IP-Over-WDM Integration Strategies

Nasir Ghani, Ph.D.
Nokia Research Center
Boston, USA

nasir.ghani@nokia.com

Sprint Research Symposium, University of Kansas, Kansas, March 8-9, 2000

Presentation Outline

- Introduction/Background
- Optical-Layering Approaches
- MPLS-Based Approaches
- Future Trends/Technologies
- Conclusions

Introduction/Background

- **WDM enabling technologies**
  - Fibers (SMF up to 600 km, dispersion optimization for more)
  - Lasers (2.5 Gb/s mature, wavelength programmability)
  - Amplifiers (wavelength/power equalization issues)
  - Increasing channel counts (C and L bands)

- **Improving optical network elements (ONE)**
  - Add-drop multiplexers (O-ADM), cross-connects (WRS/OXC)
  - Re-configurable operation, scalability/O-E challenges remain

- **Networking applications**
  - Multi-protocol support/transparency
  - Improved higher-layer connectivity
  - Traffic engineering/virtual topology control
  - Improved network survivability

Introduction/Background

- **Current deployment status**
  - Many point-to-point, O-ADM/OXC in WAN now
  - Proprietary control, static provisioning of “circuits”

- **Likely industry evolutions/migrations**
  - Increased re-configurability (switching, λ-conversion)
  - Improved survivability, traffic engineering (w. higher-layers)
  - New data framing solutions/formats
  - Futuristic: burst switching, limited/full packet switching
  - Address control plane issues (research, standardization)

- **IP data traffic profiles**
  - Over 90% is highly delay insensitive
    Computer-to-computer traffic, email, web, ftp
  - Highly asymetric profiles (time-of-day variations)
    Implies need for rapid reconfigurability
  - Multi-path diversity vs. single-path reliability

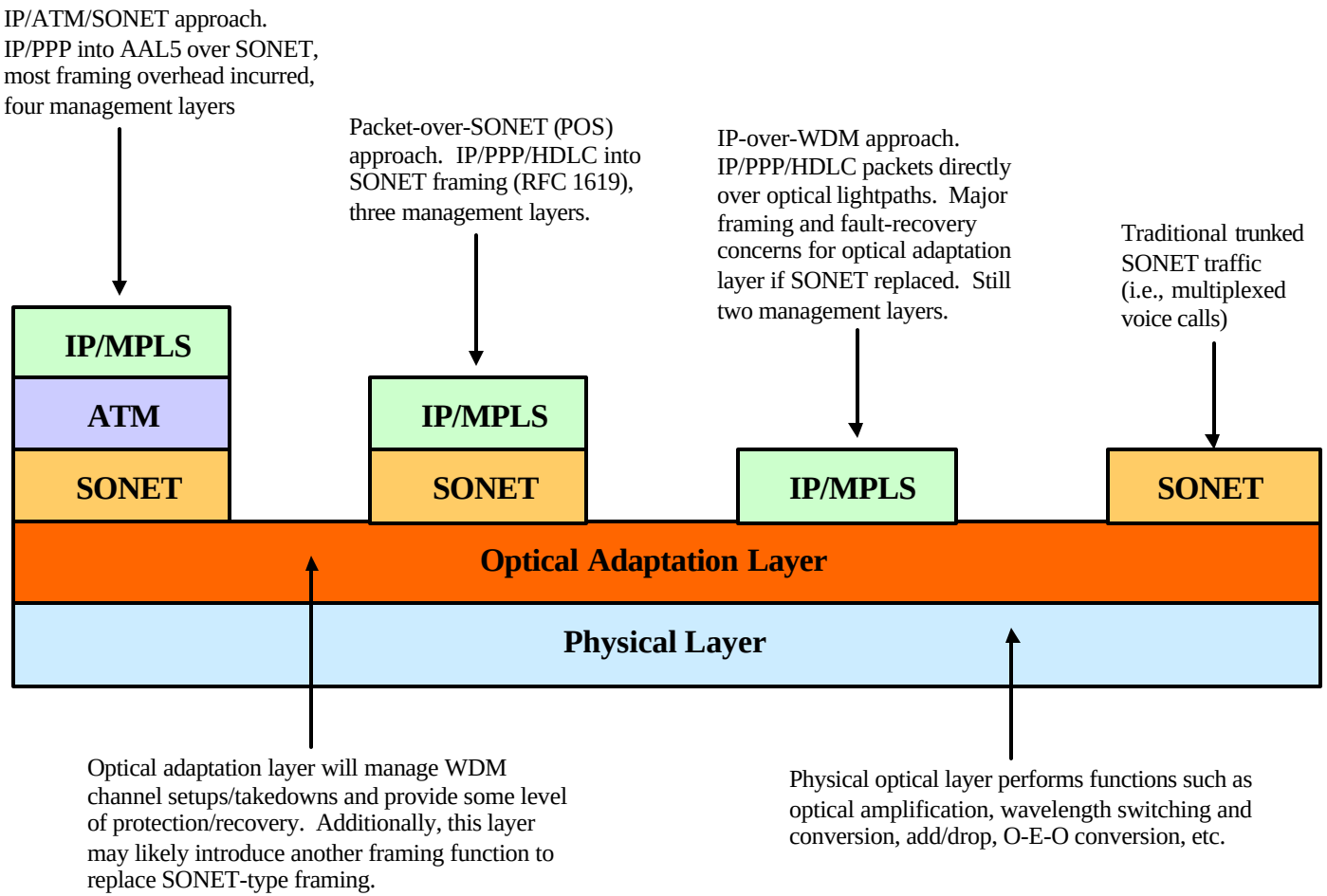
Optical-Layering Approaches

- **Overall features**
  - New “circuit-provisioning access layer” concept
    Edge interworkings, increased costs
  - Multiple “client” protocols supported
    E.g., IP, ATM, SONET, frame relay, Ethernet

- **New protocols required (optical UNI and NNI)**
  - Optical provisioning protocols (RWA, survivability)
  - Higher-layer topology/resource engineering applications
    New, automated "inter-layer" protocols required
  - Limited transparency, i.e., new framing formats
    SONET/SDH, “SONET-lite”, digital wrappers
  - Standardization activities (ITU-T, OIF, T1X1, ODSI)

- **Vendor offerings to date**
  - Mainly proprietary (complete) solutions
  - E.g., Lucent, Nortel, various startups

Optical-Layering Approaches



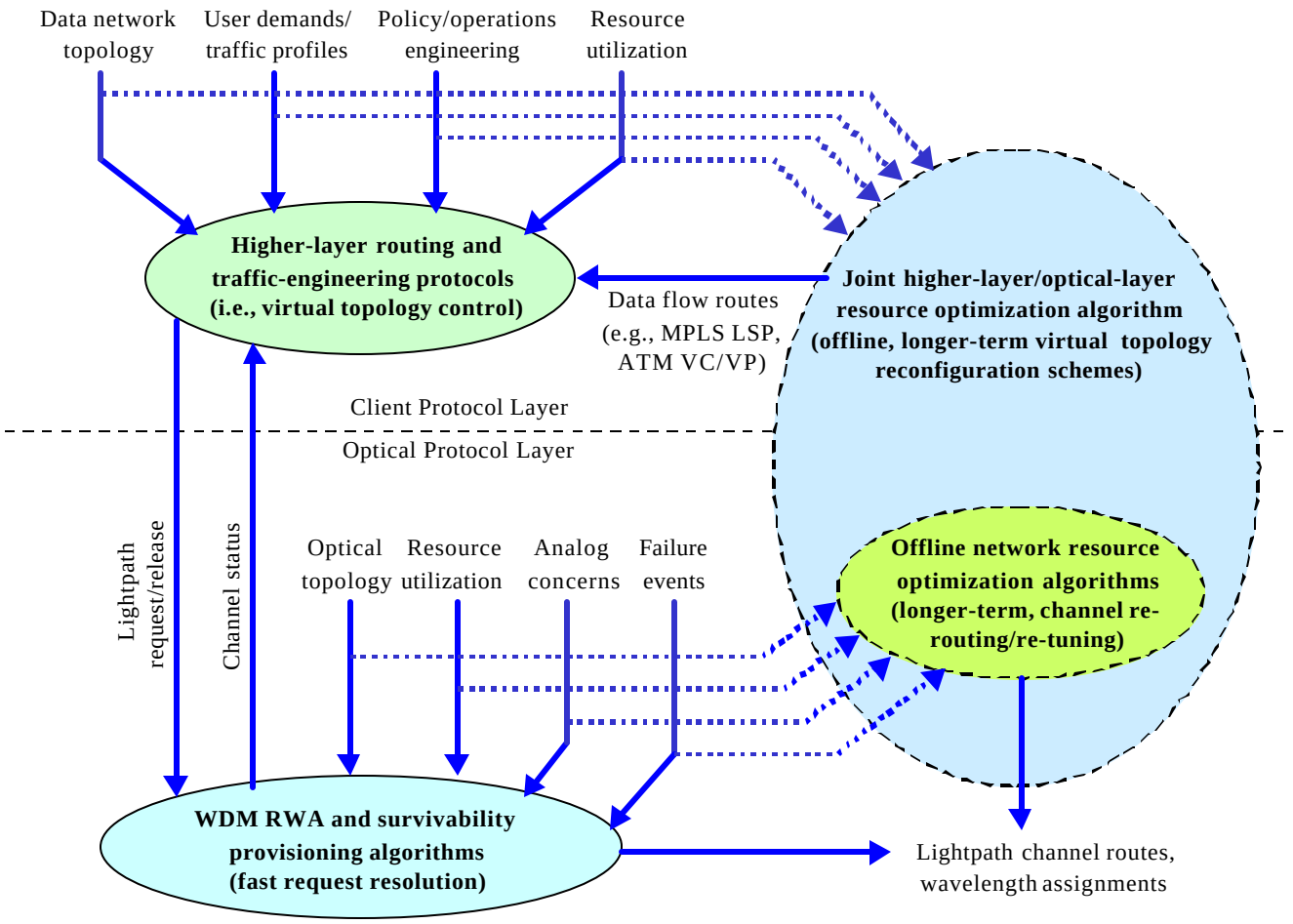
Optical-Layering Approaches

- **Wavelength-channel provisioning**
  - Routing and wavelength assignment (RWA) problem
    Maximize resource utilization, minimize costs
  - Various complications/constraints arise
    Analog concerns, λ-conversion, control architectures
  - Addressing schemes/multi-protocol address resolution
    Extend ARP or use (adapt) NHRP-type solutions
  - Edge traffic aggregation issues (e.g., FEC, LSP stacking)

- **Automated virtual topology control**
  - Application driver for RWA algorithms
  - Improve network efficiency by "re-adjusting" topology
    Lightpath channel re-routing, λ re-tuning, etc.
  - Complex "two-layer" interactions w. higher layers
    Operational timescales, information transfer issues
  - Standardized or proprietary solutions?

Optical-Layering Approaches

Protocols interaction between optical and data layers



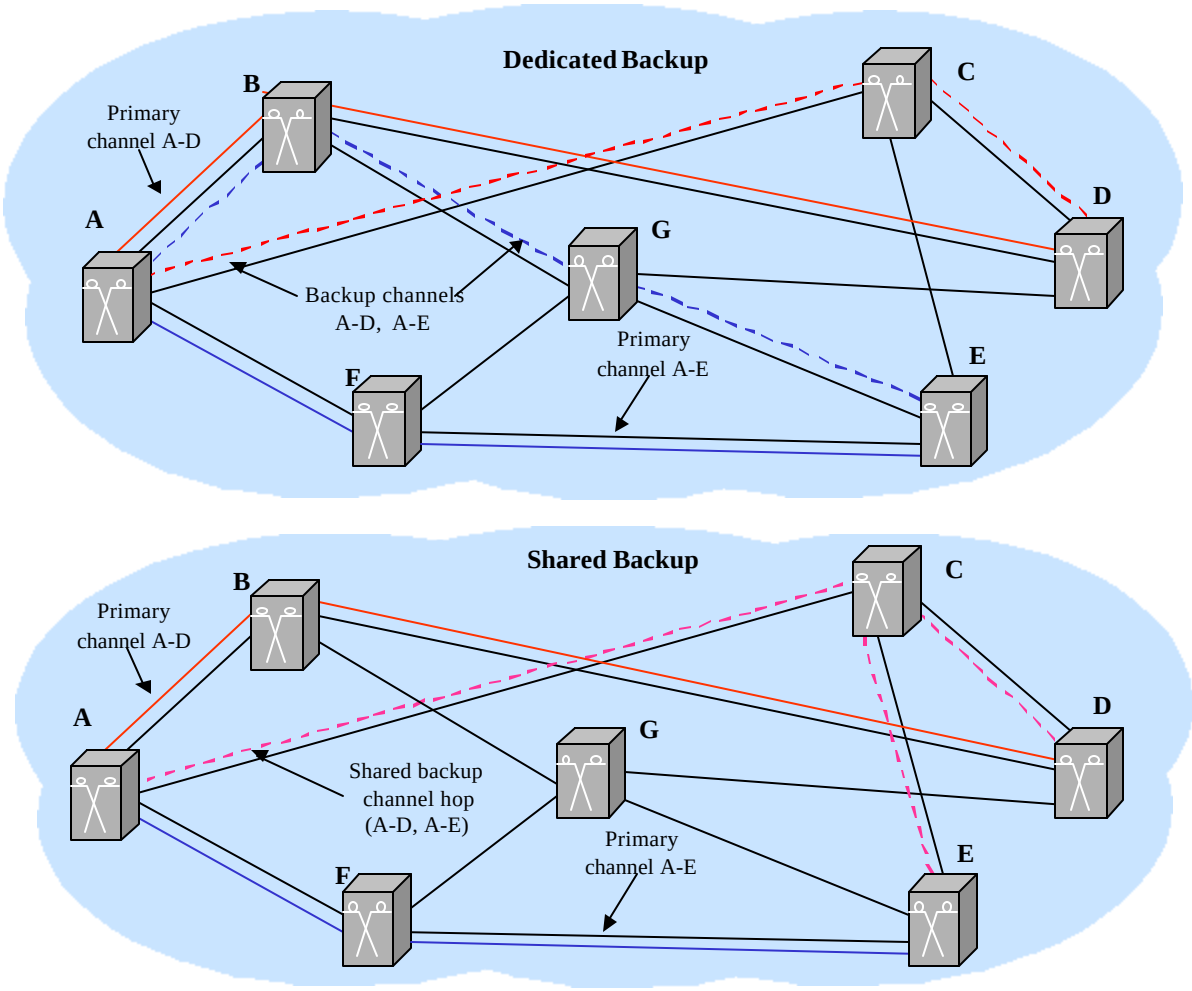
Optical-Layering Approaches

- **Channel survivability schemes**
  - **Protection schemes via backup channels**
    Dedicated/shared strategies can provide multiple levels
  - **Restoration schemes also considered**
    "Self-healing", hard-guarantees difficult to pre-specify
  - **Scalable fiber-level protection also possible**
    Reduced signaling explosion for fiber-cut events

- **Escalation strategy designs necessary**
  - **Many higher-layer protocols already provide recovery**
    E.g., IP-rerouting, ATM protection rings, SONET/SDH APS
  - **Destructive interference degrades responsiveness/efficiency**
    "All layers do not switch over to same backup resource"
  - **Escalation strategies for "coordinating" inter-layer recovery**
    Top-down and/or bottom-up schemes proposed
  - **Complex timing issues, topological considerations**

Optical-Layering Approaches

Lightpath channel protection schemes



MPLS-Based Approaches

- **Novel IP-based approaches for rapid provisioning**
  - Re-use existing signaling framework (i.e., control plane)
    Less standardization, faster vendor interoperability
  - Direct "single-layer" integration (OXC/WRS @ LSR)
    "Optical lambda-switch routers" (O-LSR)
  - Abstracts lightpath to MPLS label switched path (LSP)
  - No addressing concerns arise (use IP addresses)

- **Key MPLS features exploited**
  - LSP tunneling (label stacking/swapping)
  - Explicit routing (ER) capabilities
  - LSP survivability capabilities
  - Constraint-based routing (CBR)/resource engineering

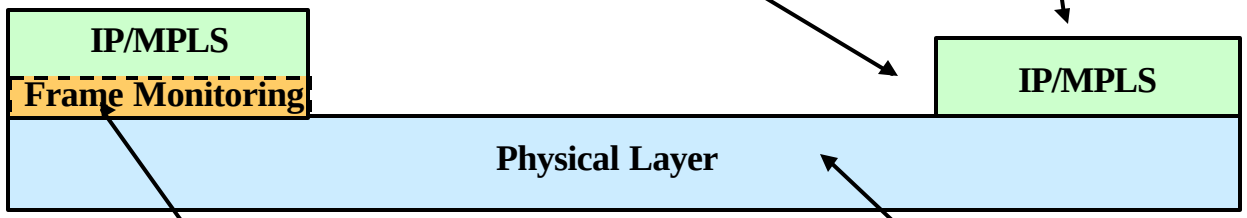
- **Increasing industry momentum**
  - Vendor proposals (Nokia, UUNET, Cisco, NTT)
    E.g., lambda-labeling, multi-protocol lambda switching
  - Standardization work ongoing (IETF, OIF)

MPLS-Based Approaches

IP-over-WDM with framing "sub-layer" for fault detection/localization purposes. IP MPLS is main provisioning layer, framing done in a strictly point-to-point manner between MPLS O-LSR nodes (e.g., SONET, "SONET-lite", digital wrappers, etc.).

IP/MPLS protocol will assume most of the functionality for data newtork and optical layer provisioning. This includes lightpath setup/takedown, protection/recovery, and possibly even fault detection/localization.

Direct packets-over-lightpath approach. For carrier-class reliability, this requires reliable, effective fault-detection/location and monitoring at the optical layer, and tight-coupling with the IP layer for highly-critical user services. Likely, this approach will take a long time to emerge. For less stringent requirements, more direct framing w/o monitoring can be used (e.g., gigabit Ethernet)



Framing "sub-layer" for fault detection and localization functions only

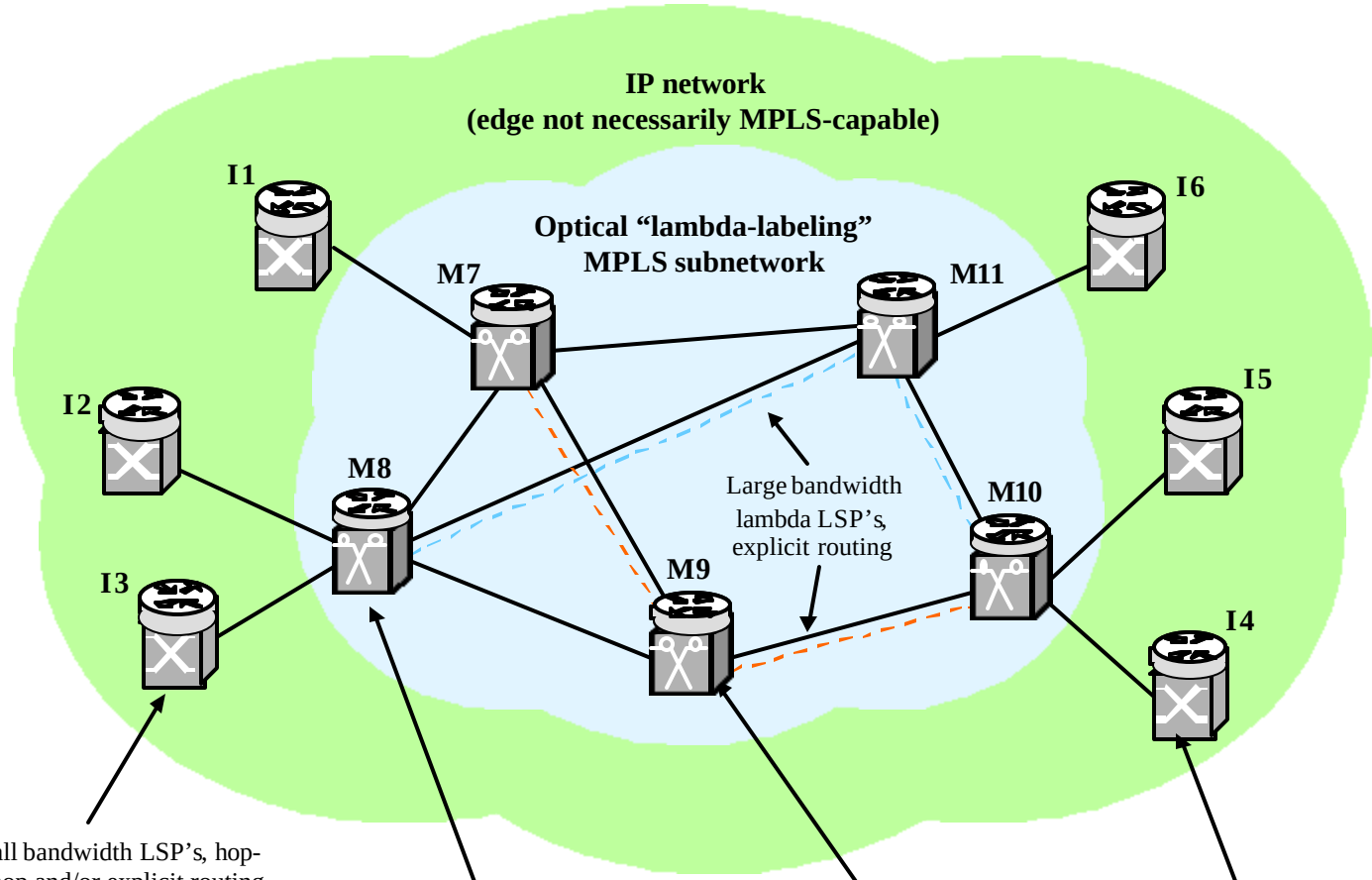
Physical optical layer performs functions such as optical amplification, wavelength switching and conversion, add/drop, O-E-O conversion, etc.

MPLS-Based Approaches

- **Lightpath LSP tunneling/routing**
  - Subsume existing RWA algorithms
    Centralized, distributed, and hybrid architectures
  - Analogy between MPLS labels and WDM wavelengths
    No explicit label encapsulation/lookup required
  - "TTL pre-decrement" operation at edges
    I.e., use existing provisions for "MPLS-over-ATM"
  - Incorporate analog concerns (TLV/MIB definitions)

- **Explicit-Routing (ER) functionality**
  - Specify LSP routes, engineer resource allocation policies
  - Can subsume most advanced WDM protocols
    I.e., traffic, policy, priority, resilience, preemption attributes
  - Incorporate with IP/MPLS traffic engineering
    MPLS CBR (RWA) protocols, IGP (OSPF) updates
  - Improved provisioning, reduced operating complexity
    "Single-layer" facilitates topology/resource information flow
  - Note: Algorithmic complexities/concerns unchanged
    E.g., RWA,virtual top. control, traffic aggregation/mapping

MPLS-Based Approaches



Small bandwidth LSP's, hop-by-hop and/or explicit routing label assignment within electronic MPLS cloud, or simply regular IP routers w. LSP aggregation functionality at edge MPLS O-LSR nodes.

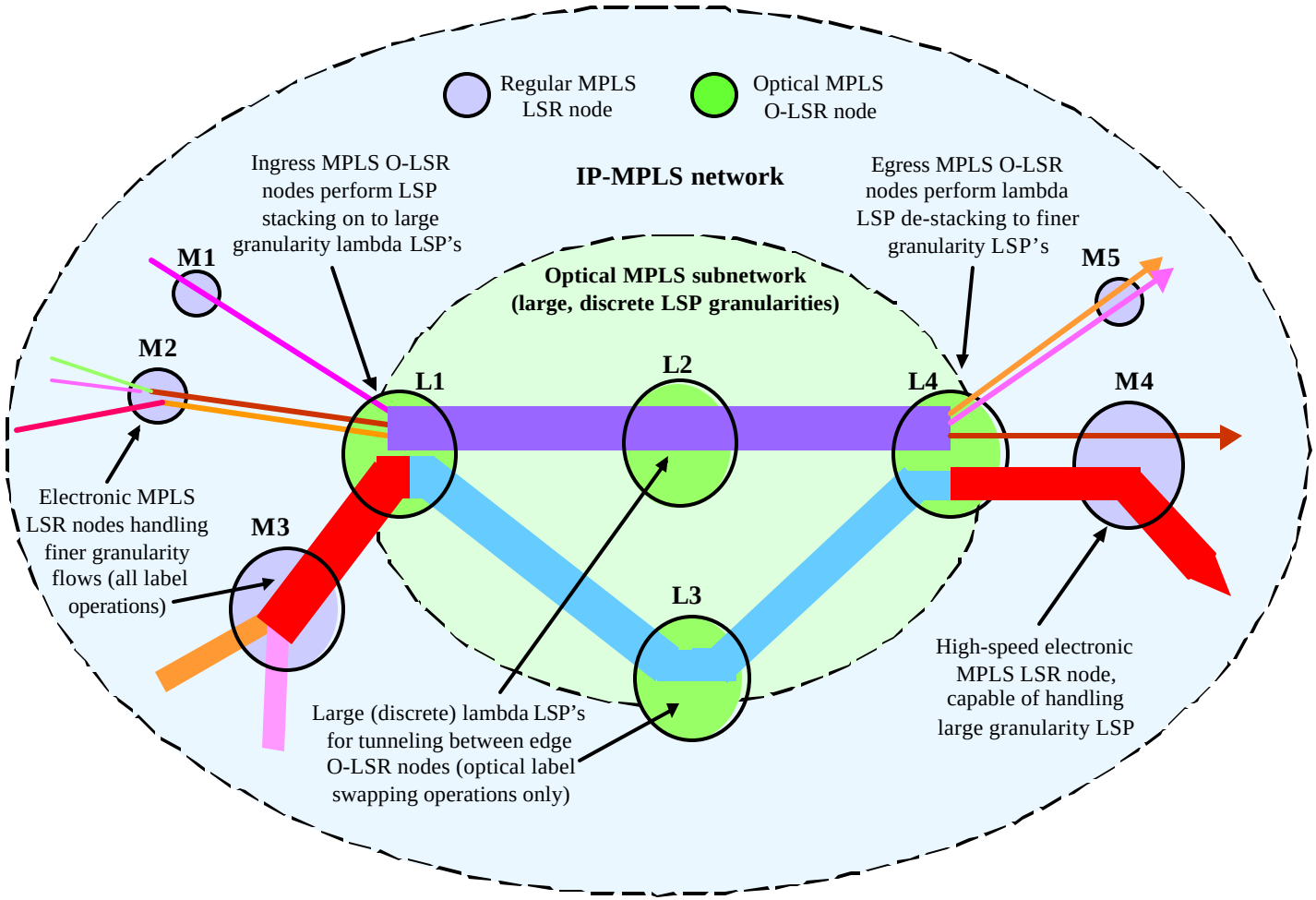
Edge MPLS O-LSR nodes perform label merging/tunneling to/from higher-bandwidth (coarser) "lambda" LSP's

Core MPLS O-LSR nodes with optical switching fabrics (performing "virtual" label encapsulation and lookup)

Electronic MPLS LSR nodes with electronic switching fabrics or simply high-speed regular IP routers

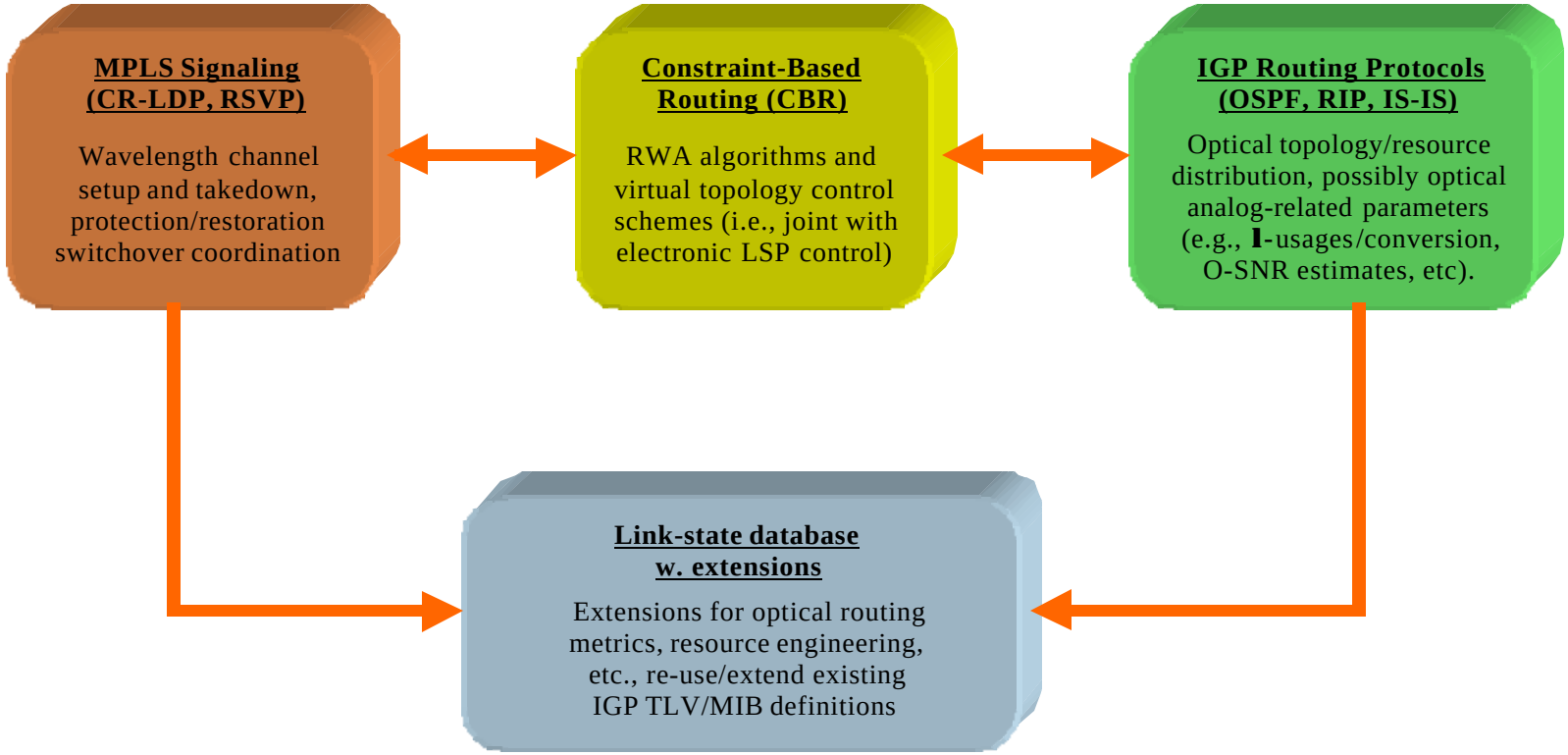
MPLS-Based Approaches

Lambda (optical) LSP tunneling in WDM networks



MPLS-Based Approaches

MPLS Protocols Framework for Optical WDM Networks



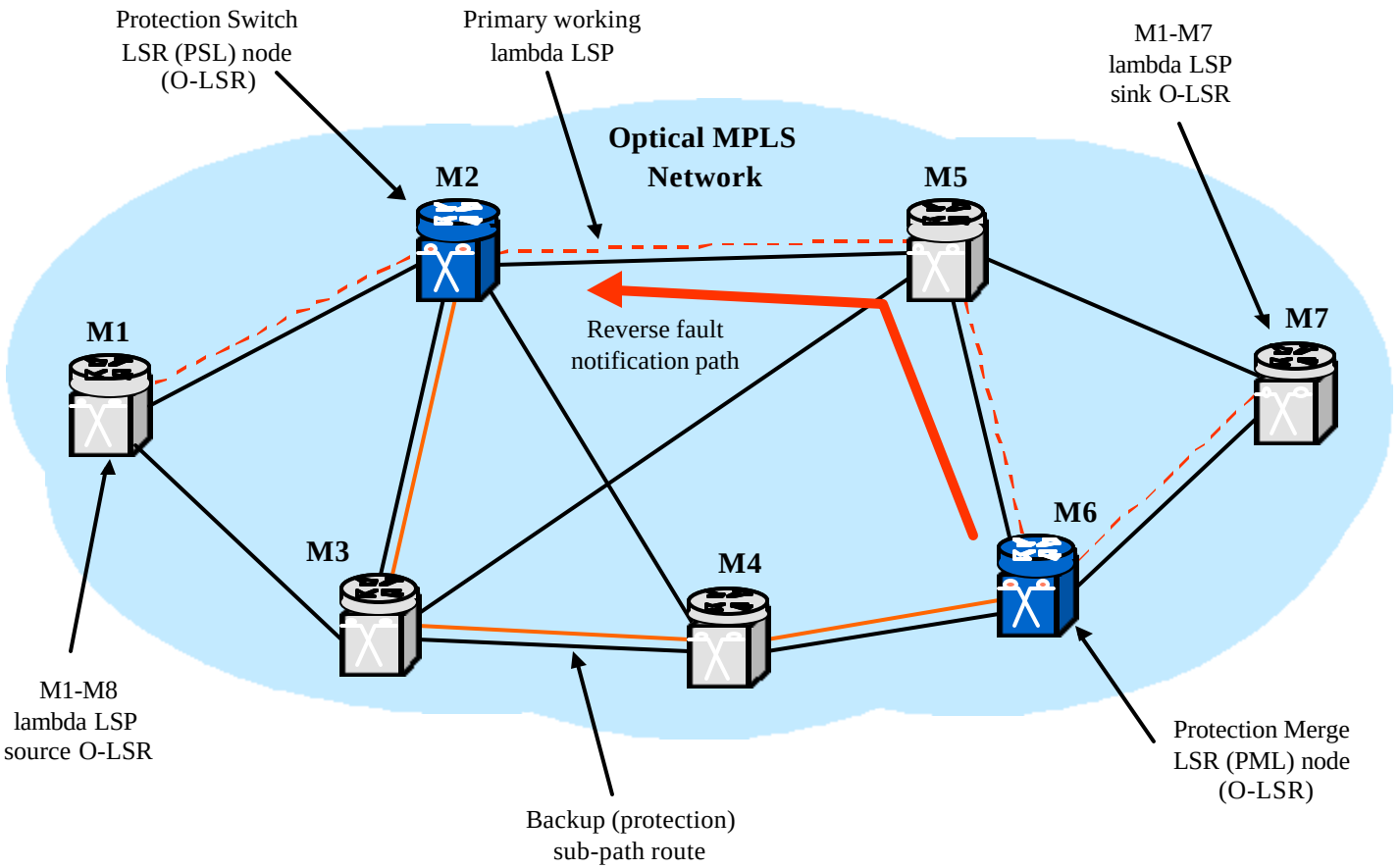
MPLS-Based Approaches

- **Lightpath LSP survivability**
  - **Joint provisioning of backup channels (w. RWA phase)**
    Use ER function, switchover on fault detection
  - **Edge-to-edge (path) and sub-path repair**
    Generic protection switch/merge nodes, FIS
  - **Restoration schemes also possible**
    Active signaling/selective-flooding after fault
  - **Label-stacking can incorporate *fiber* protection schemes**
  - **Reduced (no) multi-layer fault coordination concerns**

- **Fault detection and localization issues**
  - **Can still use electronic “frame-monitoring sub-layer”**
    "SONET-like” timescales (e.g., SONET, digital wrappers, etc)
  - **Optical monitoring for fault detection/localization**
    Power-level monitoring schemes (not-standardized yet)
  - **IP timer-based solutions for fault detection/localization**
    Reduced keepalive/hello timers, subsecond restoration
  - **“SONET-like” timescales not necessary for most IP traffic**

MPLS-Based Approaches

Proposal for MPLS LSP recovery



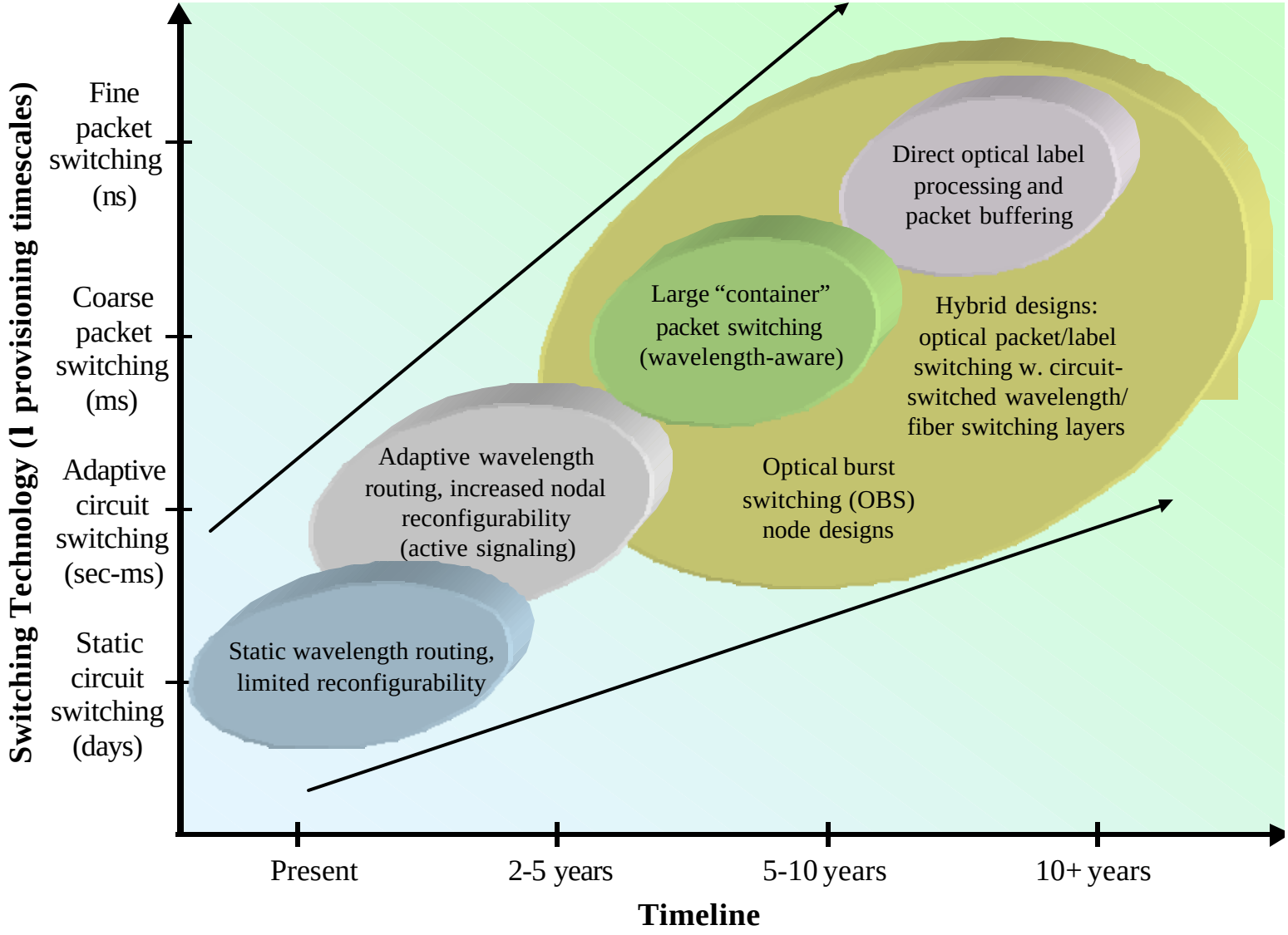
Future Trends/Technologies

- **Packet and burst switching evolutions**
  - Reduced provisioning timescales (ms to ns)
  - Large "container" packet switches exploiting WDM
    Electronic header processing overlap w. payload transfer, fiber loop/circulation buffers, optical label processing, etc.
  - Optical burst switching (OBS) concepts
    With/without (optical) buffering, ongoing research

- **Hybrid network switching paradigms**
  - Re-emergence of (optical) packet-switching in the core?
  - Hybrid nodal designs ("multiple features in single box")
    Combined circuit/packet switching
  - Trunking wavelengths across network (i.e., fiberpath)
    Enabler: MEMS technology, driver: increasing penetration
  - Fiber-wavelength-packet (FWP) node

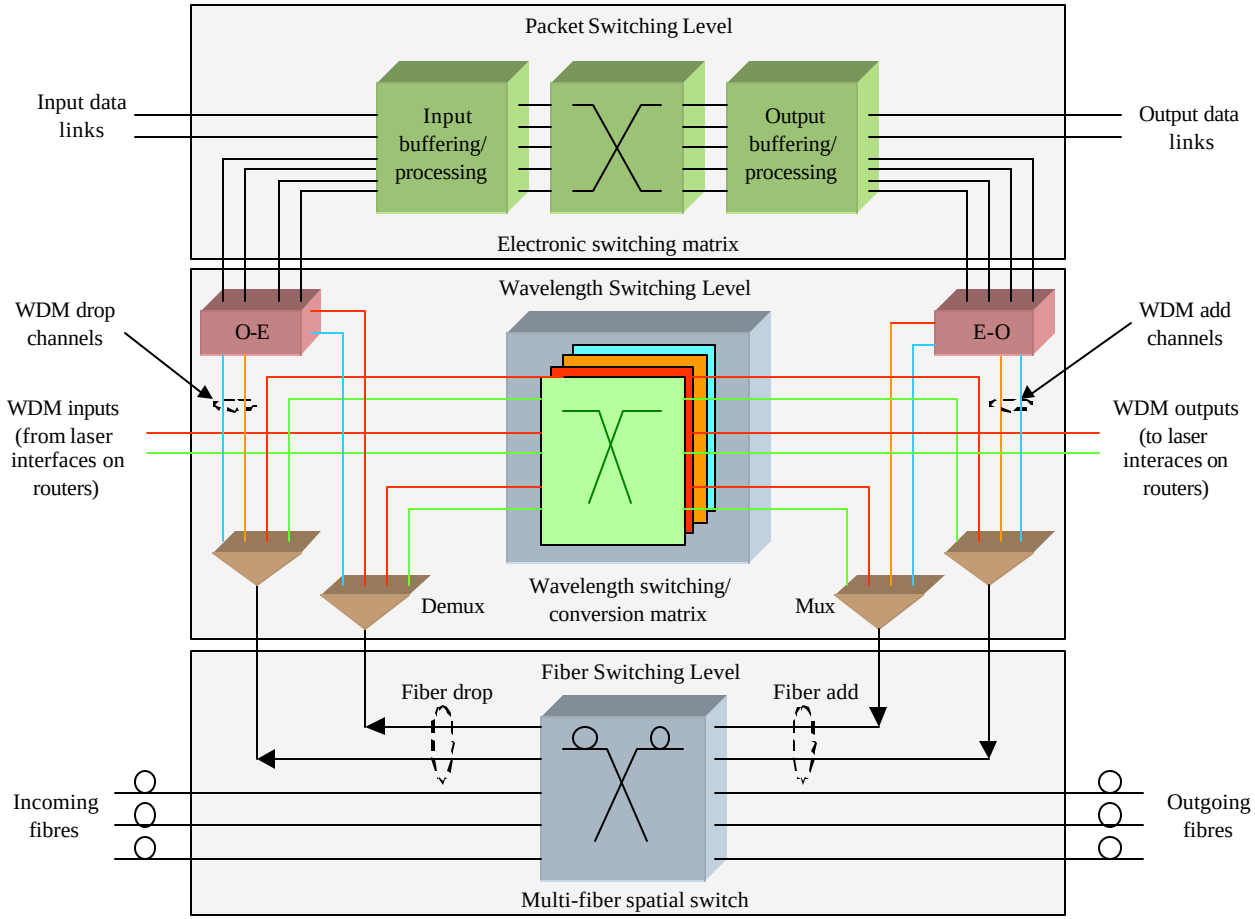
- **Optical-layering vs. MPLS-based approaches**
  - Packet/burst/hybrid switching easily incorporated w. MPLS
  - Optical-layering requires added extensions/modifications
    Likely overlap/redundancy w. many IP features

Future Trends/Technologies



Future Trends/Technologies

Hybrid Fiber-Wavelength-Packet (FWP) Node



Conclusions

- **WDM networking growth strong, new provisioning paradigms**
  - **Scalability, falling costs, increasing penetration**
  - **Wavelength switching timescales will decrease**
    Weeks Þ days Þ hrs Þ min Þ sec Þ ms Þ ns (?)

- **Optical-layering approaches**
  - **Define (standardize) a new, separate optical layer:**
    Provisioning protocols, addressing, interworking protocols
  - **Pros: Multi-protocol transparency, basic solutions exist**
  - **Cons: Added interworking complexity, standardization issues (delays), current/future migration concerns**

- **MPLS-based approaches**
  - **“Re-use” MPLS provisioning/control plane framework: Subsume many advanced concepts in IP domain**
  - **Pros: Expedited interoperability, easier IP integration, smoother future migration**
  - **Cons: Entrenched mindsets, current investments, concerns with “opening up” optical core**

References

- N. Ghani, "**Integration Strategies for IP Over WDM**," *Optical Networking Workshop* (co-sponsored by IEEE Region 5, ACM, SPIE) Dallas, TX, January 2000.
- N. Ghani, "**Lambda-Labeling: A Framework for IP Over WDM Using MPLS**," *to appear in Optical Networks Magazine*, April 2000.
- D. Awduche, *et al*, "**Multi-Protocol Lambda Switching: Combining MPLS Traffic Engineering Control With Optical Crossconnects**," *IETF Draft*, draft-awduche-mpls-te-optical-01.txt, November 1999.
- N. Ghani, "**Survivability Provisioning in Optical MPLS Networks**," to appear in *5th European Conference on Networks & Optical Communications,* Stuttgart, Germany, June 2000.
- K. Kompella, *et al*, "**Extensions to IS-IS/OSPF and RSVP in Support of MPL(ambda)S,**" *IETF Draft,* draft-kompella-mpls-optical-00.txt, February 2000.
- N. Ghani, *et al*, "**On IP Over WDM Integration,**" *IEEE Communications Magazine*, March 2000.
- N. Ghani, S. Dixit, "**Channel Provisioning for Higher-Layer Protocols in WDM Networks**," *Proceedings of SPIE All Optical Networking Conference: Architecture, Control, and Management Issues*, Boston, MA, September 1999**.**
- H. Chaskar, S. Verma, R. Rayadurgam, "**A Framework to Support IP Over WDM Using Optical Burst Switching,**" *Optical Networking Workshop* (co-sponsored by IEEE Region 5, ACM, SPIE) Dallas, TX, January 2000.