David D. Clark's paper
"The Design Philosophy of the DARPA Internet Protocols"
1988

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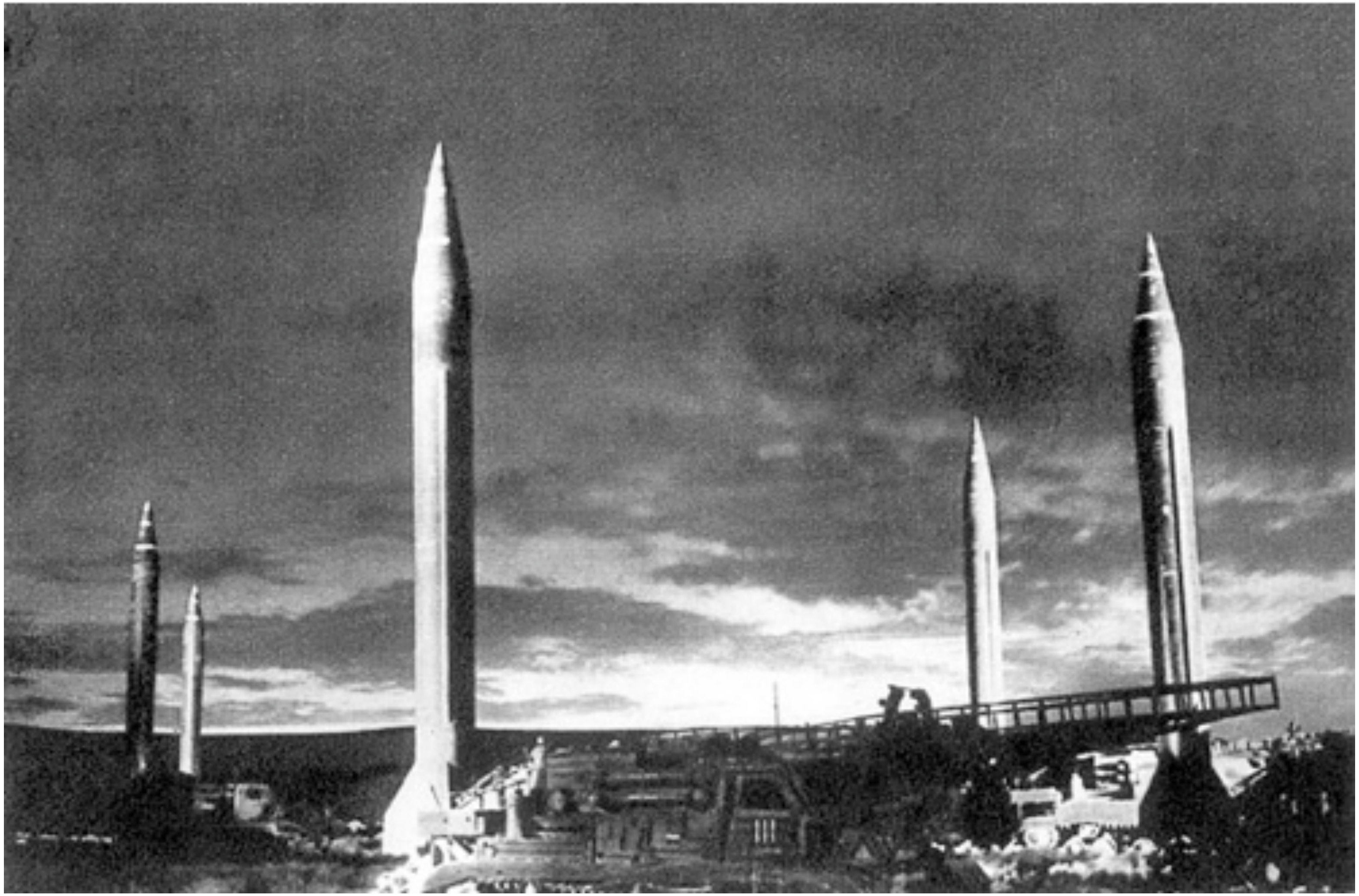
Biography:

Since the mid 70s, Dr. Clark has been leading the development of the Internet; from 1981-1989 he acted as Chief Protocol Architect in this development, and chaired the Internet ActivitiesBoard. Recent activities include extensions to the Internet to support real-time traffic, explicit allocation of service, pricing and related economic issues, and policy issues surrounding local loop employment. New activities focus on the architecture of the Internet in the post-PC era. He is chairman of the Computer Science and Telecommunications Board of the National Research Council.

Why the Internet is the way it is?

In the beginning..



Need a communication network that will survive a war:

multipath between two hosts

divide messages into message blocks

deliver the message blocks using store-and-forward switching

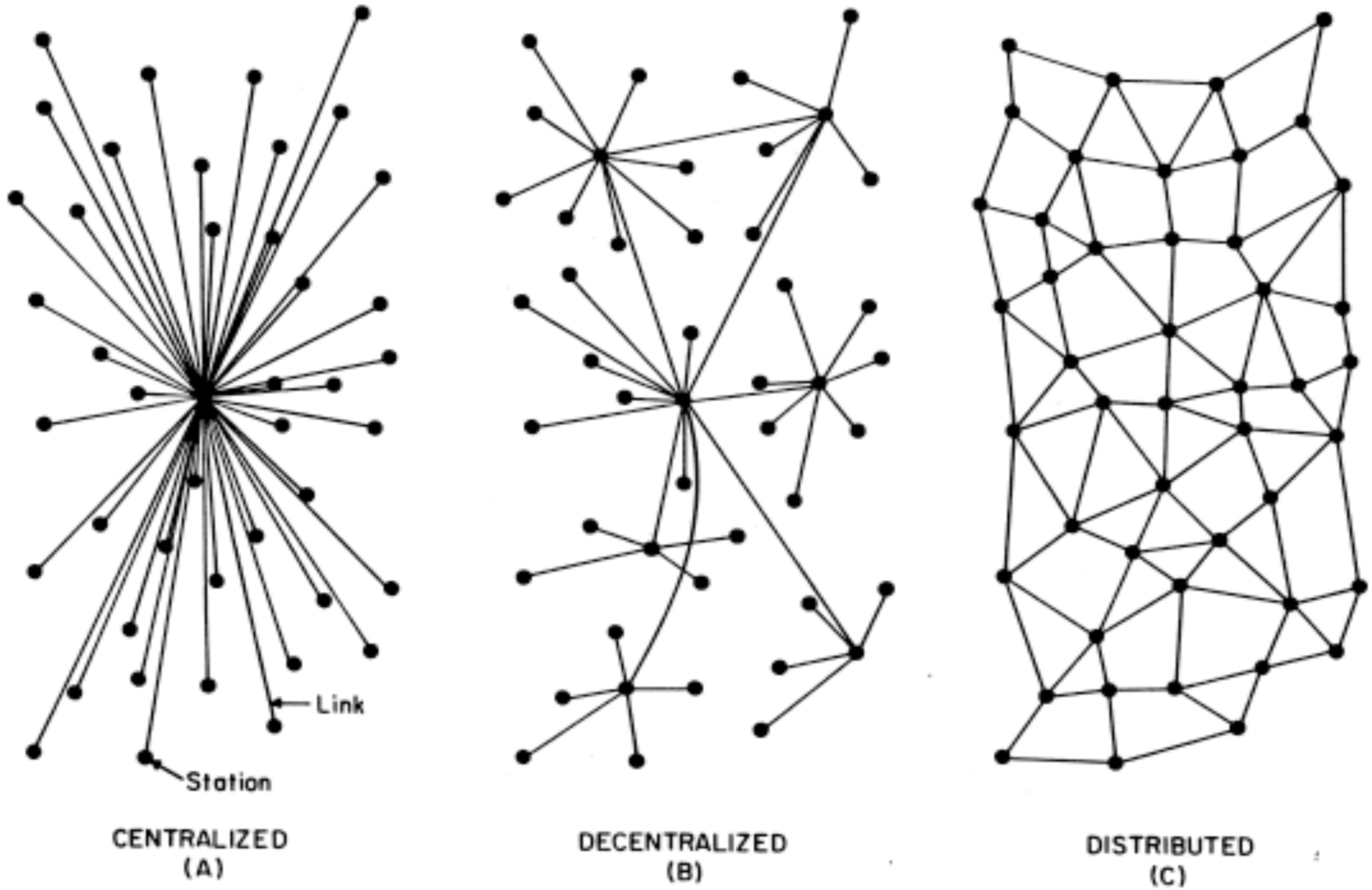
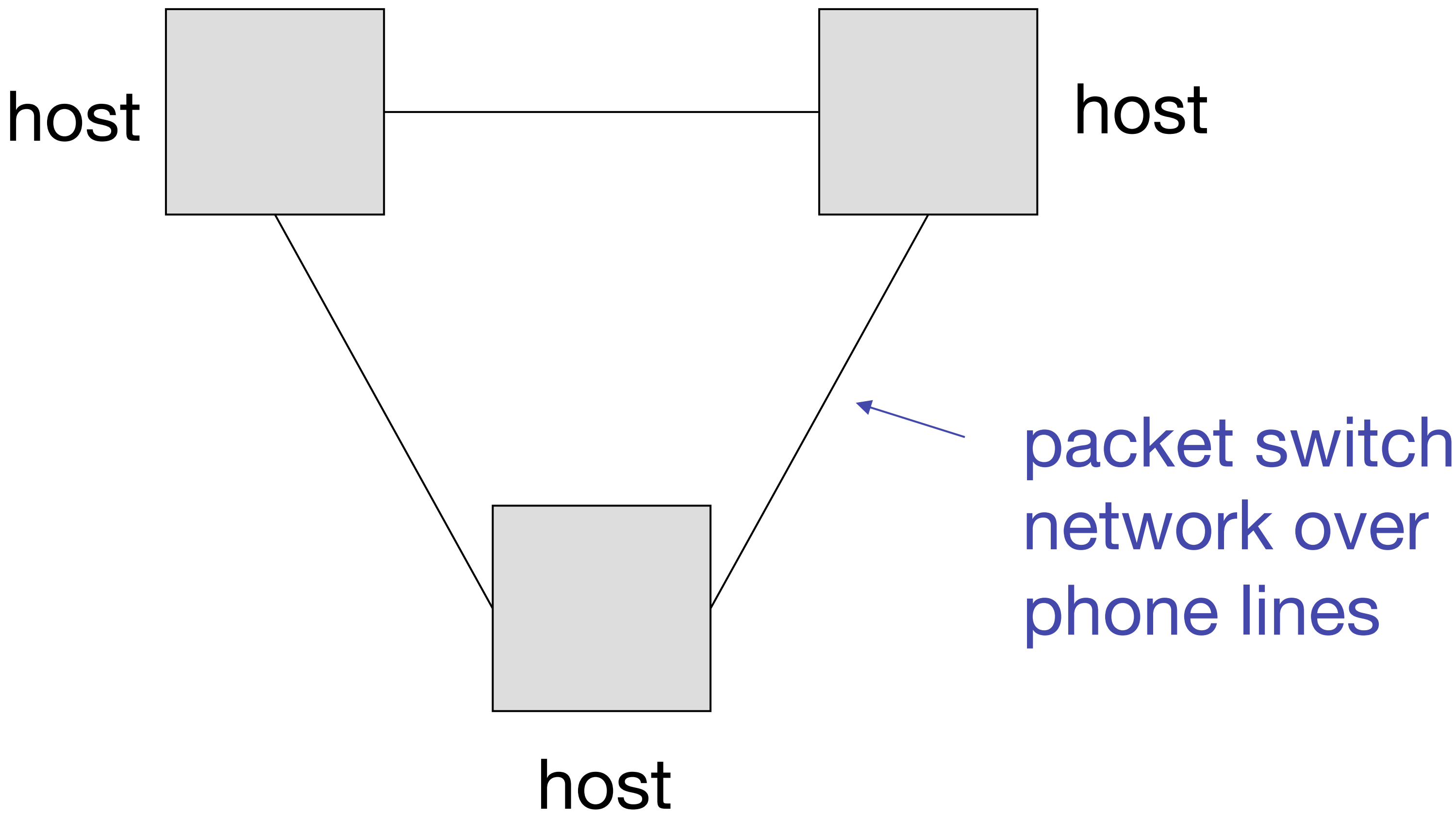


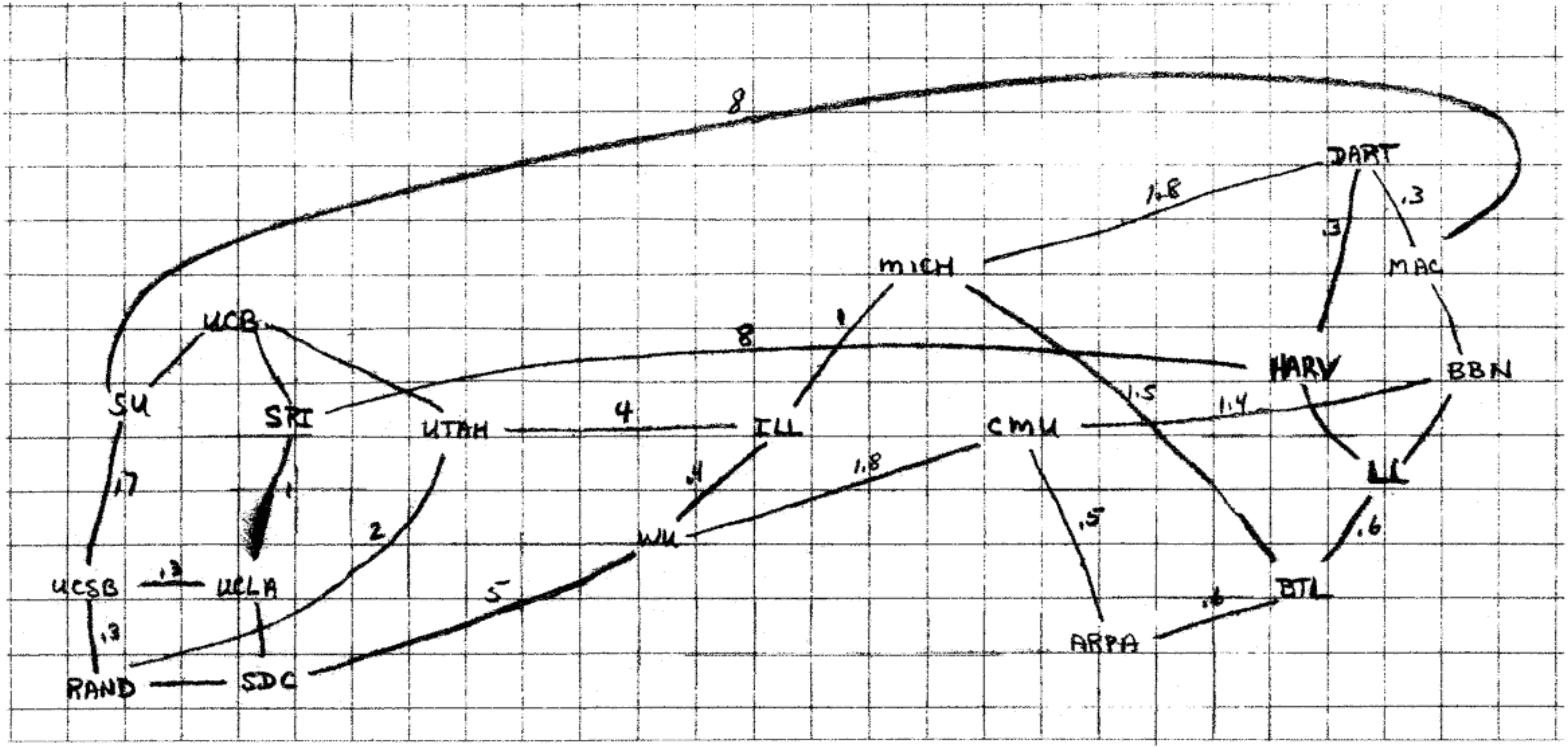
FIG. I — Centralized, Decentralized and Distributed Networks

http://www.rand.org/pubs/research_memoranda/RM3420/RM3420.chapter1.html

ARPANET



ARPANET

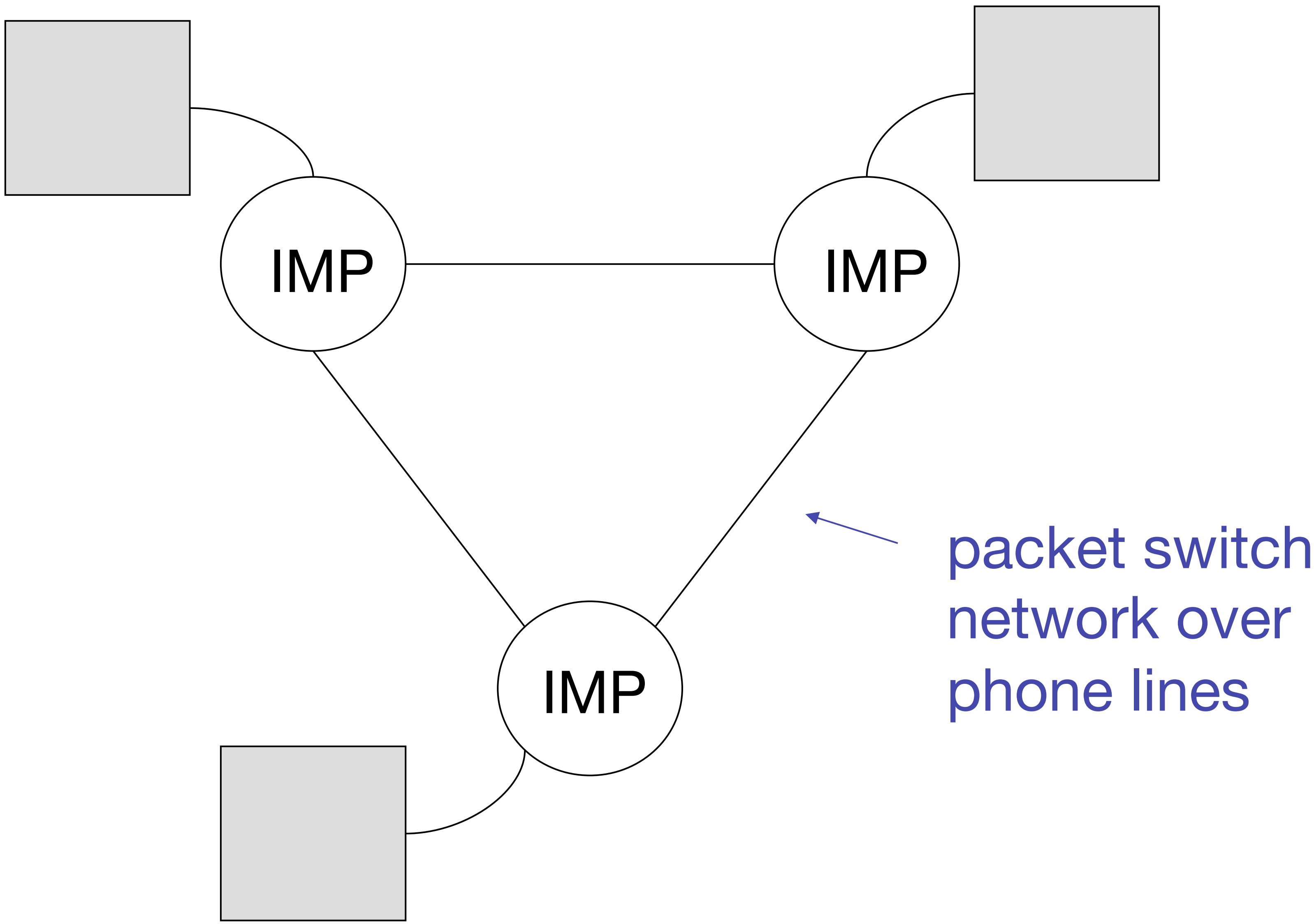


From “An Atlas of Cyberspace”, A website by Martin Dodge

"Come and write applications using our network!"

Wait, we need to write our own packet switching software??

Interface Message Processors (IMP)



http://www.webstart.com/jed/service/vs-bbn-imp.jpg

Services of IMP:

segmentation: break into 1Kb blocks

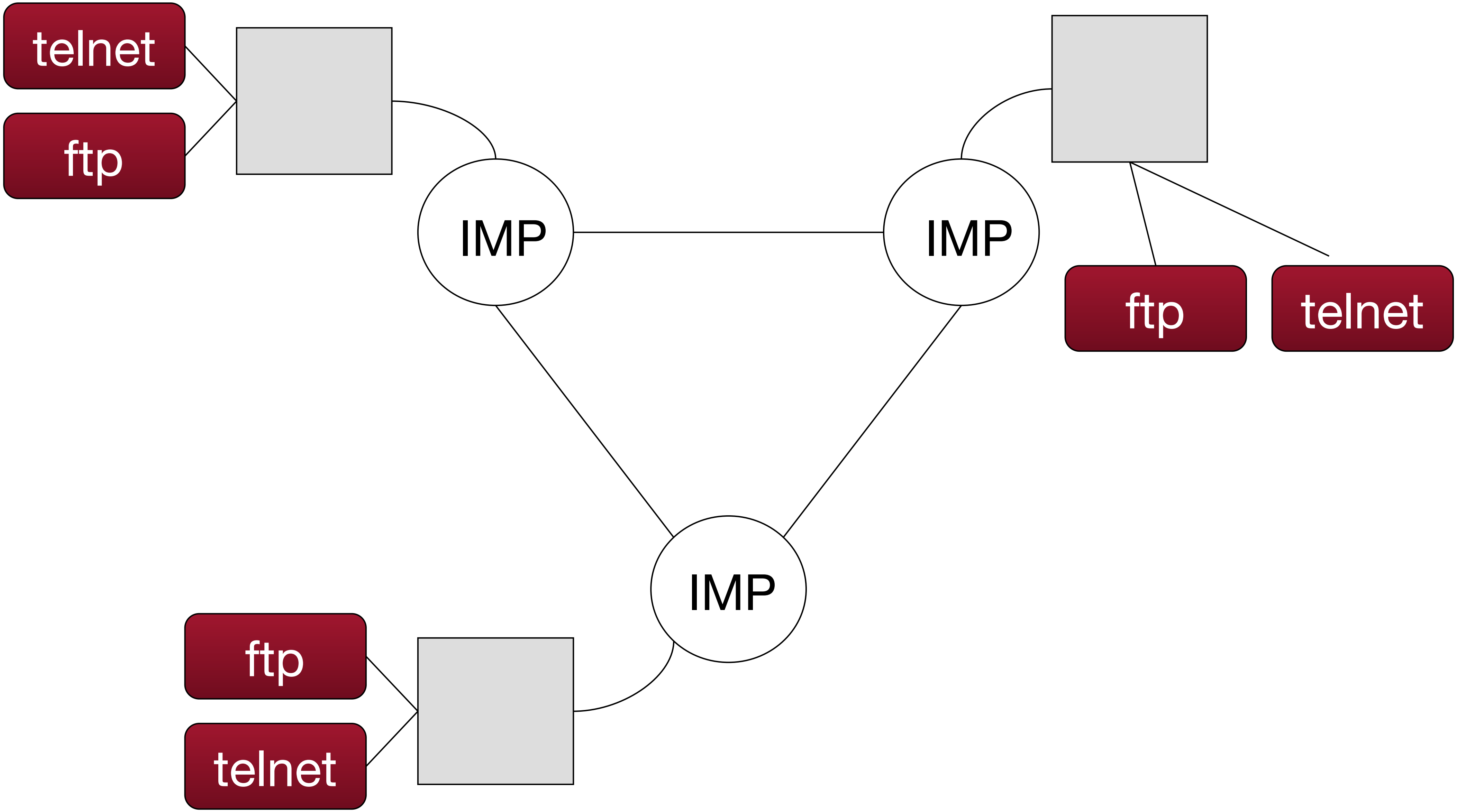
header: add header

routing

reliability: ACK, checksum

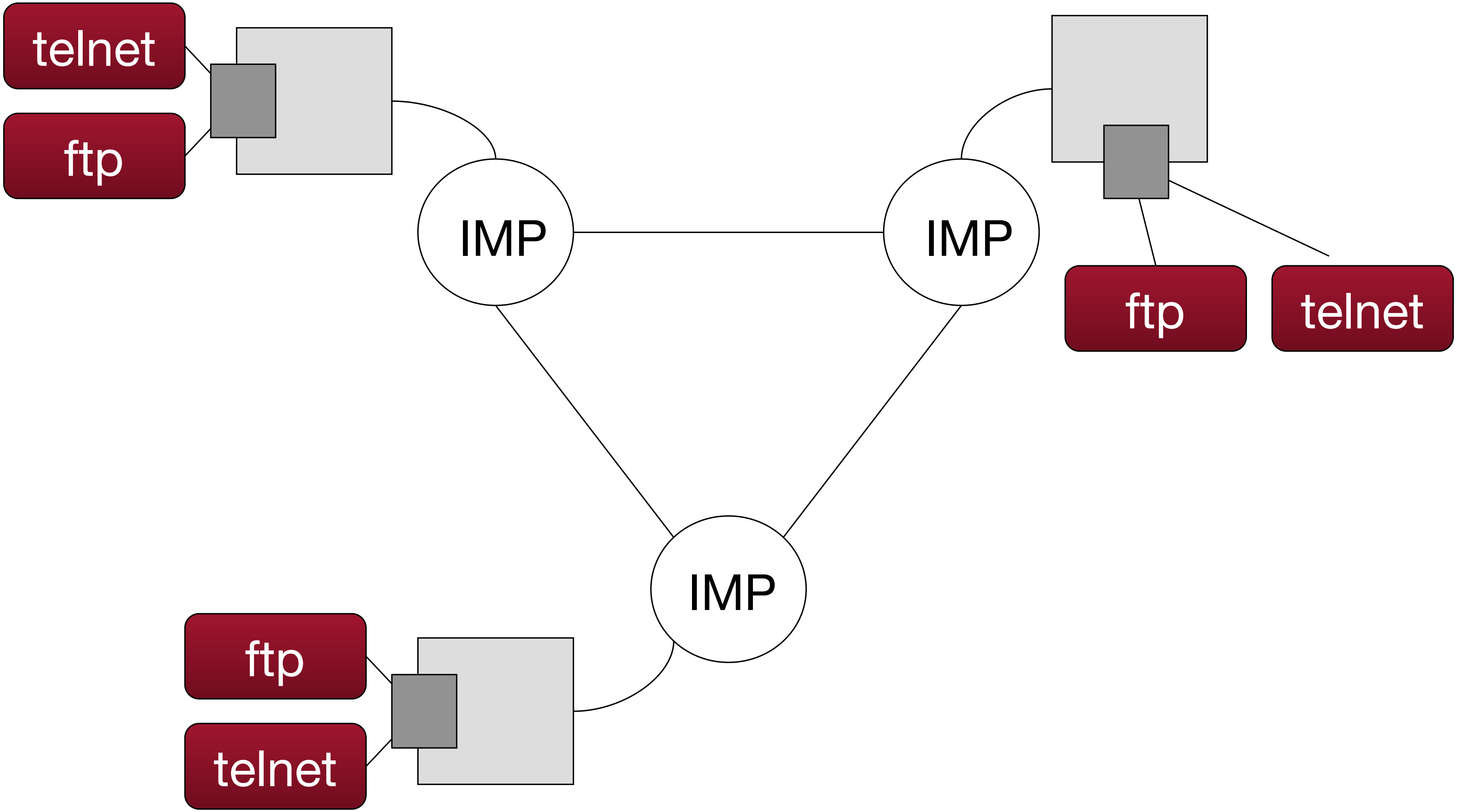
reassembly

flow control


telnet
ftp
IMP
IMP
ftp
telnet
IMP
ftp
telnet

Both applications need to establish connections

Network Control Program



Meanwhile..

PRNET
SATNET
being developed

How to make disjoint networks talk to each other effectively ?

Choices

A. Build a tightly integrated, unified network
B. Interconnect existing network

Why ?

More practical. Networks represent separately administered entities.

Choices

A. Packet Switching
B. Circuit Switching

Why ?

The networks to be integrated are packet switched network. Packet switch is natural choice for the applications at the time (remote login).

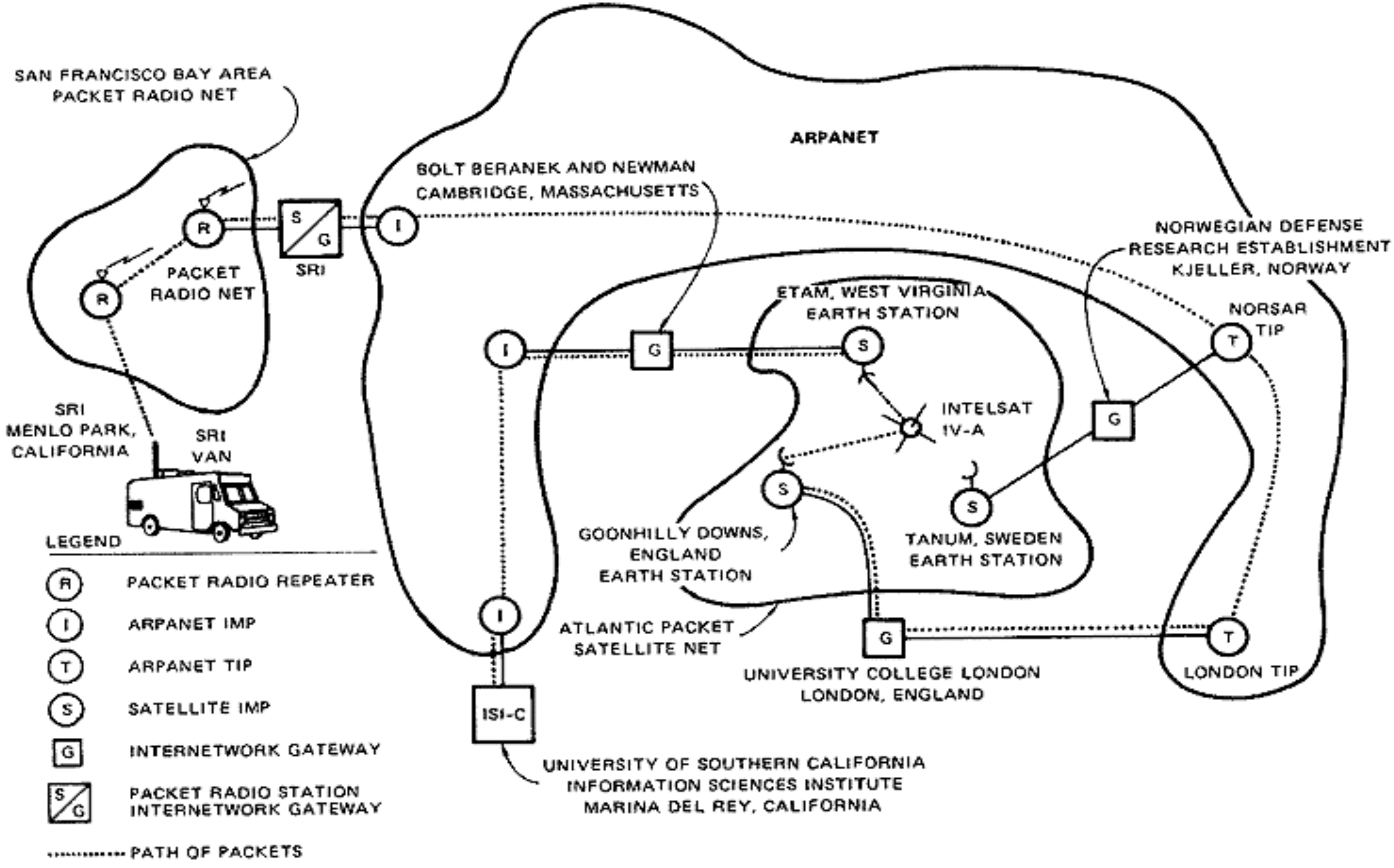


FIGURE 1 FIRST ARPA MULTINETWORK DEMONSTRATION

But, NCP assumes reliable network layer (IMP), PRNET is not reliable.

Cerf & Kahn:

What's the best design for an NCP replacement?

How should the network be attached to each other?

TCP replaces NCP

Cerf & Kahn:

What's the best design for an NCP replacement?

How should the network be attached to each other?

Introduces

Gateways
Addresses
IP

Goals

Robust - work despite failure of networks or gateways
Versatile - support a variety of services and networks
Permit distributed management of resources
Cost effective
Easy to add new hosts
Permit accounting of resources

Goal

"Survivability in the Face of Failure"

Communication between two entities should continue after temporary disruption without needing to reestablish connection states.

Or

Mask transient failure

Store connection states in

A. packet switching nodes
B. end nodes

Why ?

Easier to implement than replication. Replication only protects against finite number of node failures.

“Fate-Sharing”

The only way the states are lost is the failure of end hosts.

Consequences

Stateless packet switchers.

Need to trust end hosts.

Need to support
a variety of services

Services

Remote login - low delay, reliable

File transfer - delay not important, reliable

Teleconferencing - reliability not important, low delay

Choice

A. Introduces UDP.

Protocols

IP - datagram-based, best effort

TCP - reliable service over IP

UDP - unreliable service over IP

Compared to

X.25 - provides reliable services

(that cannot be switched off!)

Need to support a variety of networks

Make minimal assumptions

Can transport packets
Best effort delivery
Addressing
Minimum packet size

Not assuming

Reliability
Ordered delivery
Packet prioritization
Broadcast/multicast
Knowledge of network stats

Application-driven

TCP designed for dominant application at the time -- telnet e.g. stream-oriented seq no

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1988

Another David D. Clark's paper "End-to-End Arguments in System Design" 1984 (with Saltzer and Reed)

E2E Argument

A tool to guide designers: which layer to implement a given functionality?

Example

Reliable file transfer between host A and host B

Steps

1. *A* reads file from disk
2. *A* transmits file as packets
3. Network delivers packets
4. *B* receives packets
5. *B* write data to disk

Possible Errors

1. Disk fault
2. Software bugs
3. Packet loss
4. Processor/Memory errors
5. OS crashes

Choices

A. Make sure every step is reliable

B. End-to-end check and retry (compare checksum, resend if error)

The Argument

To achieve careful file transfer, the transfer application must apply application-specific, end-to-end reliability guarantee.

The Argument

"The end-to-end check of the file transfer application must still be implemented no matter how reliable the communication system becomes."

Conclusion

No need to provide reliability guarantee at lower level (e.g. network, OS, hardware)

Actually,

Lower level reliability can improve performance.

To implement at low-level?

Additional cost for applications that do not require the feature.

Less information than the “end”, less efficient.

Other Example:
Data Encryption

Choices

A. Encrypt at the network-level

B. Encrypt in the application

Why?

Intercept before reaching the network
Need to trust the network
Still need to authenticate

Other Example:
Duplicate Messages

Other Example: Delivery Guarantees

Other Example:
RISC

Other Example: Recovery in Telephony Exchange

The Argument

Any attempt by the computer designer to anticipate the client's requirements will probably miss the target and the client will end up re-implementing it anyway.

The End Point?

Applications?

Users?

Hosts?

The end-point is a trustworthy entity.

Example

Reliable file transfer between host A and host B

If I don’t trust the file transfer application, I need to check for error myself.

E2E Argument

"The function in question can completely and correctly be implemented only with the knowledge and help of the application standing at the endpoints of the communication system. Therefore, providing the 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)"