The Service-Infrastructure Cycle, Ossification, and the Fragmentation of the Internet

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A Story in Three Chapters

#1 How to say "Necessity is the Mother of Invention" in Networkingese?

#2 *e pluribus unum* (from many, one)

#3 *ex uno pluria* (from one, many)

Takeaways

- A fundamental iterative process governs successful evolution in deployed infrastructure.
- There is nothing fundamental about a single global network delivering all services.
- New ManyNets world is upon us:
  - flexibility bodes well for the future of networking and networking research.

COMPUTER COMMUNICATION REVIEW
The ACM SIGCOMM newsletter

ex uno pluria:

The Service-Infrastructure Cycle, Ossification, and the Fragmentation of the Internet

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#1 "Necessity is the mother of invention"

- In Network Speak
  - Ne
    - ployment

Service/scale support motivates infrastructure deployment

The Service-Infrastructure Cycle

New Network Service or
Increased Scale

Establish/Upgrade Infrastructure To
Meet Scale or Provide Service

Two Motivators: New Applications + Scale

- Applications:
  - Time Sharing
  - Email
  - File Transfer
  - Web Browsing
  - File Sharing
  - Social Networks
  - Video Streaming
  - On the Horizon: AR, Connected Cars, …

Two Motivators: New Applications + Scale

- Scalability: The ability to handle a large number of connected entities
- Scalability will continue as the main driving force

Scale Today

- Number of Internet users ~ 3 Billion
- Number of connected devices ~ 10 Billion
- Predicted number of devices connected in 2020 is around 20 - 40 Billion

The Service-Infrastructure Cycle

- Worked for almost 40 years to produce the current Internet

- Until in 2005 …

complaints about "the inability [of the Internet] architecture to adapt to new pressures and requirements."

Ossification

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IE

Diversifying the Internet

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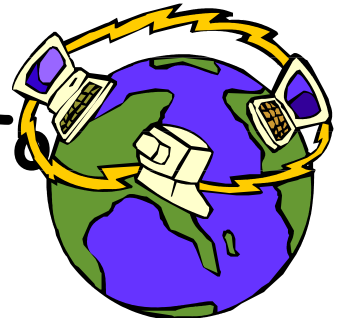
***Abstract*—The Internet has fallen victim to its own stunning success. The interplay of the end-to-end design of IP and the vested interests of competing stakeholders has led to its growing ossification. Alterations to the Internet architecture that address its fundamental deficiencies or enable new services have been restricted to incremental changes. The slow pace of this process stifles innovation and the adoption of disruptive technology. A recent call to arms advances a research agenda to confront this impasse through virtualization [1]. In addition to describing a virtual testbed for**

years, applications such as global video conferencing, telephony, and broadcast television have been touted as promising "next generation" applications. It was widely believed that this class of applications justified the tremendous investment in dark fiber and would spur the next round of vigorous innovation and deployment [6]. This promise remains largely unrealized due to the inability of the current architecture to support these applications, the inability to change the architecture, and the pro-

Ossification Explained

New Network Service or
Increased Scale

Establish/Upgrade Infrastructure To
Meet Scale or Provide Service



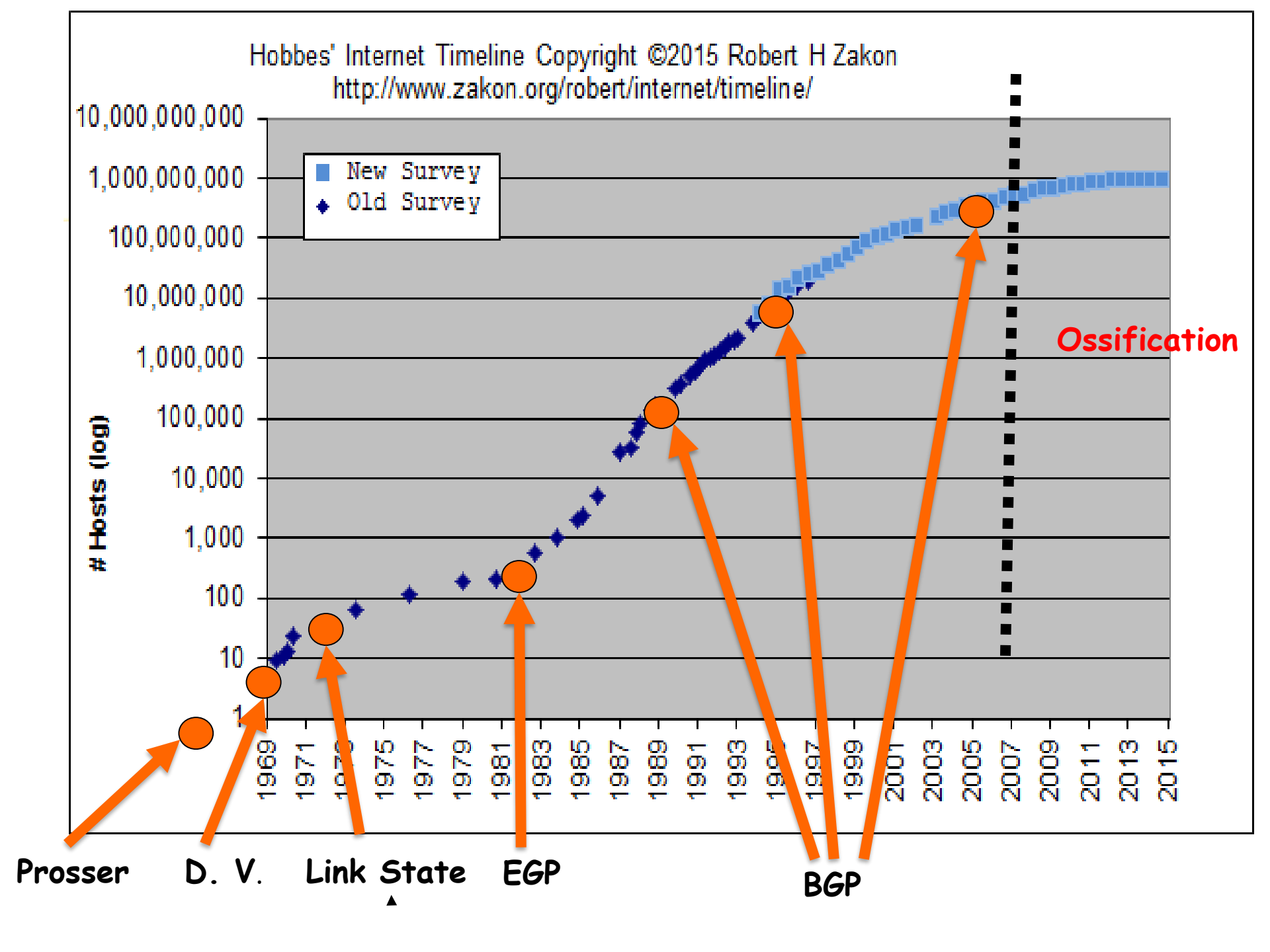
Ossification is when cycle gets stuck

But the Cycle is fundamental

- Case Studies
  - Unicast Routing
  - Multicast Routing

The Cycle in Action: Unicast Routing

- Unicast Routing: How to find and deploy network paths to single destination.
- As the Internet grew routing became more complicated


Hobbes' Internet Timeline Copyright ©2015 Robert H Zakon
http://www.zakon.org/robert/internet/timeline/
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Hosts (log)
New Survey
Old Survey
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1971
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1991
1993
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Ossification
Prosser
D. V.
Link State
EGP
BGP

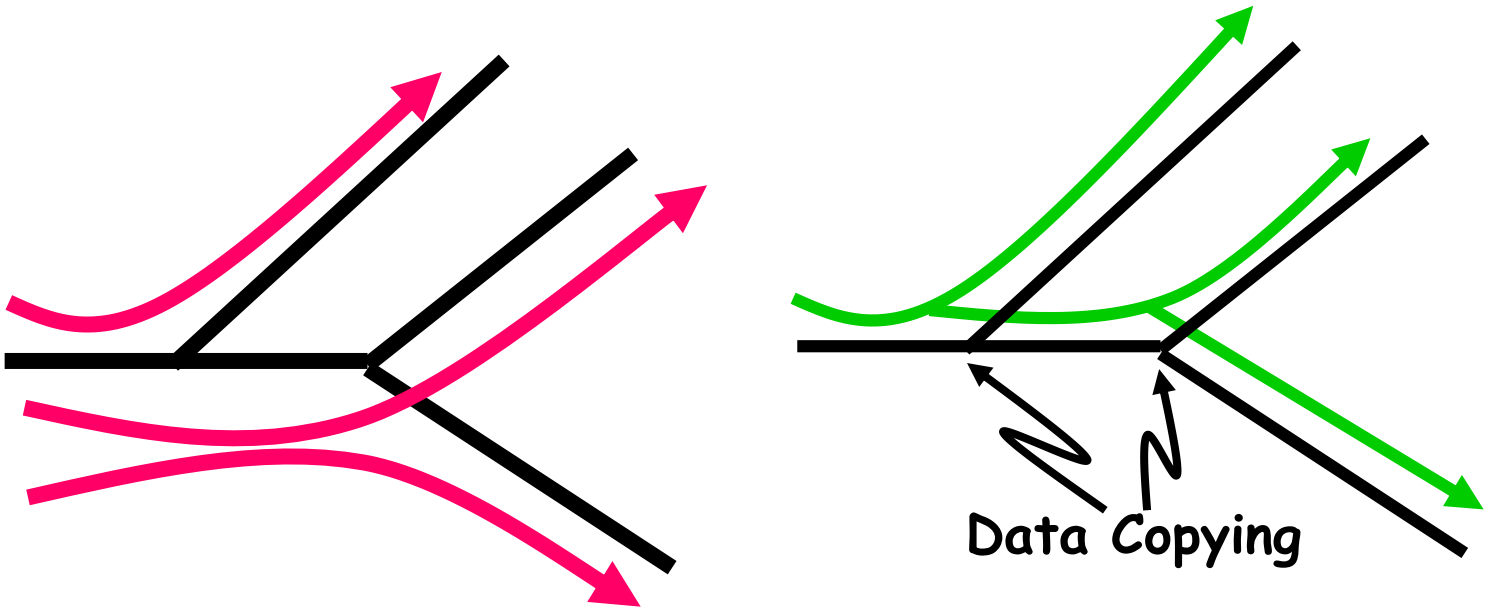
Cycle in evidence

- BGP was "built on experience gained with EGP as defined in RFC 904 and EGP usage in the NSFNET Backbone as described in RFC 1092 and RFC 1093 "

The Case of Multicast

- **Multicast**: is the act of sending a message to *multiple* receivers using a *single* local "transmit" operation.
- It is highly **Scalable**

Unicast and Multicast

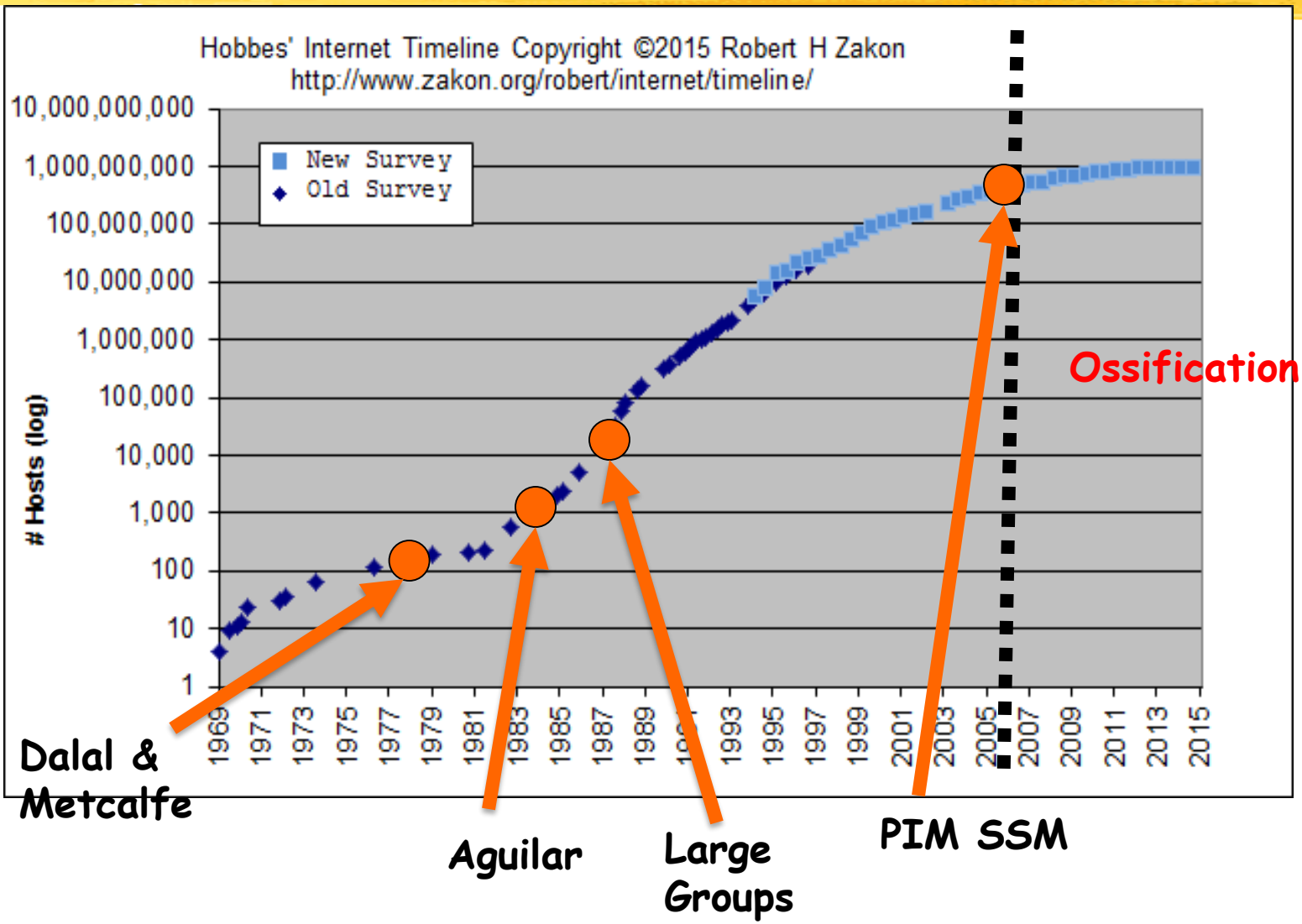


Multicast Saves

Multicast and Content Distribution

- Development anticipated the cycle and did not follow it.
- Not widely deployed today

Multicast anticipated the Cycle



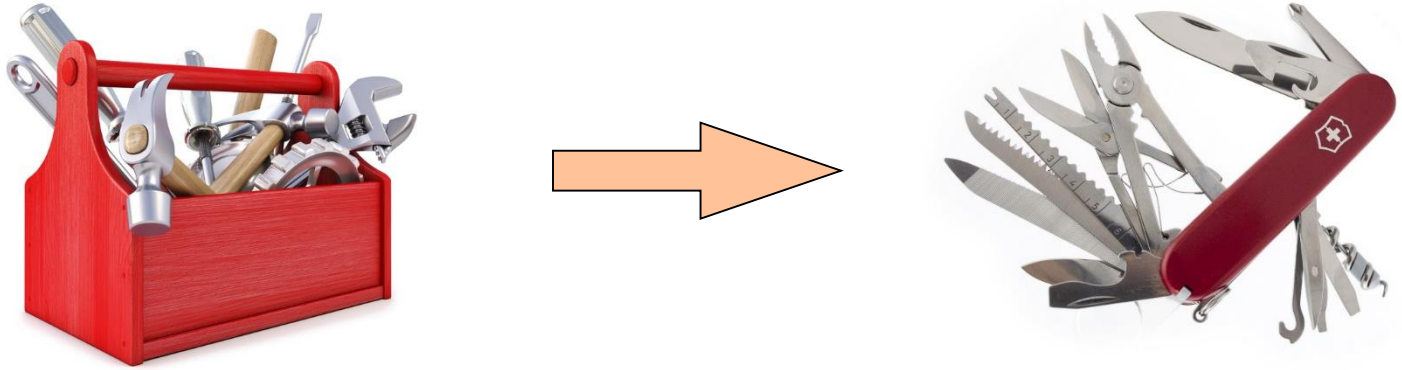
So …

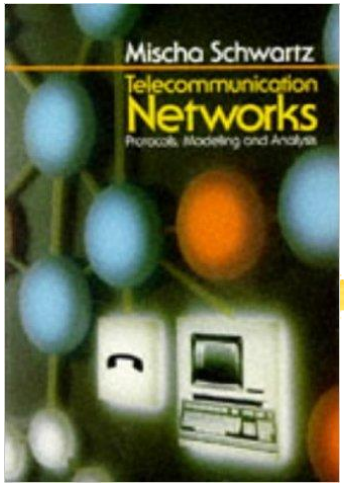
- Before Ossification, the Cycle operated to continuously enable novel applications and increased scale.
- Success when Cycle is followed
- Cycle is inoperable due to ossification

#2

e pluribus unum (From Many, One)

A single global infrastructure consumed all services





Then: Many Networks

- ca. 1987
- Tymnet (USA –public)
- GTE Telenet (USA- public)
- Transpac (France - public)
- Datapac (Canada – public)
- ARPANet (USA – research)
- BNA (Boroughs)
- SNA (IBM)
- DNA (Digital)

- A network for work
- A network for home (AOL)
- A network for experimentation

The One Network Revolution

- Having one network for everything is not an obvious choice.
- *Under-appreciated networking milestone*
- Was driven by
  - Connectivity as the main goal
  - Need for Scalability
  - Economies of scale

OneNet effect on networking research

- Stifled Innovation: Ideas rejected if
  - Not deployable on Internet
  - Not Scalable
- Difficult to validate without disrupting infrastructure
  - Eternal quest for experimentation environments
  - (MBone, QBone, 6Bone, PlanetLab, GENI)

OneNet Contributed to Ossification

- By Definition: ManyNets cannot be ossified

So …

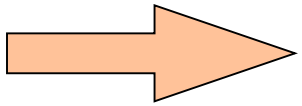
If we have OneNet and it is ossified,

are we done yet?

#3

ex uno pluria
(From One, Many)

How the OneNet is fragmenting



"It is tough to make predictions, especially about the future."
Yogi Berra

The Service-Infrastructure Cycle

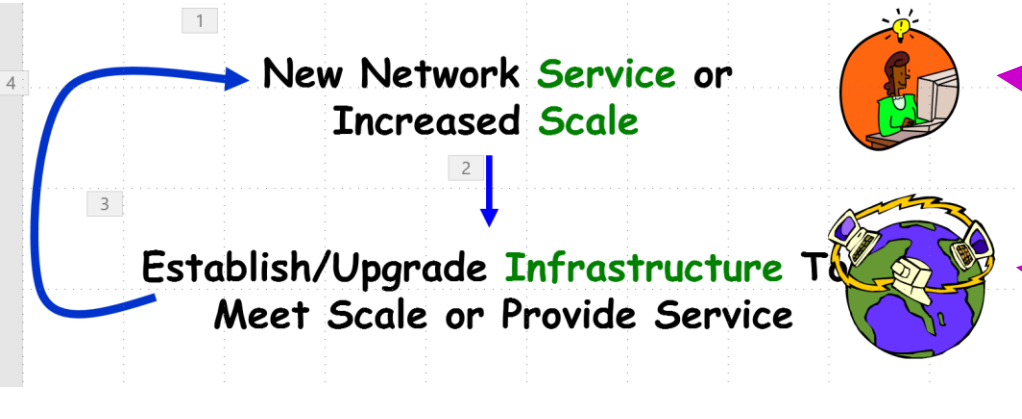
New Network Service or
Increased Scale

Establish/Upgrade Infrastructure To
Meet Scale or Provide Service

The Unstoppable Force

- The demands on the network continue to evolve
  - Increased scale
  - Content Providers reign supreme
  - Application-specific requirements, low latency, prioritization

What Happens When …



Unstoppable Force

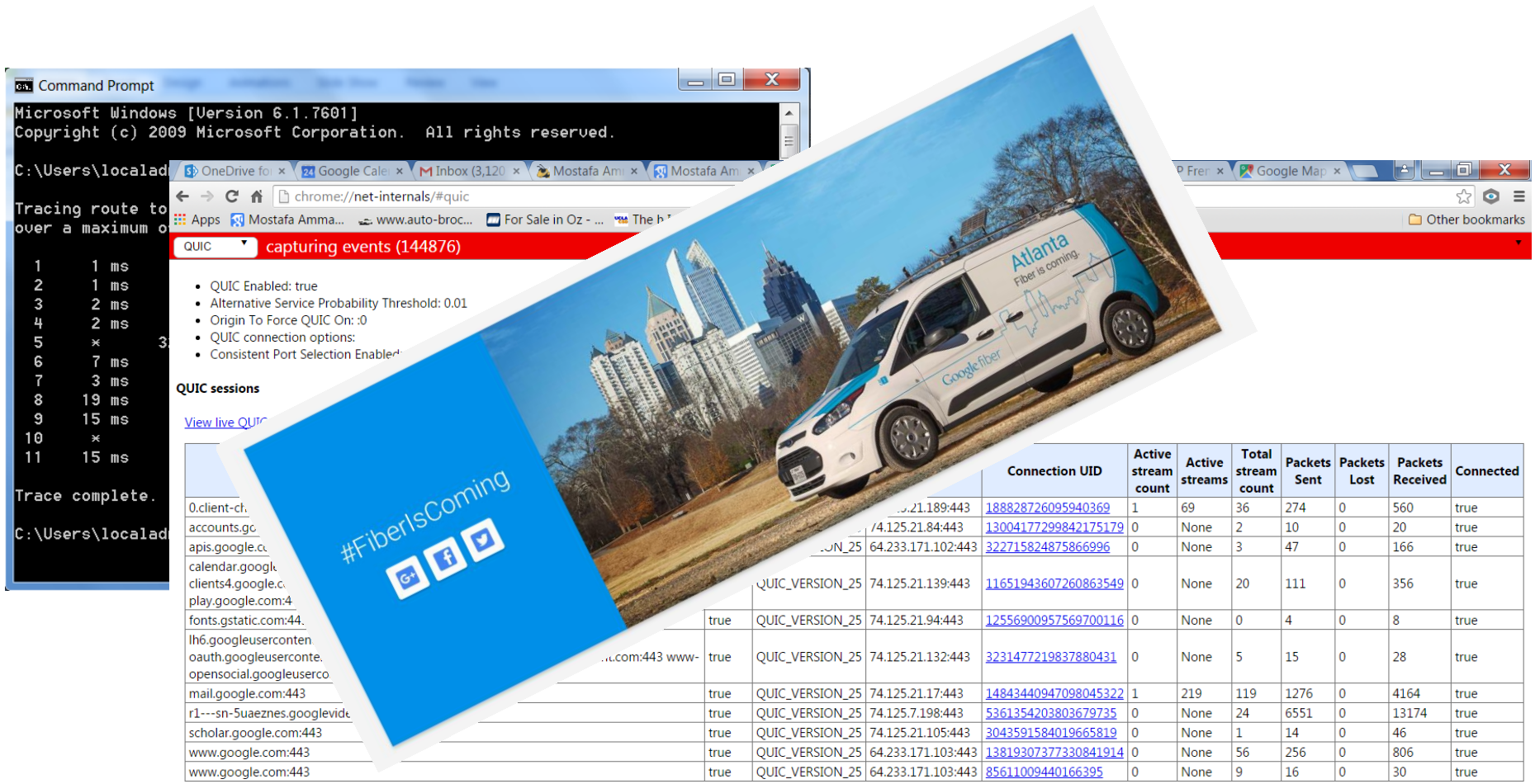
Ossified Immovable Object

The Fragmentation of the Internet

- The Ossified Internet is yielding

- Are we seeing the return of ManyNets?
  - Let's look at the early signs

Is Google using the Internet?

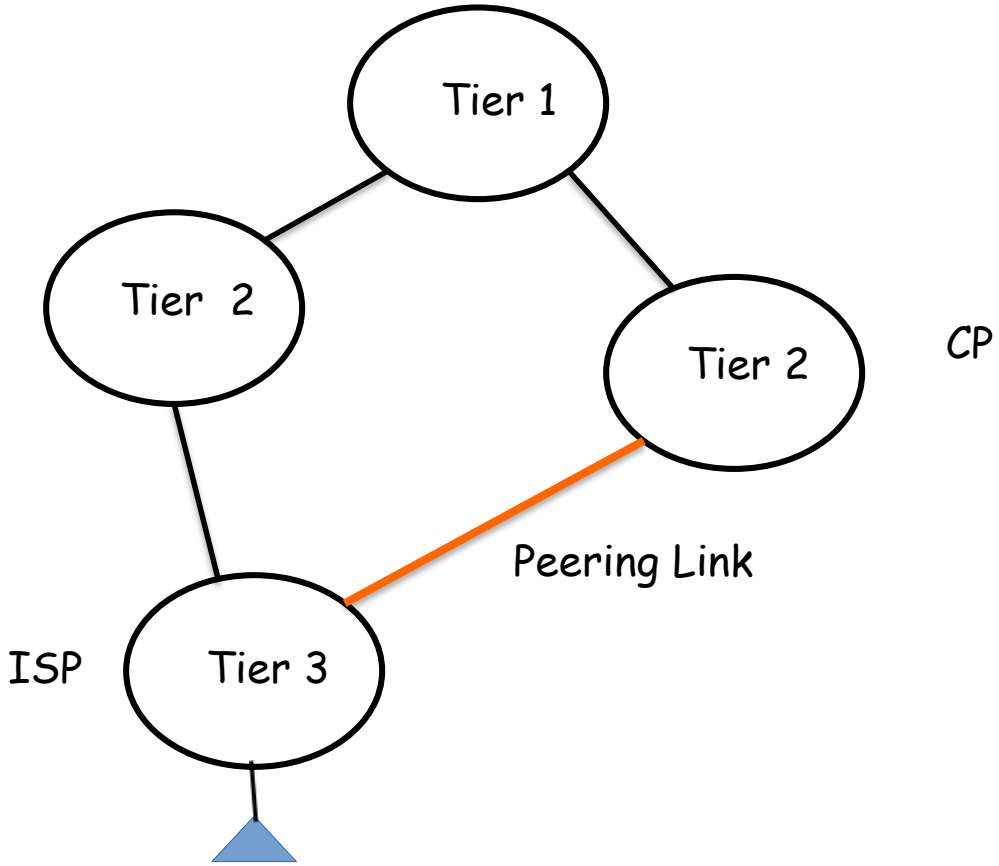


					Connection UID	Active stream count	Active streams	Total stream count	Packets Sent	Packets Lost	Packets Received	Connected
0.client-ch				.21.189:443	188828726095940369	1	69	36	274	0	560	true
accounts.gc				/4.125.21.84:443	13004177299842175179	0	None	2	10	0	20	true
apis.google.c				ON_25	64.233.171.102:443	3227158248758669 96	0	None	3	47	0	166	true
calendar.googl clients4.google.c play.google.com:4				QUIC_VERSION_25	74.125.21.139:443	11651943607260863549	0	None	20	111	0	356	true
fonts.gstatic.com:44			true	QUIC_VERSION_25	74.125.21.94:443	12556900957569700116	0	None	0	4	0	8	true
lh6.googleuserconten oauth.googleuserconte opensocial.googleuserco			true	QUIC_VERSION_25	74.125.21.132:443	3231477219837880431	0	None	5	15	0	28	true
mail.google.com:443			true	QUIC_VERSION_25	74.125.21.17:443	14843440947098045322	1	219	119	1276	0	4164	true
r1---sn-5uaeznes.googlevide			true	QUIC_VERSION_25	74.125.7.198:443	5361354203803679735	0	None	24	6551	0	13174	true
scholar.google.com:443			true	QUIC_VERSION_25	74.125.21.105:443	3043591584019665819	0	None	1	14	0	46	true
www.google.com:443			true	QUIC_VERSION_25	64.233.171.103:443	13819307377330841914	0	None	56	256	0	806	true
www.google.com:443			true	QUIC_VERSION_25	64.233.171.103:443	85611009440166395	0	None	9	16	0	30	true

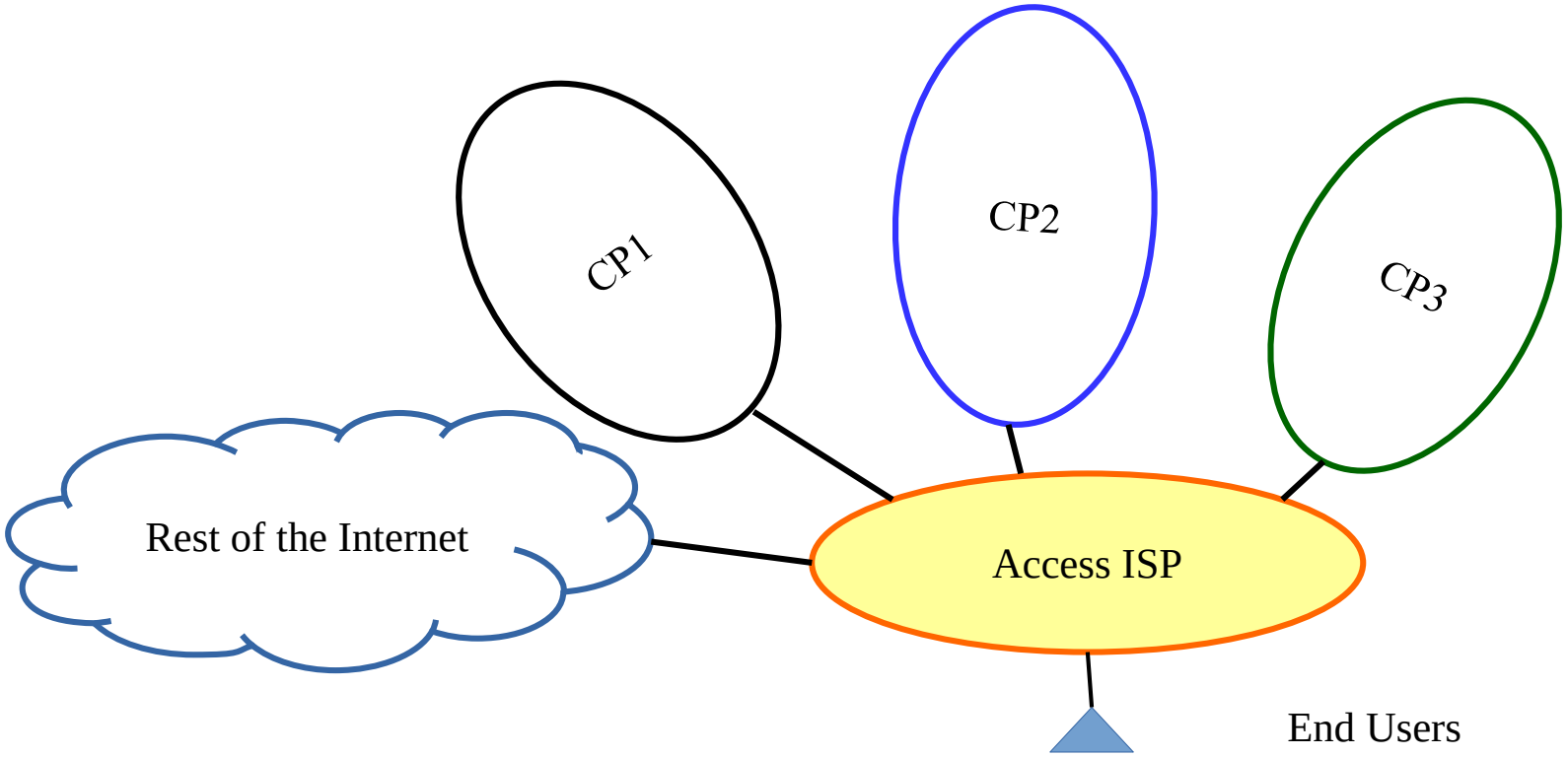
The Content-Delivery Network

- Shift from Connectivity to Content
- Content Provider
  - Needs to maximize quality of experience
  - Reduce reliance on intermediaries
  - Control interaction

Internet Multi-Domain Structure



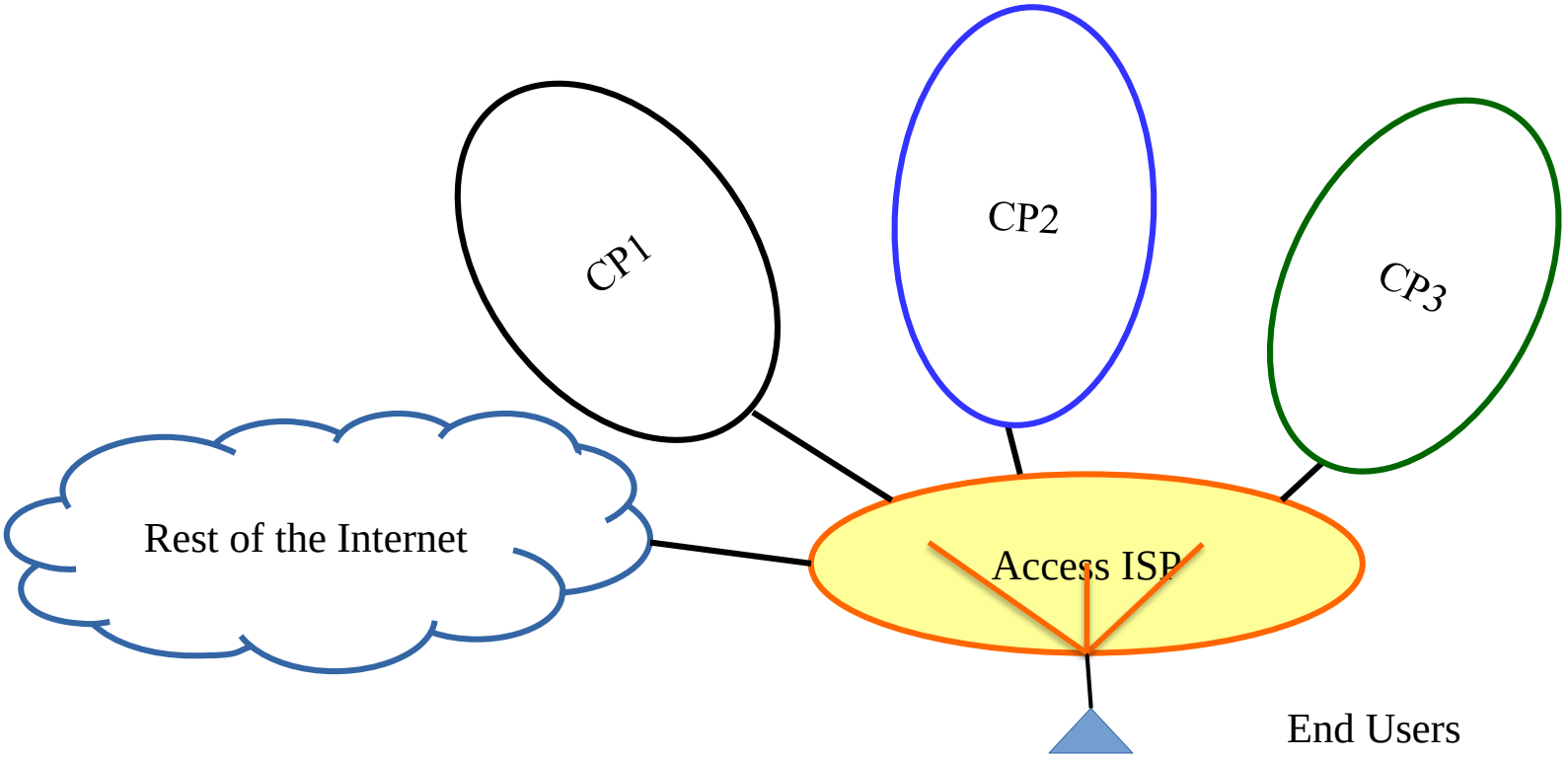
The Flattening of the Internet



CP Extensions in Access Networks

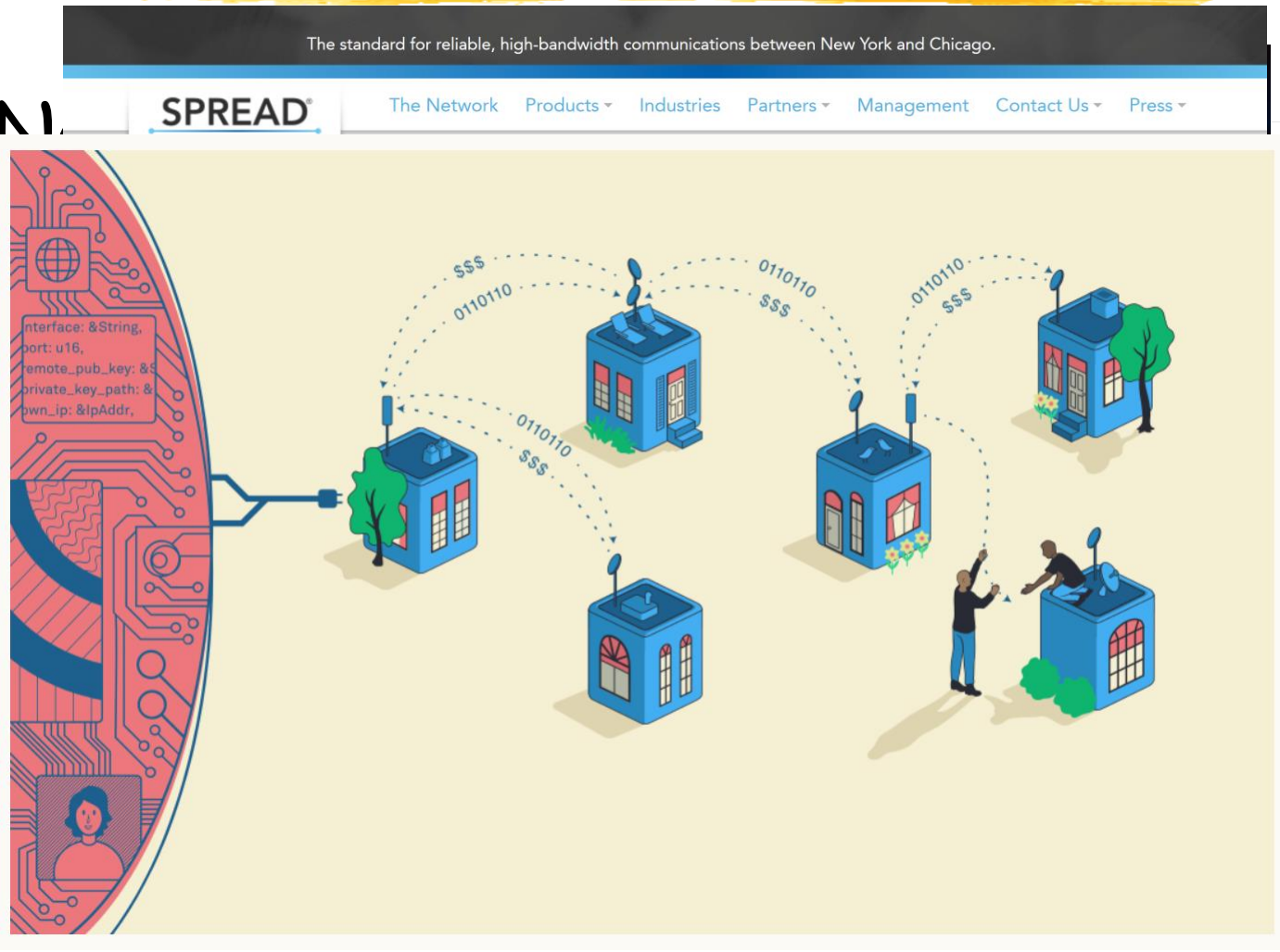
- Embedded Content Provider Appliances
- ISP Interfaces to allow CP Coordination and Collaboration

"Zero-Hop" Networks



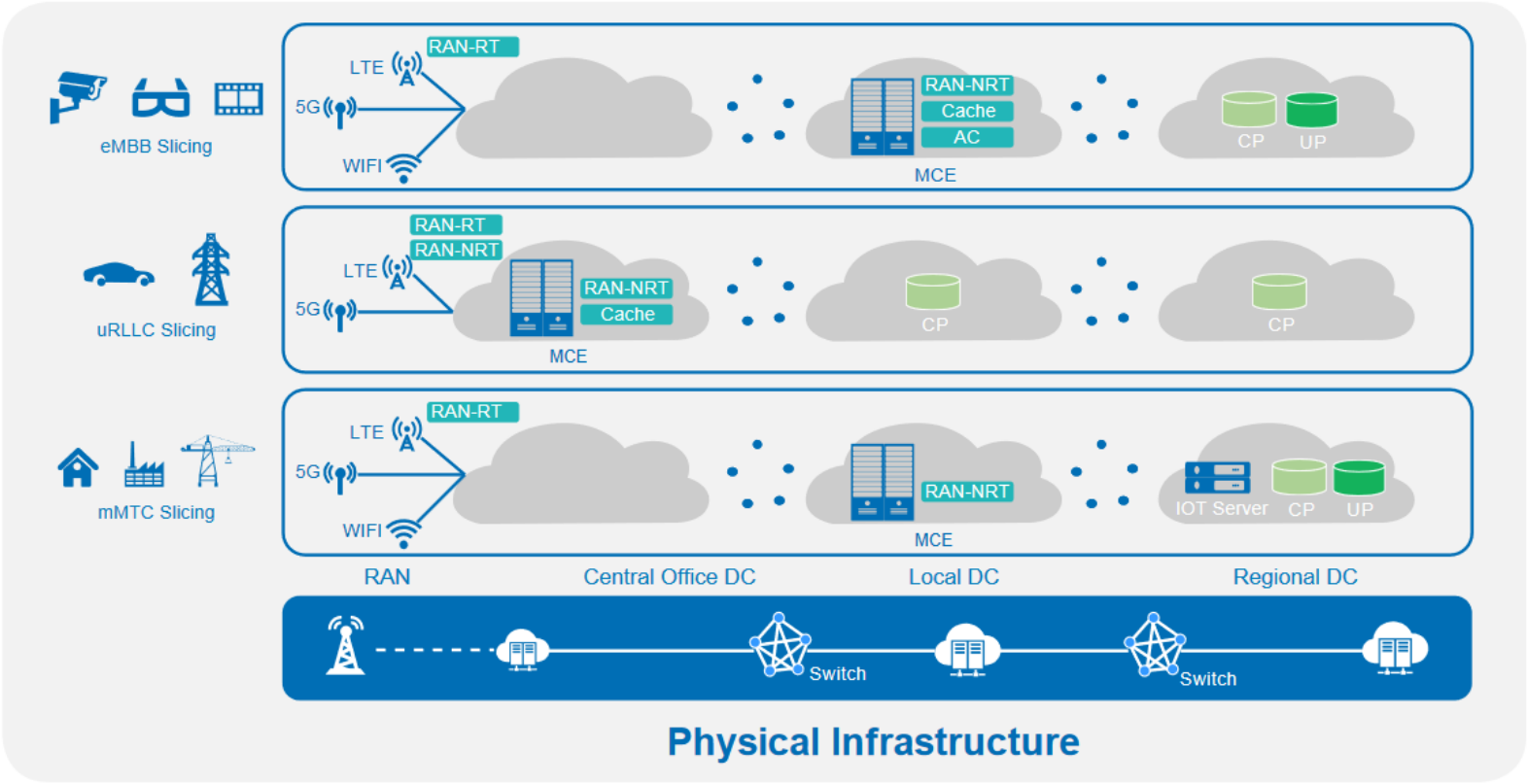
Dedicated (Bypass) networks

- SpreadN
- SIGFO
- Haste
- FirstNe
- Althea



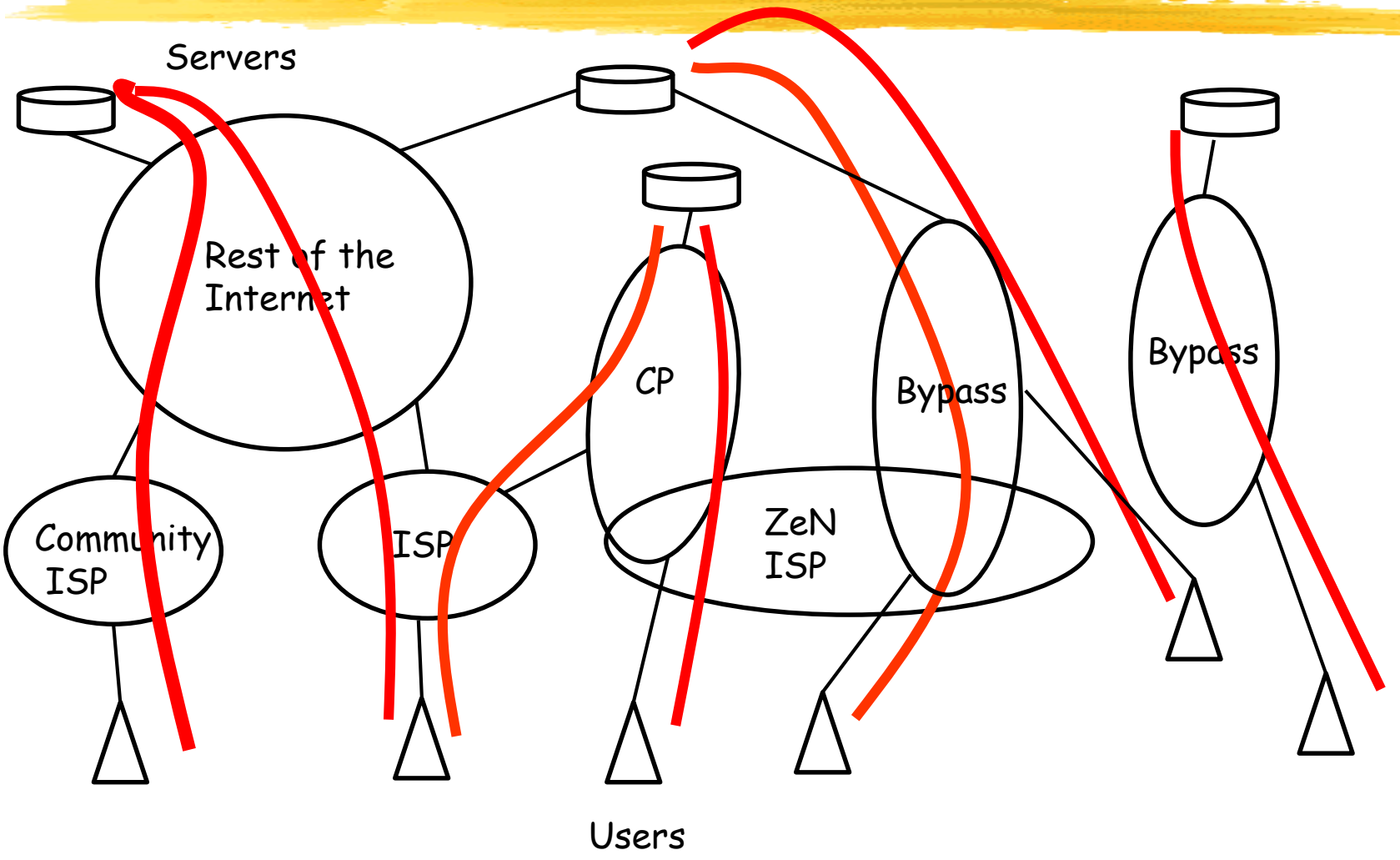
5G Slicing

- 5G = Future Mobile Broadband and Beyond



http://www.huawei.com/minisite/hwmbbf16/insights/5G-Nework-Architecture-Whitepaper-en.pdf

What does the ManyNets world look like?



So What?

- Fragmentation is a reality let's embrace it.
  - Attempts to fight ossification without fragmentation failed (see "Clean Slate")
  - Fragmentation opens up the research agenda.
- Loss of OneNet advantages:
  - Economy of scale
  - Low barrier to entry

Epilogue: The Exciting Future of Networking

- Scale and new services will continue to drive evolution
- Ossification will be a thing of the past
  - The ManyNets world will be a fertile ground for innovation
  - Network Programmability will add to its responsiveness

Takeaways

- A fundamental iterative process governs successful evolution in deployed infrastructure.
- There is nothing fundamental about a single global network delivering all services.
- New ManyNets world is upon us:
  - flexibility bodes well for the future for networking research

Thank You!