Cooperative Microsystems

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# Cooperative Microsystems

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“Cooperative Microsystems”

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Definition of a Cooperative System

Control Plane (Signaling)

Interconnect Network or Fabric (Data Plane)

Smart Subsystem

Smart Subsystem

Smart Subsystem

Smart Subsystem
Definition of a Cooperative System

Interconnect Network or Fabric (Data Plane)

Smart Subsystem
Smart Subsystem
Smart Subsystem
Smart Subsystem

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**A Cooperative Mega-System**
*(Global-Scale IP/Optical Network)*

**DARPA CORONET Program**

The Network Nodes **Cooperate** to Accomplish:

- Fast, automatic end-to-end provisioning of IP and Optical Services
- Fast, automatic recovery from multiple network failures (self healing)
- Secure, low blocking, low latency, high efficiency, and huge capacity

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Let Us Shrink the Network by Factors of 10
Each Case is a Cooperative System of Its Own

Wide-Area Network (WAN) ~5,000 km

Regional Network ~500 km

Greater Metropolitan-Area Network (MAN) ~50 km

Fiber-Optic WDM LAN ~50 m

WDM Local-Area Network (LAN) for Avionic Platforms ~500 m

Campus-Scale Local-Area Network (LAN)

Metropolitan-Area Network (MAN) ~5 km

DARPA NEW-HIP Program

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Outline of the Rest of the Talk

• A Vision for the Next-Generation, High-Performance Cooperative Microsystems Consisting of Chips, Cards, Shelves and Racks

• Chip-to-Chip Optical Interconnects
  – *Current and Future Vision*

• On-Chip Cooperative Microsystems
  – *We will hear two talks on this*

• Summary of the Vision

• Quantum-Scale Cooperative Microsystems
  – *We will hear two talks on this*

• Biological Cooperative Microsystems
  – *We will hear one talk on this*
Let Us Consider one Shelf or Chassis in a High-Performance Computer, a Multi-Terabit IP Router, or a Large Data Center Shelf

A Vision for the Next-Generation, High-Performance Cooperative Microsystems

The Heart of the Vision is Configurable, Optical, WDM-Based Interconnects to Realize a Plug-and-Play, Multi-Terabit Bus

Shelf

Optical Backplane

Micro-Chips

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A Vision for the Next-Generation, High-Performance Cooperative Microsystems

The Heart of the Vision is Configurable, Optical, WDM-Based Interconnects to Realize a Plug-and-Play, Multi-Terabit Bus

Let us now build a Multi-Shelf Rack

Shelf

Optical Backplane

Micro-Chips

Cards

Rack
A Vision for the Next-Generation, High-Performance Cooperative Microsystems

The Heart of the Vision is Configurable, Optical, WDM-Based Interconnects to Realize a Plug-and-Play, Multi-Terabit Bus

Let us now build a Multi-Rack System or Data Center
Pushing the Vision Down to the Board and Chip Levels

Chip-to-Chip Optical Interconnect

The DARPA C2OI Program

• Board-level and off-board, chip-to-chip optical communication
• Utilizing an array of VCSEL transmitters, parallel waveguides, and photo-diode receivers
• Enables higher bandwidth (>>1 Tbps) and lower power (5 pJ/bit) communication as compared to electronic alternatives.
• Do we need to add **WDM** and **Configurability** to this Vision?

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Why/How to Add WDM and Configurability?

Static, Parallel Optical Interconnect
* Reference architecture

Use WDM to Increase Capacity?
* Multi-\(\lambda\) transmitters and receiver are large and power hungry
* I do not believe that this is why one would want to do WDM

Arbitrary-\(\lambda\)
Fixed Lasers

Photo Diodes with no Filters

Multi-\(\lambda\) Sources
\(\lambda_1, \lambda_2, \ldots, \lambda_N\)

Multi-\(\lambda\) Receivers
\(\lambda_1, \lambda_2, \ldots, \lambda_N\)

Parallel Optical Waveguides
Crisscrossing Optical Interconnect

- Hard to fabricate crossing waveguides with low loss and low cross-talk
- Once made, interconnection is static
- Not an elegant solution!

Specific-λs
- Fixed Lasers
  - λ₁, λ₂, ... , λₙ
- Fixed-Filter Photo Diodes
  - λ₁, λ₂, ... , λₙ

Crisscrossing Optical Waveguides

* More elegant solution
* But, we need specific-λs, fixed lasers and filters for this vision
* Nominal loss = 1/N
* WDM in the fabric, not at the ends
Why/How to Add WDM and Configurability?

Configurable Optical Interconnect
- We need tunable lasers and specific-λs fixed filters for this vision
- Nominal loss = 1/N
- WDM in the fabric not at the ends

We need tunable lasers and specific-λs fixed filters for this vision
- Same end device requirements
- The fabric can be a static AWG or a tunable cross-bar switch
- No nominal 1/N loss
- WDM in the fabric not at the ends
The DARPA UNIC Program: Ultraperformance Nanophotonic Intrachip Communications

SUN Microsystems: Macrochip design providing 10 TB/s bisection bandwidth for 64 cores providing 10 TFLOPS

MIT Lincoln Lab: Optimization of optical communication networks among cores, and between cores and memory

Two Talks:

- Ashok Krishnamoorthy (SUN) – Intrachip Photonic Communications Networks with Seamless Off-chip Communications: Vision for the Future

- Jeremy Kepner (MIT/LL) – Photonically-enabled Optimized Embedded Microprocessors, Shared Memory Optimizing Multicore Cooperation

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Cooperative Systems of Various Orders of Magnitudes Benefiting from WDM Optical Networking

• Of course, the very same devices and components do not work at all scales of the vision

• But the same basic ideas and architectures promise higher performance (capacity and flexibility) at a reduced cost, size and power for all scales of the vision

• Much more work is needed at all scales to realize this vision of multi-terabit-per-second cooperative microsystems
Today, scientists have succeeded in realizing secure Quantum Key Distribution (QKD) over ~100-km free-space or fiber-optic links using the BB84 Protocol conceived by Bennett and Brassard in 1984. The holy grail of QKD is to extend the distance to continental scale, using entanglement-based “quantum repeaters.”

Part of the vision in this sub-session is related to the DARPA QuEST Program.
And finally for something completely different!

A Talk by:

- Joe Pancrazio (NIH) – on “Prosthetics, Interconnects, Neuro-Photonics”

Note that Interconnects is a common theme, other than that, it is a completely different story.