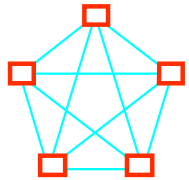
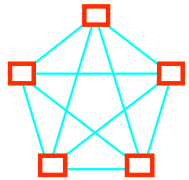
4Links 

SpaceWire Characteristics and Developments

Barry M Cook, 4Links Limited
www.4Links.co.uk

Content

4Links 

Overview

Links

Routers

Networks

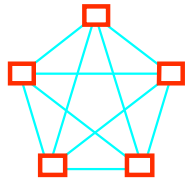
Broadcast

Other Issues

Protocols

Conclusion

Overview: **What it is**

4Links 

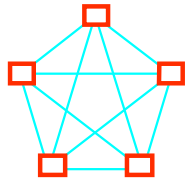
Link

- Point-to-point data connection
  - Lightweight protocols (relative to alternatives)
  - Low-latency data transfer (minimal buffering)
  - Flow controlled (avoids data loss)

Routing Switch

- Simple protocol
- Support for redundancy / FDIR

Overview: **History**

4Links 

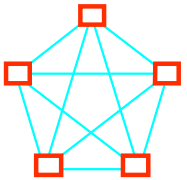
Derived from a high-performance inter-processor link (for the Inmos T9000 processor family)

Standardised as IEEE-1355 and ISO-14575 (CPHW →

Evolved into … 4Links)

- IEEE-1394(FireWire) – wire coding
- Consumer electronics – home networks (4Links)
- SpaceWire – ECSS-E-50-12A(Jan2003) (ESA,4Links,etc.)

Overview: **Take-up**

4Links 

IEEE-1355 in successful missions

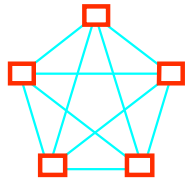
Plans to use SpaceWire in US and European missions

ESA has funded link design and router chip development

Other link designs and routers exist / are being developed

4Links has sold products to 18 countries (PCI & cPCI boards, test equipment and interfaces)

Overview: **Control**

4Links 

ESA runs the SpaceWire Working Group which agrees and publishes the standards

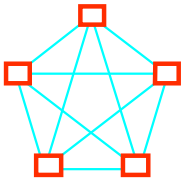
- Worldwide participation – Europe, Russia, Japan, USA

However …

- More input is needed from a wider range of users
  - There is scope for users to drive the standards

Overview: **Experience**

4Links

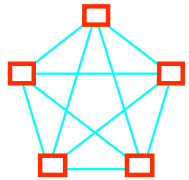


4Links has many years experience of building IEEE-1355 and SpaceWire links, switches and systems

We now have 6 generations of link design

- Each silicon architecture needs different optimisations
- Current link speeds exceed 400Mb/s with >1Gb/s projected

Overview: **Experience(2)**

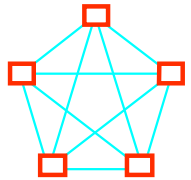
4Links 

We have several switch designs

- 4 to 8 ports, 200Mb/s
- 8 to 32 ports, 400Mb/s

We have built and demonstrated fault-tolerant systems, including an acclaimed demonstration of reliable uncompressed real-time video

Overview: **Experience(3)**

4Links 

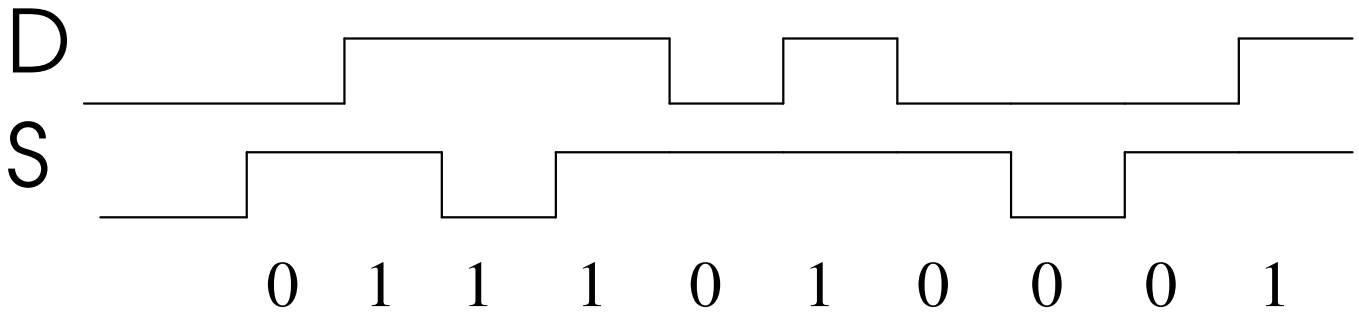
We have also built Ethernet devices and interfaces

- Routing switches
- 10Mb/s PHY to Gb/s MAC (including direct interface, MII and SGMII)

Link: **Low-level**

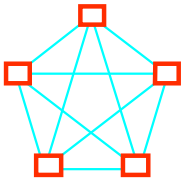
4Links

SpaceWire transmits data using a Gray code on 2 (pairs of) wires using LVDS signals –



- The clock can be recovered as (D xor S)
- Accurate control of clock frequencies is not needed
- Phase-locked-loops are not needed

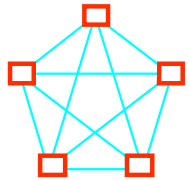
Link: **Low-level**

4Links 

- Speed can be dynamically changed
  - e.g. to save power when there is no data to send
- Link failure can be detected by the loss of the derived clock signal
  - The timeout period is nominally 850ns
  - Link recovery takes about 20µs
- Minimum speed is ~2Mb/s (due to timeout)
- Maximum ~1Gb/s (limited by connectors?)

Link: **Exchange Level**

4Links



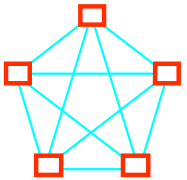
Several basic tokens are defined -

- Fundamental
  - 4-bit: Escape, Flow-control, End-of-packet(EOP,EEP)
  - 10-bit: Data
- Derived
  - 8-bit: Null (Escape + Flow-control)
  - 14-bit: Time-code (Escape + Data)

Some combinations are not permitted

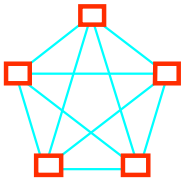
- Escape-Escape, Escape-EOP, Escape-EEP

Link: **Tokens**

4Links 

- Each has a 4-bit/10-bit flag, Parity bit and 2- or 8-bits of data
- Data tokens use 10-bits for each 8-bit byte
  - 100Mb/s SpaceWire can transfer 80Mb/s data
- BUT flow control tokens may be inserted
- One FCT (from end-B to end-A) for each 8-bytes of data (from end-A to end-B)
  - 100Mb/s SpaceWire can transfer just over 76Mb/s data
- These are per-direction: SpaceWire is a full-duplex link
- NOTE: data rate meanings differ between standards compare Ethernet, SpaceWire, FireWire/USB for coding, half- or full-duplex and bussed/shared or per link

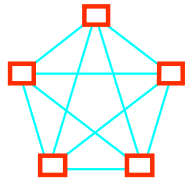
Link: **Packets**

4Links 

Data is transferred in packets

- A packet consists of an arbitrary number of data tokens followed by an end-of-packet token (EOP or EEP)
- Null, flow-control and time code tokens may be inserted into the data stream – but are not part of the packet

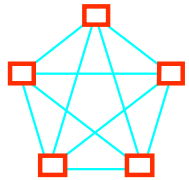
Router: **Overview**

4Links 

Connects links to allow dynamic connections

- Wormhole (cut-through) routing
  - Low-latency (no store-and-forward needed)
  - Flow-control halts data if path is blocked
- Network has arbitrary topology – including loops / multiple paths
  - User must take care configuring routing tables to avoid infinite loops
  - Broadcast is allowed only in special cases
    - e.g. time codes

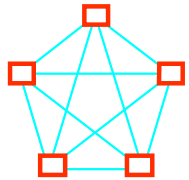
Router: **Routing**

4Links 

The first data byte in the packet is used to direct the packet

- 0: Control of the router
- 1-31: Physical addressing (source routing)
  - This byte is deleted from the packet
- 32-254: Logical addressing
  - Route is determined from a routing table
  - This byte may be deleted or retained

Router: **Contention**

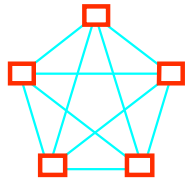
4Links 

When more than one input has data for the same output they must be sent in some order. The standard defines:

- Simple choice – e.g. round robin
- (Optional) priority

Router: **Other algorithms**

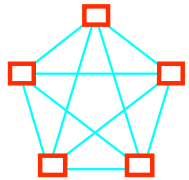
4Links



Other algorithms are also possible

- e.g. 4links has implemented an Ethernet switch and are investigating directly implementing Ethernet routing on SpaceWire switches – including support for broadcast (concurrently with previously mentioned algorithms)

Router: **Grouping**

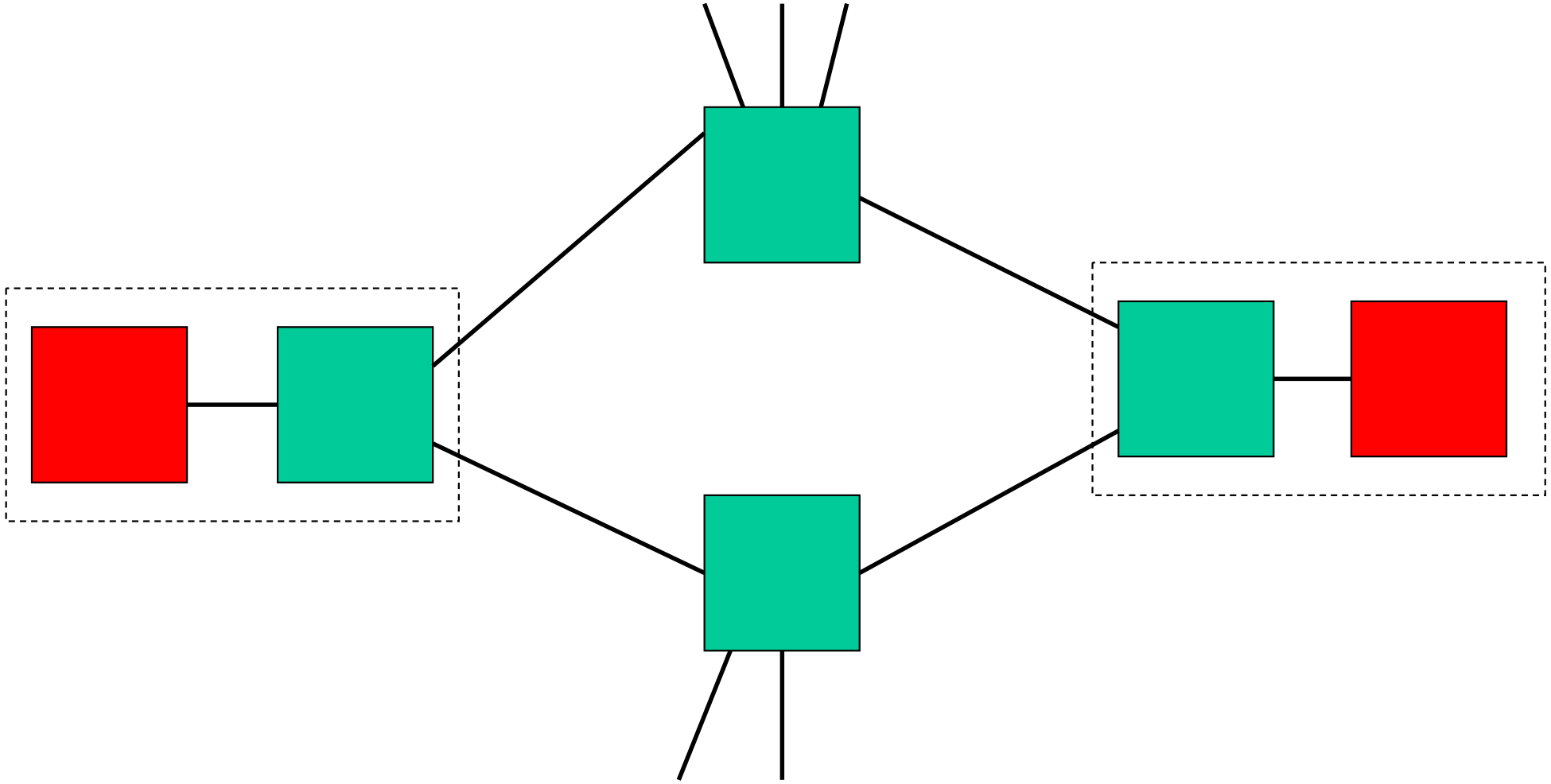
4Links 

When logical addressing is used, the table may specify more than one outgoing link

- All links are considered equal and the first free link is used
  - Group Adaptive Routing
  - Allows bandwidth aggregation
  - Allows redundancy (e.g. N+1 or N+M)
  - Provides fault tolerance

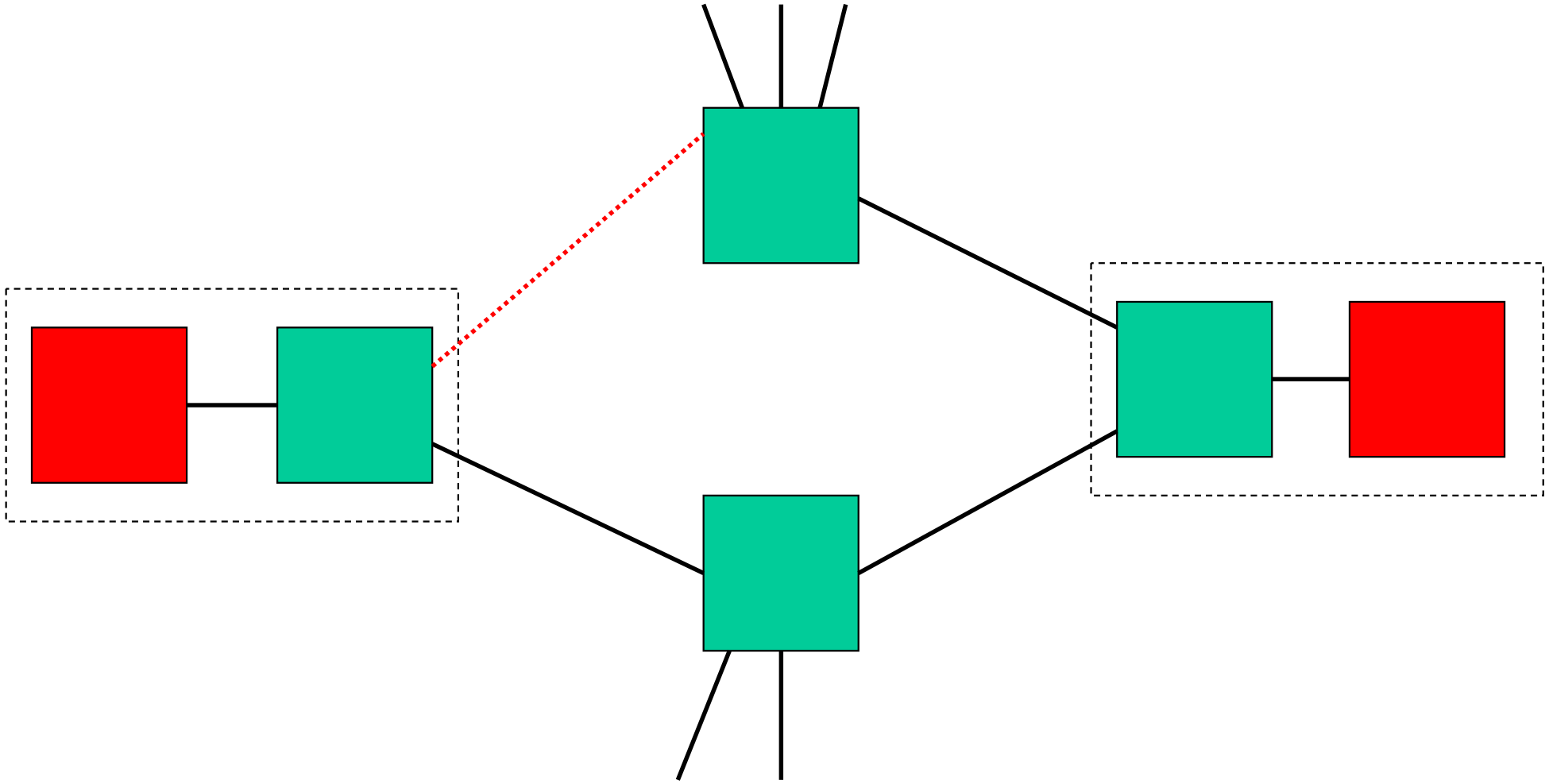
Router: **Grouping (2.1)**

4Links



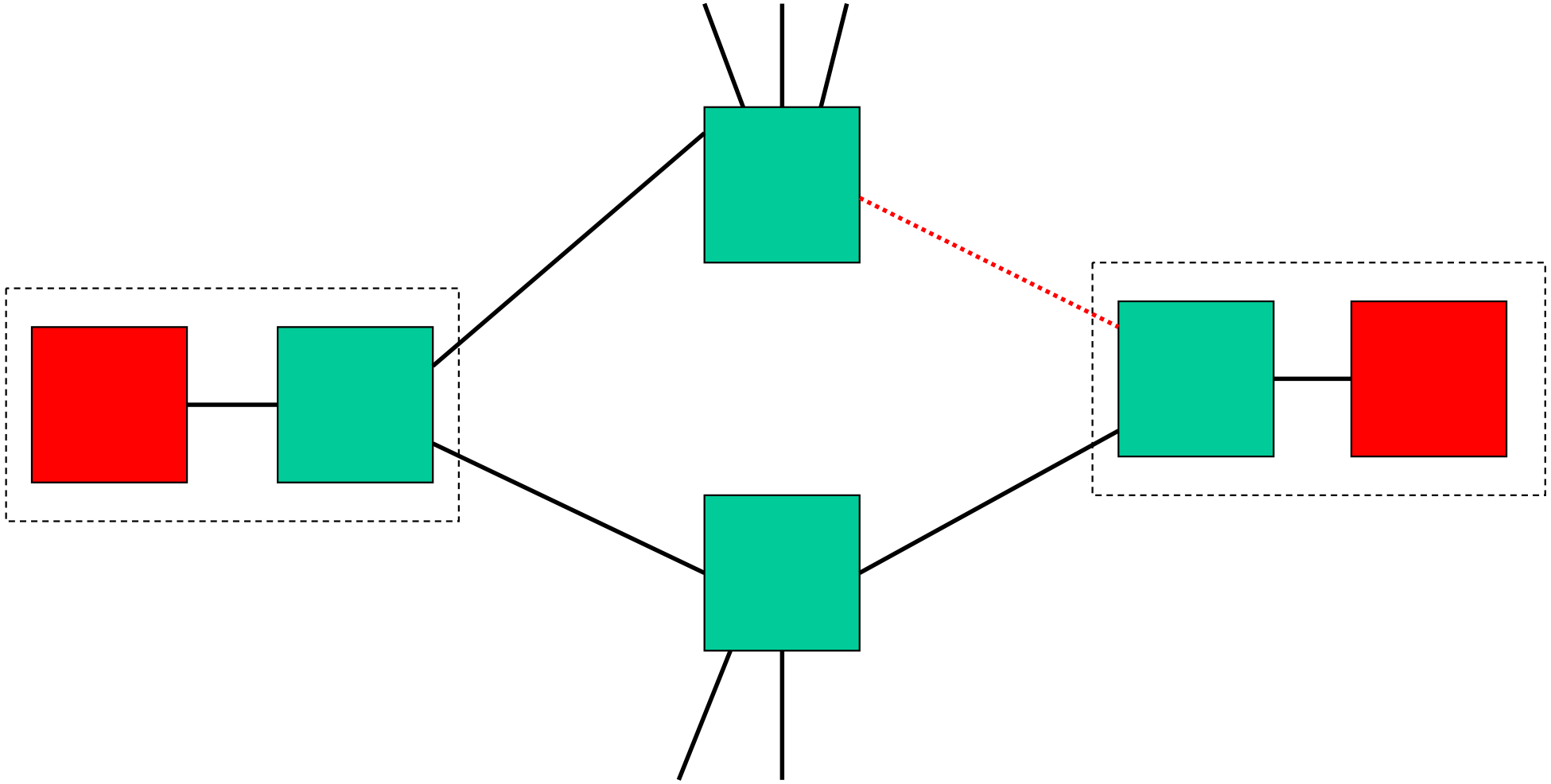
Router: **Grouping (2.2)**

4Links



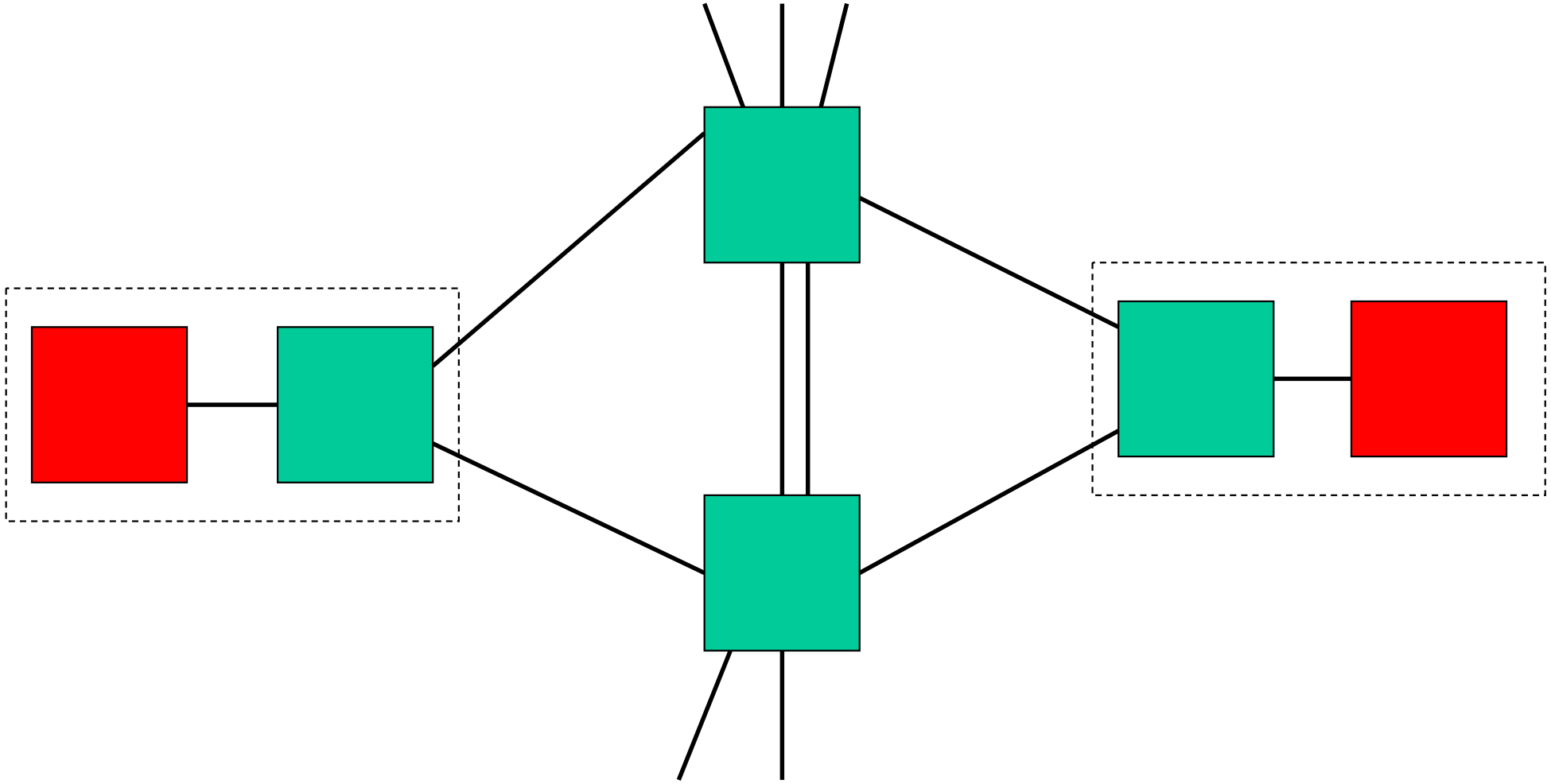
Router: **Grouping (2.3)**

4Links

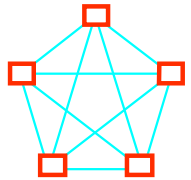


Router: **Grouping (2.4)**

4Links



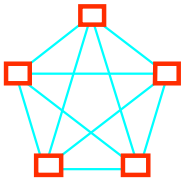
Router: **Grouping (3)**

4Links 

Careful design is required to ensure there are enough alternate routes

- Congestion on some paths is possible
  - Primary/secondary paths are not currently supported
- Network management may be used to provide re-configuration
  - Externally
  - Within the router

Broadcast: **General**

4Links 

Networks may (should) have multiple paths and hence loops

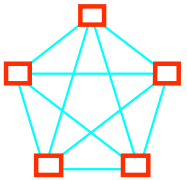
Broadcast would result in deadlock and/or infinite loops

Therefore: SpaceWire networks do not support broadcast … except:

- Time codes
- (proposed) Interrupt post / acknowledge

Broadcast: **Time codes**

4Links



For global synchronization, a time value is broadcast to all nodes

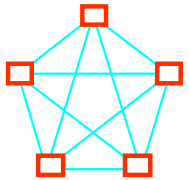
An 8-bit value is used, including an incrementing sequence number that is used to break infinite loops

Jitter and absolute error is several (10's of) micro-seconds but can be reduced to nano-seconds

- See: "Reducing SpaceWire Time-code Jitter" by Barry M Cook, 4Links Limited

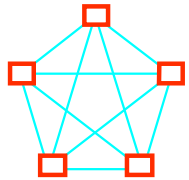
Broadcast: **Interrupt Codes**

4Links



- Yuriy Sheynin and Sergey Gorbachev of the St Petersburg State University of Aerospace Instrumentation have proposed an extended use of the time-code mechanism
- Allows broadcast of 64 interrupts and responses
  - My analysis is that it is probably OK in a working network but its behaviour in a broken network is unclear

Other issues: **Mixed Speeds**

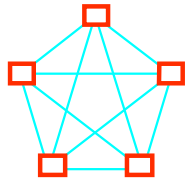
4Links 

Although SpaceWire can run at virtually any speed, care must be taken in mixed-speed systems

- A path through a network remains open for the *time* required to pass the whole packet
  - This is determined by the slowest link
  - Nulls are inserted on faster links
    - This is inefficient

A unified system speed or store-and-forward buffering is advised

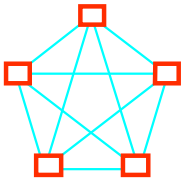
Other issues: **Real-time**

4Links 

An open path transferring a packet can not be pre-empted for a different packet

- Packet latency depends on other traffic
  - The maximum latency depends on the maximum size of packets in the network
  - Real time behaviour may be poorly defined
    - Even with SpaceWire's priority scheme
- Users are interested in more determinate real-time performance. 4Links has a solution and intends to demonstrate it soon

Protocols: **Protocol ID**

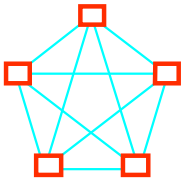
4Links 

Higher level protocols are required and several may need to co-exist in a network

The SpaceWire working group have adopted the suggestion that the first byte(s) of a packet indicate which protocol is used in the remainder of that packet

Users may propose a protocol and, if approved by the working group, have a unique ID issued for that protocol

Protocols: **RMAP**

4Links 

The first such protocol is the Remote Memory Access Protocol which provides for register, memory and data-stream transfers

Draft C defines:

- Write
  - Acknowledged / not acknowledged
  - Verified / not verified before writing
- Read
- Read-modify-write

Conclusion

4Links

SpaceWire offers a low-complexity technology for building scalable, fault tolerant networks.

BUT

There are a few loose ends to tie up

4Links provides the essential equipment and expertise to help you build systems