

Modeling the Internet as a Complex System

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The goal of the modeling exercise:



- Understanding past and future evolution of the Internet infrastructure.

Models of complex systems that aren't sufficient for this particular goal:

- Game theory.
- Physics-style models of many small things all the same.
- Doyle-style control theory and dynamical systems.
- ...

Components of such a model:



- The layered IP architecture.
- Changes over time (e.g., the general overprovisioning of backbones and transoceanic links over the last five years).
- A decentralized system, with players including companies, entire industries, ISPs, etc, rather than just individuals.
- The role (or absence of a role) of IETF standards, and of other standards.
- Economic and political factors.
- The intrusion of the real-world (e.g., firewalls, etc.).
- Chicken-and-egg deployment issues.

Specific topics:

- IPv6.
- QoS.
- Multicast.
- Middleboxes.
- ECN.
- Instant messaging.
- Security.
- DNS.
- Routing.
- Possible paths for future evolution.

Conceptual Models for The Evolution of QoS

Modeling Aspect:	Details:
The Time Line.	<ul style="list-style-type: none">* Heavy congestion in the early to mid 90's.* Overprovisioning in backbones in the late 90's and on.* Overprovisioning, now, in international links.* Recent overprovisioning at peering points.* The continued use of end-to-end congestion control for best-effort traffic.* The beginning deployment of VoIP.

<p>Protocols, Standards, and Architectural Factors.</p>	<ul style="list-style-type: none">* Congestion control mechanisms for streaming media.* Integrated Services: A disregard for administrative boundaries within networks.* Differentiated Services: Standardized in terms of per-hop behaviors, but not in terms of end-to-end performance.* The use of IPSEC, NATs, and other IP tunnels introduces difficulties for QoS deployment.* Intserv reservations within diffserv flows?* Interactions of QoS with the dynamic nature of routing.
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Economic and Political Factors:	<ul style="list-style-type: none">* The decomposition of the Internet into different administrative domains.* Difficulties in billing for per-flow services.
Implementation Issues:	<ul style="list-style-type: none">* What gets deployed first, host applications or network infrastructure?* The costs and slow time-scale of introducing additional functionality in routers.* QoS for unicast only, or for multicast?* Receiver-based or sender-based design?