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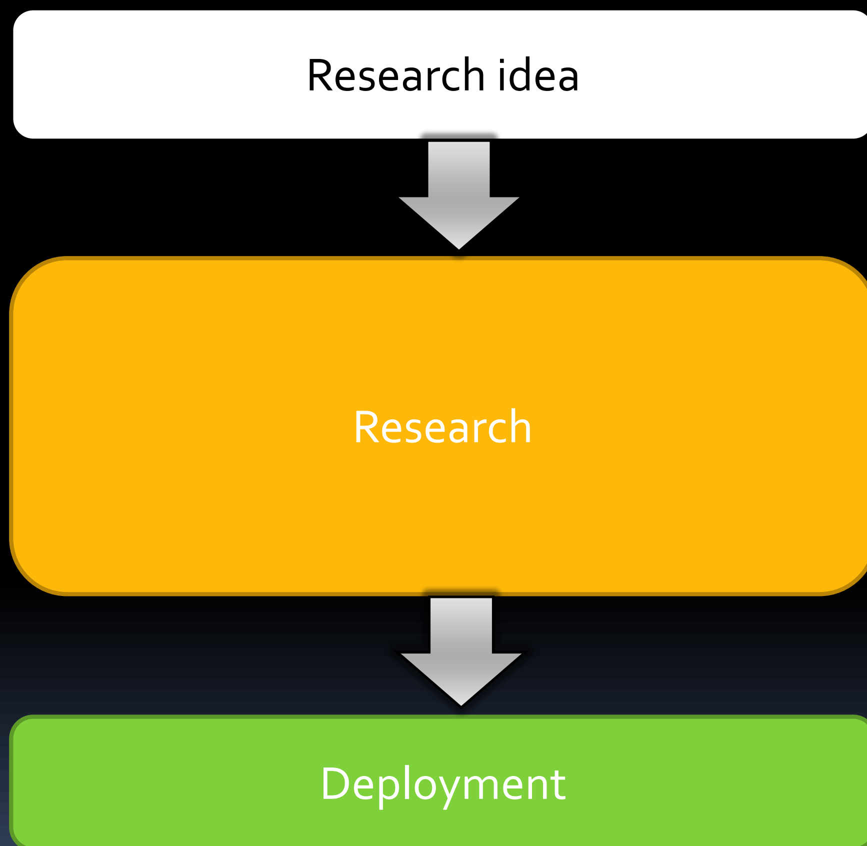
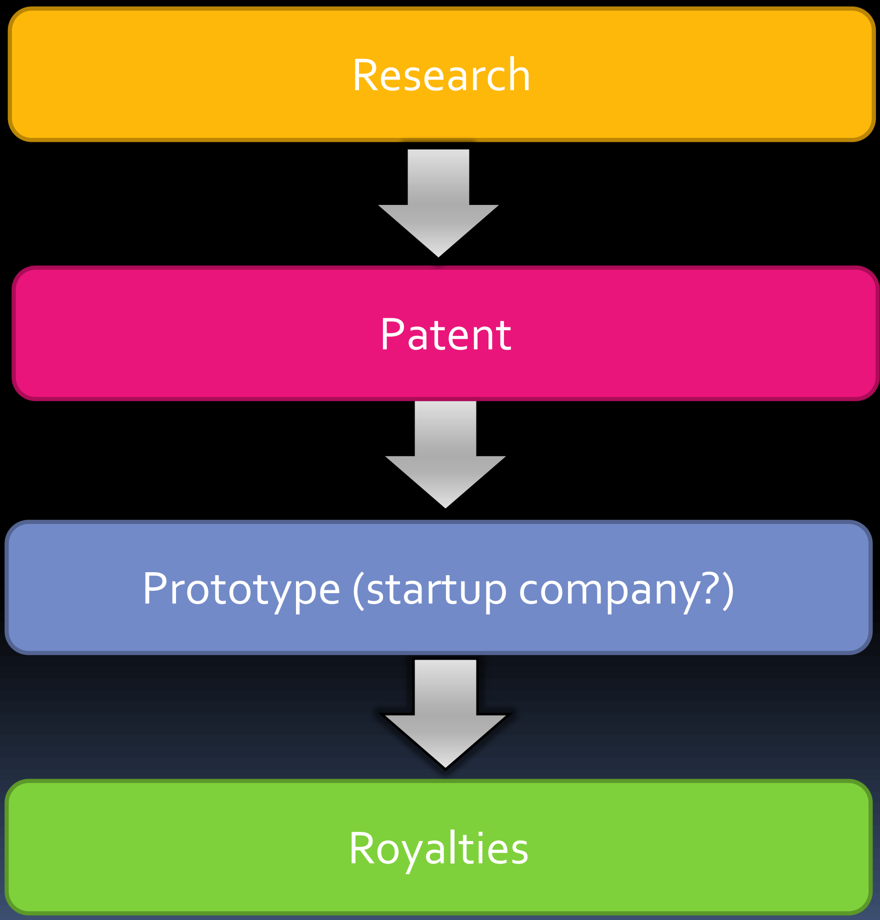
# Intersections between Information Technology Research and Public Policy

# Researcher view



# University view



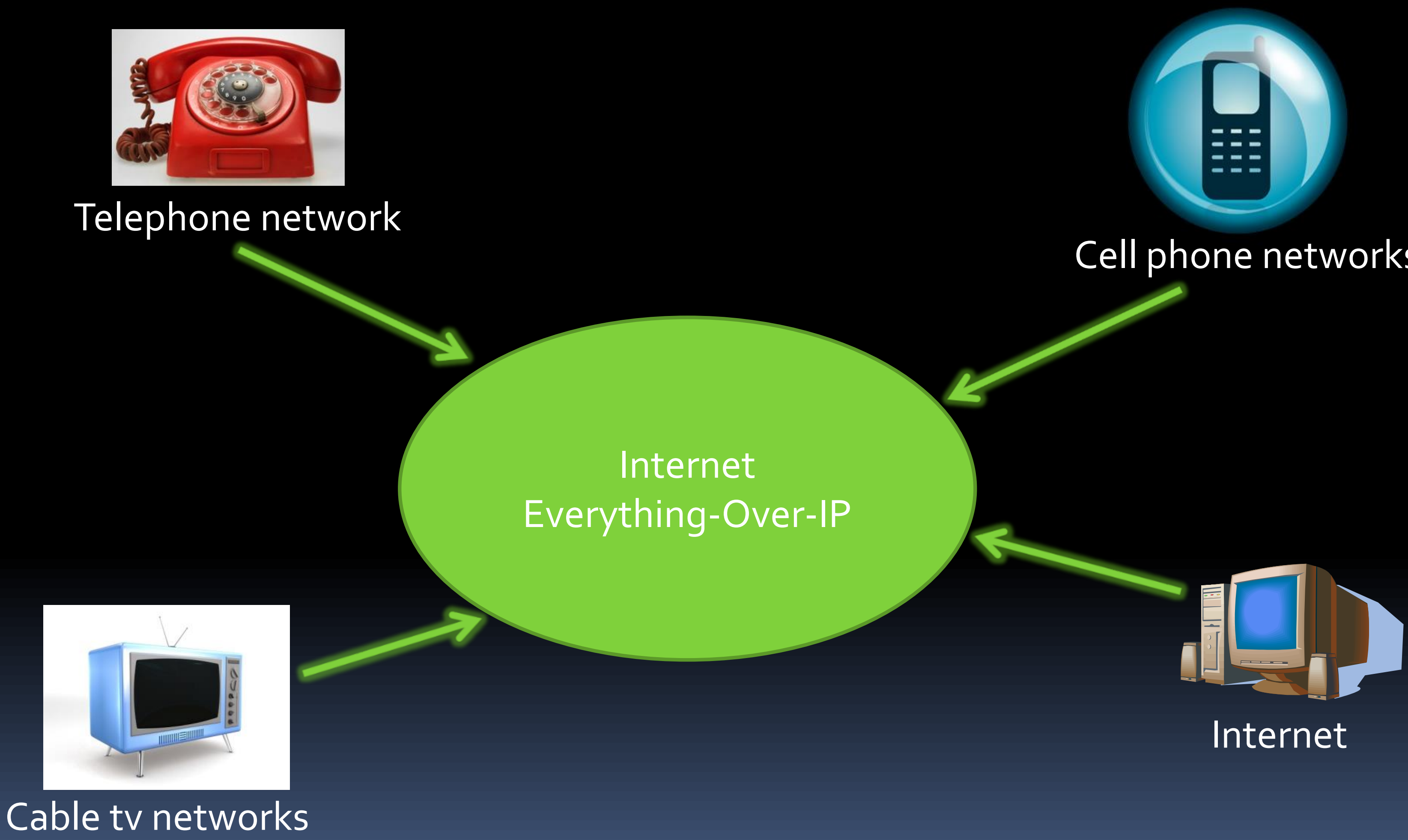
# Good networking ideas (but slow to deployment)

- QoS
- Multicast
- Convergence of PSTN, Internet, cable tv, cellular
- Configurable networks (active networks, SDN)
- Device interoperability (sensor networks, IoT)
- …

# Three case studies

- QoS
- Interconnection
- Device attachment

# QoS: original vision



# Technology convergence

*More Interactive* — *Less Interactive*

**telephone calls**
**video conferencing**

**Internet tv**
**Internet radio**

**web browsing**

**email**

**Express Mail**

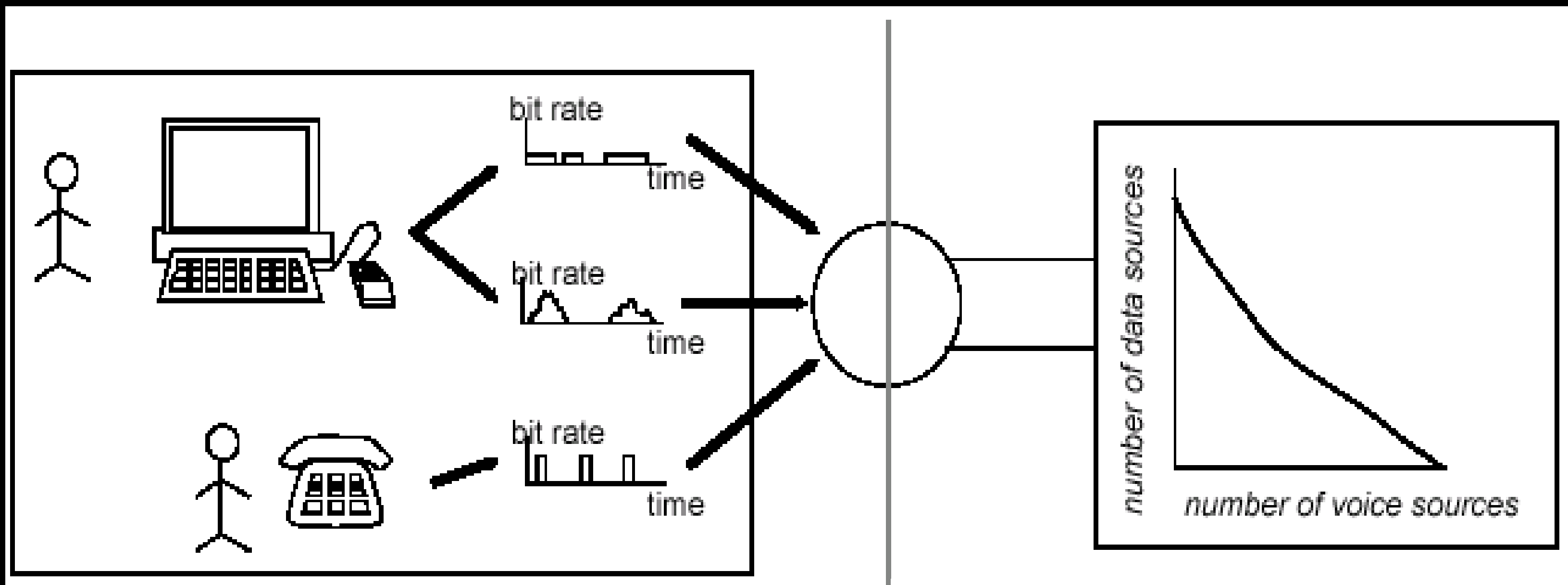
**Priority Mail**

**First Class Mail**

**Bulk Mail**

*Better Performance* — *Worse Performance*

# QoS: research




**User**

*Traffic Characterization*

*Quality of Service (QoS)*

**Network**

*CAC / Scheduling / Policing*

*Network Capacity Characterization*

**Pricing & Contract**

# QoS: research

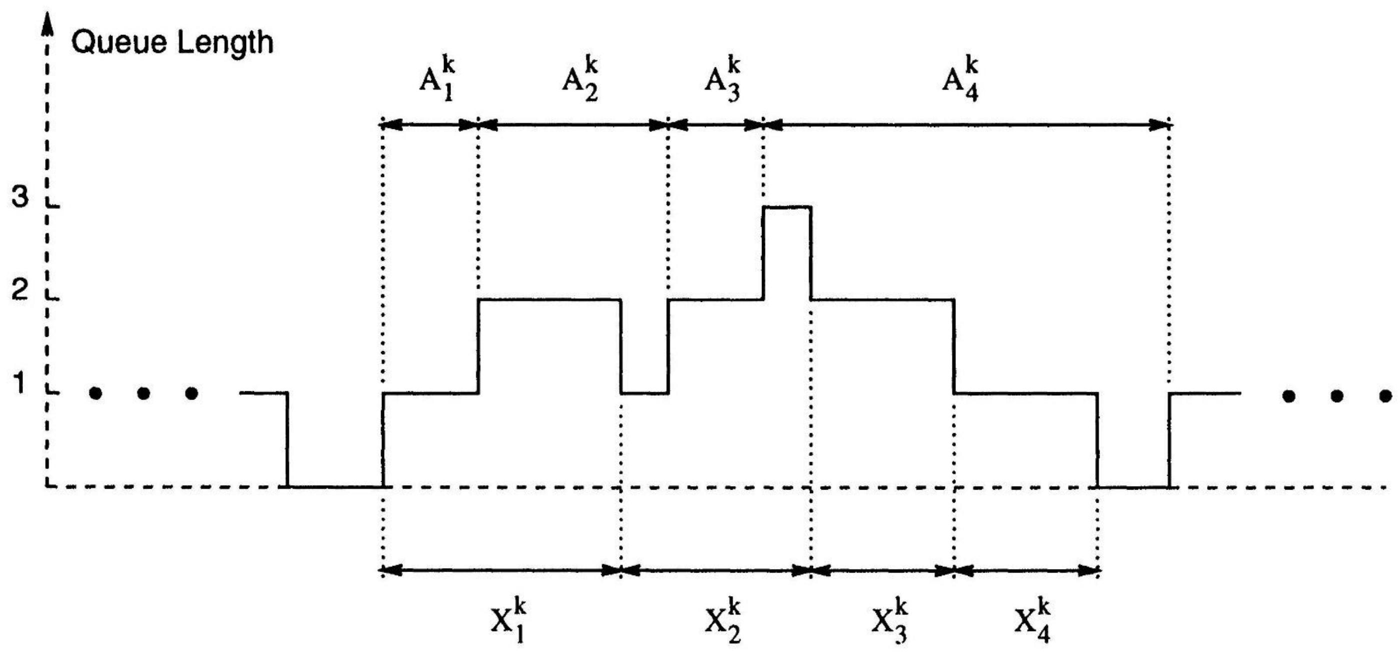


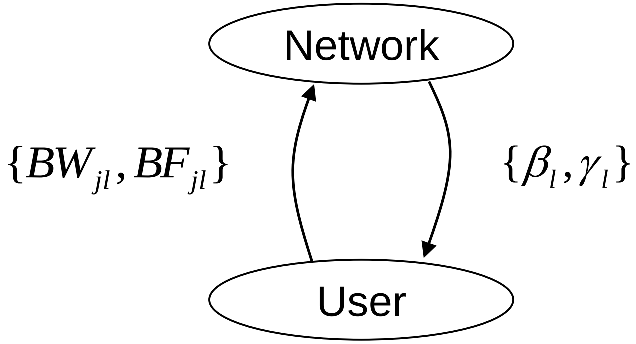
FIG. 1. *The kth busy period of the queue.*

See lots of papers by Edwin Chong in the 1990s/2000s

# QoS: research

***Network Algorithm (N1):***

Set prices to allocate all available buffer and bandwidth.

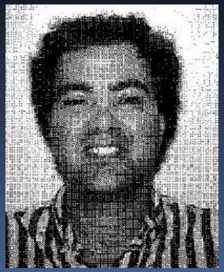



***User Algorithm (U1)***

Maximize consumer surplus:

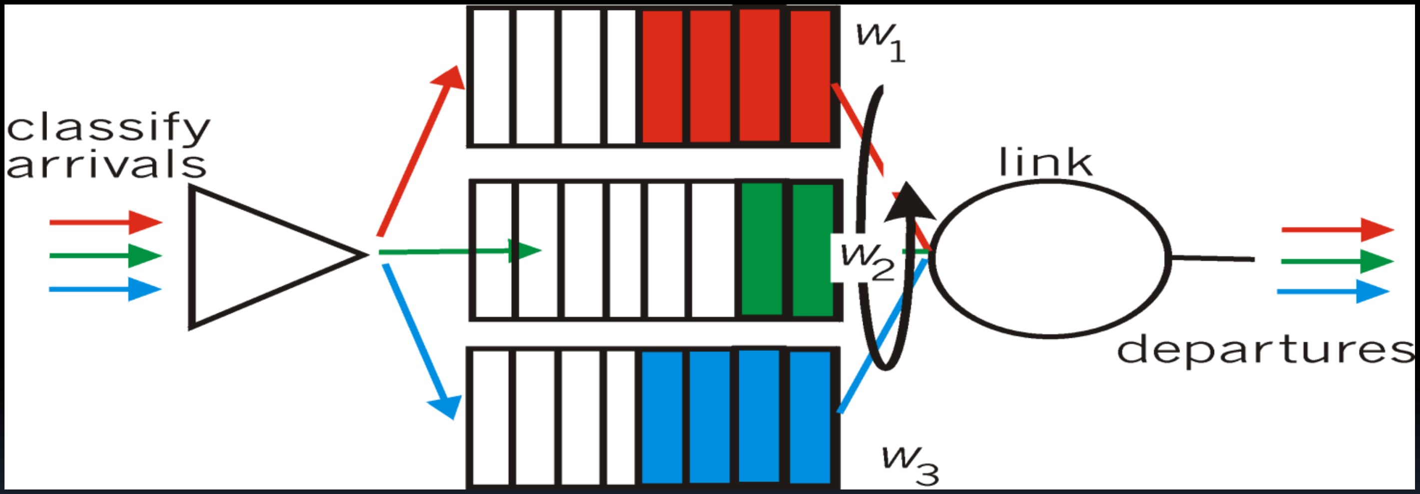
$$\max_{BW_{jl}, BF_{jl}} U_j(L_j, N_j) - \sum_{l=1}^{n_j} \left(\beta_l BW_{jl} + \gamma_l BF_{jl}\right)$$

See lots of papers by Scott Jordan in the 1990s



# QoS: standards

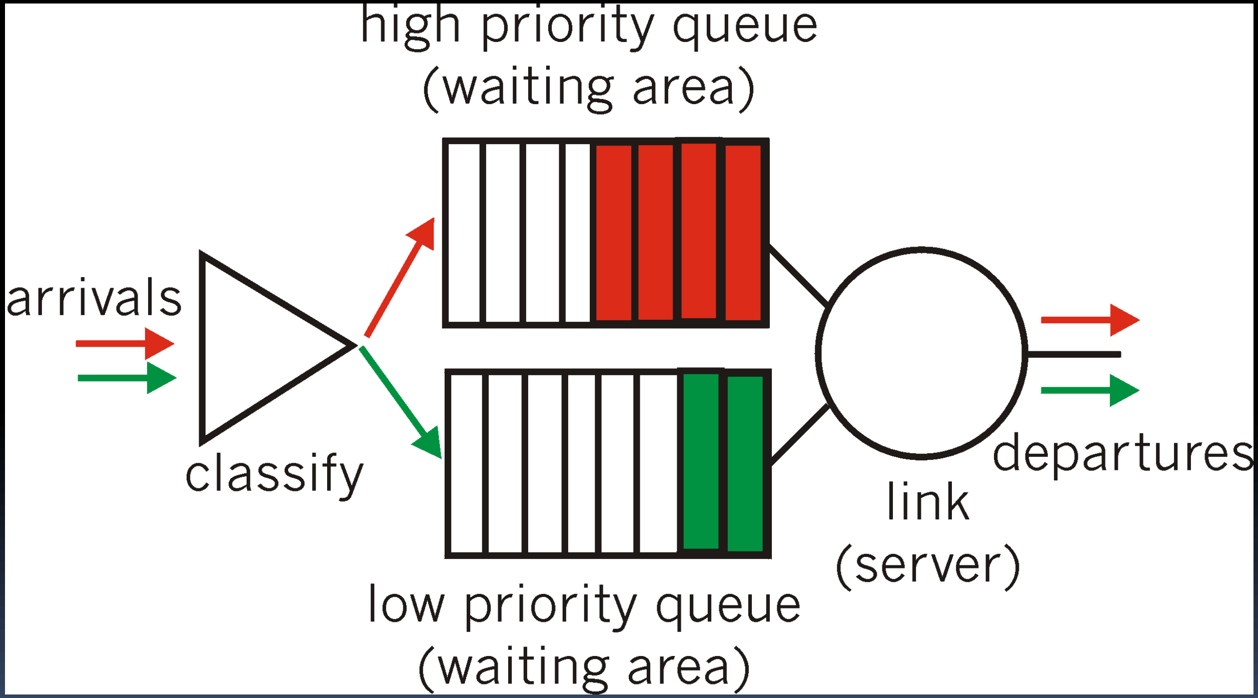
- IntServ




Kurose/Ross fig. 7.26

# QoS: standards

- diffServ




Kurose/Ross fig. 7.23

# QoS: standards

| Application | L3 Classification | | IETF |
|---|---|---|---|
| | PHB | DSCP | RFC |
| Network Control | CS6 | 48 | RFC 2474 |
| VoIP Telephony | EF | 46 | RFC 3246 |
| Call Signaling | CS5 | 40 | RFC 2474 |
| Multimedia Conferencing | AF41 | 34 | RFC 2597 |
| Real-Time Interactive | CS4 | 32 | RFC 2474 |
| Multimedia Streaming | AF31 | 26 | RFC 2597 |
| Broadcast Video | CS3 | 24 | RFC 2474 |
| Low-Latency Data | AF21 | 18 | RFC 2597 |
| OAM | CS2 | 16 | RFC 2474 |
| High-Throughput Data | AF11 | 10 | RFC 2597 |
| Best Effort | DF | 0 | RFC 2474 |
| Low-Priority Data | CS1 | 8 | RFC 3662 |

# QoS: missing pieces

- Packet scheduling standardization
- Codepoint standardization
- diffServ signaling
- Bandwidth broker
- Legal framework

# QoS: deployment

- By the late 1990s, researchers were beginning to give up …
- Cable broadband providers use QoS for own VoIP services
  - But not inter-AS
  - And not for competing VoIP services
- Telco broadband providers use QoS for own video services
  - But not for competing video services
- Cellular broadband providers use QoS for own VoIP services
  - But not inter-AS
  - And not for competing VoIP services

# QoS: public policy issue

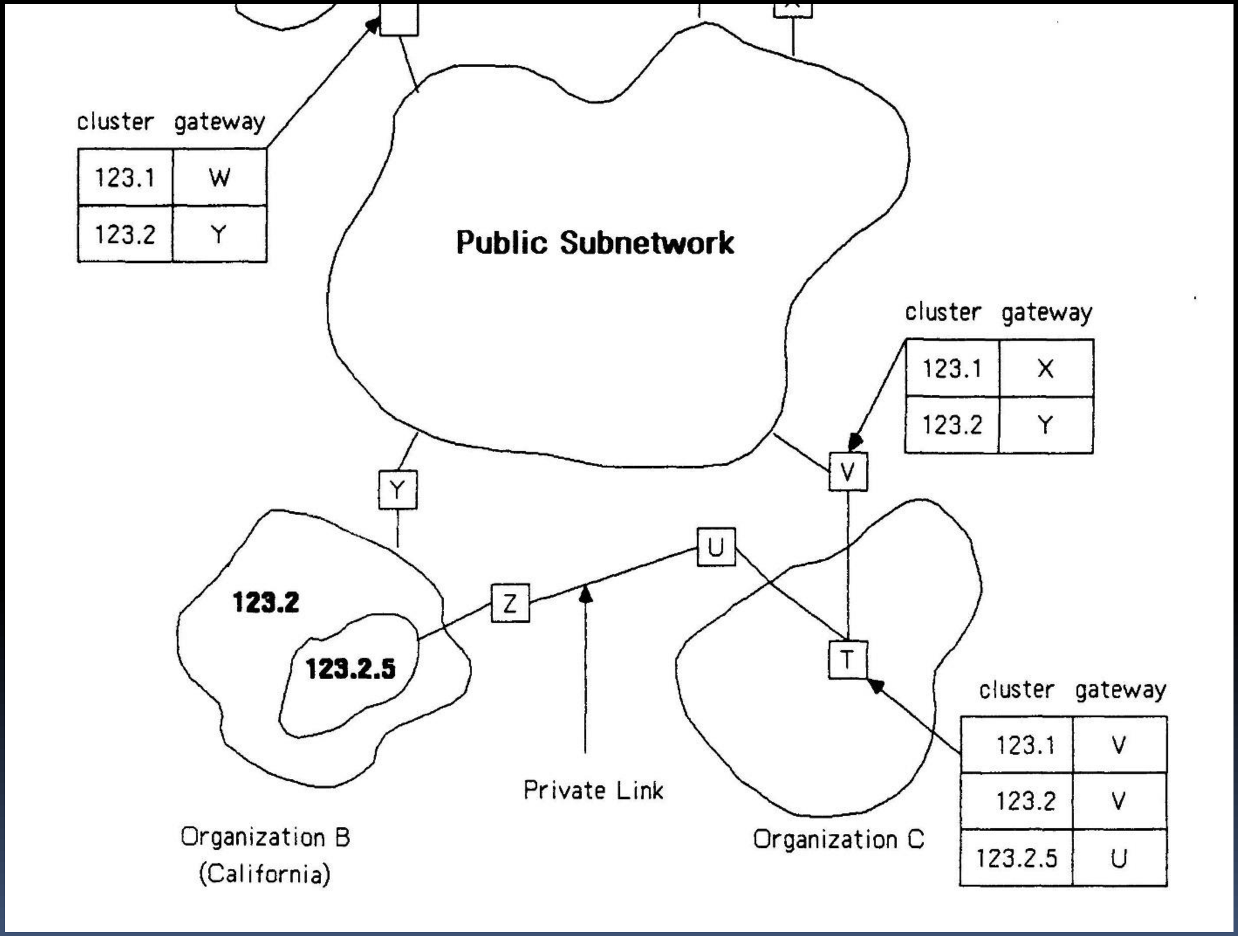

# QoS: lessons learned

- Research & standards stopped at what they saw as the technical / economic boundary
- De-facto standardization of codepoints left to Industry
- Lack of both technical and economic coordination mechanisms impeded deployment of end-to-end QoS
- Lack of communication & standardization of vision led (in part) to net neutrality debate
- Legal framework did not prohibit ISP from using QoS only for itself

# QoS: research challenges

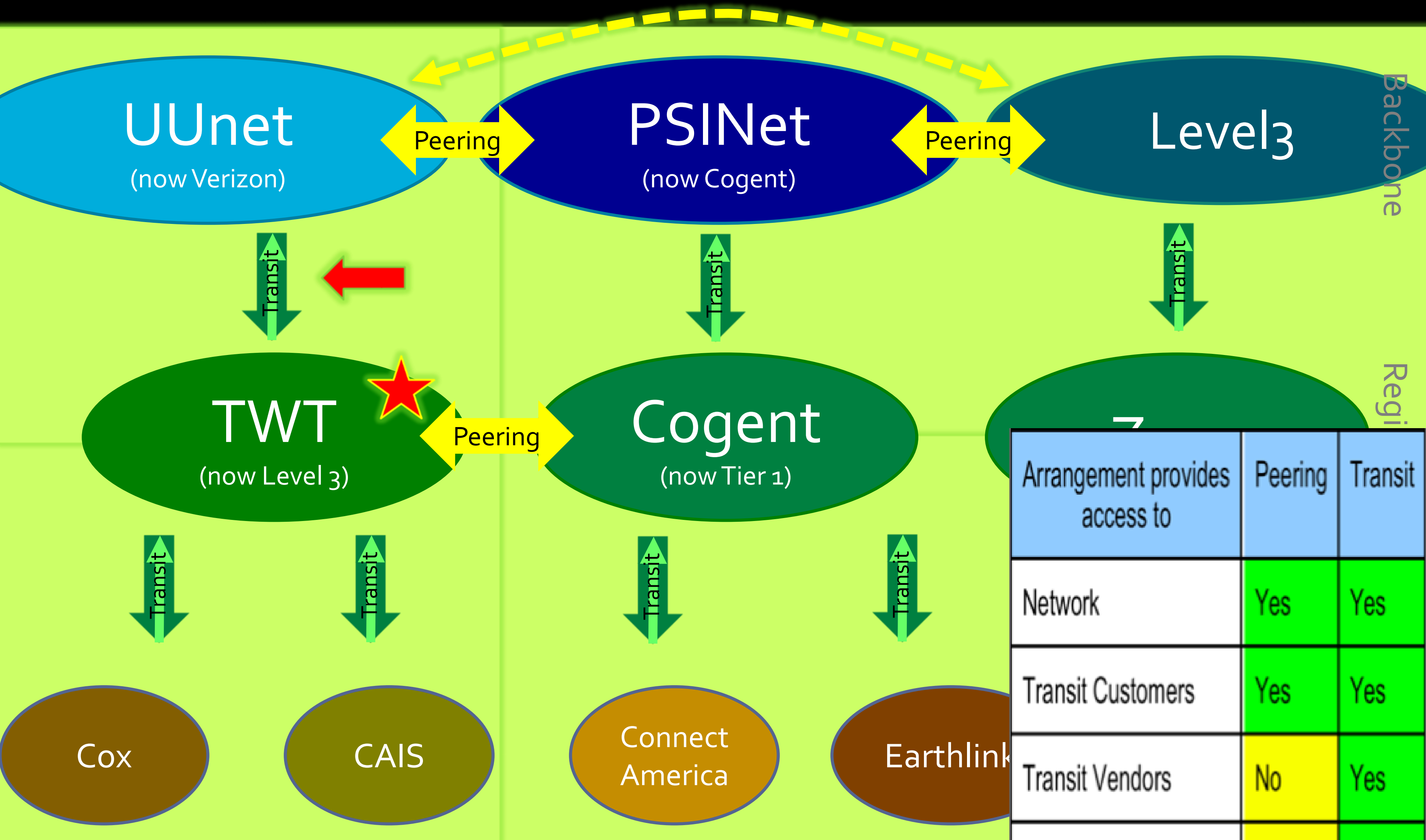
- When will an ISP choose to offer QoS to users?
- Recommended ways for QoS to be sold to a user?
- How can an application decide whether to use QoS that a user has purchased?
- How can multiple ISPs coordinate to offer end-to-end QoS?

# Interconnection: original vision




An Architecture for Routing in the ISO Connectionless Internet, Stuart J. Zakon, 1985

# Interconnection: research




| Arrangement provides access to | Peering | Transit |
|---|---|---|
| Network | Yes | Yes |
| Transit Customers | Yes | Yes |
| Transit Vendors | No | Yes |
| Peers | No | Yes |

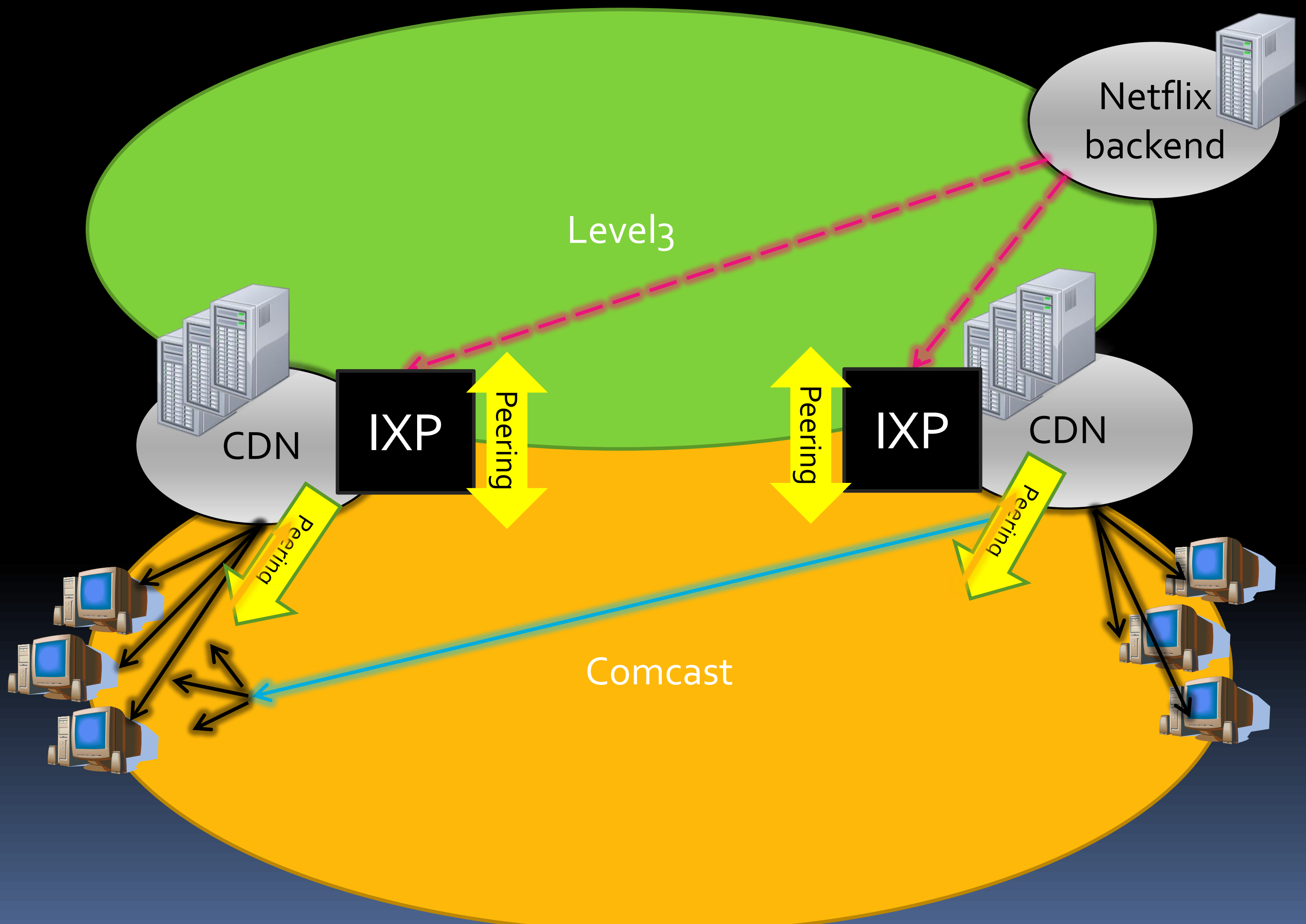
# Interconnection: standards

- BGP
  - If there are multiple possible routes to an IP prefix, use AS policies, including:
    - cost of using path
    - length of path (at AS level)
    - number of IP hops within AS on route
      - “hot-potato” = minimize this
      - “cold-potato” = maximize this

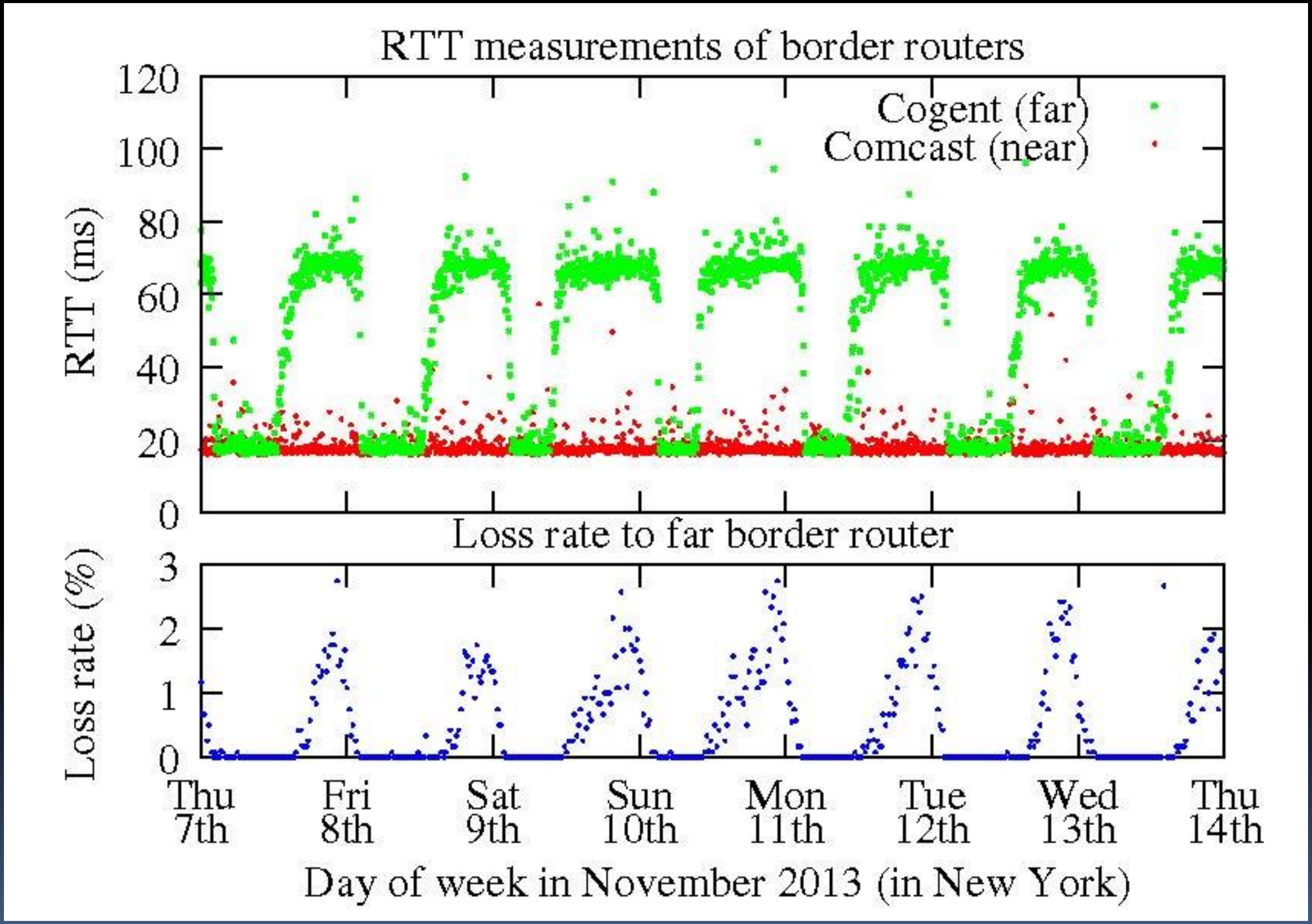
# Interconnection: missing pieces

- Services
  - Peering, transit, other?
- Coordination
  - Between sender and downstream autonomous systems
  - Between interconnecting autonomous systems
- Contract
  - SLAs
- Payment
  - Sender pays vs. receiver pays

# Interconnection: deployment



# Interconnection: disputes




*Measurement and Analysis of Internet Interconnection and Congestion*, Clark et. al., 2014

# Interconnection: public policy issue

- ISPs say:
  - Interconnecting parties should pay us to carry traffic
- Content providers, transit providers, CDNs say:
  - The ISP's customers have already paid the ISP to carry requested traffic

# Interconnection: lessons learned

- Research
  - BGP not sufficient
  - Need to define services
- Standardization
  - The coordination required to implement services (technical vs. agreement)
- Economics
  - Analysis of end-to-end two-sided market !!
- Law
  - Non-discrimination

# Interconnection: research challenges

- What interconnection services should be offered?
- How can an ISP and a content provider coordinate routing?
- How much of the route does a user pay for?
- How can we detect the exercise of market power?

# Device attachment: original vision

# Device attachment: research & standards

**Content** (layer 7)
web pages, videos, blogs, RSS feeds, online radio stations, …

**Applications** (layers 5-7)
http, email, file transfer, streaming, instant messaging, web hosting, blogging, video conferencing, remote desktop, …

**Transport** (layer 4)
TCP congestion control

**Network** (layer 3)
IP addresses, routing

**Physical & Link "LAN-link"** (layers 1-2)
Ethernet, DSL, cable modems, Wi-Fi, local loop, …

Hourglass shape allows for innovation here and here

# Device attachment: missing pieces

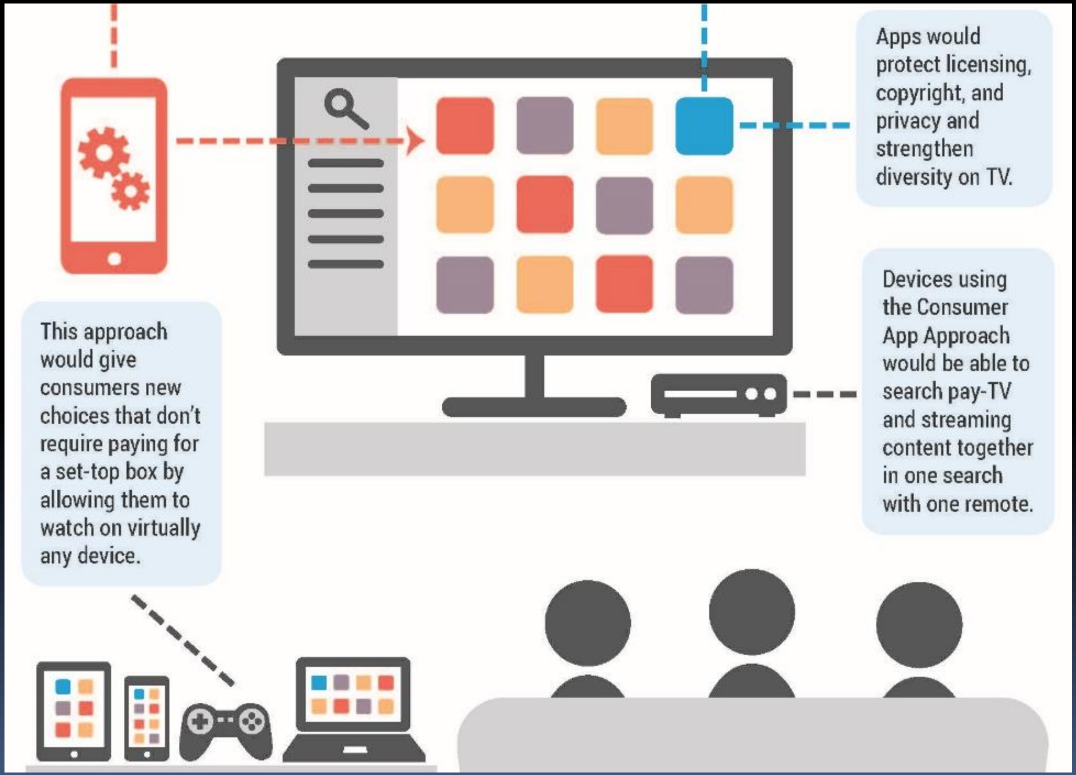
- Open operating systems
- Standardized authentication
- Standardized signaling

# Device attachment: deployment

- Variety of devices
- But:
  - Closed gardens
  - By OS
    - Apple
    - Google
  - By service provider
    - Home gateways
    - Set-top boxes

# Device attachment: public policy issue


Comcast




NCTA

# Device attachment: lessons learned

- Research
  - Security/networking interfaces
  - Computing/networking interfaces
- Standardization
  - IETF not in the game?
- Economics
  - What are the motivations of each party?
- Law
  - Right to attach non-harmful devices

# Device attachment: research challenges

- What are the rights of a {user, device manufacturer, content provider} with respect to devices?
- What are the interfaces that allow a device to be attached to a service?
- Who should standardize these interfaces?

# convergence