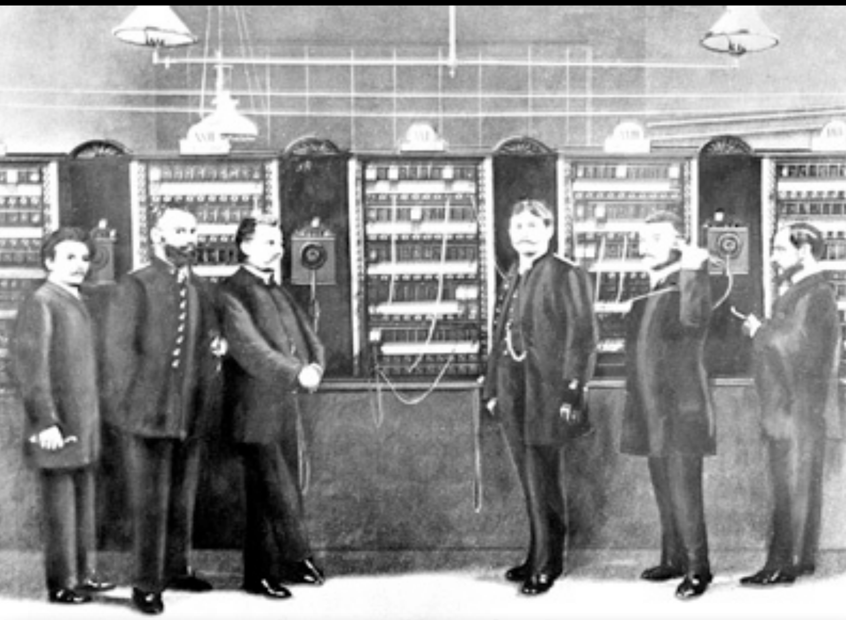
Beyond Wires – Moving Communications out of the 19th Century

Van Jacobson, PARC

1 December 2011
Global Future Internet Summit
Seoul, Korea



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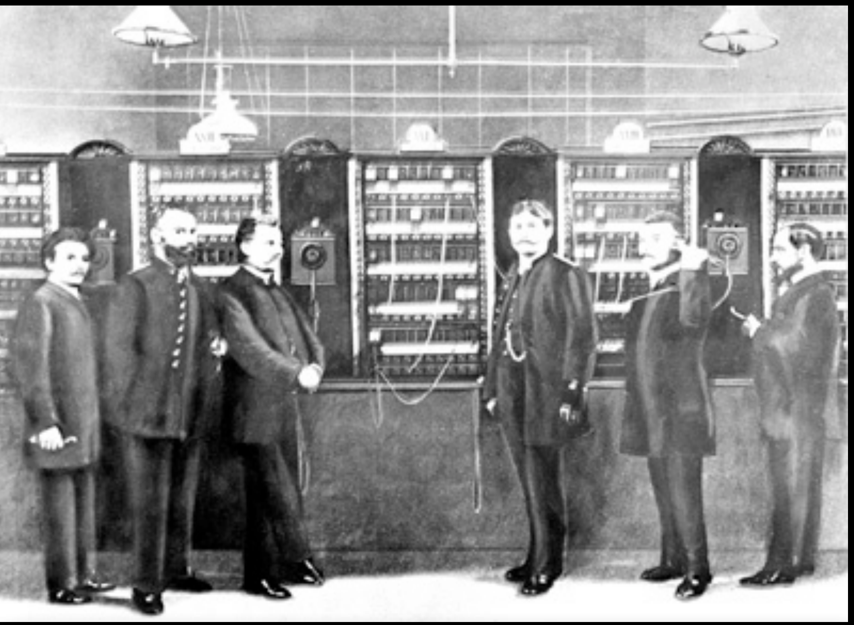

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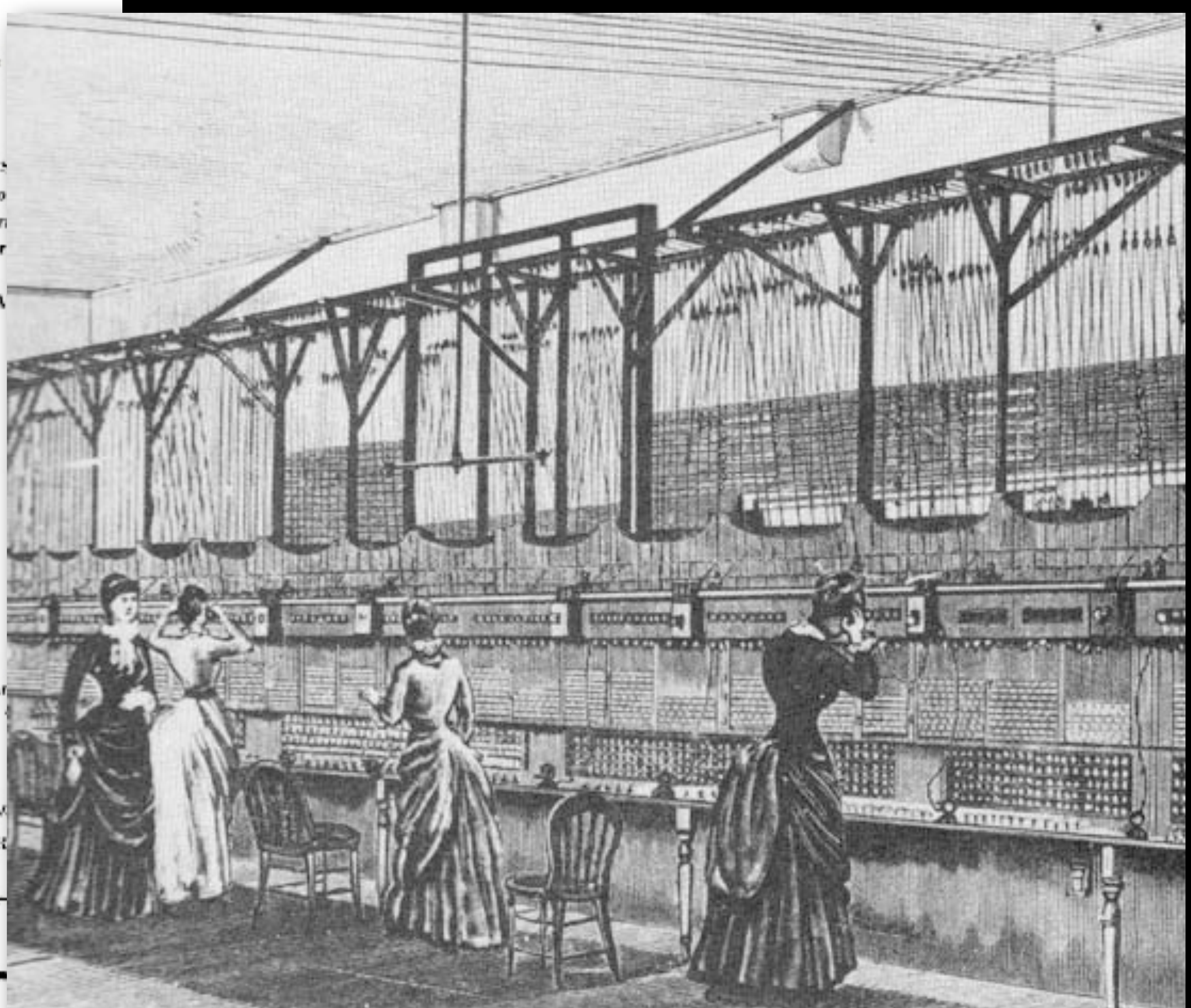

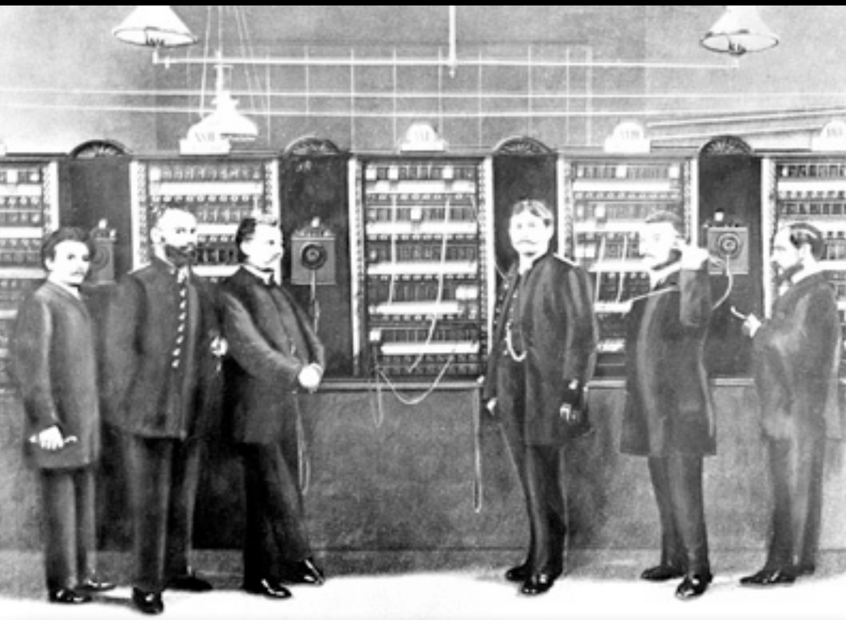

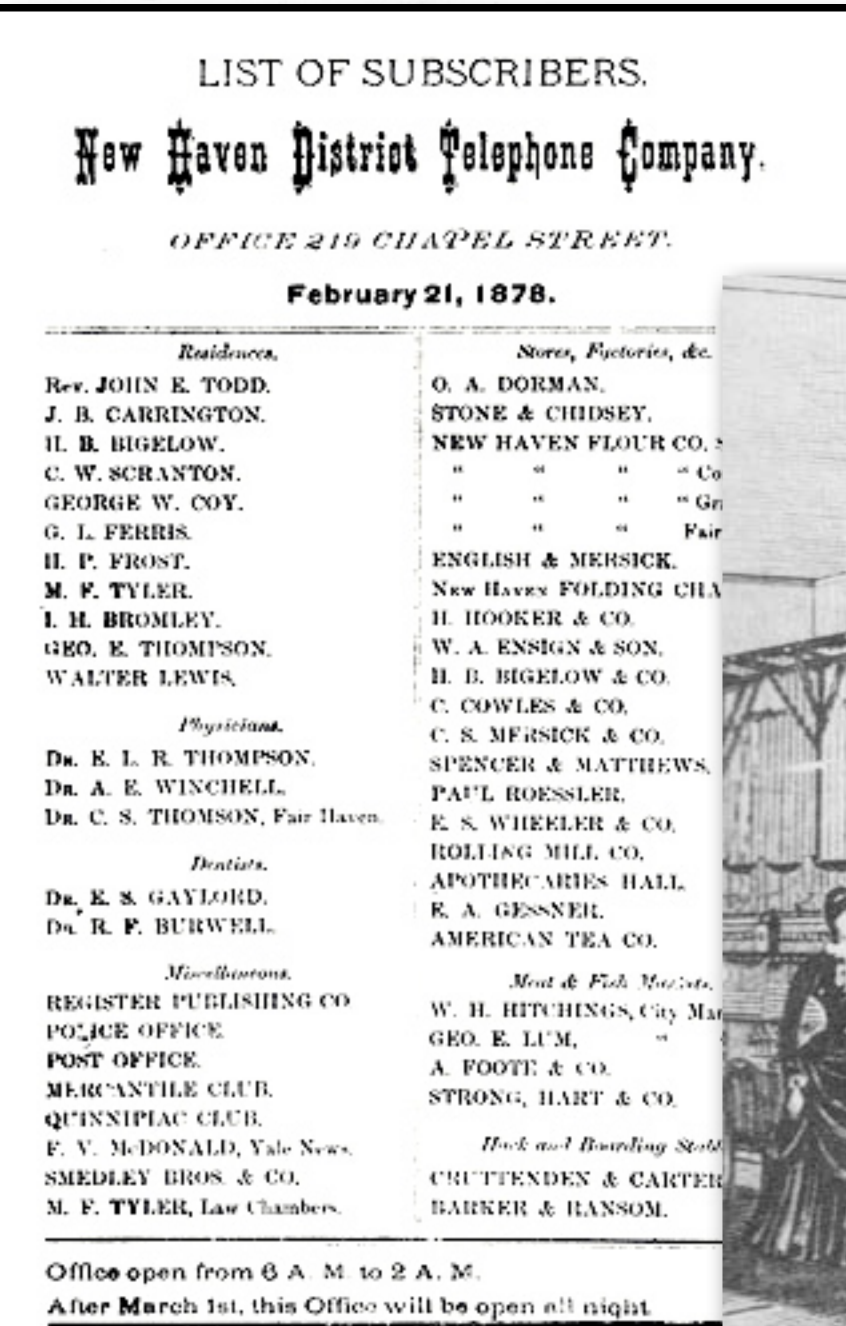

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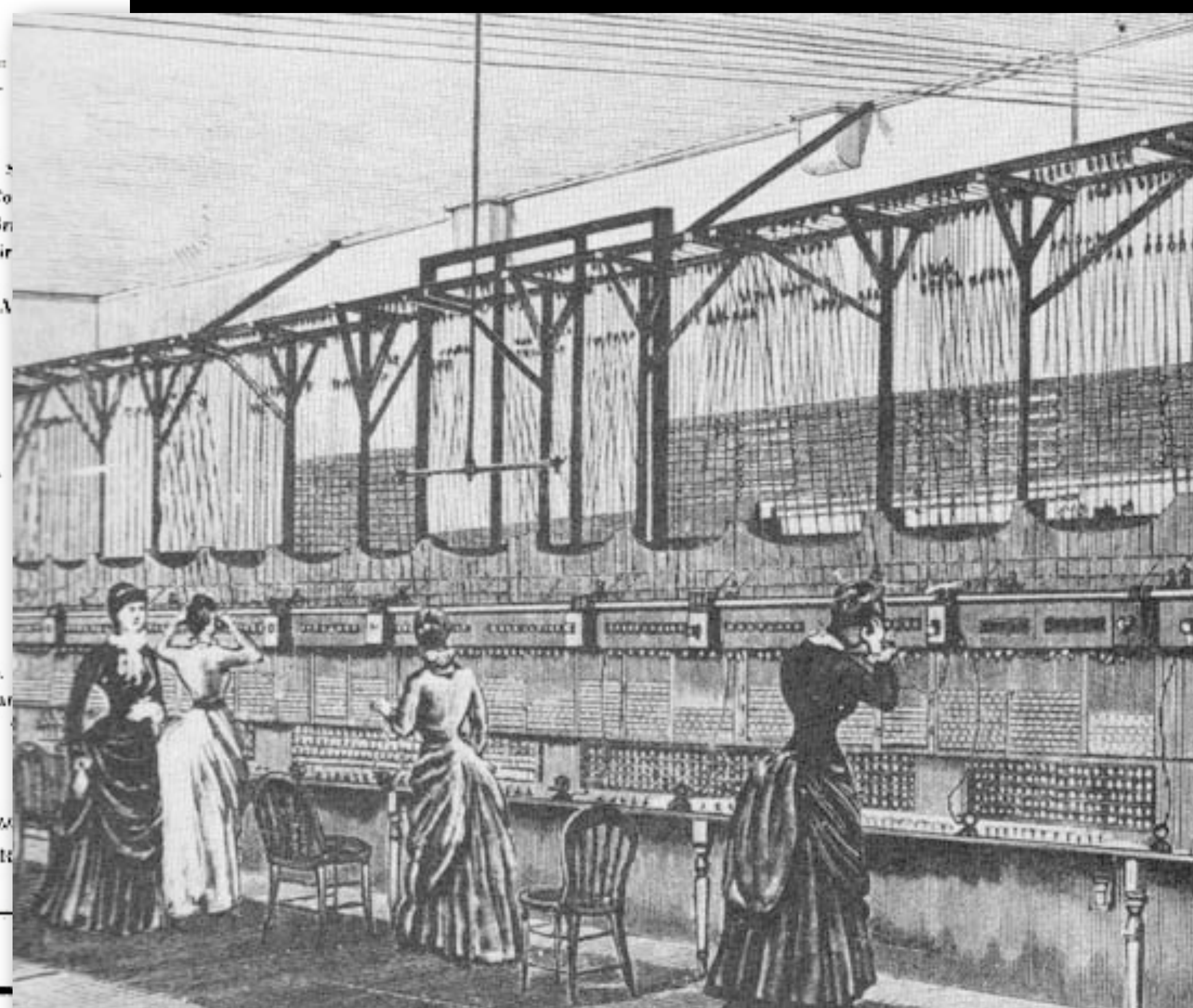

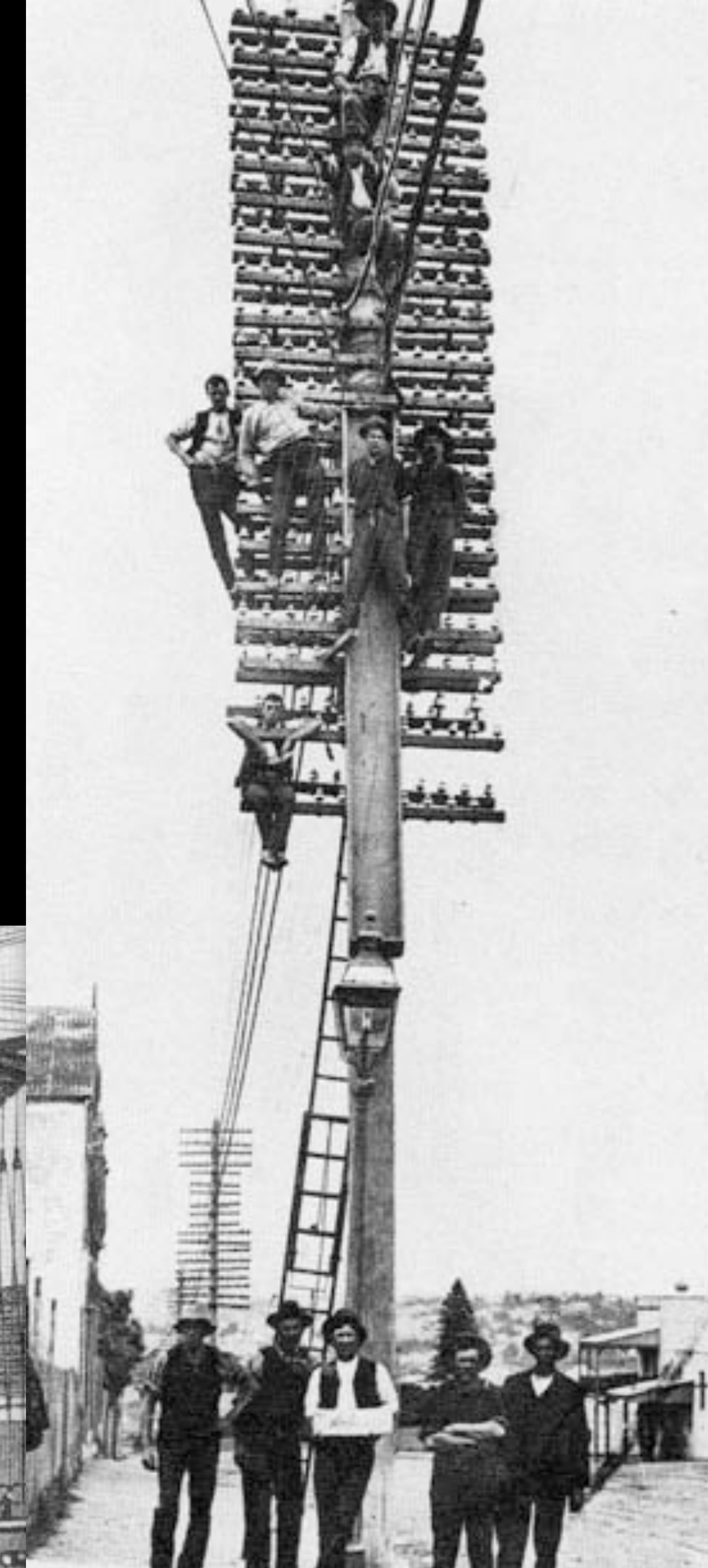

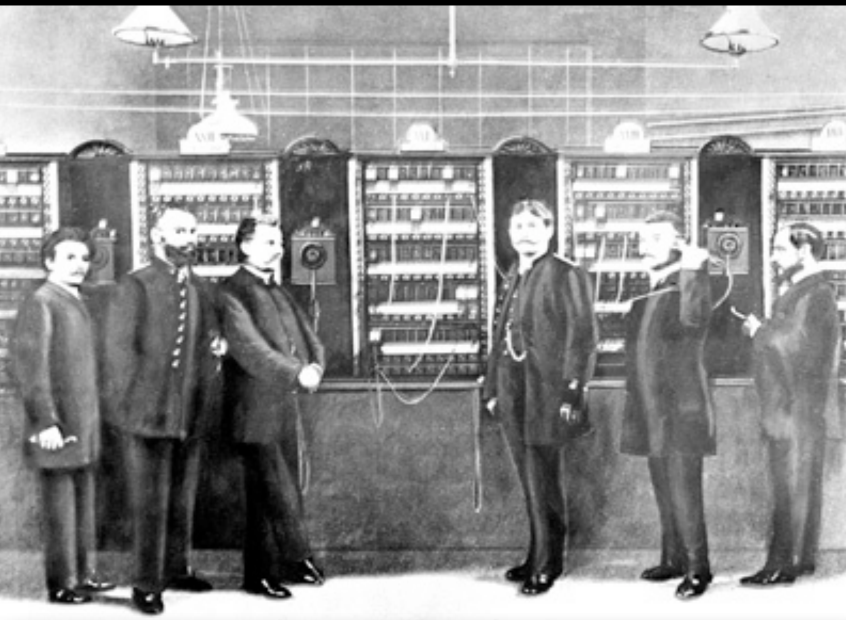

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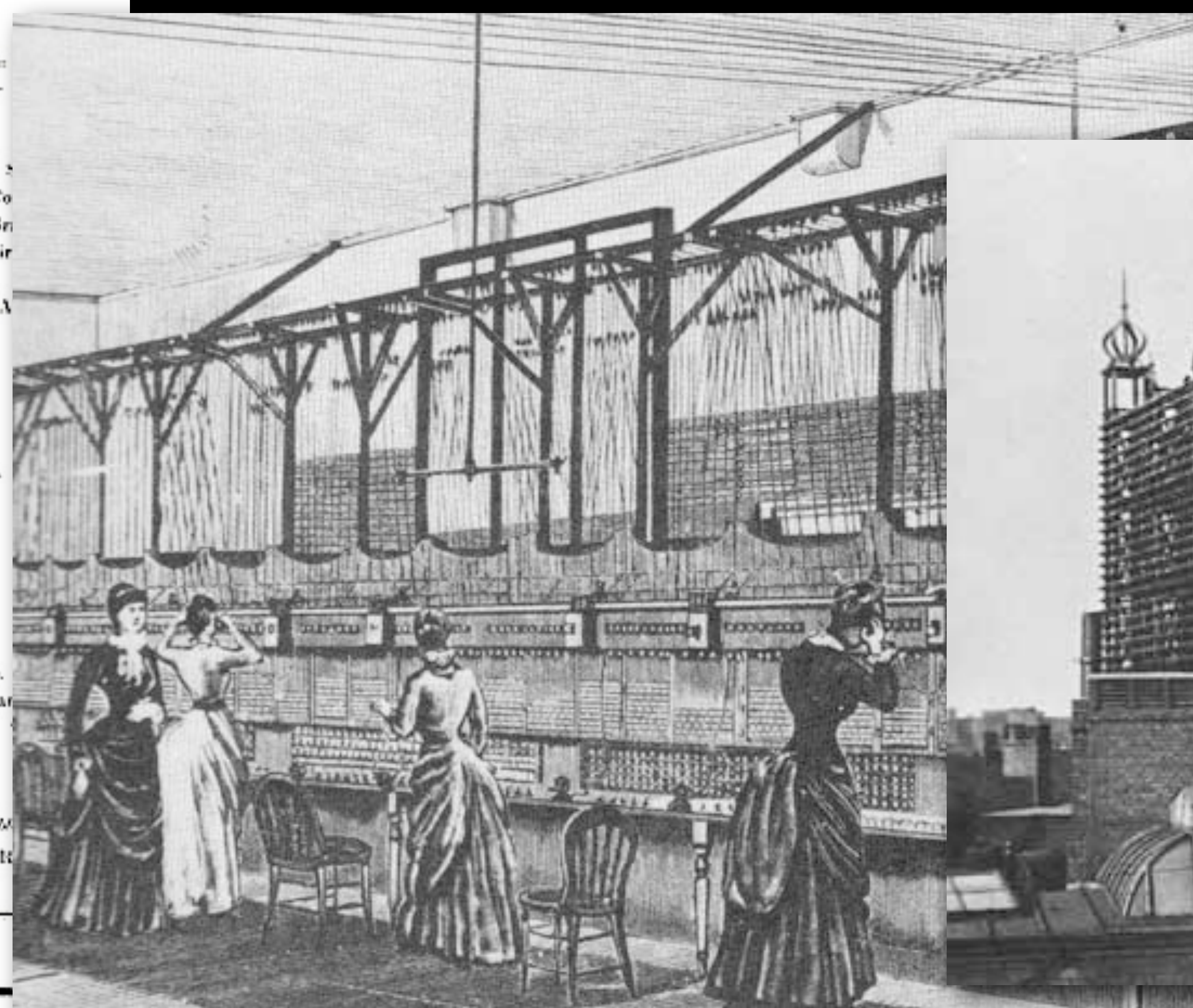

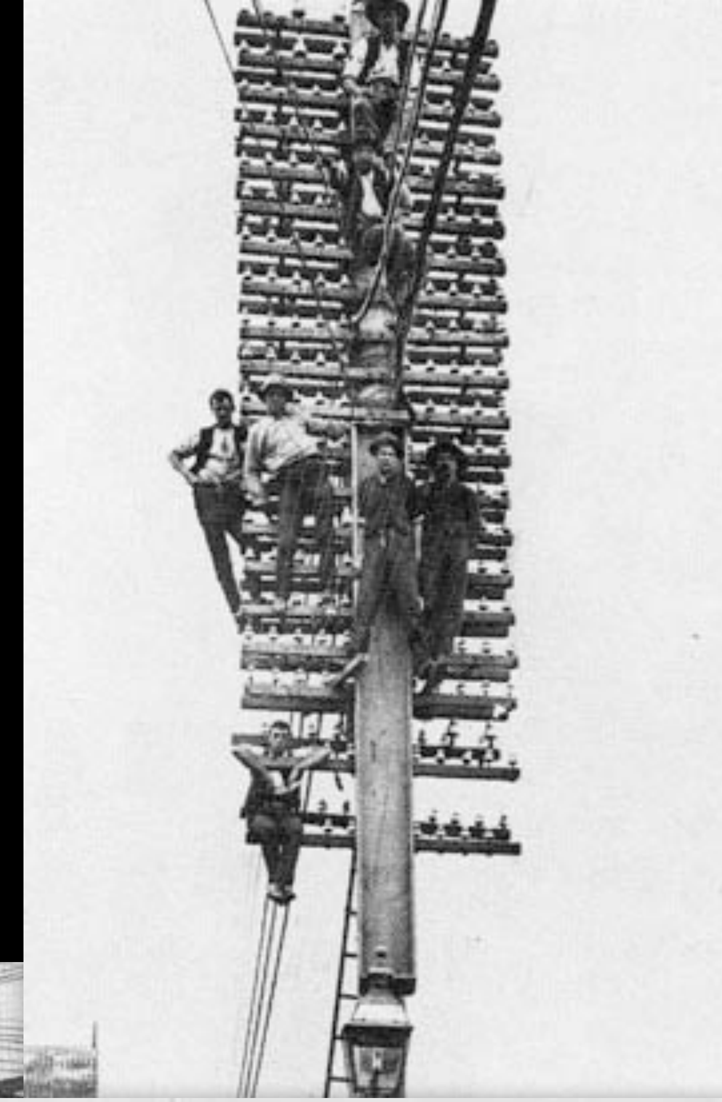

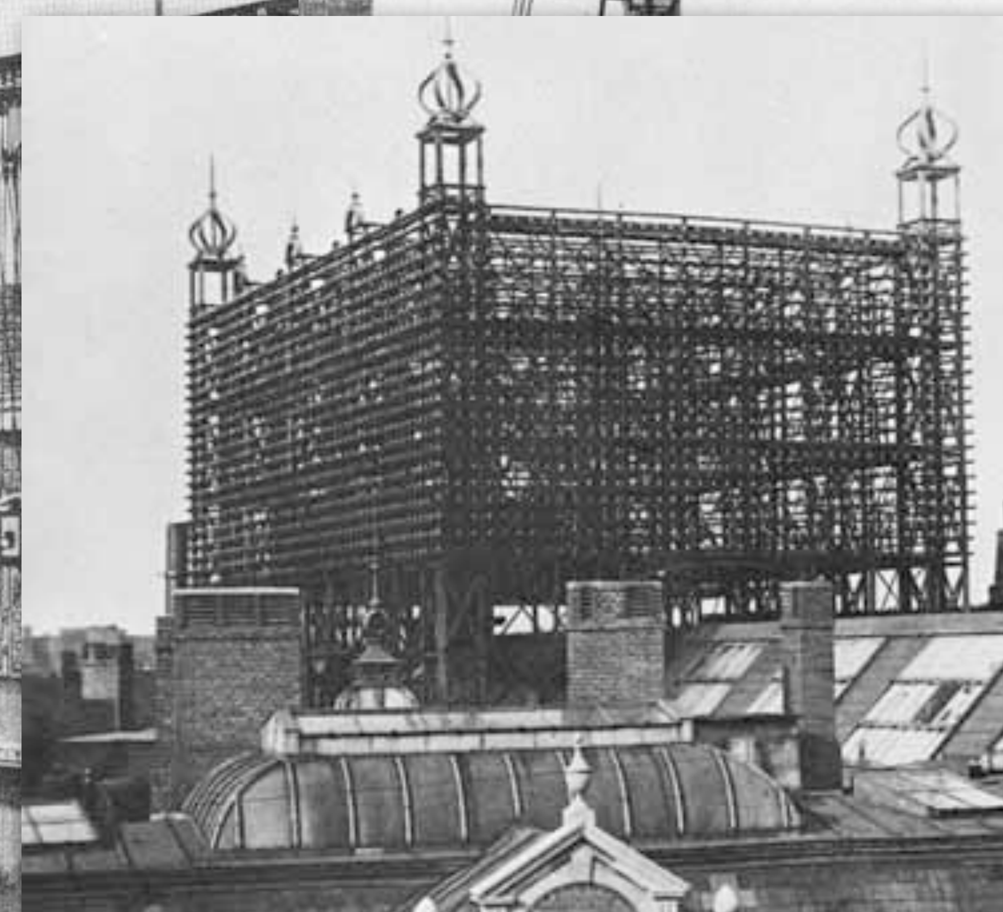

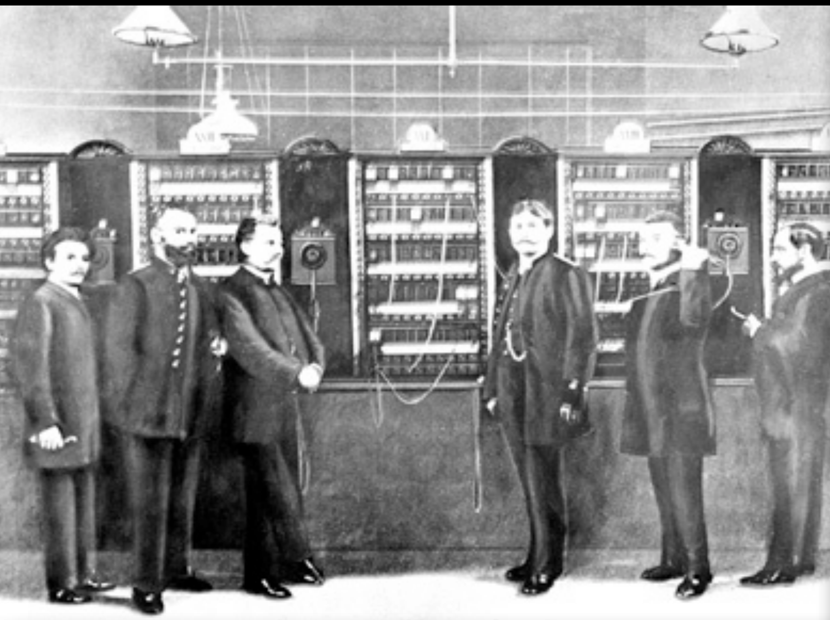

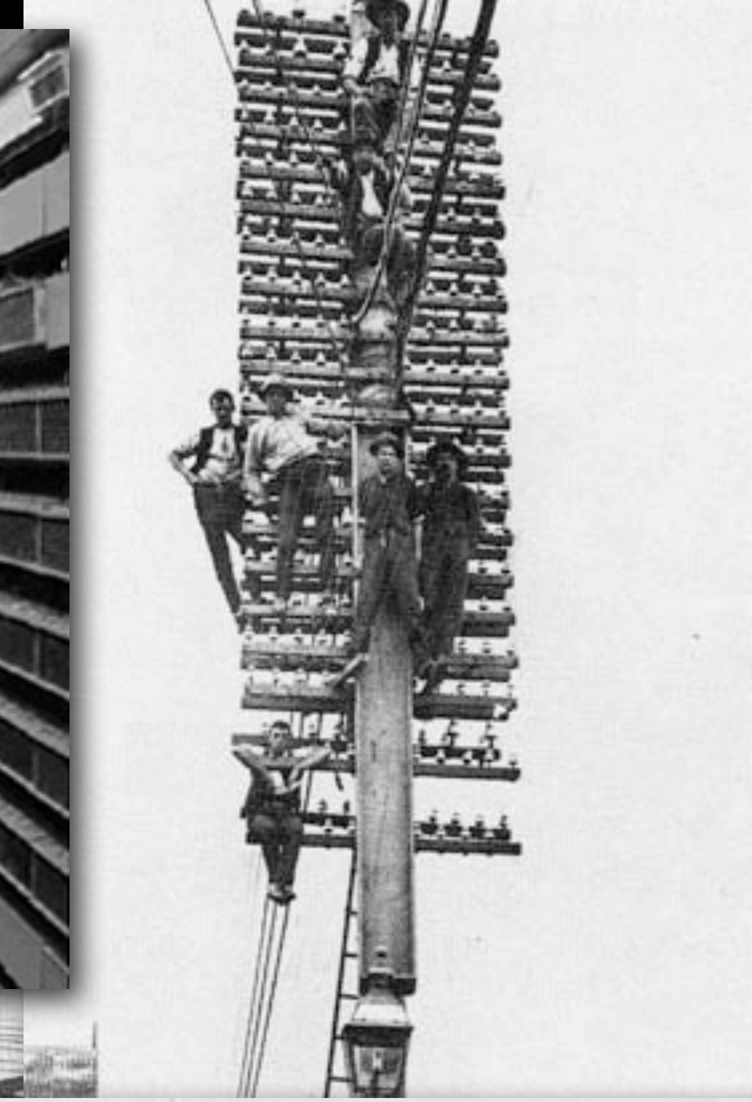

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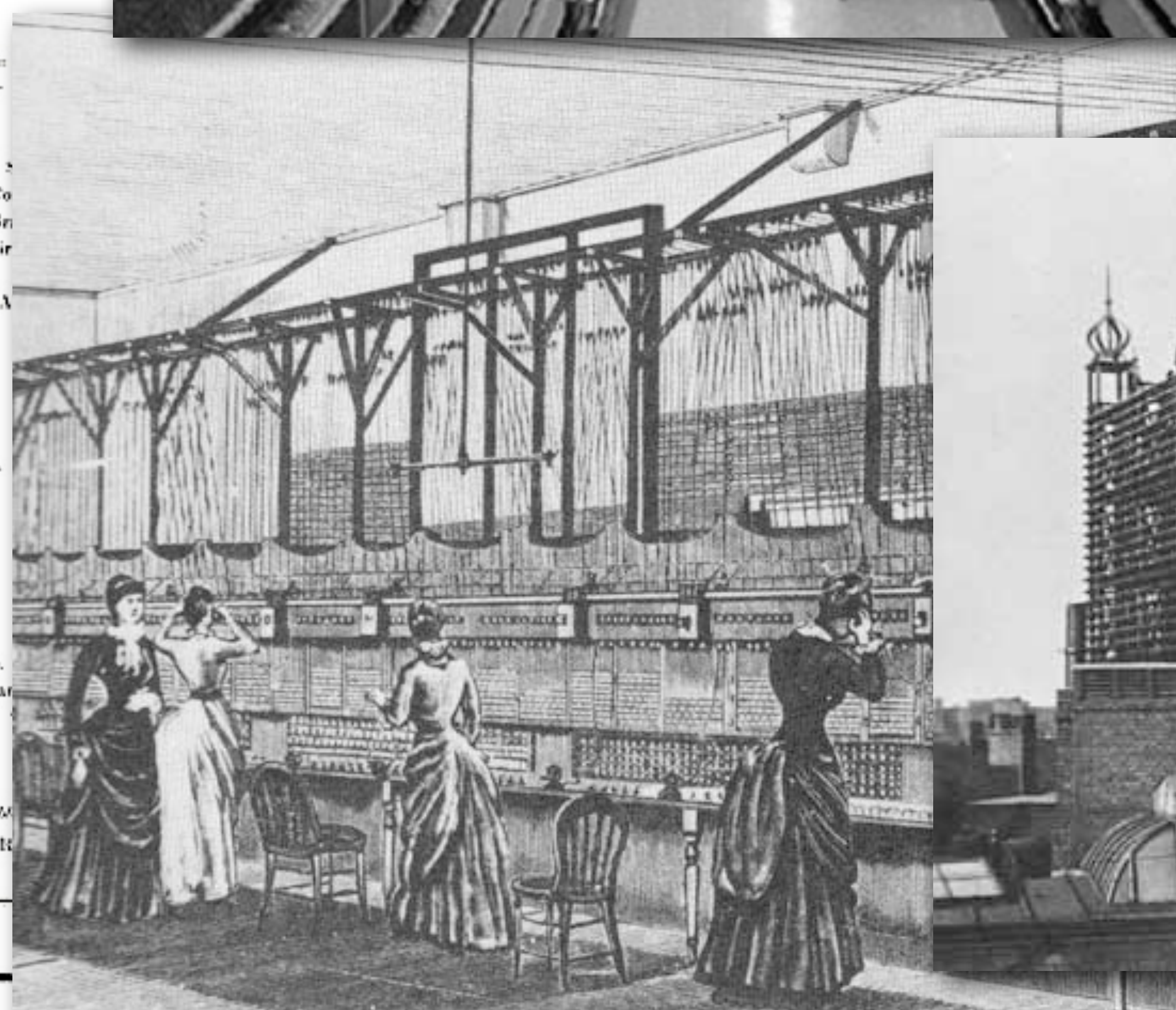

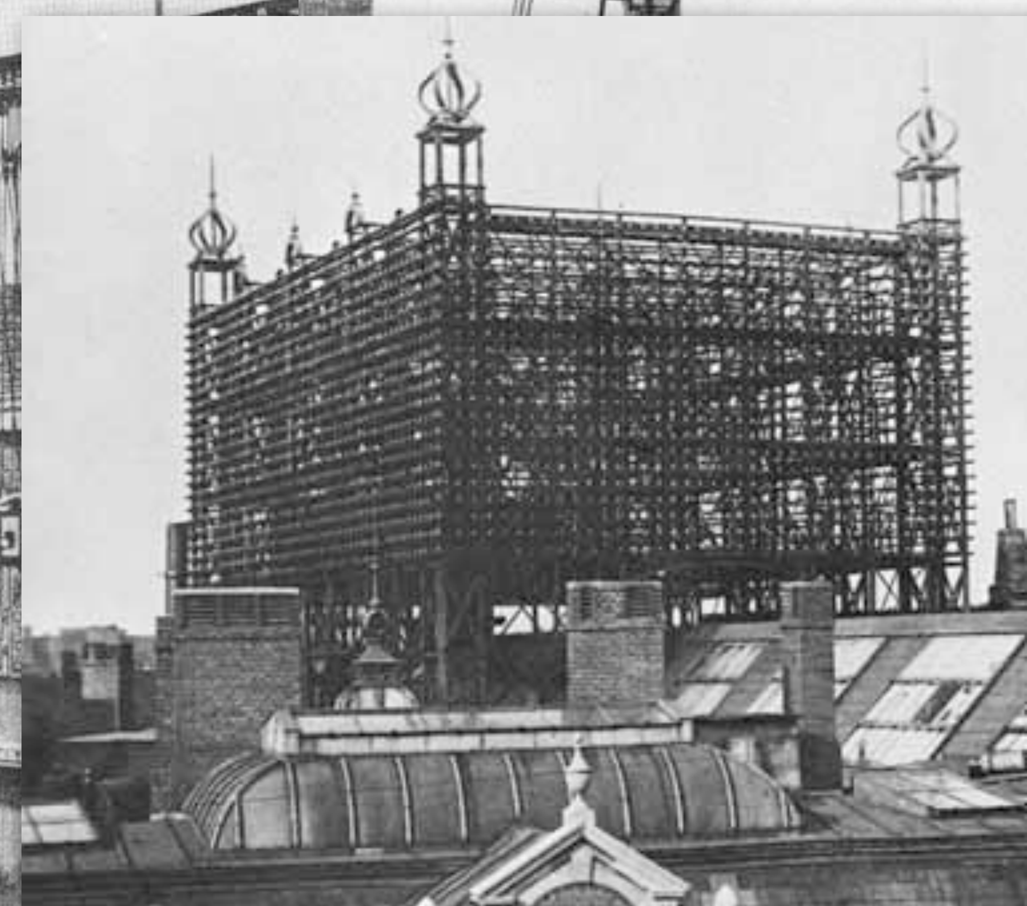

On Distributed Communications Networks

PAUL BARAN, SENIOR MEMBER, IEEE

Summary—This paper[1] briefly reviews the distributed communication network concept in which each station is connected to all adjacent stations rather than to a few switching points, as in a centralized system. The payoff for a distributed configuration in terms of survivability in the cases of enemy attack directed against nodes, links or combinations of nodes and links is demonstrated.

A comparison is made between diversity of assignment and perfect switching in distributed networks, and the feasibility of using low-cost unreliable communication links, even links so unreliable as to be unusable in present type networks, to form highly reliable networks is discussed.

The requirements for a future all-digital data distributed network which provides common user service for a wide range of users having different requirements is considered. The use of a standard format message block permits building relatively simple switching mechanisms using an adaptive store-and-forward routing policy to handle all forms of digital data including digital voice. This network rapidly responds to changes in the network status. Recent history of measured network traffic is used to modify path selection. Simulation results are shown to indicate that highly efficient routing can be performed by local control without the necessity for any central, and therefore vulnerable, control point.

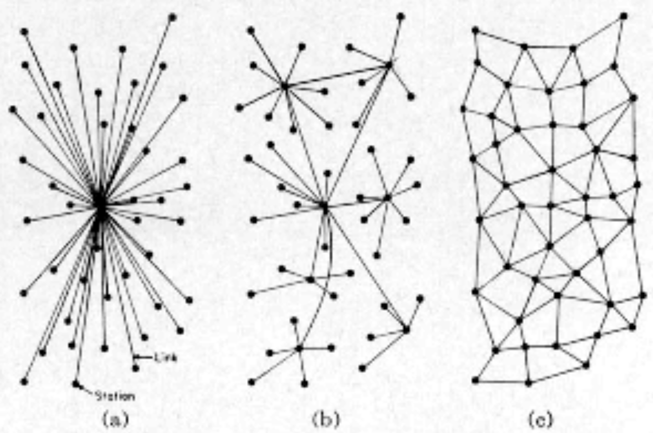

Fig. 1—(a) Centralized. (b) Decentralized. (c) Distributed networks.

Introduction

LET US CONSIDER the synthesis of a communication network which will allow several hundred major communications stations to talk with one another after an enemy attack. As a criterion of survivability we elect to use the percentage of stations both surviving the physical attack and remaining in electrical connection with the largest single group of surviving stations. This criterion is chosen as a conservative measure of the ability of the surviving stations to operate together as a coherent entity after the attack. This means that small groups of stations isolated from the single largest group are considered to be ineffective.

Although one can draw a wide variety of networks, they all factor into two components: centralized (or star) and distributed (or grid or mesh). (See types (a) and (c), respectively, in Fig. 1.)

The centralized network is obviously vulnerable as destruction of a single central node destroys communication between the end stations. In practice, a mixture of star and mesh components is used to form communications networks. For example, type (b) in Fig. 1 shows the hierarchical structure of a set of stars connected in the form of a larger star with an additional link forming a loop. Such a network is sometimes called a "decentralized" network, because complete reliance upon a single point is not always required.

Examination of a Distributed Network

Since destruction of a small number of nodes in a decentralized network can destroy communications, the properties, problems, and hopes of building "distributed" communications networks are of paramount interest.

The term "redundancy level" is used as a measure of connectivity, as defined in Fig. 2. A minimum span network, one formed with the smallest number of links possible, is chosen as a reference point and is called "a network of redundancy level one." If two times as many links are used in a gridded network than in a minimum span network, the network is said to have a redundancy level of two. Fig. 2 defines connectivity of levels 1, $1\frac{1}{2}$, 2, 3, 4, 6 and 8. Redundancy level is equivalent to link-to-node ratio in an infinite size array of stations. Obviously, at levels above three there are alternate methods of constructing the network. However, it was found that there is little difference regardless of which method is used. Such an alternate method is shown for levels three and four, labelled R'. This specific alternate mode is also used for levels six and eight.[2]

Each node and link in the array of Fig. 2 has the capacity and the switching flexibility to allow transmission between any ith station and any jth station, provided a path can be drawn from the ith to the jth station.

Starting with a network composed of an array of stations connected as in Fig. 3, an assigned percentage of nodes and links is destroyed. If, after this operation,

Manuscript received October 9, 1963. This paper was presented at the First Congress of the Information Systems Sciences, sponsored by the MITRE Corporation, Bedford, Mass., and the USAF Electronic Systems Division, Hot Springs, Va., November, 1962.

The author is with The RAND Corporation, Santa Monica, Calif.

[1] Any views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of The RAND Corporation or the official opinion or policy of any of its governmental or private research sponsors.

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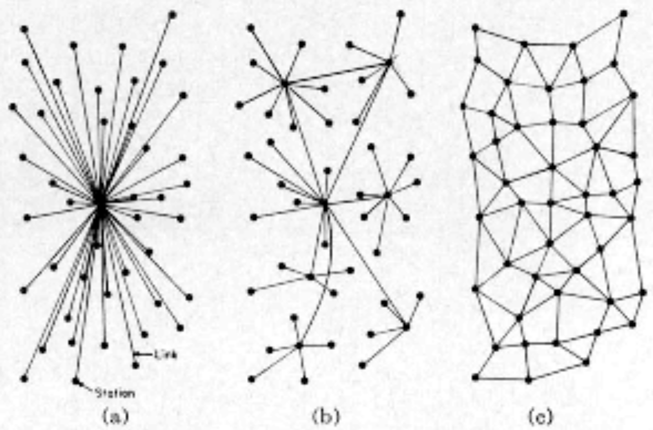

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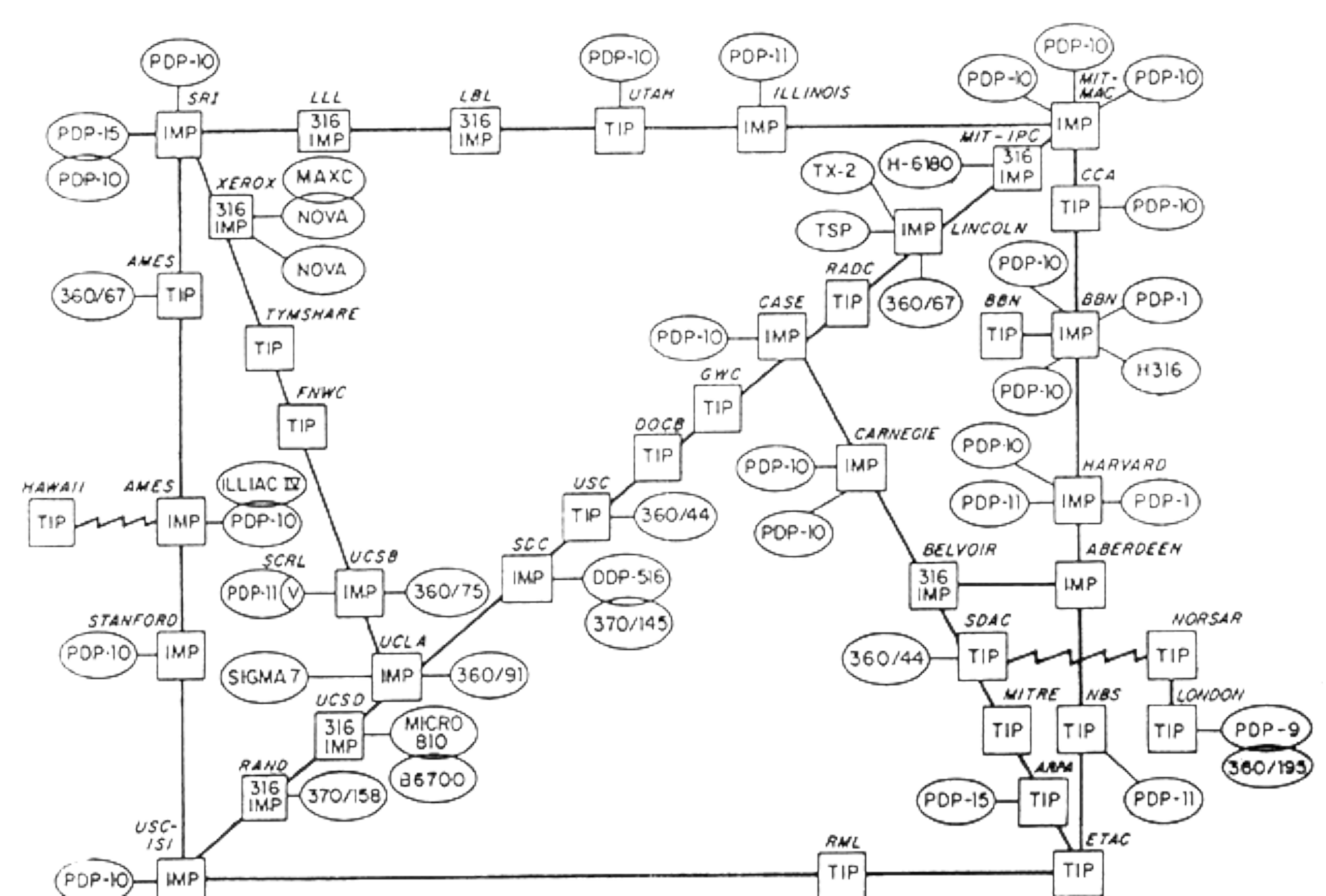

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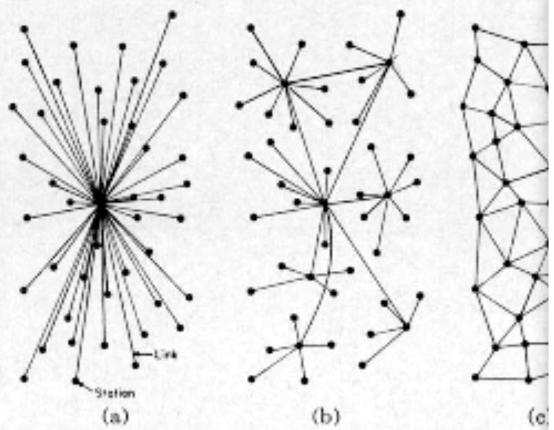

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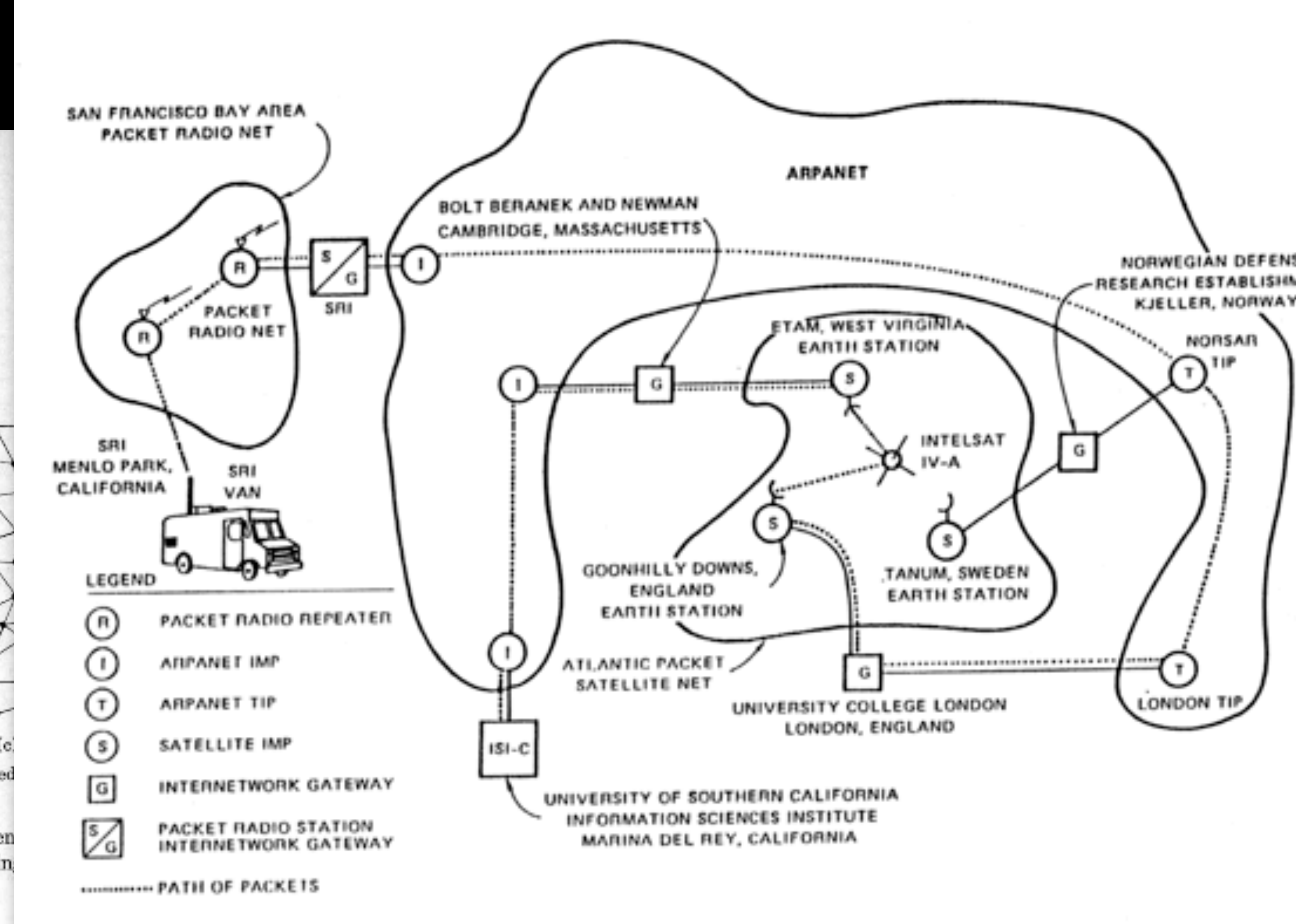
Starting with a network composed of an array of stations connected as in Fig. 3, an assigned percentage of nodes and links is destroyed. If, after this operation,

Manuscript received October 9, 1963. This paper was presented at the First Congress of the Information Systems Sciences, sponsored by the MITRE Corporation, Bedford, Mass., and the USAF Electronic Systems Division, Hot Springs, Va., November, 1962.

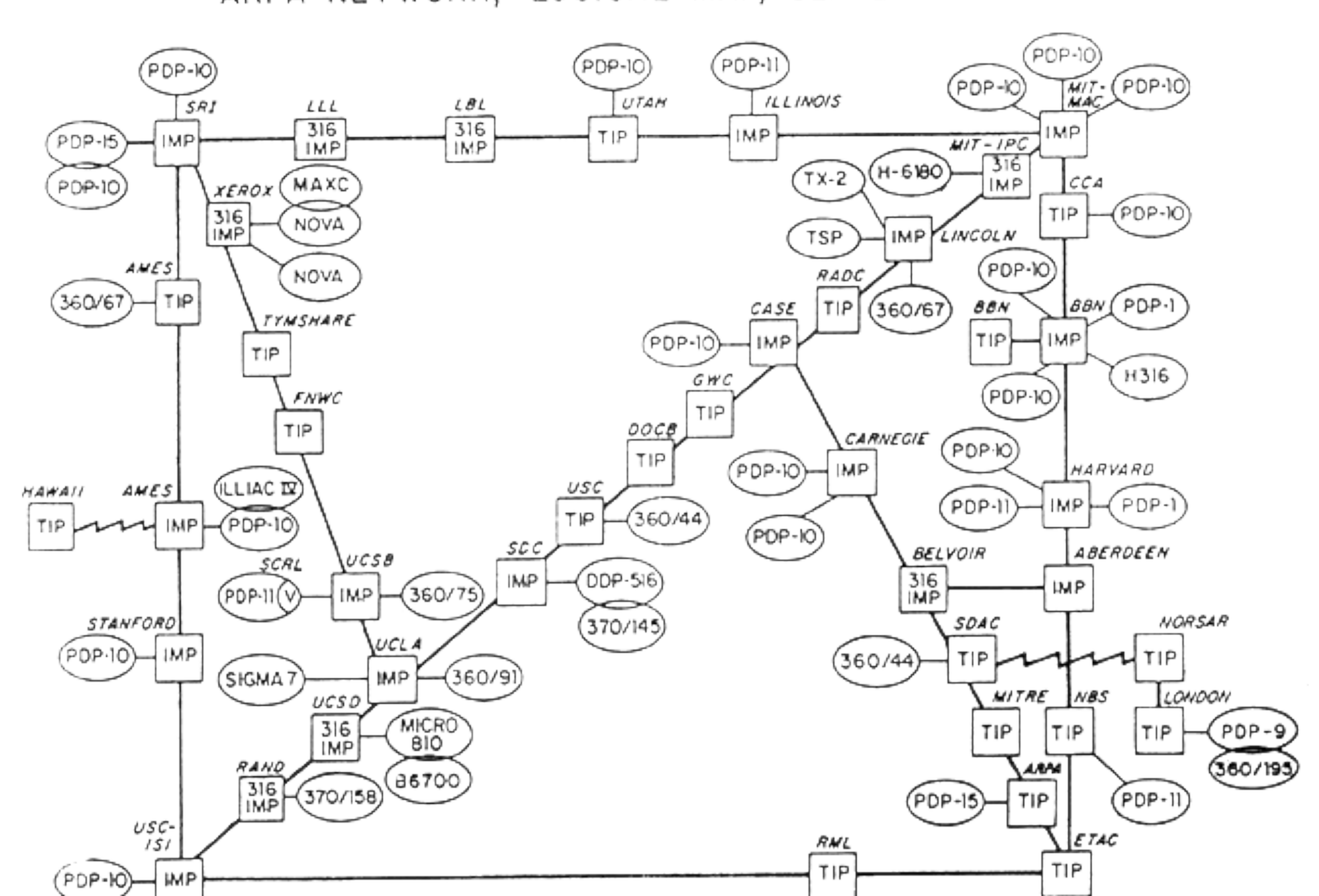
The author is with The RAND Corporation, Santa Monica, Calif.

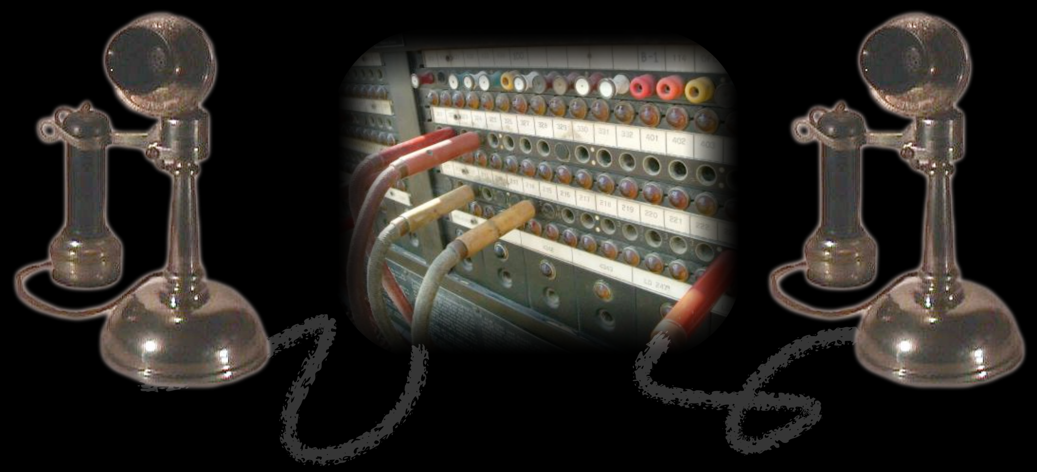
[1] Any views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of The RAND Corporation or the official opinion or policy of any of its governmental or private research sponsors.

[2] See L. J. Craig, and I. S. Reed, "Overlapping Tessellated Communications Networks," The RAND Corporation, Santa Monica, Calif., paper P-2359; July 5, 1961.

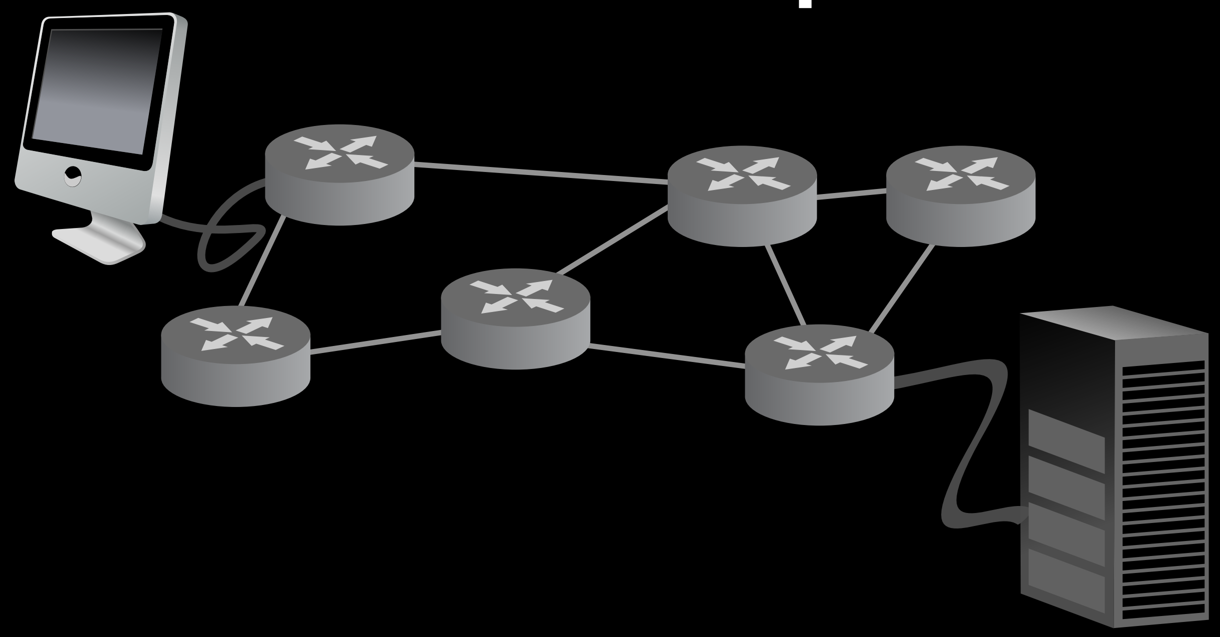


ARPA NETWORK, LOGICAL MAP, SEPTEMBER 1973





The IP model let us separate the act of conversation from the process of building a circuit.

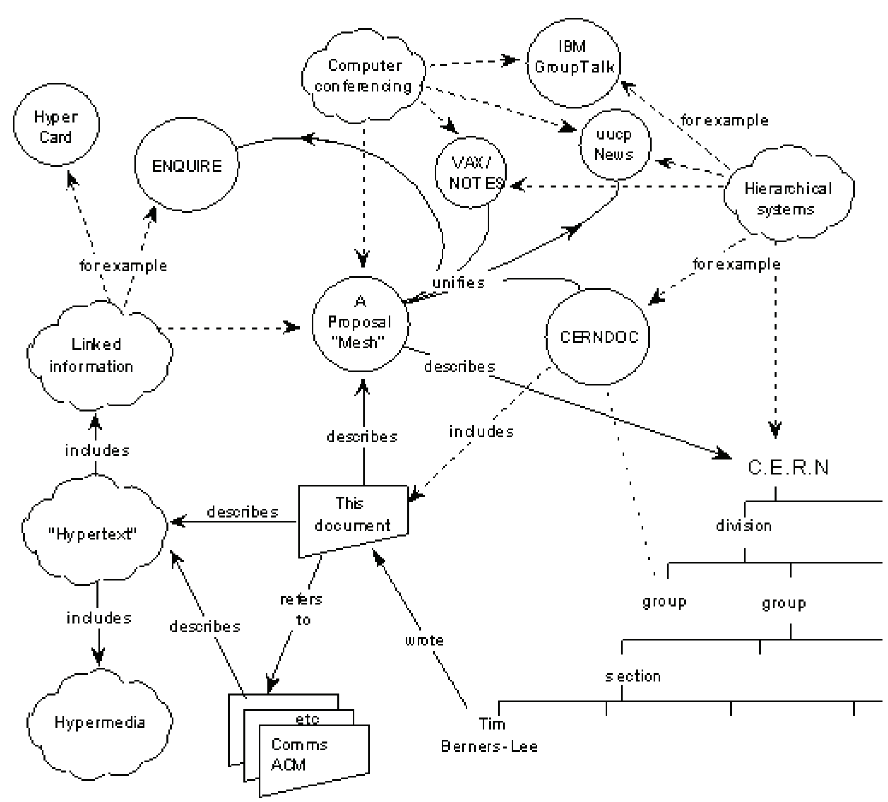


the Web is today's communication model

Information Management: A Proposal

Tim Berners-Lee, CERN
March 1989, May 1990

This proposal concerns the management of general information about accelerators and experiments at CERN. It discusses the problems of loss of information about complex evolving systems and derives a solution based on a distributed hypertext system.



Overview

Many of the discussions of the future at CERN and the LHC era end with the question - ªYes, but how will we ever keep track of such a large project?º This proposal provides an answer to such questions. Firstly, it discusses the problem of information access at CERN. Then, it introduces the idea of linked information systems, and compares them with less flexible ways of finding information.

the Web is today's communication model

w3 archive 1990

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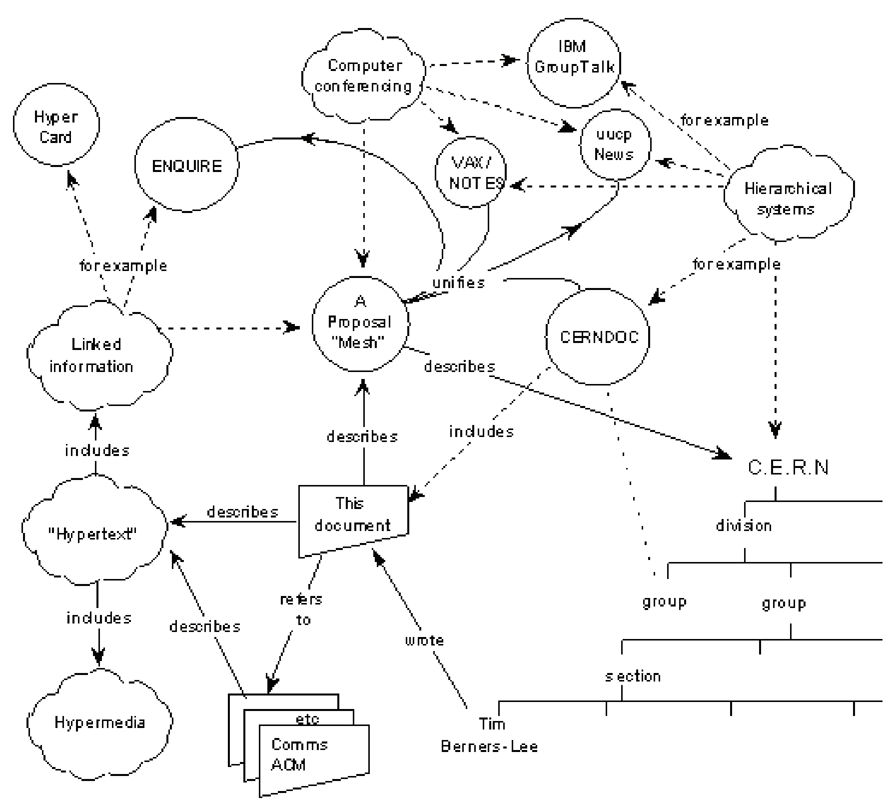

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The web model let us separate the information communicated from the act of conversation.

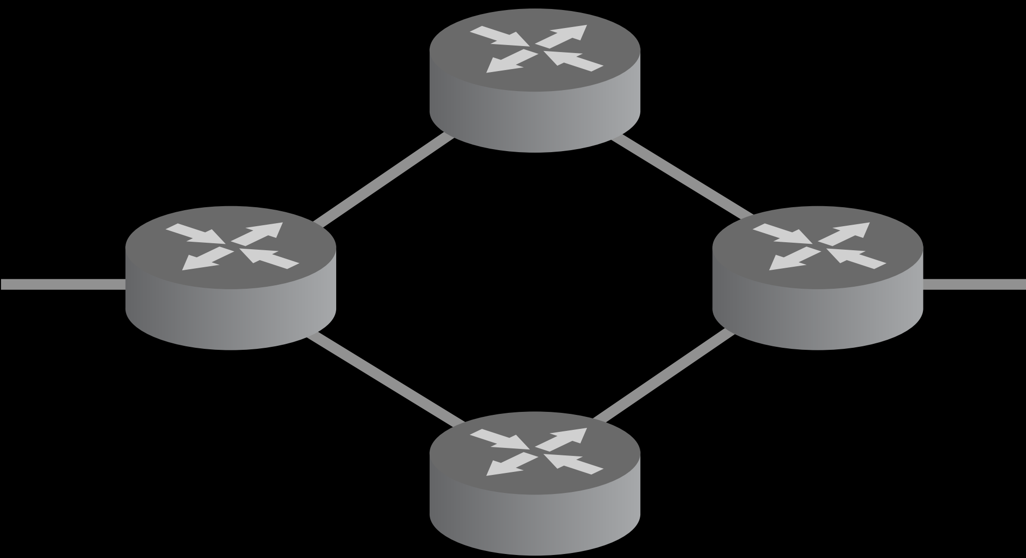
Communication is ...

Telephone:	the Wires
Internet:	the Endpoints
Web:	the Information

Communication is ...

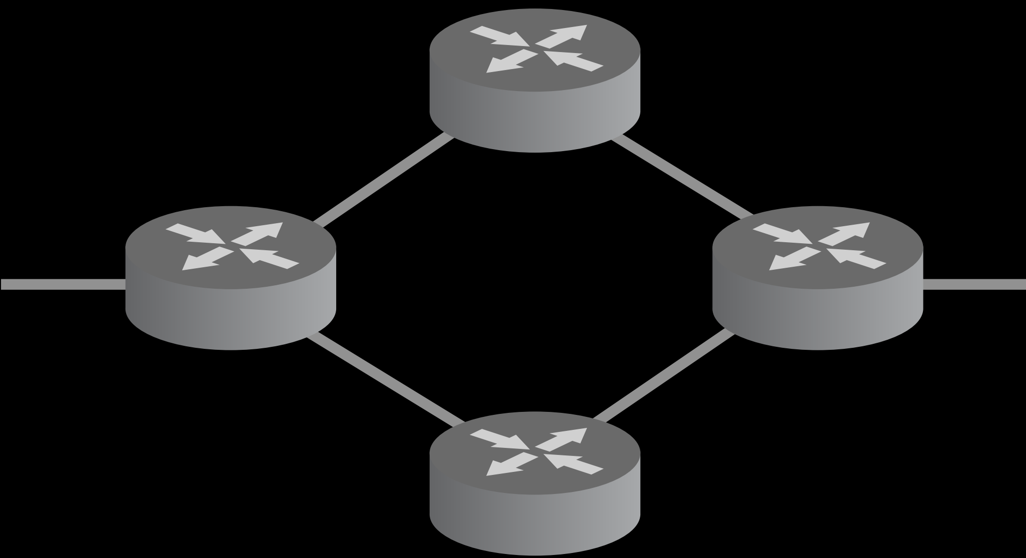
Telephone:	the Wires
Internet:	the Endpoints
Web:	the Information

But only for end users!



Today's network architecture
embraces wires & interconnects

but not cycles or storage.



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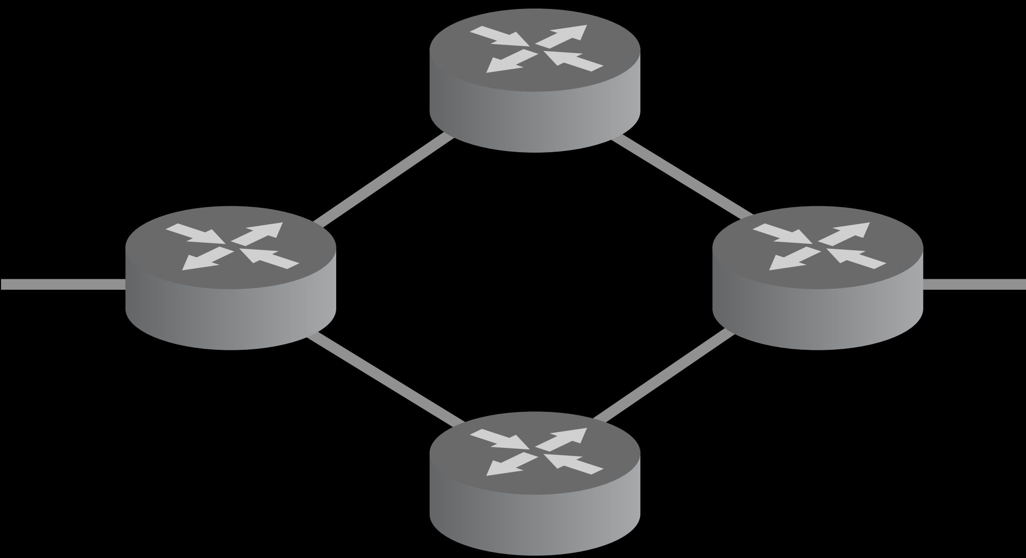
They are different because we conceptualize in
terms of *process* rather than *outcome*.



Today's network architecture
embraces wires & interconnects

but not cycles or storage.

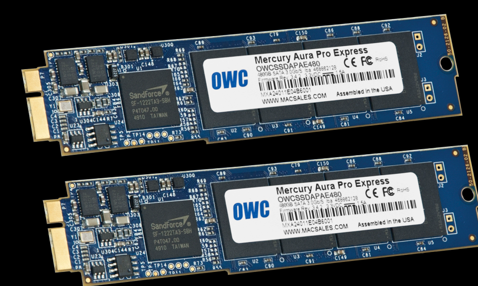
They are different because we conceptualize in terms of *process* rather than *outcome*.

If we view networking as *information delivery* all three can work together seamlessly.

Customer-edge PoP

Customer-edge PoP

1 TB SATA-3 SSD



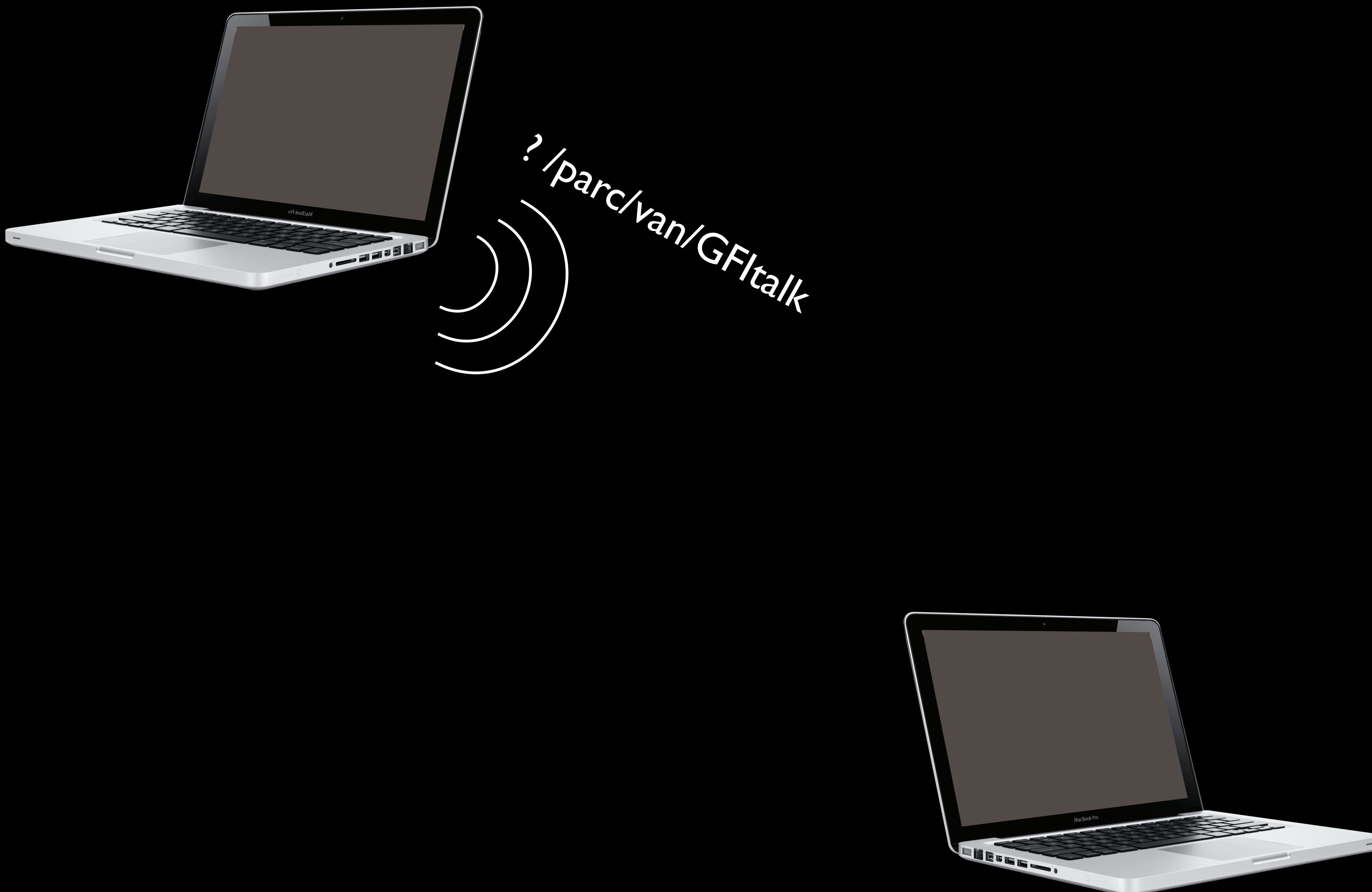
48 Gbps
4”x0.75”
5mW
$2K / TB

Ethernet
line card

40 Gbps
20”x14”x2”
500W
$65K

Customer-edge PoP

Making storage behave like a line card isn't an engineering or manufacturing problem, it's an *architectural challenge!*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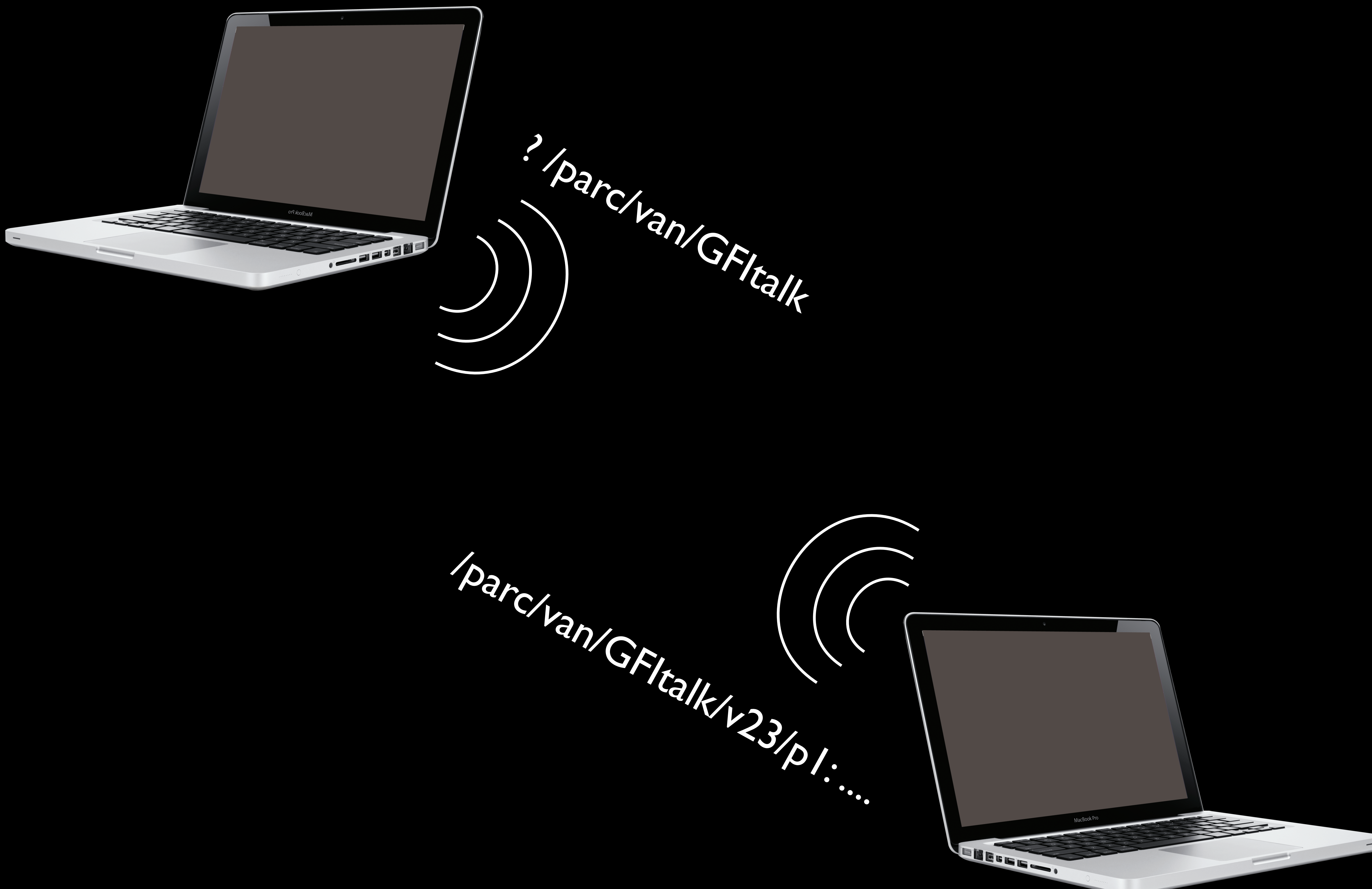
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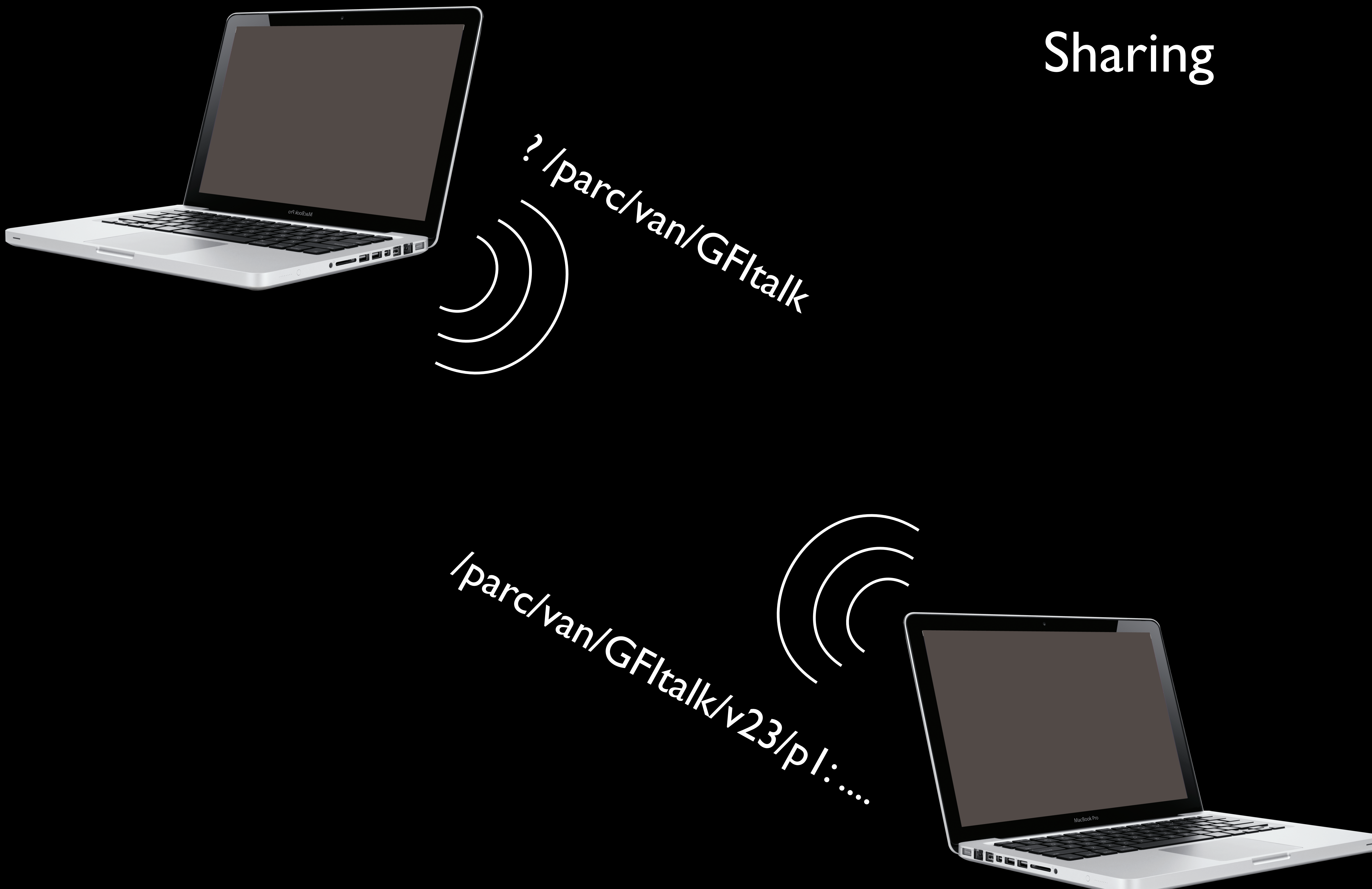
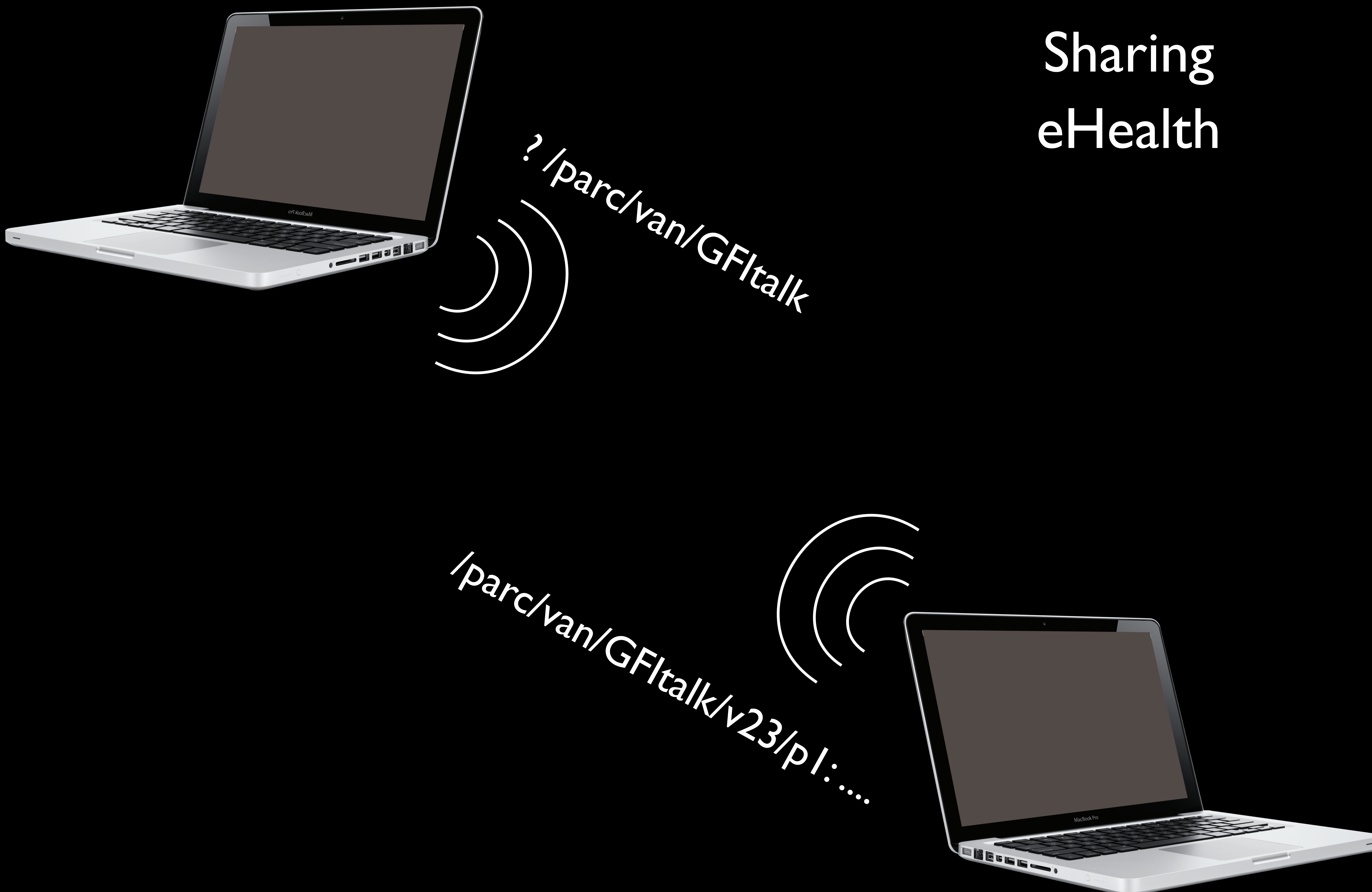
Sharing




Sharing
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Sharing eHealth Devices

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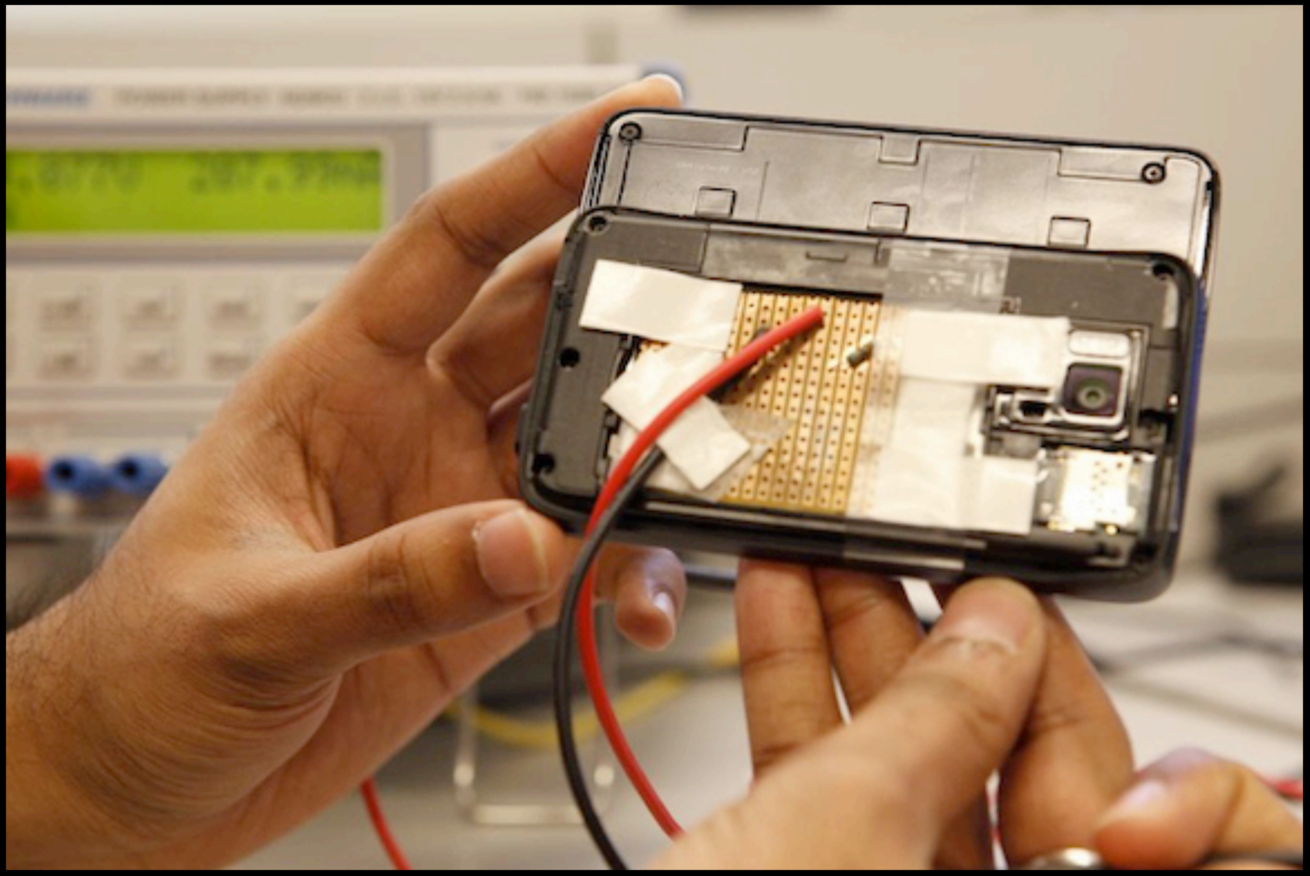
Blog Cite

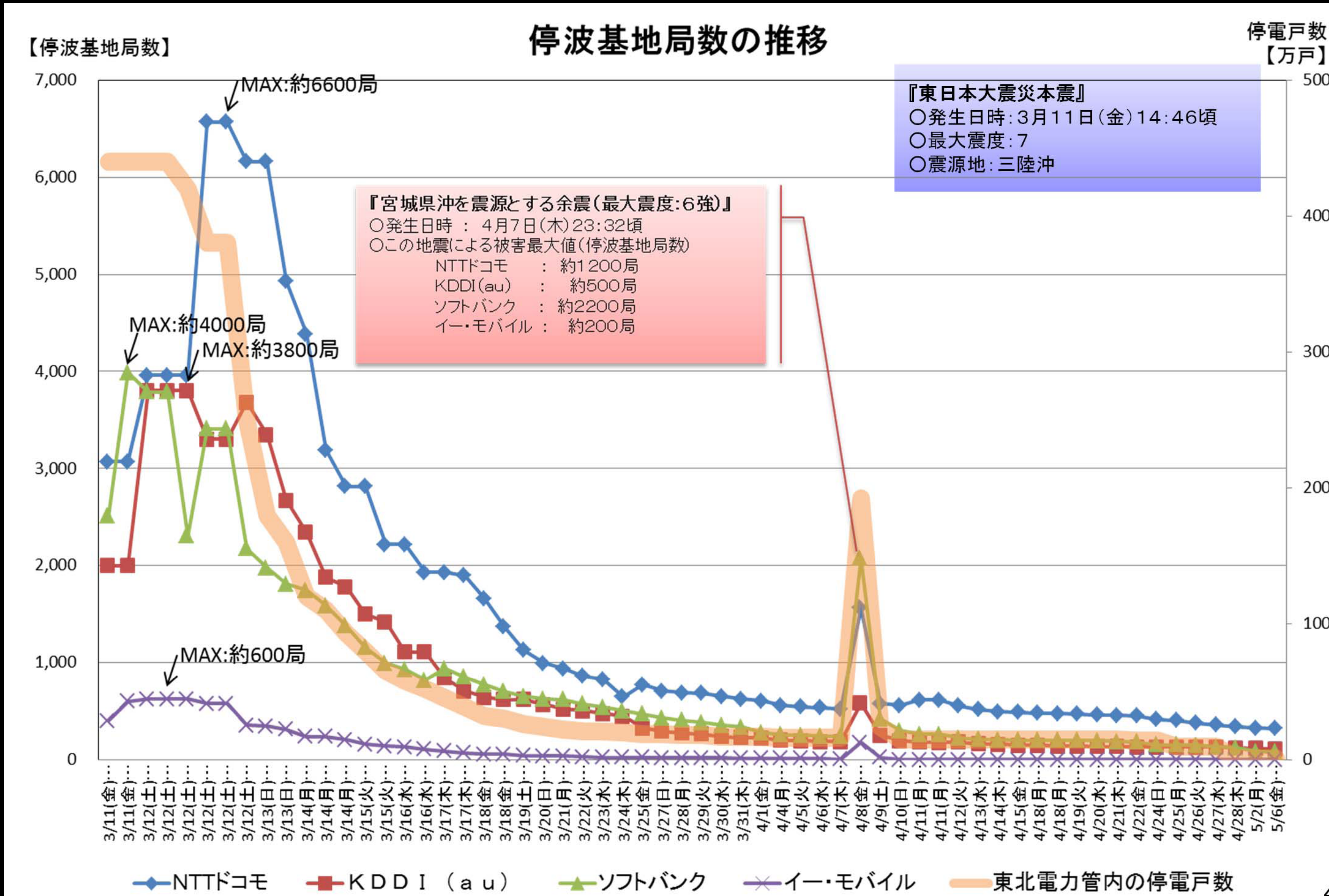
Smart Phone Power Consumption Cut by More Than 70 Percent

ScienceDaily (Nov. 25, 2011) — Researchers at Aalto University in Finland have designed a network proxy that can cut the power consumption of 3G smart phones up to 74 percent. This device enhances performance and significantly reduces power usage by serving as a middleman for mobile devices to connect to the Internet and handling the majority of the data transfer for the smart phone. Historically, the high energy requirements of mobile phones have slowed the adoption of mobile Internet services in developing countries.



J. Manner, et.al., AFRICOMM 2011:

Proxy at wireless base station reduces 3G mobile power consumption by 4x for streaming audio (but not for TCP/IP)



Fukushima earthquake NTT base station outage:
3000 initially, 3600 more over
next 28 hours as batteries failed.

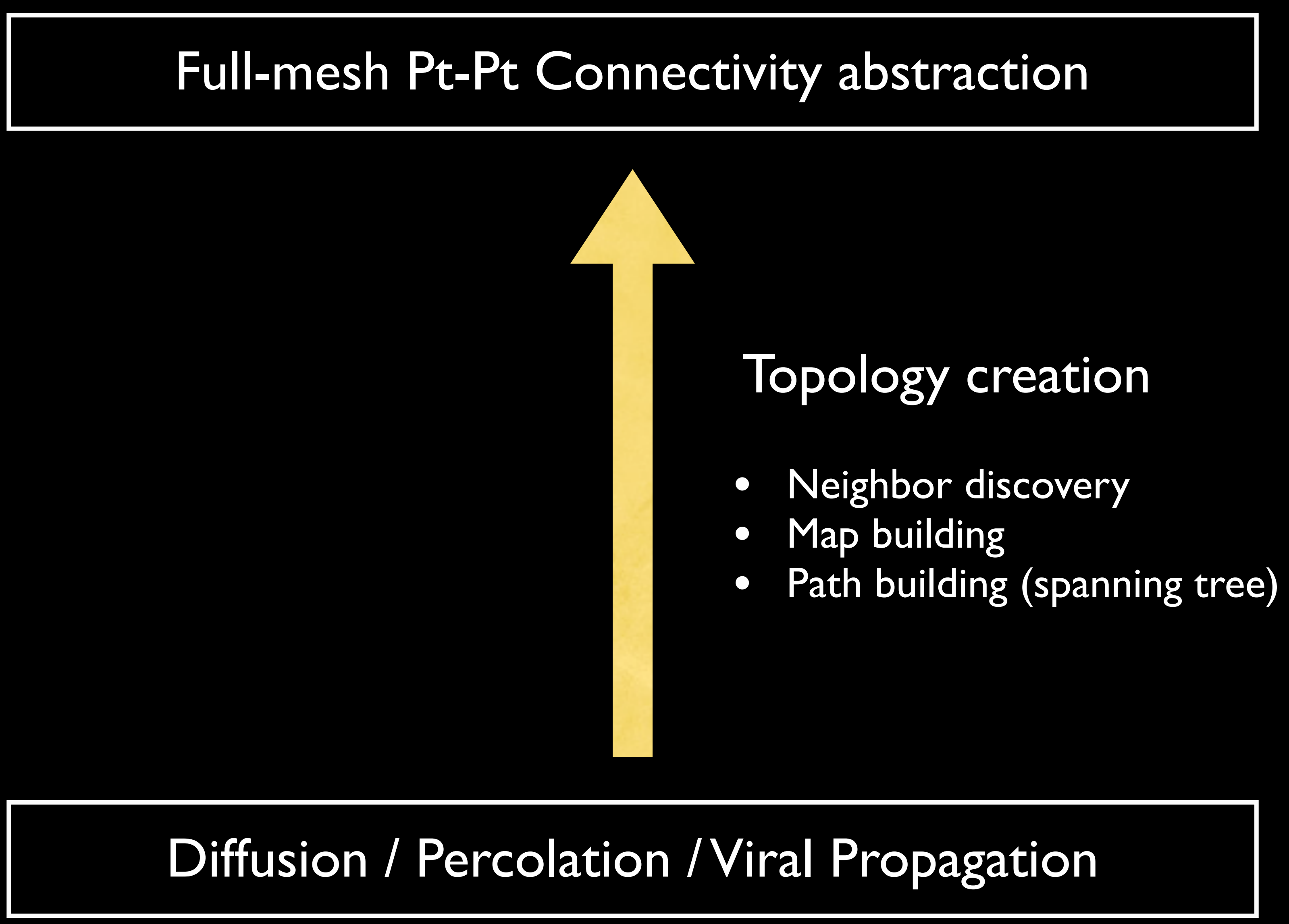
Diffusion / Percolation / Viral Propagation

Full-mesh Pt-Pt Connectivity abstraction

Topology creation

- Neighbor discovery
- Map building
- Path building (spanning tree)

Diffusion / Percolation / Viral Propagation



Full-mesh Pt-Pt Connectivity abstraction
Topology creation
• Neighbor discovery
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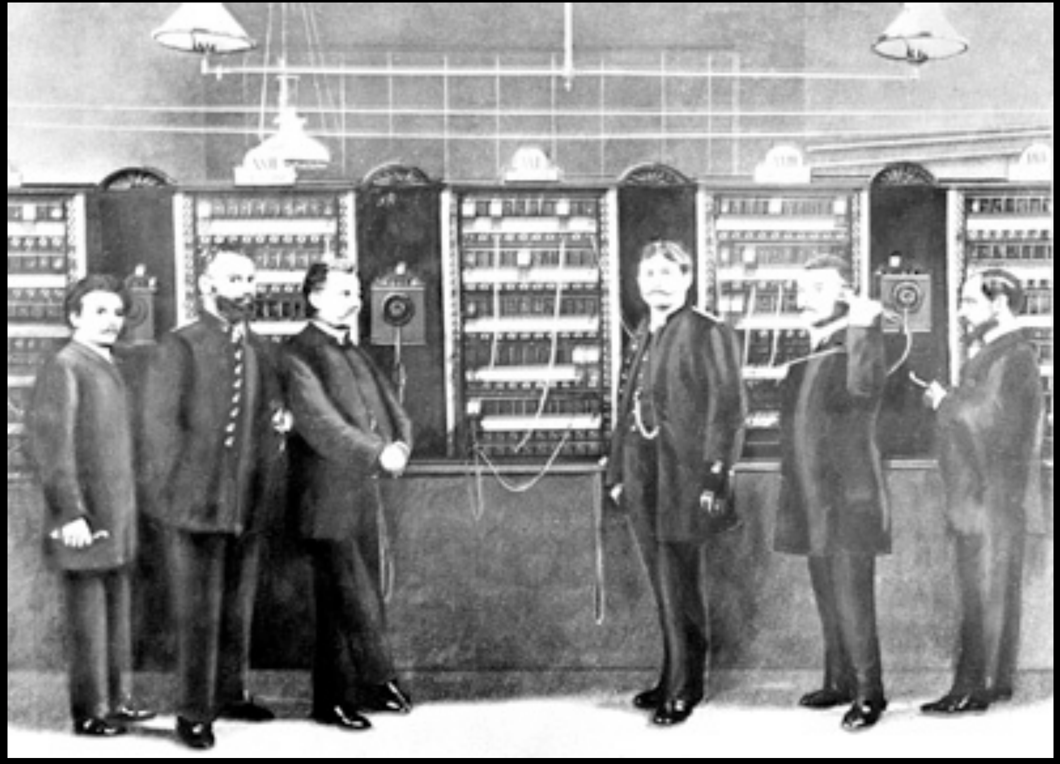
Diffusion / Percolation / Viral Propagation



To communicate, we first construct a model of the 1880s!

Full-mesh Pt-Pt Connectivity abstraction

Topology creation

- Neighbor discovery
- Map building
- Path building (spanning tree)

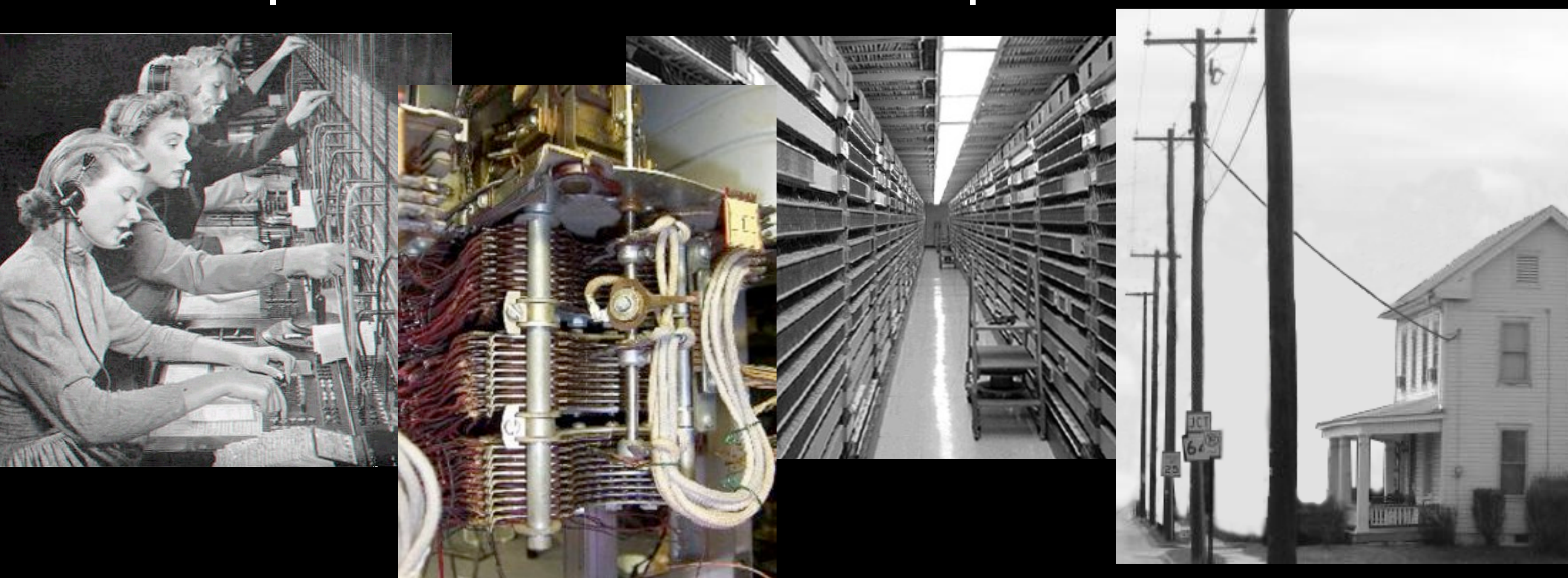
Diffusion / Percolation / Viral Propagation

Can we evolve?

(we did once before with landline to cell)

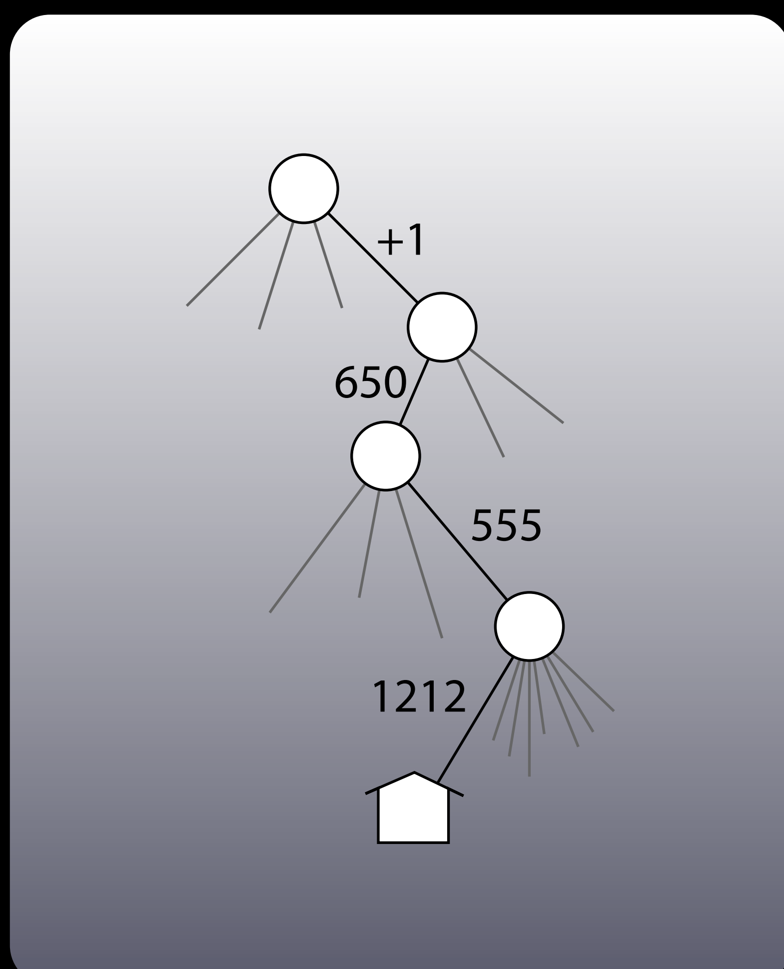
What is a phone number?

- A landline phone number represents a path through the switching system to some particular customer’s wire pair.



What is a phone number?

- It is the <u>location</u> of the line, both in the switching hierarchy and in space.



This creates a problem:

Callers want to reach a person,
not a location.

A 1990s Business Card

Ernest Orlando Lawrence
Berkeley National Laboratory

BERKELEY LAB

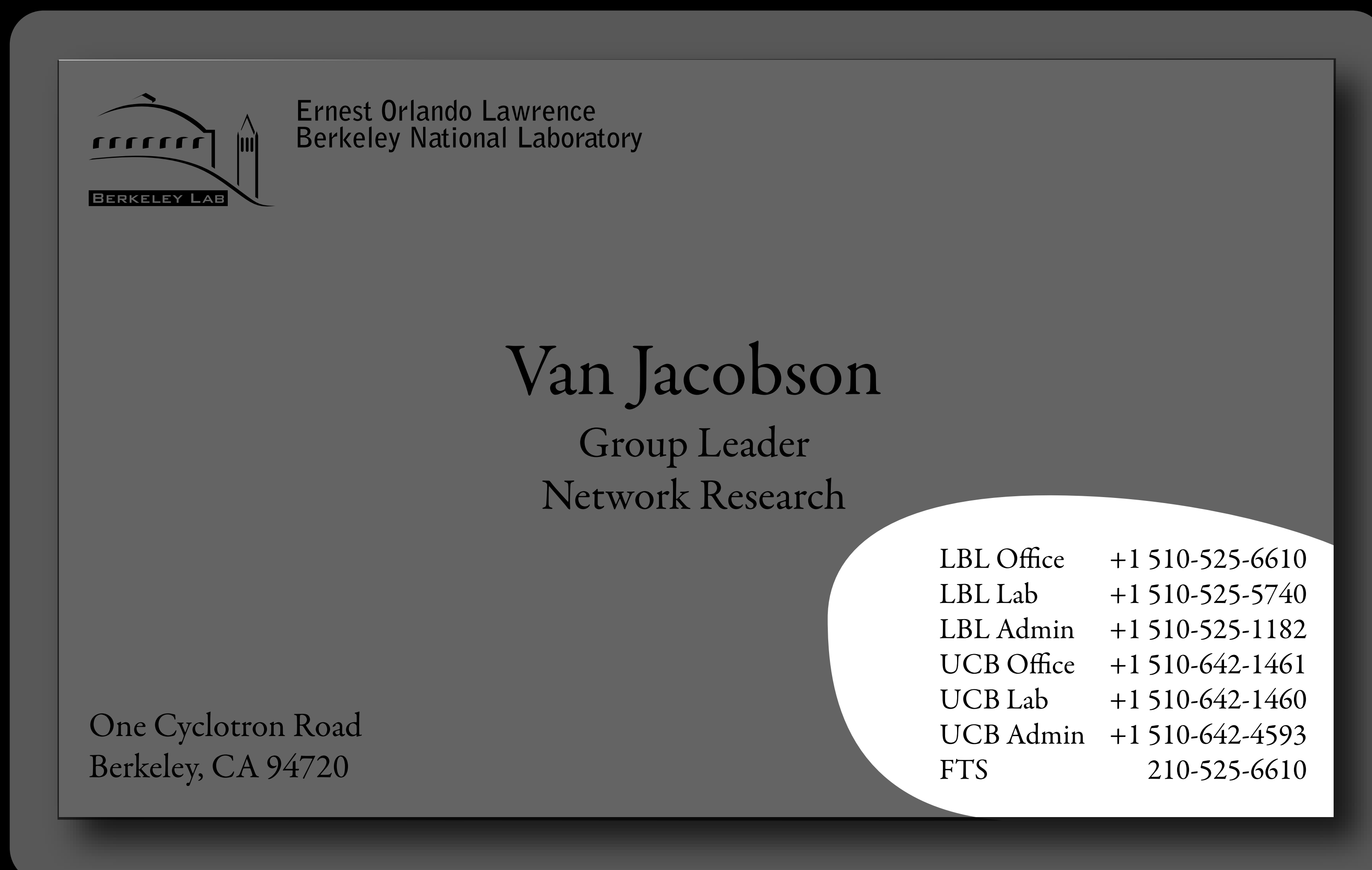
Van Jacobson

Group Leader
Network Research

LBL Office	+1 510-525-6610
LBL Lab	+1 510-525-5740
LBL Admin	+1 510-525-1182
UCB Office	+1 510-642-1461
UCB Lab	+1 510-642-1460
UCB Admin	+1 510-642-4593
FTS	210-525-6610

One Cyclotron Road
Berkeley, CA 94720

A 1990s Business Card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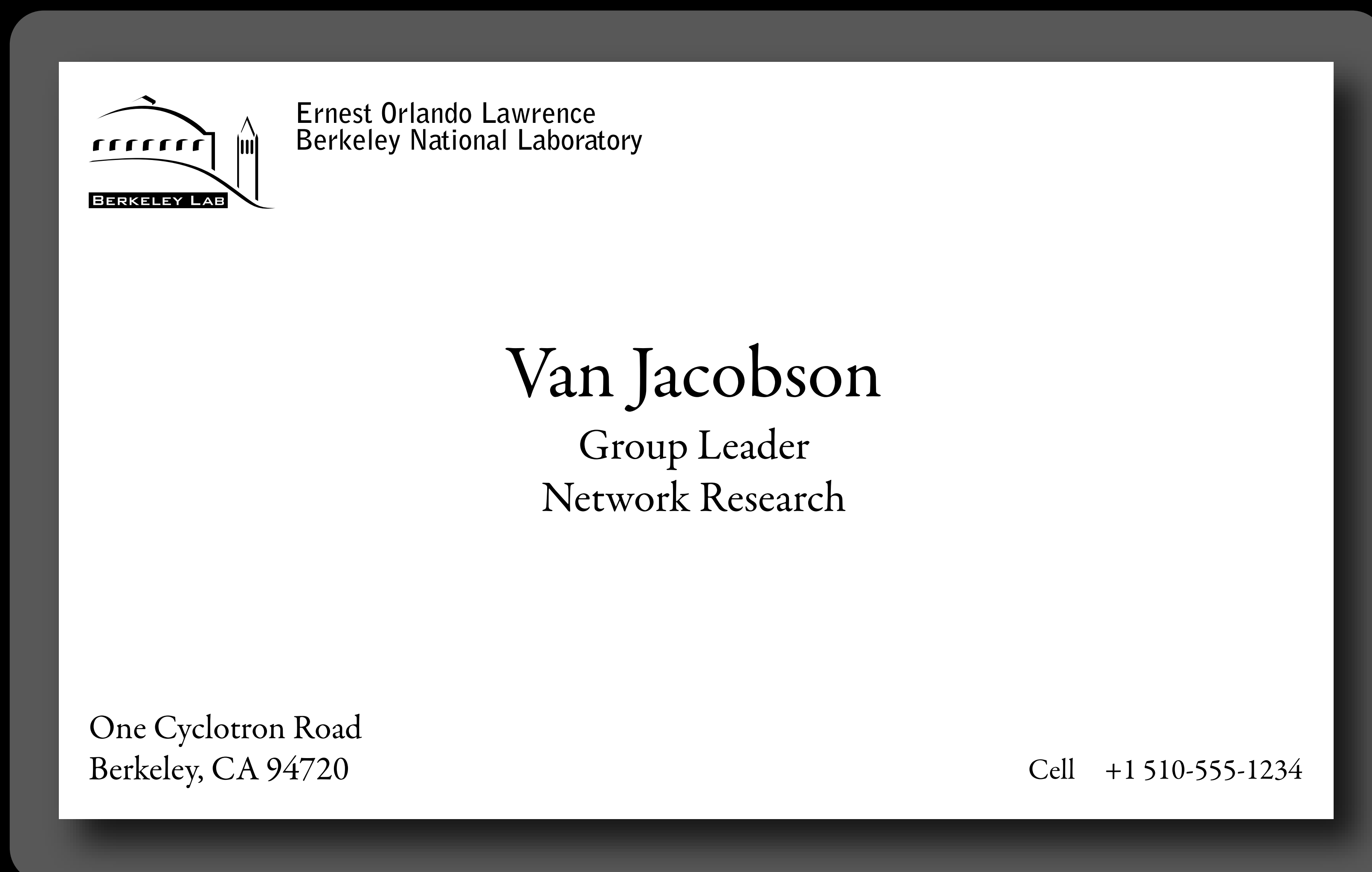
Berkeley, CA 94720

Post-cell Business Card



What is a phone number?

- Cell phone number is treated as the ‘name’ of the phone.
- It has no fixed topological or spatial location - both are dynamically bound.
- Cell system is a strict superset of landline system but looks the same to a user (phone numbers didn’t change).

We can evolve

- The landline-cell transition was possible because *users* had *always* viewed phone numbers as the name of the phone.
- Because of the web, users view the Internet in terms of named information.
- *Only the preconceptions of network engineers keep us stuck in the past.*