Cross Layer Optical Research in GENI

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The rationale for GENI and its inherent tie to optics

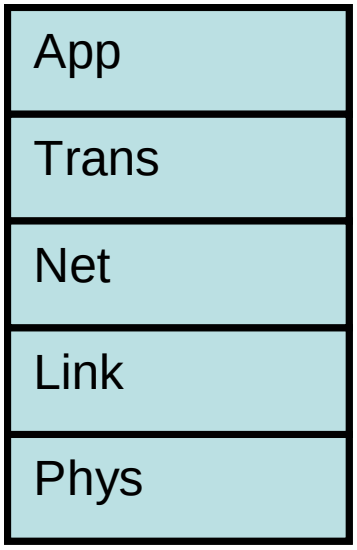
- **Serious problems facing today's internet:**
  - Security, Reliability, Manageability, Evolvability
  - Numerous opportunities cannot be realized because of internet technical limitations
- **There are solutions…but:**
  - Severe experimental barriers
  - No way to evaluate, validate
  - Impedes future progress
- **GENI will enable realistic, experimentation:**
  - *Transforming* research, GENI is not just augmenting
  - Focus on *necessary* research agenda, not just desirable, useful

Optics dual role

- Optics will be a major part of the GENI physical infrastructure
  - Core of GENI will have a high degree of photonic componentry, leading edge commercially available
  - High bandwidth WDM transmission, network elements, ROADMs, OXCs, etc.
- Should research on optical systems be part of the GENI agenda?
  - The case must be made that it is ***required*** and ***transforming***
- Rethinking and redesigning the core should take an *integrated approach:*
  - Network architecture co-designed with opportunities and challenges presented by advanced optical technologies

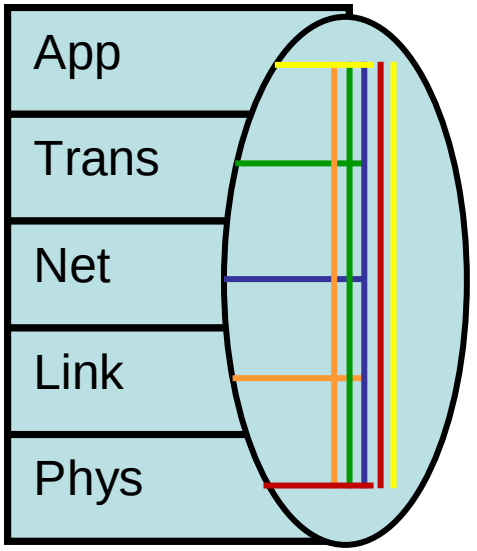
Cross-layer communications

- Today's Internet design based on (favorable) notion of **layering**:
  - Each layer is designed to provide barebones functionality that can be used by layers above
  - Barebones philosophy was generally good, enabled rapid independent development of the layers: protocols, applications, services
- Layering is also limiting:
  - Often, lower layers technology can perform additional *functionality* but cannot deliver to higher layers
  - Network layers can perform QoS but applications cannot invoke it and derive benefit



Cross-layer communications

- Bi-directional information exchange between layers
- Cross-layer designs improves broad range of network performance and applications
  - QoS, flow prioritization
  - Wireless security and authentication
- With cross-layer communications optical substrate can deliver **functionalities** (in addition to bandwidth) that enable GENI networking
- To achieve this requires integrated network architecture/optical substrate research agenda



GENI network research

- Examine GENI network research challenges, identify critical necessary role for optics
  - **Optical layer aware and enabled networking**
- Virtualization of general, flexible, global network resources:
  - No longer assume single packet format
  - virtualized network connections, dynamically sliced into shares for different users and applications
  - One format for information dissemination, another for real-time communications, another for bulk data transfers, video distribution, etc.
  - **For the optical substrate this means dynamically programmable, simultaneous operation of optical circuits, optical packets with vast ranges in data flow granularities**

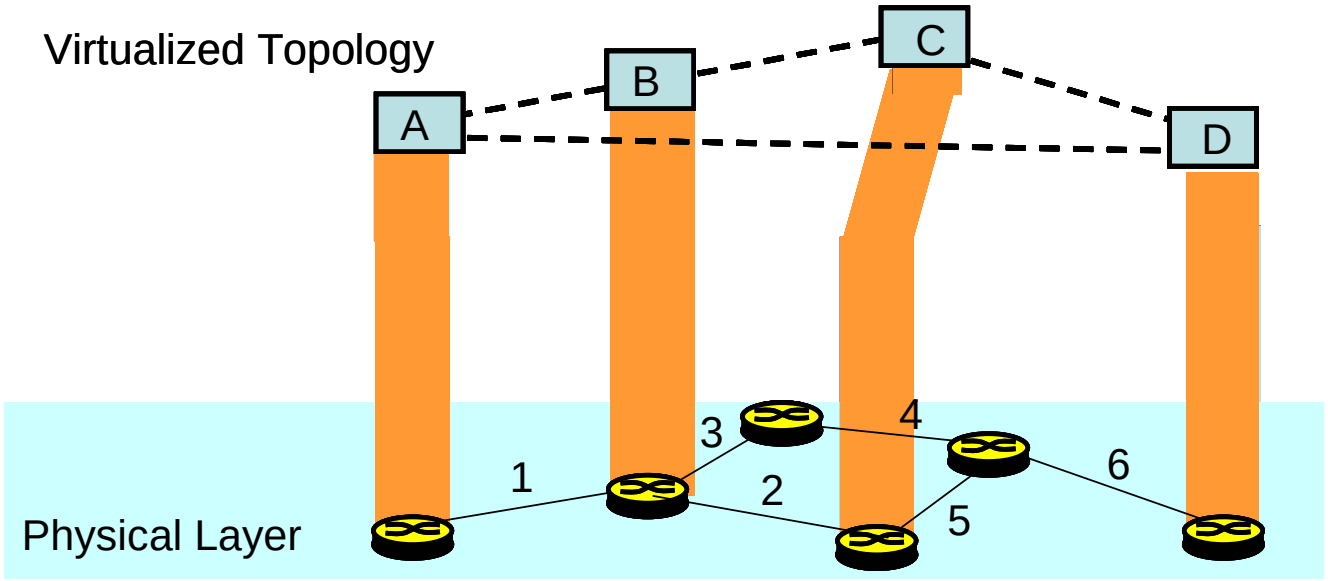
GENI network research

- Global network for multiple communications patterns of information dissemination
  - Point-to-point, one-to-many, range of transport
- Architecture that supports multiple traffic time sensitivities
  - Real-time with bounded delay
  - Delay tolerate traffic
- **These critical research challenges for GENI clearly require cross-layer communications capabilities**
  - **Programmable interaction with optical substrate, provide upper layers dynamic access to full bandwidth at any granularity,**
  - **Optical switching and routing that can be configured to process diverse traffic – with multiple time sensitivities**

Security and robustness

- GENI requirements:
  - Any set of well behaved hosts can communicate reliably, malicious or corrupted nodes should not
  - Security and robustness must extend across layers, need entire chain secure: phy+net+app
- **Optics cross-layer traffic engineering:**
  - **Optical substrate monitoring inherent part of network management and operation via bi-directional cross-layer communications**
  - **Network configuration using operator automated tools relies on sound optical substrate**

Survivability via path diversity

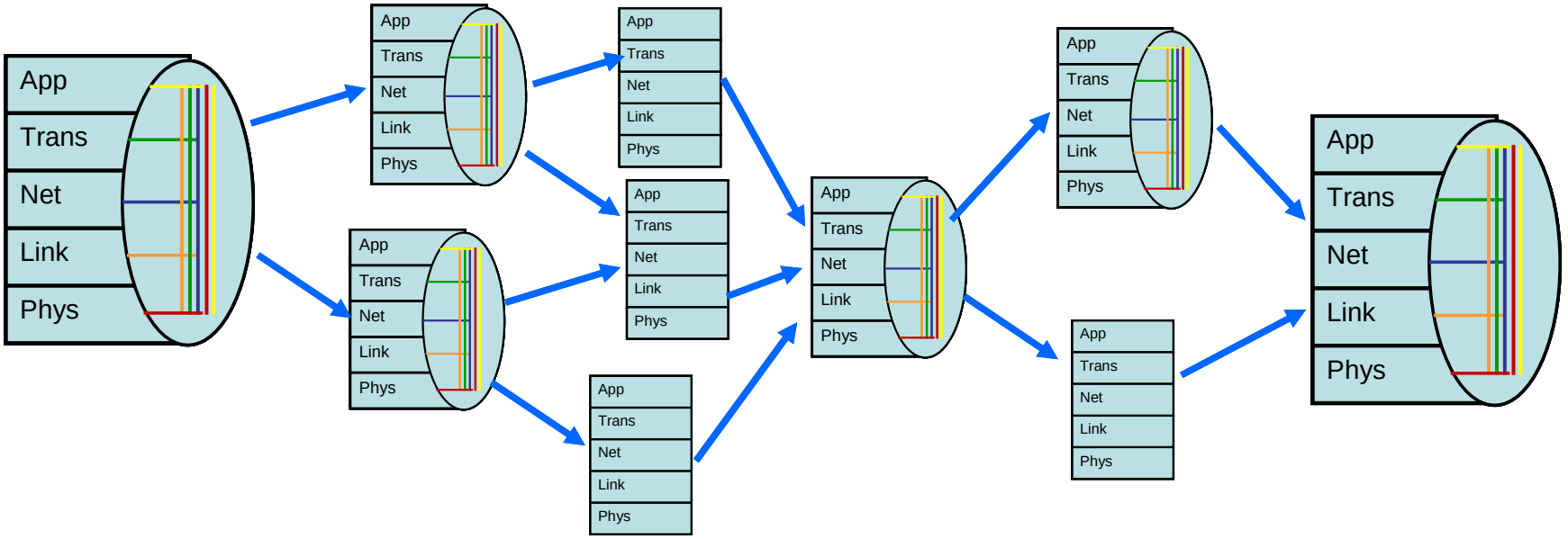


- Network resilience through additional path provisioning in case of primary link failure
- Path diversity viewed by application from node A to D is false because at least 2 of links are shared
- Cross-layer communications can expose optical physical layer and relate information directly to application

Example of cross-layer traffic engineering

- Increasingly, high speed optical links are subject to continuous but time-variant processes that can degrade the signal quality
  - Digital Group Delay (DGD) is an example
  - For >40 Gbps links, DGD is prime contributor to increased BER
  - Variance of the DGD is continuous, temperature, stress, or vibration.
- Forward error correction can detect and correct [DGD induced] bit errors up to a threshold. Beyond threshold bit errors are too numerous to correct → leads to dropped packets at network layer. Application performance suffers
- DGD BER is time variant, one can monitor the "pre-FEC" errors looking for increasing trends at the optical layer
- Cross-layer communications to transport/network layers can re-route traffic on the failing link before the user and application performance adversely impacted.

Example: Multipath Routing



- Nodes with cross-layer communications functionality can realize multipath routing with significantly better performance
  - Knowledge of physical true path diversity
  - Security requirements – which nodes can be addressed
  - QoS requirements – query the physical layer
  - Routing, switching -- is packet reordering permitted?
  - Time sensitivity
- Nodes without CL functionality simply route unicast to the next hop

Cross-layer optical research

- Optical substrate: no longer a static black box
- Intelligent, dynamic, programmable, network and applications aware:
  - Not just high-bandwidth
  - Provides functionality
- This is NOT available with commercial off-the-shelf optical system technology
- GENI network research agenda demands new functionalities from the optical substrate
- Research is required on network architectures in synergy with the optical substrate that can lead to integrated solutions.
- Additional issues for discussion:
  - Experimentation infrastructure GENI slice
  - Boundary to wireless