

Part I Syllabus

Date	Subject	File
Week 1: 9/Jan/2023 11/Jan/2023	Introduction: course logistics and Internet history	M1-L1-Introduction.pptx
	Layered Network Architecture	First part of M1-L2-Network Layer & Physical Resilience.pptx
Week 2: 16/Jan/2023 18/Jan/2023	Physical Layer: Network Resilience	Second part of M1-L2-Network Layer & Physical Resilience.pptx
	Data link layer – Flow control	M1-L3-DLL-Flow Control.pptx
Week 3: 25/Jan/2023	Data link layer – Error control	M1-L4-DLL-Error Control.pptx
Week 4: 30/Jan/2023 01/Feb/2023	Local area network – Introduction	M1-L5-LAN-Introduction.pptx
	Local area network – MAC	M1-L6-LAN-MAC.pptx
Week 5: 06/Feb/2023 08/Feb/2023	Local area network – Ethernet	First part of M1-L7-LAN-Ethernet.pptx
	Local area network – Ethernet Evolutions	Second part of M1-L7-LAN-Ethernet.pptx
Week 6: 13/Feb/2023 15/Feb/2023	Local area network – WLAN	M1-L8-LAN-WLAN.pptx
	Network paradigms	M1-L9-Paradigms.pptx

Which one is more valuable?



SC2008/CZ3006/CE3005

Computer Network

Lecture 2

Network Layers and Physical Resilience



Contents

- **Layered Network Architecture**
 - Motivations and Benefits
 - OSI 7-Layer **Model**
 - Internet 5-Layer **Implementation** (i.e., TCP/IP)
- **Physical Resilience**
 - Link Failure probability
 - Network resilience calculation

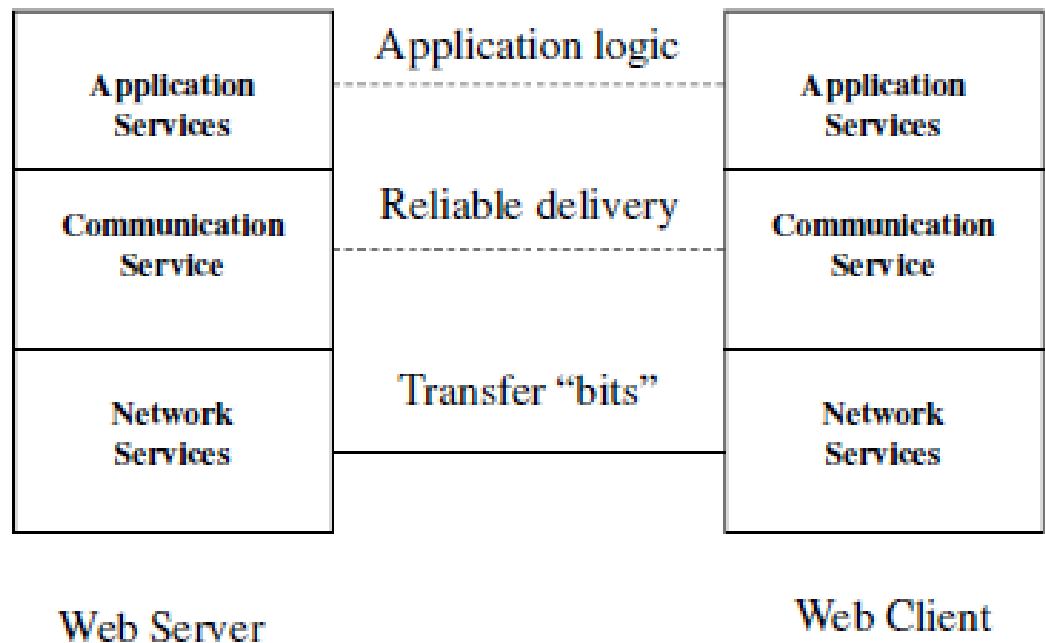
Layered Network Architecture

Motivations for Layered Network Architecture

- **Networks are complex** with many pieces
 - Hosts, routers, links, applications, protocols, hardware, software
- **Dealing with complex systems**
 - Explicit structure allowing identification, relationship of different pieces
 - Layered reference model for discussion
 - **Modularization** easing maintenance and updating
 - Change of layer's service transparent to rest of system
 - Change in network technology does not affect rest of system
 - **Layering** (design vs implementation)

A Layered Example for Web

- **Browser requests web page from server**
- **Server determine if access is granted**
- **Reliable transfer page from server to client**
- **Physical transfer of bits from server to client**



Layered Network Architecture

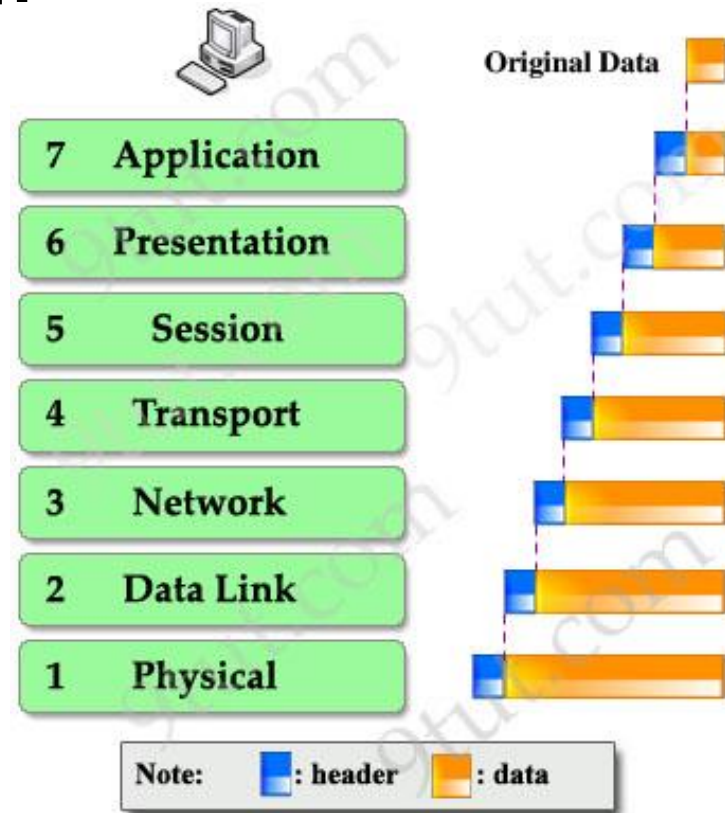
- **Network organized as a stack of layers**
 - Purpose of layer is to offer services to the layer above it and passes data & control information to the layer below, using a well-defined interface
 - Reducing design complexity
- **Protocols: a set of rules governing communication between two peering parties/computers**
 - define format, order of messages sent and received among network entities, and actions taken on message transmission & receipt.
- **Network Architecture: a set of layers and protocols with specifications enabling hardware/software developers to build systems compliant with a particular architecture**

Benefits of Layers

- **Simplicity**
 - Easy to design once layers and their interactions are defined clearly
- **Flexibility**
 - Easy to modify and develop networks by separate layers modifications
- **Incremental Changes**
 - Easy to add new layers, add new functions to a layer

OSI 7-Layer Model

- **Function Decomposition**
 - Weakly-decoupled stack
- **Encapsulation**
 - Each layer adding new headers
- **Peering**
 - Only peer layer “communicating” with each other

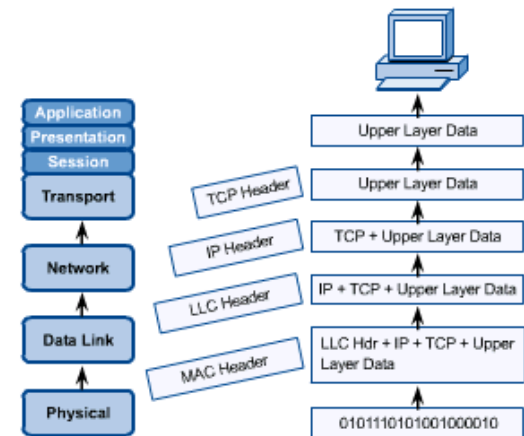
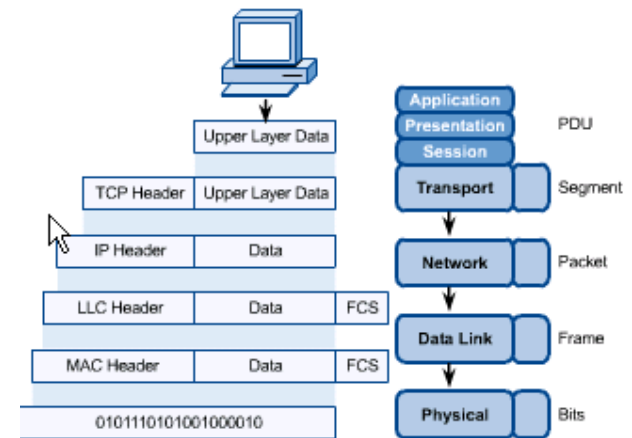


OSI Reference Model: 7 Layers (More on Supplementary Materials)

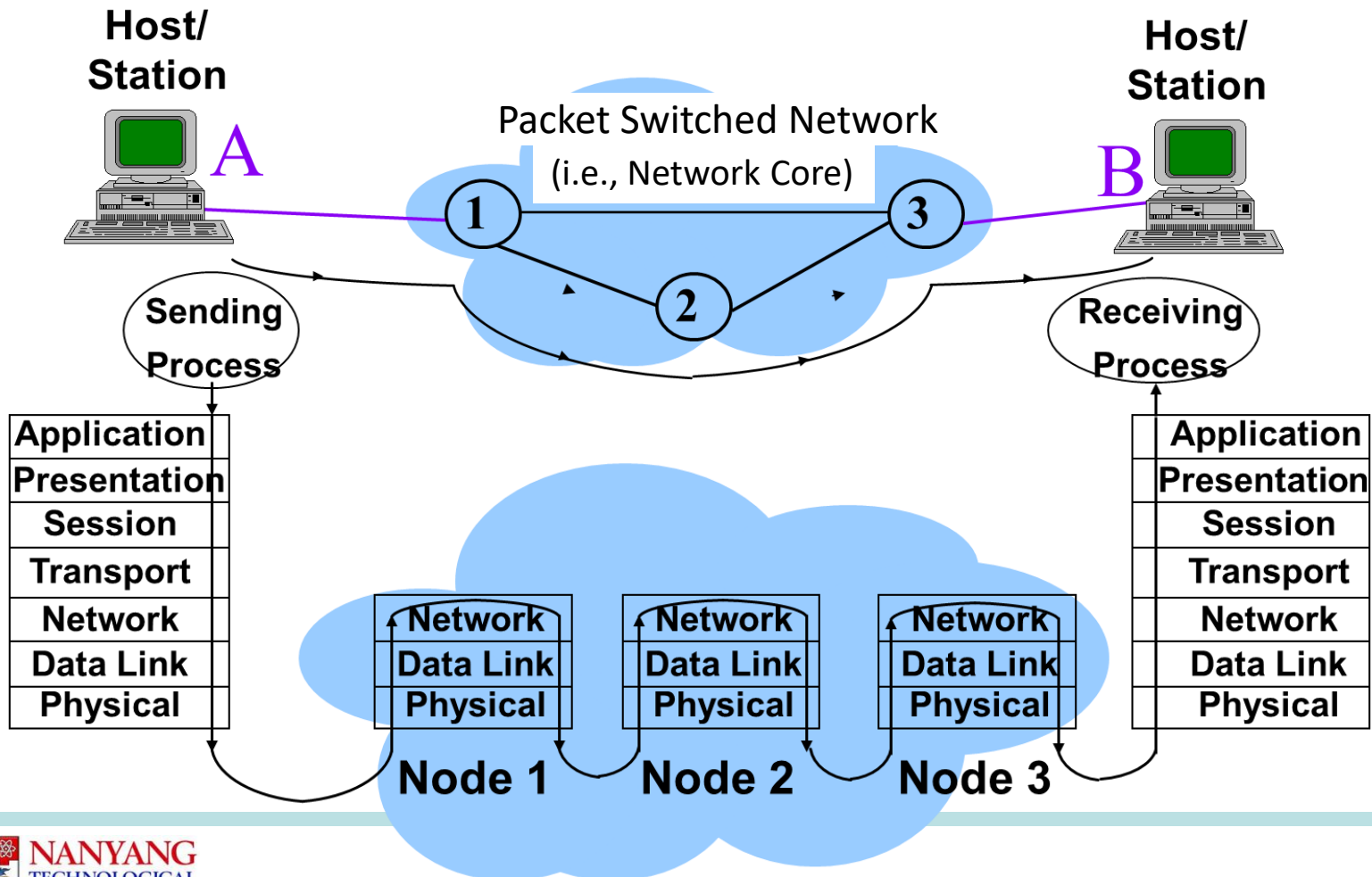
OSI Model			
	Data unit	Layer	Function
Host layers	<u>Data</u>	7. <u>Application</u>	Network process to application
		6. <u>Presentation</u>	Data representation, encryption and decryption, convert machine dependent data to machine independent data
		5. <u>Session</u>	Inter-host communication, managing sessions between applications
	<u>Segment</u>	4. <u>Transport</u>	End-to-end connections, reliability and <u>flow control</u>
Media layers	<u>Packet</u>	3. <u>Network</u>	Path determination and <u>logical addressing</u>
	<u>Frame</u>	2. <u>Data link</u>	<u>Physical addressing</u>
	<u>Bit</u>	1. <u>Physical</u>	Media, signal and binary transmission

OSI in Action: Encapsulation

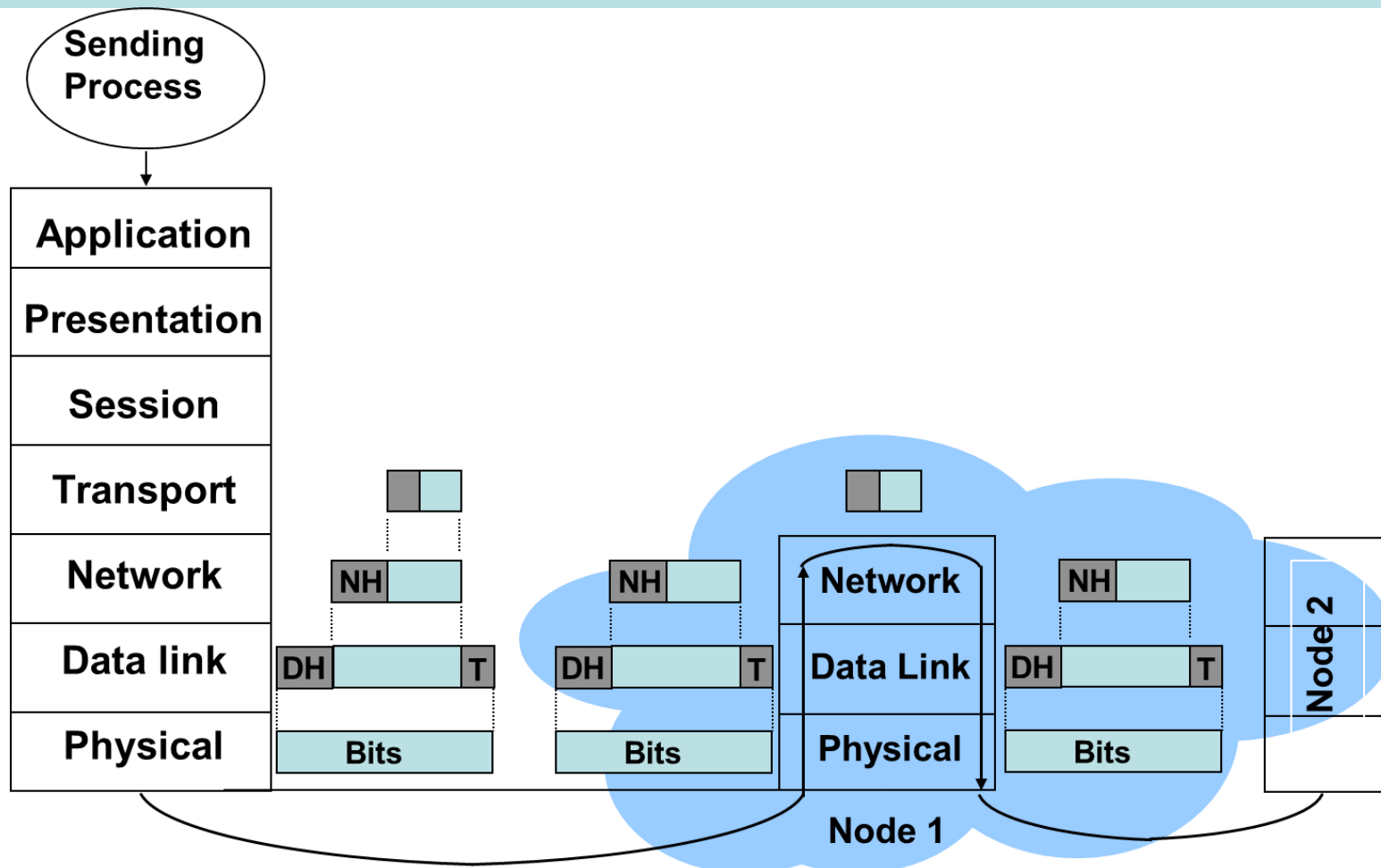
- A message begins at the top application layer and moves down the OSI layers to the bottom physical layer
- As the message descends, each successive OSI model layers adds a header to it
- A header is layer-specific information that basically explains what functions the layer carries out
- Conversely, at the receiving end, headers are stripped from the message as it travels up the OSI layers.



A Simple Computer Network

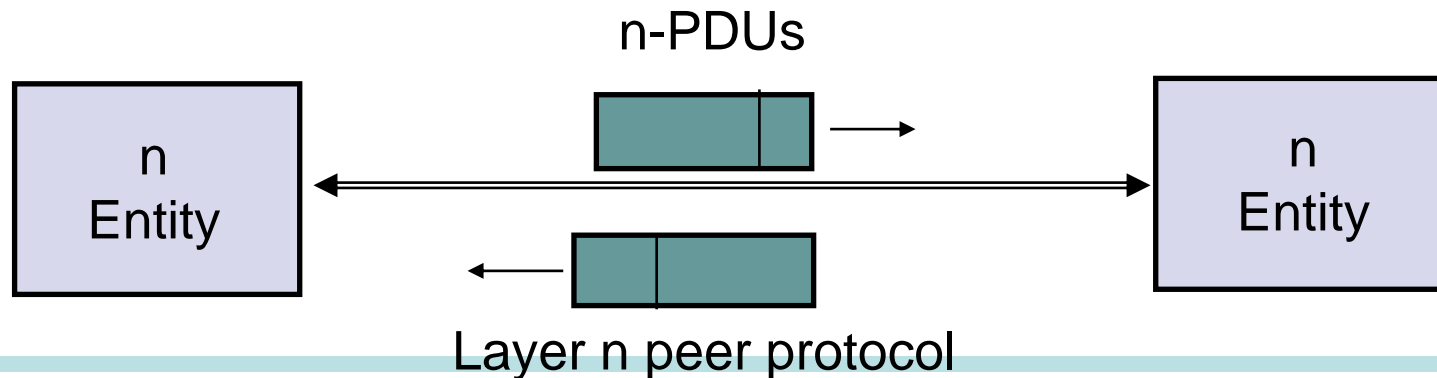


Header Processing at Switch Node



OSI Unified View: Protocols

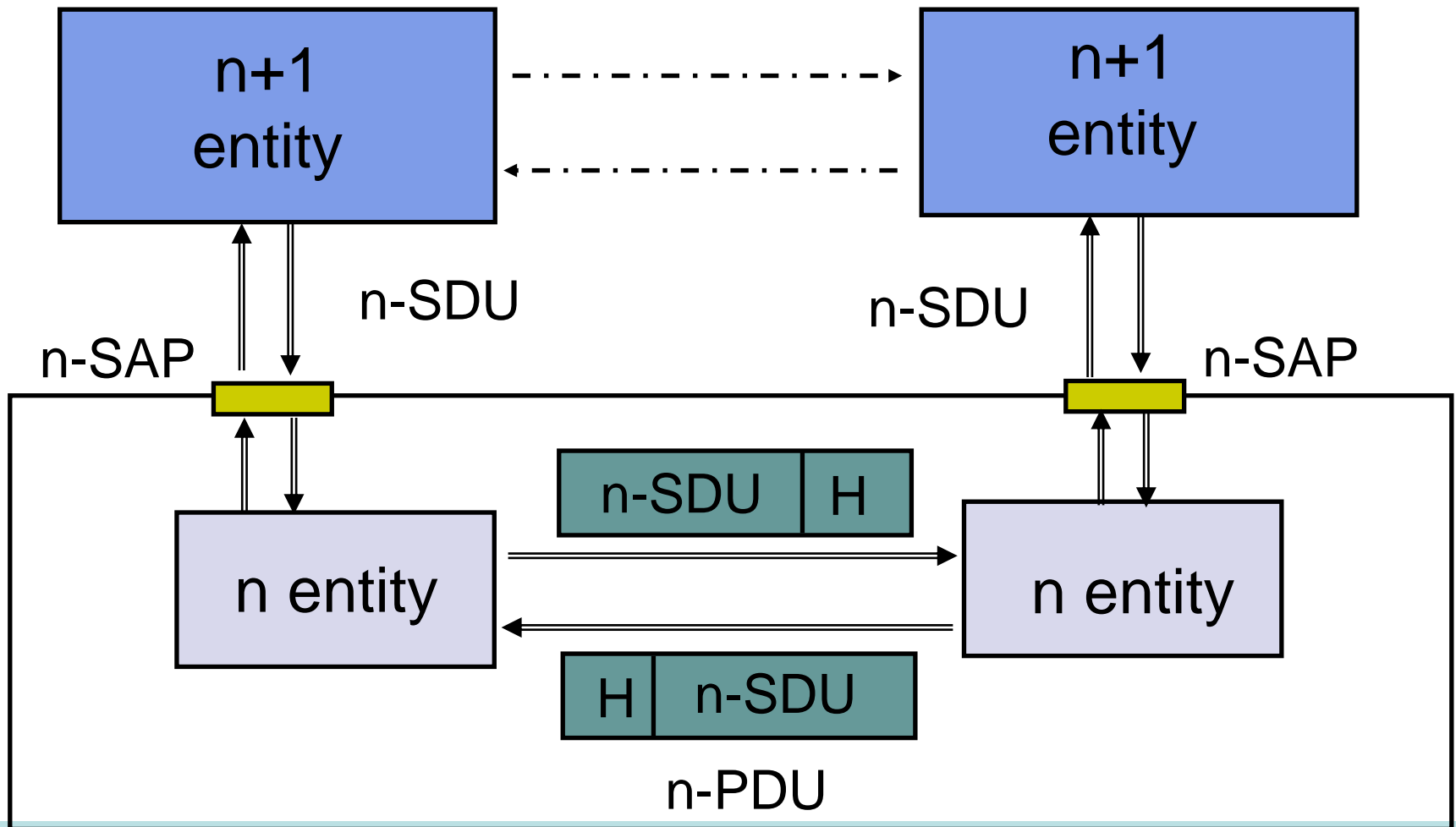
- Layer n in one machine interacts with layer n in another machine to provide a service to layer $n + 1$
- The entities comprising the corresponding layers on different machines are called *peer processes*.
- The machines use a set of rules and conventions called the *layer- n protocol*.
- Layer- n peer processes communicate by exchanging *Protocol Data Units (PDUs)*



OSI Unified View: Services

- Communication between peer processes is virtual and actually indirect
- Layer $n+1$ transfers information by invoking the services provided by layer n
- Services are available at *Service Access Points* (SAP's)
- Each layer passes data & control information to the layer below it until the physical layer is reached and transfer occurs
- The data passed to the layer below is called a *Service Data Unit* (SDU)
- SDU's are *encapsulated* in PDU's

Layers, Services & Protocols



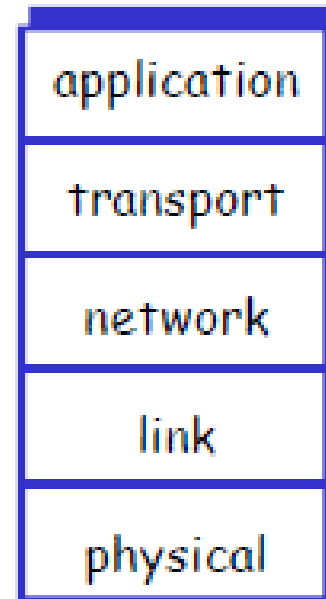
OSI Model in a Nutshell

OSI (Open Source Interconnection) 7 Layer Model

Layer	Application/Example	Central Device/ Protocols		DOD4 Model
Application (7) Serves as the window for users and application processes to access the network services.	End User layer Program that opens what was sent or creates what is to be sent Resource sharing • Remote file access • Remote printer access • Directory services • Network management	User Applications SMTP	G A T E W A Y	Process
Presentation (6) Formats the data to be presented to the Application layer. It can be viewed as the "Translator" for the network.	Syntax layer encrypt & decrypt (if needed) Character code translation • Data conversion • Data compression • Data encryption • Character Set Translation	JPEG/ASCII EBDIC/TIFF/GIF PICT		
Session (5) Allows session establishment between processes running on different stations.	Synch & send to ports (logical ports) Session establishment, maintenance and termination • Session support - perform security, name recognition, logging, etc.	Logical Ports RPC/SQL/NFS NetBIOS names		
Transport (4) Ensures that messages are delivered error-free, in sequence, and with no losses or duplications.	TCP Host to Host, Flow Control Message segmentation • Message acknowledgement • Message traffic control • Session multiplexing	F I L T E R I N G P A C K E T	TCP/SPX/UDP	Host to Host
Network (3) Controls the operations of the subnet, deciding which physical path the data takes.	Packets ("letter", contains IP address) Routing • Subnet traffic control • Frame fragmentation • Logical-physical address mapping • Subnet usage accounting		Routers IP/IPX/ICMP	Internet
Data Link (2) Provides error-free transfer of data frames from one node to another over the Physical layer.	Frames ("envelopes", contains MAC address) [NIC card — Switch — NIC card] (end to end) Establishes & terminates the logical link between nodes • Frame traffic control • Frame sequencing • Frame acknowledgment • Frame delimiting • Frame error checking • Media access control	Switch Bridge WAP PPP/SLIP	Land Based Layers	Network
Physical (1) Concerned with the transmission and reception of the unstructured raw bit stream over the physical medium.	Physical structure Cables, hubs, etc. Data Encoding • Physical medium attachment • Transmission technique - Baseband or Broadband • Physical medium transmission Bits & Volts	Hub		

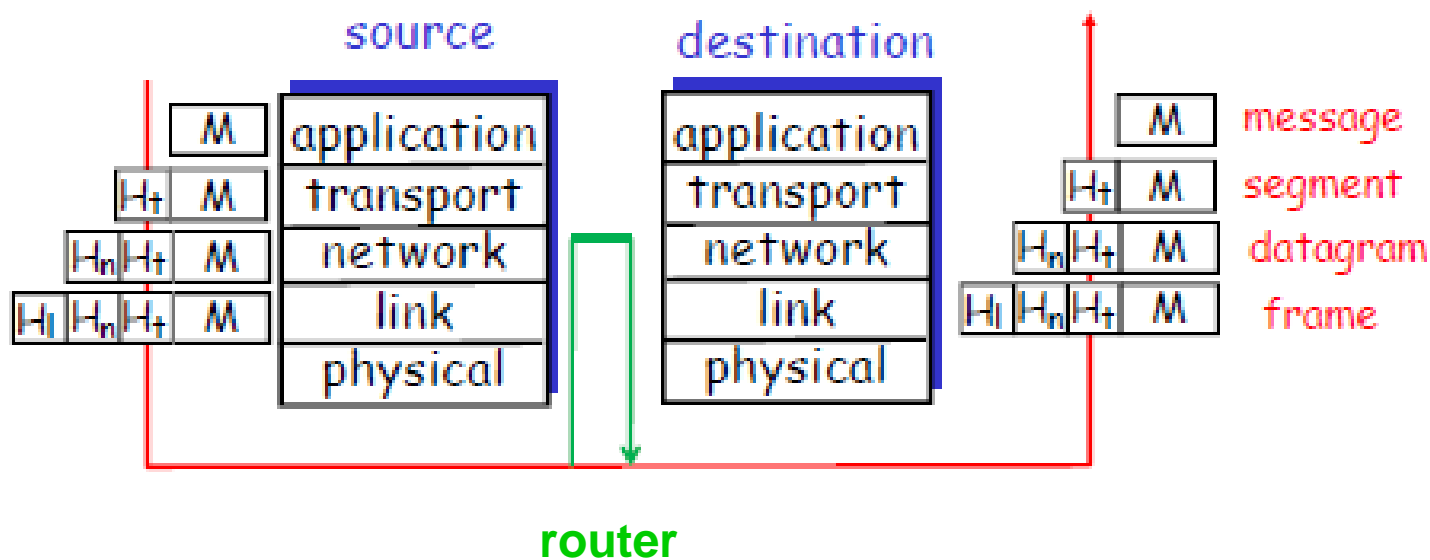
TCP/IP Model: 5 Layers

- **Application**: supporting network applications
 - FTP, SMTP, HTTP
- **Transport**: host-host data transfer
 - **Transmission Control Protocol (TCP)**, UDP
- **Network**: routing of datagrams from source to destination
 - **Internet Protocol (IP)**, routing protocols
- **Link**: data transfer between neighboring network elements
 - PPP, Ethernet
- **Physical**: bits on the wire

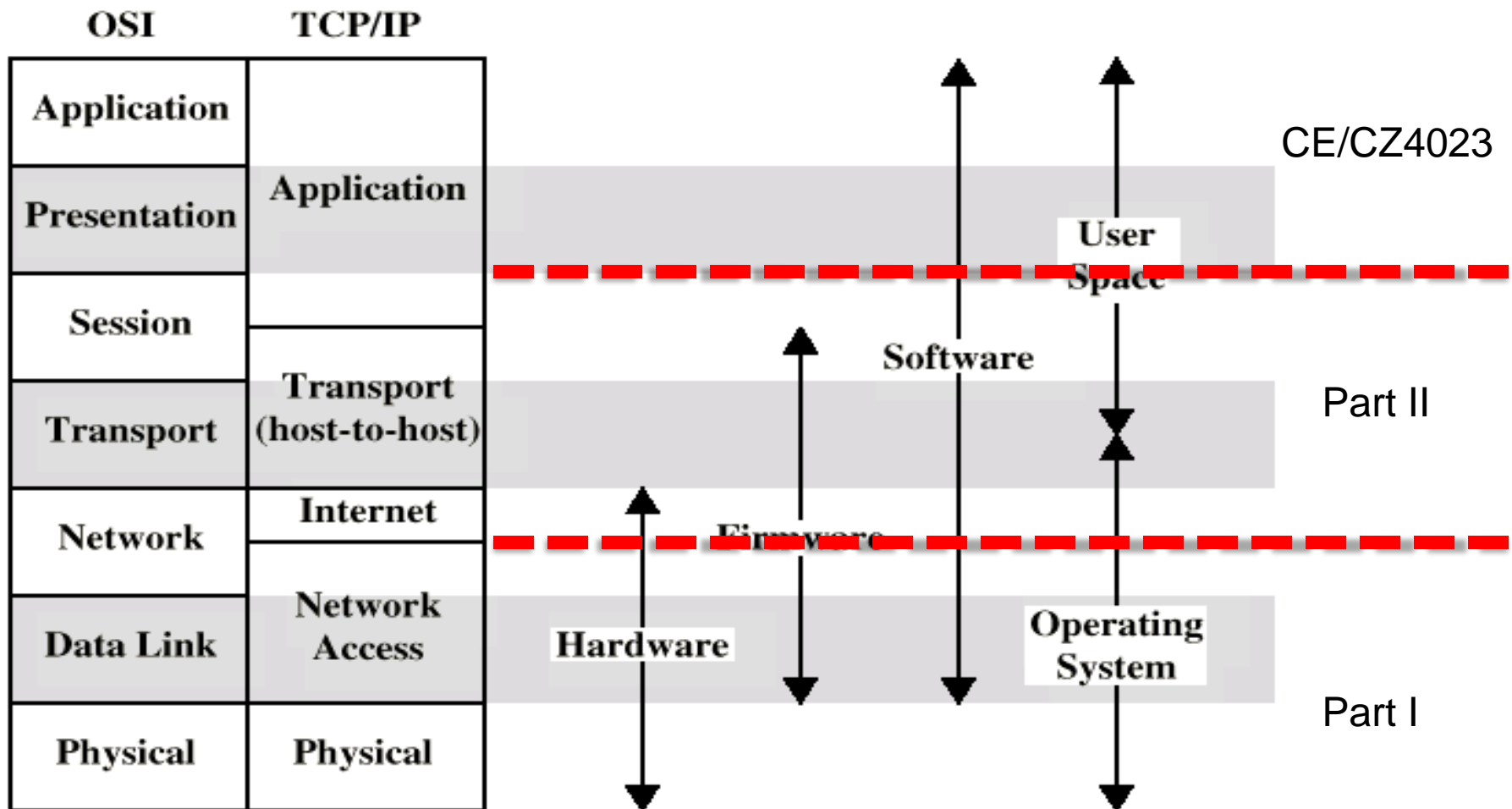


TCP/IP Internetworking

- **Each layer takes data from above**
 - Adds header information to create new data unit
 - Passes new data unit to layer below



TCP/IP vs OSI Models



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	Network paradigms	M1-L10-Paradigms.pptx

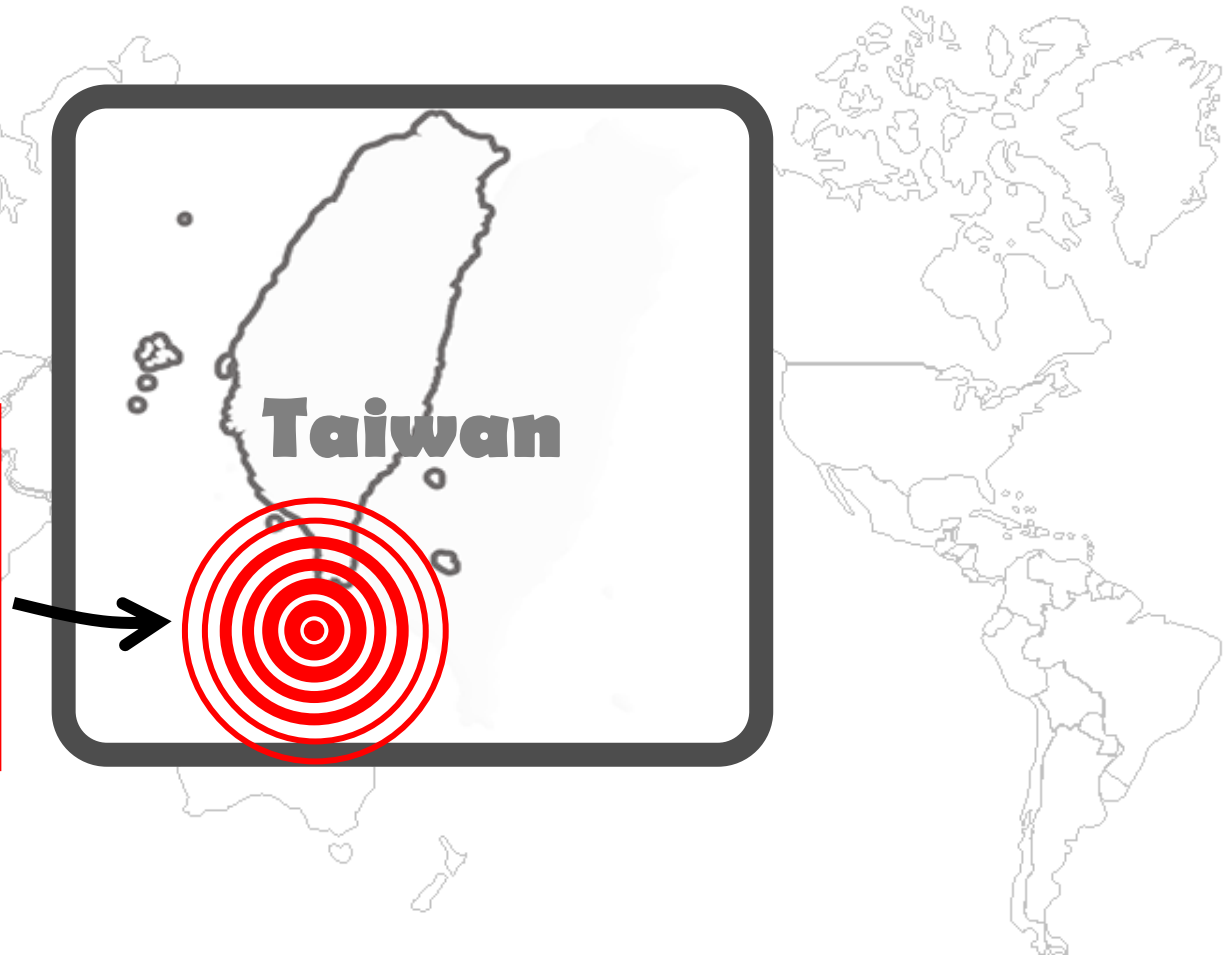
Physical Layer: Network Resilience

ASIA COVERAGE

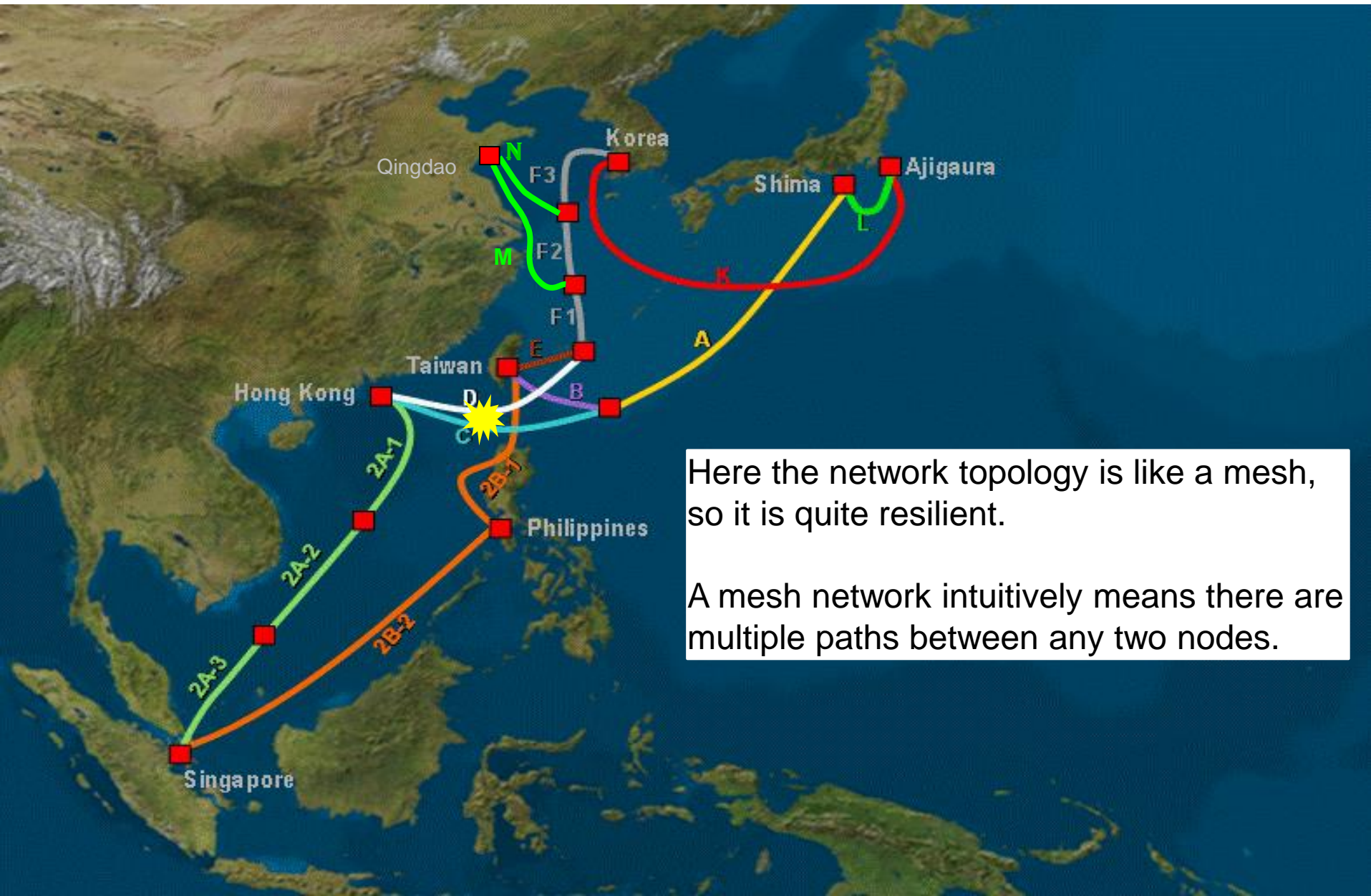


GMT 12:26:01, 26 December 2006

- 7.1 magnitude quake
- Multiple aftershocks
- 6 cable systems effected



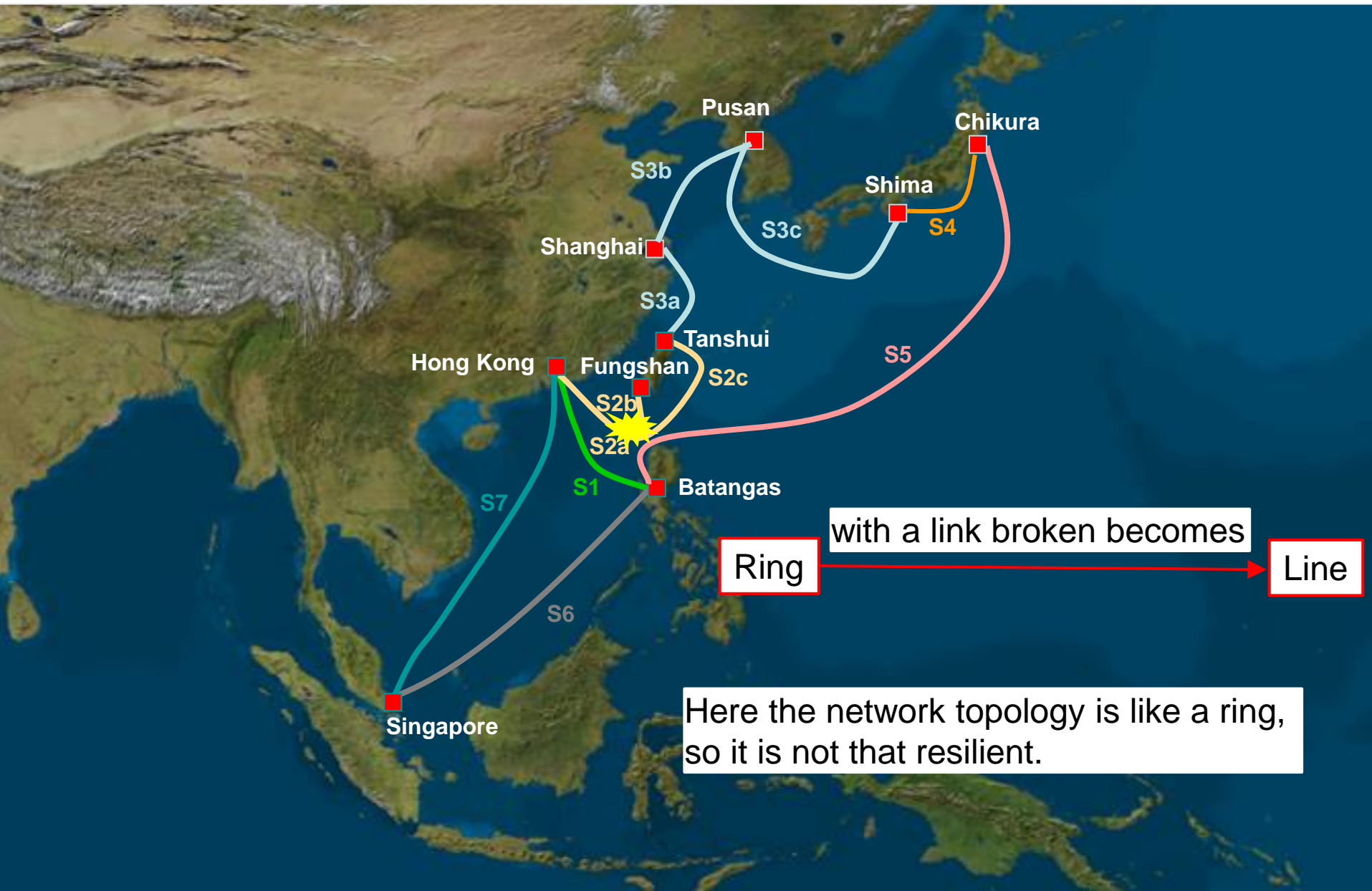
East Asia Crossing (EAC) Cable Network



Here the network topology is like a mesh, so it is quite resilient.

A mesh network intuitively means there are multiple paths between any two nodes.

City-to-City (C2C) Cable Network



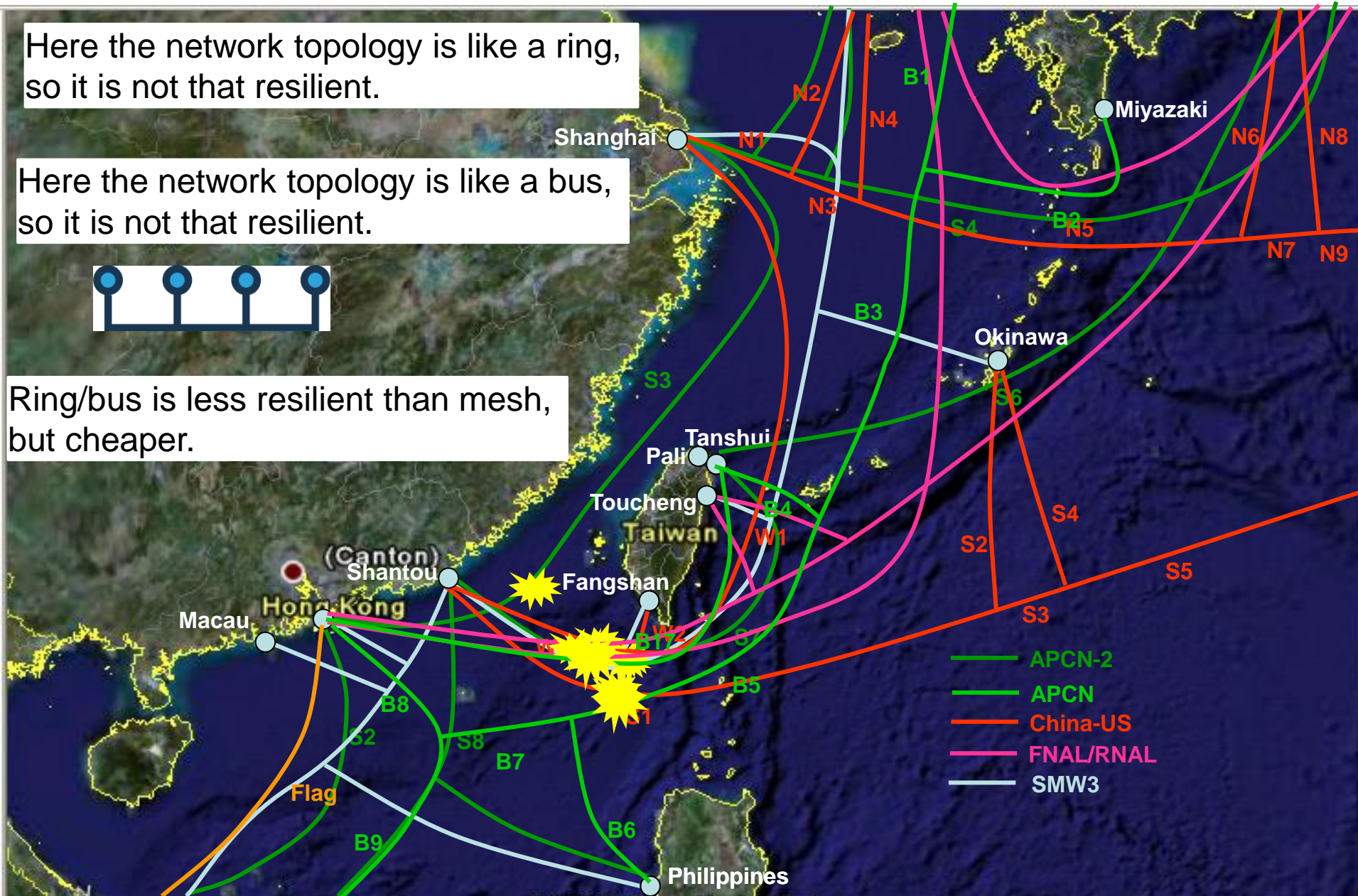
Other Cable Network

Here the network topology is like a ring, so it is not that resilient.

Here the network topology is like a bus, so it is not that resilient.



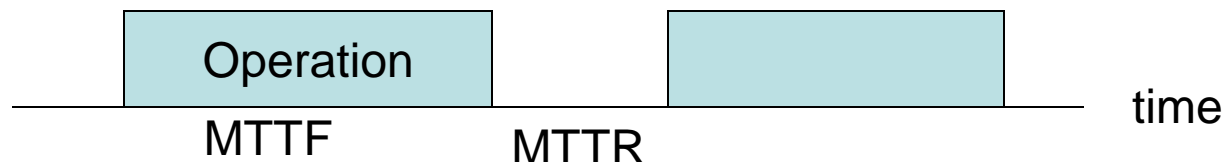
Ring/bus is less resilient than mesh, but cheaper.



Network Reliability

- **Probability that a network performs satisfactorily over a period of time**
- **Parameters:**
 - Mean Time Between Failures (MTBF)
 - Mean Time to Failure (MTTF)
 - Mean Time to Repair (MTTR)

$$\text{MTBF} = \text{MTTF} + \text{MTTR}$$



Link Failure Probability

- **Link Failure Probability**: percentage of time during which the link is dysfunctional
- **Link Availability**: percentage of time during which the link is functional

- b_i : Probability link “i” is broken
- r_i : Probability link “i” is available, i.e., not broken
- $r_i = 1 - b_i$

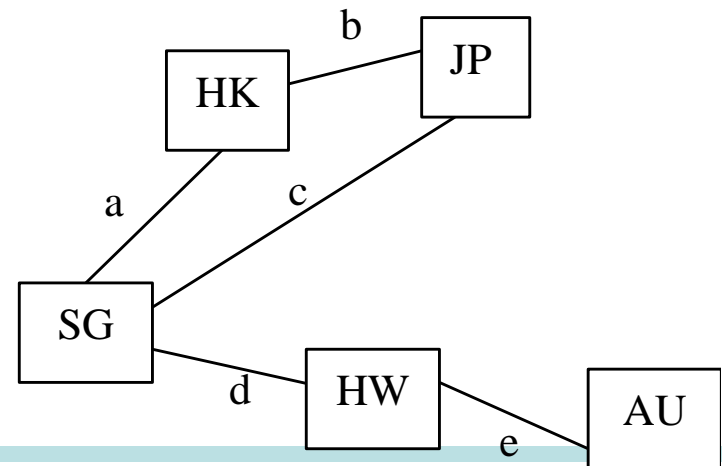
Availability %	Downtime per year	Downtime per month*	Downtime per week
90% ("one nine")	36.5 days	72 hours	16.8 hours
95%	18.25 days	36 hours	8.4 hours
97%	10.96 days	21.6 hours	5.04 hours
98%	7.30 days	14.4 hours	3.36 hours
99% ("two nines")	3.65 days	7.20 hours	1.68 hours
99.5%	1.83 days	3.60 hours	50.4 minutes
99.8%	17.52 hours	86.23 minutes	20.16 minutes
99.9% ("three nines")	8.76 hours	43.8 minutes	10.1 minutes
99.95%	4.38 hours	21.56 minutes	5.04 minutes
99.99% ("four nines")	52.56 minutes	4.32 minutes	1.01 minutes
99.999% ("five nines")	5.26 minutes	25.9 seconds	6.05 seconds
99.9999% ("six nines")	31.5 seconds	2.59 seconds	0.605 seconds
99.99999% ("seven nines")	3.15 seconds	0.259 seconds	0.0605 seconds

Network Resilience Issues

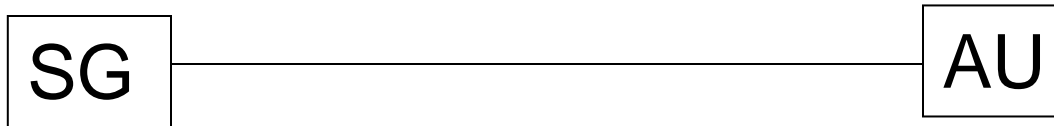
- **What's the probability of a link failure?**
- **Are there alternative paths?**
- **Is there a single point of failure ?**
- **What is the probability for two nodes to stay connected in a network?**

Network Resilience

- A measure of Network Fault Tolerance
- Express in terms of probability that the network remains connected.
- Assumptions
 - The probability of link failures are independent of each other.



Network Availability: Single Link



Given that the failure probability of the link is 0.05,

Failure probability:

$$b_{\text{SG-AU}} = 0.05$$

Availability probability:

$$r_{\text{SG-AU}} = 1 - 0.05 = 0.95$$

Network Availability: Series



Given that each link has a failure probability of 0.05,

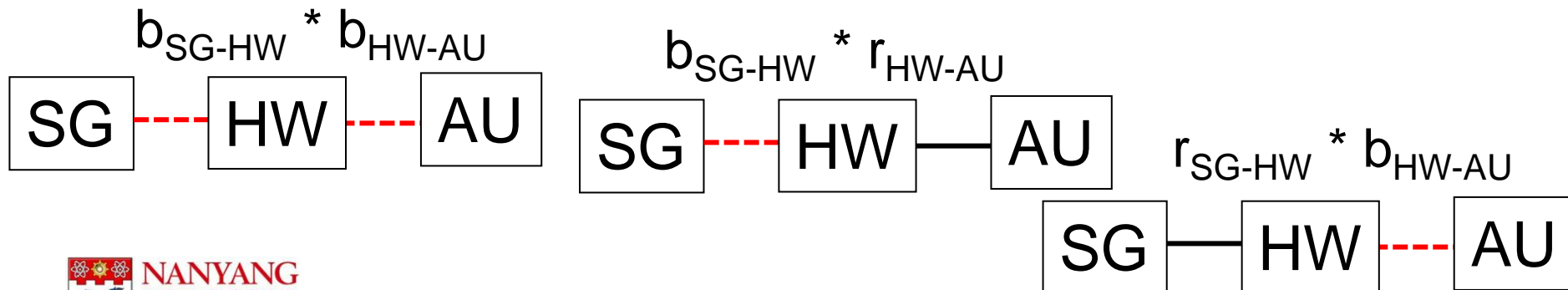
Prob that SG can communicate with AU:

$$r_{\text{SG-HW-AU}} = \Pr[\text{both links survive}] = r_{\text{SG-HW}} * r_{\text{HW-AU}} = (1-0.05)*(1-0.05) = 0.9025$$

What is the probability that SG cannot communicate with AU?

$$b_{\text{SG-HW-AU}} = 1 - 0.9025 = 0.0975$$

Computing $1 - r_{\text{SG-HW}} * r_{\text{HW-AU}}$ above is easier than summing the three products below:

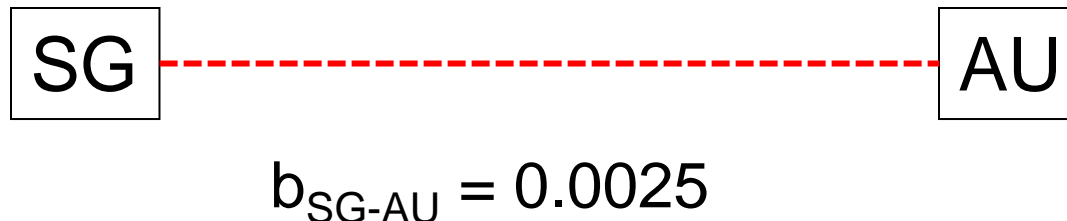


Network Availability: Parallel

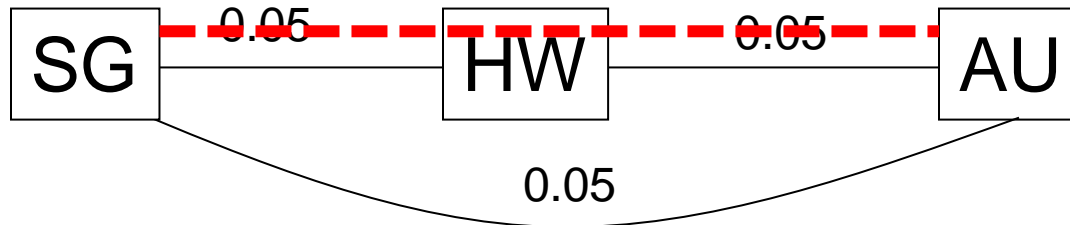


Given that each link has a failure probability of 0.05,
What is the probability that SG is isolated from AU ?

$$\begin{aligned}\text{Prob(break)} &= \text{Pr}[\text{both links break}] \\ &= b_A * b_B \\ &= 0.05 * 0.05 = 0.0025\end{aligned}$$



Hybrid Graphs: Path-Based Approach



Given that each link has a failure probability of 0.05,
Calculate the Prob that SG is isolated from AU.

$$\begin{aligned} r_{\text{SG-HW-AU}} &= r_{\text{SG-HW}} * r_{\text{HW-AU}} \\ &= (1-0.05)*(1-0.05) \\ &= 0.9025 \end{aligned}$$

$$\begin{aligned} b_{\text{SG-HW-AU}} &= 1 - r_{\text{SG-HW-AU}} \\ &= 1 - 0.9025 \\ &= 0.0975 \end{aligned}$$

$$\begin{aligned} \text{Prob. SG Disconnected from AU} &= b_{\text{SG-HW-AU}} * b_{\text{SG-AU}} \\ &= 0.0975 * 0.05 \\ &= 0.004875 \end{aligned}$$

Rules for Network Availability

- **Link in series**
 - Calculate that probability that all links in the series are working
- **Link in parallel**
 - Calculate the probability that all links are broken.
- **Combination of series and parallel**
 - Decompose them into paths
 - Calculate network availability using path-based approach

Learning Objectives

- **Layered Network Architecture**
 - Why layering?
 - OSI model and its functions
 - TCP/IP model and its functions
 - Mapping between OSI and TCP/IP Models
- **Physical Layer Resilience**
 - Definition of link availability and calculation
 - Path-based approach

Supplementary Materials

Physical Layer

- **Provides physical interface for transmission of information**
- **Defines rules by which bits are passed from one system to another on a physical communication medium**
- **Covers all – mechanical, electrical, functional and procedural – aspects for physical communication**
- **Such characteristics as voltage levels, timing of voltage changes, physical data rates, maximum transmission distances, physical connectors, and other similar attributes are defined by physical layer specifications**

Data Link Layer

- **Data link layer attempts to provide reliable communication over the physical layer interface**
- **Breaks the outgoing data into frames and reassemble the received frames**
- **Create and detect frame boundaries**
- **Handle errors by implementing an acknowledgement and retransmission scheme**
- **Implement flow control**
- **Supports points-to-point as well as broadcast communication**
- **Supports simplex, half-duplex or full-duplex communication**

Network Layer

- **Implements routing of frames (packets) through the network**
- **Defines the most optimum path the packet should take from the source to the destination**
- **Defines logical addressing so that any endpoint can be identified**
- **Handles congestion in the network**
- **Facilitates interconnection between heterogeneous networks (Internetworking)**
- **The network layer also defines how to fragment a packet into smaller packets to accommodate different media**

Transport Layer

- **Purpose of this layer is to provide a reliable mechanism for the exchange of data between two processes in different computers**
- **Ensures that the data units are delivered error free**
- **Ensures that data units are delivered in sequence**
- **Ensures that there is no loss or duplication of data units**
- **Provides connectionless or connection oriented service**
- **Provides for the connection management**
- **Multiplex multiple connection over a single channel**

Session Layer

- Provides mechanism for controlling the dialogue between the two end systems. It defines how to start, control and end conversations (called sessions) between applications
- Requests for a logical connection to be established on an end-user's request
- Any necessary log-on or password validation is also handled by this layer
- Session layer is also responsible for terminating the connection
- This layer provides services like dialogue discipline which can be full duplex or half duplex
- Session layer can also provide check-pointing mechanism such that if a failure of some sort occurs between checkpoints, all data can be retransmitted from the last checkpoint

Presentation Layer

- **Presentation layer defines the format in which the data is to be exchanged between the two communicating entities**
- **Also handles data compression and data encryption (cryptography)**

Application Layer

- **Application layer interacts with application programs and is the highest level of OSI model**
- **Application layer contains management functions to support distributed applications**
- **Examples of application layer are applications such as file transfer, electronic mail, remote login etc.**