Internetworking Over SpaceWire: A Link-Layer Broadcast Service for Network Stack Support

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**Advantages**

- Software reuse; mature APIs and implementations.
- Simpler application code.
- Rapid development.
- Lower cost.
- Interoperability.

**Disadvantages**

- Protocol assumptions may not hold (e.g., TCP assumes delay is related to congestion, IP assumes end-to-end connectivity, …).
- Performance may not be optimal.
SpaceWire Overview

- Switched LAN designed for high speed on-board data handling.
- Low power, low cost.
- Scalable
- 2 to 400 Mbps, low latency.
- Backplane or Cables.
- Based on IEEE 1355 and LVDS.
- Wormhole routing
- ESA Specification ECSS-E-50-12A
SpaceWire Path Addressing

- Header contains output port of each hop (0 .. 32)
- SpaceWire Routers apply header deletion
- Example: N1 sends to N6  \(<4><2><3><\text{cargo}><\text{EOP}>\)
SpaceWire Logical Addressing

- Header contains logical address of destination (32 .. 254)
- Path determined by router forwarding tables.
- Example: N1 sends to N6  \(<131><cargo><EOP>\)
SpaceWire Regional Logical Addressing

- Regional addressing used for larger networks.
- Logical addresses may be reused in different regions.
- Routers configured as gateways between regions.
- Example: N1 sends to N9  <165><43><cargo><EOP>

![Diagram showing regional logical addressing with routers and nodes in two regions.](image-url)
• Interest in on-board IP / SCPS-NP, esp. for rapid development programs.

• Need to level the playing field with Ethernet by providing full support for network protocols and standard network management.

• SpaceWire is missing 2 key elements:
  • Encapsulation service
  • Address Resolution Protocol (ARP)
Encapsulation Service

- **1 byte Encapsulation header (Virtual Channel ID).**
- Identifies network protocol or software module on destination.
- Enables SpaceWire to support multiple network types.
- **Lightweight but sufficient.**
  - SpaceWire Virtual Channel ID: 8 bits
  - Ethernet Type field: 16 bits

<table>
<thead>
<tr>
<th>Type</th>
<th>Virtual Channel ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARP</td>
<td>1</td>
</tr>
<tr>
<td>IPv4</td>
<td>2</td>
</tr>
<tr>
<td>IPv6</td>
<td>3</td>
</tr>
<tr>
<td>CCSDS SCPS-NP</td>
<td>4</td>
</tr>
<tr>
<td>CCSDS Source Packet</td>
<td>5</td>
</tr>
<tr>
<td>Broadcast</td>
<td>254</td>
</tr>
</tbody>
</table>
SpaceWire Address Resolution

- No ARP defined for SpaceWire
  - Manual configuration of address resolution tables:
    - Assign SpaceWire and IP addresses.
    - Install table on each node.
  - Tables are static. Changing network topology requires new tables.

- SpaceWire cannot use standard ARP (RFC 826)
  - Logical addresses not unique.
  - No link-layer broadcast for full network.
  
  Solution: Develop these and use standard ARP

<table>
<thead>
<tr>
<th>IP Address</th>
<th>SpaceWire Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.168.0.1</td>
<td>41</td>
</tr>
<tr>
<td>192.168.0.2</td>
<td>129</td>
</tr>
<tr>
<td>192.168.0.3</td>
<td>54</td>
</tr>
</tbody>
</table>
Broadcast Service

Features

• Guarantees loop-free broadcast

• Link-layer implementation, no modification to the network layer (e.g. IP, SCPS-NP)

• Host implementation; no modification to Spacewire routers.

• Driver software implementation, no modification to Spacewire interface hardware.

• Adheres to SpaceWire standard.
Broadcast Service

- Introducing Concept of a SpaceWire Subnet
  - Set of nodes attached to one routing switch
  - 1 Broadcast Server
Broadcast Service

- **Protocol Messages**
  - **Type 0: Subnet Broadcast**

  1 byte

<table>
<thead>
<tr>
<th>2</th>
<th>254</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpaceWire header: <em>Port Address</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encapsulation header: <em>Protocol 254 = Broadcast</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broadcast header: <em>Type 0</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

  Broadcast Message Payload
Protocol Messages

- Type 0: Subnet Broadcast

SpaceWire header: Port Address
Encapsulation header: Protocol 254 = Broadcast
Broadcast header: Type 0
Encapsulation header: Protocol 1 = ARP
• Protocol Messages
  ➢ Type 1: Server Broadcast

  1 byte

  | 45  |
  | 254 |
  | 1   |

  SpaceWire header: *Logical Address*
  Encapsulation header: *Protocol 254 = Broadcast*
  Broadcast header: *Type 1*

  Broadcast Message Payload
Broadcast Service

• Protocol Operation

➢ Node sends Subnet Broadcast
  • Sends Type 0 message to all other ports on local router using path addressing.
  • Neighbor Routers configured to discard LA 254

➢ Broadcast Server sends Server Broadcast
  • On receipt of Type 0 message, extracts the broadcast payload, encapsulates in Type 1 message and sends to all other Broadcast Servers.

➢ Remote Server sends Subnet Broadcast
  • On receipt of Type 1 message, extracts the broadcast payload, encapsulates in Type 0 message and sends to all other ports on local router.
Broadcast Service

- Node N3 sends Subnet Broadcast (Type 0)
Broadcast Service

- Broadcast Server sends Server Broadcast (Type 1)

Type 1 Message Sent as Unicast to All Servers
Broadcast Service

- Remote Server sends Subnet Broadcast (Type 0)
Test Network

- **SwRI SpaceWire Link Interface Module (SLIM)**
  - Single Channel, full-duplex SpaceWire Link Interface
  - Fully Compliant CompactPCI target interface
  - 3U cPCI form-factor

- **Star Dundee Routers (8 port)**

- **4Links SpaceWire-PCI**
Summary

- By adding missing elements, standard network stacks can be supported with SpaceWire
  - Encapsulation Service
  - Address Resolution Protocol (ARP)
- Standard ARP is possible if Broadcast Service supported
- Supports multiple network layer protocols (IPv4, IPv6, SCPS-NP).

**Next step:** Implement Broadcast and Encapsulation Service in device drivers for SwRI SLIM and COTS interface boards, and test IP and SCPS-NP applications on multi-router SpaceWire test network (SCPS-FP, DHCP, SNMP, HTTP, FTP, etc.).