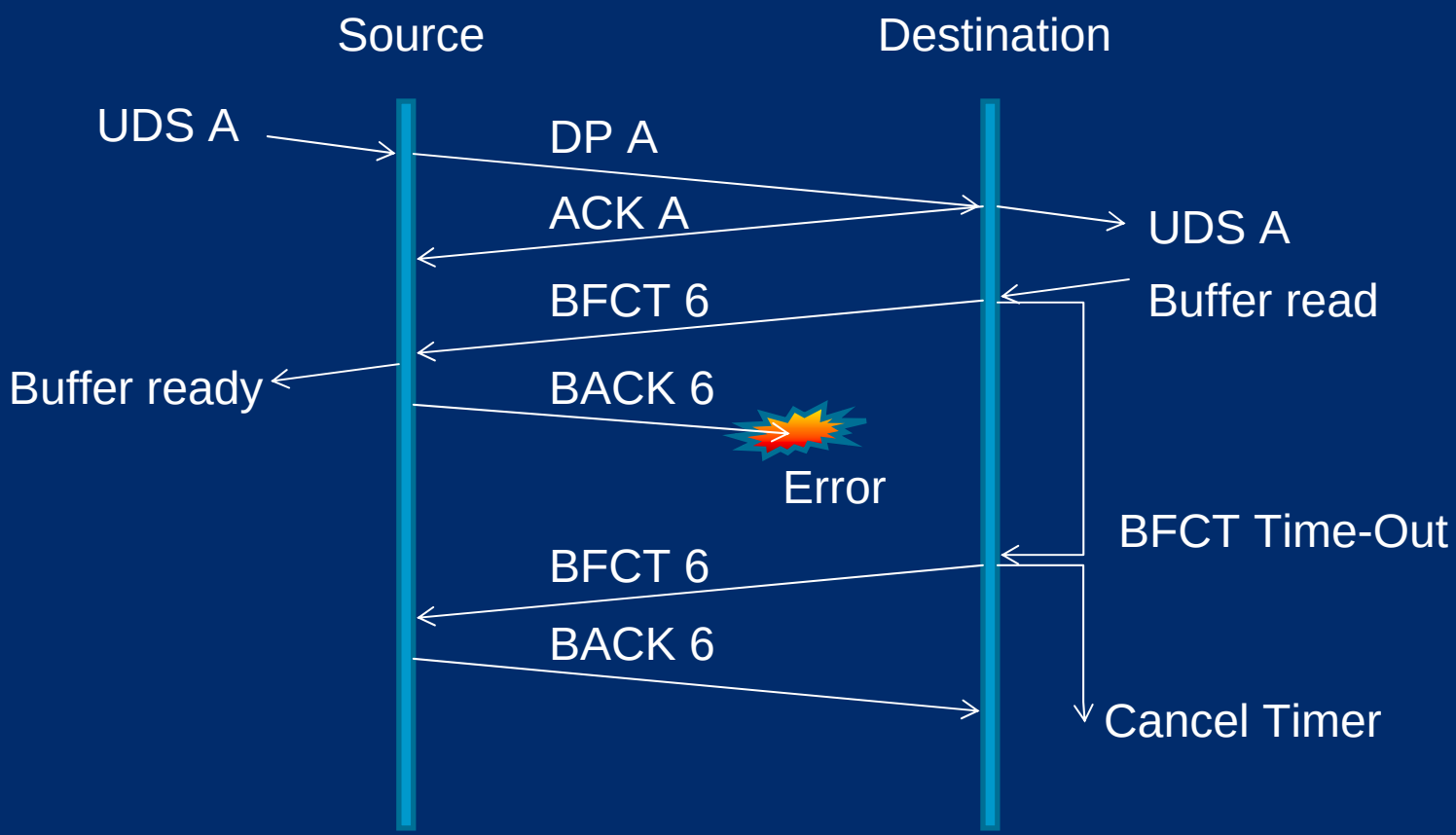
Space Technology Centre
University of Dundee

Flow-Control: Cancelling BFCT Timers



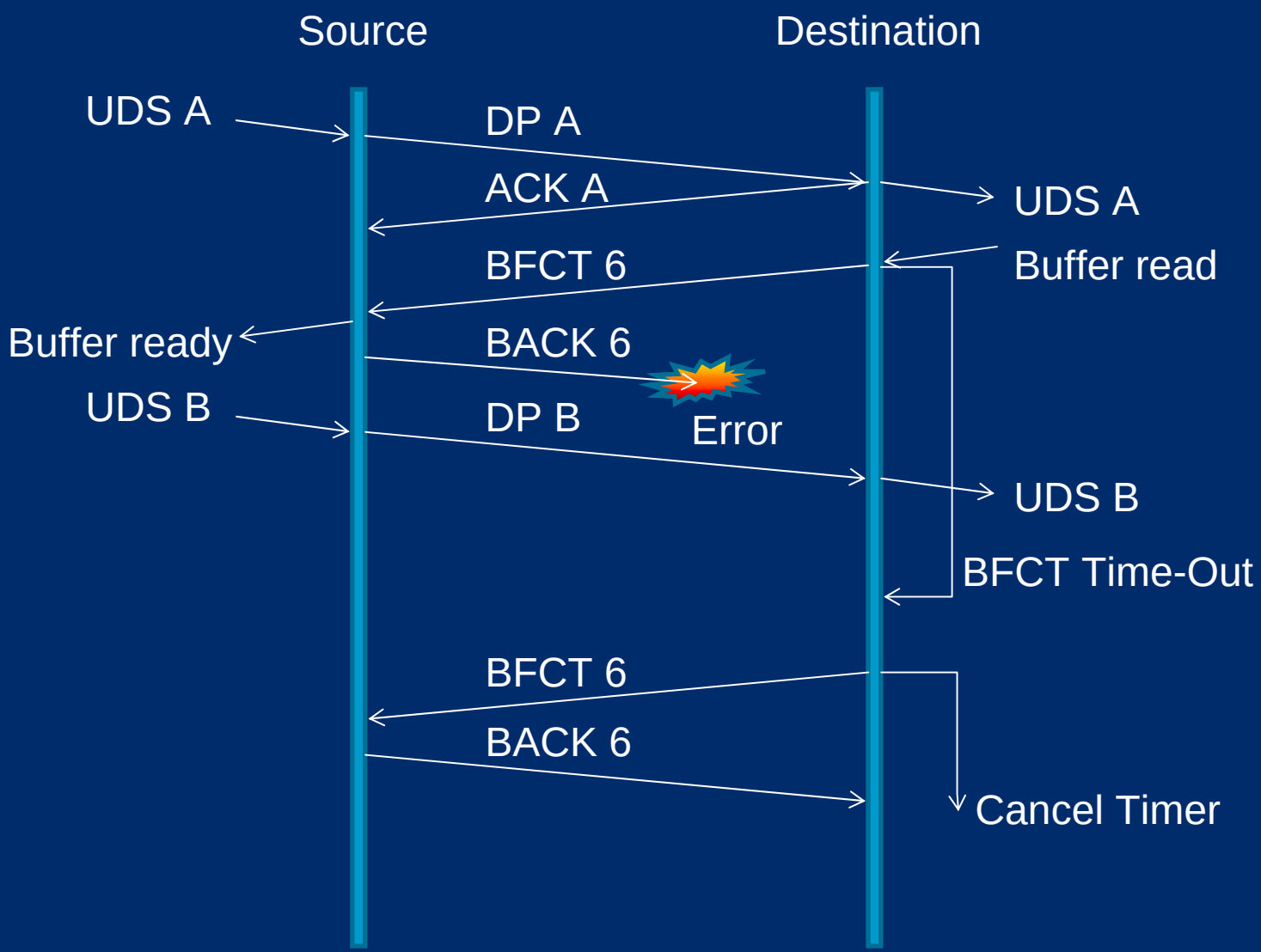
Space Technology Centre
University of Dundee

Flow-Control: Missing BACK



Space Technology Centre
University of Dundee

Flow-Control: Missing BACK, SDU Ready



Encapsulation

- Encapsulates
  - PDUs
  - ACKs
  - BFCTs
  - BACKs
  - Etc
- Into SpaceWire packets

PDU Encapsulation

First byte sent

	Destination SpW Address	Destination SpW Address	Destination SpW Address
Destination Logical Address	SpW Protocol ID	Source Logical Address	Channel
Type / Redundancy	Sequence Number	Data Length	Header CRC
Data	Data	Data	Data
Data	Data	Data	Data
Data	Data	Data	Data
Data	Data	Data	Data
Data	Data	Data CRC MS	EOP

Last byte sent

Space Technology Centre
University of Dundee

Data PDU Encapsulation

- Type field
  - Packet type field (3-bits)
    - DP (data PDU)
    - ACK
    - BFCT
    - BACK
    - Scheduled ACK
    - Scheduled BFCT
  - Redundancy field (2-bits)
    - Path DP or control code is taking through network
    - Prime / Redundant / Other
    - So that any response can use same path

Data PDU Encapsulation

- Type field (continued)
  - Start/End (2-bits)
    - 10: DP contains UDS which is start of SDU
    - 01: DP contains UDS which is end of SDU
    - 00: DP contains UDS which is middle of SDU
    - 11: DP contains UDS which holds entire SDU
  - Reserved (1-bit)

Control Code Encapsulation

First byte sent

	Destination SpW Address	Destination SpW Address	Destination SpW Address
Destination Logical Address	SpW Protocol ID	Source Logical Address	Channel
Type / Redundancy	Sequence Number	Data Length	Header CRC

EOP

Last byte sent

Space Technology Centre
University of Dundee

Space Technology Centre
University of Dundee

Scheduled Network Functions

Scheduled Network,
Retry, Flow-Control, Encapsulation

Scheduled Network

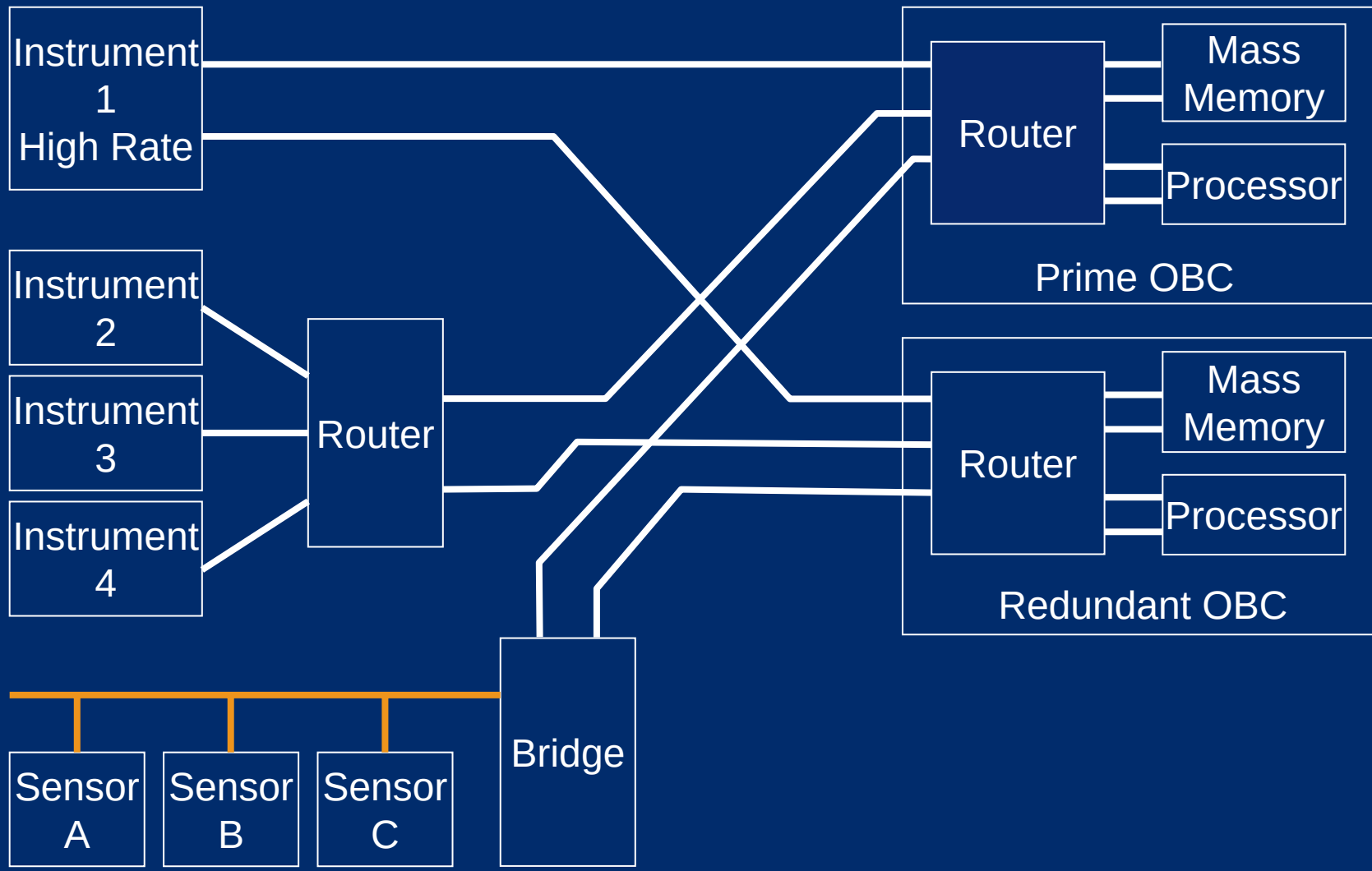
- In an asynchronous network
  - No guarantees about timeliness of delivery
  - Higher priority data PDUs go first
- In a scheduled network
  - Network bandwidth divided using time-slots
  - Schedule table assigns communication to time-slots
  - Avoids conflict
  - Ensures timeliness of delivery

SpaceWire Links as Resources

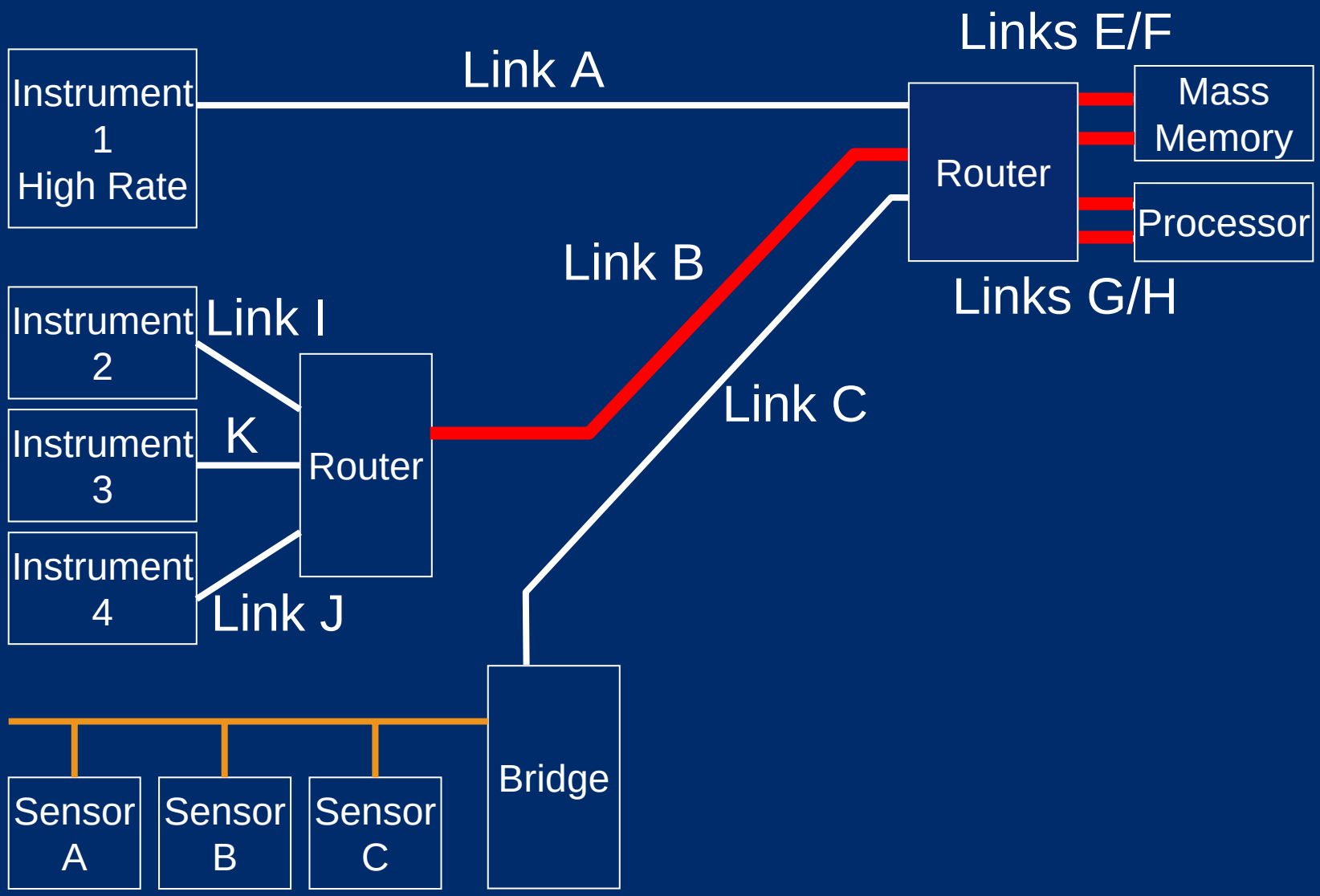
- Resources to be managed are:
  - Source buffers
  - SpaceWire links
  - Destination buffers
- Routers need not be managed
  - Since they are “non-blocking” switches
  - If the links are available the switch will always be able to forward a packet
- Source and destination buffers
  - Allocated to each channel
  - No conflict

Space Technology Centre
University of Dundee

Example Onboard Data-Handling Architecture



Example Shared Resources



Space Technology Centre
University of Dundee

Example Channels

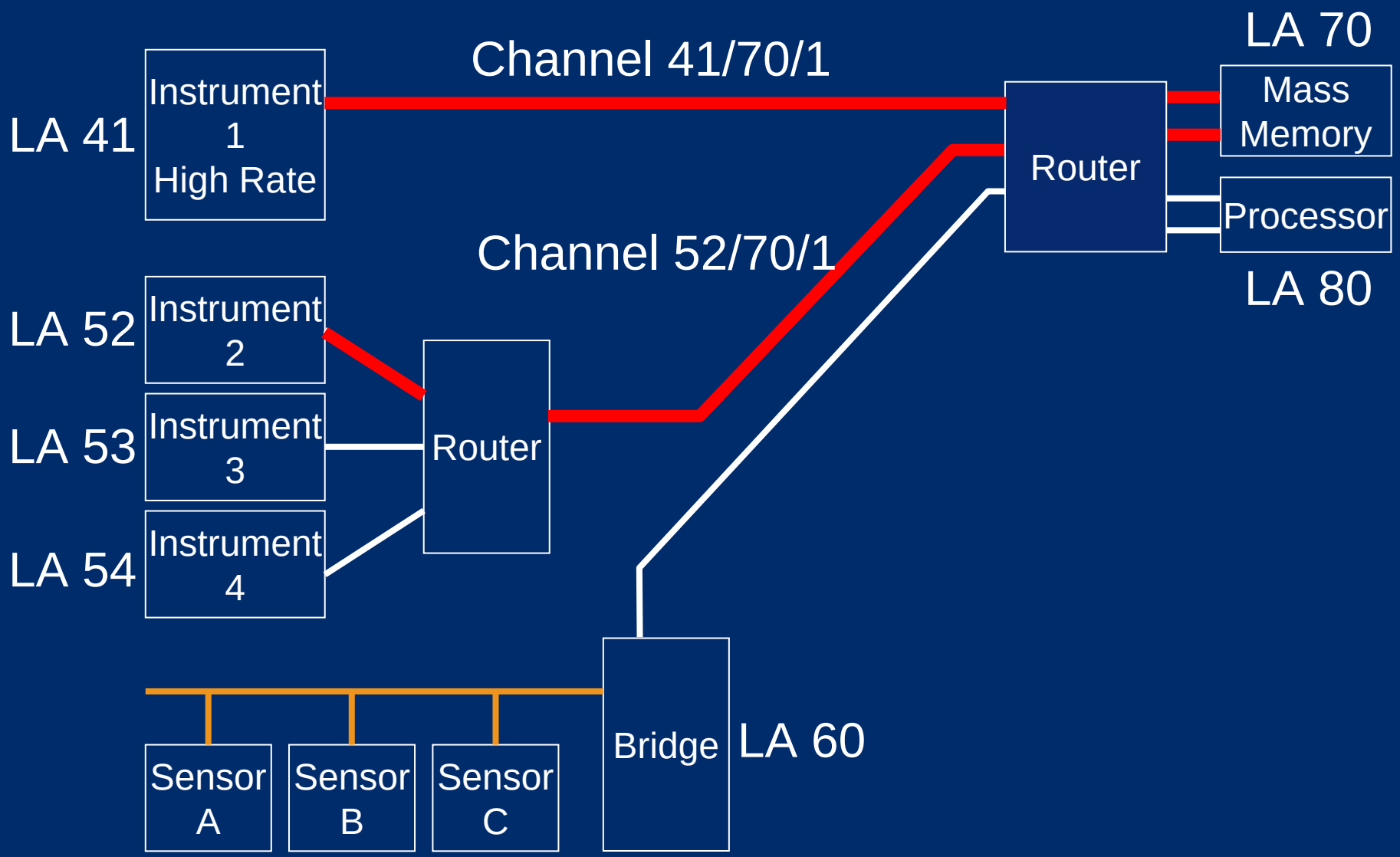


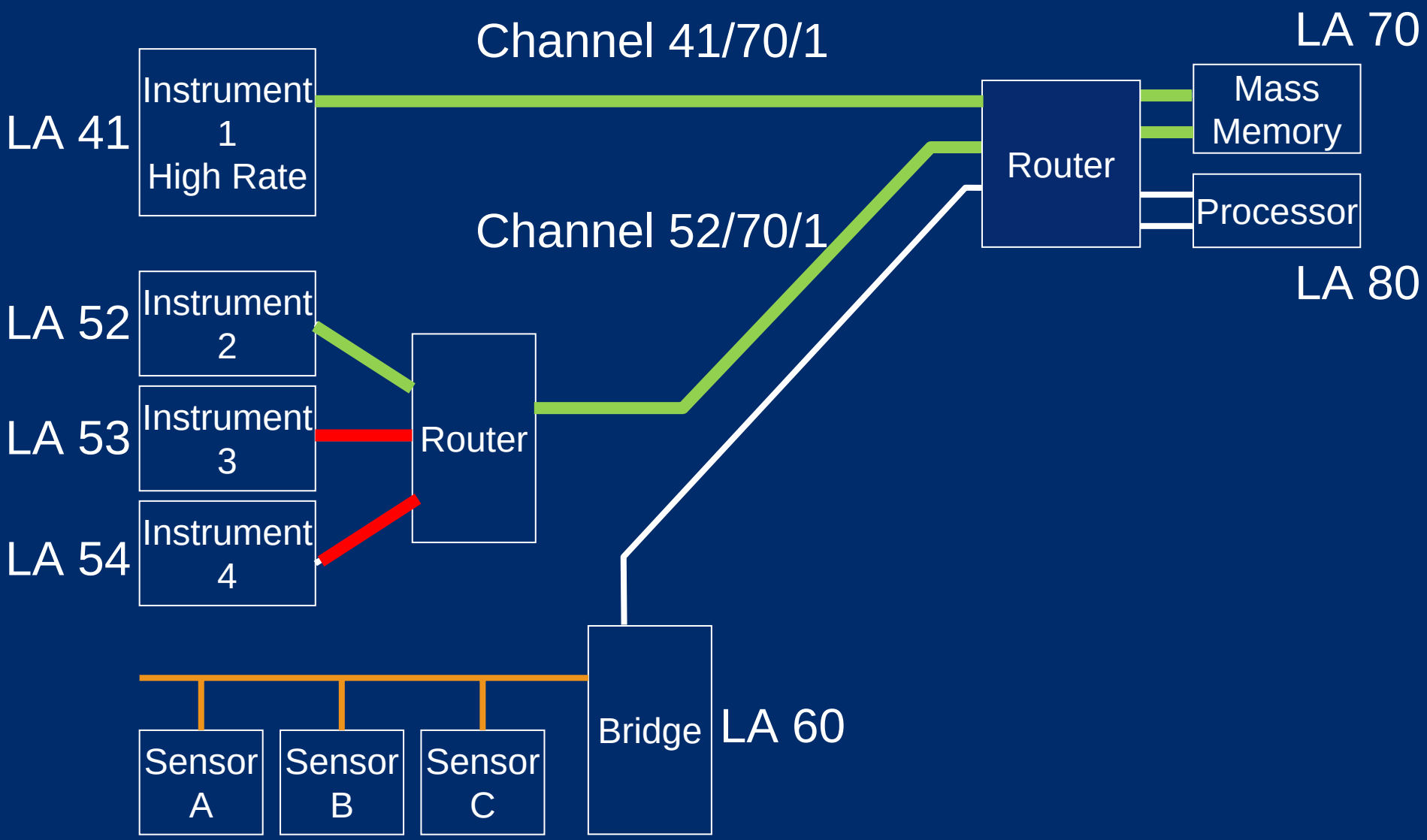
Table 3-2 Channel allocations

Channel No.	Traffic	Links used L to R / Up	Links used R to L / Down
41/70/1	Instrument 1 to memory	A, E/F	
52/70/1	Instrument 2 to memory	I, B, E/F	
53/70/1	Instrument 3 to memory	J, B, E/F	
54/80/1	Instrument 4 to processor for processing	K, B, G/H	
60/70/1	RTC sensor data to memory	C, E/F	
80/70/1	Processor to memory – processed data	E/F	g/h
80/xx/1	Processor commands to any other unit	E/F	g/h, a, b, c, i, j, k

Table 3-2 Channel allocations

Channel No.	Traffic	Links used L to R / Up	Links used R to L / Down
41/70/1	Instrument 1 to memory	A, E/F	
52/70/1	Instrument 2 to memory	I, B, E/F	
53/70/1	Instrument 3 to memory	J, B, E/F	
54/80/1	Instrument 4 to processor for processing	K, B, G/H	
60/70/1	RTC sensor data to memory	C, E/F	
80/70/1	Processor to memory – processed data	E/F	g/h
80/xx/1	Processor commands to any other unit	E/F	g/h, a, b, c, i, j, k

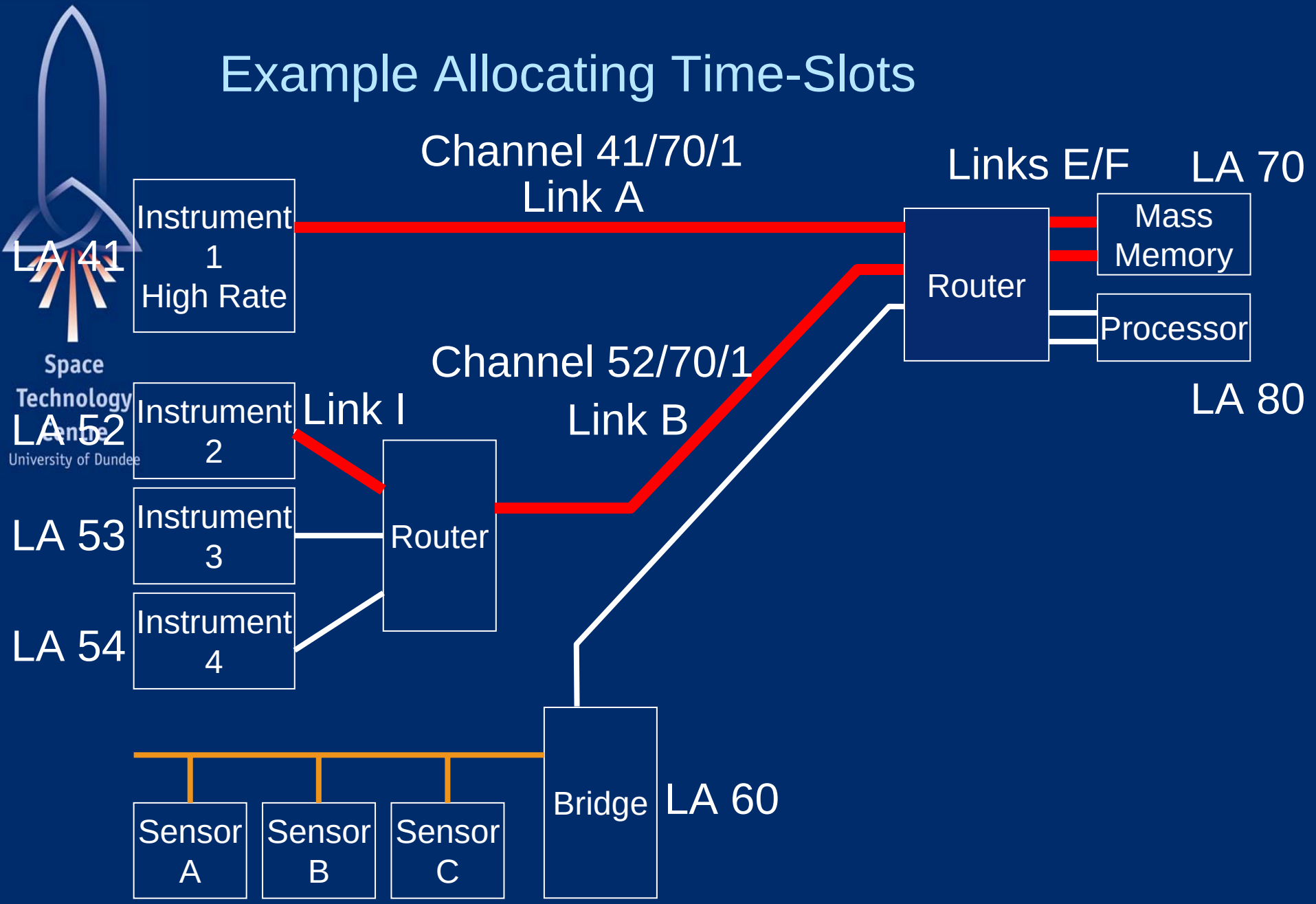
Example Scheduling



Allocating Channels to Time-Slots

	Slot 0
41/70/1	A, E/F
52/70/1	I, B, E/F
53/70/1	
54/70/1	
60/60/1	
80/70/1	
80/xx/1	

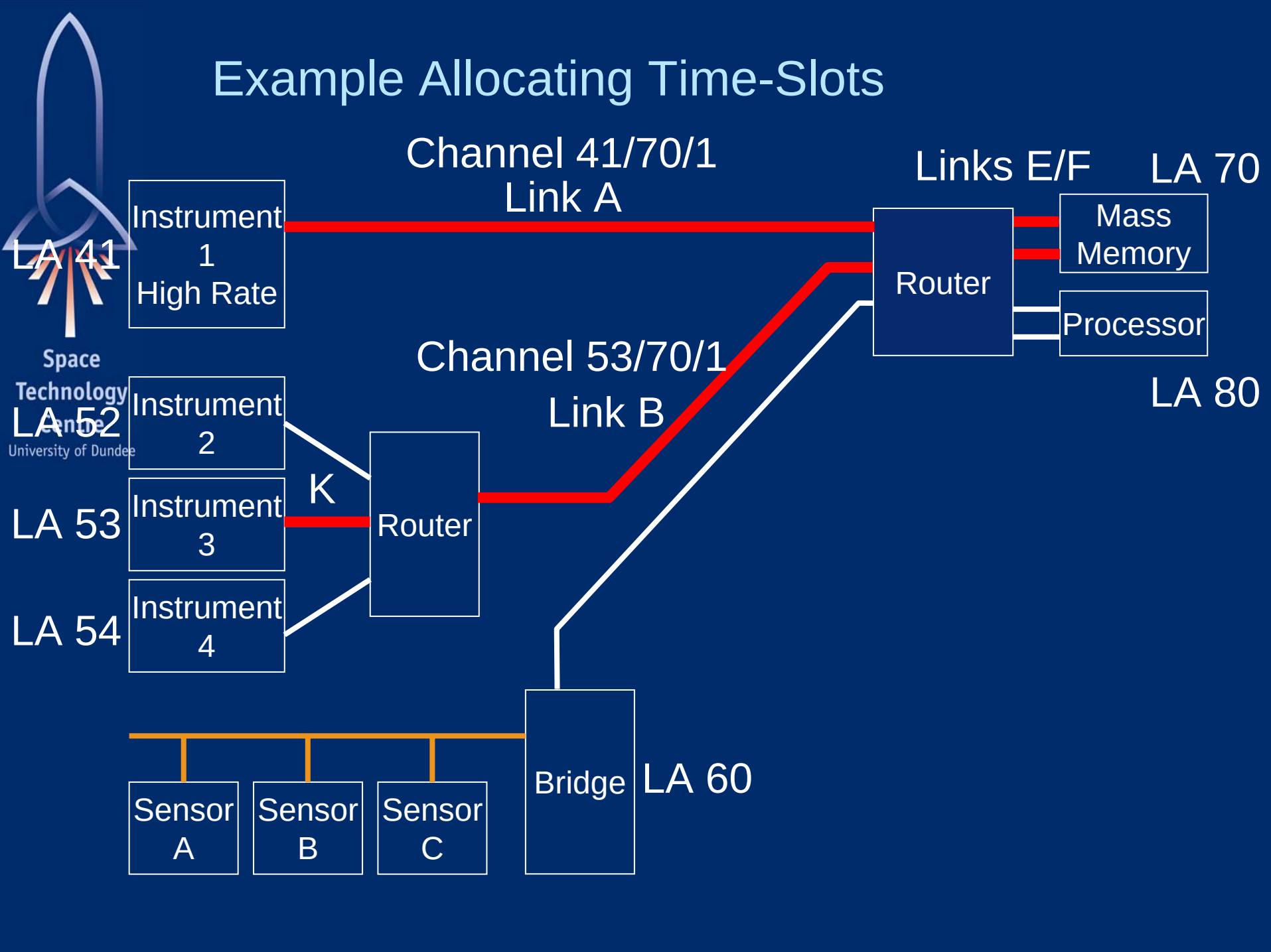
Example Allocating Time-Slots



Allocating Channels to Time-Slots

	Slot 0	Slot 1
41/70/1	A, E/F	A, E/F
52/70/1	I, B, E/F	
53/70/1		J, B, E/F
54/70/1		
60/60/1		
80/70/1		
80/xx/1		

Example Allocating Time-Slots



Allocating Channels to Time-Slots

	Slot 0	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8	…	Slot 63
41/70/1	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
52/70/1	I, B, E/F				I, B, E/F						
53/70/1		J, B, E/F									
54/70/1			K, B, G/H								
60/60/1				C, E/F							
80/70/1						g/h, E/F					
80/xx/1							E/F, g/h, a,b,c, I,j,k				

Resources for Flow-Control and ACKs

- Flow control & ACKs
  - Travel in opposite direction to data
  - May conflict with other data PDUs
- Not a problem for asynchronous network
  - As timeliness is not a requirement
- For scheduled network
  - Resource has to be allocated for
    - Acknowledgements
    - Flow control information

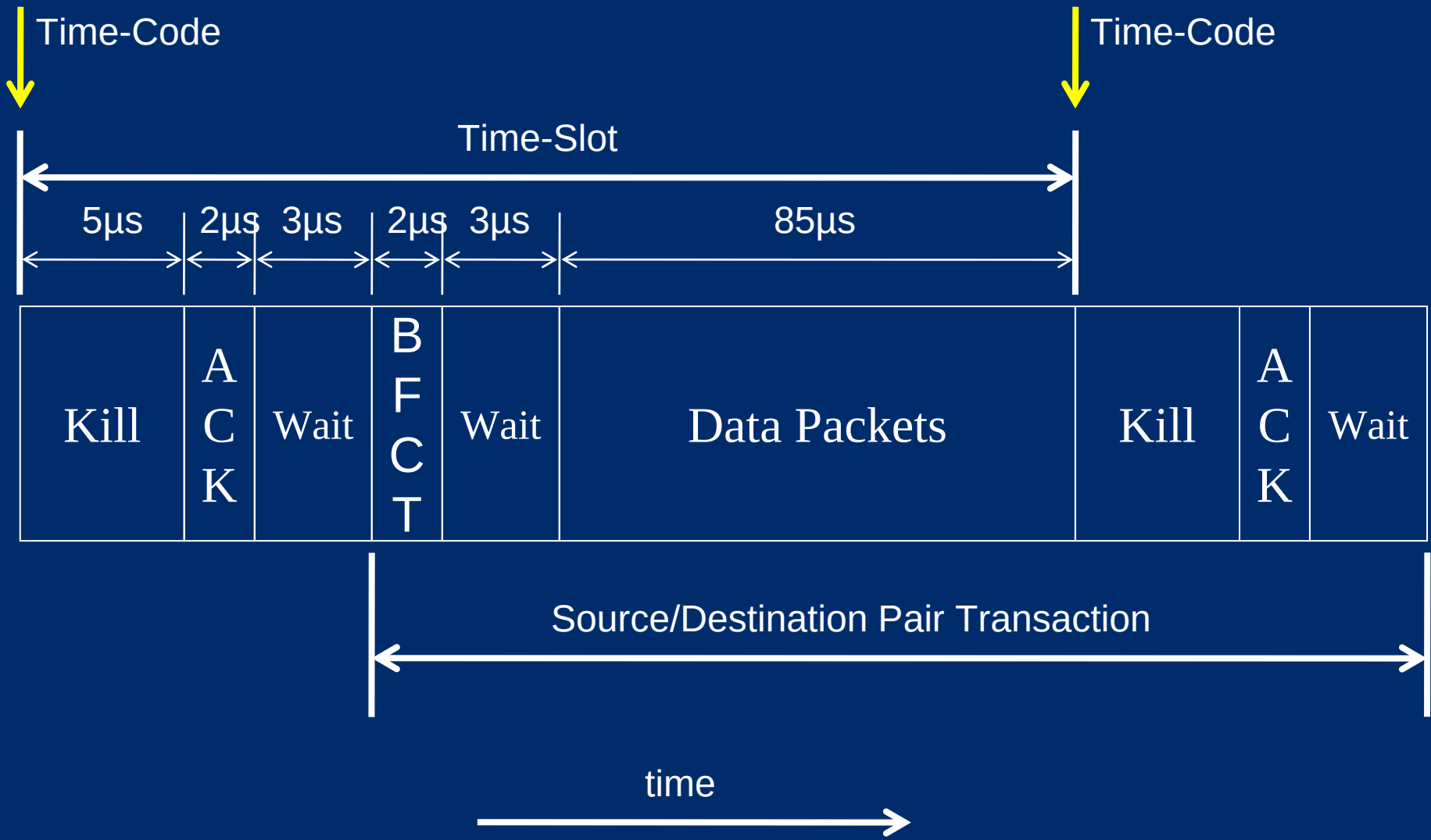
Resources for Flow-Control and ACKs

- Time-slots split into three parts:
  - Flow control phase
    - Which channels for this time-slot have room in destination channel buffer?
  - Data PDU transfer phase
    - Send data PDUs
    - For channels with room in destination channel buffer
  - Acknowledgment phase
    - Send acknowledgement of receipt of data PDUs
- This is the logical ordering

Resources for Flow-Control and ACKs

- This it the actual ordering
  - Receive time-code
  - Everyone stops sending
  - Wait long enough for network to become silent
  - Send acknowledgments for previous time-slot
  - Wait for ACKs to propagate across network
  - Send Buffer Flow Control Tokens (BFCTs)
  - To indicate room in destination buffers
  - Wait for BFCTs to propagate across network
  - Send Data PDUs

Resources for Flow-Control and ACKs



QoS over Scheduled Network

- Guaranteed
  - Time-slots (bandwidth) allocated to a specific channel
  - One-to-one or one-to-many mapping between channel and time-slots
  - Priority is not supported
    - since this service has to be fully deterministic.
  - Retry in the event of an error
  - Additional network bandwidth allocated for retry
    - in subsequent time-slot
    - to send a retry in the case of an error.

QoS over Scheduled Network

- Resource-reserved
  - Time-slots are allocated to a specific channel
  - One-to-one or one-to-many mapping between the channel and time-slots
  - Priority is not supported
    - since this service has to be fully deterministic.
  - No retry in the case of an error

QoS over Scheduled Network

- Allocated
  - Time-slots assign to
    - one or more basic, best effort, or assured channels
    - that connect a specific source to a specific destination
  - Channel that sends data
    - is one with highest priority
    - that has data ready to send
  - Reserves network bandwidth for a set of otherwise asynchronous channels.
  - Allocated channel is not intended to provide determinism.
  - It reserves network resources
    - for a number of channels to share
    - uses priority to provided timeliness of delivery

QoS over Scheduled Network

- Allocated Basic
  - provides basic QoS over an allocated channel
- Allocated Best Effort
  - provides best effort QoS over an allocated channel
- Allocated Assured
  - provides assured QoS over an allocated channel
  - will retry in the event of a failure
  - in the next allocated time-slot for the specific source-destination pair

Space Technology Centre
University of Dundee

QoS over Scheduled Network

- Opportunistic
  - No time-slots are allocated for opportunistic traffic
  - Opportunistic channels have to wait for unused
    - guaranteed,
    - resource-reserved
    - or allocated time-slot
  - Channel(s) associated with the time-slot have no data to send
    - So no data transfer would otherwise occur in that time-slot.
  - Opportunistic QoS uses
    - otherwise wasted network bandwidth
    - to support transfer of data
    - that does not have to be delivered promptly

QoS over Scheduled Network

- Opportunistic Basic
  - provides basic QoS over an opportunistic channel
- Opportunistic Best Effort
  - provides best effort QoS over an opportunistic channel
- Opportunistic Assured
  - provides assured QoS over an opportunistic channel
  - in the event of a failure to deliver
    - retry in next guaranteed, resource-reserved or allocated time-slot
    - for the specific source-destination pair
    - which has no data ready to send.

QoS over Scheduled Network

- Allocated
  - Allocated time-slots for
  - asynchronous type of traffic
    - Basic
    - Best Effort
    - Assured
- Opportunistic
  - Sends data PDUs opportunistically
  - When nothing else is sending
  - Can send asynchronous type traffic
    - Basic
    - Best Effort
    - Assured

QoS over Scheduled Network

Table 3-4 Example Schedule Table Source node 231		
Time-slot	**Channel**	**Channel QoS**
0	-	
1	231/68/3	Guaranteed
2	-	
3	231/68/3	Guaranteed (retry slot)
4	231/82/1	Resource-reserved
...		
62	231/49/5	Resource-reserved
63	-	

Space Technology Centre
University of Dundee

QoS over Scheduled Network

Table 3-5 Example Schedule Table with Allocated QoS Source node 231		
Time-slot	**Channel**	**Channel QoS**
0	-	
1	231/68/1, 231/68/3	Allocated Best Effort and Assured
2	231/49/1	Resource-Reserved
3	231/82/1, 231/82/2, 231/82/3, 231/82/4	Allocated Best Effort with four priority levels
...		
62	231/49/2	Allocated Best Effort
63	-	

Space Technology Centre
University of Dundee

QoS over Scheduled Network

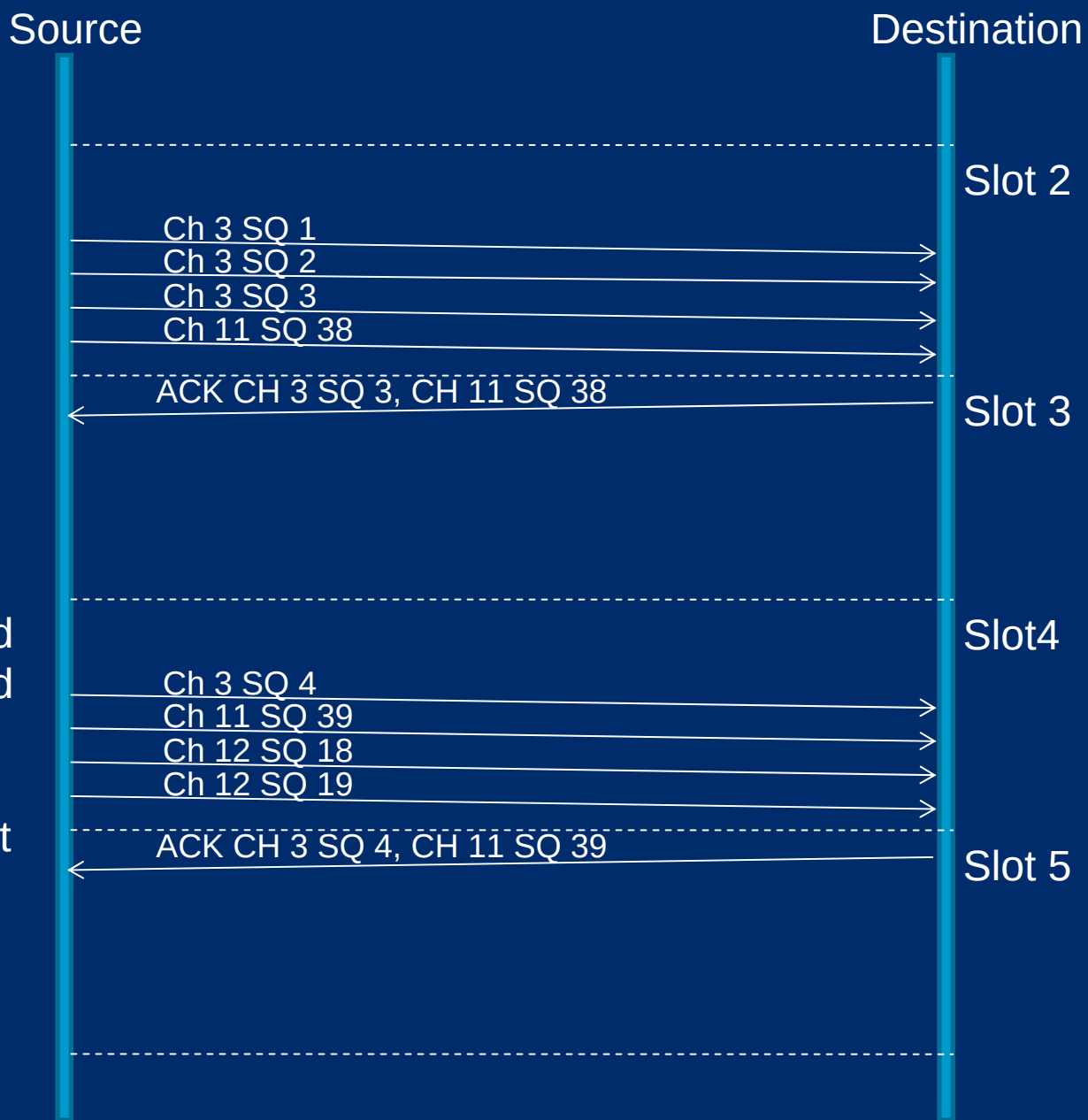
Table 3-6 Example Schedule Table with Opportunistic QoS

Time-slot	Channel	Channel QoS	Opportunist Channels	Opportunistic QoS
0	-			
1	231/68/3	Guaranteed	231/68/4 231/68/5	Assured Best Effort
2	231/49/1	Resource-Reserved	231/49/2	Best Effort
3	231/68/3	Guaranteed (retry slot)	231/68/4 231/68/5	Assured Best Effort
4	231/82/1 231/82/2 231/82/3 231/82/4	Allocated Best Effort with four priority levels	-	

QoS over Scheduled Network

- Master
  - Single node given access to whole scheduled network
  - For duration of time-slot
  - Send and receive response
  - Intended for network configuration and management
  - Using RMAP

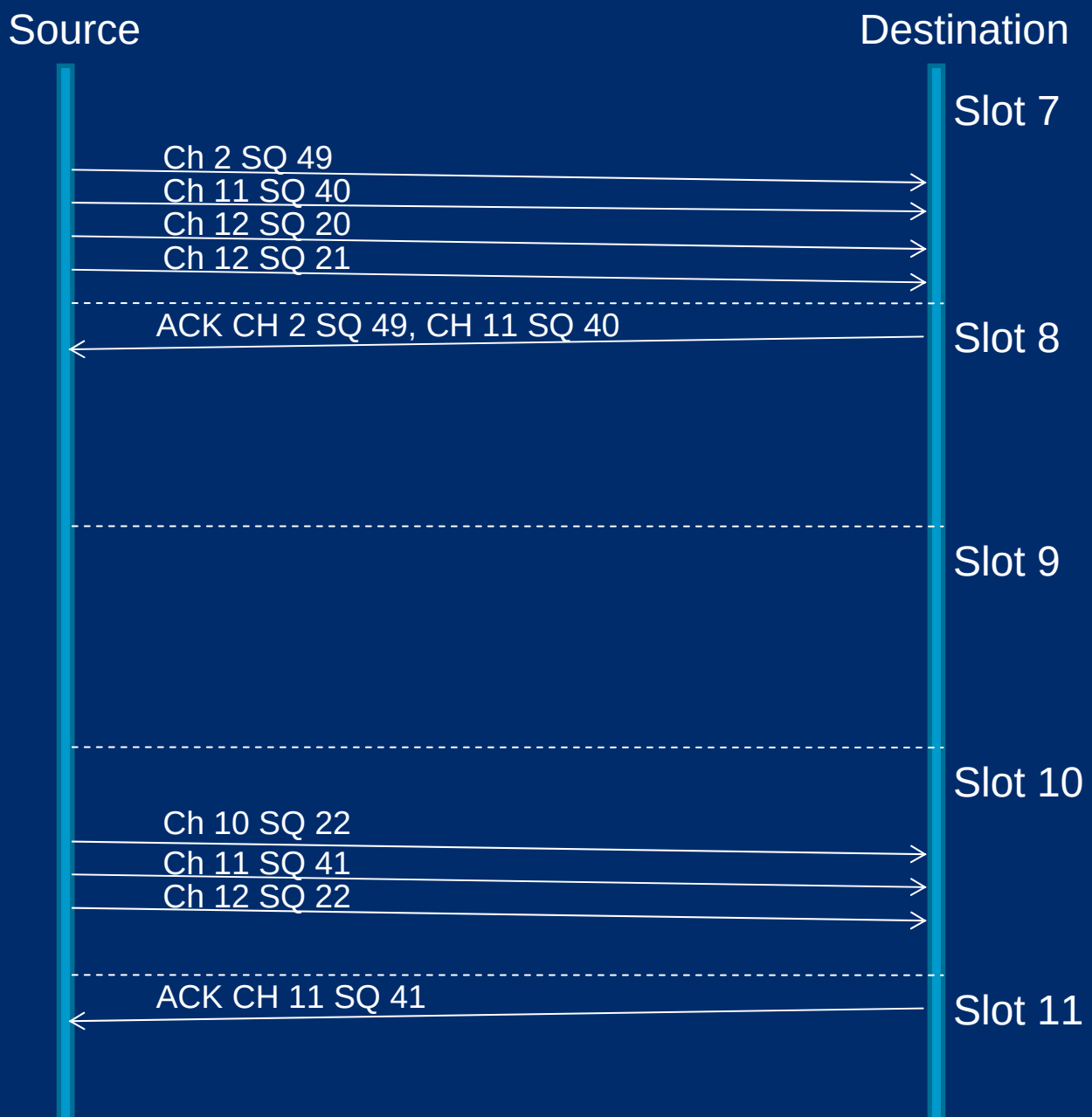
Scheduled: Normal Operation of ACK



Slot-Allocation
Ch 2 slots 7 &12
Ch 3 slots 2 & 4
Ch 10 slot 10

Channel QoS
Ch 2 Guaranteed
Ch 3 Guaranteed
Ch 10 Reserved
Ch 11 Assured
Ch 12 Best Effort

Scheduled: Normal Operation of ACK



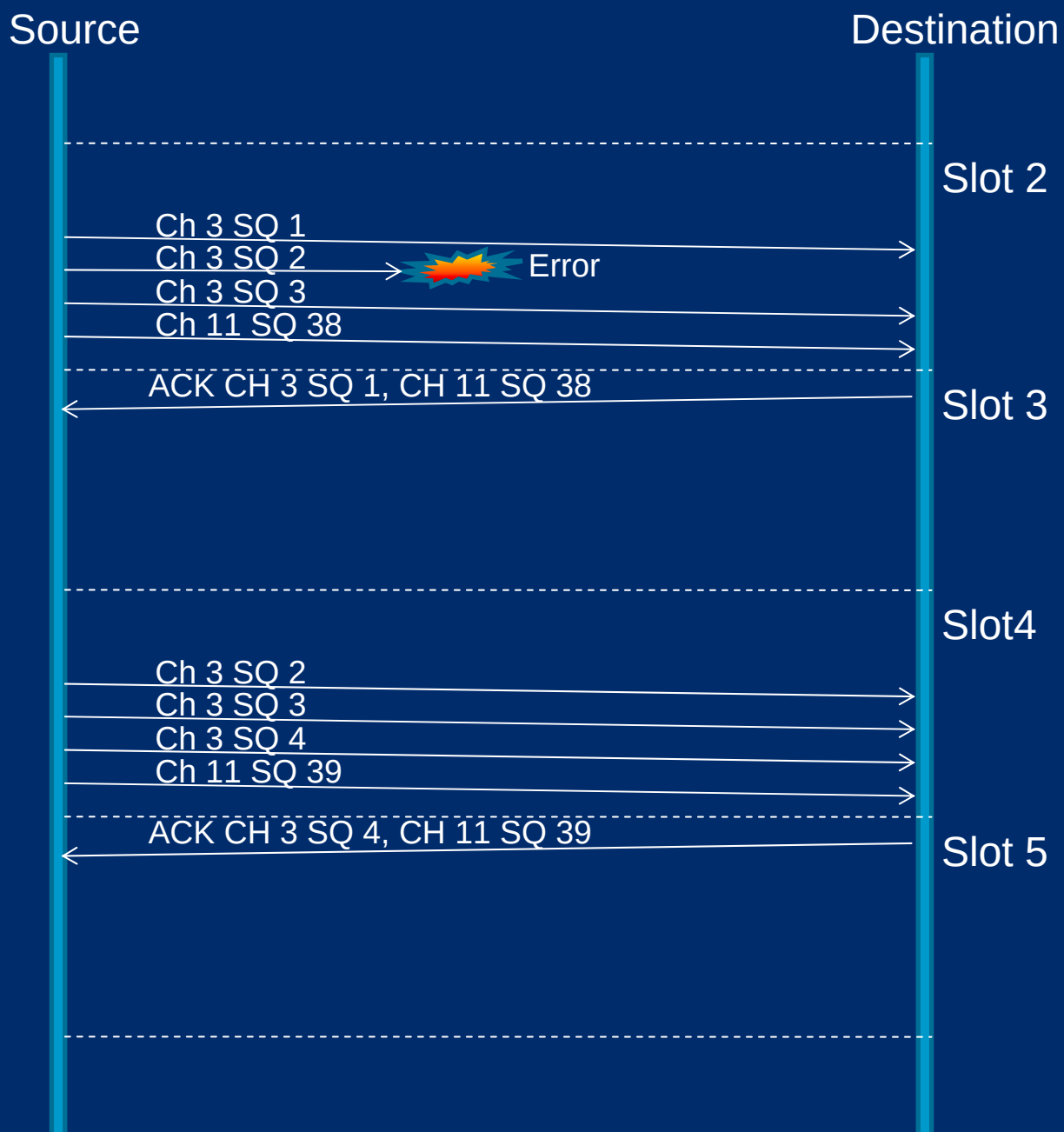
Slot-Allocation
Ch 2 slots 7 &12
Ch 3 slots 2 & 4
Ch 10 slot 10

Channel QoS
Ch 2 Guaranteed
Ch 3 Guaranteed
Ch 10 Reserved
Ch 11 Assured
Ch 12 Best Effort

Scheduled: Data PDU Error

<u>Slot-Allocation</u>
Ch 2 slots 7 &12
Ch 3 slots 2 & 4
Ch 10 slot 10

<u>Channel QoS</u>
Ch 2 Guaranteed
Ch 3 Guaranteed
Ch 10 Reserved
Ch 11 Assured
Ch 12 Best Effort



Scheduled: Data PDU Error

Source

Destination

Slot 7

Ch 2 SQ 49

Ch 11 SQ 40

Error

Ch 12 SQ 18

Ch 12 SQ 19

ACK CH 2 SQ 49

Slot 8

Slot 9

Slot 10

Ch 10 SQ 22

Ch 11 SQ 40

Ch 12 SQ 20

ACK CH 11 SQ 40

Slot 11

<u>Slot-Allocation</u>

Ch 2 slots 7 &12

Ch 3 slots 2 & 4

Ch 10 slot 10

<u>Channel QoS</u>

Ch 2 Guaranteed

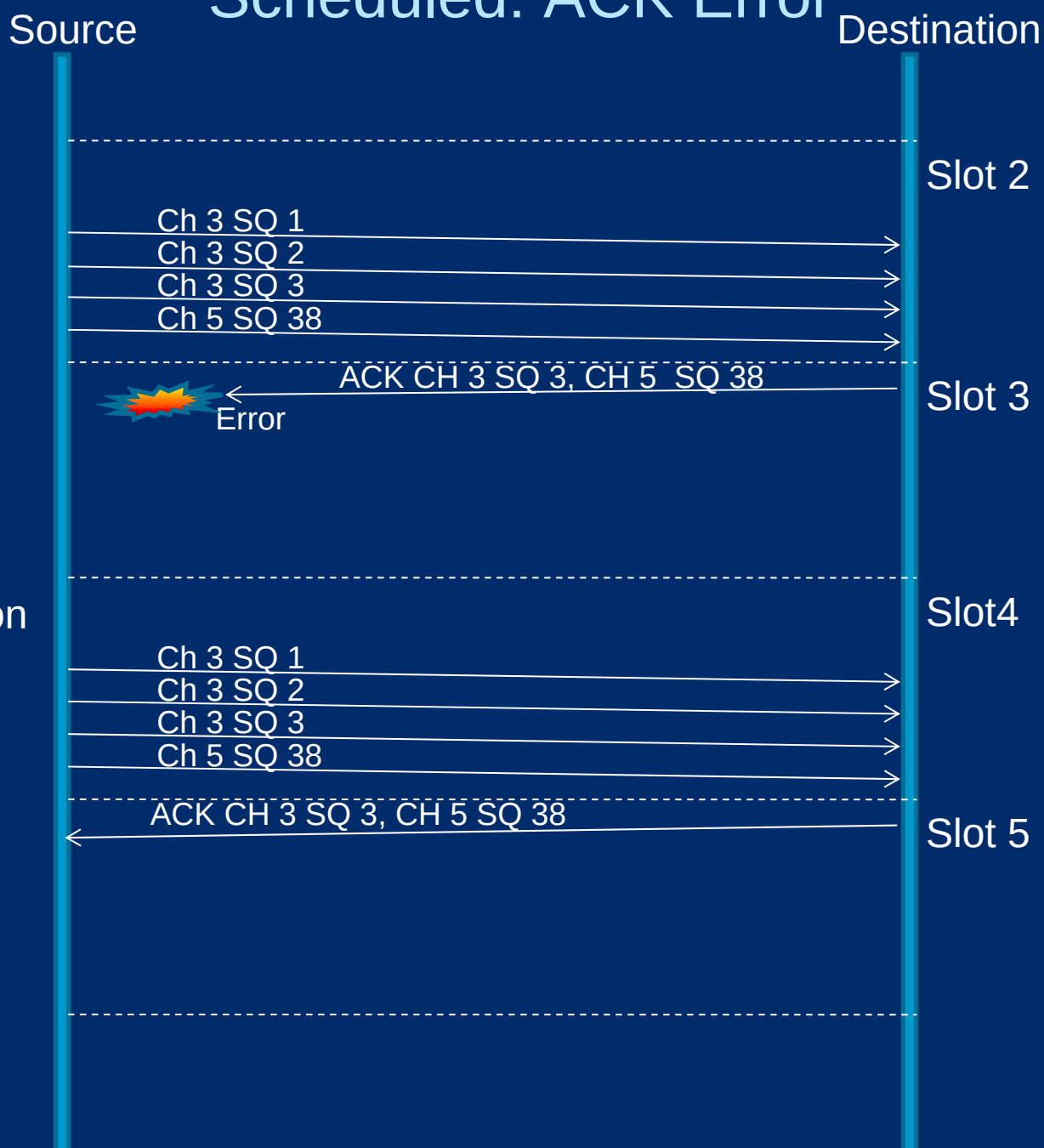
Ch 3 Guaranteed

Ch 10 Reserved

Ch 11 Assured

Ch 12 Best Effort

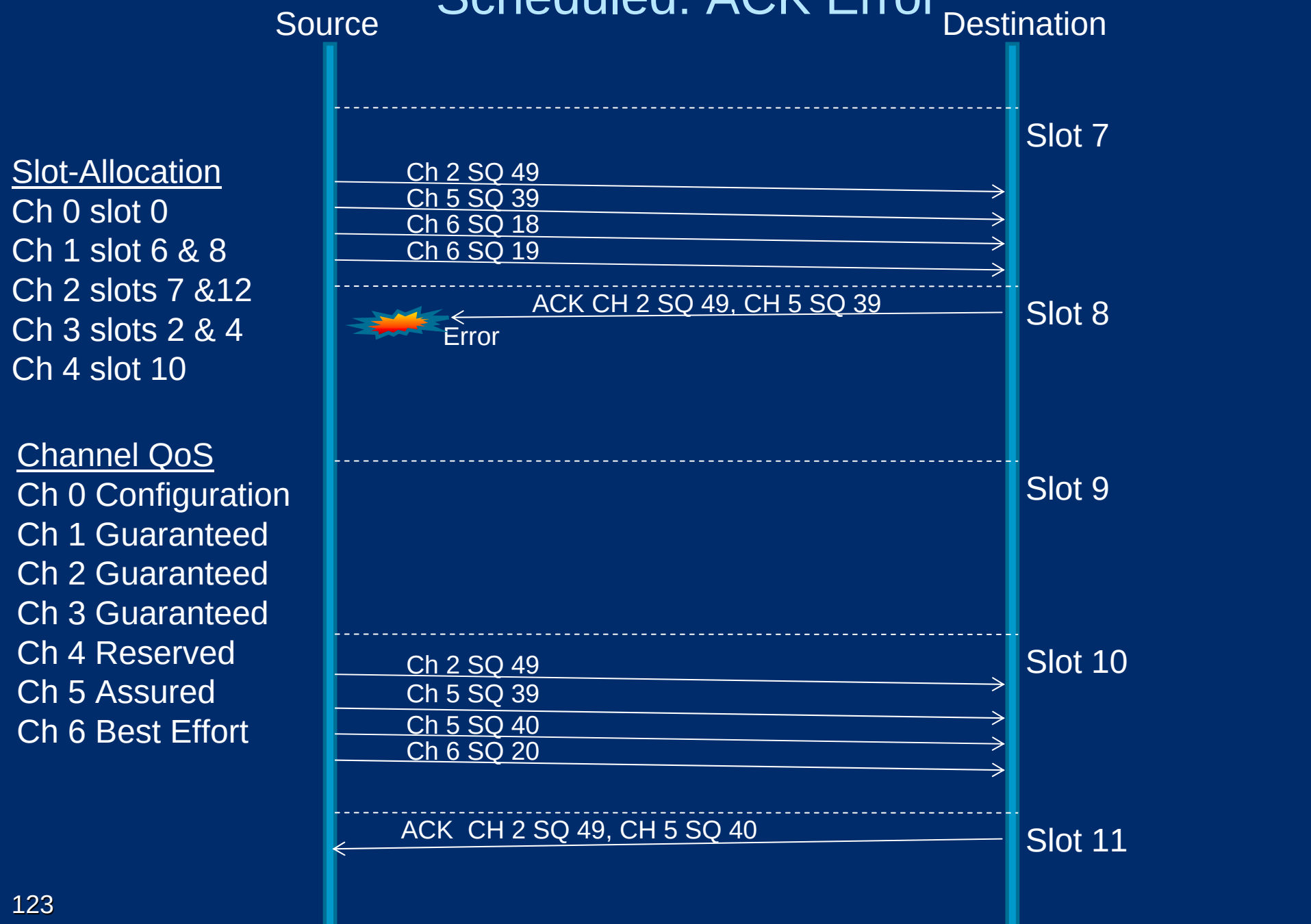
Scheduled: ACK Error



Slot-Allocation
Ch 0 slot 0
Ch 1 slot 6 & 8
Ch 2 slots 7 &12
Ch 3 slots 2 & 4
Ch 4 slot 10

Channel QoS
Ch 0 Configuration
Ch 1 Guaranteed
Ch 2 Guaranteed
Ch 3 Guaranteed
Ch 4 Reserved
Ch 5 Assured
Ch 6 Best Effort

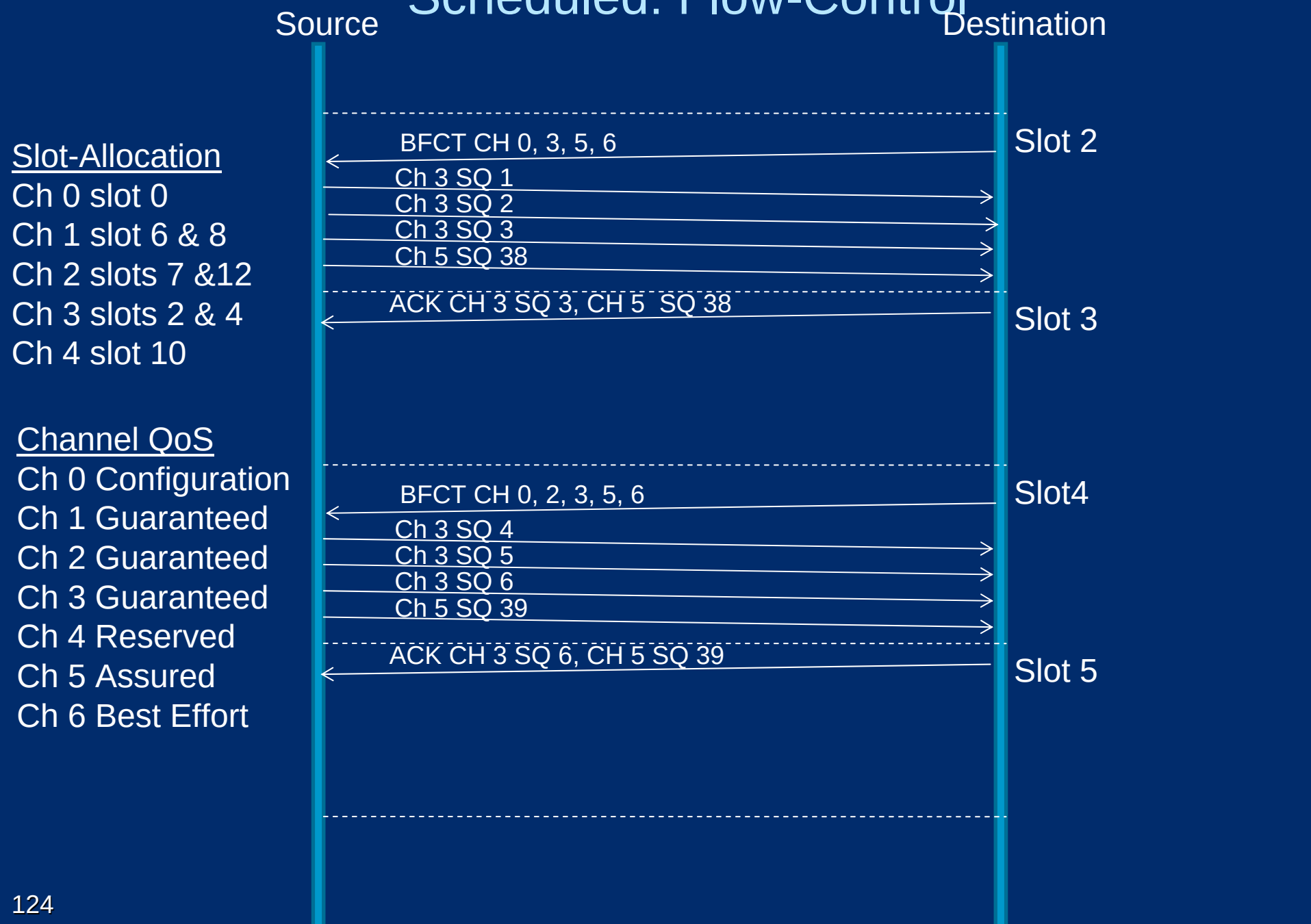
Scheduled: ACK Error



Slot-Allocation
Ch 0 slot 0
Ch 1 slot 6 & 8
Ch 2 slots 7 &12
Ch 3 slots 2 & 4
Ch 4 slot 10

Channel QoS
Ch 0 Configuration
Ch 1 Guaranteed
Ch 2 Guaranteed
Ch 3 Guaranteed
Ch 4 Reserved
Ch 5 Assured
Ch 6 Best Effort

Scheduled: Flow-Control



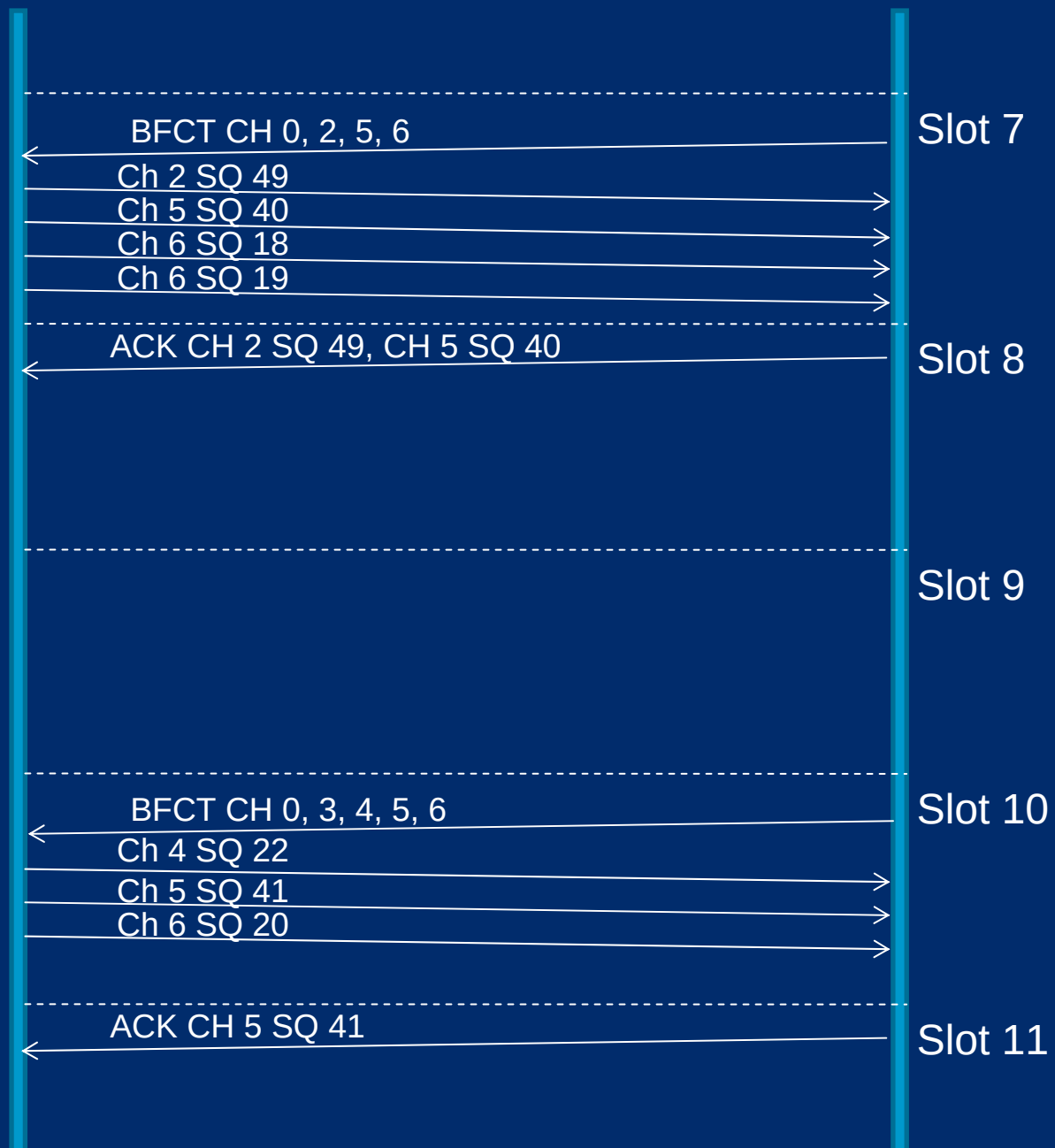
Scheduled: Flow-Control

Source

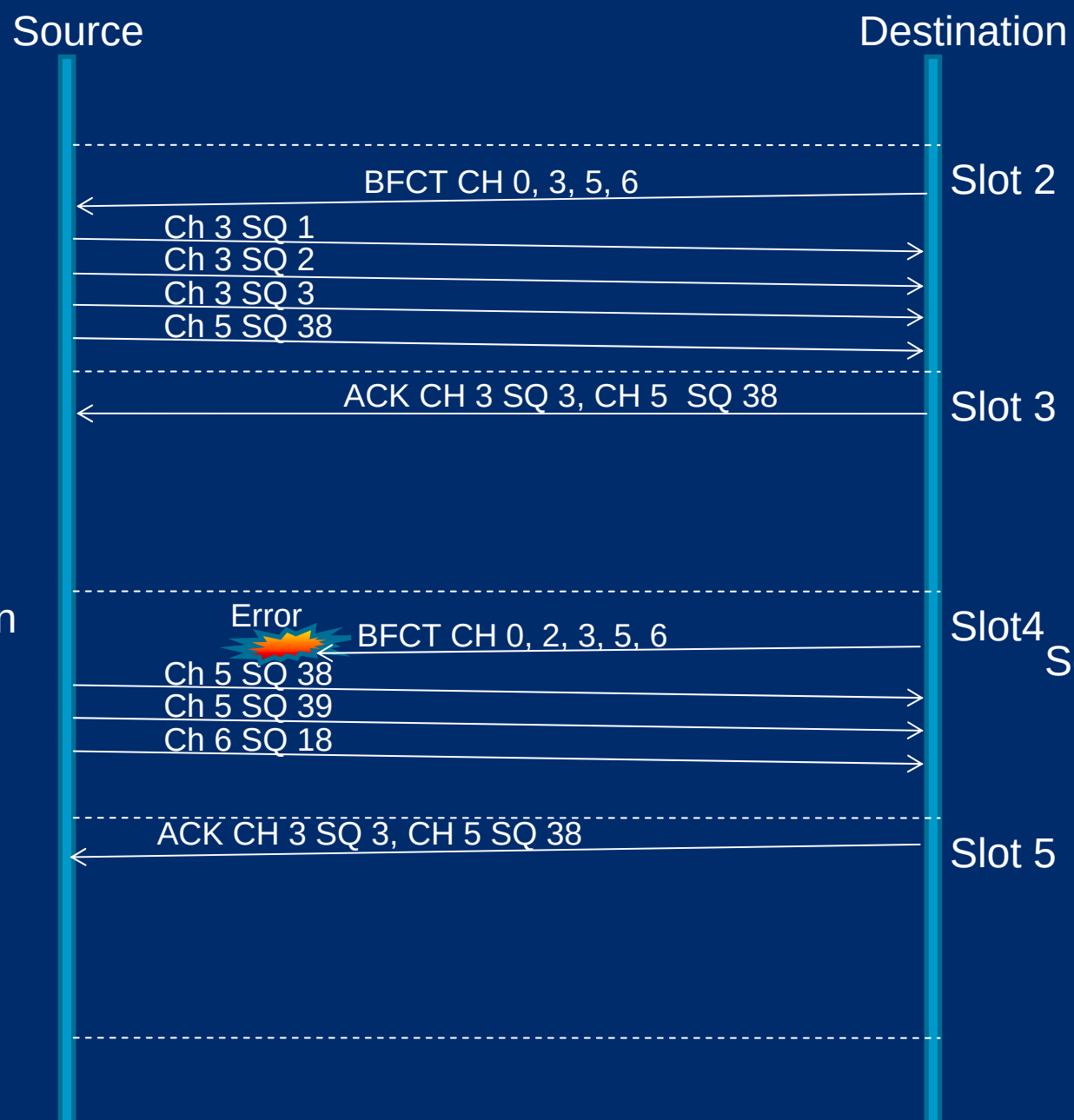
Destination

<u>Slot-Allocation</u>
Ch 0 slot 0
Ch 1 slot 6 & 8
Ch 2 slots 7 &12
Ch 3 slots 2 & 4
Ch 4 slot 10

<u>Channel QoS</u>
Ch 0 Configuration
Ch 1 Guaranteed
Ch 2 Guaranteed
Ch 3 Guaranteed
Ch 4 Reserved
Ch 5 Assured
Ch 6 Best Effort



Scheduled: Flow-Control Error



Slot-Allocation
Ch 0 slot 0
Ch 1 slot 6 & 8
Ch 2 slots 7 &12
Ch 3 slots 2 & 4
Ch 4 slot 10

Channel QoS
Ch 0 Configuration
Ch 1 Guaranteed
Ch 2 Guaranteed
Ch 3 Guaranteed
Ch 4 Reserved
Ch 5 Assured
Ch 6 Best Effort

Scheduled Data PDU Encapsulation

First octet sent

	Destination SpW Address	Destination SpW Address	Destination SpW Address
Destination Logical Address	SpW Protocol ID	Source Logical Address	Type / Redundancy
Channel	Sequence Number	Data Length	Header CRC
Data	Data	Data	Data
Data	Data	Data	Data
Data	Data	Data	Data
Data	Data	Data	Data
Data CRC	EOP		

Last octet sent

Space Technology Centre
University of Dundee

Scheduled ACK PDU Encapsulation

First octet sent

	Destination SpW Address	Destination SpW Address	Destination SpW Address
Destination Logical Address	SpW Protocol ID	Source Logical Address	Type = ACK, BFCT or BACK
Channel Number	Sequence Number	Channel Number	Sequence Number
Channel Number	Sequence Number	Channel Number	Sequence Number
Channel Number	Sequence Number	Channel Number	Sequence Number
Header CRC	EOP		

Last octet sent

Space Technology Centre
University of Dundee

Scheduled ACK PDU Encapsulation

First octet sent

	Destination SpW Address	Destination SpW Address	Destination SpW Address
Destination Logical Address	SpW Protocol ID	Source Logical Address	Type = ACK, BFCT or BACK
BFCT 0-3	BFCT 4-7	BFCT 8-11	BFCT 12-15
BFCT 16-19	BFCT 20-23	BFCT 24-27	BFCT 28-31
BFCT 32-35	BFCT 36-39	Header CRC	EOP

Last octet sent

Space Technology Centre
University of Dundee

Network Management

Space Technology Centre
University of Dundee

Configuring Channels

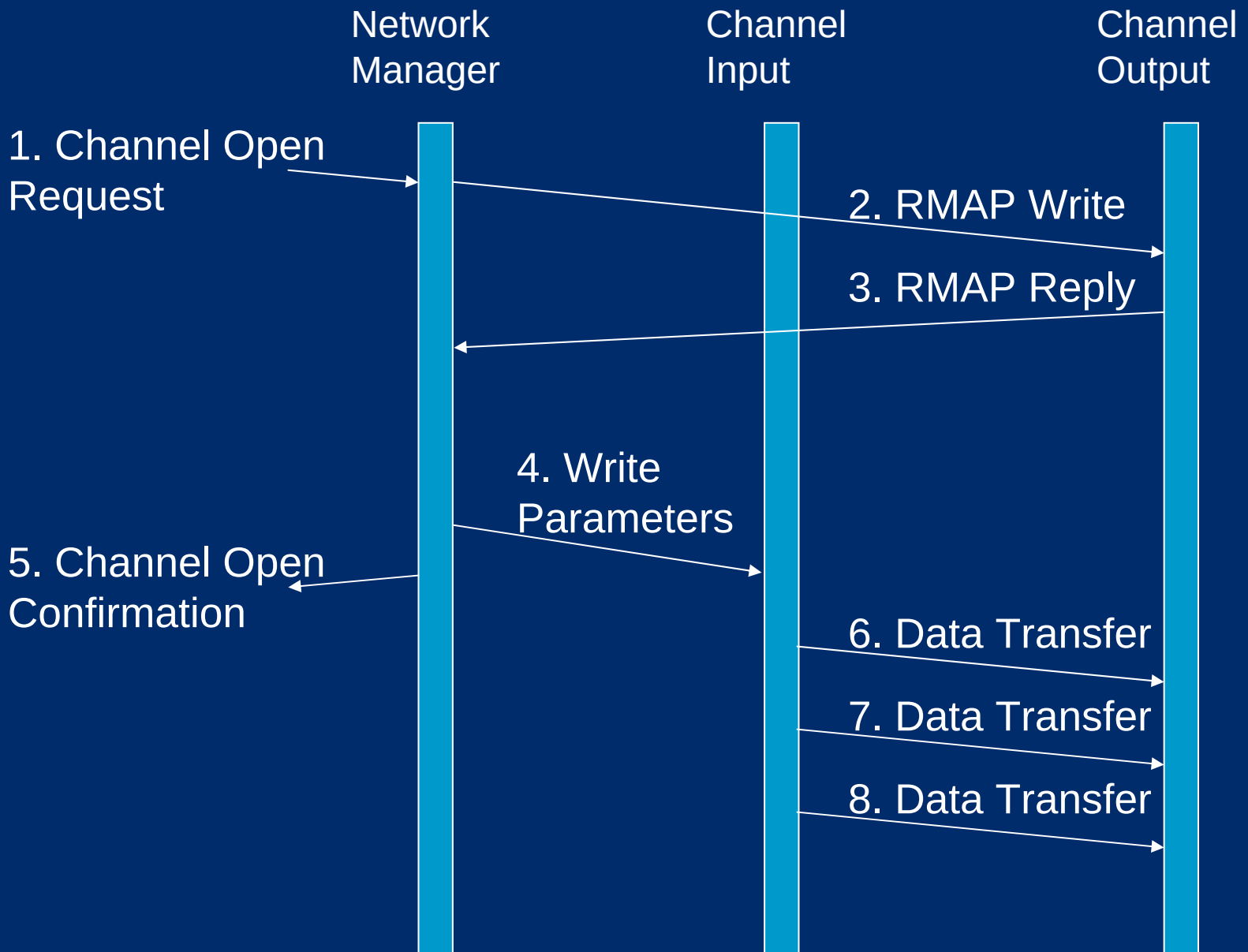
- During configuration the Basic QoS is used
  - since it cannot be assumed that channels have been set up prior to configuration
- RMAP protocol is used for channel configuration
  - Initial configuration prior to time-codes
  - Uses Master time-slot once schedule running
  - RMAP write of configuration parameters
  - RMAP Reply acknowledges Channel Open
- To open a bi-directional channel
  - Need to open each direction separately
- Can remotely set up channel between two other nodes

Configuring Channels

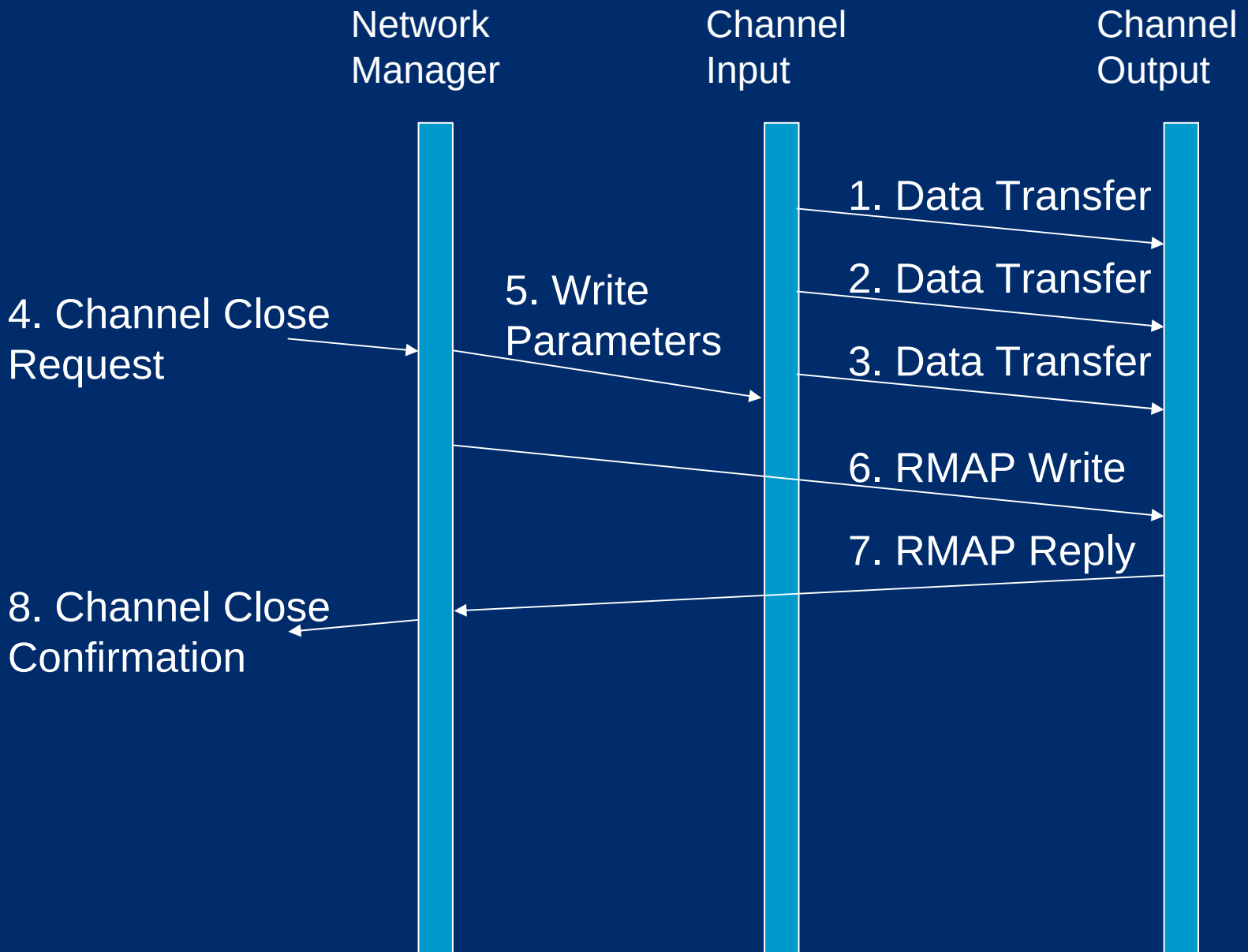
- Channel open parameters:
  - Source logical address
  - Destination logical address
  - Channel number
  - QoS parameters
- Channel close parameters
  - Source logical address
  - Destination logical address
  - Channel number

Space Technology Centre
University of Dundee

Channel Open (local input)



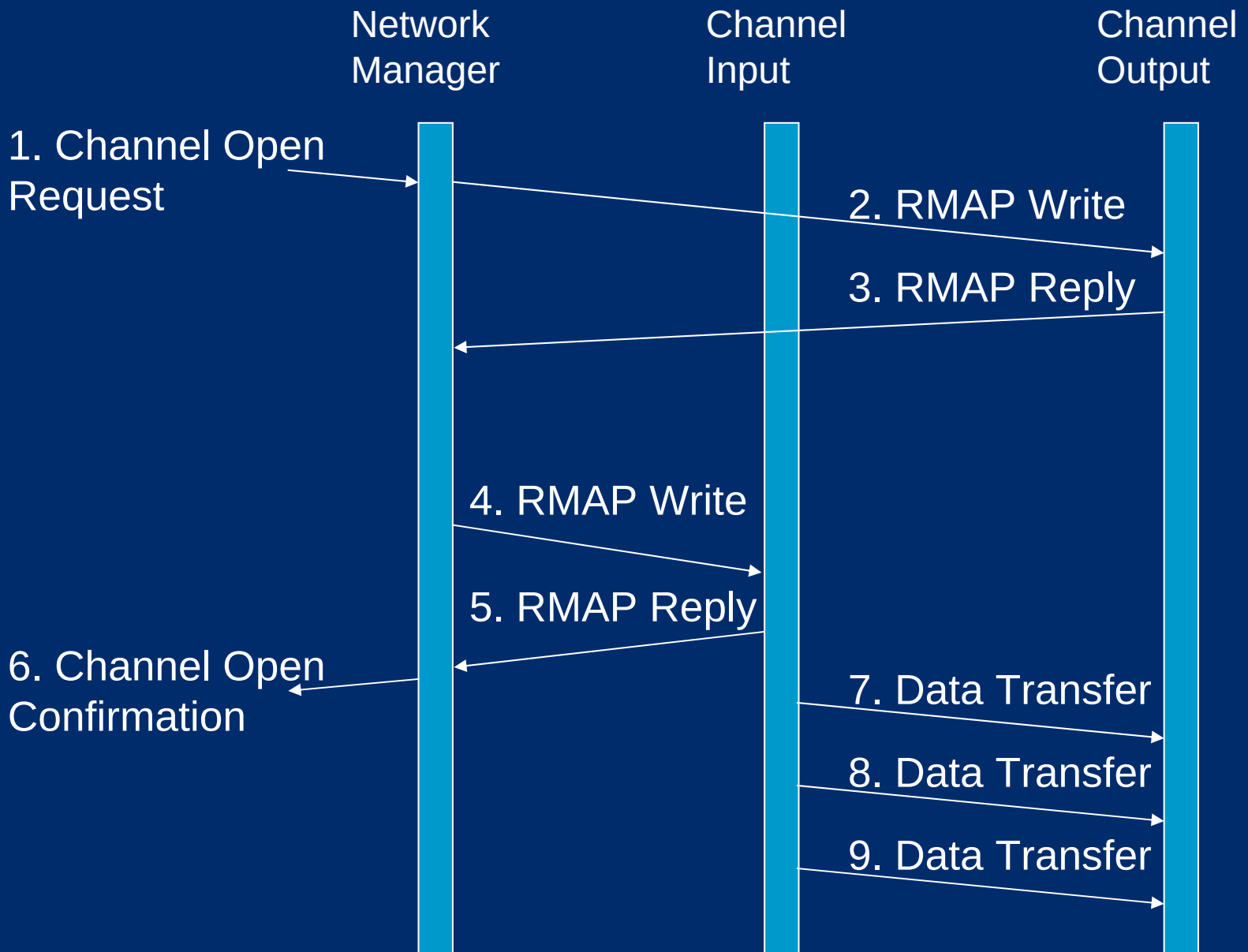
Channel Close (local input)



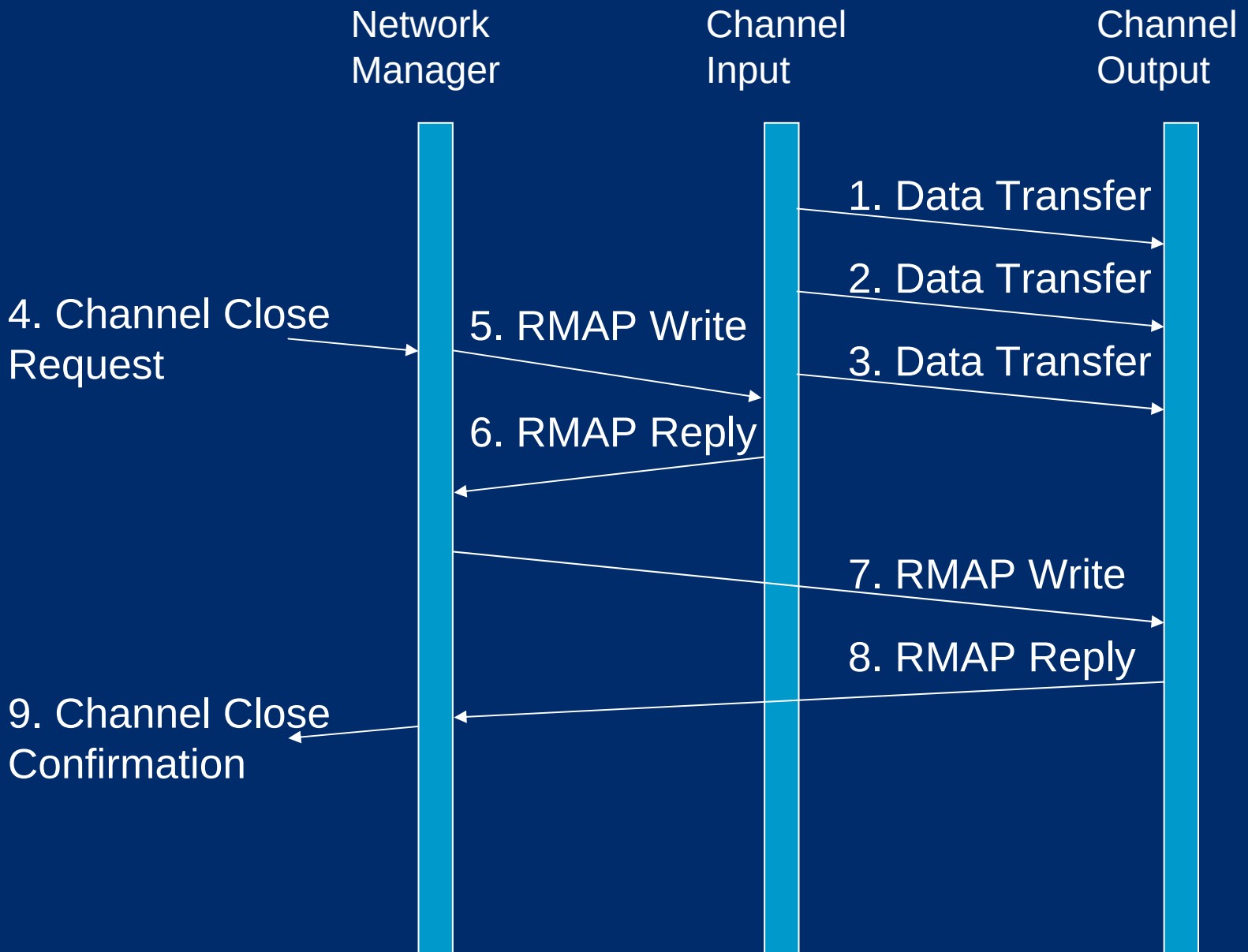
Space Technology Centre
University of Dundee

Space Technology Centre
University of Dundee

Channel Open (remote input and output)



Channel Close (remote input and output)



Space Technology Centre
University of Dundee

Current and Future Work

- Currently completing a new draft protocol specification
- Extensive prototyping done to evaluate competing concepts

- Future
  - Dynamic channels
  - Network management
  - SOIS Plug and Play