Slide 1

IK1552 Internetworking/Internetteknik

prof. Gerald Q. Maguire Jr. http://people.kth.se/~maguire/

School of Electrical Engineering and Computer Science (EECS), KTH Royal Institute of Technology

IK1552 Spring 2019, Period 4 2019.03.13

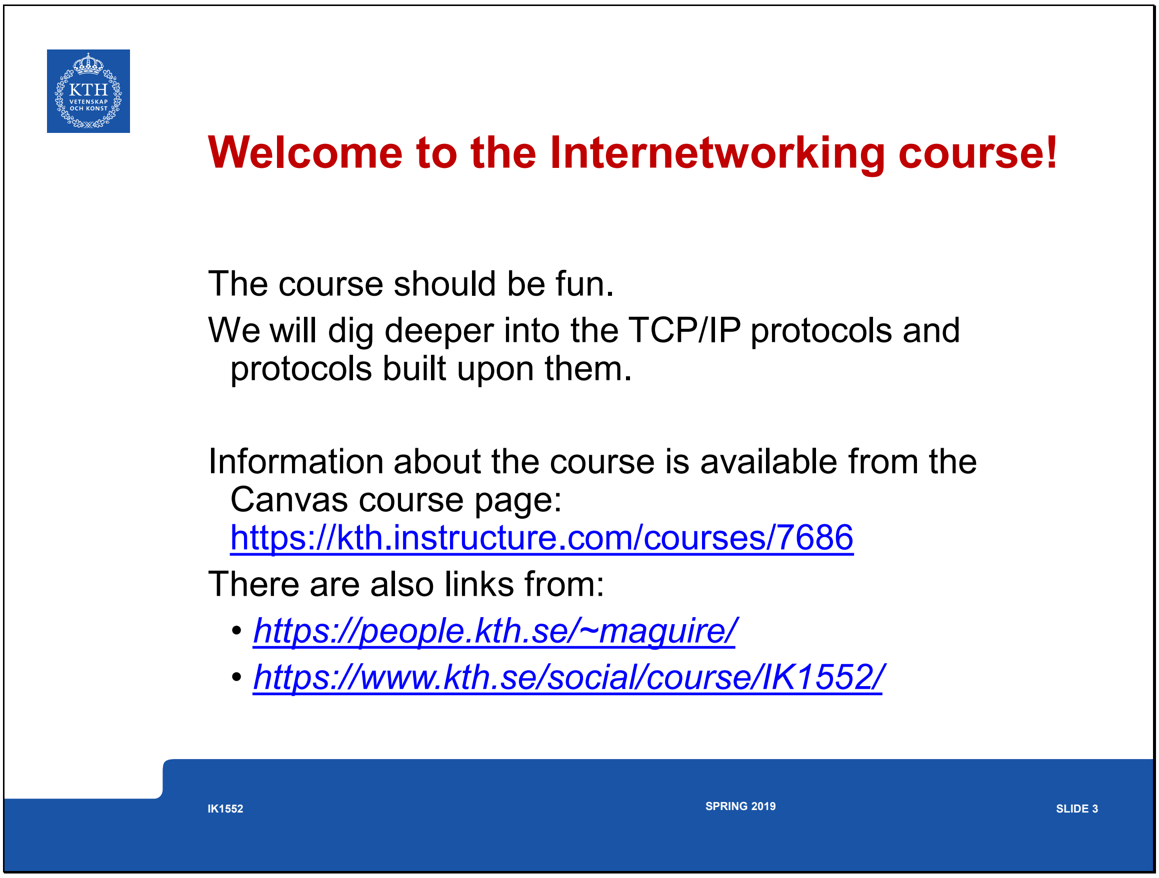
Slide 2

Module 1: Introduction

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with James F. Kurose and Keith W. Ross, *Computer Networking: A Top-Down Approach*, Sixth Edition, Pearson/Addison Wesley. ISBN-10: 0273768964, ISBN-13: 9780273768968. 2012 (for the International Edition)

Slide 3


Welcome to the Internetworking course!
The course should be fun.
We will dig deeper into the TCP/IP protocols and protocols built upon them.
Information about the course is available from the Canvas course page: https://kth.instructure.com/courses/7686
There are also links from:
• https://people.kth.se/~maguire/
• https://www.kth.se/social/course/IK1552/
IK1552
SPRING 2019
SLIDE 3

Slide 4

Staff Associated with the Course

Instructor (Kursansvarig)

prof. Gerald Q. Maguire Jr. <maguire@kth.se>

Slide 5

Goals, Scope and Method

Goals of the Course

- To give deep knowledge and competence (*designing*, *analyzing,* and *developing*) of Internet protocols and architecture, both practical and analytical.
- To be able to read and understand the Internet standardization documents (IETF Requests for Comments (RFCs) and Internet Drafts) and current Internet literature.
- You should have the knowledge and competence to do exciting Internet related research and development.

Scope and Method

- Dig deeper into the TCP/IP protocol suite by using diagnostic tools to examine, observe, and analyze these protocols in action. Understanding the details!
- Demonstrate this by writing a written report.

Slide 6

Aim

This course will give both practical and general knowledge on the **protocols** that are the basis of the Internet. After this course you should have a good knowledge about Internet protocols and internetworking architecture. You should have a general knowledge aiding you in reading research and standardization documents in the area.

IK1552 SPRING 2019 SLIDE 6

Slide 7

Learning Outcomes

Following this course a student should be able to:

- Understand the principles on which internetworking is based - which define the Internet (both what it is and why it has proven to be so successful)
- Understand TCP/IP protocol stack, layering, encapsulation and multiplexing
- Understand multiplexing, demultiplexing, upward and downward multiplexing
- Encapsulation as used for Mobile IP, Virtual Private Networks (VPNs), IP security, ... and other tunneling protocols
- Understand how information is encoded in headers and how the choice of this encoding and field size may effect the use and evolution of a protocol
- Understand how data is encoded in the body of a packet and how this may effect internetworking - especially in the presence of firewalls and network address translators.
- Understand IP Addressing, subnetting, and address resolution - including the interaction of protocols across layers
- Understand a number of higher layer protocols including the security risks and performance limitations of each

Slide 8

Learning Outcomes (continued)

- Understand the basic details of routing and routing protocols (RIP, BGP, OSPF) - with an emphasis on their limitations and behaviors
- Understand autoconfiguration and naming (BOOTP, DHCP, DNS, DDNS, DNSsec, ENUM, ...) - with an emphasis on risks, limitations, scaling, and evolution
- Understand the nature and pressures on the design and operations of internets - particularly on scaling, performance, delay bounds, due to new Internet applications (VoIP, streaming, games, peer-to-peer, etc.)
- Understand the advantages and disadvantages of IPv6 (in comparison to IPv4)
- Read the current literature at the level of conference papers in this area.

  While you may not be able to understand all of the papers in journals, magazines, and conferences in this area - you **should** be able to read 90% or more of them and have good comprehension. In this area it is especially important that develop a habit of reading the journals, trade papers, etc. *In addition, you should also be aware of both standardization activities, new products/services, and public policy in the area.*
- Demonstrate knowledge of this area in writing.

  By *writing* a paper suitable for submission to a trade paper or national conference in the area.

Slide 9

Prerequisites

IK1203: Nätverk och kommunikation/Networks and Communication

or

Equivalent knowledge in Computer Communications (check with the instructor)

Slide 10

Contents

This course will focus on the **protocols** that are the fundaments of the Internet. We will explore what internetworking means and what it requires. We will give both practical and more general knowledge concerning the Internet network architecture.

The course consists of 14 hours of lectures (combined with 14 hours of recitations (övningar)), and 40-100 hours of written assignments.

Slide 11

Lectures + Recitations (Combined)

https://www.kth.se/social/course/IK1552/calendar

IK1552 SPRING 2019 SLIDE 11

Slide 12

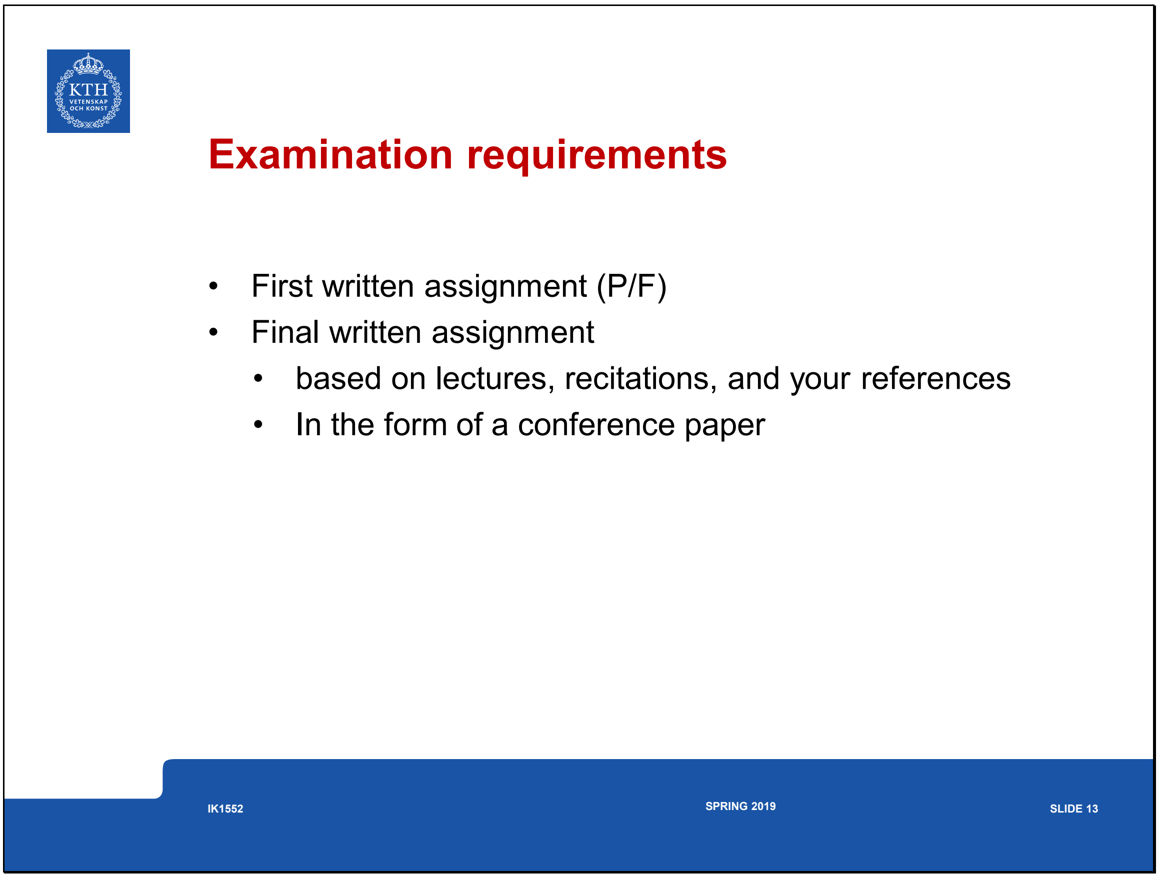
Topics

- What an internet is and what is required of protocols to allow internetworking
- details of routing and routing protocols (RIP, BGP, OSPF, …)
- multicasting
- Domain Name System (DNS, Dynamic DNS)
- what happens from the time a machine boots until applications are running (RARP, BOOTP, DHCP, TFTP)
- details of the TCP/IP protocols and some performance issues
- details of a number of application protocols (especially with respect to distributed file systems)
- network security (including firewalls, AAA, IPSec, SOCKs, …)
- differences between IPv6 and IPv4
- network management (SNMP) and
- We will also examine some emerging topics:

  cut-through routing, tag switching, flow switching, QoS, Mobile IP, Voice over IP, SIP, NAT, VPN, Diffserv, … .

IK1552 SPRING 2019 SLIDE 12

Slide 13


Examination requirements
• First written assignment (P/F)
• Final written assignment
• based on lectures, recitations, and your references
• In the form of a conference paper
IK1552
SPRING 2019
SLIDE 13

Slide 14

Grades: A..F (ECTS grades)

- To get an "A" you need to write an outstanding or excellent paper.
- To get a "B" you need to write a very good paper, i.e., it should be either a very good review or present a new idea.
- To get a "C" you need to write a paper which shows that you understand the basic ideas underlying internetworking and that you understand one (or more) particular aspects at the level of an average undergraduate student in the area.
- ‘To get a "D" you need to demonstrate that you understand the basic ideas underlying internetworking, however, your depth of knowledge is shallow in the topic of your paper.

Slide 15

Grades (continued)

- If your paper has *some* errors (including **incomplete references**) but you show basic understanding of the material, then the grade will be an "E".
- If your paper has serious errors the grade will be an "F".

  If your paper is close to passing, but not at the passing level, then you will be offered the opportunity for "komplettering", i.e., students whose written paper does not pass can submit a revised version of their paper (or a completely new paper) - which will be evaluated.

IK1552 SPRING 2019 SLIDE 15

Slide 16

Grades (continued)

Note that there is **no** opportunity to raise your grade, once you have a grade of "E" or higher.

Slide 17

First Written Assignment

Goals: to gain some knowledge about a *current* Internetworking topic and get some feedback on your writing

- Work to be done individually
- There will be one or more suggested topics, additional topics are possible (discuss this with the teacher **before** starting).

This report (in .docx or PDF format) should be uploaded in Canvas before **22 April 2019 at 23:59**.

Slide 18

Final Written Assignment (report)

Goal: to gain analytical or practical experience and to show that you have mastered some Internetworking knowledge

- Can be done in a group of **1 to 3** students (formed by yourself). Each student must contribute to the report.
- There will be one or more suggested topics, additional topics are possible (discuss this with the teacher **before** starting).

Slide 19

Register a topic for your paper

Submit your project registration via Canvas by **2 May 2019**
Group members, leader, and topic selected

Slide 20

Report

- The report should clearly describe: (1) what you have done; (2) if you have done some implementation and measurements you should describe the methods and tools used, along with the test or implementation results, and your analysis.
- The length of the final report should be 7-8 pages for each student (detailed measurements, configuration scripts, etc. can be in additional pages in an appendix or appendices).†
- Contribution by each member of the group - must be clear

Final Report: written report due before **4 June 2019 at 23:59**

Upload your .docx or a PDF file in Canvas

Late assignments will not be accepted (i.e., there is no guarantee that they will graded in time for the end of the term)

Note that it is permissible to start working *well in advance* of the deadlines!

†Papers which are longer than 8 pages per student will have a maximum grade of "E".

IK1552 SPRING 2019 SLIDE 20

Slide 21

Literature

The course will mainly be based on the book:

James F. Kurose and Keith W. Ross, *Computer Networking: A Top-Down Approach*, Sixth Edition, Pearson Education, 2012, ISBN-13: 9780273768968, ISBN-10 0-27376-896-4.

Other additional references include:

- *TCP/IP Illustrated, Volume 1: The Protocols* by *W. Richard Stevens*, Addison-Wesley, 1994, ISBN 0-201-63346-9 and *Internetworking with TCP/IP: Principles, Protocols, and Architectures, Vol. 1,* by Douglas E. Comer, Prentice Hall, 4th edition. 2000, ISBN 0-13-018380-6.
- the commented source code in *TCP/IP Illustrated, Volume 2: The Implementation* by Gary R. Wright and W. Richard Stevens, Addison-Wesley, 1995, ISBN 0-201-63354-X

Slide 22

Literature

- Christian Huitema, *IPv6: The New Internet Protocol*, Prentice-Hall, 1996, ISBN 0-13-241936-X.
- concerning HTTP we will refer to *TCP/IP Illustrated, Volume 3: TCP for Transactions, HTTP, NNTP, and the UNIX Domain Protocols*, Addison-Wesley, 1996, ISBN 0-201-63495-3.

With regard to Mobile IP the following two books are useful as additional sources:

- Charles E. Perkins, *Mobile IP: Design Principles and Practices,* Addison-Wesley, 1998, ISDN 0-201-63469-4.
- James D. Solomon, *Mobile IP: the Internet Unplugged* Prentice Hall, 1998, ISBN 0-13-856246-6.

Kevin Downes (Editor), H. Kim Lew, Steve Spanier, and Tim Stevenson, *Internetworking Technologies Handbook* (http://www-fr.cisco.com/univercd/cc/td/doc/cisintwk/ito_doc/index.htm)

We will refer to other books, articles, and RFCs as necessary.

IK1552 SPRING 2019 SLIDE 22

Slide 23

Observe proper academic ethics and properly cite your sources!

You will be searching & reading the literature in conjunction with your projects. Please make sure that you properly reference your sources in your report - keep in mind the **KTH Ethics policies.**

In particular:

- If you use someone else's words - they must be clearly indicated as a **quotation** (***with a proper citation***).
- Note that individual figures have their own copyrights, so if you are going to use a figure/picture/… from some source, you need to **both cite this source & <u>have the copyright owner's permission to use it</u>**.

Slide 24

Ethics, Rights, and Responsibilities

At KTH there is a policy of zero tolerance for **cheating, plagiarism, etc.** - for details see relevant KTH policies, such as *http://www.kth.se/student/studentratt*

See also the KTH Ethics Policies at: https://www.kth.se/polopoly_fs/1.586972!/Etisk%20policy%202016%20antagen%20av%20US%202016-06-01.pdf

Before starting to work on your paper read the page about **plagiarism** at *http://www.kth.se/en/student/studentliv/studentratt/fusk-och-plagiering-1.323885*

See also the book: Jude Carroll and Carl-Mikael Zetterling, *Guiding students away from plagiarism*, KTH Learning Lab, 2009, ISBN 987-91-7415-403-0 http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-83704

Slide 25

Context of the course

"The network called the Internet is the single most important development in the communications industry since the public switched voice network was constructed…"

-- John Sidgmore when he was CEO, UUNET Technologies and COO, later president and CEO, WorldCom†

†http://www.lucent.com/enterprise/sig/exchange/present/slide2.html {this URL no longer functions}

Slide 26

More Context

Communication systems have been both increasing their number of users and increasing the variety of communication systems. Additionally, increasingly communicating entities are ***not*** people, but rather things.

	numbers	sources
Micro controllers	6×10^9 **per year**	http://doi.ieeecomputersociety.org/10.1109/MM.2002.10015
People	7×10^9	http://en.wikipedia.org/wiki/World_population
Mobile subscribers	$> 5 \times 10^9$	as of end of 2010 http://www.itu.int/ITU-D/ict/newslog/Mobile+Broadband+Subscriptions+To+Hit+One+Billion+In+2011.aspx
PCs	$> 1 \times 10^9$	as of June 23, 2008 http://www.gartner.com/it/page.jsp?id=703807
Automobiles	59.87×10^6	http://oica.net/category/production-statistics/
Commercial vehicles	20×10^6	

Ericsson's former CEO (Hans Vestberg) predicted the future (~2020) Internet will have 50 billion interconnected devices, while Intel predicted 15 billion connected devices by 2015 [Higginbotham2010].

Increasing numbers of these devices are connected via a wireless link.

[Higginbotham2010] Stacey Higginbotham, Ericsson CEO Predicts 50 Billion Internet Connected Devices by 2020, GigaOM , Apr. 14, 2010, 10:08am PT, http://gigaom.com/2010/04/14/ericsson-sees-the-internet-of-things-by-2020/

Slide 27

Running out of IPv4 addresses

IPv4 Address Report as of 14-Mar-2019 08:28 UTC

http://www.potaroo.net/tools/ipv4/

- IANA Unallocated Address Pool Exhaustion**: 03-Feb-2011**
- Projected Regional Internet Registries (RIR) Unallocated Address Pool Exhaustion (where "exhaustion" is defined as down to the last /8)

RIR	Projected Exhaustion Date	Remaining Addresses in RIR Pool (/8s)
APNIC	**19-Apr-2011** (actual)	0.2155
RIPE NCC	**14-Sep-2012** (actual)	0.3094
LACNIC	**10-Jun-2014** (actual)	0.0741
ARIN	**24 Sep-2015** (actual)	
AFRINIC	05-Oct-2019	0.3648

Slide 28

Efforts to prepare and raise awareness

World IPv6 day was 8 June 2011

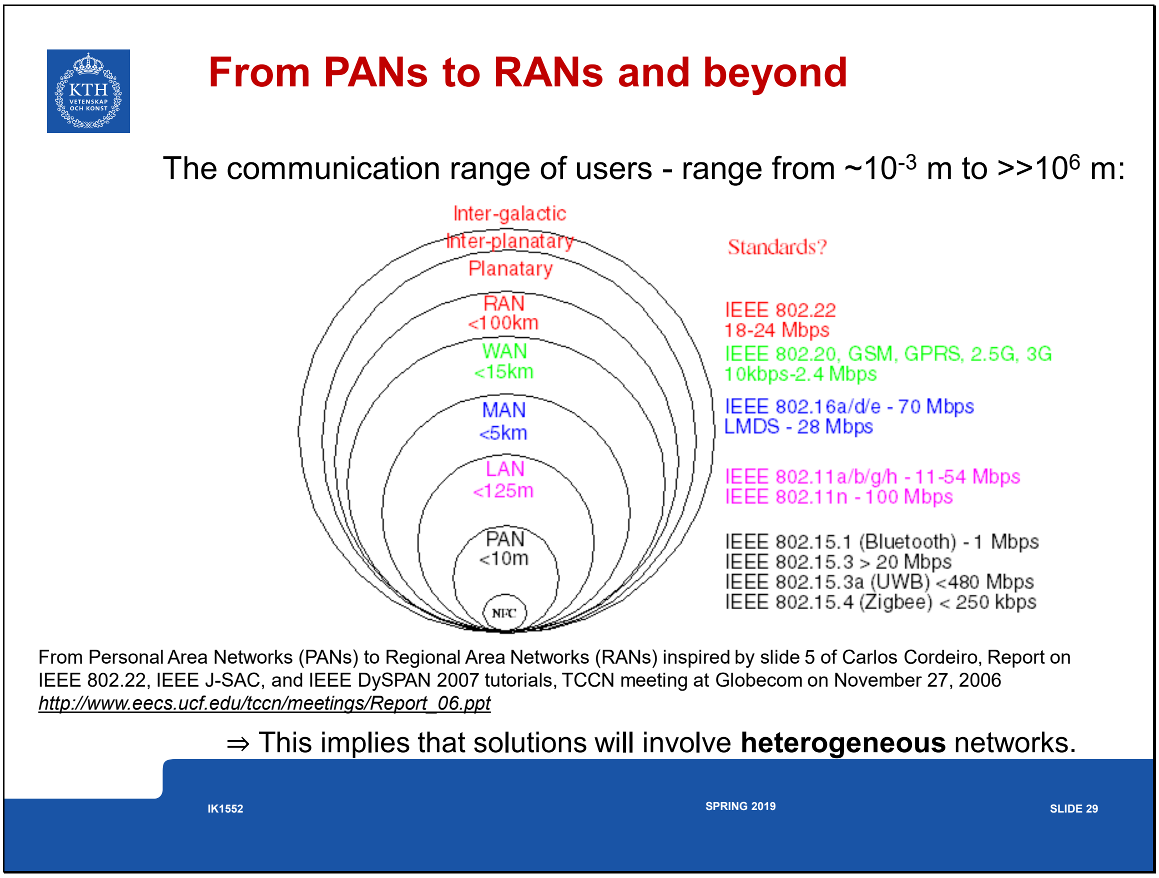
World IPv6 Launch - permanently enabling IPv6 products & services - 6 June 2012

https://www.internetsociety.org/what-we-do/internet-technology-matters/ipv6

The Internet Society Deploy360 Programme:

https://www.internetsociety.org/deploy360/ipv6/

Slide 29



Carlos Cordeiro, Report on IEEE 802.22, IEEE J-SAC, and IEEE DySPAN 2007 tutorials, TCCN meeting at Globecom on November 27, 2006
http://www.eecs.ucf.edu/tccn/meetings/Report_06.ppt

Slide 30

How can we deal with all of these different networks?

- Force a single winner
- Use a single network architecture
  - Everything will be ATM
  - Everything will be UMTS

  …
- Use a single network protocol
  - IP
  - IPX
  - SNA

  …
- Live with multiple winners
  - Specialized networks: a circuit switched PSTN, a cable TV network, …
  - Niche networks: local point to point links (such as IRDA, Bluetooth, …), RFID, …

Slide 31

Internetworking

Internetworking is

- based on the interconnection (concatenation) of multiple networks
- accommodates multiple underlying hardware technologies by providing a way to interconnect **heterogeneous** networks and makes them inter-operate - via a common network layer.

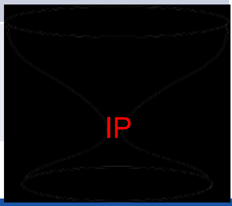
These interconnections have technical, political, and regulatory effects ⇒ Rise of truly international operators - one logical network independent of geography (independent of the fact that it is built of multiple cooperating & competing networks)

IK1552 SPRING 2019 SLIDE 31

Slide 32

Basic concepts

open-architecture networking	**Each distinct network stands on its own makes its own technology choices, etc. ⇒ no changes within each of these networks in order to internet** • **Based on best-effort delivery of datagrams** • **Gateways interconnect the networks** • **No global control**
The End2End Argument	Some basic design principles for the Internet: • Specific application-level functions should **not** be built into the lower levels • Functions implemented **in** the network should be simple and general. • Most functions are implemented (as software) at the edge ⇒ complexity of the core network is reduced ⇒ increases the chances that new applications can be easily added. See also [Clark and Blumenthal; Clark, et al.]
Hourglass (Stuttgart wineglass) Model	• Anything over IP • IP over anything Note the broad (and open) top - enabling lots and lots of application



David D. Clark and Marjory S. Blumenthal, “Rethinking the Design of the Internet: The end to end arguments vs. the brave new world”, In ACM Transactions on Internet Technology, Vol 1, No 1, August 2001, pp 70-109.*http://www.ana.lcs.mit.edu/papers/PDF/Rethinking_2001.pdf*

D. Clark, J. Wroclawski, K. Sollins, and R. Braden, “Tussle in Cyberspace: Defining Tomorrow’s Internet”, Proceedings of Sigcomm 2002.*http://www.acm.org/sigs/sigcomm/sigcomm2002/papers/tussle.pdf*

Slide 33

How does this avoid the "B-ISDN debacle"?

Internetworking is completely different from the B-ISDN:

- Rather than a single cell based circuit switched network - the focus is on **interconnecting networks** via a common network layer protocol
- **Lots of products** and **lots of vendors** selling these products
  Note: there is significant competition with a very fast development cycle

The technology is "**good enough**" vs. trying to be an improved version of ISDN, see examples in:

  - Carlos Cordeiro, Report on IEEE 802.22, IEEE J-SAC, and IEEE DySPAN 2007 tutorials, TCCN meeting at Globecom on November 27, 2006
  - Clayton Christianson's *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* [Christianson]

- It exploits the very rapid advances at the **edge of the network** - which *the users pay for*!
- Encourages both **cooperation** by different network operators and **competition** between different network operators!

⇒ network connectivity as a commodity using commodity products to deliver a wide range of services

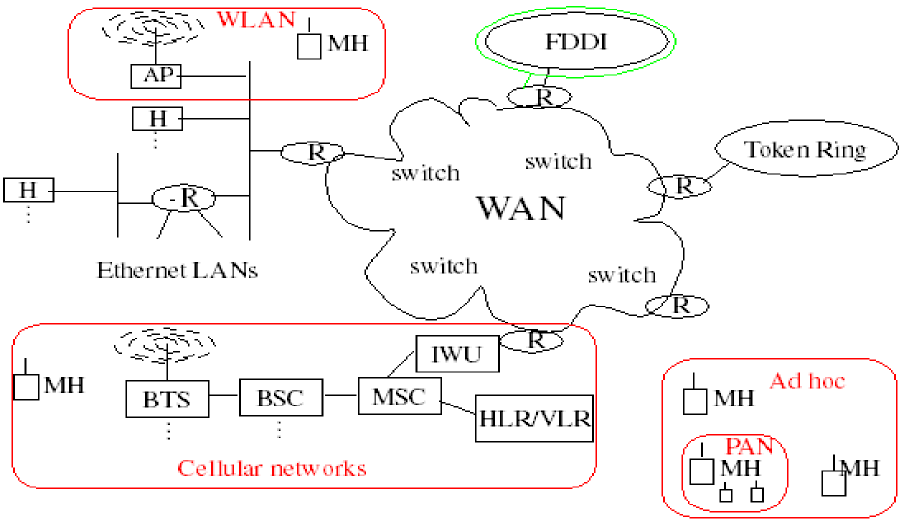
IK1552 SPRING 2019 SLIDE 33

Clayton Christianson, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard Business School Press, Boston, MA, USA, 1997, 225 pages, ISBN 0-87584-585-1

Carlos Cordeiro, Report on IEEE 802.22, IEEE J-SAC, and IEEE DySPAN 2007 tutorials, TCCN meeting at Globecom on November 27, 2006 formerly available from http://www.eecs.ucf.edu/tccn/meetings/Report_06.ppt

Slide 34

Internet Architecture



Multiple network technologies - *internetworked* together

Facilitates **disaggregation** - since **functionality** can be located anywhere on the internet.

Note that some of the routers act as **gateways** between different types of networks.

Slide 35

Internet Trends

- Numbers of users and internet devices increases very rapidly
  - Network Wizards' Internet Domain Survey - https://www.isc.org/solutions/survey Jul. 2012: 908,585,739, Jan 2011: 818,374,269; July 2009: 681,064,561; Jan. 2008: 541,677,360; Jan. 2005: 317,646,084 hosts
  - RIPE's survey hosts: IPv4: 341,067,118 IPv6: 73,238 (Dec. 2010)
  - RIPE's survey - Sweden: IPv4: 8,717,221, IPv6: 6,365 (Dec. 2010 - total=real+duplicate)
    - Estimates are based on DNS information
    - Note that RIPE's host count survey ended in Dec. 2010 as counting address records no longer provides accurate information (since many TLD operators block zone transfers) - https://labs.ripe.net/Members/markd/hostcount/
- QoS: Demand for integrating many different types of traffic, such as video, audio, and data traffic, into one network ⇒ **Multicast**, **IPv6**, **RSVP**, **DiffServ**, emphasis on **high performance**, and TCP **extensions**
- Mobility: both users and devices are mobile
  - There is a difference between portable (bärbar) vs. mobile (mobil).
  - IP is used in wireless systems (for example 3G cellular).
  - Increasing use of wireless in the last hop (WLAN, PAN, Wireless MAN, …)
- Security:
  - Wireless mobile Internet - initial concern driven by wireless link
  - Fixed Internet - distributed denial of service attacks, increasing telecommuting, …

Slide 36

Context of the course

Personal communication systems have been both increasing their number of users and increasing the variety of personal communication systems. Some of these system (such as GSM) have had *growth* rates of millions of new customers each month! Wireless communication systems have been very successful in many places around the world.

- In many countries the 3G license fees were many thousand of euros per potential customer.
- Data is the dominant source of the traffic, rather than conversational voice
- Europe has introduced so-called fourth generation (4G) cellular systems
- Researcher are exploring 5G.

Last of IPv4 addresses were allocated to the regional registrars in 2011⇒ major push for transition to IPv6 (see IPv6 resource allocations at http://bgp.potaroo.net/iso3166/v6cc.html)

See also: RFC 6459: IPv6 in 3rd Generation Partnership Project (3GPP) Evolved Packet System (EPS)

[RFC 6459J Korhonen, J. Soininen, B. Patil, T. Savolainen, G. Bajko, and K. Iisakkila, ‘IPv6 in 3rd Generation Partnership Project (3GPP) Evolved Packet System (EPS)’, *Internet Request for Comments*, vol. RFC 6459 (Informational), Jan. 2012 [Online]. Available: http://www.rfc-editor.org/rfc/rfc6459.txt

Slide 37

Trends: Shifting from traditional telecommunications to data communications

This is often referred to as the shift to "All-IP" networking.

This embodies:

- A shift from circuit-switched to packet-switched
  such as: from Intelligent network (IN) to IP Multimedia Core Network Subsystem (IMS)
- Introduction of new technologies:
  - Voice over IP (VoIP)
  - Number portability
  - Context-awareness (including location-awareness) in services
- From services being what the telecommunication operator offers *to you* to what anyone offers to you. This is accompanied by a major shift in:
  - How services are created
  - Where services are provisioned
  - Where data is stored and who stores it
- Desperate efforts to retain control, market share, high profits, access to phone numbers, and call contents, … - the genie is reluctant to go back into the bottle!

Slide 38

Power of the Internet (chaos)

'"Historically, the Internet has been an environment in which to experiment. There have been a few basic rules. The most important is the standard for IP and TCP.

The are other important standards for promulgating routing information and the like, but the real power of the Internet idea is that there are not mandated standards for what can run over the 'Net.

Anyone who adheres to TCP/IP standards can create applications and run them without getting anyone's permission. No ISP even has to know you are experimenting (or playing, which is also OK). This freedom produces unpredictable results. New industries can be created almost overnight and existing industries severely affected. …"

-- Scott O. Bradner, "The Importance of Being a Dynamist", Network World, December 13, 1999, p. 48 (www.nwfusion.com)

Scott O. Bradner's home page: http://www.sobco.com/sob/sob.html

Slide 39

IP traffic growing exponentially!

Traffic increasing (but not **due to voice)**

- IP traffic between US and Sweden many times the total voice+FAX traffic
- many >Gbit/s transatlantic fibers

Fixed Links - arbitrarily fast:

- LANs: 10Mbits/s, 100Mbits/s, 1Gbits/s, 10Gbits/s, 40Gbits/s, 100Gbits/s, …
- Backbones: Gigabits/s & Terabits/sTransoceanic fibers between continents ⇒ Gbit/s ⇒ Tbit/s ⇒ Pbit/s
- Major sites link to backbones: increasingly 1Gbit/s to 40 Gbit/s
- Individual users links: ⇒ xDSL (2 Mbits/s .. 100 Mbits/s), ethernet (10/100/1000)

Points of Presence (PoPs) + FIX/CIX/GIX/MAE† ⇒ GigaPoPs

(George) **Guilder's Law**: network speeds will triple every year for the next 25 years. This dwarfs Moore's law that predicts CPU processor speed will double every 18 months.

†Federal Internet eXchange (FIX), Commercial Internet eXchange (CIX), Global Internet eXchange (GIX), Metropolitan Access Exchange (MAE)

Slide 40

Example of mismatch in growth rates

Over a 100 Gbit/sec Ethernet (100GbE) with 64 bytes frames a new frame can arrive at the interface every 5.12ns

Consider a processor clock speed of ~3GHz – How many instructions can you execute in 5.12ns?

Alireza Farshin, Amir Roozbeh, Gerald Q. Maguire Jr., and Dejan Kostić, “Make the Most out of Last Level Cache in Intel Processors”, in Fourteenth EuroSys Conference 2019 (EuroSys '19),. March 25–28, 2019
https://people.kth.se/~dejanko/documents/publications/slice-aware-eurosys19.pdf

Slide 41

Speed

"... The Internet world moves fast. The integration of voice and data onto a single network is not being lead by the International Telecommunications Union or by Bellcore. Rather, its being lead by entrepreneurs like …. Until now, the voice networks dominated. Data could ride on top of the phone network -- when it was convenient. The explosion of data networking and Internet telephony technology is making the opposite true. Now voice can ride on data networks -- when it is convenient." †

Because of bandwidth constraints, Internet telephony would not be a major factor "**for a long time -- maybe nine to twelve months.**"

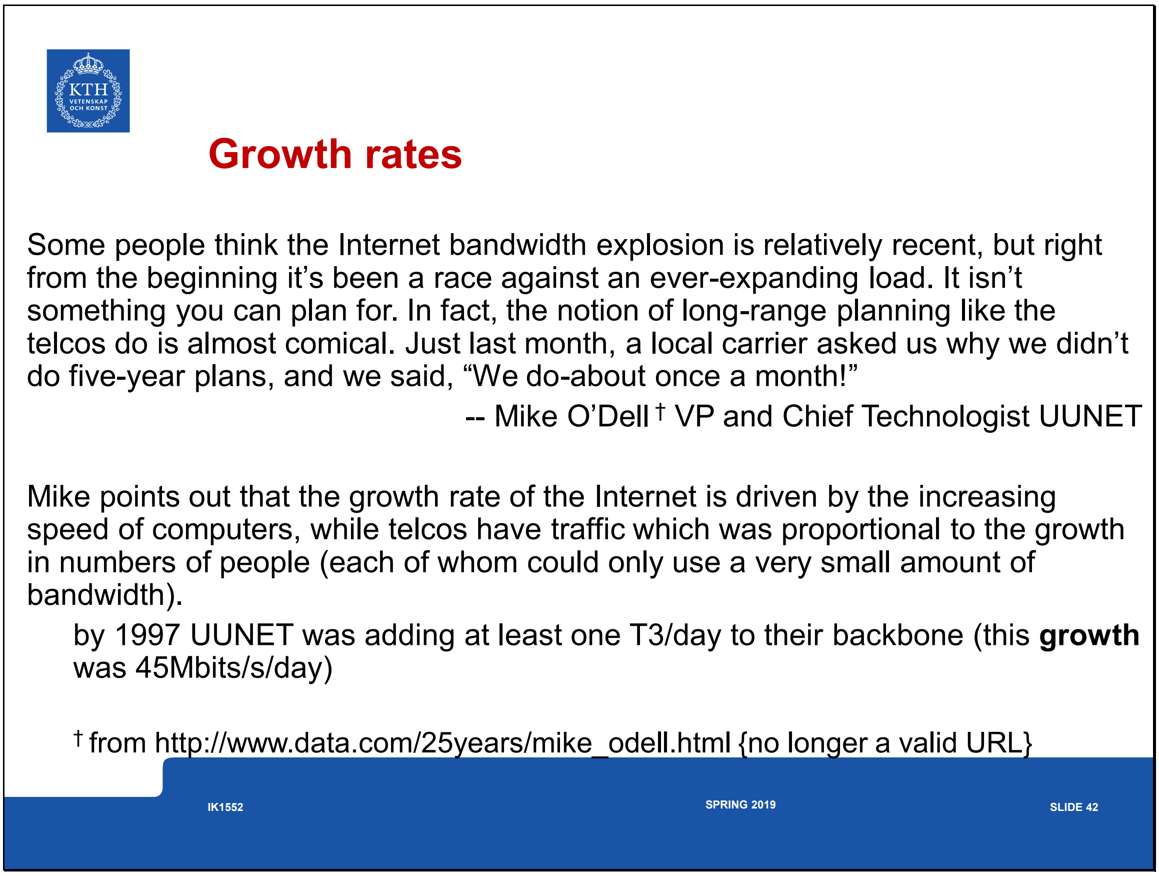
-- president of a major ISP †

Internet time - 7x real time

-- Ira Goldstein, HP

†from http://www.dialogic.com/solution/internet/apps.htm {no longer a valid URL}

Slide 42


Growth rates
Some people think the Internet bandwidth explosion is relatively recent, but right from the beginning it's been a race against an ever-expanding load. It isn't something you can plan for. In fact, the notion of long-range planning like the telcos do is almost comical. Just last month, a local carrier asked us why we didn't do five-year plans, and we said, "We do-about once a month!"
-- Mike O'Dell † VP and Chief Technologist UUNET
Mike points out that the growth rate of the Internet is driven by the increasing speed of computers, while telcos have traffic which was proportional to the growth in numbers of people (each of whom could only use a very small amount of bandwidth).
by 1997 UUNET was adding at least one T3/day to their backbone (this growth was 45Mbits/s/day)
† from http://www.data.com/25years/mike_odell.html {no longer a valid URL}
IK1552
SPRING 2019
SLIDE 42

Slide 43

Question from 1997

"Which would you rather have twice as fast: your computer's processor or modem?

After 30 years of semiconductor doublings under Moore's Law, processor speed are measured in megahertz. On the other hand, after 60 years of telco's snoozing under monopoly law, modem speeds are measure in kilobits. Modems are way too slow for Internet access, but you knew that." †

-- Bob Metcalfe, inventor of Ethernet in 1973

† by Bob Metcalfe, "From the Ether: Moving intelligence and Java Packets into the Net will conserve bandwidth", Inforworld, Oct., 6, 1997, pg. 171.

Slide 44

Increasing Data Rates

"Ethernet'
- 3 Mbps Ethernet (actually 2.944 Mbits/sec)
- 10 Mbps Ethernet (which became IEEE 802.3)
- 100 Mbps Ethernet (100Tx)
- Gigabit Ethernet (IEEE 802.3z, IEEE 802.3ab), 10 GbE (IEEE 802.3ae), 40GbE, 100GbE, 200GbE, and 400GbE

Optical
- Dense Wavelength Division Multiplexing (DWDM) - allowing 1000s of multi-Gbits/s channels to be carried on existing fibers

Wireless
- UMTS (with HSPA ~10Mbps), LTE (100 Mbps), LTE Advanced (1Gbps)
- IEEE 802.11 Wireless LAN (2 .. 600 Mbps, up to 7 Gbps)
- IEEE 802.15 Wireless Personal Area Network (WPAN)
- IEEE 802.16 Metropolitan Area Networks - Fixed Broadband Wireless

The "Get IEEE 802®" program makes the IEEE 802 standards available on-line: *http://standards.ieee.org/getieee802/index.html*
Note that the 200GbE and 400GbE standards were approved 6 December 2017

Helen Xenos, Standards Update: 200GbE, 400GbE and Beyond with Pete Anslow – "Live" from Geneva, Ciena, January 29, 2018
https://www.ciena.com/insights/articles/Standards-Update-200GbE-400GbE-and-Beyond-with-Pete-Anslow--Live-from-Geneva.html

Slide 45

Internetworking

Internetworking is

- based on the interconnection (concatenation) of multiple networks
- accommodates multiple underlying hardware technologies by providing a way to interconnect **heterogeneous** networks and makes them inter-operate.

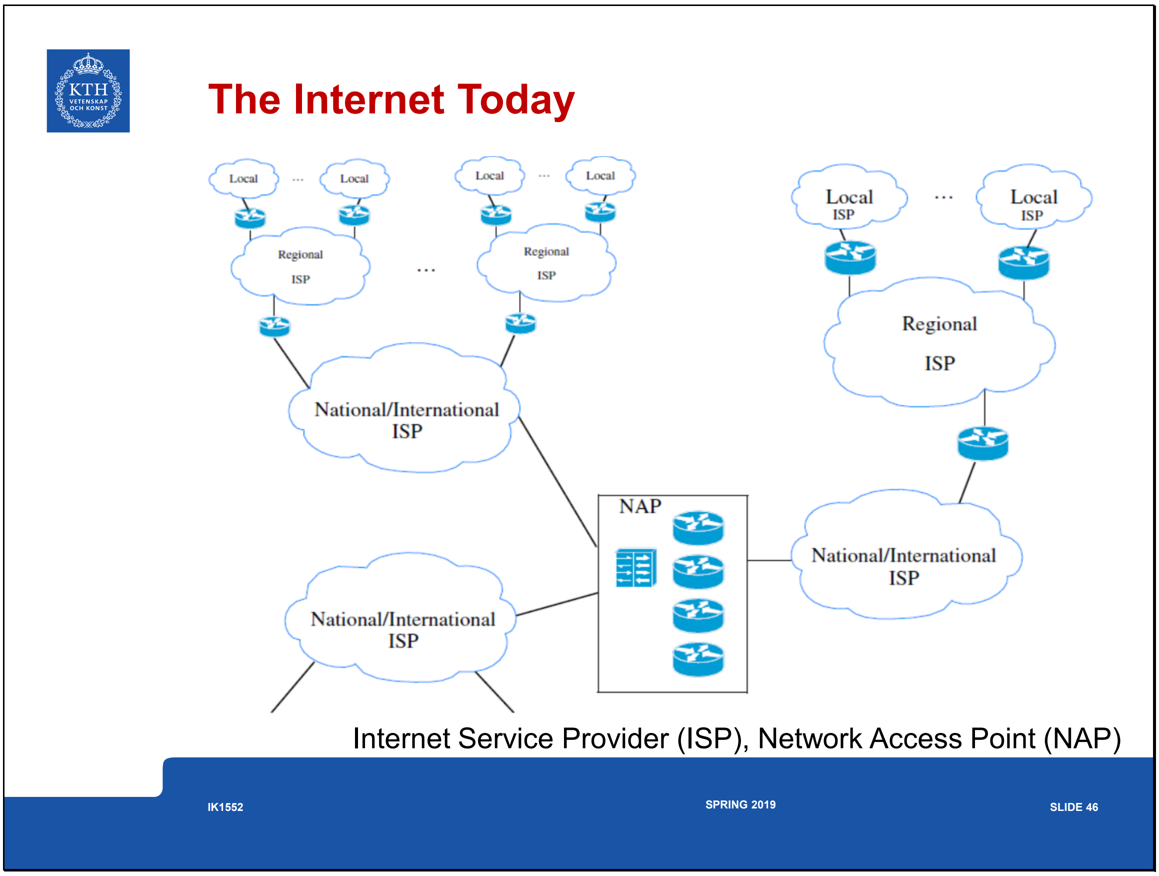
We will concern ourselves with one of the most common internetworking protocols IP (there *are* other internetworking protocols, such as Novell's Internetwork Packet Exchange (IPX), Xerox Network Systems (XNS), IBM's Systems Network Architecture (SNA), OSI's ISO-IP).

We will examine both IP:

- version 4 - which is in wide use
- version 6 - which is coming into use

Internet: the worldwide internet

Slide 46



The Internet Today
Local
Local
Local
Local
Regional
ISP
Regional
ISP
Local
ISP
Local
ISP
Regional
ISP
National/International
ISP
NAP
National/International
ISP
National/International
ISP
Internet Service Provider (ISP), Network Access Point (NAP)
IK1552
SPRING 2019
SLIDE 46

Slide 47

Clean slate re-design of the Internet

Many have questioned one or more of the basic concepts (open-architecture networking, End2End Argument, and Hourglass Model) and currently several groups are attempting to do a clean slate re-design of the Internet.

Consider for example the two research questions that researchers at Stanford University are asking as part of their Clean Slate program:

- "With what we know today, if we were to start again with a clean slate, how would we design a global communications infrastructure?", and
- "How should the Internet look in 15 years?"

-- Quoted from *http://cleanslate.stanford.edu/*

See also: *http://cleanslate.stanford.edu/about_cleanslate.php*

This is only one of many such projects, see also:

- U. S. National Science Foundation GENI: *http://geni.net*
- European Union Future Internet Research and Experimentation (FIRE): *https://www.ict-fire.eu/*

IK1552 SPRING 2019 SLIDE 47

Van Jacobson, "If a Clean Slate is the solution what was the problem?",Stanford Clean Slate Seminar, slide 26: "Digression on Implicit vs. Explicit Information", February 27, 2006 *http://cleanslate.stanford.edu/seminars/jacobson.pdf*

Slide 48

Implicit vs. Explicit Information

Van Jacobson expresses this as:

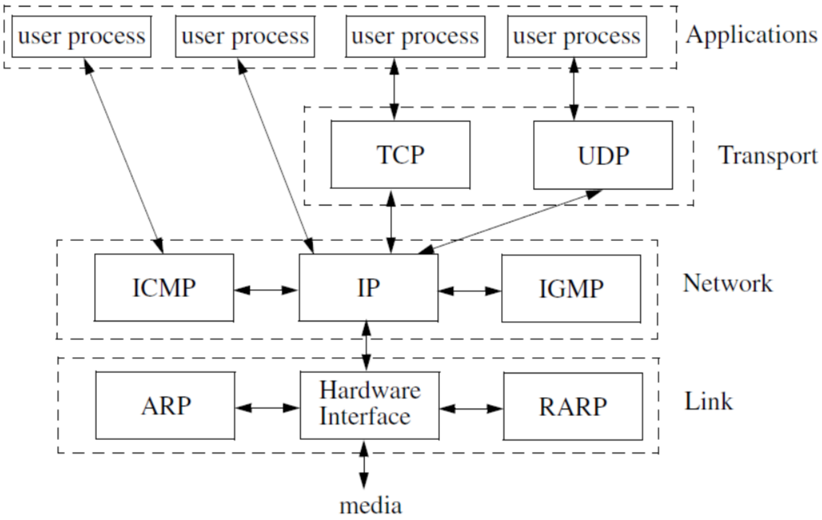
- "The nice properties of packet switching result from moving source & destination information *implicit* in a circuit switch's time slot assignments into *explicit* addresses in the packet header. (But its easy to do this wrong, e.g., ATM.)
- The nice properties of dissemination result from making the time & sequence information *implicit* in a conversation be *explicit* in a fully qualified name."

-- slide 26: "Digression on Implicit vs. Explicit Information" of Van Jacobson, "If a Clean Slate is the solution what was the problem?", Stanford Clean Slate Seminar, February 27, 2006 *http://cleanslate.stanford.edu/seminars/jacobson.pdf*

The emphasis (in *italic red characters*) in the above quotation were added by Maguire.

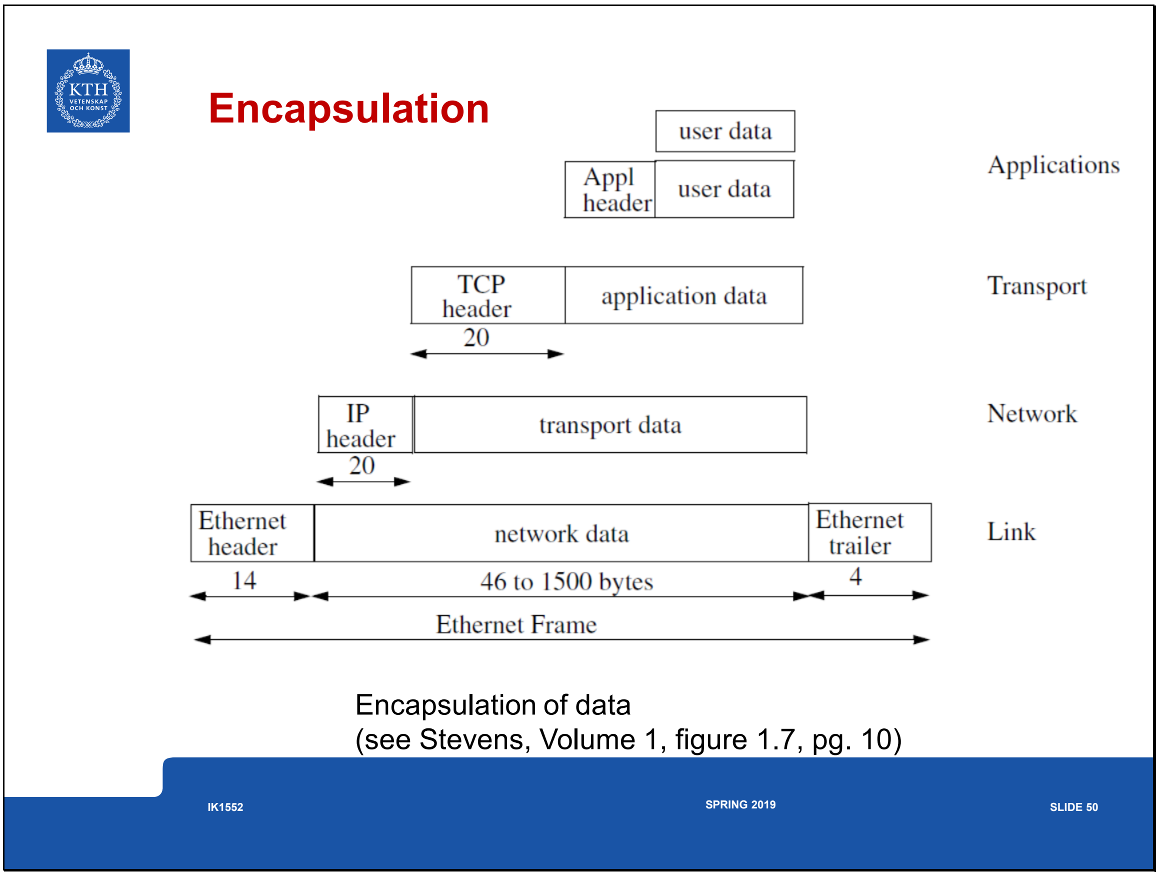
Slide 49

Review of Layering

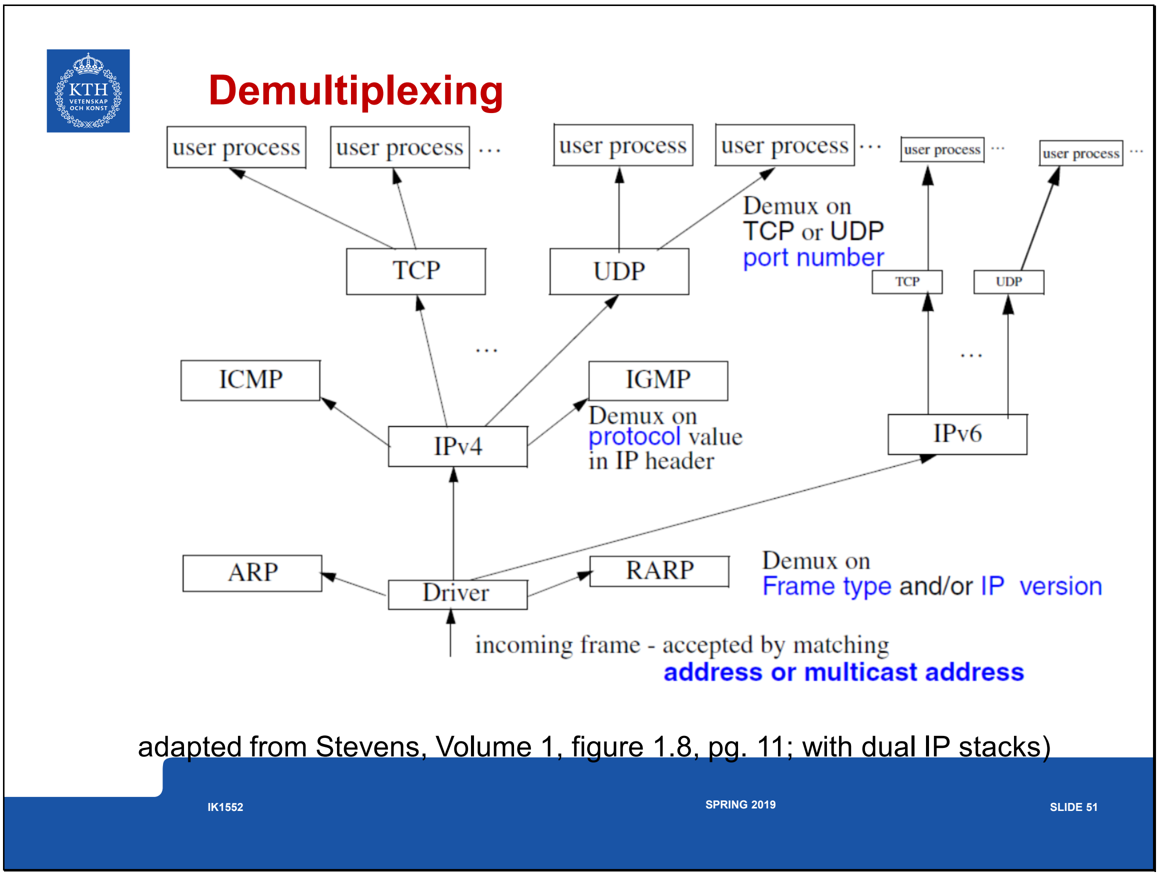


protocol layers in the TCP/IP protocol suite
(see Stevens, Volume 1, figure 1.4, pg. 6)

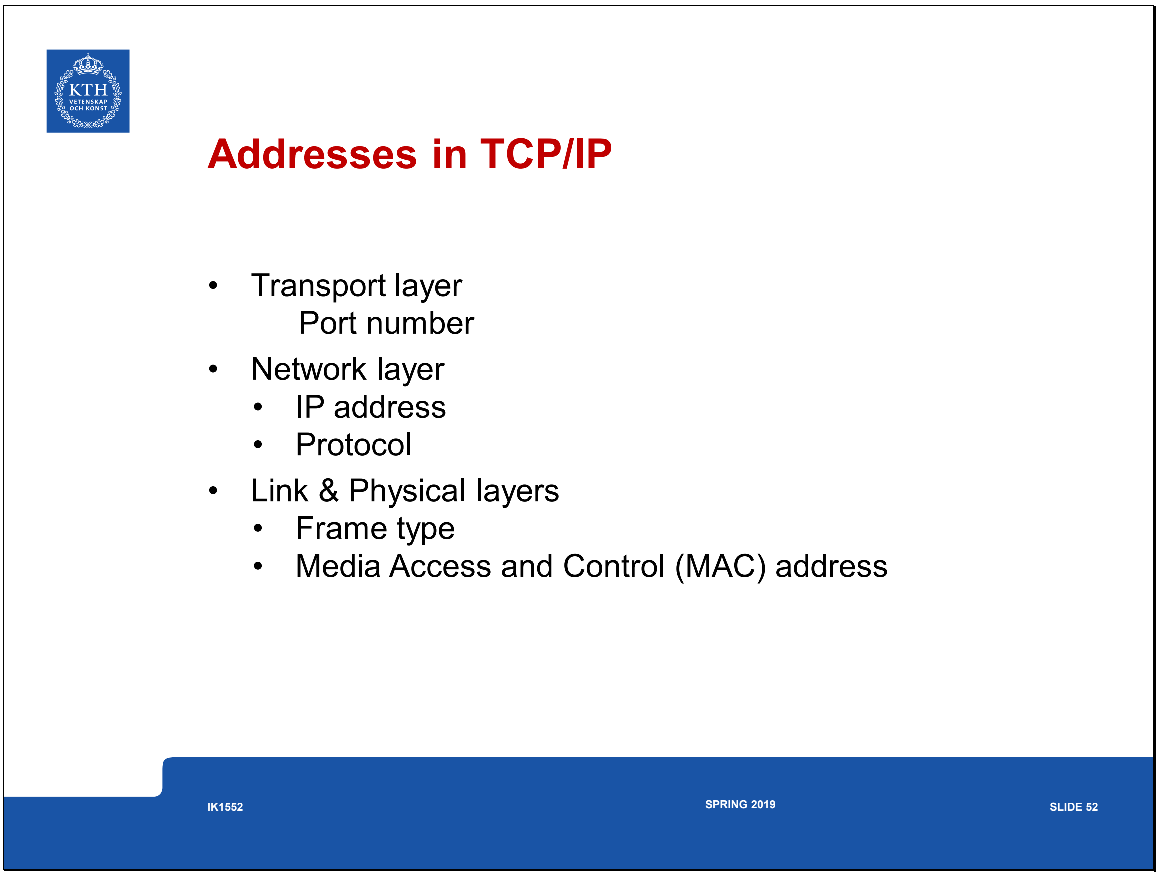
Slide 50


Encapsulation
user data
Appl header
user data
Applications
TCP header
application data
20
Transport
IP header
transport data
20
Network
Ethernet header
network data
Ethernet trailer
Link
14
46 to 1500 bytes
4
Ethernet Frame
Encapsulation of data
(see Stevens, Volume 1, figure 1.7, pg. 10)
IK1552
SPRING 2019
SLIDE 50

Slide 51


Demultiplexing
user process
user process
user process
user process
user process
user process
TCP
UDP
Demux on
TCP or UDP
port number
TCP
UDP
ICMP
IGMP
IPv4
Demux on
protocol value
in IP header
IPv6
ARP
Driver
RARP
Demux on
Frame type and/or IP version
incoming frame - accepted by matching
address or multicast address
adapted from Stevens, Volume 1, figure 1.8, pg. 11; with dual IP stacks)
IK1552
SPRING 2019
SLIDE 51

Slide 52


Addresses in TCP/IP
Transport layer
Port number
Network layer
IP address
Protocol
Link & Physical layers
Frame type
Media Access and Control (MAC) address
IK1552
SPRING 2019
SLIDE 52

Slide 53

Internet Protocol version 4 (IPv4) (RFC 791)

<table>
<tr><td>0 … 7</td><td>8 … 15</td><td colspan="2">16 … 23 24 … 31</td><td></td></tr>
<tr><td>4 bit version</td><td>4-bit header length</td><td>8-bit Type of Service (TOS)</td><td colspan="2">16 bit total length</td><td rowspan="5">20 bytes</td></tr>
<tr><td colspan="3">16 bit identification</td><td>3-bit flags</td><td>13 bit Fragment Offset</td></tr>
<tr><td colspan="2">8-bit Time to Live (TTL)</td><td>8-bit Protocol</td><td colspan="2">16 bit header checksum</td></tr>
<tr><td colspan="5">32 bit Source IP address</td></tr>
<tr><td colspan="5">32 bit Destination IP address</td></tr>
<tr><td colspan="5">options (padded to 32 bit length)</td><td></td></tr>
<tr><td colspan="5">data</td><td></td></tr>
</table>

IP header (see Stevens, Vol. 1, figure 3.1, pg. 34)

The fields: Version, Protocol, and Source & Destination IP addresses are all used for **demultiplexing** the incoming IP packet.

We will first examine version 4, then later in the course version 6.

Slide 54

IP "Protocol" field (RFC 1700)

In the Internet Protocol (IP), RFC 791, there is a field, called Protocol, to identify the next level protocol. This is an 8 bit field.

Assigned Internet Protocol Numbers (assigned by *Internet Assigned Numbers Authority* (IANA) *http://www.iana.org/assignments/protocol-numbers* (last updated 2017-10-13)

Decimal	Keyword	Protocol	IPv6 Extension Header	Reference
0	HOPOPT	IPv6 Hop-by-Hop Option	Y	[RFC2460]
1	ICMP	Internet Control Message		[RFC792]
2	IGMP	Internet Group Management		[RFC1112]
3	GGP	Gateway-to-Gateway		[RFC823]
4	IPv4	IPv4 encapsulation		[RFC2003]
5	ST	Stream		[RFC1190][RFC1819]
6	TCP	Transmission Control		[RFC793]
7	CBT	CBT		[Tony_Ballardie]
8	EGP	Exterior Gateway Protocol		[RFC888][David_Mills]
9	IGP	any private interior gateway (used by Cisco for their IGRP)		[Internet_Assigned_Numbers_Authority]
10	BBN-RCC-MON	BBN RCC Monitoring		[Steve_Chipman]
11	NVP-II	Network Voice Protocol		[RFC741][Steve_Casner]
12	PUP	PUP		[Boggs, D., J. Shoch, E. Taft, and R. Metcalfe, "PUP: An Internetwork Architecture", XEROX Palo Alto Research Center, CSL-79-10, July 1979; also in IEEE Transactions on Communication, Volume COM-28, Number 4, April 1980.][XEROX]]

IK1552 SPRING 2019 SLIDE 54

J. Reynolds and J. Postel, Assigned Numbers, Request for Comments: 1700 (RFC 1700), USC/Information Sciences Institute, October 1994.
J. Postel, 'Internet Control Message Protocol', *Internet Request for Comments*, vol. RFC 792 (INTERNET STANDARD), Sep. 1981 [Online]. Available: http://www.rfc-editor.org/rfc/rfc792.txt
S. Deering and R. Hinden, 'Internet Protocol, Version 6 (IPv6) Specification', *Internet Request for Comments*, vol. RFC 2460 (Draft Standard), Dec. 1998 [Online]. Available: http://www.rfc-editor.org/rfc/rfc2460.txt
J. Postel, 'Internet Control Message Protocol', *Internet Request for Comments*, vol. RFC 792 (INTERNET STANDARD), Sep. 1981 [Online]. Available: http://www.rfc-editor.org/rfc/rfc792.txt
S. E. Deering, 'Host extensions for IP multicasting', *Internet Request for Comments*, vol. RFC 1112 (INTERNET STANDARD), Aug. 1989 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1112.txt
R. M. Hinden and A. Sheltzer, 'DARPA Internet gateway', *Internet Request for Comments*, vol. RFC 823 (Historic), Sep. 1982 [Online]. Available: http://www.rfc-editor.org/rfc/rfc823.txt

C. Perkins, 'IP Encapsulation within IP', *Internet Request for Comments*, vol. RFC 2003 (Proposed Standard), Oct. 1996 [Online]. Available: http://www.rfc-editor.org/rfc/rfc2003.txt
C. Topolcic, 'Experimental Internet Stream Protocol: Version 2 (ST-II)', *Internet Request for Comments*, vol. RFC 1190 (Experimental), Oct. 1990 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1190.txt
L. Delgrossi and L. Berger, 'Internet Stream Protocol Version 2 (ST2) Protocol Specification - Version ST2+', *Internet Request for Comments*, vol. RFC 1819 (Experimental), Aug. 1995 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1819.txt
J. Postel, 'Transmission Control Protocol', *Internet Request for Comments*, vol. RFC 793 (INTERNET STANDARD), Sep. 1981 [Online]. Available: http://www.rfc-editor.org/rfc/rfc793.txt
L. Seamonson and E. C. Rosen, '"STUB" Exterior Gateway Protocol', *Internet Request for Comments*, vol. RFC 888, Jan. 1984 [Online]. Available: http://www.rfc-editor.org/rfc/rfc888.txt
D. Cohen, 'Specifications for the Network Voice Protocol (NVP)', *Internet Request for Comments*, vol. RFC 741, Nov. 1977 [Online]. Available: http://www.rfc-editor.org/rfc/rfc741.txt

Slide 55

13	ARGUS	ARGUS	[Robert_W_Scheifler]
14	EMCON	EMCON	[<mystery contact>]
15	XNET	Cross Net Debugger	[Haverty, J., "XNET Formats for Internet Protocol Version 4", IEN 158, October 1980.][Jack_Haverty]
16	CHAOS	Chaos	[J_Noel_Chiappa]
17	UDP	User Datagram	[RFC768][Jon_Postel]
18	MUX	Multiplexing	[Cohen, D. and J. Postel, "Multiplexing Protocol", IEN 90, USC/Information Sciences Institute, May 1979.][Jon_Postel]
19	DCN-MEAS	DCN Measurement Subsystems	[David_Mills]
20	HMP	Host Monitoring	[RFC869][Bob_Hinden]
21	PRM	Packet Radio Measurement	[Zaw_Sing_Su]
22	XNS-IDP	XEROX NS IDP	["The Ethernet, A Local Area Network: Data Link Layer and Physical Layer Specification", AA-K759B-TK, Digital Equipment Corporation, Maynard, MA. Stamford, CT., October 1980.][[XEROX]] …
23	TRUNK-1	Trunk-1	[Barry_Boehm]
24	TRUNK-2	Trunk-2	[Barry_Boehm]
25	LEAF-1	Leaf-1	[Barry_Boehm]
26	LEAF-2	Leaf-2	[Barry_Boehm]
27	RDP	Reliable Data Protocol	[RFC908][Bob_Hinden]
28	IRTP	Internet Reliable Transaction	[RFC938][Trudy_Miller]
29	ISO-TP4	ISO Transport Protocol Class 4	[RFC905][<mystery contact>]

IK1552 SPRING 2019 SLIDE 55

Slide 56

30	NETBLT	Bulk Data Transfer Protocol		[RFC969][David_Clark]
31	MFE-NSP	MFE Network Services Protocol		[Shuttleworth, B., "A Documentary of MFENet, a National Computer Network", UCRL-52317, Lawrence Livermore Labs, Livermore, California, June 1977.][Barry_Howard]
32	MERIT-INP	MERIT Internodal Protocol		[Hans_Werner_Braun]
33	DCCP	Datagram Congestion Control Protocol		[RFC4340]
34	3PC	Third Party Connect Protocol		[Stuart_A_Friedberg]
35	IDPR	Inter-Domain Policy Routing Protocol		[Martha_Steenstrup]
36	XTP	XTP		[Greg_Chesson]
37	DDP	Datagram Delivery Protocol		[Wesley_Craig]
38	IDPR-CMTP	IDPR Control Message Transport Proto		[Martha_Steenstrup]
39	TP++	TP++ Transport Protocol		[Dirk_Fromhein]
40	IL	IL Transport Protocol		[Dave_Presotto]
41	IPv6	IPv6 encapsulation		[RFC2473]
42	SDRP	Source Demand Routing Protocol		[Deborah_Estrin]
43	IPv6-Route	Routing Header for IPv6	Y	[Steve_Deering]
44	IPv6-Frag	Fragment Header for IPv6	Y	[Steve_Deering]
45	IDRP	Inter-Domain Routing Protocol		[Sue_Hares]
46	RSVP	Reservation Protocol		[RFC2205][RFC3209][Bob_Braden]
47	GRE	Generic Routing Encapsulation		[RFC2784][Tony_Li]
48	DSR	Dynamic Source Routing Protocol		[RFC4728]
49	BNA	BNA		[Gary Salamon]

IK1552 SPRING 2019 SLIDE 56

Slide 57

50	ESP	Encap Security Payload	Y	[RFC4303]
51	AH	Authentication Header	Y	[RFC4302]
52	I-NLSP	Integrated Net Layer Security TUBA		[K_Robert_Glenn]
53	SWIPE (deprecated)	IP with Encryption		[John_Ioannidis]
54	NARP	NBMA Address Resolution Protocol		[RFC1735]
55	MOBILE	IP Mobility		[Charlie_Perkins]
56	TLSP	Transport Layer Security Protocol using Kryptonet key management		[Christer_Oberg]
57	SKIP	SKIP		[Tom_Markson]
58	IPv6-ICMP	ICMP for IPv6		[RFC2460]
59	IPv6-NoNxt	No Next Header for IPv6		[RFC2460]
60	IPv6-Opts	Destination Options for IPv6	Y	[RFC2460]
61		any host internal protocol		[Internet_Assigned_Numbers_Authority]
62	CFTP	CFTP		[Forsdick, H., "CFTP", Network Message, Bolt Beranek and Newman, January 1982.][Harry_Forsdick]
63		any local network		[Internet_Assigned_Numbers_Authority]
64	SAT-EXPAK	SATNET and Backroom EXPAK		[Steven_Blumenthal]
65	KRYPTOLAN	Kryptolan		[Paul Liu]
66	RVD	MIT Remote Virtual Disk Protocol		[Michael_Greenwald]
67	IPPC	Internet Pluribus Packet Core		[Steven_Blumenthal]
68		any distributed file system		[Internet_Assigned_Numbers_Authority]
69	SAT-MON	SATNET Monitoring		[Steven_Blumenthal]

IK1552 SPRING 2019 SLIDE 57

Slide 58

70	VISA	VISA Protocol		[Gene_Tsudik]
71	IPCV	Internet Packet Core Utility		[Steven_Blumenthal]
72	CPNX	Computer Protocol Network Executive		[David Mittnacht]
73	CPHB	Computer Protocol Heart Beat		[David Mittnacht]
74	WSN	Wang Span Network		[Victor Dafoulas]
75	PVP	Packet Video Protocol		[Steve_Casner]
76	BR-SAT-MON	Backroom SATNET Monitoring		[Steven_Blumenthal]
77	SUN-ND	SUN ND PROTOCOL-Temporary		[William_Melohn]
78	WB-MON	WIDEBAND Monitoring		[Steven_Blumenthal]
79	WB-EXPAK	WIDEBAND EXPAK		[Steven_Blumenthal]
80	ISO-IP	ISO Internet Protocol		[Marshall_T_Rose]
81	VMTP	VMTP		[Dave_Cheriton]
82	SECURE-VMTP	SECURE-VMTP		[Dave_Cheriton]
83	VINES	VINES		[Brian Horn]
84	TTP	Transaction Transport Protocol		[Jim_Stevens]
84	IPTM	Internet Protocol Traffic Manager		[Jim_Stevens]
85	NSFNET-IGP	NSFNET-IGP		[Hans_Werner_Braun]
86	DGP	Dissimilar Gateway Protocol		[M/A-COM Government Systems, "Dissimilar Gateway Protocol Specification, Draft Version", Contract no. CS901145, November 16, 1987.][Mike_Little]
87	TCF	TCF		[Guillermo_A_Loyola]
88	EIGRP	EIGRP		[Cisco Systems, "Gateway Server Reference Manual", Manual Revision B, January 10, 1988.][Guenther_Schreiner]
89	OSPFIGP	OSPFIGP		[RFC1583][RFC2328][RFC5340][John_Moy]

IK1552 SPRING 2019 SLIDE 58

Slide 59

90	Sprite-RPC	Sprite RPC Protocol		[Welch, B., "The Sprite Remote Procedure Call System", Technical Report, UCB/Computer Science Dept., 86/302, University of California at Berkeley, June 1986.][Bruce Willins]
91	LARP	Locus Address Resolution Protocol		[Brian Horn]
92	MTP	Multicast Transport Protocol		[Susie_Armstrong]
93	AX.25	AX.25 Frames		[Brian_Kantor]
94	IPIP	IP-within-IP Encapsulation Protocol		[John_Ioannidis]
95	MICP (deprecated)	Mobile Internetworking Control Pro.		[John_Ioannidis]
96	SCC-SP	Semaphore Communications Sec. Pro.		[Howard_Hart]
97	ETHERIP	Ethernet-within-IP Encapsulation		[RFC3378]
98	ENCAP	Encapsulation Header		[RFC1241][Robert_Woodburn]
99		any private encryption scheme		[Internet_Assigned_Numbers_Authority]
100	GMTP	GMTP		[[RXB5]]
101	IFMP	Ipsilon Flow Management Protocol		[Bob_Hinden][November 1995, 1997.]
102	PNNI	PNNI over IP		[Ross_Callon]
103	PIM	Protocol Independent Multicast		[RFC4601][Dino_Farinacci]
104	ARIS	ARIS		[Nancy_Feldman]
105	SCPS	SCPS		[Robert_Durst]
106	QNX	QNX		[Michael_Hunter]
107	A/N	Active Networks		[Bob_Braden]
108	IPComp	IP Payload Compression Protocol		[RFC2393]
109	SNP	Sitara Networks Protocol		[Manickam_R_Sridhar]

IK1552 SPRING 2019 SLIDE 59

Slide 60

110	Compaq-Peer	Compaq Peer Protocol		[Victor_Volpe]
111	IPX-in-IP	IPX in IP		[CJ_Lee]
112	VRRP	Virtual Router Redundancy Protocol		[RFC5798]
113	PGM	PGM Reliable Transport Protocol		[Tony_Speakman]
114		any 0-hop protocol		[Internet_Assigned_Numbers_Authority]
115	L2TP	Layer Two Tunneling Protocol		[RFC3931][Bernard_Aboba]
116	DDX	D-II Data Exchange (DDX)		[John_Worley]
117	IATP	Interactive Agent Transfer Protocol		[John_Murphy]
118	STP	Schedule Transfer Protocol		[Jean_Michel_Pittet]
119	SRP	SpectraLink Radio Protocol		[Mark_Hamilton]
120	UTI	UTI		[Peter_Lothberg]
121	SMP	Simple Message Protocol		[Leif_Ekblad]
122	SM	Simple Multicast Protocol		[Jon_Crowcroft][draft-perlman-simple-multicast]
123	PTP	Performance Transparency Protocol		[Michael_Welzl]
124	ISIS over IPv4			[Tony_Przygienda]
125	FIRE			[Criag_Partridge]
126	CRTP	Combat Radio Transport Protocol		[Robert_Sautter]
127	CRUDP	Combat Radio User Datagram		[Robert_Sautter]
128	SSCOPMCE			[Kurt_Waber]
129	IPLT			[[Hollbach]]

IK1552 SPRING 2019 SLIDE 60

Slide 61

130	SPS	Secure Packet Shield		[Bill_McIntosh]
131	PIPE	Private IP Encapsulation within IP		[Bernhard_Petri]
132	SCTP	Stream Control Transmission Protocol		[Randall_R_Stewart]
133	FC	Fibre Channel		[Murali_Rajagopal][RFC6172]
134	RSVP-E2E-IGNORE			[RFC3175]
135	Mobility Header		Y	[RFC6275]
136	UDPLite			[RFC3828]
137	MPLS-in-IP			[RFC4023]
138	manet	MANET Protocols		[RFC5498]
139	HIP	Host Identity Protocol	Y	[RFC7401]
140	Shim6	Shim6 Protocol	Y	[RFC5533]
141	WESP	Wrapped Encapsulating Security Payload		[RFC5840]
142	ROHC	Robust Header Compression		[RFC5858]

Slide 62

143-252		Unassigned		[Internet_Assigned_Numbers_Authority]
253		Use for experimentation and testing	Y	[RFC3692]
254		Use for experimentation and testing	Y	[RFC3692]
255	Reserved			[Internet_Assigned_Numbers_Authority]

As of Feb. 2010, there were ~46 fewer available protocol numbers than at the time of the course in 1999.

Slide 63

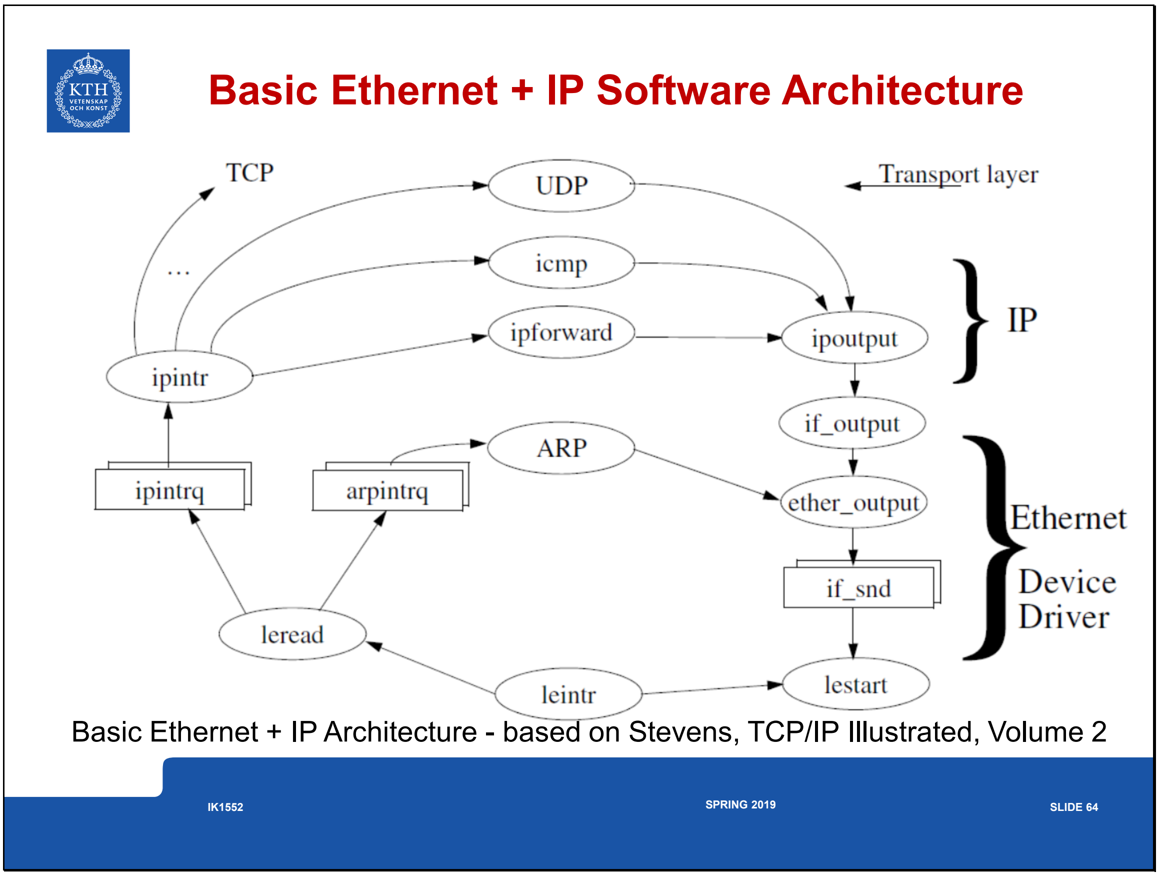
Basic communication mechanism: datagram

Properties of datagrams:

- Best effort
- Each message handled independently — global addressing.
- IP packets (datagrams) are forwarded according to the network address (which is in each datagram) by **routers**.

Later in the course we will look at other than best effort handling of datagrams.

Slide 64


Basic Ethernet + IP Software Architecture
TCP
UDP
Transport layer
...
icmp
ipforward
ipoutput
IP
ipintr
if_output
ARP
ipintrq
arpintrq
ether_output
Ethernet
if_snd
Device
Driver
leread
leintr
lestart
Basic Ethernet + IP Architecture - based on Stevens, TCP/IP Illustrated, Volume 2
IK1552
SPRING 2019
SLIDE 64

Slide 65

Common Used Simple Services

Name	TCP port	UDP port	RFC	Description
echo	7	7	862	server returns what the client sends
discard	9	9	863	server discards what the client sends
daytime	13	13	867	Server returns the time and date in a human readable format
chargen	19	19	864	TCP server sends a continual stream of character, until the connection is terminated by the client. UDP server sends a datagram containing a random number of characters each time the client sends a datagram.
ftp-data	20			File Transfer Protocol (Data)
ftp	21			File Transfer Protocol (Control)
telnet	23			Virtual Terminal Protocol
smtp	25			Simple Mail Transfer Protocol
time	37	37	868	Server returns the time as a 32-bit binary number. This number is the time in seconds since 1 Jan. 1990, UTC

Slide 66

Link Layer

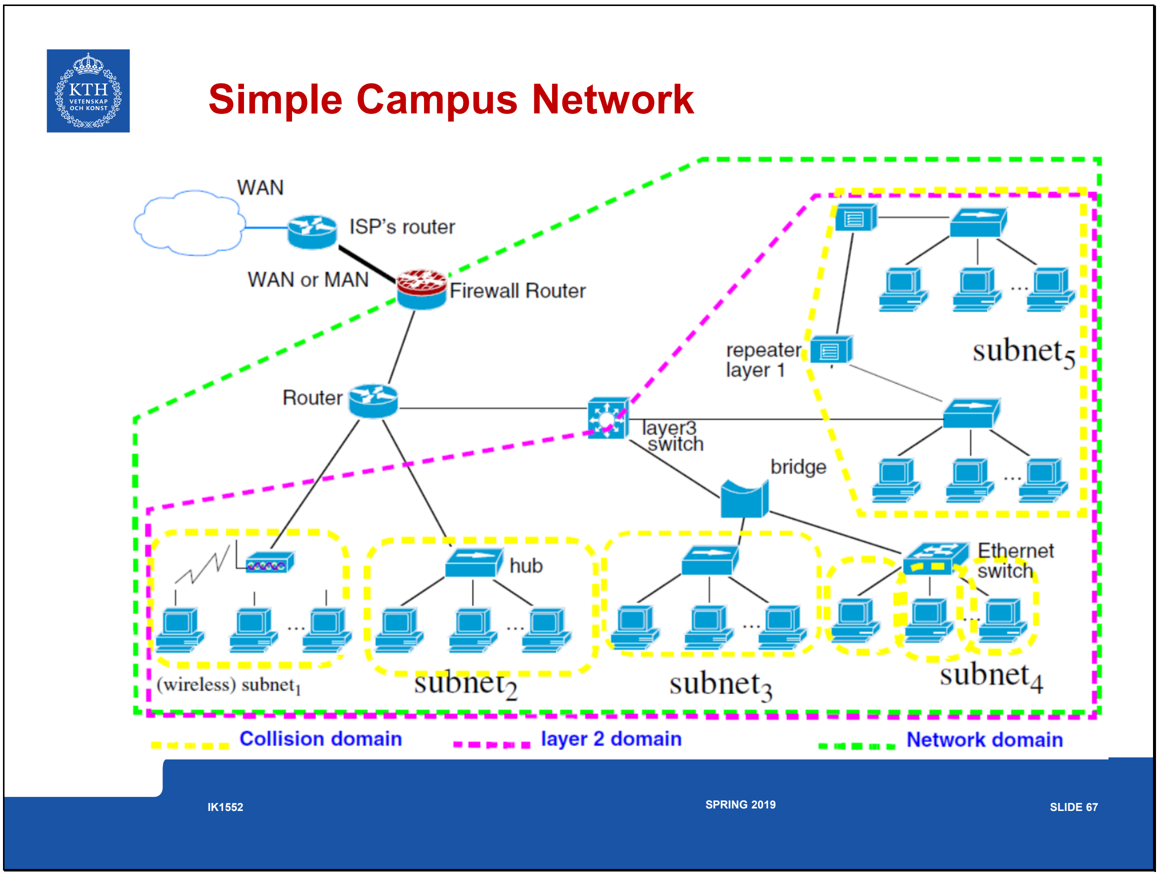
Possible link layers include:

- Ethernet and IEEE 802.3 Encapsulation
- with possible Trailer Encapsulation
- SLIP: Serial Line IP
- CSLIP: Compress SLIP
- PPP: Point to Point Protocol
- Loopback Interface
- Virtual Interface
- …
- carrier pigeons - CPIP (Carrier Pigeon Internet Protocol) April 1st 1990, RFC 1149 was written. A protocol for IP over avian carriers. Implementation (April 28 2001): *http://www.blug.linux.no/rfc1149/*

Some of the issues concerning links are:

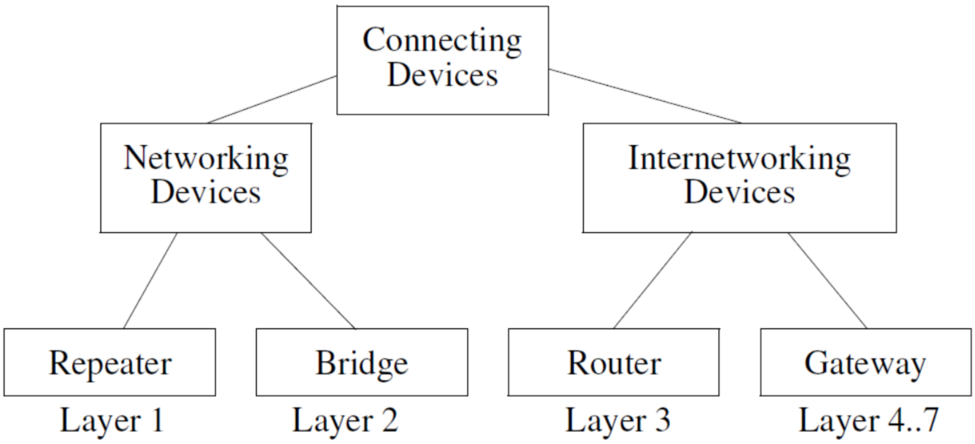
- MTU and Path MTU
- Serial line throughput

Slide 67


Simple Campus Network
WAN
ISP's router
WAN or MAN
Firewall Router
Router
repeater layer 1
layer3 switch
bridge
hub
Ethernet switch
subnet$_5$
(wireless) subnet$_1$
subnet$_2$
subnet$_3$
subnet$_4$
Collision domain
layer 2 domain
Network domain
IK1552
SPRING 2019
SLIDE 67

Slide 68

Connecting Devices



- Ethernet hub = a multiport repeater
- Ethernet switch = a multiport bridge
- Layer 3 switch = combines functions of an ethernet switch and a router

Slide 69

How important are switches vs. routers?

There are an enormous number of switches sold per year. Probably more than one switch port sold per wired Ethernet interface!

Cisco	25 July 2015	Percentage of net product sales
Routers	US$ 7,704 M	20.4%
Switches	US$14,741 M	39.1%
Collaboration	US$ 4,000 M	10.6%
Service Provider Video	US$ 3,555 M	9.4%
Data center	US$ 3,220 M	8.5%
Wireless	US$ 2,542 M	6.7%
Security	US$ 1,747 M	4.6%
Other	US$ 241 M	0.7%
Total	**US$37,750M**	

Data from page 47 of Cisco's Annual Report 2015: http://www.cisco.com/c/dam/assets/about/ar/pdf/2015-cisco-annual-report.pdf

Slide 70

For comparison purposes

HP's Corporate Investments (which includes their Ethernet switch business) was US$566 M in 2006 - and had grown 8% over the previous year due to gigabit switch products [HP 2006]; while in 2007 it was US$762 M with a 33% growth attributed to enterprise class gigabit network switches! [HP 2007]

From CyberMedia India Online Ltd. "Infonetics Study: Ethernet switch grows, enterprise routers disappoint",, Thursday, March 03, 2011,
http://www.ciol.com/Technology/Networking/News-Reports/Ethernet-switch-grows-enterprise-routers-disappoint/147305/0/

Market	quarterly revenue in 4Q2010
Ethernet switch	**US$4.79 billion**
Enterprise router	US$0.920 billion
WLAN equipment	US$0.769 billion

[HP 2006] Hewlett-Packard Company Annual Report, 2006, page 60
[HP 2007] Hewlett-Packard Company Form 10-K, 2007, page 60

Slide 71

Facebook Open Switching System ("FBOSS") and the top-of-rack **Wedge** Switch

1. Developed for its own networks as part of the **Open Compute Project** (http://www.opencompute.org/)
2. From Accton Technology Corporation (http://www.accton.com/)

https://code.facebook.com/posts/681382905244727/introducing-wedge-and-fboss-the-next-steps-toward-a-disaggregated-network/

https://code.facebook.com/posts/843620439027582/facebook-open-switching-system-fboss-and-wedge-in-the-open/

http://uk.businessinsider.com/facebooks-shot-at-cisco-just-got-deadly-2015-3?r=US

and

Alex Eckert, Luis Martin Garcia, Reza Niazmand, and Xu Wang, 'Wedge 100: More open and versatile than ever', *Facebook Code*, 18-Oct-2016. [Online]. Available: https://code.facebook.com/posts/1802489260027439/wedge-100-more-open-and-versatile-than-ever/. [Accessed: 15-Mar-2018]

IK1552 SPRING 2019 SLIDE 71

Slide 72

High speed switch chips

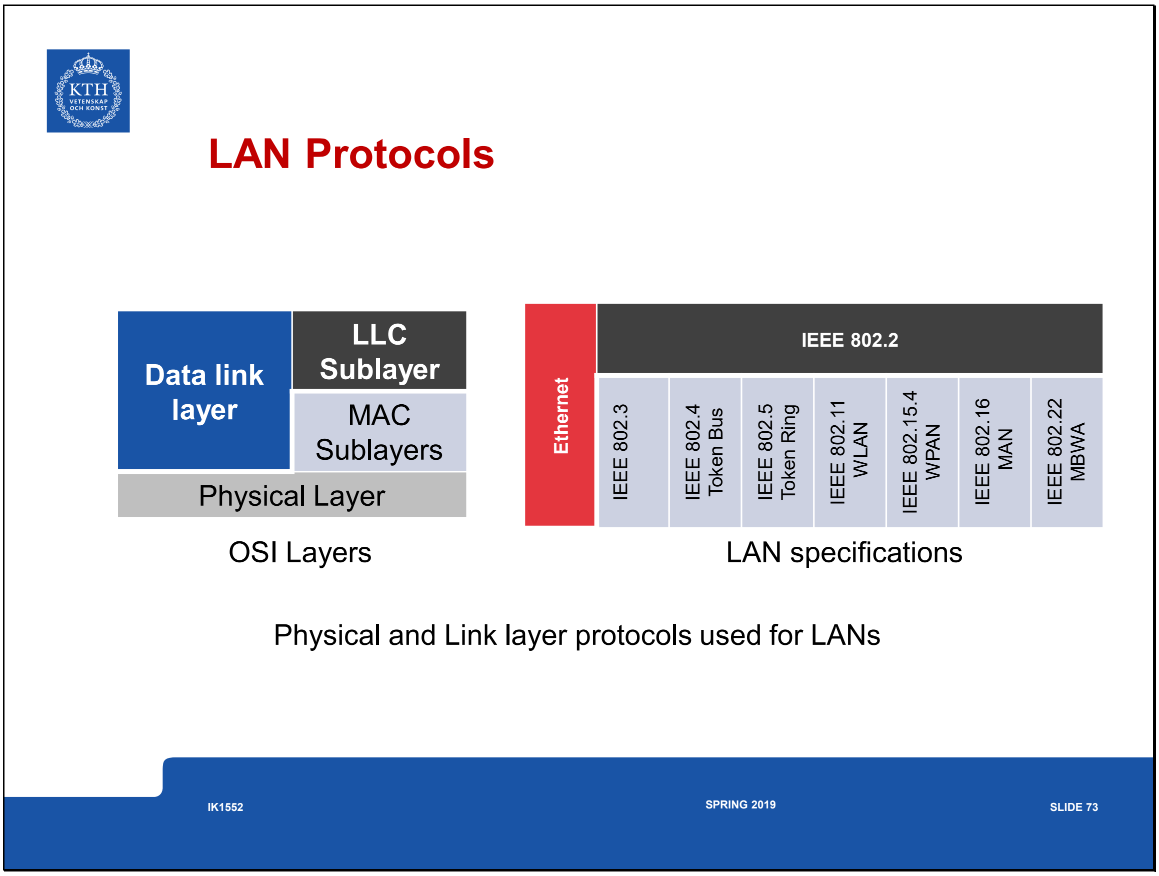
Broadcom BCM56980 Series, 12.8 Tbps StrataXGS® Tomahawk® 3 Ethernet Switch Series

- https://www.broadcom.cn/products/ethernet-connectivity/switching/strataxgs/bcm56980-series

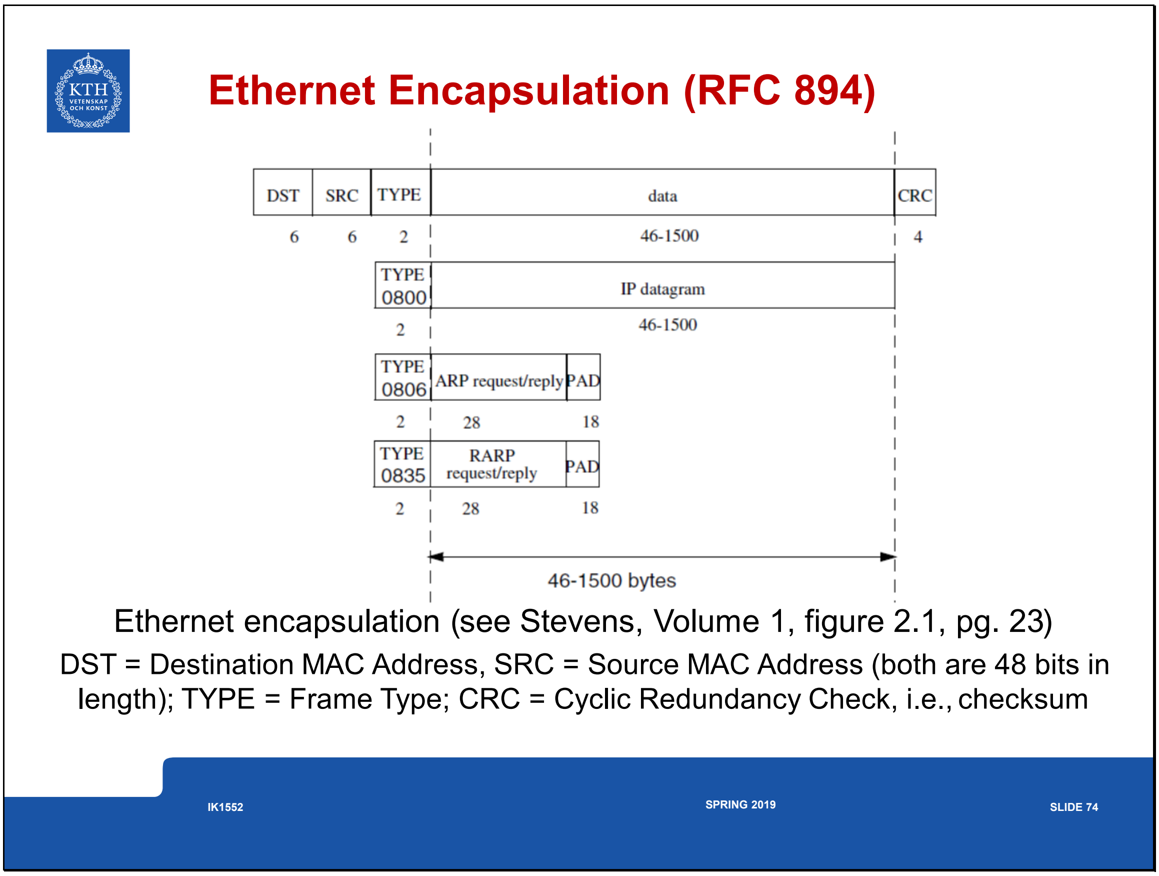
Mellanox Technologies, Spectrum™-2 Ethernet Switch ASIC, 6.4Tb/s Ethernet Switch

- http://www.mellanox.com/page/products_dyn?product_family=277&mtag=spectrum2_ic

Slide 73


LAN Protocols
Data link layer
LLC Sublayer
MAC Sublayers
Physical Layer
OSI Layers
Ethernet
IEEE 802.2
IEEE 802.3
IEEE 802.4 Token Bus
IEEE 802.5 Token Ring
IEEE 802.11 WLAN
IEEE 802.15.4 WPAN
IEEE 802.16 MAN
IEEE 802.22 MBWA
LAN specifications
Physical and Link layer protocols used for LANs
IK1552
SPRING 2019
SLIDE 73

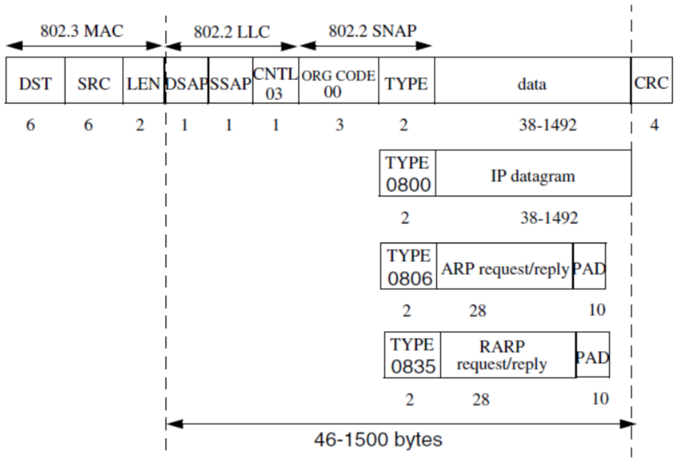
Slide 74



[RFC 894] C. Hornig, ‘A Standard for the Transmission of IP Datagrams over Ethernet Networks’, *Internet Request for Comments*, vol. RFC 894 (INTERNET STANDARD), Apr. 1984 [Online]. Available: http://www.rfc-editor.org/rfc/rfc894.txt

Slide 75

IEEE 802.2/802.3 Encapsulation (RFC 1042)



IEEE802.2/802.3 (see Stevens, Volume 1, figure 2.1, pg. 23)
DSAP ≡ Destination Service Access Point; SSAP ≡ Source Service Access Point; SNAP ≡ Sub-Network Access Protocol; for other TYPE values see http://www.iana.org/assignments/ieee-802-numbers/ieee-802-numbers.xhtml

IK1552 SPRING 2019 SLIDE 75

[RFC 1042] J. Postel and J. K. Reynolds, ‘Standard for the transmission of IP datagrams over IEEE 802 networks’, *Internet Request for Comments*, vol. RFC 1042 (INTERNET STANDARD), Feb. 1988 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1042.txt

EtherTypes were previous specified in:
[RFC 1700] J. Reynolds and J. Postel, ‘Assigned Numbers’, *Internet Request for Comments*, vol. RFC 1700 (Historic), Oct. 1994 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1700.txt
[RFC 3232] J. Reynolds, ‘Assigned Numbers: RFC 1700 is Replaced by an On-line Database’, *Internet Request for Comments*, vol. RFC 3232 (Informational), Jan. 2002 [Online]. Available: http://www.rfc-editor.org/rfc/rfc3232.txt

Slide 76

IEEE 802 Numbers of Interest

"… IEEE 802 Networks. These systems may use a Link Service Access Point (LSAP) field in much the same way the MILNET uses the "link" field. Further, there is an extension of the LSAP header called the Sub-Network Access Protocol (SNAP).

The IEEE likes to describe numbers in binary in bit transmission order, which is the opposite of the big-endian order used throughout the Internet protocol documentation." - see http://www.iana.org/assignments/ieee-802-numbers/ieee-802-numbers.xhtml#ieee-802-numbers-3 (last updated 2015-10-06) **Logical Link Control (LLC) Numbers**

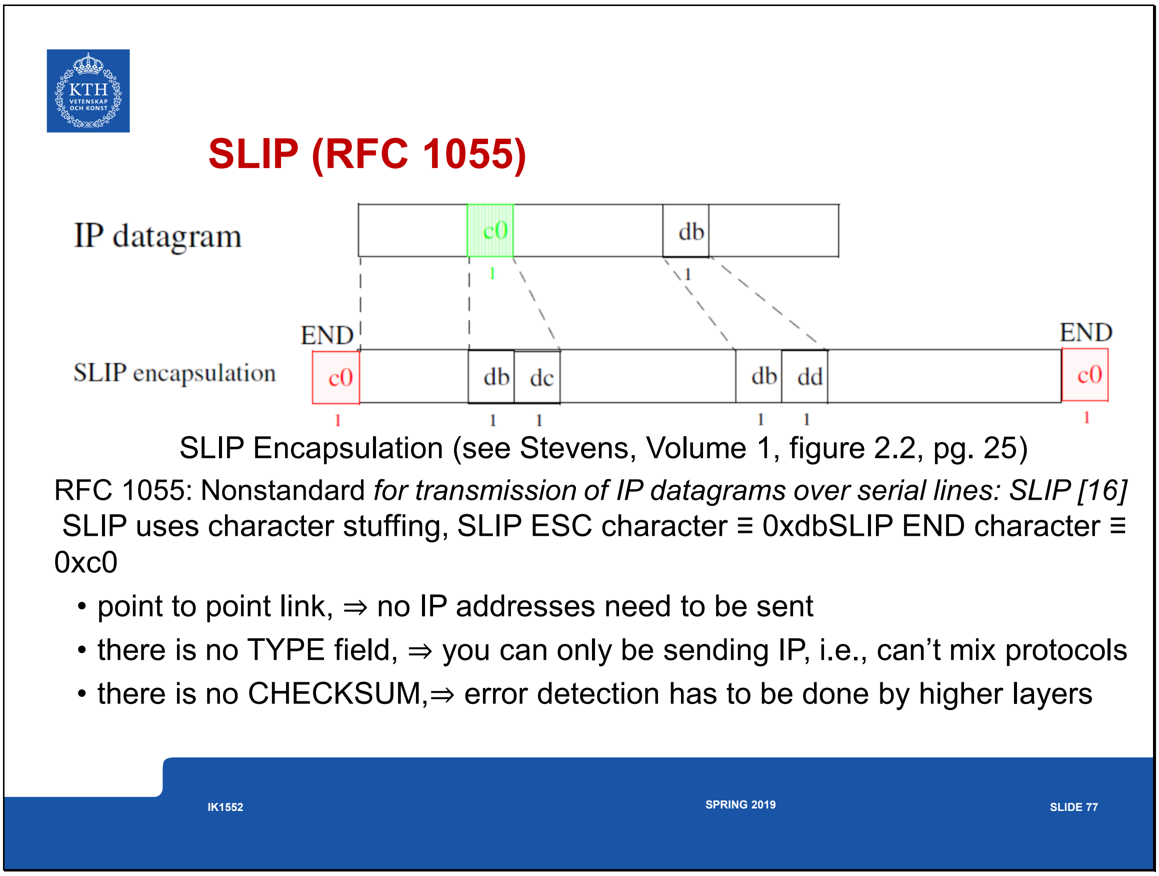
Link Service Access Point (IEEE Binary)	Link Service Access Point (Internet Binary)	Link Service Access Point (Decimal)	Description
0	0	0	Null LSAP
1000000	10	2	Indiv LLC Sublayer Mgt
11000000	11	3	Group LLC Sublayer Mgt
100000	100	4	SNA Path Control
1100000	110	6	Reserved (DOD IP) - RFC 768
1110000	1110	14	PROWAY-LAN
1110010	1001110	78	EIA-RS 511
1111010	1011110	94	ISI IP
1110001	10001110	142	PROWAY-LAN
1010101	10101010	170	SNAP - RFC 1042
1111111	11111110	254	ISO CLNS IS 8473 – RFC 926
11111111	11111111	255	Global DSAP

J. Postel, 'User Datagram Protocol', *Internet Request for Comments*, vol. RFC 768 (INTERNET STANDARD), Aug. 1980 [Online]. Available: http://www.rfc-editor.org/rfc/rfc768.txt

J. Postel and J. K. Reynolds, 'Standard for the transmission of IP datagrams over IEEE 802 networks', *Internet Request for Comments*, vol. RFC 1042 (INTERNET STANDARD), Feb. 1988 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1042.txt

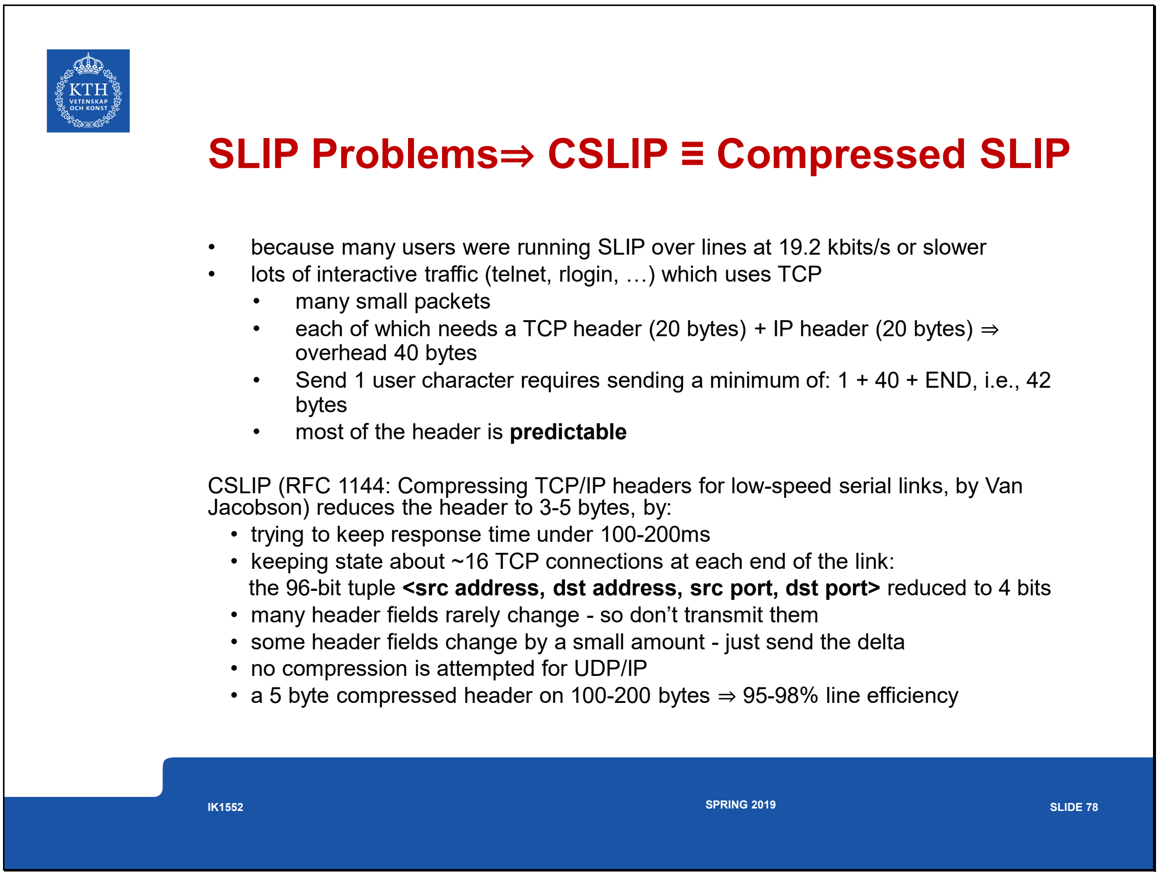
International Organization for Standardization, 'Protocol for providing the connectionless mode network services', *Internet Request for Comments*, vol. RFC 926, Dec. 1984 [Online]. Available: http://www.rfc-editor.org/rfc/rfc926.txt

Slide 77



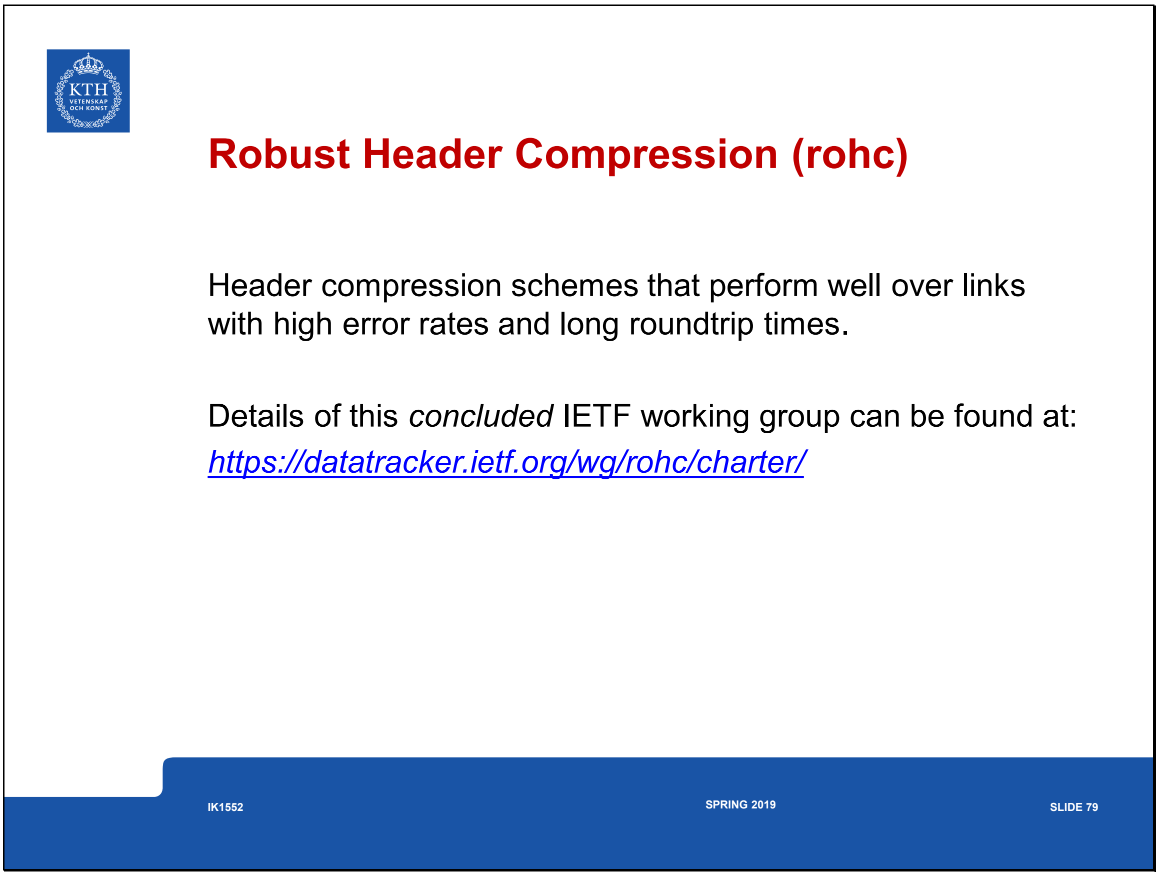
J. L. Romkey, 'Nonstandard for transmission of IP datagrams over serial lines: SLIP', *Internet Request for Comments*, vol. RFC 1055 (INTERNET STANDARD), Jun. 1988 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1055.txt

Slide 78



V. Jacobson, ‘Compressing TCP/IP Headers for Low-Speed Serial Links’, *Internet Request for Comments*, vol. RFC 1144 (Proposed Standard), Feb. 1990 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1144.txt

Slide 79


Robust Header Compression (rohc)
Header compression schemes that perform well over links with high error rates and long roundtrip times.
Details of this *concluded* IETF working group can be found at:
https://datatracker.ietf.org/wg/rohc/charter/
IK1552
SPRING 2019
SLIDE 79

Slide 80

PPP: Point to Point Protocol

PPP (RFCs 1331 &1332) corrects the deficiencies in SLIP:

- **encapsulation** for either asynchronous or synchronous links, such as HDLC (see RFC 1549), X.25 (see RFC 1598), ISDN (see RFC 1618), SONET/SDH (see RFC 1619)
- **Link Control Protocol**
  - establish, configure, and test data-links [includes option negotiation]
  - authentication (see RFC 1334)
- **Family of Network Control Protocols** (NCPs) - specific to different network protocols, currently:
  - IP (see RFC 1332)
  - DECnet (see RFC 1376)
  - OSI network layer (see RFC 1377)
  - AppleTalk (see RFC 1378)
  - XNS (see RFC 1764)

See: James D. Carlson, “PPP Design, Implementation, and Debugging”, Second edition, Addison-Wesley, 2000, ISBN 0-201-70053-0

IK1552 SPRING 2019 SLIDE 80

W. Simpson, ‘The Point-to-Point Protocol (PPP) for the Transmission of Multi-protocol Datagrams over Point-to-Point Links’, *Internet Request for Comments*, vol. RFC 1331 (Proposed Standard), May 1992 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1331.txt

G. McGregor, ‘The PPP Internet Protocol Control Protocol (IPCP)’, *Internet Request for Comments*, vol. RFC 1332 (Proposed Standard), May 1992 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1332.txt

W. Simpson, ‘PPP in HDLC Framing’, *Internet Request for Comments*, vol. RFC 1549 (Draft Standard), Dec. 1993 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1549.txt

W. Simpson, ‘PPP in X.25’, *Internet Request for Comments*, vol. RFC 1598 (Proposed Standard), Mar. 1994 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1598.txt

W. Simpson, ‘PPP over ISDN’, *Internet Request for Comments*, vol. RFC 1618 (Proposed Standard), May 1994 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1618.txt

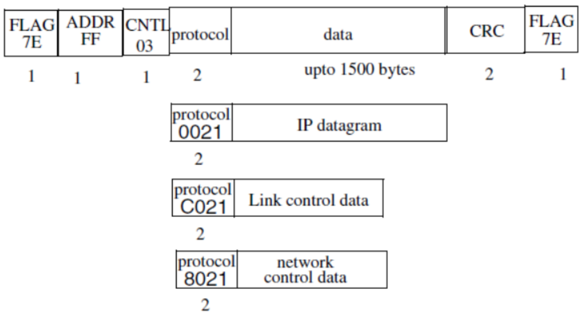
W. Simpson, ‘PPP over SONET/SDH’, *Internet Request for Comments*, vol. RFC 1619 (Proposed Standard), May 1994 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1619.txt

B. Lloyd and W. Simpson, ‘PPP Authentication Protocols’, *Internet Request for Comments*, vol. RFC 1334 (Proposed Standard), Oct. 1992 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1334.txt
G. McGregor, ‘The PPP Internet Protocol Control Protocol (IPCP)’, *Internet Request for Comments*, vol. RFC 1332 (Proposed Standard), May 1992 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1332.txt
S. Senum, ‘The PPP DECnet Phase IV Control Protocol (DNCP)’, *Internet Request for Comments*, vol. RFC 1376 (Proposed Standard), Nov. 1992 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1376.txt
D. Katz, ‘The PPP OSI Network Layer Control Protocol (OSINLCP)’, *Internet Request for Comments*, vol. RFC 1377 (Proposed Standard), Nov. 1992 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1377.txt
B. Parker, ‘The PPP AppleTalk Control Protocol (ATCP)’, *Internet Request for Comments*, vol. RFC 1378 (Historic), Nov. 1992 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1378.txt
S. Senum, ‘The PPP XNS IDP Control Protocol (XNSCP)’, *Internet Request for Comments*, vol. RFC 1764 (Historic), Mar. 1995 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1764.txt

James D. Carlson, “PPP Design, Implementation, and Debugging”, Second edition, Addison-Wesley, 2000, ISBN 0-201-70053-0

Slide 81

PPP frames



Format of PPP frame (see Stevens, Volume 1, figure 2.3, pg. 26)

The protocol field behaves like the Ethernet TYPE field.

- CRC can be used to detect errors in the frame.
- Either character or bit stuffing is done depending on the link.
- you can negotiate away the CNTL and ADDRESS fields, and reduce the protocol field to 1 byte ⇒ minimum overhead of 3 bytes
- Van Jacobson header compression for IP and TCP

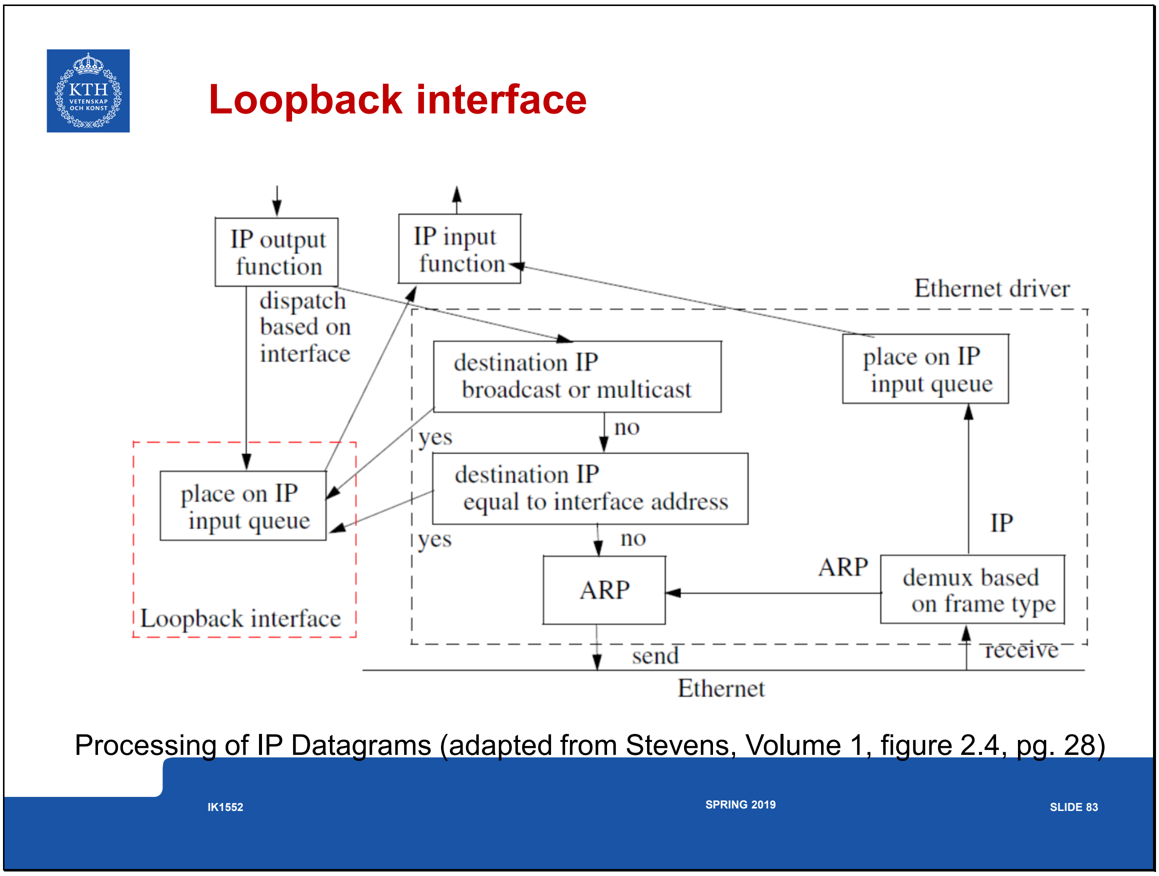
Slide 82

PPP summary

- support for multiple protocols on a link
- CRC check on every frame
- dynamic negotiation of IP address of each end
- header compression (similar to CSLIP)
- link control with facilities for negotiating lots of data-link options

All at a price averaging 3 bytes of overhead per frame.

Slide 83


Loopback interface
IP output function
IP input function
dispatch based on interface
Ethernet driver
destination IP broadcast or multicast
place on IP input queue
no
yes
destination IP equal to interface address
place on IP input queue
IP
yes
no
ARP
ARP
demux based on frame type
Loopback interface
send
receive
Ethernet
Processing of IP Datagrams (adapted from Stevens, Volume 1, figure 2.4, pg. 28)
IK1552
SPRING 2019
SLIDE 83

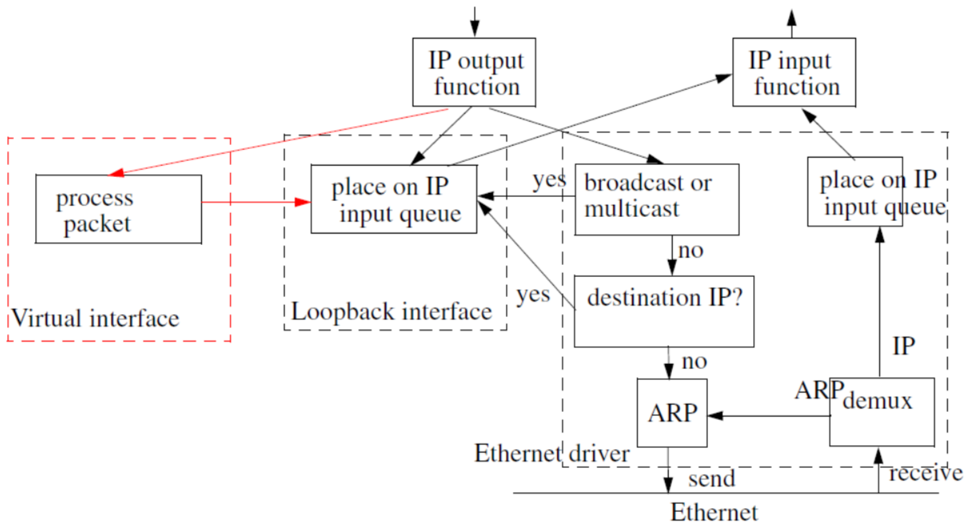
Slide 84

Loopback interface summary

- loopback address ≡ 127.0.0.1 generally called “localhost”
- all broadcasts and multicasts get sent to the loopback - because the sender gets a copy too!
- everything sent to the host’s **own** IP address is sent to the loopback interface

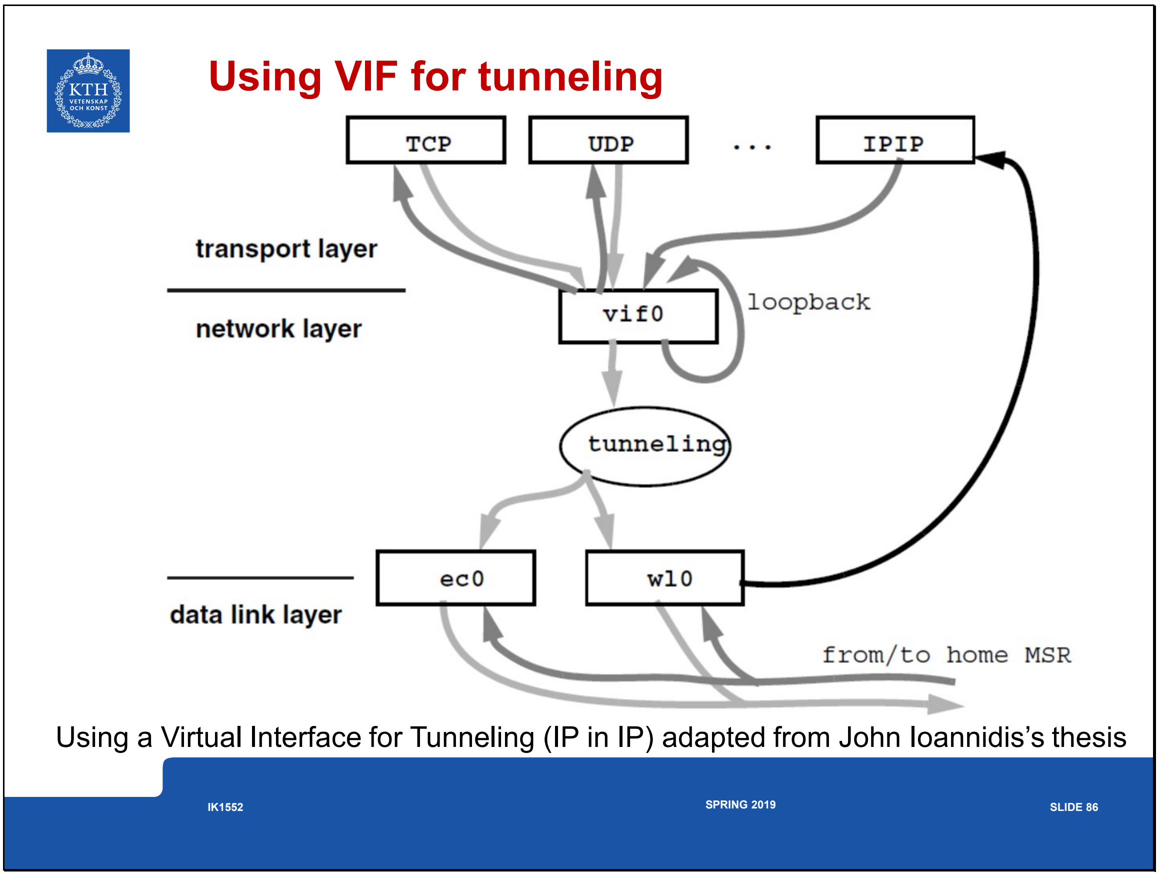
Slide 85

Virtual Interface (VIF)



Processing of network packets via a Virtual Interface

Slide 86

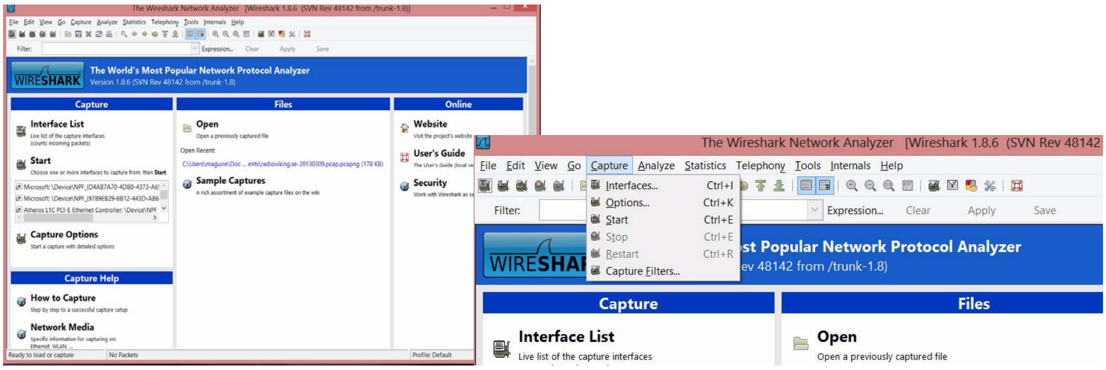

Using VIF for tunneling
TCP
UDP
...
IPIP
transport layer
network layer
vif0
loopback
tunneling
ec0
wl0
data link layer
from/to home MSR
Using a Virtual Interface for Tunneling (IP in IP) adapted from John Ioannidis's thesis
IK1552
SPRING 2019
SLIDE 86

Slide 87

Wireshark, tcpdump, etc.

Wireshark *http://www.wireshark.org/* is a tool for capturing, visualizing, analyzing, … network traffic

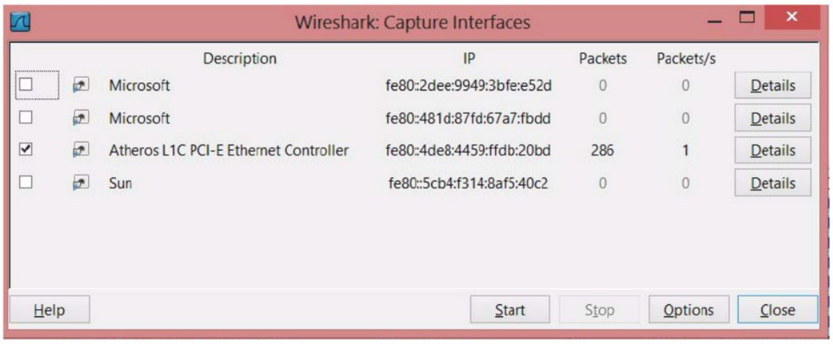
It builds on the earlier tcpdump program and utilizes the ability to **promiscuously** listen to a network interface.



IK1552 SPRING 2019 SLIDE 87

Gerald Combs, Wireshark web page, *http://www.wireshark.org/* , last accessed 4 January 2008 15:06:48 PM EST

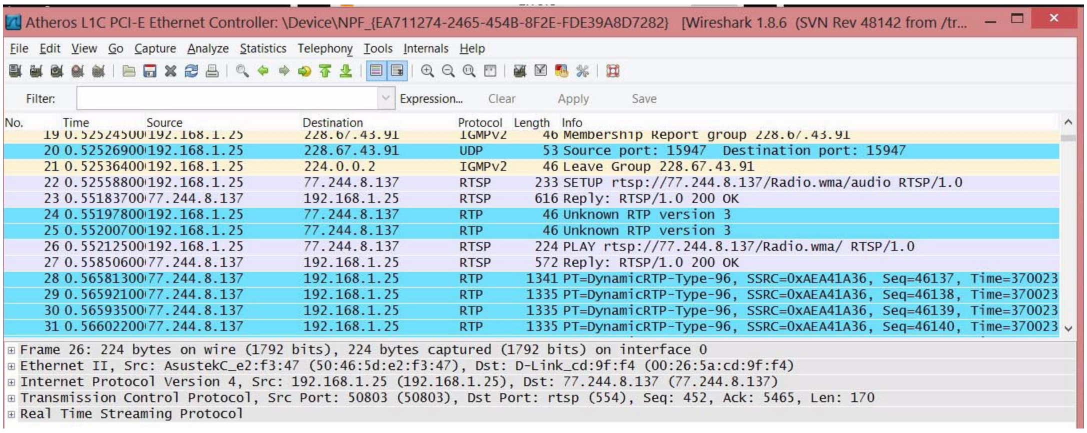
Slide 88



Select the interface

Note that the Microsoft Windows drivers will not allow you to promiscuously listen on a WLAN interface.

Slide 89



After capturing some packets

IK1552 SPRING 2019 SLIDE 89

Slide 90

Exporting data to other tools

By exporting the data we can process it with lots of different tools:

- tshark (can generate Packet Details Markup Language (PDML), Packet Summary Markup Language (PSML), PostScript, text, Fields (csv formatted files)
- tcpdump (and similar tools),
- Perl, AWK, Ruby, … scripts,
- spreadsheets,
- …
- custom programs

IK1552 SPRING 2019 SLIDE 90

Slide 91

Comma Separated Values

Example:

"No.","Time","Source","Destination","Protocol","Info"

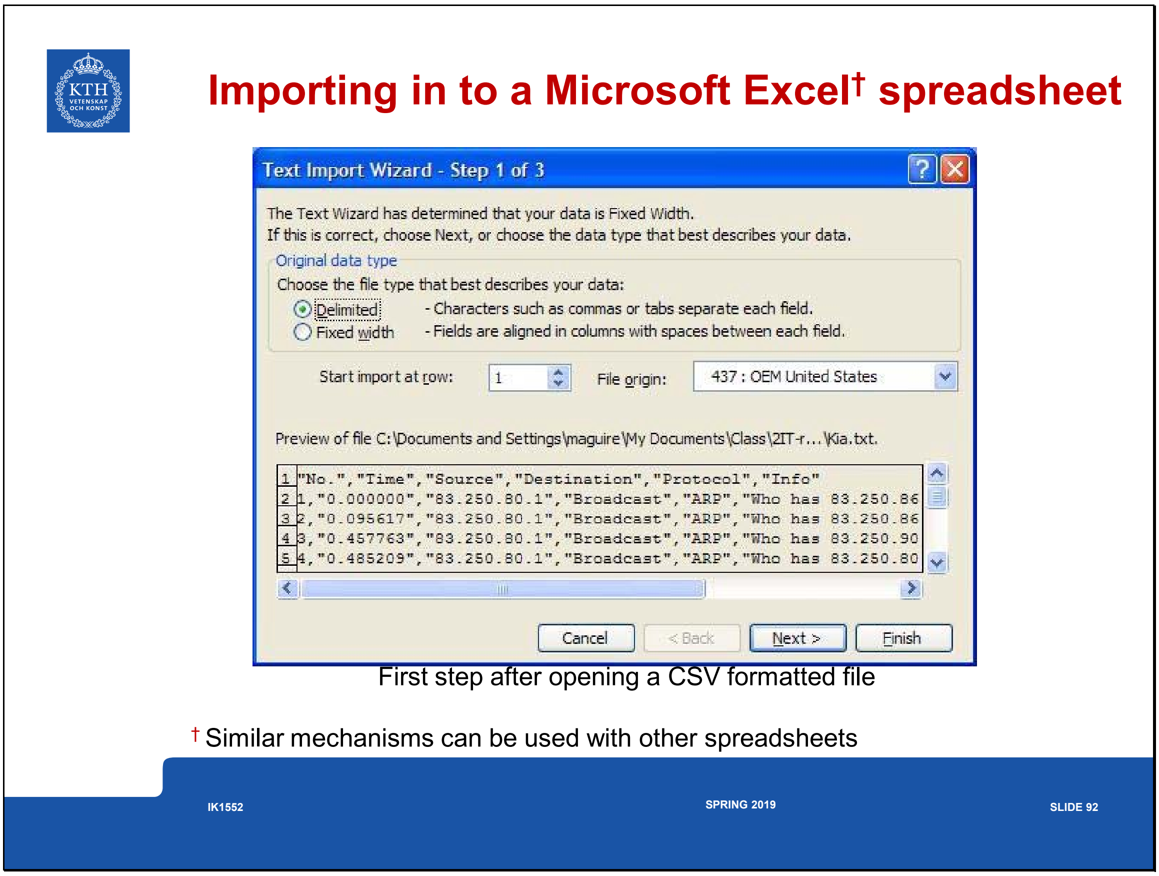
"1","0.000000","192.168.1.197","192.168.1.255","BROWSER
","Host Announcement CCSNONAME, Workstation, Server, NT Workstation"

"2","2.208042","Cisco-Li_4d:3d:a2","Broadcast","ARP","Who has 192.168.1.219? Tell 192.168.1.1"

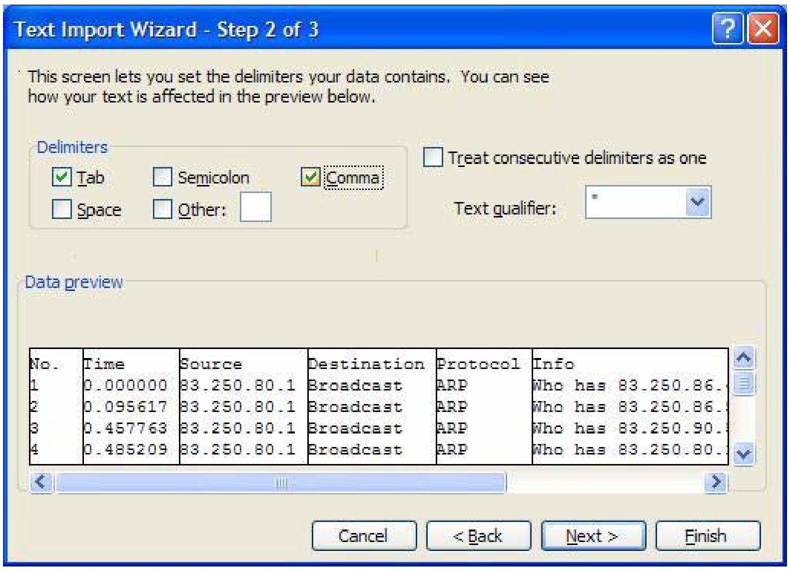
"3","3.206115","Cisco-Li_4d:3d:a2","Broadcast","ARP","Who has 192.168.1.219? Tell 192.168.1.1"

"4","4.206193","Cisco-Li_4d:3d:a2","Broadcast","ARP","Who has 192.168.1.219? Tell 192.168.1.1"

Slide 92


Importing in to a Microsoft Excel† spreadsheet
Text Import Wizard - Step 1 of 3
The Text Wizard has determined that your data is Fixed Width.
If this is correct, choose Next, or choose the data type that best describes your data.
Original data type
Choose the file type that best describes your data:
Delimited - Characters such as commas or tabs separate each field.
Fixed width - Fields are aligned in columns with spaces between each field.
Start import at row: 1
File origin: 437 : OEM United States
Preview of file C:\Documents and Settings\maguire\My Documents\Class\2IT-r...\Kia.txt.
1 "No.","Time","Source","Destination","Protocol","Info"
2 1,"0.000000","83.250.80.1","Broadcast","ARP","Who has 83.250.86
3 2,"0.095617","83.250.80.1","Broadcast","ARP","Who has 83.250.86
4 3,"0.457763","83.250.80.1","Broadcast","ARP","Who has 83.250.90
5 4,"0.485209","83.250.80.1","Broadcast","ARP","Who has 83.250.80
Cancel
< Back
Next >
Finish
First step after opening a CSV formatted file
† Similar mechanisms can be used with other spreadsheets
IK1552
SPRING 2019
SLIDE 92

Slide 93



Second step in conversion

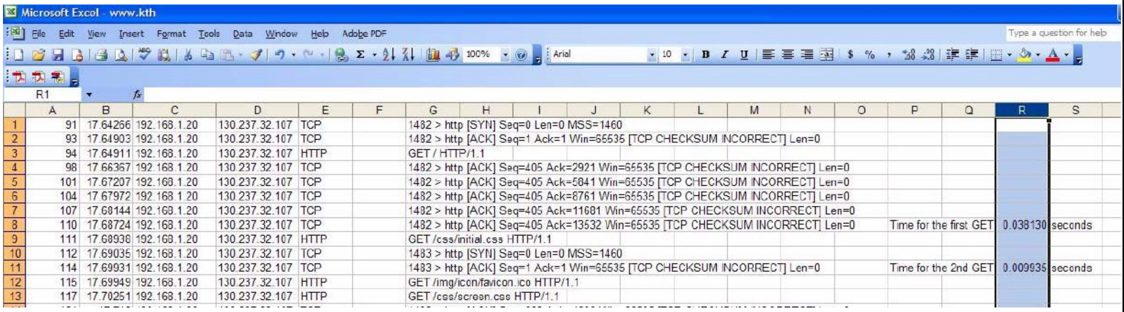
IK1552 SPRING 2019 SLIDE 93

Slide 94

Final step -- Note that in this step if you are using the Swedish language version of Microsoft's Excel - you need to indicate that the "." in the Time column, should be converted to a "," - otherwise you can not do arithmetic on these values (since they look like strings!!!)

Slide 95

Example of what can be done



	A	B	C	D	E	G	P	R	S
1	91	17.64266	192.168.1.20	130.237.32.107	TCP	1482 > http [SYN] Seq=0 Len=0 MSS=1460			
2	93	17.64903	192.168.1.20	130.237.32.107	TCP	1482 > http [ACK] Seq=1 Ack=1 Win=65535 [TCP CHECKSUM INCORRECT] Len=0			
3	94	17.64911	192.168.1.20	130.237.32.107	HTTP	GET / HTTP/1.1			
4	98	17.66367	192.168.1.20	130.237.32.107	TCP	1482 > http [ACK] Seq=405 Ack=2921 Win=65535 [TCP CHECKSUM INCORRECT] Len=0			
5	101	17.67207	192.168.1.20	130.237.32.107	TCP	1482 > http [ACK] Seq=405 Ack=5841 Win=65535 [TCP CHECKSUM INCORRECT] Len=0			
6	104	17.67972	192.168.1.20	130.237.32.107	TCP	1482 > http [ACK] Seq=405 Ack=8761 Win=65535 [TCP CHECKSUM INCORRECT] Len=0			
7	107	17.68144	192.168.1.20	130.237.32.107	TCP	1482 > http [ACK] Seq=405 Ack=11681 Win=65535 [TCP CHECKSUM INCORRECT] Len=0			
8	110	17.68724	192.168.1.20	130.237.32.107	TCP	1482 > http [ACK] Seq=405 Ack=13532 Win=65535 [TCP CHECKSUM INCORRECT] Len=0	Time for the first GET	0.038130	seconds
9	111	17.68938	192.168.1.20	130.237.32.107	HTTP	GET /css/initial.css HTTP/1.1			
10	112	17.69035	192.168.1.20	130.237.32.107	TCP	1483 > http [SYN] Seq=0 Len=0 MSS=1460			
11	114	17.69931	192.168.1.20	130.237.32.107	TCP	1483 > http [ACK] Seq=1 Ack=1 Win=65535 [TCP CHECKSUM INCORRECT] Len=0	Time for the 2nd GET	0.009935	seconds
12	115	17.69949	192.168.1.20	130.237.32.107	HTTP	GET /img/icon/favicon.ico HTTP/1.1			
13	117	17.70251	192.168.1.20	130.237.32.107	HTTP	GET /css/screen.css HTTP/1.1			

Use spreadsheet operations over the values

Slide 96

Using a Perl script

```
#!/usr/bin/perl -w
# each input line consists of a triple: Time,Source,RSSI
# separate the file based upon making a file for each source
#  containing only the Time and RSSI
# 2007.12.27 G. Q. Maguire Jr. and M. E. Noz
#
# Security blankets - Perl authors claim programs are unsafe without this
# This only removes directories that have no files in them
#Use only perl libary
#@INC = $INC[$#INC - 1];
#die "Perl library is writable by the world!\n" if $< && -W $INC[0];
$ENV{'IFS'} = '' if $ENV{'IFS'};
umask 002;
# get the main directory paths
$project_dir = '/home/noz';
$filename = 'all-time-source-RSSId.csv';
#$filename = 'all-time.small';
$sourcename = '';
$sourcename1 = '';
$time = '';
$RRSID = '';
$count = 0;
&create_tmp_file;
```

```
#open the data file for reading
open(DATA_FILE, $filename) || die "Can't open data file: $!\n";
while ($varrec = <DATA_FILE>) {
        if ($varrec =~ /^#/) {
        $count = 1;
        next;
        }
        else {
        chop($varrec);
        print "count is $count\n";
        # print "varrec is $varrec\n";
        ($time, $sourcename, $RSSId) = split(/,/, $varrec);
        # print "time is $time, sourcename is $sourcename, 
RSSId is $RSSId\n";
        if ($count == 1) {
        $sourcename1=$sourcename;
        print PTMP "$time $RSSId\n";
        $count++;
        print "sourcename is $sourcename; sourcename1 is 
$sourcename1 \n";
        }
```

Slide 97

This script process captured IEEE 802.11 packets to put measurements of the different sources into their own files, based upon the source MAC address. (In this case the program assumes that the file has already been sorted based upon the source MAC address.)

```
        else {
        if ($sourcename =~ $sourcename1) {
                print PTMP "$time $RSSId\n";
        }
        else {
        print "sourcename is $sourcename, old
sourcename is $sourcename1\n";
        close PTMP;
        chmod 0664, '/tmp/ptmp';
        system("mv /tmp/ptmp $sourcename1");
        $sourcename1 = $sourcename;
        &create_tmp_file;
        print PTMP "$time $RSSId\n";
        }
} } }
```

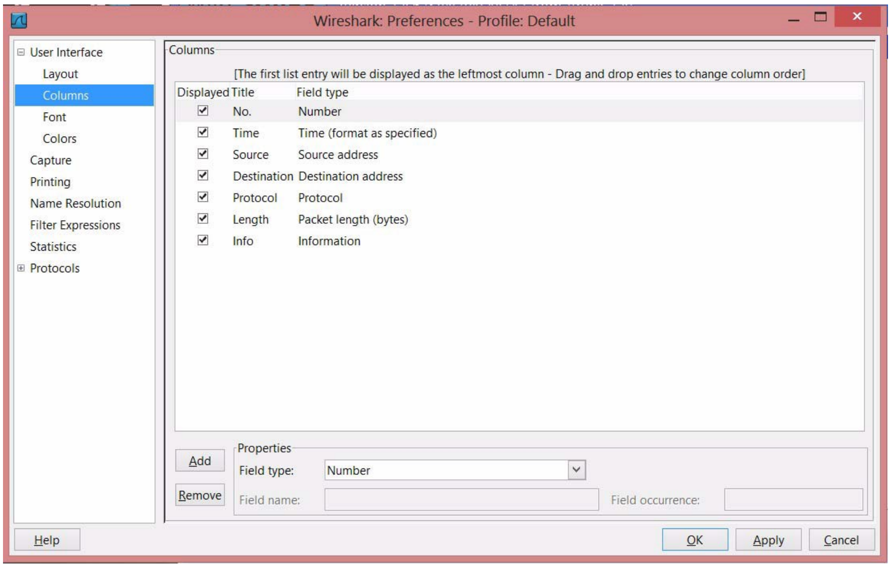
```
close PTMP;

chmod 0664, '/tmp/ptmp';
system("mv /tmp/ptmp $sourcename1");
close DATA_FILE;

sub create_tmp_file {
# open(PTMP, ">/tmp/ptmptmp$$") || die
"Can't create tmp file $!\n";
# close (PTMP);
# $locked = link("/tmp/ptmptmp$$",
'/tmp/ptmp');
# unlink "/tmp/ptmptmp$$";
# $locked || die "Can't lock temporary
file.\n";
open(PTMP, ">/tmp/ptmp") || die "Can't
open tmp file $! for writing\n";
}
```

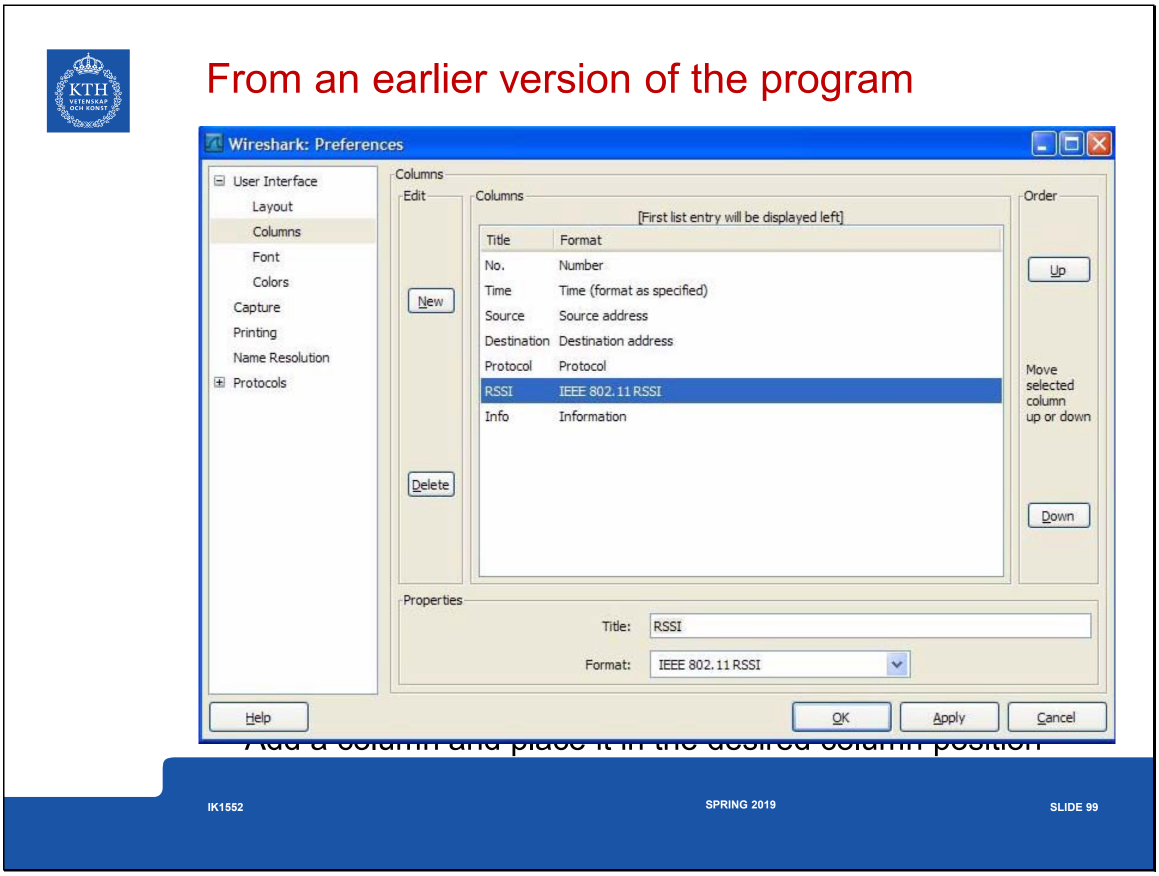
Slide 98

Choosing which columns to display

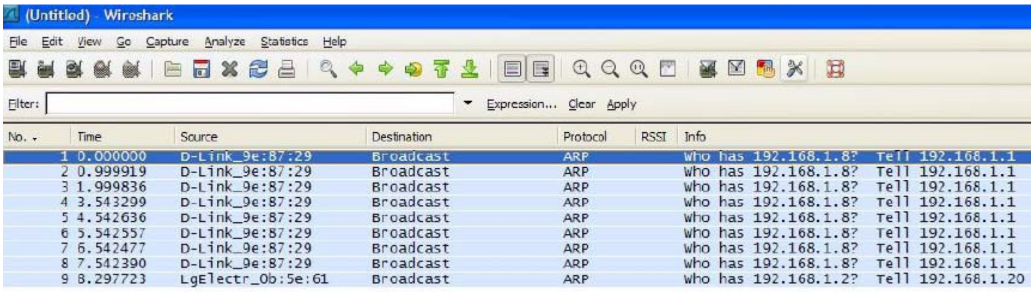


Set your preferences for the User Interface

Slide 99


From an earlier version of the program
Wireshark: Preferences
User Interface
Layout
Columns
Font
Colors
Capture
Printing
Name Resolution
Protocols
Columns
Edit
New
Delete
[First list entry will be displayed left]
Title Format
No. Number
Time Time (format as specified)
Source Source address
Destination Destination address
Protocol Protocol
RSSI IEEE 802.11 RSSI
Info Information
Order
Up
Move selected column up or down
Down
Properties
Title: RSSI
Format: IEEE 802.11 RSSI
Help
OK
Apply
Cancel
IK1552
SPRING 2019
SLIDE 99

Slide 100



No.	Time	Source	Destination	Protocol	RSSI	Info
1	0.000000	D-Link_9e:87:29	Broadcast	ARP		Who has 192.168.1.8? Tell 192.168.1.1
2	0.999919	D-Link_9e:87:29	Broadcast	ARP		Who has 192.168.1.8? Tell 192.168.1.1
3	1.999836	D-Link_9e:87:29	Broadcast	ARP		Who has 192.168.1.8? Tell 192.168.1.1
4	3.543299	D-Link_9e:87:29	Broadcast	ARP		Who has 192.168.1.8? Tell 192.168.1.1
5	4.542636	D-Link_9e:87:29	Broadcast	ARP		Who has 192.168.1.8? Tell 192.168.1.1
6	5.542557	D-Link_9e:87:29	Broadcast	ARP		Who has 192.168.1.8? Tell 192.168.1.1
7	6.542477	D-Link_9e:87:29	Broadcast	ARP		Who has 192.168.1.8? Tell 192.168.1.1
8	7.542390	D-Link_9e:87:29	Broadcast	ARP		Who has 192.168.1.8? Tell 192.168.1.1
9	8.297723	LgElectr_0b:5e:61	Broadcast	ARP		Who has 192.168.1.2? Tell 192.168.1.20

Save your parameters and restart the program to use the newly configured user interface

Slide 101

IPv4 addresses

Address types

- **Unicast** = one-to-one
- **Multicast** = one-to-many
- **Broadcast** = one-to-all

32 bit address divided into two parts:

NetID	Host ID

Note that although we refer to it as the Host ID part of the address, it is really **the address of an interface**.

Dotted decimal notation: write each byte as a decimal number, separate each of these with a “.” i.e., 10000010 11101101 00100000 00110011 ⇒ 130.237.32.51or in hexadecimal as: 0x82ED2033

Slide 102

Classful addressing

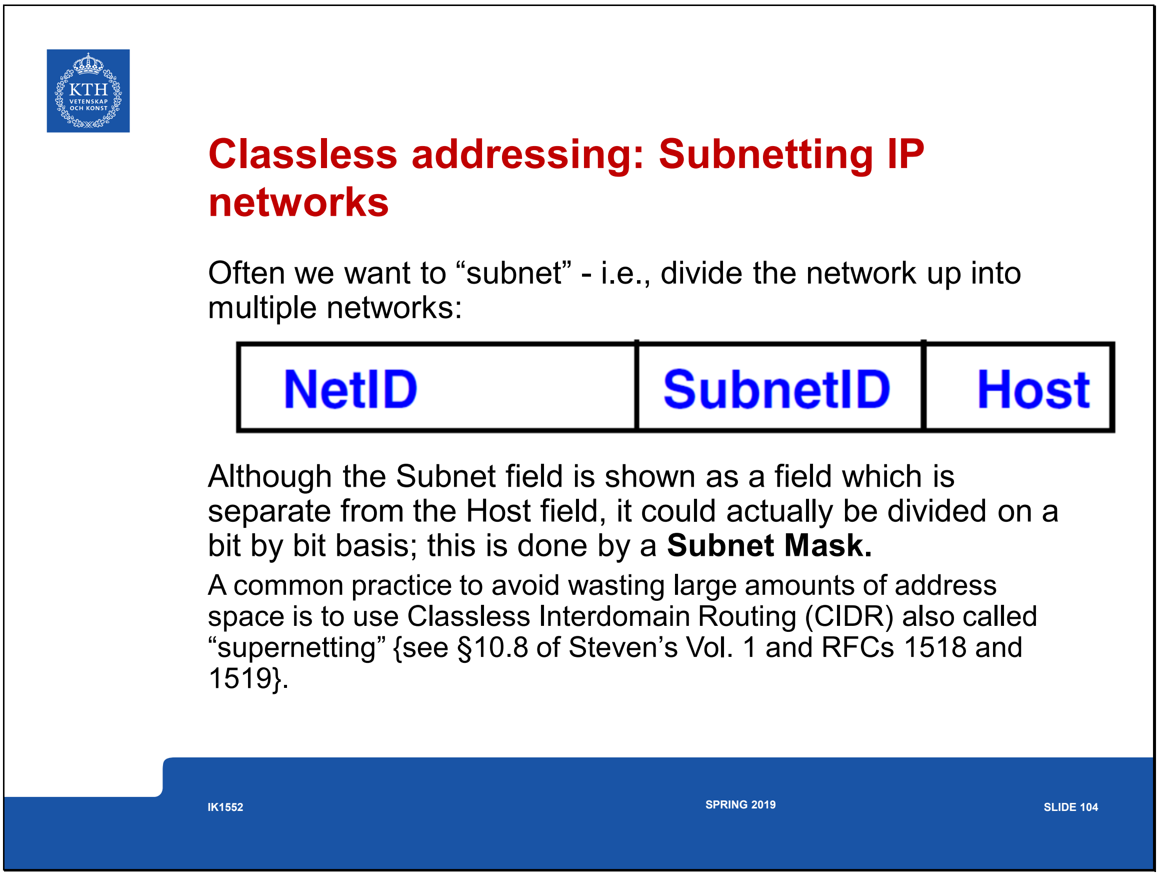
Class	NetID		Range (dotted decimal notation)	host ID
A	0	+ 7- bit NetID	0.0.0.0 to **127**.255.255.255	24 bits of host ID
B	1 0	+ 14-bit NetID	**128**.0.0.0 to **191**.255.255.255	16 bits of host ID
C	1 1 0	+ 21-bit NetID	**192**.0.0.0 to **223**.255.255.255	8 bits of host ID
D	1 1 1 0		**224**.0.0.0 to **239**.255.255.255	28 bits of Multicast address
E	1 1 1 1 0		**240**.0.0.0 to **247**.255.255.255	Reserved for future use

Slide 103

Implications of classful addressing

- Globally addressable IP addresses must be unique
  Later in the course we will see how network address translators (NATs) affect this
- addresses roughly $2^{7}*2^{24} + 2^{14}*2^{16} + 2^{21}*2^{8} =$ 3,758,096,384 interfaces (**not** the number of hosts)
- in 1983 this seemed like a lot of addresses
- problems with the size of the blocks ⇒ lots of wasted addresses
- lead to classless addressing!

Slide 104



Y. Rekhter and T. Li, 'An Architecture for IP Address Allocation with CIDR', *Internet Request for Comments*, vol. RFC 1518 (Historic), Sep. 1993 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1518.txt
V. Fuller, T. Li, J. Yu, and K. Varadhan, 'Classless Inter-Domain Routing (CIDR): an Address Assignment and Aggregation Strategy', *Internet Request for Comments*, vol. RFC 1519 (Proposed Standard), Sep. 1993 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1519.txt

See also:
V. Fuller and T. Li, 'Classless Inter-domain Routing (CIDR): The Internet Address Assignment and Aggregation Plan', *Internet Request for Comments*, vol. RFC 4632 (Best Current Practice), Aug. 2006 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4632.txt
V. Fuller, T. Li, J. Yu, and K. Varadhan, 'Supernetting: an Address Assignment and Aggregation Strategy', *Internet Request for Comments*, vol. RFC 1338 (Informational), Jun. 1992 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1338.txt

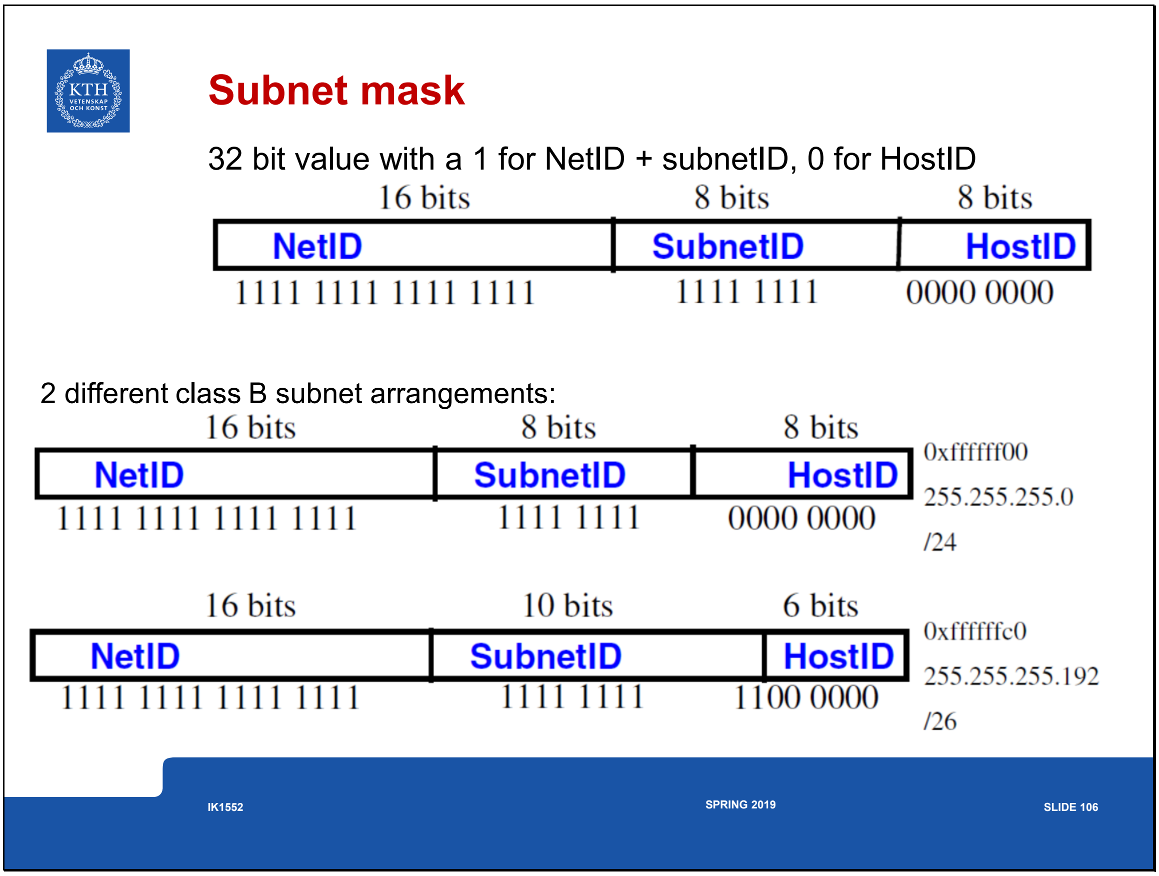
Slide 105

Special Case IP Addresses

IP Address			Can appear as		Description
net ID	**subnet ID**	**host ID**	**source?**	**Destination**	
0		0	OK	never	**this** host on **this** net
0		hostid	OK	never	specified host on **this** net
127		any	OK	OK	loopback address
-1		-1	never	OK	limited broadcast (never forwarded)
netid		-1	never	OK	net-directed broadcast to **netid**
netid	**subnetid**	-1	never	OK	subnet-directed broadcast to **netid**, **subnetid**
netid	**-1**	-1	never	OK	all-subnets-directed broadcast to **netid**

IK1552 SPRING 2019 SLIDE 105

Slide 106


Subnet mask
32 bit value with a 1 for NetID + subnetID, 0 for HostID
16 bits
8 bits
8 bits
NetID
SubnetID
HostID
1111 1111 1111 1111
1111 1111
0000 0000
2 different class B subnet arrangements:
16 bits
8 bits
8 bits
NetID
SubnetID
HostID
1111 1111 1111 1111
1111 1111
0000 0000
0xffffff00
255.255.255.0
/24
16 bits
10 bits
6 bits
NetID
SubnetID
HostID
1111 1111 1111 1111
1111 1111
1100 0000
0xffffffc0
255.255.255.192
/26
IK1552
SPRING 2019
SLIDE 106

Slide 107

Classless Inter-Domain Routing (CIDR)

Length (CIDR)			Length (CIDR)		
/0	0.0.0.0	All 0's≡ no mask	/8	255.0.0.0	≡ Class A
/1	128.0.0.0		/9	255.128.0.0	
/2	192.0.0.0		/10	255.192.0.0	
/3	224.0.0.0		/11	255.224.0.0	
/4	240.0.0.0		/12	255.240.0.0	
/5	248.0.0.0		/13	255.248.0.0	
/6	252.0.0.0		/14	255.252.0.0	
/7	254.0.0.0		/15	255.254.0.0	

IK1552 SPRING 2019 SLIDE 107

Y. Rekhter and T. Li, 'An Architecture for IP Address Allocation with CIDR', *Internet Request for Comments*, vol. RFC 1518 (Historic), Sep. 1993 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1518.txt
V. Fuller, T. Li, J. Yu, and K. Varadhan, 'Classless Inter-Domain Routing (CIDR): an Address Assignment and Aggregation Strategy', *Internet Request for Comments*, vol. RFC 1519 (Proposed Standard), Sep. 1993 [Online]. Available: http://www.rfc-editor.org/rfc/rfc1519.txt
V. Fuller and T. Li, 'Classless Inter-domain Routing (CIDR): The Internet Address Assignment and Aggregation Plan', *Internet Request for Comments*, vol. RFC 4632 (Best Current Practice), Aug. 2006 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4632.txt

Slide 108

CIDR (continued)

Length (CIDR)			Length (CIDR)		
/16	255.255.0.0	≡ Class B	/24	255.255.255.0	≡ Class C
/17	255.255.128.0		/25	255.255.255.128	
/18	255.255.192.0		/26	255.255.255.192	
/19	255.255.224.0		/27	255.255.255.224	
/20	255.255.240.0		/28	255.255.255.240	
/21	255.255.248.0		/29	255.255.255.248	
/22	255.255.252.0		/30	255.255.255.252	
/23	255.255.254.0		/31	255.255.255.254	All 1's(host specific mask)

Slide 109

IP address assignments

Internet Service Providers (ISPs) should contact their upstream registry or their appropriate Regional Internet Registries (RIR) at one of the following addresses:

Region	URL
APNIC (Asia-Pacific Network Information Center)	http://www.apnic.net
ARIN (American Registry for Internet Numbers)	http://www.arin.net
RIPE (Réseaux IP Européens) NCC	http://www.ripe.net
LANIC (Latin America and Caribbean Network Information Centre)	http://www.lacnic.net/en/index.html
AfriNIC (Africa NIC)	http://www.afrinic.net/

Slide 110

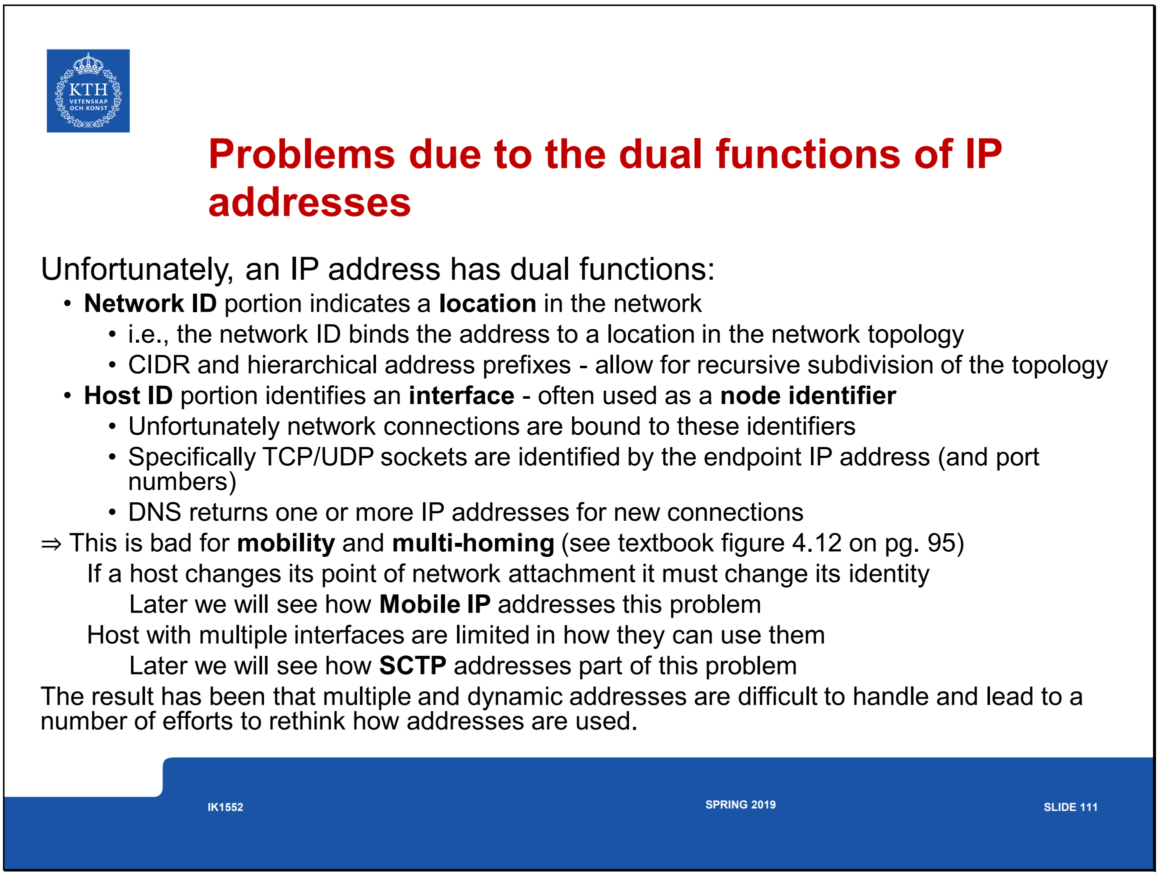
Private addresses

Private addresses - these IP addresses are for strictly **private** use:

Class	Netids	block
A	10	1
B	172.16 to 172.31	6
C	192.168.0 to 192.168.255	26

For an example of how these private addresses are used **within** an organization see: *http://www.lan.kth.se/norm/priv-net-usage.txt*

Slide 111


Problems due to the dual functions of IP addresses
Unfortunately, an IP address has dual functions:
• Network ID portion indicates a location in the network
• i.e., the network ID binds the address to a location in the network topology
• CIDR and hierarchical address prefixes - allow for recursive subdivision of the topology
• Host ID portion identifies an interface - often used as a node identifier
• Unfortunately network connections are bound to these identifiers
• Specifically TCP/UDP sockets are identified by the endpoint IP address (and port numbers)
• DNS returns one or more IP addresses for new connections
⇒ This is bad for mobility and multi-homing (see textbook figure 4.12 on pg. 95)
If a host changes its point of network attachment it must change its identity
Later we will see how Mobile IP addresses this problem
Host with multiple interfaces are limited in how they can use them
Later we will see how SCTP addresses part of this problem
The result has been that multiple and dynamic addresses are difficult to handle and lead to a number of efforts to rethink how addresses are used.
IK1552
SPRING 2019
SLIDE 111

Slide 112

ifconfig, route, and netstat Commands

- ifconfig: to configure interface.
- route: to update routing table.
- netstat: to get interface and routing information.

For example: to configure interface, add an network and add a gateway:

```
root# ifconfig eth0 192.71.20.115 netmask 255.255.255.0 up
root# route add -net 192. 71.20.0 netmask 255.255.255.0 eth0
root# route add default gw 192.71.20.1 eth0
```

We will discuss these commands in more detail.

Note: These commands are being replaced in Linux OSs by the use of the "ip" command, as it handles both IPv4 and IPv6.

Another useful command on Linux systems is "lsof" - LiSt Open Files - since network sockets are files; useful to see what process has what sockets open.

Slide 113

Standardization Organizations

The most relevant to the Internet are:

- Internet Society (ISOC) - http://www.internetsociety.org/
- Internet Engineering Task Force (IETF) - http://www.ietf.org/
- World-wide-web consortium (W3C) - http://www.w3.org/
- International Standards Organization (ISO) - http://www.iso.org/iso/home.html
- International Telecommunications Union - Telecommunication Standards Sector (ITU-T) - http://www.itu.int/en/ITU-T/Pages/default.aspx
- Institute of Electrical and Electronics Engineers (IEEE) .- http://www.ieee.org/index.html
- …

Slide 114

Summary

Course Introduction

- Internet Basics
  - Multiplexing and demultiplexing
  - Datagrams
- Link Layer Protocols for the Internet
  - Ethernet
  - SLIP, PPP
- IP: Internet Protocol
  - IP addressing
  - Subnetting

Slide 115

W. Richard Stevens

Born in Luanshya, Northern Rhodesia (now Zambia) in 1951, Died on September 1, 1999
- He studied Aerospace Engineering, Systems Engineering (image processing major, physiology minor)
- flight instructor and programmer

His many books helped many people to understand and use TCP/IP
- UNIX Network Programming, Prentice Hall, 1990.
- Advanced Programming in the UNIX Environment, Addison-Wesley, 1992.
- TCP/IP Illustrated, Volume 1: The Protocols, Addison-Wesley, 1994.
- TCP/IP Illustrated, Volume 2: The Implementation, Addison-Wesley, 1995.
- TCP/IP Illustrated, Volume 3: TCP for Transactions, HTTP, NNTP, and the UNIX Domain Protocols, Addison-Wesley, 1996.
- UNIX Network Programming, Volume 1, Second Edition: Networking APIs: Sockets and XTI, Prentice Hall, 1998.
- UNIX Network Programming, Volume 2, Second Edition: Interprocess Communications, Prentice Hall, 1999.

A web site with lots of material is at http://www.kohala.com/start/

Slide 116

References

1. Barry M. Leiner, Vinton G. Cerf, David D. Clark, Robert E. Kahn, Leonard Kleinrock, Daniel C. Lynch, Jon Postel, Larry G. Roberts, and Stephen Wolff, "A Brief History of the Internet", On The Internet, May/June 1997 *http://www.isoc.org/oti/articles/0597/leiner.html*
2. R. Kahn, Communications Principles for Operating Systems. Internal BBN memorandum, Jan. 1972.
3. V. Cerf and R. Kahn, "A protocol for packet network interconnection", IEEE Transactions on Communications Technology, Vol. COM-22, Number 5, May 1974, pp. 627-641. *http://global.mci.com/us/enterprise/insight/cerfs_up/technical_writings/protocol_paper/*
4. Jerome H. Saltzer, David P. Reed, David D. Clark, "End-To-End Arguments In System Design" In ACM Transactions on Computer Systems, V2, #4, Nov. 1984, pages 277-288 *http://citeseer.ist.psu.edu/saltzer84endtoend.html*
5. David D. Clark and Marjory S. Blumenthal, "Rethinking the Design of the Internet: The end to end arguments vs. the brave new world", In ACM Transactions on Internet Technology, Vol 1, No 1, August 2001, pp 70-109. *http://www.ana.lcs.mit.edu/papers/PDF/Rethinking_2001.pdf*
6. D. Clark, J. Wroclawski, K. Sollins, and R. Braden, "Tussle in Cyberspace: Defining Tomorrow's Internet", Proceedings of Sigcomm 2002. *http://www.acm.org/sigs/sigcomm/sigcomm2002/papers/tussle.pdf*
7. Wendell Odom and Rick McDonald, Routers and Routing Basics CCNA 2 Companion Guide (Cisco Networking Academy Program), 1st edition, Cisco Press, 2006 ISBN 1-587113-166-8.

See also the Zotero library https://www.zotero.org/groups/335735/ik1552 for more references.

IK1552 SPRING 2019 SLIDE 116

Slide 117