Advanced Topics on Information Technology (IT) 2:
Software Defined Networks

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References

Larry Peterson, Carmelo Cascone, Brian O'Connor and Thomas Vachuska, Software-Defined Networks: A Systems Approach, Systems Approach, LLC, 2021.

Konstantinos Poularakis, Leandros Tassiulas, and T.V. Lakshman, Modeling and Optimization in Software-Defined Networks, Morgan & Claypool, 2021.

Paul Göransson, et al, Software Defined Networks – A Comprehensive Approach, Second edition, Morgan Kaufmann, 2016.

Larry L. Peterson and Bruce S. Davie, Computer Networks: A systems approach, 6th Edition, Morgan Kaufmann Publisher, 2022.

Grading

Active participation in class and discussion	5%
Paper presentation It includes three mid-term papers selected by the instructor and one final paper selected by the student. The presenter is expected to provide slides as well as writing a report (3-5 pages) for each paper.	40%
Programming assignments	25%
Final project	30%

Bonus grades	
New ideas and innovations during presenting the final paper	+5%
Presenting a paper from the optional reading list	+5%

A History of Computing Industry as Vertical Market

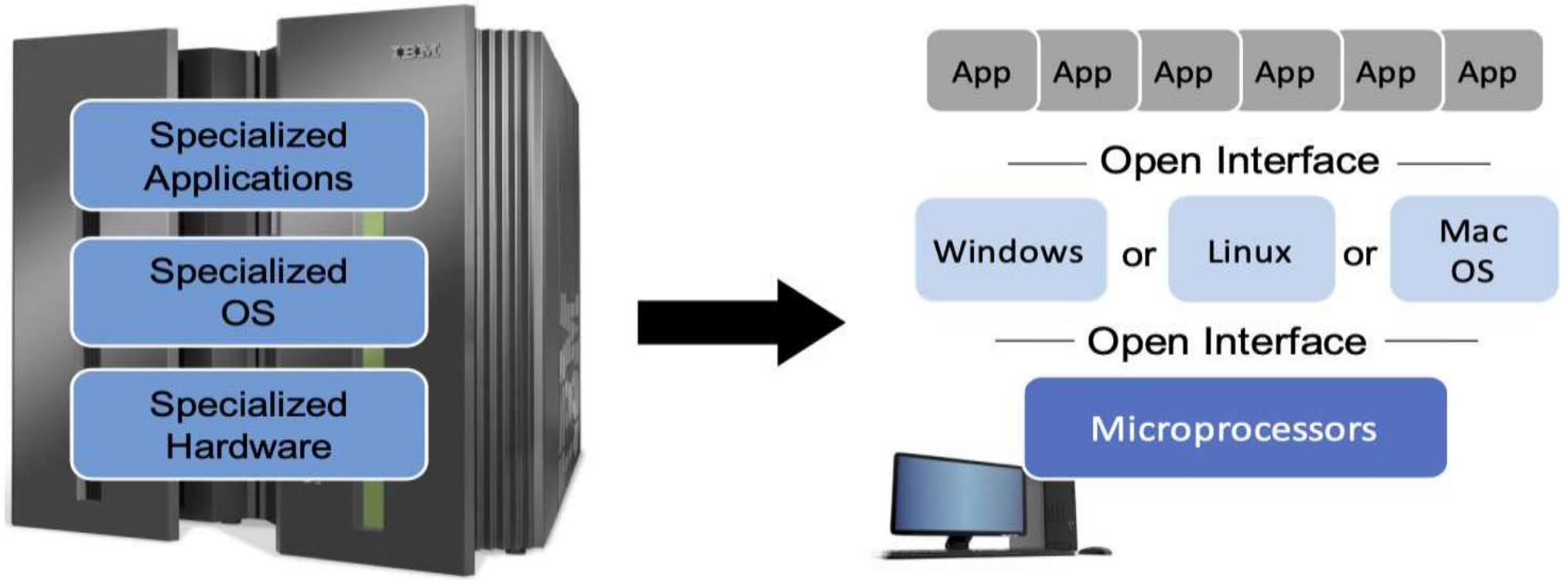


Figure 1. Transformation of the vertical mainframe market to a horizontal marketplace with open interfaces and multiple options available at every level.

Transformation of the vertical router market to horizontal marketplace

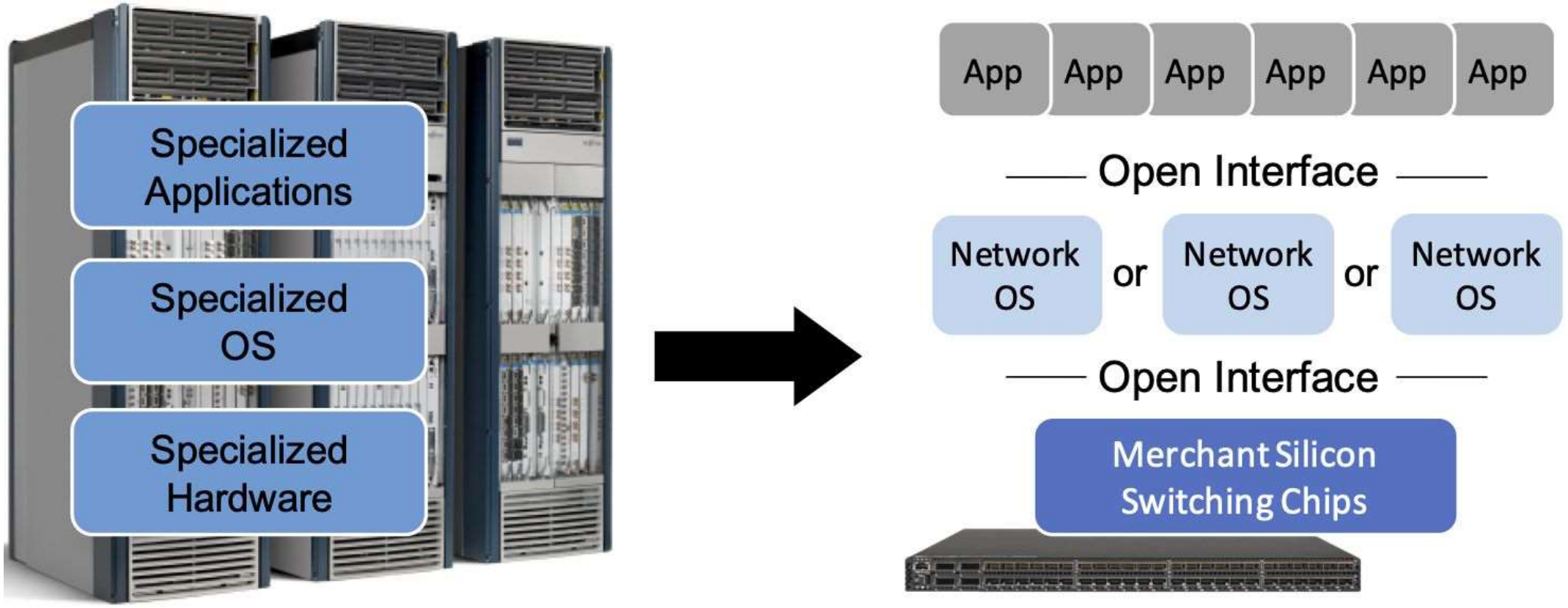


Figure 2. Transformation of the vertical router market to a horizontal marketplace with open interfaces and multiple options available at every level.

Technical Landscape

- SDN is an approach not a point solution.
- What are the design principles at the core of this approach?
- One important takeaway is that there would be more than one possible end-state.
- Each network operator would be free to pick different design points and build out their network accordingly.

The Main Objective of SDN

Given that the whole point of SDN is to disrupt the existing vertical market, it should come as no surprise that incumbent vendors would offer *hybrid* solutions that align with their established business models and ease adoption.

Disaggregating the Control and Data Planes

- The seminal idea behind SDN is that networks have distinct *control* and *data* planes, and the separation of these two planes should be codified in an open interface.
- In the most basic terms, the control plane determines *how* the network should behave, while the data plane is responsible for implementing that behavior on individual packets.

An Example

- For example, one job of the control plane is to determine the route packets should follow through the network (perhaps by running a routing protocol like BGP, OSPF, or RIP),
- and the task of forwarding packets along those routes is the job of the data plane, in which switches making forwarding decisions at each hop on a packet-by-packet basis.

Decoupling the Control and Data Planes

In practice, decoupling the control and data planes manifests in parallel but distinct data structures:

- the control plane maintains a *routing table* that includes any auxiliary information needed to select the best route at a given point in time,
- while the data plane maintains a *forwarding table* that is optimized for fast packet processing.

RIB & FIB

- The routing table is often called the *Routing Information Base (RIB)*
- and the forwarding table is often called the *Forwarding Information Base (FIB*), as depicted in Figure 3.

Disaggregating the Control and Data Planes

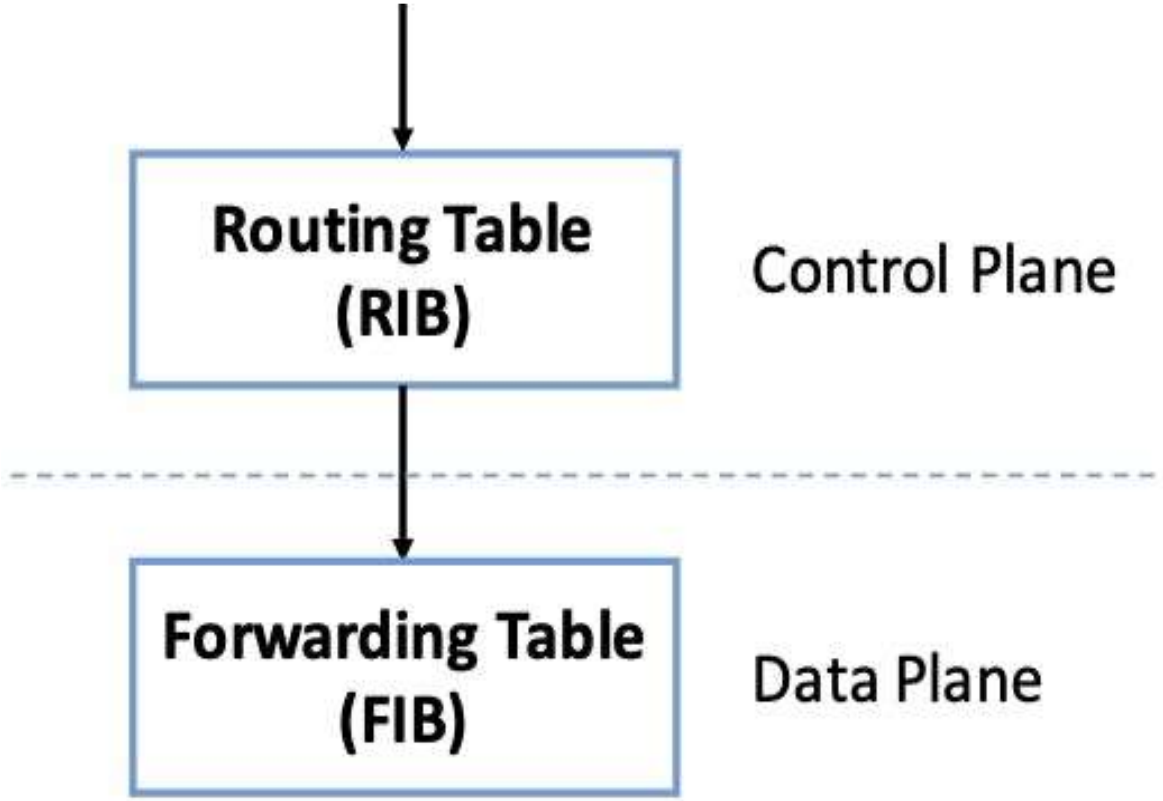


Figure 3. Control plane (and corresponding RIB) decoupled from the data plane (and the corresponding FIB).

Disaggregation

- But the first principle of SDN is that the interface between the control and data planes should be both well-defined and open.
- This strong level of modularity is often referred to as *disaggregation*, and it makes it possible for different parties to be responsible for each plane.

OpenFlow

- The original interface supporting disaggregation, called *OpenFlow*, was introduced in 2008,
- and although it was hugely instrumental in launching the SDN journey, it proved to be only a small part of what defines SDN today.

Header Fields in Original OpenFlow Specification

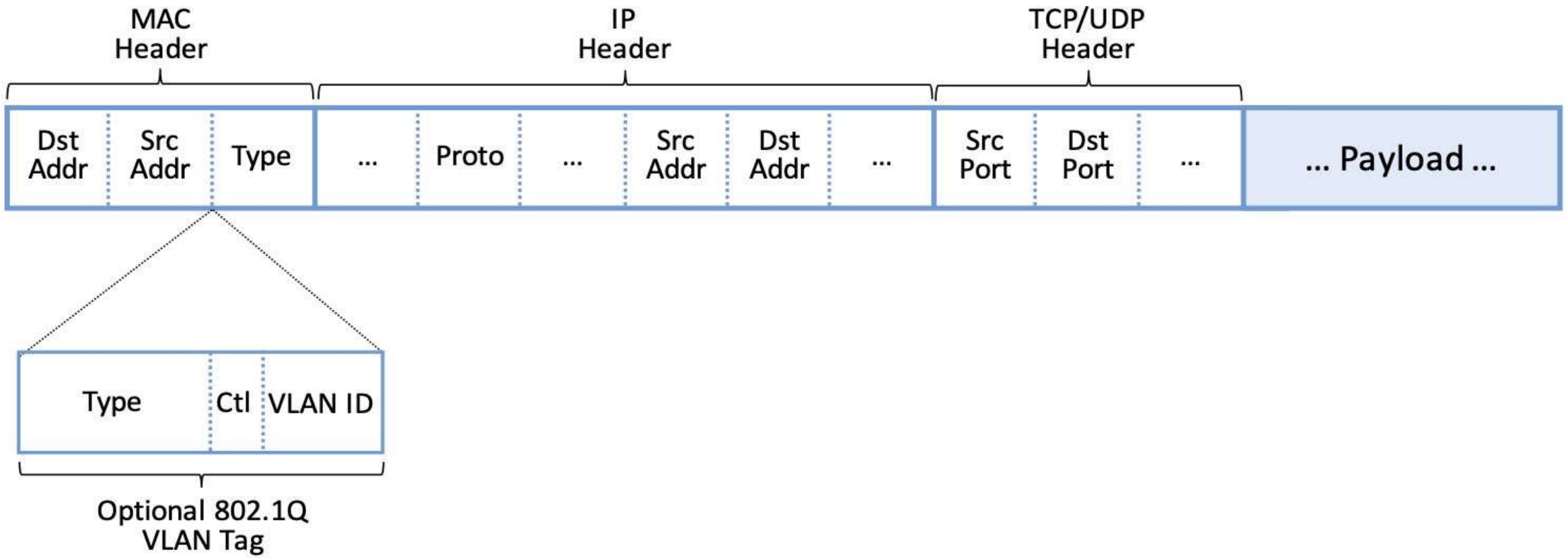


Figure 4. Header Fields Matched in Original OpenFlow Specification.

Flow Table

- Building on the flow rule abstraction, each switch then maintains a *Flow Table* to store the set of flow rules the controller has passed to it.
- OpenFlow also defined a secure protocol with which flow rules could be passed between the controller and the switch, making it possible to run the controller off-switch.

OpenFlow Protocol

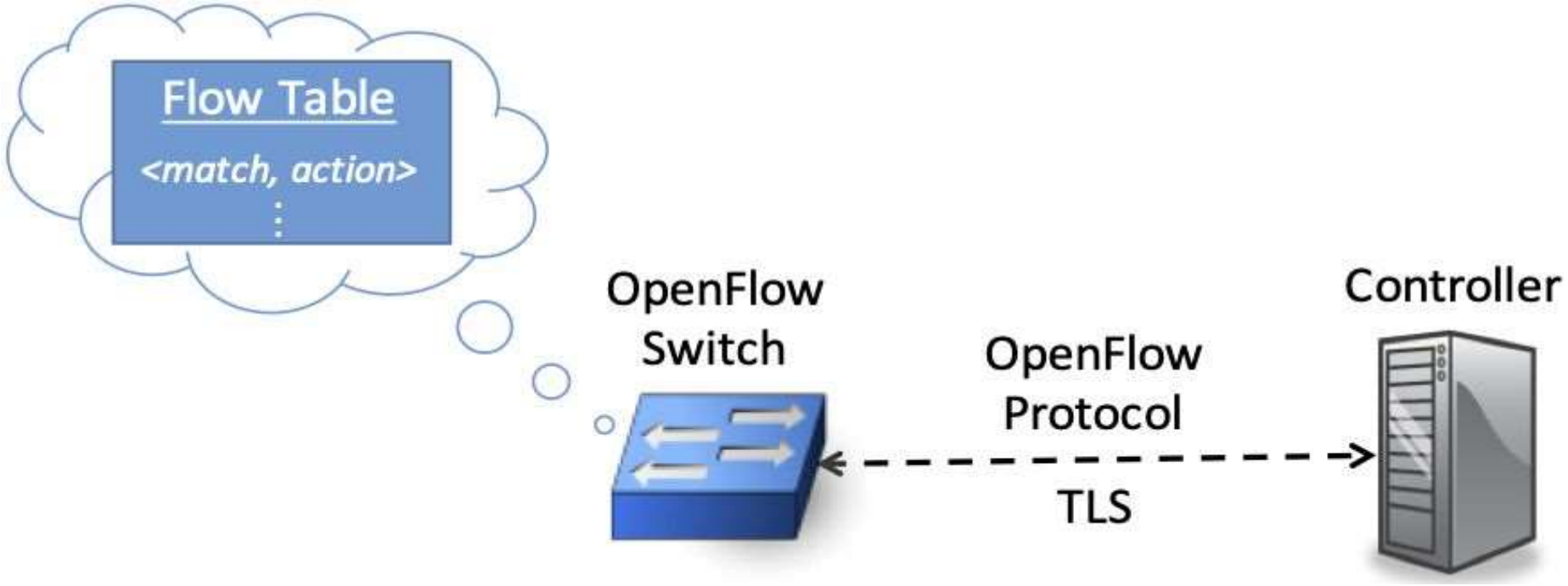


Figure 5. Controller securely passes flow rules to an OpenFlow-enabled switch, which maintains a Flow Table.

P4 Programming Language

- Today, the OpenFlow specification has been through multiple revisions, and work is underway to replace it with a more flexible (i.e., programmable) alternative.
- We return to OpenFlow—and P4, the alternative programming language—in Chapter 4.

Control Plane: Distributed

- One option is to run the software that implements the control plane *on-switch*.
- Doing so implies each switch operates as an autonomous device, communicating with its peer switches throughout the network to construct a local routing table.

Control Plane: Centralized

- An alternative is that the control plane should be fully independent of the data plane and logically centralized. This implies the control plane is implemented *off-switch*, for example, by running the controller in the cloud.
- It is also possible to adopt a mixed approach, with some control functionality running on-switch and some running off-switch, in a cloud-hosted controller.

Logically Centralized Controller

We say logically centralized because while the state collected by the controller is maintained in a global data structure (think of this as the centralized counterpart to the per-switch routing table), the implementation of this data structure could still be distributed over multiple servers, as is now the best practice for cloud-hosted, horizontally scalable services.

Network Operating System (NOS) as a logically centralized point of control

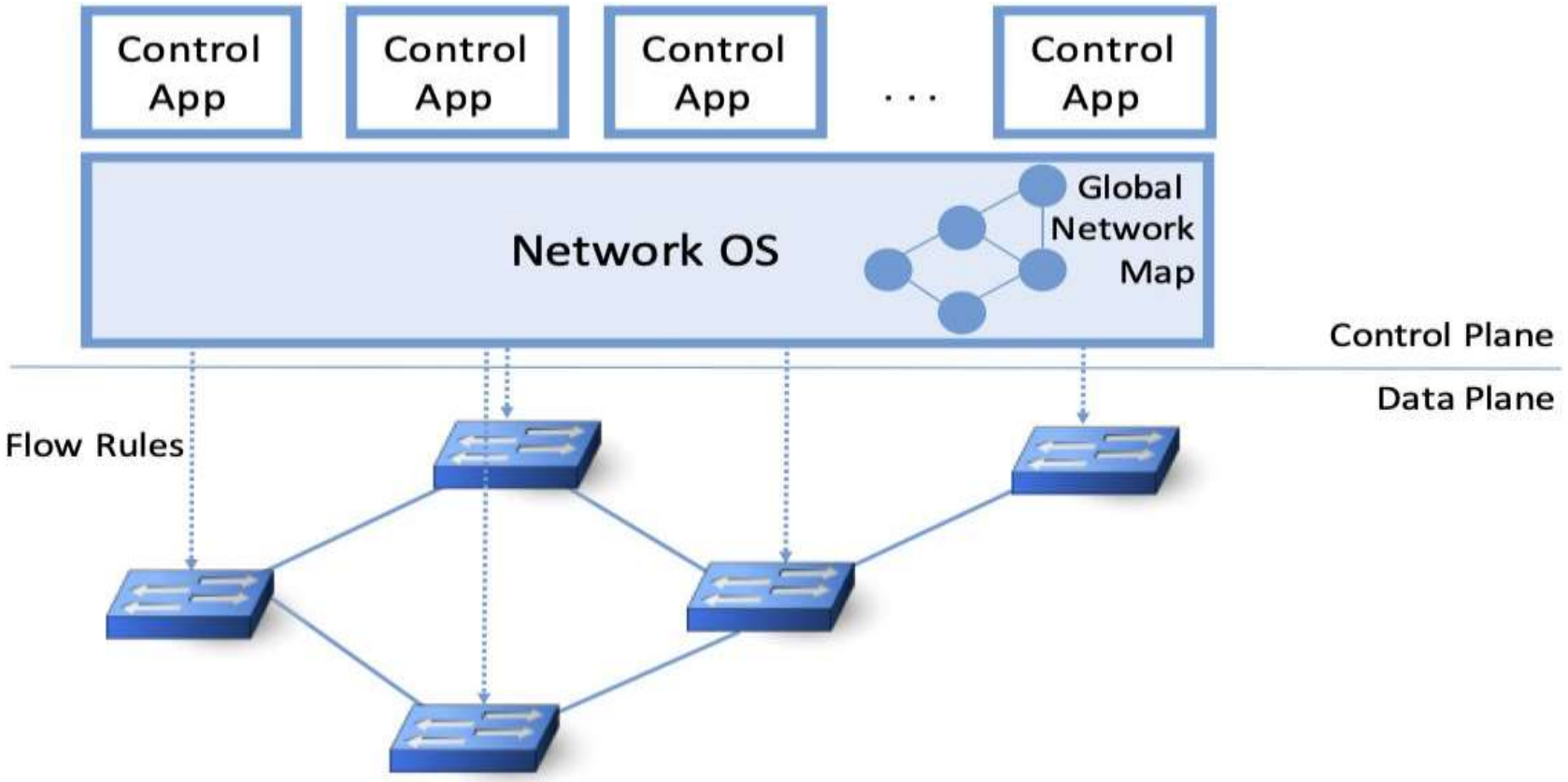


Figure 6. Network Operating System (NOS) hosting a set of control applications and providing a logically centralized point of control for an underlying network data plane.

Data Plane: Programmable vs Fixed- Function

The final dimension of the design space is whether the switches that implement the data plane are programmable or fixed-function.

An OpenFlow Switch

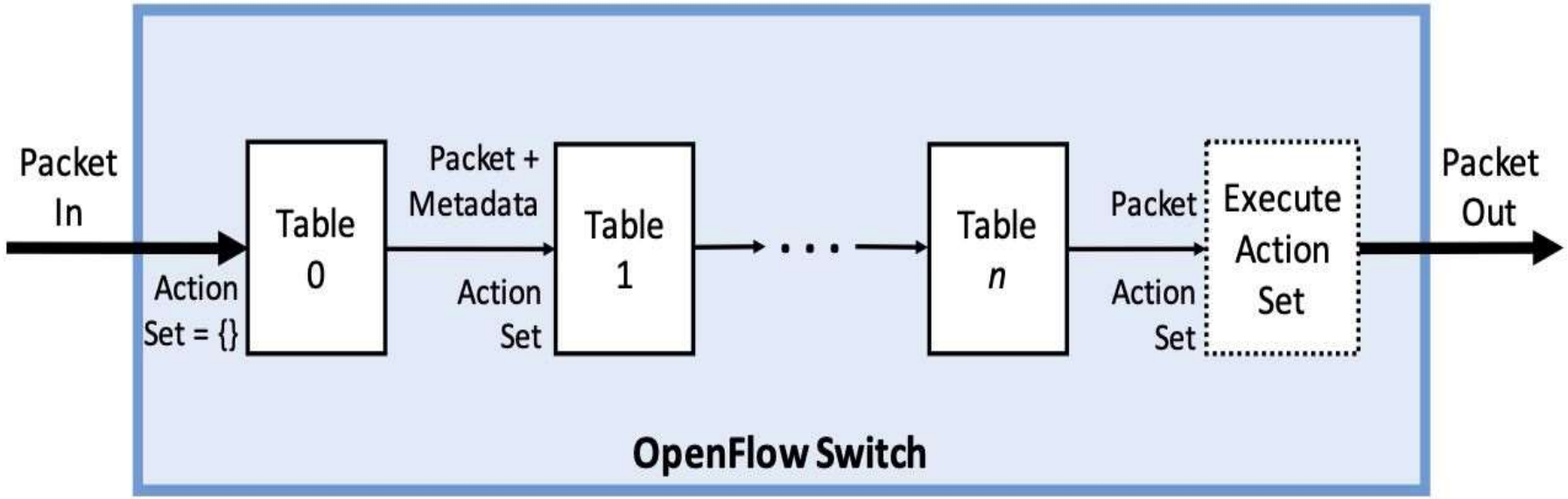


Figure 7. Simple Schematic of an OpenFlow Forwarding Pipeline.

Virtual Extensible LAN (VXLAN)

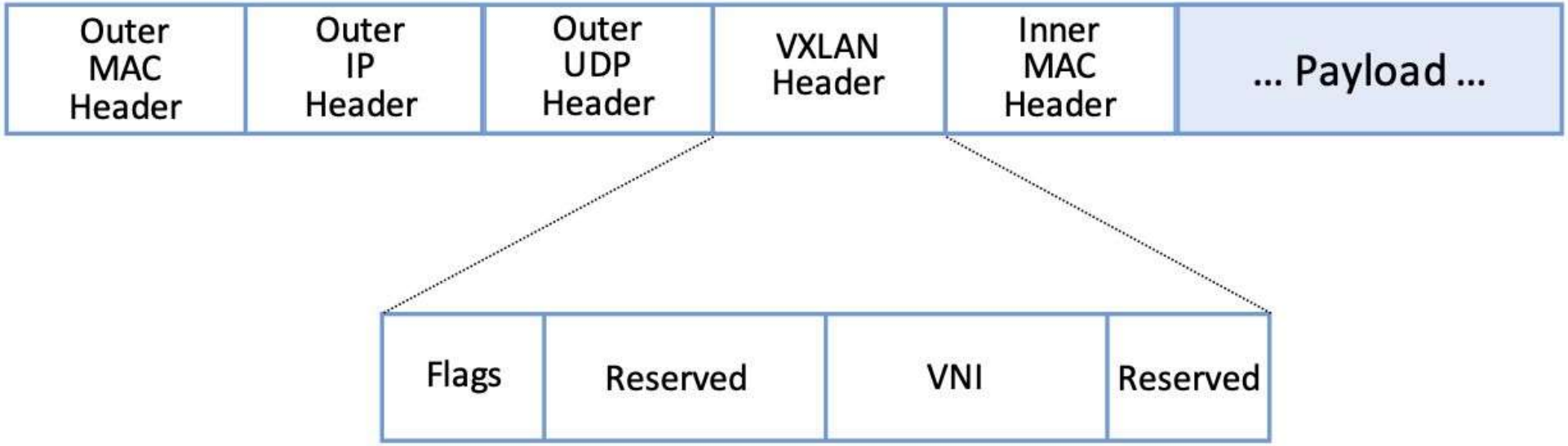


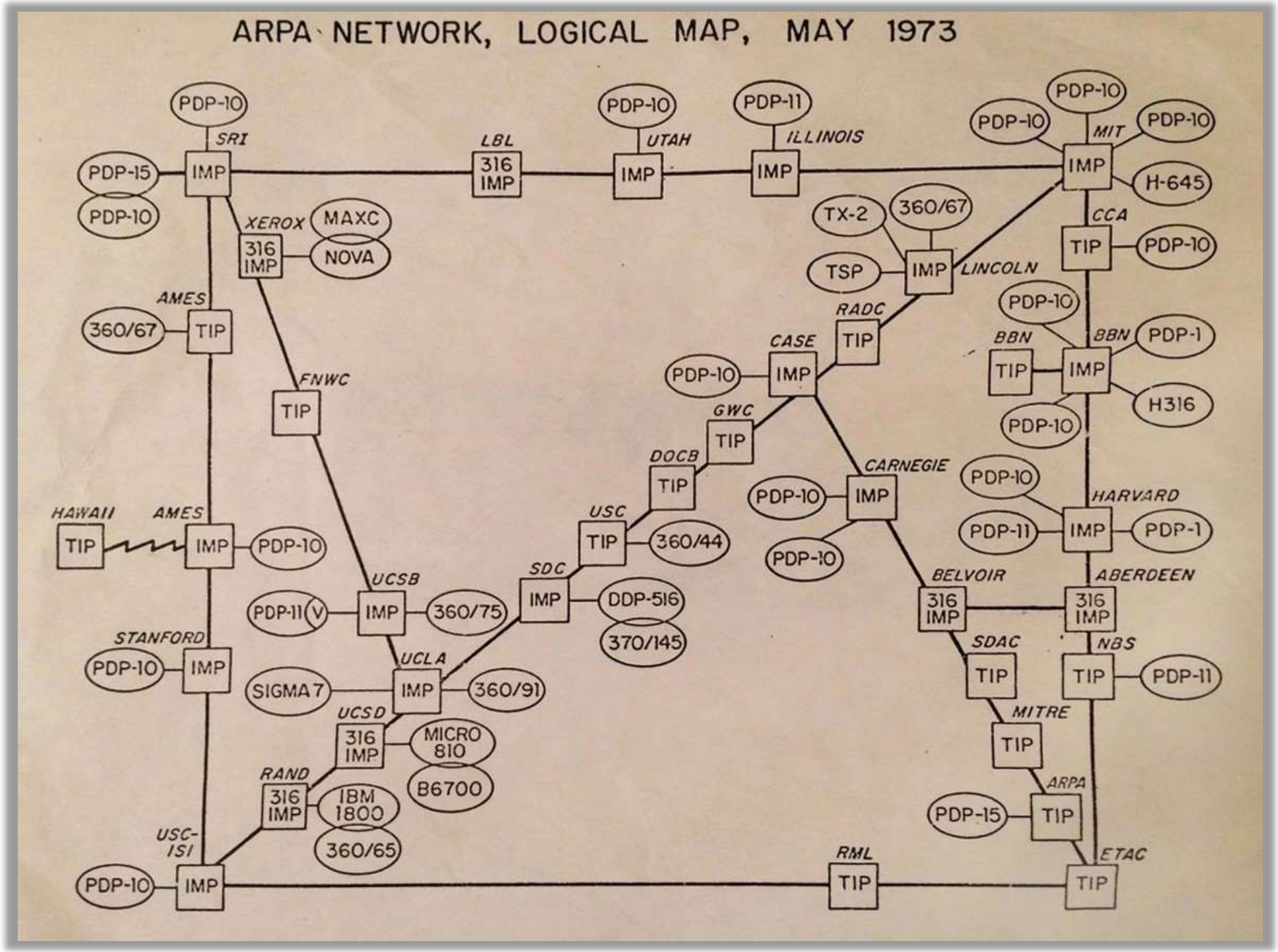
Figure 8. VXLAN Header encapsulated in a UDP/IP packet.

SDN: A Definition

From Nick McKeown's 2013 presentation entitled *Software Defined Networking*:

A network in which the control plane is physically separate from the forwarding plane, and a single control plane controls several forwarding devices.

What are the Origins of Today's Internet?


ARPA NETWORK, LOGICAL MAP, MAY 1973
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ILLINOIS
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H-645
XEROX
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MAXC
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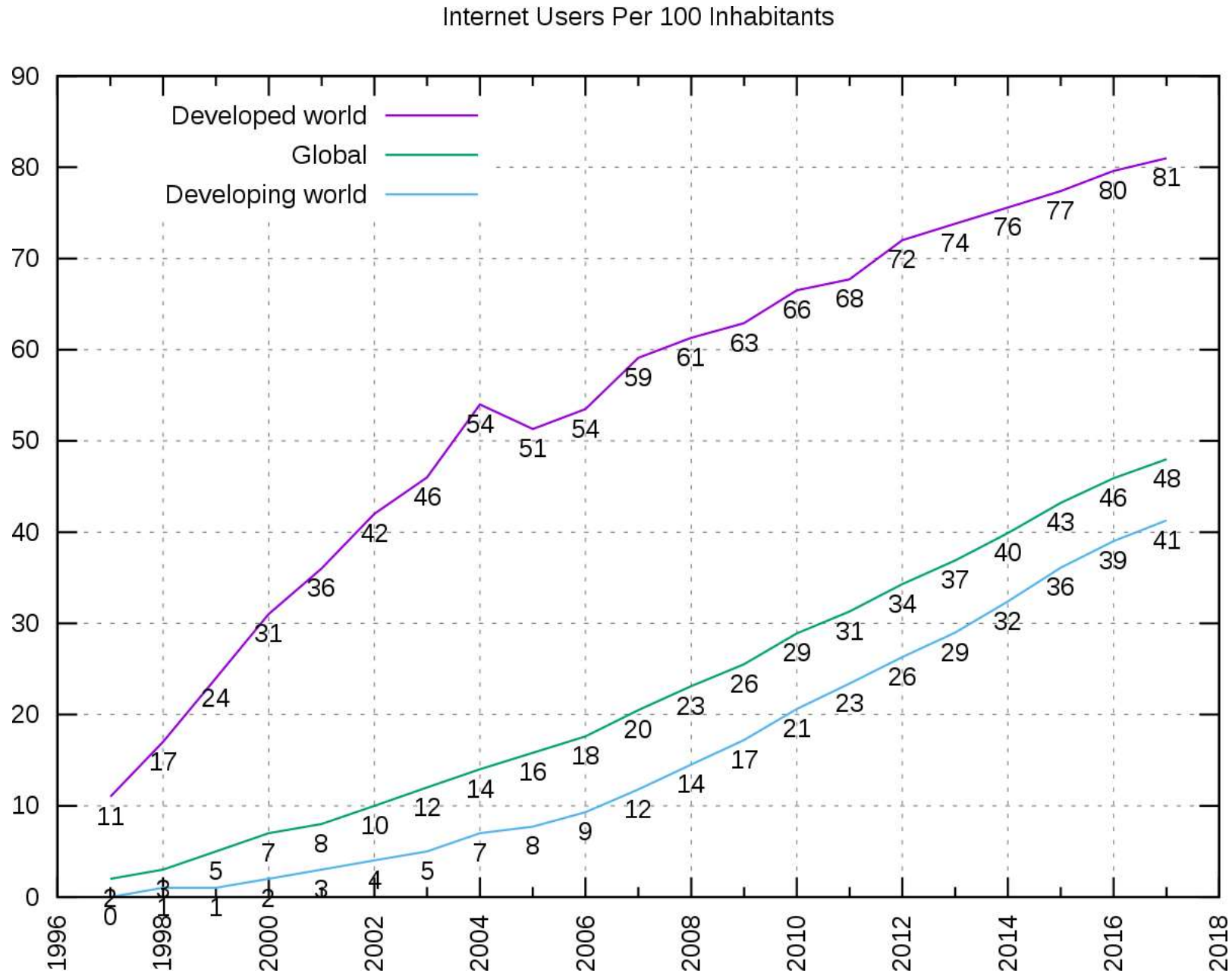
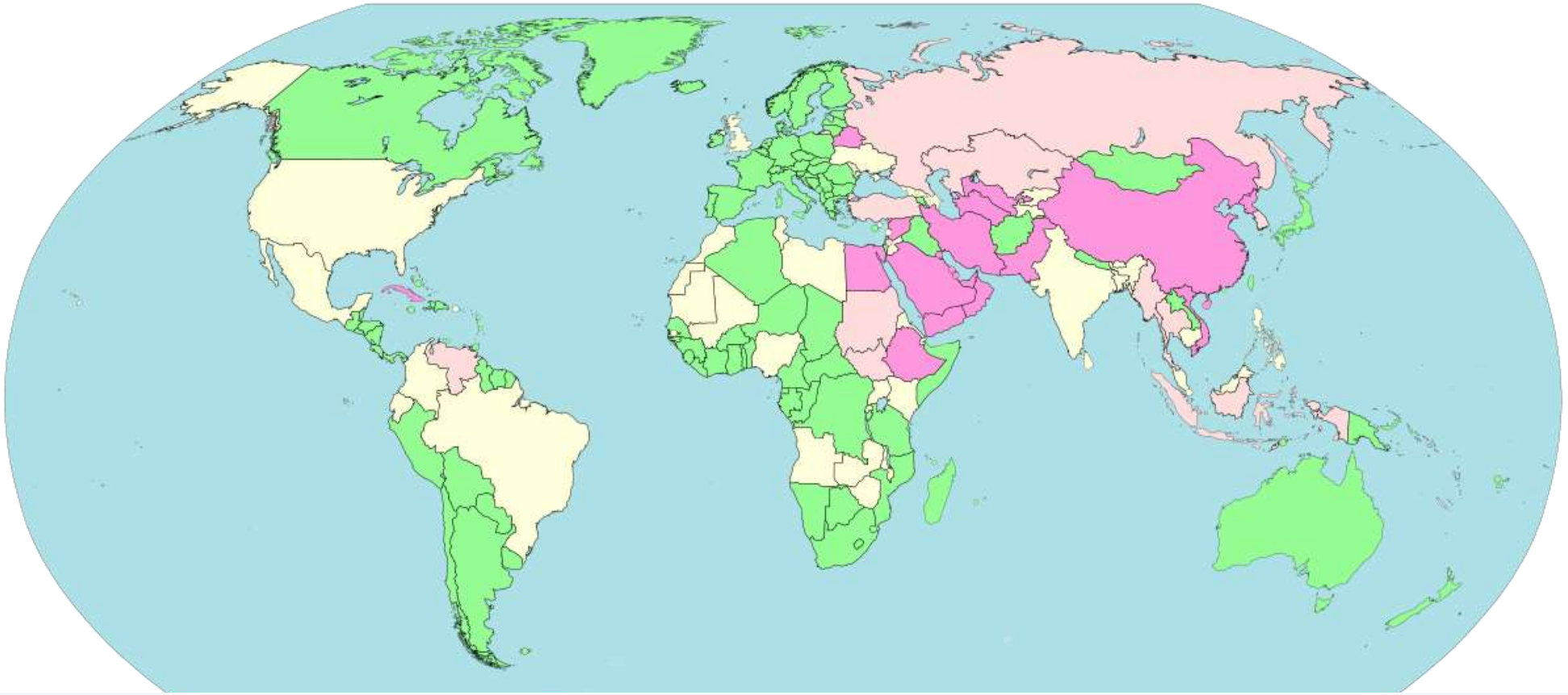


https://en.wikipedia.org/wiki/Global_Internet_usage

How does the design of the Internet support growth and foster innovation?

The Internet is a Tense Place



Internet censorship and surveillance by country (2018)

- Pervasive censorship and/or surveillance
- Substantial censorship and/or surveillance
- Selective censorship and/or surveillance
- Little or no censorship and/or surveillance
- Not classified / No data

https://en.wikipedia.org/wiki/Global_Internet_usage

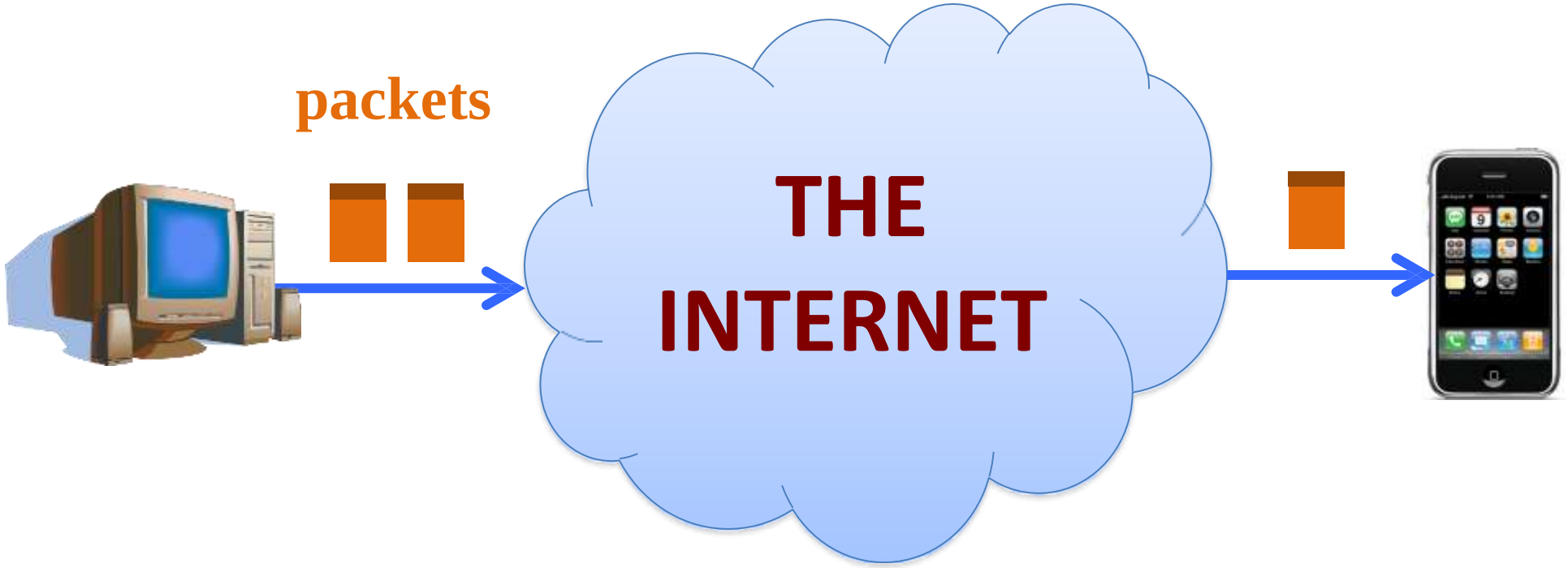
What is the Internet?

http://en.wikipedia.org/wiki/Internet

The Internet is the worldwide, publicly accessible network of interconnected computer networks that transmit data by packet switching using the standard Internet Protocol (IP).

It is a "network of networks" that consists of millions of smaller domestic, academic, business, and government networks, which together carry various information and services.

“Best-Effort Packet Delivery Service”



Power at the Edge

End-to-End Principle

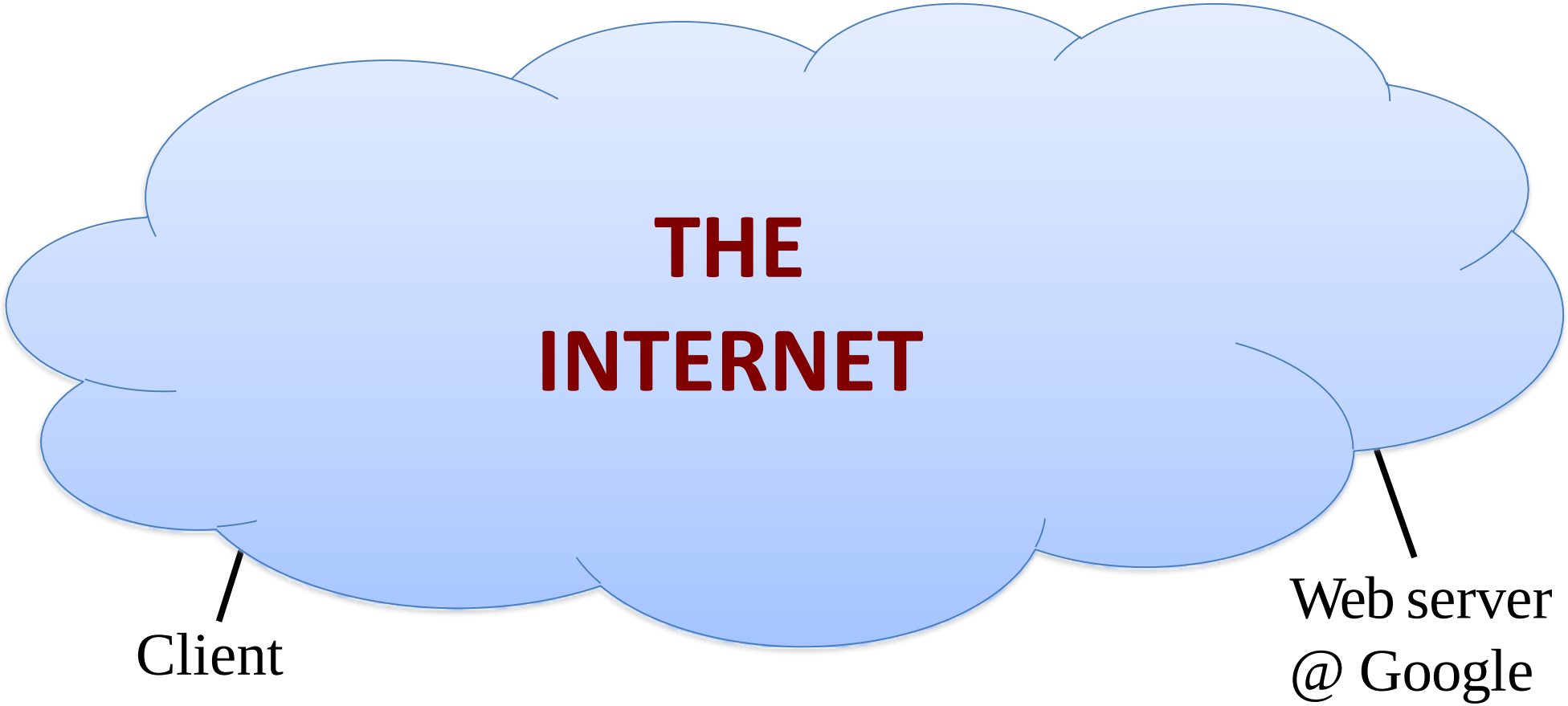
Whenever possible, communications protocol operations should be defined to occur at the end-points of a communications system.

Programmability

With programmable end hosts, new network services can be added at any time, by anyone.

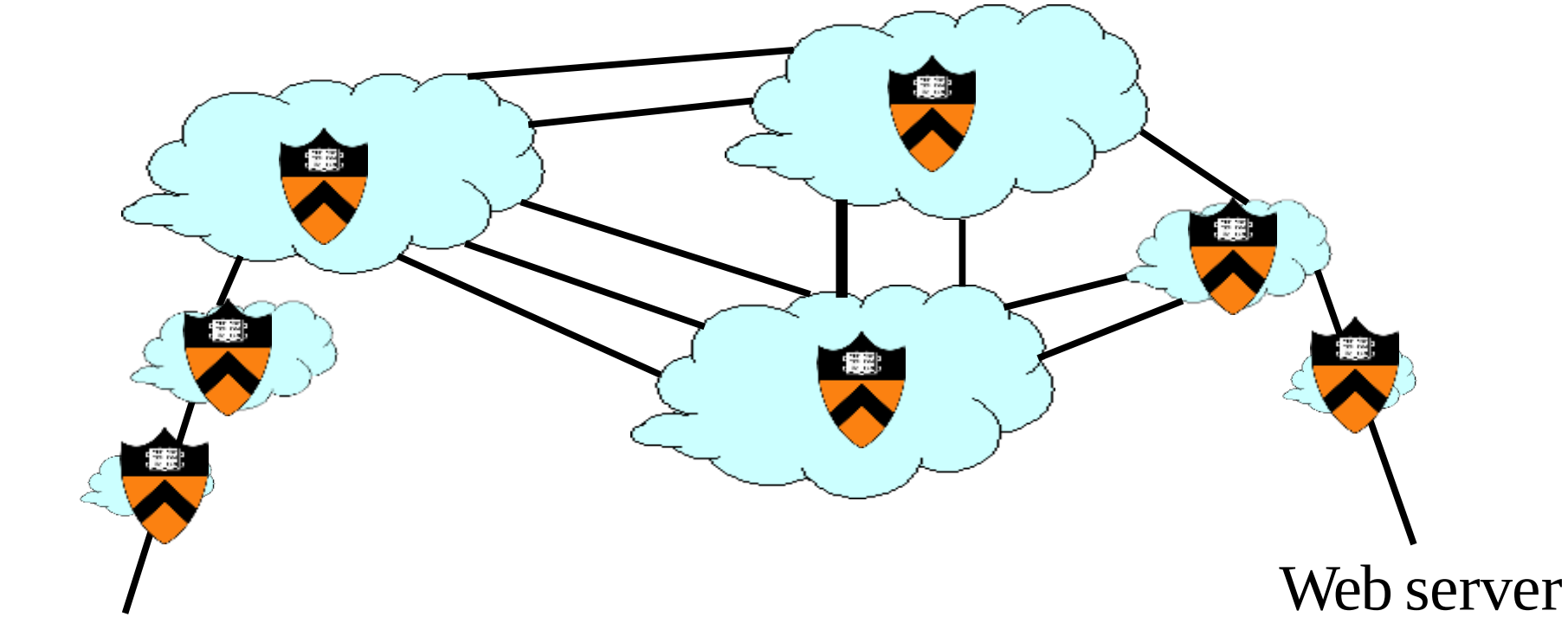
And end hosts became powerful and ubiquitous….

“A Network of Networks”



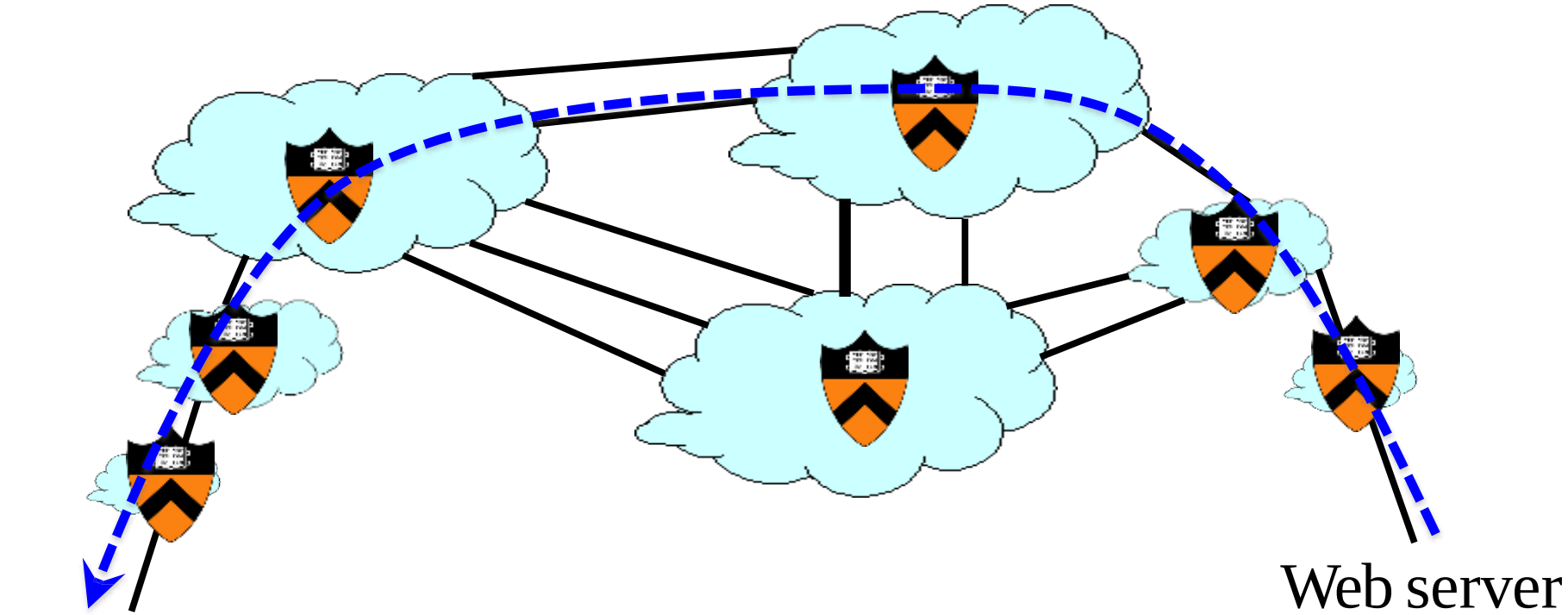
- How do you name?
- How do you find a name?

Announcing a Route



"Sharif is in this direction"

Forwarding Traffic



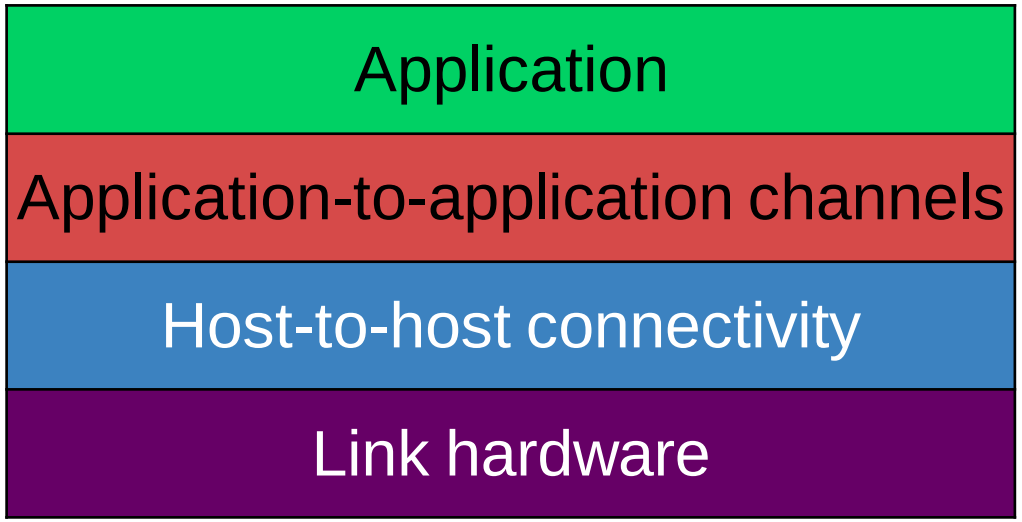
Client
Browser
@ Sharif

Web server
@ Google

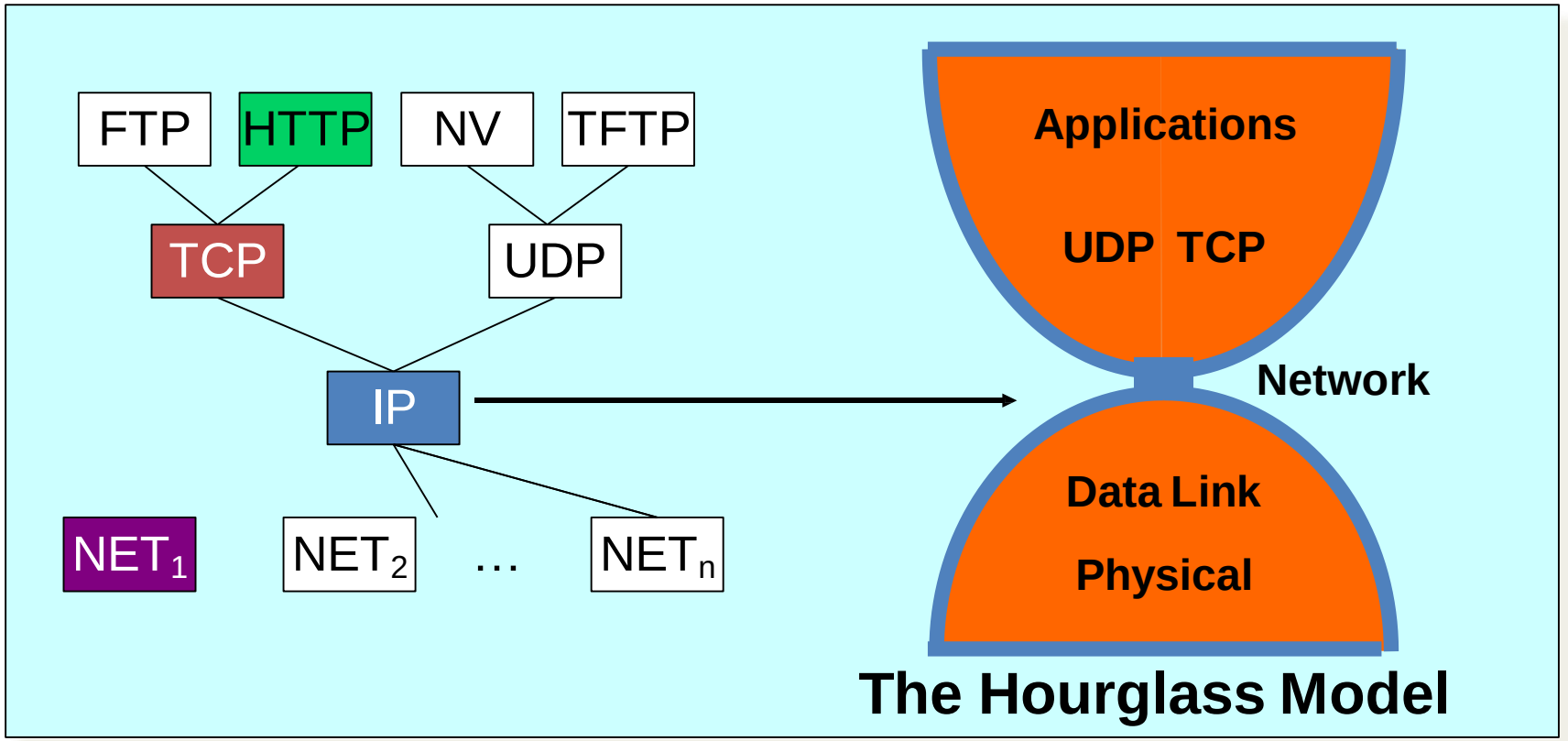
Central concepts in networking

Abstraction through Protocol Layering

- Layers partition the system
  - Each layer solely relies on services from layer below
  - Each layer solely exports services to layer above
- Interface between layers defines interaction
  - Hides implementation details
  - Layers can change without disturbing other layers

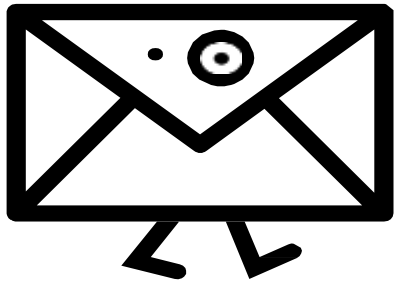


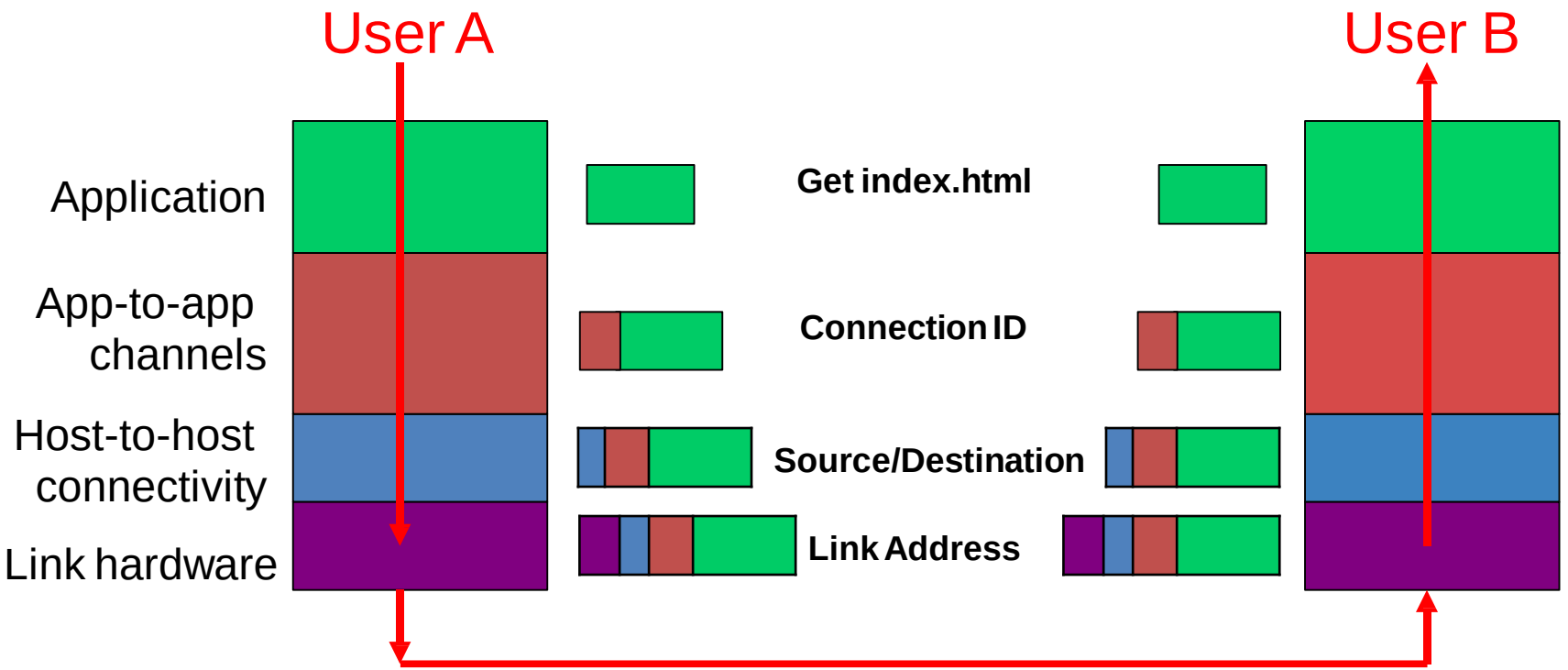
The Internet Protocol Suite



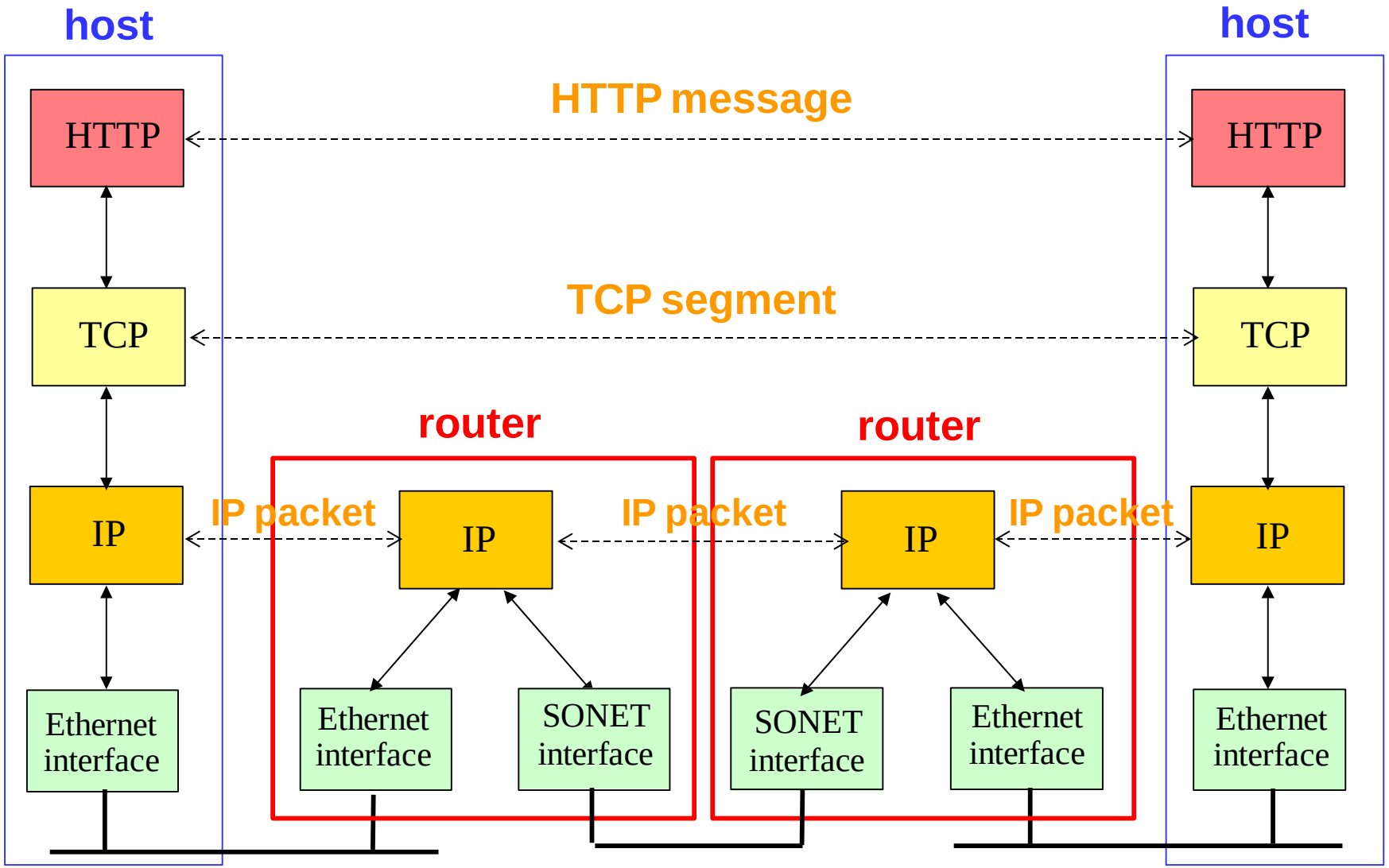
The thin Network layer facilitates **interoperability**

Layer Encapsulation in HTTP





End Hosts vs. Routers



Key Concepts in Networking

- Naming
  - What to call computers, services, protocols, …
- Layering
  - Abstraction is the key to managing complexity
- Protocols
  - Speaking the same language
  - Syntax and semantics
- Resource allocation
  - Dividing scare resources among competing parties
  - Memory, link bandwidth, wireless spectrum, paths