Keynote

An End to the End-to End Arguments

Hisashi Kobayashi

Professor Emeritus, Princeton University

Executive Advisor, NICT, Japan

EuroView 2009

Würzburg, Germany. July 28, 2009

End-to-End Argument

- **J. H. Saltzer, D. P. Reed and D. D. Clark**, "**End-to-End Argument in System Design,**" ACM TOCS, Vol. 2, No. 4, November 1984, pp. 278-288.

  - The function in question can completely and correctly be implemented only with the knowledge and help of the application standing at the end points of the communication system. Therefore, providing that questioned function as a feature of the communication system itself is not possible. (Sometimes an incomplete version of the function provided by the communication system may be useful as a performance enhancement.)

The E2E Design of the Internet

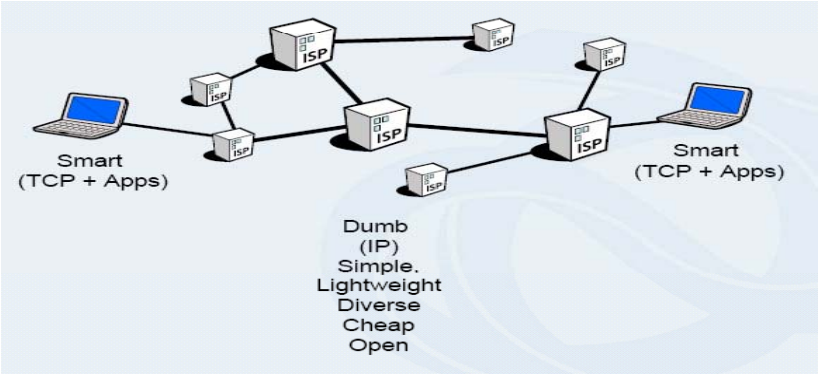


Diagram : Paul Wilson, Asia Pacific Network Information Center

Telephone Network Architecture

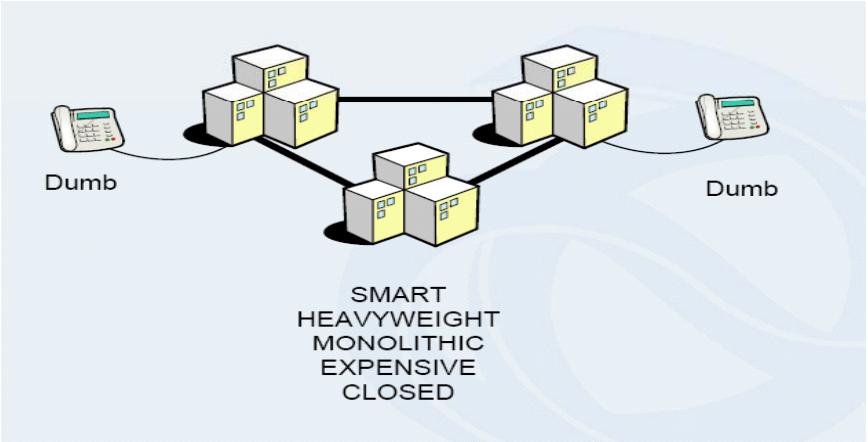


Diagram : Paul Wilson, Asia Pacific Network Information Center

Telephone Network of Today

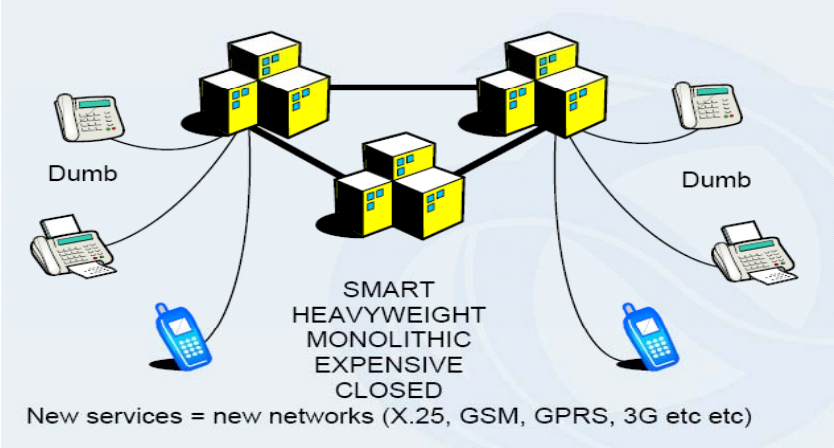
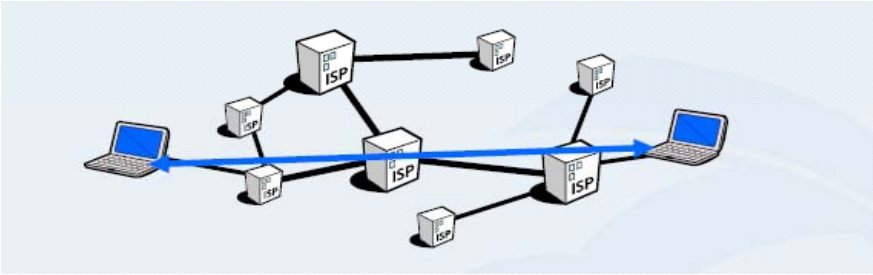


Diagram : Paul Wilson, Asia Pacific Network Information Center

Significance of the E2E Design

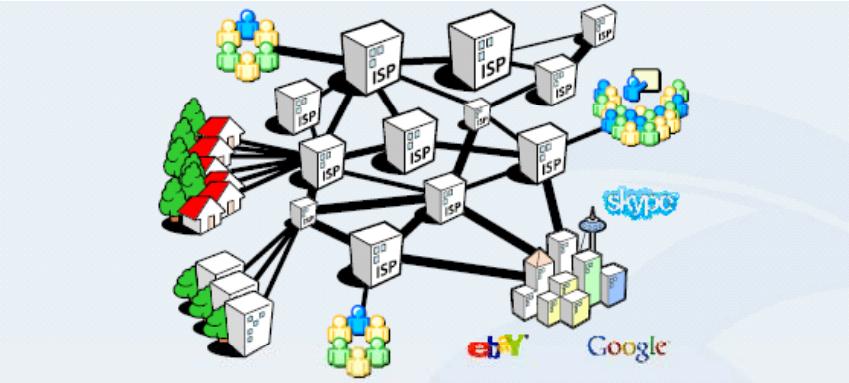


- The network provides basic packet delivery service (i.e., **datagram** service)
- Applications are implemented in end hosts, leading to

⇒**CPE-based network**. (CPE: customer premise equipment)

- The network is unaware of the services in upper layers.
- **Openness** of such network led to **innovations**.

Today's Internet Landscape



- Every service is another end-to-end application.
- New applications can be deployed by anyone
- Applications need not conform to any particular model

Problems with the E2E Argument

- **Saltzer et al.'s argument has a flaw.**
  - **End hosts must be involved in implementing E2E services/applications (of course!).**
  - **Placing partial functions within the network should be avoided (why?)**
- **Their example on "Error control in file transfer" contains false arguments.**
  - **Localized (i.e., hop-by-hop) ARQ vs. End-to-End ARQ.**
  - **End-to-End ARQ is better, when the channels are almost error-free, but not because of the E2E argument.**

Localized Error Control

- Reduces *undetectable* or *uncorrectable* errors.
- Reduces retransmission *delay*
- Reduces network *traffic load* ⇒ Improve *efficiency* of *resource usage* ⇒ Improve *flow* and *congestion control.*
- Does not require immediate availability of the other endpoint ⇒ rapid transfer of email
- The above benefits are more significant in *multicasting*
- *Content distribution networks* (CDNs) can be viewed as an effective way to reduce delay and traffic, by avoiding end-to-end transmission and acknowledgement.

Observations

- E2E implementation is *antithetic* to *resource sharing*.
  - The notion of multiplexing and switching/routing comes from the network-based implementation approach.
  - A network with broadcast medium would be the best for the E2E implementation.
- Thus, E2E implementation does not lead to economies of scale.

Why was the Argument Well Accepted?

- E2E ARQ became a favored choice in 1980s.
  - Links are faster and cleaner than the X25 days.
  - Memory and processing within the network were still costly.
- Distributed algorithms for routing were found suited to the E2E implementation.
- Open network systems were appealing to the Internet researchers.

TCP/UDP Performance Problems

- When an overload occurs, packets are dropped randomly, because of the absence of flow-state information in the IP-router ⇐ A consequence of the E2E design
- The above problem is getting more serious as voice and video traffic that run on UDP/IP grow.
- The problem is also due to the fact that TCP/IP does not provide *call admission control* (CAC). ⇐ A consequence of the E2E design

Problems of the E2E Approach

- "Transmission error control" and "Packet Routing" are only a small part of bigger problems:
- Cannot provide *true* **QoS of TCP/IP;**
- Cannot work with **Trust breakdown;**
- Cannot meet **New Service Models;**
- Cannot deal with **Social Pressure.**

"Quality of Service" Problems

- An E2E design cannot implement **Connection Admission Control** (CAC).
- Add-on protocols (e.g., IntServ, DiffServ) found **unsatisfactory**.
- It's clear that we must do away with the "end-to-end" constraint.

  - DARPA's "**Control Plane Project**".

  - "**Flow router**" by Larry Roberts.

cf. L. G. Roberts, "The Internet is broken. Let's fix it.." IEEE Spectrum, July 2009, pp. 34-39.

Trust breakdown and Security

- **Lack of trust** among users of the Internet today.
- **Establishment of trust** must be part of the core network architecture, not add-on protocols.
- **Network-based approach** can facilitate sharing of security functions by multiple applications.

Pros of Network-Based Approach

- **Network-based approach** can provide
  - Resource sharing, economies of scale.
  - Interworking between services.
  - Necessary services (e.g., authentication) for mobile users at where they are.
- Most users **don't want** to **load, update and troubleshoot** applications.

Conclusion about the E2E

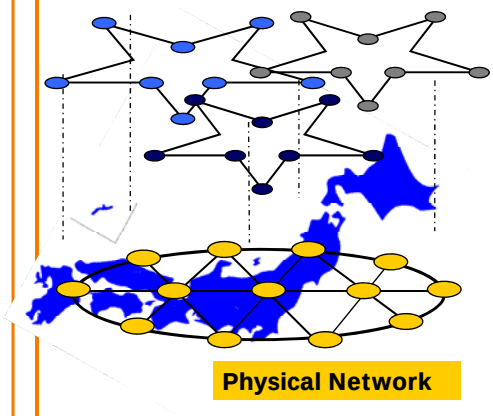
- Adhering to the E2E principle will **do more harm** than do good.
- Take advantage of **shrinking memory** and **processing costs**, and make the network smarter.

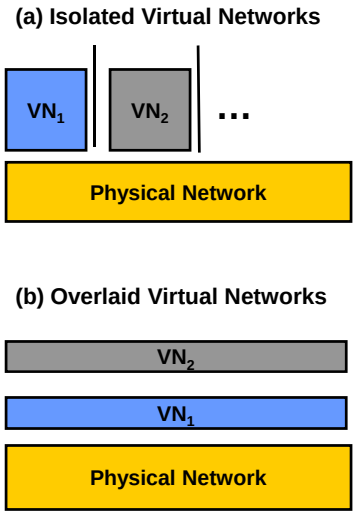
  - Routers should know “states” of the network and individual flows.

  - “Trust and reliability” should be built into lower layers.

- Give protocol designers & application developers with an **“open” virtual network** as their test bed.

Network Virtualization





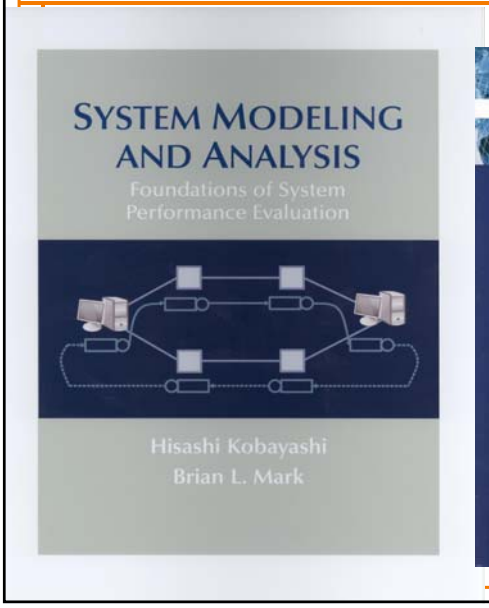
Modeling & Analysis of V.N.

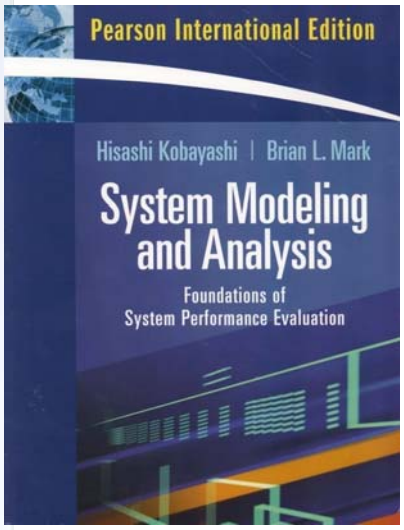
- Few literature on modeling & analysis of VNs.
  - Empirical studies of specific installations.
  - How can a desired set of VNs be formed, given a set of available network resources?
- Some analytical models will be relevant:
  - Processor sharing
  - Loss network model
  - Equivalent bandwidth

Conclusions

- The antiquated “End-to-End approach” should not be a guiding design principle in future networks.
- We should make the network “smart” enough to guarantee QoS and secure enough to cope with trust breakdown among the network users.
- Network virtualization allows us to create multiple logical networks on a given set of physical network resources.
- Modeling techniques needed to provide insights into performance implications of network virtualization and performance of a given virtualized network.

Instructor's Manual is now available.





Acknowledgments

- Ioannis Avramopoulos, Deutsche Telekom
- Hiroaki Harai, NICT
- Brian L. Mark, George Mason University
- Jennifer Rexford, Princeton University