Network Computing courses

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ENSIBS - UBS

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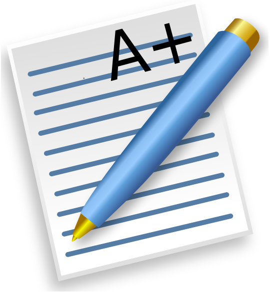
Course details

Objectives

- How do *computers* communicate?
- What are the mechanisms **under** an HTTP request or a telegram message?
- Networks are all around us, better study them!

Course details



Evaluation

- Short test at the beginning of every lesson (5 min) ?
- Project
- Final exam (1 hour)
- All same weighting

Material

- Slides available at teaching.auzias.net (github too)

Presentation Outline

Definitions and presentation

- **Network:** an **interconnected** group or system

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- **Internet:** world wide **interconnected system of networks** RFC791 (September 1981)
- **IP:** Internet **Protocol** provides the functions necessary to deliver a package of bits from a source to a destination over a network
- **(world wide) Web: network** consisting of a collection of Internet websites using HTTP

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- **RFC:** Request For Comments (Internet Draft (ID), RFC, Internet Standard)

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- **NAT:** Network Address Translation, router modifying IP address into another IP address.

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- **Thin client: application** where most functions are carried out on a central server

Network classification

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- **MAN:** Metropolitan Area Networks, can cover a whole city
- **WAN:** Wide Area Networks cover a broad area (Internet)

Topologies

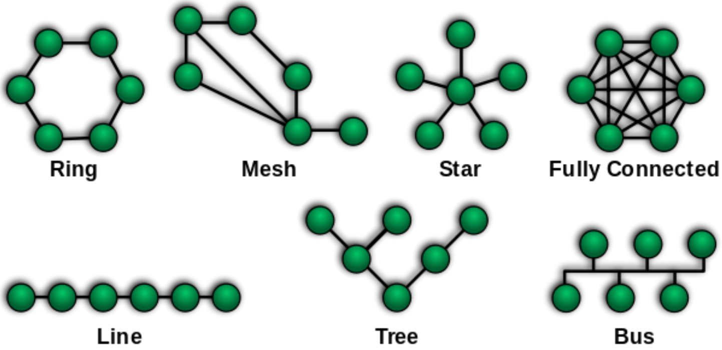

Figure: upload.wikimedia.org

Topologies

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[1] Hong Kong protesters use a mesh network to organize

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- **Tree:** hierarchical topology, such as a binary tree.

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Bonus

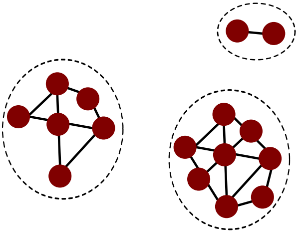

Figure: Disconnected MANET illustration [?]

Bonus

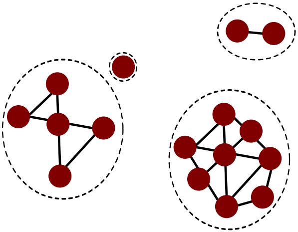

Figure: Store-carry-and-forward [?]

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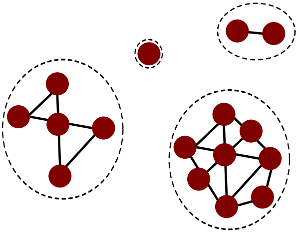

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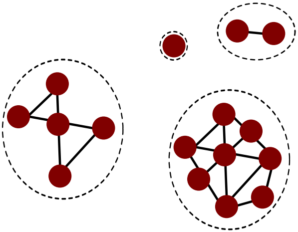

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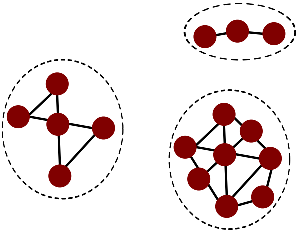

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HTTP request/response example

Enter getbootstrap.com in your browser

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Source	Destination	Protocol	Length	Info
192.168.0.48	208.67.222.222	DNS	76	Standard query 0x4797 A getbootstrap.com
208.67.222.222	192.168.0.48	DNS	108	Standard query response 0x4797 A 192.30.252.154 A 192.30.252.153

Figure: DNS request/response

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Source	Destination	Protocol	Length	Info
127.0.0.1	127.0.0.13	TCP	74	36159 > http [SYN] Seq=0 Win=43690 Len=0 MSS=65495 SACK_PERM=1 TSval=12
127.0.0.13	127.0.0.1	TCP	74	http > 36159 [SYN, ACK] Seq=0 Ack=1 Win=43690 Len=0 MSS=65495 SACK_PERM
127.0.0.1	127.0.0.13	TCP	66	36159 > http [ACK] Seq=1 Ack=1 Win=43776 Len=0 TSval=122257 TSecr=12225
127.0.0.1	127.0.0.13	HTTP	356	GET /index.html HTTP/1.1
127.0.0.13	127.0.0.1	TCP	66	http > 36159 [ACK] Seq=1 Ack=291 Win=44800 Len=0 TSval=122259 TSecr=122
127.0.0.13	127.0.0.1	HTTP	354	HTTP/1.1 200 OK (text/html)
127.0.0.1	127.0.0.13	TCP	66	36159 > http [ACK] Seq=291 Ack=289 Win=44800 Len=0 TSval=122259 TSecr=1
127.0.0.1	127.0.0.13	HTTP	357	GET /favicon.ico HTTP/1.1
127.0.0.13	127.0.0.1	HTTP	565	HTTP/1.1 404 Not Found (text/html)
127.0.0.1	127.0.0.13	TCP	66	36159 > http [ACK] Seq=582 Ack=788 Win=45952 Len=0 TSval=122269 TSecr=1

Figure: HTTP request/response

How do messages reach their destination?

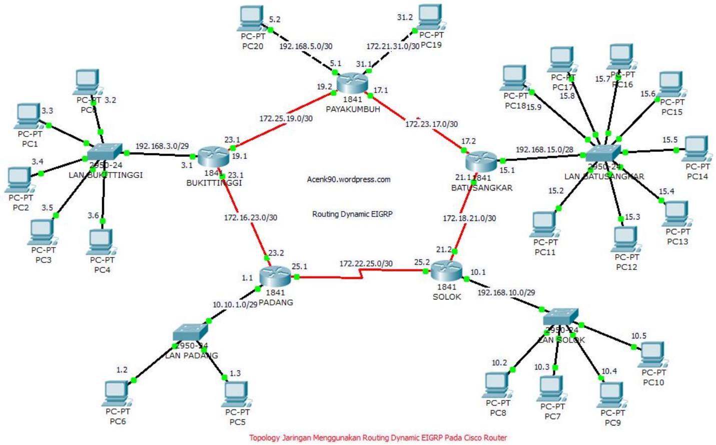


Figure: acenk90.files.wordpress.com

More like this...

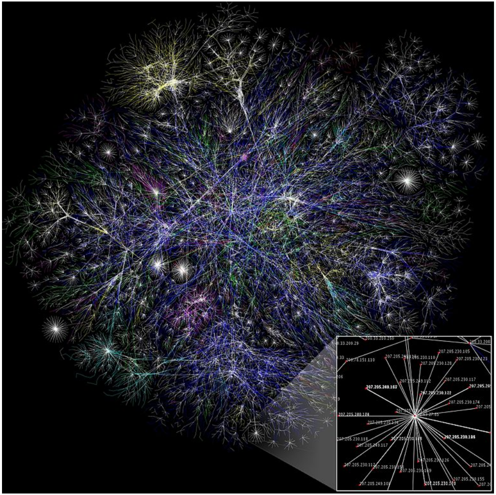


Figure: wikimedia.org

Models overview (OSI and TCP/IP)

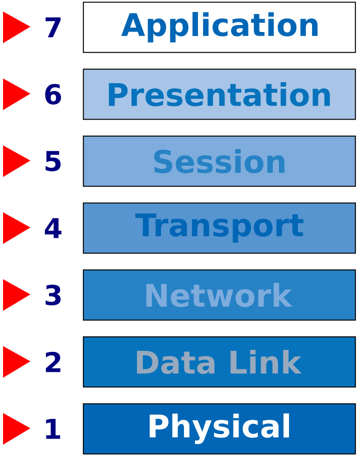
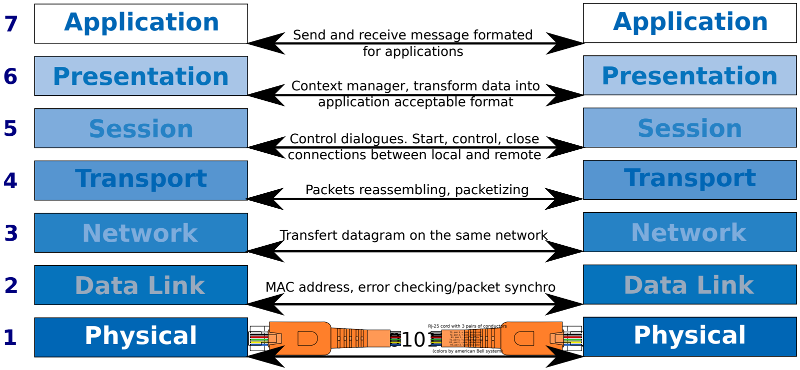
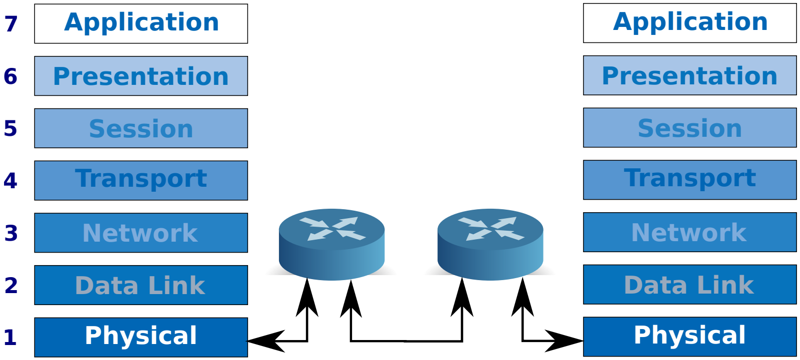


Figure: OSI model

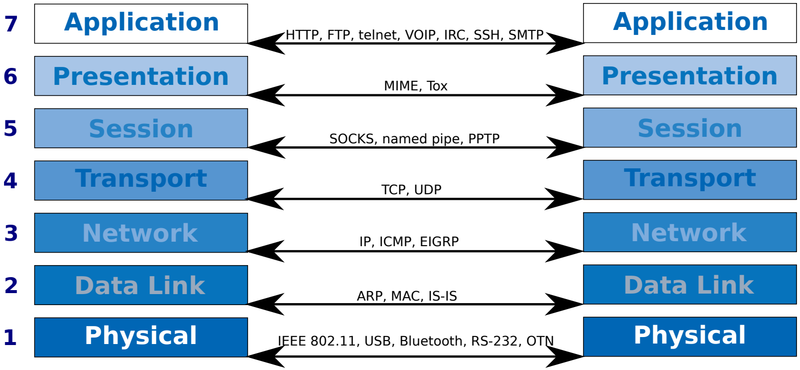
N^{th} layer communicate with N^{th} layer..



.. thanks to 3-th layers



One single protocol, one single layer



Encapsulation

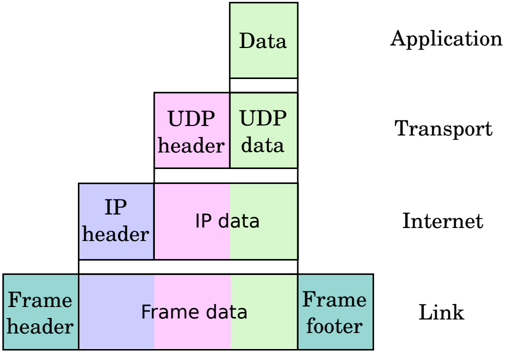


Figure: Encapsulation

Presentation Outline

Aims

- Interface data link layer,

Aims

- Interface data link layer,
- (De)Encode,

Aims

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- (De)Encode,
- Transmit: 1 after 0 (after 0 or 1, after 0... or 1)

Hardware medium

- IEEE 802.3 (a.k.a. Ethernet): $<$100Gbit/s

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- USB, serial port such as RS-232...

Hardware medium: IEEE 802.3 (Ethernet)

Figure: RJ45 connector

Hardware medium: IEEE 802.15.1 (Bluetooth)

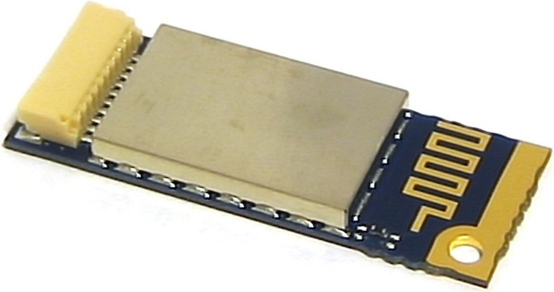

Figure: Bluetooth card

Hardware medium: IEEE 802.15.4 (ZigBee)

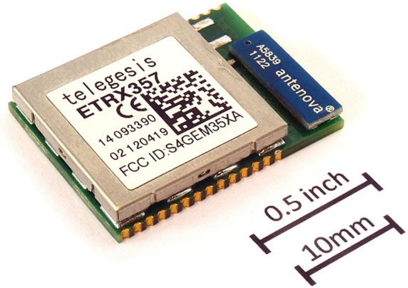

Figure: ZigBee card

Hardware medium: IEEE 802.16 (Wi-Max)

Figure: Wi-Max antenna

Hardware medium: IEEE 1394 (Firewire)

Figure: Firewire connector

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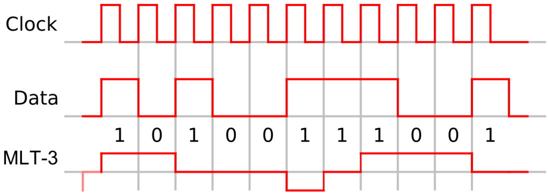

Figure: Multi-Level Transmit

Encoding: Alternate Mark Inversion

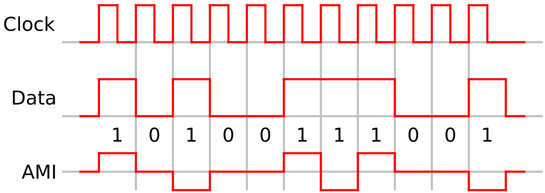

Figure: Alternate Mark Inversion

Encoding: Manchester

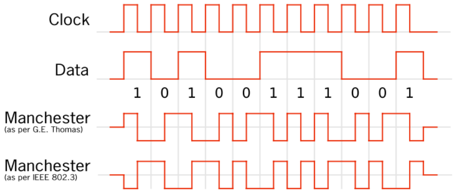

Figure: Manchester

Encoding: Biphase Mark Code

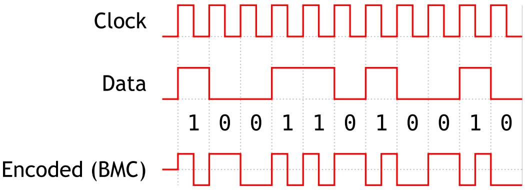

Figure: Biphase Mark Code

Transmitting

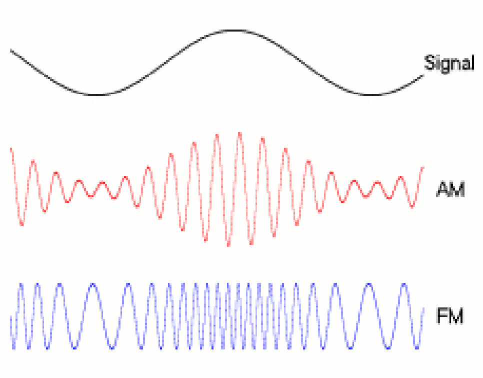

Figure: Amplitude and phase modulation

Error detection

- Repetition (hum...)

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- Parity (XOR)

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Error correcting

- Repetition (again)

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- Hamming

Error correcting

- Repetition (again)
- Hamming
- MDPC (Multidimensional parity-check code)

Correction: MDPC

Raw data to send: 0x01 02 03 04

0x01	0x02	0x03
0x03	0x04	0x07
0x04	0x06	

Figure: Data received with MDPC

Data sent (with MDPC): 0x01 02 03 03 04 07 04 06

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- Interface network layer,

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- Delivery to unique(?) hardware addresses,

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- Framing,
- Data transfer

Layer composition (of its two sublayers)

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    - end to end flow control
    - end to end error control
    - (transmitting/receiving) protocols, over MAC sublayer, multiplexing

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2. Media Access Control (MAC):
   - physical (hardware) addressing
   - collision detection and retransmission
   - data packet scheduling (and queuing)
   - QoS
   - VLAN

Carrier Sense Multiple Access with Collision Avoidance

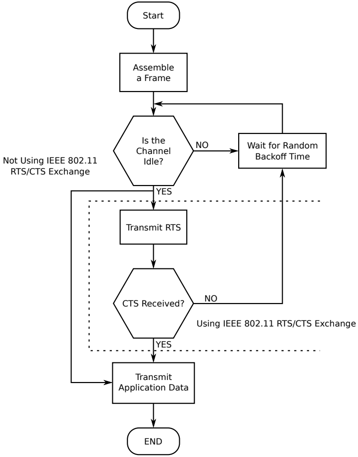

Figure: CSMA CA

Layer 2 Ethernet packet

MAC dest. (6)	MAC src. (6)	VLAN tag* (4)	Ethertype (2)
Payload (42-1500)		Frame check sequence (4)	

Figure: Layer 2 Ethernet packet

optional, Content (size in bytes)

Ethertype 0x	Protocol
0800	IPv4
0806	ARP
0842	Wake-on-LAN
86dd	IPv6

Figure: Data received with MDPC

ARP example

0000	ff	ff	ff	ff	ff	ff	fa	ba	00	ab	ab	af	08	06	00	01
0010	08	00	06	04	00	01	fa	ba	00	ab	ab	af	ac	11	22	37
0020	00	00	00	00	00	00	ac	11	00	f9	00	00	00	00	00	00
0030	00	00	00	00	00	00	00	00	00	00	00	00				

Figure: ARP request

MAC address destination MAC address source Ethertype Hardware type Protocol type OpCode (1 request, 2 reply) IP address source IP address destination

ARP example

0000	ff	ff	ff	ff	ff	ff	fa	ba	00	ab	ab	af	08	06	00	01
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0020	00	00	00	00	00	00	ac	11	00	f9	00	00	00	00	00	00
0030	00	00	00	00	00	00	00	00	00	00	00	00				

Figure: ARP request

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ARP example

0000	fa	ba	00	ab	ab	af	be	be	00	00	eb	eb	08	06	00	01
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0020	fa	ba	00	ab	ab	af	ac	11	22	37	00	00	00	00	00	00
0030	00	00	00	00	00	00	00	00	00	00	00	00				

Figure: ARP reply

MAC address destination MAC address source Ethertype Hardware type Protocol type OpCode (1 request, 2 reply) IP address source IP address destination

ARP example

0000	fa	ba	00	ab	ab	af	be	be	00	00	eb	eb	08	06	00	01
0010	08	00	06	04	00	01	be	be	00	00	eb	eb	ac	11	00	f9
0020	fa	ba	00	ab	ab	af	ac	11	22	37	00	00	00	00	00	00
0030	00	00	00	00	00	00	00	00	00	00	00	00				

Figure: ARP reply

MAC address destination MAC address source Ethertype Hardware type Protocol type OpCode (1 request, 2 reply) IP address source IP address destination

Presentation Outline

Aims

- Interface transport layer,

Aims

- Interface transport layer,
- Host addressing,

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- End-to-end packet transmission (data link? Connectionless? Switch? Router?),

Aims

- Interface transport layer,
- Host addressing,
- End-to-end packet transmission (data link? Connectionless? Switch? Router?),
- Routing, load balancing

Concepts

- IP addressing fundamentals,
- Classfull IP addressing,
- Subnet and VLSM (Variable length subnet masks),
- CIDR (Classless inter-domain routing),
- Routing,
- IPv6.

IP addressing fundamentals

IP address

32 bits (4x4 bytes)

mask	
Networks part	Host part

Figure: IP address parts

IP addressing fundamentals

Masks

- Separates network and host bits,

IP addressing fundamentals

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- MSB **always** are ones and then zeros! 255.254.255.0 is not possible,

IP addressing fundamentals

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- MSB **always** are ones and then zeros! 255.254.255.0 is not possible,
- Indicates how many bits are used for the network part:
  - A 8-bit mask leaves 24 bits for the hosts,
  - A 16-bit mask leaves 16 bits for the hosts,
  - A 24-bit mask leaves 8 bits for the hosts,
  - A N-bit mask leaves 32-N bits for the hosts.

IP addressing fundamentals

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- Separates network and host bits,
- MSB **always** are ones and then zeros! 255.254.255.0 is not possible,
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  - A 8-bit mask leaves 24 bits for the hosts,
  - A 16-bit mask leaves 16 bits for the hosts,
  - A 24-bit mask leaves 8 bits for the hosts,
  - A N-bit mask leaves 32-N bits for the hosts.
- Two different masks (differences seen further):
  - Network mask,
  - Subnet mask.

IP addressing fundamentals

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Figure: IP address parts and mask

IP addressing fundamentals

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ones mask	zeros mask
Networks part	Host part

Figure: IP address parts and mask

IP addressing fundamentals

Is that an address?

- Network address,

IP addressing fundamentals

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- Network address,
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Within the same network

- All addresses have the same network bits,
- Network address has zeros for host bits: x.x.x.0*,
- All hosts have different host bits: x.x.x.[0-1]*,
- Broadcast address has ones for host bits: x.x.x.1*.

IP addressing fundamentals

Mask /24 254 hosts	255 11111111	255 11111111	255 11111111	0 00000000
Network address	192 11000000	168 10101000	1 00000001	0 00000000
First host	192 11000000	168 10101000	1 00000001	1 00000001
Last host	192 11000000	168 10101000	1 00000001	254 11111110
Broadcast address	192 11000000	168 10101000	1 00000001	255 11111111

Figure: IP address example 1

IP addressing fundamentals

Mask /16 65.534 hosts	255 11111111	255 11111111	0 00000000	0 00000000
Network address	172 10101100	64 01000000	0 00000000	0 00000000
First host	172 10101100	64 01000000	0 00000000	1 00000001
Last host	172 10101100	64 01000000	255 11111111	254 11111110
Broadcast address	172 10101100	64 01000000	255 11111111	255 11111111

Figure: IP address example 2

IP addressing fundamentals

Formula: how many hosts with a N-bit mask?

$2^{32-N} - 2$

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- 24-bit mask: $2^{32-24} - 2 = 2^8 - 2 = 254$ hosts
- 16-bit mask: $2^{32-16} - 2 = 2^{16} - 2 = 65.534$ hosts
- 8-bit mask: $2^{32-8} - 2 = 2^{24} - 2 = 16.777.214$ hosts

IP addressing fundamentals

Public addresses

- Most of IP addresses

[2] Internet Assigned Numbers Authority

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- Usage of not registered public addresses is forbidden.

Private addresses

- Privates addresses are A, B and C classes (not all, see after)
- No registration needed
- Not routed across the Internet
- Proxy, NAT and private addresses solved IPv4 shortage.

[2] Internet Assigned Numbers Authority

Classful IP Addressing

Class	A	B	C
First octet	1 - 126	128 - 191	192 - 223
First octet 0b	0*	10*	110*
Network mask	255.0.0.0 /8	255.255.0.0 /16	255.255.255.0 /24
IP addresses range	1.0.0.0 126.0.0.0	128.0.0.0 191.255.0.0	192.0.0.0 223.255.255.0
Private range	10.0.0.0 10.255.255.255	176.16.0.0 176.31.255.255	192.168.0.0 192.168.255.0
Number of hosts	16.777.214	65.534	254

Figure: Three main classes

Where did 127.0.0.0/8 go ?!

Classful IP Addressing

Class D

- First octet: 224 - 239

Classful IP Addressing

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- Everything left

Classful IP Addressing

Class D

- First octet: 224 - 239
- First octet pattern: 1110*
- Theses IP addresses are multicast addresses.

Class E

- Everything left
- Experimental class.

Classful IP Addressing

Reserved addresses

- 0.0.0.0 used in routing (seen further)

Classful IP Addressing

Reserved addresses

- 0.0.0.0 used in routing (seen further)
- 127.0.0.0/8: loopback addresses (127.0.0.1 - 127.255.255.254).

Classful IP Addressing

- Class A (16 m-addresses) and B (65 k-adresses) are too large!

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Means to limit the number of nodes on a network (regardless of the class) and, thus, improve the manageability, are needed. Three means for it:

- Subnet,

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- CIDR (Classless Inter-Domain Routing).

Subnet and VLSM

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Subnet and VLSM

Mask /16 65.534 hosts	255 11111111	255 11111111	0 00000000	0 00000000
Network address	172 10101100	64 01000000	0 00000000	0 00000000
First host	172 10101100	64 01000000	0 00000000	1 00000001
Last host	172 10101100	64 01000000	255 11111111	254 11111110
Broadcast address	172 10101100	64 01000000	255 11111111	255 11111111

Figure: IP address example 2

Subnet and VLSM

Mask /12 1.048.574 hosts	255 11111111	240 11110000	0 00000000	0 00000000
Network address	172 10101100	64 01000000	0 00000000	0 00000000
First host	172 10101100	64 01000000	0 00000000	1 00000001
Last host	172 10101100	79 01001111	255 11111111	254 11111110
Broadcast address	172 10101100	79 01001111	255 11111111	255 11111111

Figure: IP address example 3

Subnet and VLSM

Mask /10 4.194.302 hosts	255 11111111	192 11000000	0 00000000	0 00000000
Network address	172 10101100	64 01000000	0 00000000	0 00000000
First host	172 10101100	64 01000000	0 00000000	1 00000001
Last host	172 10101100	127 01111111	255 11111111	254 11111110
Broadcast address	172 10101100	127 01111111	255 11111111	255 11111111

Figure: IP address example 4

Subnet and VLSM

Mask /31 0 host	255 11111111	255 11111111	255 11111111	254 11111110
Network address	172 10101100	64 01000000	0 00000000	254 11111110
First host	172 10101100	64 01000000	0 00000000	? 1111111?
Last host	172 10101100	64 01000000	255 00000000	? 1111111?
Broadcast address	172 10101100	64 01000000	255 00000000	255 11111111

Figure: IP address example 5

Subnet and VLSM

Mask /30 2 hosts	255 11111111	255 11111111	255 11111111	252 11111100
Network address	172 10101100	64 01000000	0 00000000	252 111111100
First host	172 10101100	64 01000000	0 00000000	253 111111101
Last host	172 10101100	64 01000000	255 00000000	254 111111110
Broadcast address	172 10101100	64 01000000	255 00000000	255 111111111

Figure: IP address example 6

Netmask		CIDR	hosts
255.255.255.255	11111111.11111111.11111111.11111111	/32	single address
255.255.255.254	11111111.11111111.11111111.11111110	/31	Unusable
255.255.255.252	11111111.11111111.11111111.11111100	/30	2
255.255.255.248	11111111.11111111.11111111.11111000	/29	6
255.255.255.240	11111111.11111111.11111111.11110000	/28	14
255.255.255.224	11111111.11111111.11111111.11100000	/27	30
255.255.255.192	11111111.11111111.11111111.11000000	/26	62
255.255.255.128	11111111.11111111.11111111.10000000	/25	126
255.255.255.0	11111111.11111111.11111111.00000000	/24	254
255.255.254.0	11111111.11111111.11111110.00000000	/23	510
255.255.252.0	11111111.11111111.11111100.00000000	/22	1.022
255.255.248.0	11111111.11111111.11111000.00000000	/21	2.046
255.255.240.0	11111111.11111111.11110000.00000000	/20	4.094
255.255.224.0	11111111.11111111.11100000.00000000	/19	8.190
255.255.192.0	11111111.11111111.11000000.00000000	/18	16.382
255.255.128.0	11111111.11111111.10000000.00000000	/17	32.766
255.255.0.0	11111111.11111111.00000000.00000000	/16	65.534
255.254.0.0	11111111.11111110.00000000.00000000	/15	131.070
255.252.0.0	11111111.11111100.00000000.00000000	/14	262.142
255.248.0.0	11111111.11111000.00000000.00000000	/13	524.286
255.240.0.0	11111111.11110000.00000000.00000000	/12	1.048.574
255.224.0.0	11111111.11100000.00000000.00000000	/11	2.097.152
255.192.0.0	11111111.11000000.00000000.00000000	/10	4.194.302
255.128.0.0	11111111.10000000.00000000.00000000	/9	8.388.606
255.0.0.0	11111111.00000000.00000000.00000000	/8	16.777.214
254.0.0.0	11111110.00000000.00000000.00000000	/7	33.554.430
252.0.0.0	11111100.00000000.00000000.00000000	/6	67.108.862
248.0.0.0	11111000.00000000.00000000.00000000	/5	134.217.726
240.0.0.0	11110000.00000000.00000000.00000000	/4	268.435.454
224.0.0.0	11100000.00000000.00000000.00000000	/3	536.870.910
192.0.0.0	11000000.00000000.00000000.00000000	/2	1.073.741.822
128.0.0.0	10000000.00000000.00000000.00000000	/1	2.147.483.646
0.0.0.0	00000000.00000000.00000000.00000000	/0	IP space

CIDR

Classless Inter-domain Routing?

CIDR

Classless Inter-domain Routing?

- Wait! What is routing?

Routing Principles

Algorithm processed to decide where to forward a packet

Any router must

- know where any packet should be directed
- send directly the packets to the packet's destination if the router and the destination are on the same network

Any node

- on any network can communicate directly with all the nodes within the same network
- can connect to any node using its gateway
- needs to be aware of its gateway to communicate with nodes on other networks

Routing Principles

Route

- Destination
- Gateway
- Masks
- Metric

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- Destination
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```
>sudo route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         192.168.0.254   0.0.0.0         UG    0      0        0 eth0
192.168.0.0     0.0.0.0         255.255.255.0   U     0      0        0 eth0
```

Figure: Routing table

Routing Principles

```
>sudo route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
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192.168.0.0     0.0.0.0         255.255.255.0   U     0      0        0 eth0
```

Figure: Routing table

0.0.0.0 ?

- Default address
- Default route
- Default gateway

Routing Principles

Example

What would the routing table of this router will look like?

Routing Principles

Static or dynamic ?

Routing Principles

Static or dynamic ?

We will see this later

CIDR

Combine 2+ networks' into one bigger to facilitate routing.

CIDR

Combine 2+ networks' into one bigger to facilitate routing.

Classless Inter-domain Routing?

- Does a routing table having both (192.168.0.0/24, E0), (192.168.1.0/24, E0), (10.0.0.0/8, S0) can be shorten?

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- Does a routing table having both (192.168.0.0/24, E0), (192.168.1.0/24, E0), (192.168.8.0/24, E0), (10.0.0.0/8, S0) can be shorten?
- Does a routing table having both (192.168.0.0/24, E0), (192.168.4.0/24, E0), (192.168.1.0/24, E1), (10.0.0.0/8, S0) can be shorten?

Routing Protocol

- RIP: Routing Information Protocol

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- OSPF: Open Shortest Path First

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- OSPF: Open Shortest Path First
- EIGRP: Enhanced Interior Gateway Routing Protocol

Routing Protocol

RIP v1

- Classful routing

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- Periodic updates (30 sec) ..

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- Metric is hop-count (max $= 15$, infinite $= 16$)
- Timer (180 sec) to tag route as invalid (metric $= 16$)

Routing Protocol

RIP v1

- Classful routing
- Periodic updates (30 sec) ..
- ..by broadcasting (!)
- Metric is hop-count (max = 15, infinite = 16)
- Timer (180 sec) to tag route as invalid (metric = 16)
- no subnet, no VLSM, no CIDR, no router authentication

Routing Protocol

RIP v2

- Classless routing

Routing Protocol

RIP v2

- Classless routing
- Multicast (224.0.0.9)

Routing Protocol

RIP v2

- Classless routing
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- VLSM support

Routing Protocol

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RIP v2

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RIPng is the next RIP version for support of IPv6

Routing Protocol

1. Router getting online broadcasts Request message

[3] not always all the routing table

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2. RIP Router send broadcasts Response message with their routing table

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4. When Invalid timer expires, the metric of the route is set to 16 (unreachable)
5. When Flush timer expires, the 16-metric routes are removed from the routing table
6. When a new router (or new metric) is sent, a Hold-down timer is started to stabilize the network.

[3] not always all the routing table

Routing Protocol

OSPF

- Classless

Routing Protocol

OSPF

- Classless
- IPv4 and IPv6

Routing Protocol

OSPF

- Classless
- IPv4 and IPv6
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- Subdivided into area (a 32-bit number)

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Routing Protocol

OSPF

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- IPv4 and IPv6
- VSLM
- CIDR
- Build a topology of the network
- Dijkstra
- Metric = f(hop-count, bandwidth, link reliability)
- Subdivided into area (a 32-bit number)
- Multicast
- Authentication support (update only from trusted routers)

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- Unicast address format:

bits	48 (or more)	16 (or fewer)	64
field	routing prefix	subnet id	interface identifier

Figure: Unicast IPv6 address format

IPv6 adoption

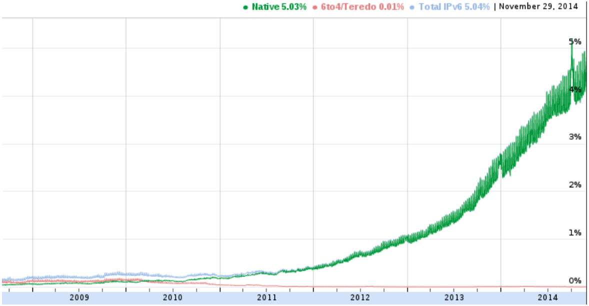

Figure: IPv6 adoption (among Google users)[4]

Belgium: 28%, USA and Germany: 11%

[4] https://www.google.com/intl/en/ipv6/statistics.html

Presentation Outline

Aims

- Interface session layer,

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    - ip.ad.dr.ess:port

Port	Protocol
21	FTP
22	SSH
23	Telnet
25	SMTP
465	SMTPS
80	HTTP
443	HTTPS
3128 - 8080	Web Proxy
9418	git

Figure: Default port for well known protocol

TCP header

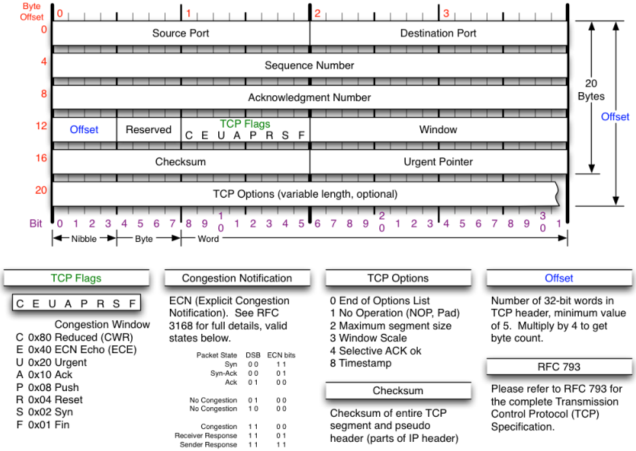

Figure: nmap.org: TCP header

UDP header

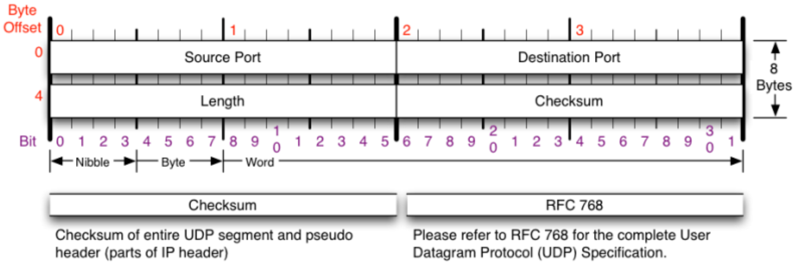

Figure: nmap.org: UDP header

Socket Primitives (TCP)

Order	Primitive	Meaning
1	SOCKET	Creates a new communication endpoint
2	BIND	Links local IP address to the socket
3	LISTEN	Signs up for incoming connections
4	ACCEPT	Blocking call till a connection attempt occurs
-	CONNECT	**Tries** to connect to another communication endpoint
-	SEND	Sends data through the established connection
-	RECEIVE	Receives data through the established connection
last	CLOSE	Releases the connection

Figure: TCP primitives

A socket does not have an IP address until it is bound, just an allocation in the transport entity. A server must listen before any client is able to connect.

What are theses?

- **Frame**: Physical layer representation
- **Datagram**: UDP[5] or IP packet (IP datagram, UDP datagram)
- **Segment**: TCP data unit
- **PDU**: Protocol Data Unit, generic term.
- **Fragment**: Any data unit **fragmented**

[5] User **Datagram** Protocol

Hope you liked it and learnt about networking!

Figure: teaching.auzias.net

Take a look:

- "Computer Networks" by A Tanenbaum, Andrew S., G ISBN 013162959X
- http://nmap.org/book/toc.html
- http://blog.nodenexus.com/2014/11/28/a-shark-on-the-network/
- and many many other resources on the Internet freely available. If you can read it, knowledge is reachable!