Highly Scalable and Dynamic Traffic Engineering Scheme for MPLS Networks

Girish P. Saraph
Associate Professor, Indian Institute of Technology, Bombay
Founder, Vegayan Systems, Mumbai, India
girishs@ee.iitb.ac.in

Contributions:
Nishant Kumar, Darshan Mujumdar

Outline

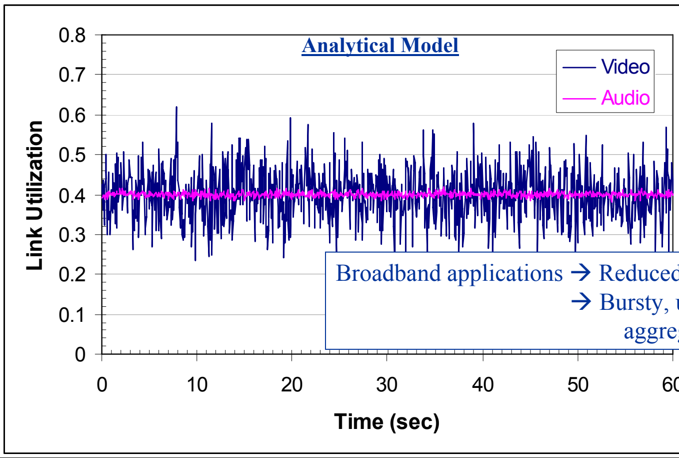
- Rationale for MPLS traffic engineering
- MPLS traffic engineering implementation
- New VS routing approach to MPLS path selection
- Technical merits of Virtual Space routing
- Traffic engineering simulations
- QoS in Inter-domain Routing
- Alliance model for end-to-end QoS
- VS based AS-path selection
- Conclusions

Broadband Applications

Statistical Multiplexing on OC-3 (155Mbps) Link

~ 6250 **audio** (G.729) channels with ~ 9.6 kbps rate

~ 33 MPEG **video** channels with ~ 1.82 Mbps rate



Broadband applications → Reduced smoothening
→ Bursty, unpredictable aggregate traffic

Rationale for Active MPLS Traffic Engineering

- Broadband applications → bursty, unpredictable aggregate traffic
  → high peak-to-average ratios in link loading
- Common approach – Static over-provisioning with load-balancing
  e.g. 2 links carrying <40% average traffic
  – Not an acceptable QoS solution under a link failure
- Achieve high network utilization with overlapping path protection
- Support QoS from the user perspective using application based aggregation (FEC) and traffic engineering
- Intelligent path selection based on specific QoS requirements, network resources, and performance parameters

Multi-parameter Optimization

Traffic engineering objectives require multi-parameter optimization based on:

- Network performance parameters:
  - Total network throughput (total user connections x bandwidth)
  - Total number of hops in each path (affects network loading)
  - Link loading distribution (congestion and under-utilization of links)
  - Blocking probability for arbitrary connection-requests
  - Stability and scalability of implementation
- Flow or connection based QoS parameters:
  - Available bandwidth
  - Total path delay
  - Packet drop rate
  - Path protection
  - Priority level (or CoS)
  - Delay jitter
  - Path attributes
  - Reliability

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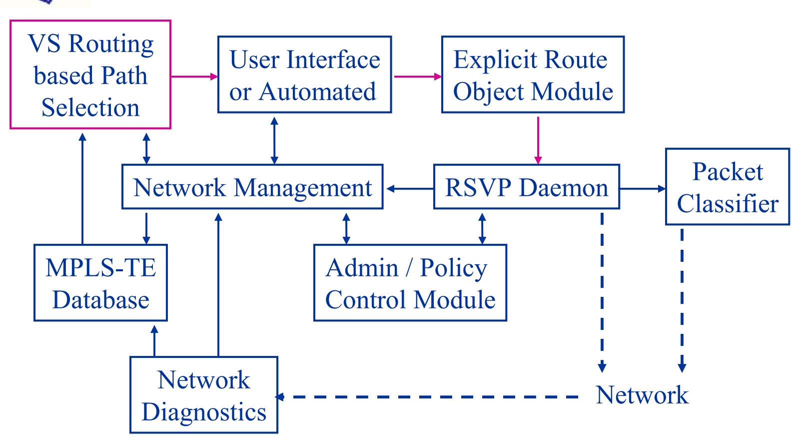
MPLS Traffic Engineering Tool Implementation



Introducing Virtual Space (VS) routing for multi-parameter optimization

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Common Routing Protocols

- Link-state algorithms: OSPF, CSPF, PNNI, etc.
- Distance-vector / path-vector algorithms: RIP, BGP, etc.

- Each node forms consistent picture of entire network topology
- Information processing at each node increases with size of network
- Frequency of dynamic events increases with the size of network
- Each dynamic event leads to cascaded updates ~ $\boldsymbol{O}(N^2)$
- Cascaded updates, processing time, and propagation delay
  → long convergence & potential instability → Limit dynamic events
- Excessive information exchange and processing needs limit
  dynamic adaptability, scalability, stability, and performance

New Philosophical Approach

- Minimize routing information – concise representation
  – elimination of redundant info.
  → better scalability, fast adaptability, and simple implementation
- Transform network topology information (VS embedding)
  into multi-dimensional network map (VS configuration)
  capable of geometric routing (directivity property)
- Utilize concept of locality (1 or 2 hops) in VS configuration
  → dynamic link / node conditions are only locally significant
- Combine directivity and dynamic link info. for path selection (VS routing)
- Use VS routing for multiple path selection & multi-parameter optimization

Virtual Space Routing

- Differentiate between static and dynamic information
  - Static → Network topology, Dynamic → Link status & loading
- Static (topology) information is embedded into VS configuration
  - VS configuration enables simple geometric routing
  - Directed distance to destination represents available path choices
- VS Embedding: Evolution of multi-dimensional VS configuration
  - Energy minimization process in equivalent multi-body system
  - Definitions of VS interaction forces to enhance directivity property
- Dynamic link/node costs: Reflects link (or node) status & loading
  - Link or node failure represents extreme link or node cost
  - Link / node costs are only distributed locally in VS space

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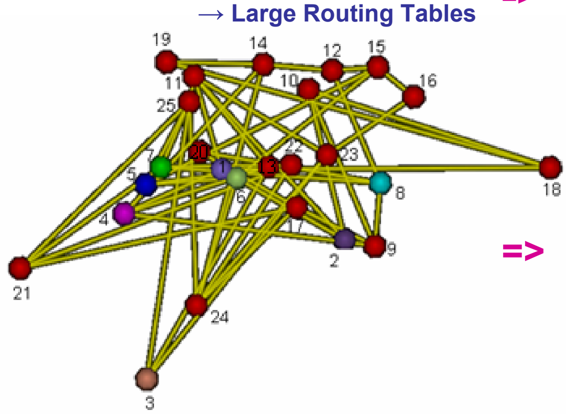
Virtual Space (VS) Embedding

Topology Information: Connectivity Matrix → Large Routing Tables **=>** **VS: 18 → 5 => 18–19–14–24–6–5 or 18–10–9–8–7–25–5**



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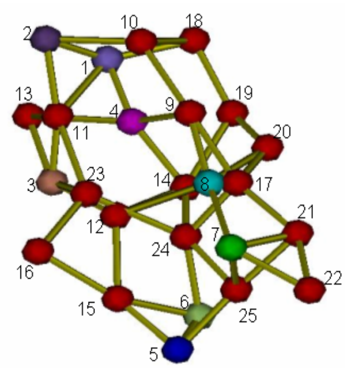

25-node, random network topology **3-D Virtual Space configuration**

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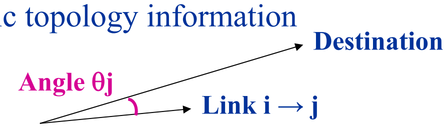
VS Routing: Path Selection

- Total link cost: $C_{ij} = C_1 * (1 - \cos\theta_j) + C_{2ij} + C_{3j}$
  - Angle cost ($C_1 * (1 - \cos\theta_j)$), Link cost (C_{2ij}), Node cost (C_{3j})
- Angle cost → Quasi-static topology information



- Link cost → Dynamic cost based on link loading or failure
- Node cost → Average of link costs → Gives forward visibility
- **Routing decision** → Lowest total link cost or within 0.5 from it

Technical Merits

	Traditional scheme	VS scheme
• Routing information scaling:	$N^2 - N^3$	log(N)
• Information database:	Thousands of strings	<100 numbers
• Peak link loading:	–	~ 25% less
• Minimum link state update time:	200+ ms	~ 10-25 ms
• Information flow distance:	multiple hops	single hop
• Multiple QoS parameter support:	Partial	Yes
• Inter-domain QoS support:	X	Yes
• Resource requirements:	High	Low
• Failure recovery & convergence:	Slow	Fast

=> **VS routing scheme is highly scalable, dynamic, robust, and simple.**

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Link Loading Distributions

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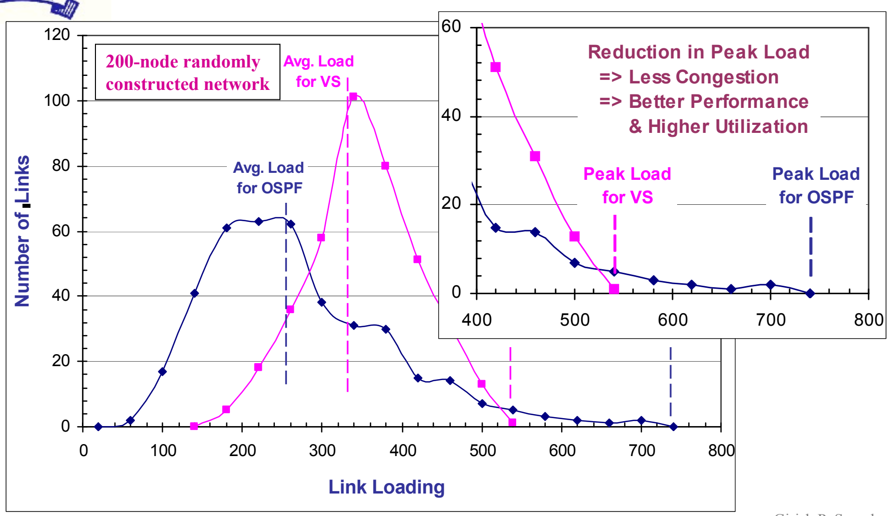

MPLS Traffic Engineering & Network Management Tool

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- QOS support for VVD convergence in the core
- Capability to handle hundreds of MPLS tunnels
- Path selection based on multiple QoS parameters:

  (i) hops (ii) delay (iii) bandwidth (iv) congestion (v) link status
- Efficient overlapping back-up paths for MPLS Fast Reroute
- Quick restoration of service after catastrophic multi-link failure
- Hourly update of inefficient MPLS tunnels
- Identification of critical links and analysis of "what-if" scenarios
- Enhanced network resource utilization and performance
- Improved network management and planning

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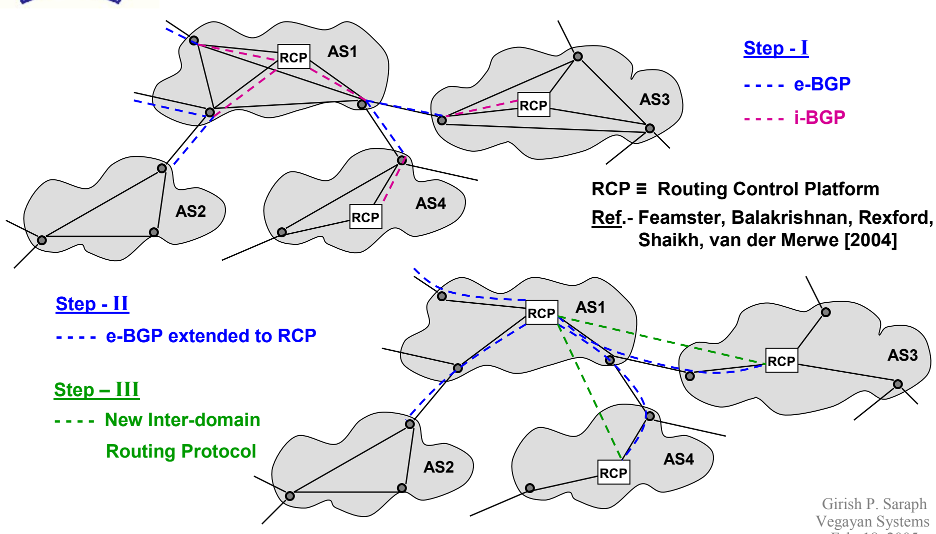
Inter-domain Traffic Engineering & QoS Support

Important features of inter-domain TE & QoS support:

- Ability to generate additional revenues through end-to-end QoS
- Flexibility to support different classes of service
  - best-effort and premium services with specific QoS
- Evolutionary path for existing infrastructure
  - full compatibility with BGP protocol
- Improved network performance and resource utilization
- Efficient selection of primary and back-up paths
- Fast convergence under multiple failure events

End-to-End QoS in Inter-domain Routing



RCP ≡ Routing Control Platform

Ref.- Feamster, Balakrishnan, Rexford, Shaikh, van der Merwe [2004]

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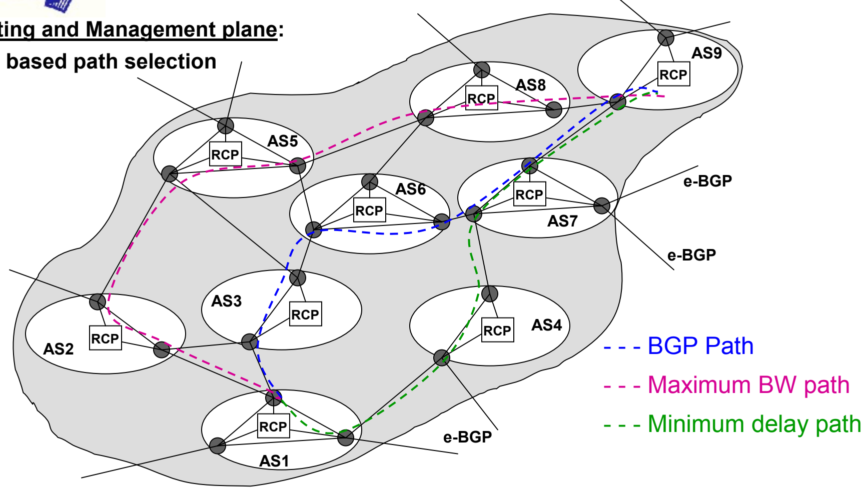
Alliance Model for Inter-domain Routing

Routing and Management plane:

RCP based path selection



Introducing VS routing for multiple path selection

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Alliance Model for Inter-domain Routing

- A set of interconnected AS'es from multiple tiers form an alliance network
  - to provide end-to-end QoS support for end users
  - by sharing QoS parametric information within the network
  - enabling multi-parameter based inter-domain path selection
  - along with resource reservation for MPLS tunnels
  - based on revenue sharing mechanisms between providers
  - that provides cost-performance based choices to the user
  - through a single partner provider for billing and support.

- Advantages of the Alliance Model:
  - enhanced geographical reach and market penetration
  - flexibility to provide different CoS's and better SLA's
  - capability to support new applications with tight QoS spec's
  - utilization of spare capacity to generate revenues

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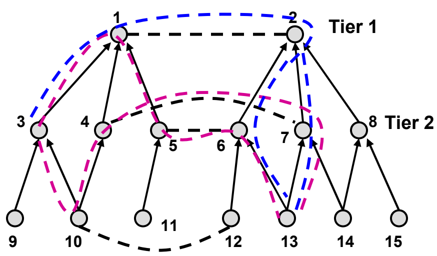
Inter-AS Path Choices

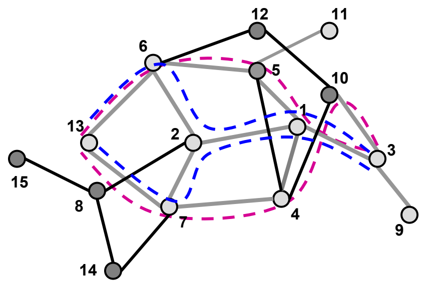
Flexibility in Path Selection

- - - Peering Relation
Customer ⟶ Provider

- - - BGP Advertised Paths
- - - Non- BGP Paths



BGP- based Tier Structure



Tier-less Mesh Structure

(Proposed)

Ref.- L. Gao [2001], L. Subramanian, et.al.[2002]

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VS based Path Selection Table

No.	AS-Path	BGP based	Available Bandwidth (MB)	Total Delay (ms)	Delay Jitter (ms)	Cumulative Cost (units/MB-hr)	Reserva-tion Possible
P1	3-1-2-6-13	Yes	7.5	160	< 1.00	22	Yes
P2	3-1-2-7-13	Yes	4.5	145	< 1.00	25	No
P3	3-1-5-6-13	No	40	145	< 1.00	25	Yes
P4	3-10-4-7-13	No	12	95	< 0.50	32	Yes

{P1, P2} – BGP-advertised paths, good for best-effort traffic, load-balancing

P3 – High-bandwidth tunnel (with reservation) for end-to-end QoS

P4 – High-cost, low-delay, low-jitter tunnel for real-time traffic

{P1, P4} & {P3, P4} – No overlap in paths => Good for back-up tunnels

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Vegayan Systems
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Concluding Comments

- MPLS traffic engineering and network management tool is being developed based on new VS routing scheme.
- VS routing scheme is highly scalable, dynamic, robust, and simple.
  It supports path selection based on multiple parameters.
- Alliance model for inter-domain QoS support has been proposed.
  It is compatible with the existing infrastructure and systems.

Note: Parts of the technology, presented here, are being patented by the author and being commercialized through Vegayan Systems. Please contact the author for further details.

Girish P. Saraph
Vegayan Systems
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