INFORMATION DATA SYSTEMS FOR ADVANCED AEROSPACE MISSIONS, SUCH AS SPACE STATION AND ITS CO-ORBITING PLATFORMS, ARE NEEDED THAT ARE EVOLVABLE, ADAPTIVE, AND FAULT TOLERANT. LOCAL AREA INFORMATION NETWORKS ARE CONSIDERED A MOST LIKELY TECHNOLOGY SOLUTION; ITS PRINCIPLE NEEDS ARE: 1) THAT INFORMATION FLOW BETWEEN DEVICES ON A NETWORK AND ITS CONTROL REQUIRES IMPROVEMENT, PARTICULARLY FOR MODERATELY OR TIGHTLY COUPLED HIGH PERFORMANCE PROCESSES; 2) THAT THE NETWORK SHOULD POSSESS FAULT TOLERANT PROPERTIES TO MEET SAFETY RELATED CRITICALITIES; AND 3) THAT HIGH PERFORMANCE (>100 MBPS) IS REQUIRED IF SPACE STATION IS TO HAVE AN INTEGRATED SYSTEM DATA NETWORK FORM WHERE VIDEO, VOICE, AND DATA ARE TO BE SIMULTANEOUSLY ACCOMMODATED. THE BRAIDED MESH FORM OF NETWORK HELPS MEET THESE NEEDS WITH THE FOLLOWING FEATURES: 1) SIMULTANEOUS ADAPTABLE DATA COMMUNICATION LINKS OFFERS DYNAMIC AND HIGH PERFORMANCE ACCOMMODATION, AND 2) ALTERNATE COMMUNICATION LINKS PROVIDE A CAPABILITY FOR SELF-CORRECTING AND REPAIRING (OR FAULT TOLERANT) PROPERTIES. ALSO, THE HIGH PERFORMANCE REQUIREMENT LEADS TO THE CONCEPT OF A NETWORK THAT USES FIBER OPTICS LINKS AND OPTICAL NODES; FIBER OPTICS WITH WAVELENGTH DIVISION MULTIPLEXING WOULD BE USED.

THIS EFFORT IS TO RESEARCH AND CHARACTERIZE THE ARCHITECTURAL ISSUES OF THE BRAIDED MESH FORM OF NETWORK, AND ALSO TO DEVELOP AN OPTICAL NODE WHICH WOULD FORM THE USER INTERFACE INTO THE NETWORK, CONTROL USER ACCESS TO THE NETWORK, PROVIDE ADAPTABLE MULTIPLE PATH DATA COMMUNICATIONS FROM/TO OTHER NODES, AND PROVIDE FOR OVERALL CONTROL OF THE NETWORK. SUCH A NODE NEEDS A MEANS OF LOW LOSS OPTICAL SWITCHING, WHICH IS CURRENTLY BEING DEVELOPED THROUGH INTEGRATED OPTICS. FUTURE EFFORTS WOULD BE TO CONSTRUCT A LABORATORY HIGH PERFORMANCE NETWORK, POPULATE IT WITH HIGH PERFORMANCE NETWORK USER DEVICES, AND EVALUATE/CHARACTERIZE THE NETWORK.
INFORMATION NETWORK ARCHITECTURES
506-58-13/N. MURRAY

OBJECTIVE

INFORMATION NETWORK ARCHITECTURE - RESEARCH AND DEVELOP INFORMATION NETWORKS TO MEET THE SPACE STATION NEEDS OF SELF-CORRECTING AND REPAIRING, HIGH PERFORMANCE, EVOLVABILITY, ADAPTABILITY, SECURITY, AND EFFICIENCY.

APPROACH

- RESEARCH, EVALUATE AND CHARACTERIZE THE ARCHITECTURAL TYPE NETWORKS.
  - CENTRAL CONTROL, STATIC, SELF CORRECTING/REPAIRING (MESH)
  - DISTRIBUTED CONTROL, ADAPTIVE, SELF CORRECTING/REPAIRING (MESH)

  C. S. DRAPER LABS
  RTI/NORTH CAROLINA STATE UNIVERSITY
  UNIVERSITY OF ILLINOIS, URBANNA

  IN-HOUSE EMULATION

- RESEARCH AND DEVELOP AN ADAPTIVE OPTIC NODE:
  - OPTIC X-SWITCH TEST ARTICLE
  - INTERMEDIATE OPTIC NODE
  - FINAL OPTIC NODE

- RESEARCH, EVALUATE AND CHARACTERIZE A HIGH PERFORMANCE, ADAPTIVE, OPTICAL NODE TYPE NETWORK. (FOCUSED TECHNOLOGY PROPOSAL)
## Manned Space Station

<table>
<thead>
<tr>
<th>Requirements for Information Processing</th>
<th>Criticality</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Experiments and Manufacturing</td>
<td>HIGH</td>
<td>MODERATE</td>
</tr>
<tr>
<td>2. Observations</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td>o Earth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Near Earth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Solar System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Deep Space</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Communications</td>
<td>HIGH</td>
<td>MODERATE</td>
</tr>
<tr>
<td>4. Construction</td>
<td>HIGHER</td>
<td>HIGH</td>
</tr>
<tr>
<td>5. Stability and Control</td>
<td>HIGHEST</td>
<td>MODERATE</td>
</tr>
<tr>
<td>6. Autonomy/Automaintenance</td>
<td>HIGHEST</td>
<td>MODERATE</td>
</tr>
<tr>
<td>7. Housekeeping</td>
<td>HIGHEST</td>
<td>MODERATE</td>
</tr>
</tbody>
</table>

**Criticality** - Highest implies man rated or spacecraft rated safety.

**High** implies high cost but not safety related.

**Performance** - Communication:
- Moderate ~ 50 MBPS
- High > 100 MBPS

**Processing**:
- Moderate ~ 10 MOPS
- High > 50 MOPS
<table>
<thead>
<tr>
<th>TRAFFIC TYPE</th>
<th>NDM, MESSAGE LENGTH (BITS)</th>
<th>RATE BPS</th>
<th>CALL GEN RATE</th>
<th>HOLDING TIME</th>
<th>DELAY REQUIREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>STREAM VOICE</td>
<td>CONTINUOUS</td>
<td>64K</td>
<td>LOW</td>
<td>LONG</td>
<td>ALMOST INSTANTANEOUS</td>
</tr>
<tr>
<td>STREAM DATA</td>
<td>CONTINUOUS</td>
<td>64K</td>
<td>LOW</td>
<td>LONG</td>
<td>VARIABLE</td>
</tr>
<tr>
<td>INTERACTIVE DATA</td>
<td>HUNDREDS TO THOUSANDS</td>
<td>64K</td>
<td>HIGH</td>
<td>SHORT</td>
<td>FRACTION SEC. TO SECONDS</td>
</tr>
<tr>
<td>INQUIRY/RESPONSE DATA</td>
<td>HUNDREDS TO THOUSANDS</td>
<td>64K</td>
<td>LOW</td>
<td>SHORT</td>
<td>SECONDS TO MINUTES</td>
</tr>
<tr>
<td>DATA BASE UPDATE</td>
<td>HUNDREDS</td>
<td>TBD</td>
<td>LOW</td>
<td>SHORT</td>
<td>SECONDS TO MINUTES</td>
</tr>
<tr>
<td>BULK DATE TRANSFER</td>
<td>GREATER THAN $10^4$</td>
<td>TBD</td>
<td>LOW</td>
<td>MED TO LONG</td>
<td>SECONDS TO HOURS</td>
</tr>
<tr>
<td>DIGITAL VIDEO</td>
<td>CONTINUOUS</td>
<td>100M</td>
<td>LOW</td>
<td>LONG</td>
<td>ALMOST INSTANTANEOUS</td>
</tr>
</tbody>
</table>
INFORMATION NETWORK ARCHITECTURES
506-58-13/N. MURRAY

- INTEGRATED - DATA, VOICE, VIDEO

- KEY ISSUES OF NETWORKS
  - INFORMATION FLOW/OPERATING SYSTEM (SEPARATE DATA, CONTROL COMMUNICATIONS)
  - SELF-CORRECTING AND REPAIRING/FAULT TOLERANCE (MESH TOPOLOGY)
  - HIGH PERFORMANCE (FIBER OPTICS/INTEGRATED OPTICS, MESH TOPOLOGY)

INFORMATION FLOW BETWEEN COMPUTERS AND OTHER DEVICES REQUIRES A SYSTEM AND ARCHITECTURAL SOLUTION THAT AFFECTS BOTH HARDWARE AND SOFTWARE. CURRENT SYSTEMS USE EXTENSIVE SOFTWARE FOR THE INFORMATION FLOW RESULTING IN A SOFTWARE BOTTLENECK; CONTROL ALGORITHMS AND METHODS FOR TIGHTLY COUPLED, HIGH PERFORMANCE, DISTRIBUTED PROCESSING ARE INADEQUATE; SELF CORRECTING AND REPAIRING TECHNIQUES ARE NOT BEING FULLY APPLIED TO TODAY'S SYSTEMS. REAL-TIME, FULL MOTION, DIGITAL COLOR VIDEO REQUIRES DATA RATES IN EXCESS OF 100 MBPS.
NETWORK ARCHITECTURE/TOPOLOGY

OPTICAL INTERFACE

VIDEO CAMERAS DISPLAYS

BYTE WIDE ELECTRONIC INTERFACE

COMPUTERS TERMINALS SENSORS

SERIAL ELECTRONIC INTERFACE

VOICE TRANSCEIVERS

WDM OPTICAL BUSES

HIGH PERFORMANCE

FAULT TOLERANT
ELECTRONIC EMULATION OF OPTIC NETWORK

DATA ACCUMULATION
- EVENTS
- TIME

USER SERVICE DEMAND

STATISTICAL EVALUATIONS

EVALUATION OF:
- FAILURE DETECT/RECOVER
- CENTRALIZED ROUTING
- DISTRIBUTED ROUTING
- FLOW CONTROL
- NETWORK UTILIZATION
- NUC/NODE INTERFACES

PARAMETRICALLY CONTROLLED DISTRIBUTIONS
ADDRESS NODES

LINK PROC

LINK PROC

LINK PROC

LINK PROC

LINK SWITCH SET

INTERFACE PROC

NODE MANAGE. PROC

ALL PROCESSORS MOTOROLA M68K
PRODUCE HARDCOPY REPORT AFTER EA, TEST

REAL-TIME STATUS DISPLAY

ACCUMULATE STATISTICS

RECORD GIN STATE CHANGES

MESSAGE SINK

MESSAGE SOURCE

ACQUIRE GIN STATE CHANGES

ACCEPT MESSAGES

OUTPUT MESSAGES

NATIVE OPERATING SYSTEM (VAX/VMS, VERSA-DOS, CP/M-86)

PASCAL LANGUAGE

ASSEMBLY LANGUAGE

GIN

NETWORK

2-72
ROUTING ALGORITHMS

1) NON-ADAPTIVE

- NO ATTEMPT TO ADJUST TO CHANGING NET CONDITIONS
- FIXED OR RANDOM ROUTING

2) CENTRALIZED ADAPTIVE

- CENTRAL AUTHORITY DICTATES ROUTING DECISIONS
- MORE NEAR OPTIMAL ROUTING
- ROUTING CONTROL CENTER CAN REPRESENT PERFORMANCE BOTTLENECK

3) ISOLATED ADAPTIVE

- INDEPENDENT OPERATION
- ADAPTABILITY VIA EXCLUSIVE USE OF LOCAL NODE DATA

4) DISTRIBUTED ADAPTIVE

- UTILIZE INTERNODE COOPERATION
- NODES EXCHANGE INFORMATION TO ARRIVE AT ROUTING DECISIONS

-McQUILLAN, BBN
PATH SEARCH ALGORITHM

Purpose

1. Routing data through a meshed network
2. Establishing a circuit set up
3. Adaptive to topological changes
4. Simultaneous communication desirable
### ROUTING ALGORITHM

**Example:** for node 3

<table>
<thead>
<tr>
<th>Link Priority</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5,6,7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LP 2 → 1</td>
<td>LP 3 → 2</td>
<td>—</td>
<td>LP 0 → 4</td>
<td>LP 1 → 5</td>
</tr>
<tr>
<td>2</td>
<td>LP 3 → 2</td>
<td>LP 2 → 1</td>
<td>—</td>
<td>LP 1 → 5</td>
<td>LP 0 → 4</td>
</tr>
<tr>
<td>3</td>
<td>LP 0 → 4</td>
<td>LP 0 → 4</td>
<td>—</td>
<td>LP 3 → 2</td>
<td>LP 3 → 2</td>
</tr>
<tr>
<td>4</td>
<td>LP 1 → 5</td>
<td>LP 1 → 5</td>
<td>—</td>
<td>LP 2 → 1</td>
<td>LP 2 → 1</td>
</tr>
</tbody>
</table>
EX 1: NORMAL OPERATION

1. PSS
2. PS
3. OK
4. PS
5. OK
6. REC
7. OKS
8. MON
9. OKS
10. TRANS

1-2-3-4-5-6-7-8-9-10
ADAPTIVE NODE DEFINITION

FIBER OPTIC BUSES

INTEGRATED OPTIC SWITCHES

OPTIC TRANSMITTERS/RECEIVERS

NODAL CONTROL PROCESSOR

BYTE WIDE ELECTRONIC BUS
## INTELLIGENT OPTIC NODE TECHNOLOGY TIMELINE

<table>
<thead>
<tr>
<th>FUNCTIONS</th>
<th>TIME</th>
<th>NEAR TERM (1-2 YEARS)</th>
<th>MEDIUM TERM (3-5 YEARS)</th>
<th>LONG TERM (5-10 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E/O</td>
<td></td>
<td>GaAlAs (discrete)</td>
<td>GaAlAs with drive/</td>
<td>Monolithic GaAs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>detector electronics</td>
<td></td>
</tr>
<tr>
<td>O/E</td>
<td></td>
<td>Si</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiber</td>
<td></td>
<td>Single mode, non-polarization preserving</td>
<td>polarization preserving?</td>
<td></td>
</tr>
<tr>
<td>Taps, Delay</td>
<td></td>
<td>Fiber</td>
<td>SAW</td>
<td>TBD</td>
</tr>
<tr>
<td>Amplification</td>
<td></td>
<td>Si</td>
<td>GaAs</td>
<td>Monolithic GaAs</td>
</tr>
<tr>
<td>Switching</td>
<td></td>
<td>LiNbO₃ (bulk)</td>
<td>LiNbO₃ / ZnO ?</td>
<td>ZnO? / ALGaAs</td>
</tr>
<tr>
<td>Synchronization</td>
<td></td>
<td>Si / GaAs</td>
<td>GaAs (discrete)</td>
<td>Monolithic GaAs</td>
</tr>
<tr>
<td>Frame/Address Recognition</td>
<td></td>
<td>Fiber / GaAs</td>
<td>SAW / GaAs</td>
<td>TBD</td>
</tr>
<tr>
<td>Conflict Resolution</td>
<td></td>
<td>Si / GaAs</td>
<td>GaAs</td>
<td>Monolithic GaAs</td>
</tr>
<tr>
<td>Routing</td>
<td></td>
<td>N/A</td>
<td>Si / GaAs (discrete)</td>
<td></td>
</tr>
<tr>
<td>Higher Level Protocols</td>
<td></td>
<td>N/A</td>
<td>Si</td>
<td></td>
</tr>
<tr>
<td>MATERIALS</td>
<td>GaAs/GaAlAs</td>
<td>InGaAsP</td>
<td>AlInGaAs</td>
<td>InGaAs</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------</td>
<td>----------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>EMISSION WAVELENGTH</td>
<td>.82-.9 μm</td>
<td>1.0-1.6 μm</td>
<td>1.0-20 μm</td>
<td>3.3-3.8</td>
</tr>
<tr>
<td>LASERS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>NO</td>
</tr>
<tr>
<td>LED's</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>INTEGRATABLE</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>WITH ELECTRONICS</td>
<td>GaAs</td>
<td>InP</td>
<td>InGaAs</td>
<td>(LOW LEVEL)</td>
</tr>
<tr>
<td>EASE OF FABRICATION</td>
<td>MATURE</td>
<td>ALMOST MATURE LPE GROWTH</td>
<td>EXPERIMENTAL MBE/MOLVD</td>
<td>NEXT TO IMPOSSIBLE LPE</td>
</tr>
</tbody>
</table>
# X-Switch Loss Estimates

<table>
<thead>
<tr>
<th></th>
<th>Polarization Preserving Fiber</th>
<th>Single Mode Fiber</th>
<th>Multi Mode Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
<td>0.5</td>
<td>3.5</td>
<td>?</td>
</tr>
<tr>
<td><strong>Cross</strong>(^{(1)})</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Bar</strong>(^{(2)})</td>
<td>0.2(^{(3)})</td>
<td>0.2(^{(3)})</td>
<td>0.2(^{(3)})</td>
</tr>
<tr>
<td><strong>Waveguide</strong></td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

|             | Total 1.8 DB                     | 4.8 DB            | 1.3 + \(X\)^{(4)} |

\(^{(1)}\) A switch in cross state  
\(^{(2)}\) A switch in the bar state  
\(^{(3)}\) Total excess loss  
\(^{(4)}\) \(X\) is unbounded: could be time dependent
## COMMON FEATURES FOR ALTERNATIVE DISTRIBUTED OPTICAL SWITCHING ARCHITECTURES

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Linear/Star</th>
<th>Ring</th>
<th>Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functions</td>
<td>Bus</td>
<td>Bus</td>
<td>Mesh</td>
</tr>
<tr>
<td>Transmitter/ Receiver</td>
<td>Burst</td>
<td>Synchronous</td>
<td>Burst</td>
</tr>
<tr>
<td>Switch</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coupler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channelization</td>
<td>(WDMUX-WDMUX)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplifier</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compare</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conflict</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Routing/Gateway</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Level Protocol</td>
<td>Ring or Star</td>
<td>Common</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table (1)**
[EXAMPLE HIGH PERFORMANCE NETWORK]