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Content

- Introduction to TCP/IP
- Wireless Networks & Satellite Systems
- TCP/IP in Wireless Networks
1.1 Introduction to TCP/IP

- History
  - TCP/IP reference model created by U.S. Department of Defence (DoD) for a network surviving any conditions
  - “standardisation” through RFCs (requests for Comments) of IETF (Internet Engineering Task Force)
  - 4 layer model
Comparing TCP/IP with the OSI Model

TCP/IP Model

- Application
- Transport
- Internet
- Network Access

OSI Model

- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical

TCP/IP Protocols for Multimedia Traffic in Wireless and Satellite Communication Systems,
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Protocol Graph: TCP/IP

TCP
- HTTP
- SMTP
- DNS
- TFTP

UDP

IP

- Internet
- Your LAN
- Many LANs and WANs

TCP/IP Protocols for Multimedia Traffic in Wireless and Satellite Communication Systems,
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Internet layer

- Internet Path Determination
  - Select best path through the network for packets to travel

IPv4 Header

<table>
<thead>
<tr>
<th>Version</th>
<th>IHL</th>
<th>Type of Service</th>
<th>Total length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Identification</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D M F</td>
<td>Fragment Offset</td>
</tr>
<tr>
<td>Time to live</td>
<td>Protocol</td>
<td></td>
<td>Header checksum</td>
</tr>
<tr>
<td>Source Address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destination Address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Options (0 or more words)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

32 bit
IPv4 Addressing Format

- Unique IP address for each networking device (OSI layer 3)

10000011011011000111101011001100

32 Bits

Decimal presentation: 131.108.122.204

- Also MAC address (OSI layer 2)

Address Classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Network</th>
<th>Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Octet</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Class B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Octet</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Class C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Octet</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Class D</td>
<td>Host</td>
<td></td>
</tr>
<tr>
<td>Octet</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Class D addresses are used for multicast groups. There is no need to allocate octets or bits to separate network and host addresses. Class E addresses are reserved for research use only.
Internet Architecture:
Routers connect Local and Remote Networks

Transport layer

- **TCP**
  - Reliable transmission of packets
  - connection-oriented protocol
    - prior to data transmission, a virtual connection is setup between any two communicating hosts

- **UDP**
  - unguaranteed transmission of packets
  - connectionless
**Transmission Control Protocol (TCP)**

- **Reliable transport**
  - Received segments are acknowledged to the sender
  - Retransmission of any segments that are not acknowledged
  - Re-establishing correct order of segments
  - Provision of congestion avoidance and control
    - Flow control

**TCP Segment Format**

<table>
<thead>
<tr>
<th>Bit 0</th>
<th>Bit 15 Bit 16</th>
<th>Bit 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Port (16)</td>
<td>Destination Port (16)</td>
<td></td>
</tr>
<tr>
<td>Sequence Number (32)</td>
<td>Acknowledgement Number (32)</td>
<td></td>
</tr>
<tr>
<td>Header Length (4)</td>
<td>Reserved (6)</td>
<td>Code Bits (6)</td>
</tr>
<tr>
<td>Window (16)</td>
<td>Checksum (16)</td>
<td>Urgent (16)</td>
</tr>
<tr>
<td>Options (0 or 32 if any)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data (varies)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Establishing a virtual Connection by Three-Way Handshake

1. Send SYN (seq=100 ctl=SYN)
2. Send SYN, ACK (seq=300 ack=101 ctl=syn,ack)
3. SYN received

TCP Sequence and Acknowledgement

<table>
<thead>
<tr>
<th>Source Port</th>
<th>Destination Port</th>
<th>Sequence Number</th>
<th>Acknowledgment Numbers</th>
<th>...</th>
</tr>
</thead>
</table>

I sent #10.

I received #10. now send #11.
TCP flow control: Sliding Window

- **Sender**
  - send 1
  - send 2
  - send 3
  - receive ACK 4
  - send 4
  - send 5
  - send 6
  - receive ACK 7

- **Receiver**
  - receive 1
  - receive 2
  - receive 3
  - send ACK 4
  - receive 4
  - receive 5
  - receive 6
  - send ACK 7

Window size = 3

TCP Slow Start Algorithm

- **2 variables:**
  - Congestion Window (cwnd)
  - Slow Start Threshold (ssthresh)

- **At beginning of connection**
  - Congestion Window = 1 packet (1460 Byte)
  - Ssthresh = Window size of receiver
  - For each ACK, cwnd is increased by 1 packet until ssthresh is reached

- **Lost packet => Slow Start**
- **After slow start -> congestion avoidance**
UDP Segment Format

<table>
<thead>
<tr>
<th>Bit 0</th>
<th>Bit 15 Bit 16</th>
<th>Bit 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Port (16)</td>
<td>Destination Port (16)</td>
<td></td>
</tr>
<tr>
<td>Length (16)</td>
<td>Checksum (16)</td>
<td>8 Byte</td>
</tr>
<tr>
<td>Data (if any)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Less overhead:
  - Smaller header
  - No acks
  - No retransmissions

1.2 QoS mechanisms in IP networks

- Integrated Services (IntServ)
  - IETF, 1994
  - Flow centric
  - Admit /reject new calls depending on availability of resources

- Differentiated Services (DiffServ)
  - IETF, 1998
  - Aggregates flows to classes
Integrated Services (IntServ) (1)

- Guarantee each flow required transmission resources
- End-to-end resource reservation
- for each flow
  - Admission control
  - Setup process for transmission
  - Classifying
  - Packet scheduling

Integrated Services (IntServ) (2)

- Status of admitted flows stored at each router along the path
  - Storage / processing capabilities!
- Signalling protocol needed for resource reservation
  - e.g. RSVP (ReSerVation Protocol)
- Policy control (authorisation, legitimacy to apply for resource reservation)
- Traffic control
IntServ – Traffic Control (3)

- Admission control
  - At call setup
  - Each device checks for availability of resources
- Classifier
  - Maps incoming packet to certain class
  - Different classifiers at different routers
- Packet scheduler
  - Forwarding of different flows
  - Queues at link layer
  - Depends on estimator

IntServ service types

- Guaranteed Quality of Service (GS)
  - Assures end-to-end queueing delay and bandwidth
- Controlled load network element service (CL)
  - QoS like flow in unloaded network
  - “better then best effort”
Differentiated Services (DiffServ) (1)

- Flows with same QoS are aggregated to classes (or macroflows)
- Classification only at edge of network
- DiffServ class: ID in IP packet header
- Router:
  - Separate queue for each class
  - No state information
  - Per hop behaviour (PHB) depending on class

DiffServ Domains

- Set of network nodes with same policies
- Well defined boundaries
  - Interior nodes
  - Boundary nodes (ingress / egress node)
- Network edge
  - Packet classifiers: set DiffServ codepoint (DSCP) based on source and destination IP address, port number and protocol identifier
  - Traffic conditioner: metering, (re)-marking, shaping and dropping
**Per Hop Behaviour (PHB)**

- Can be defined by network administrator
- **Recommended PHBs**
  - Expedited Forwarding (DSCP: 101110)
    - Low delay, low jitter, low loss
    - Specified data rate
  - Assured Forwarding (12 DSCPs)
    - 4 traffic classes with 3 drop precedences

**Comparison**

- **IntServ:**
  - fine-grained system; QoS on per flow decisions with high granularity
  - State information at every router
  - Not scalable
- **DiffServ:**
  - Traffic classes
  - No state information
  - Scalable
2.1 Introduction to Wireless Transmission

Principle:
- Electromagnetic waves propagate through free space (even in vacuum)
  * predicted by James C. Maxwell in 1865
  * first produced by Heinrich Hertz in 1887
  * first radio transmission by Guglielmo Marconi 1895
- Electromagnetic waves can be transmitted / received by an antenna of appropriate size being attached to an electrical circuit
Electromagnetic waves

- Frequency \( f = \text{number of oscillations / s} \)
- Wavelength \( \lambda = \text{distance between two consecutive maxima} \)
- Speed of light \( c = 3 \times 10^{-8} \text{ m/s} \)

\[
\lambda = \frac{c}{f}
\]

Electromagnetic Spectrum

Electromagnetic Spectrum

- Transmission properties are frequency depended:
  - Low frequencies: radio waves pass through obstacles, power \( \sim 1/r^3 \);
    VLF, LF, MF: ground waves
    HF, VHF: ground waves are absorbed
  - High frequencies: radio waves travel in straight lines and bounce off obstacles (multipath fading); absorbed by rain

Radio Propagation

- Distance-related attenuation
  - Signal strength \( \sim 1/d^2 \) (LOS)
- Propagation effects
  - Reflection
  - Diffraction
  - Scattering
- Theoretical propagation models
  - Free space propagation
Free Space Propagation Model

- **Line-Of-Sight Channel**

\[ P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \]

- **Received power** \( P_r \)
- **Transmitted power** \( P_t \)
- **Transmitter antenna gain** \( G_t \)
- **Receiver antenna gain** \( G_r \)
- **Distance between TX and RX** \( d \)
- **Wavelength** \( \lambda \)
- **System loss factor** \( L \)

\[ \text{Path loss [dB]} = -10\log \left( \frac{\lambda^2}{(4\pi)^2 d^2} \right) \]

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Broadband wireless spectrum

- **Commercial broadband wireless spectrum**: 1- 40 GHz (70/80/90 GHz)
- **2 categories**
  - < 10 GHz (“microwave”)
  - > 10 GHz (“millimetre wave”)

---
### Broadband wireless spectrum

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Microwave</th>
<th>Millimetre wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>&lt; 10 GHz</td>
<td>&gt; 10 GHz</td>
</tr>
<tr>
<td>Cost</td>
<td>Less than millimetre wave</td>
<td>Higher than microwave</td>
</tr>
<tr>
<td>Complexity</td>
<td>Less than millimetre wave</td>
<td>Greater than microwave</td>
</tr>
<tr>
<td>Nominal range</td>
<td>5 – 30 km</td>
<td>&lt; 8 km</td>
</tr>
<tr>
<td>Typical use</td>
<td>multipoint</td>
<td>Point-to-point</td>
</tr>
<tr>
<td>Multipath an issue?</td>
<td>yes</td>
<td>Generally no</td>
</tr>
<tr>
<td>Affected by weather</td>
<td>Usually no</td>
<td>Usually yes</td>
</tr>
</tbody>
</table>

### Wireless Transmission

1. Digital data
2. (Encryption)
3. Encoding
4. Modulation
5. Wireless channel

6. Digital data
7. (Decryption)
8. Decoding
9. Demodulation
Error Control

- Redundancy added to digital data for error detection
- Error detection
  - determines BER
  - Parity check bit
  - Cyclic redundancy (CRC)
- Error correction
  - = forward error correction (FEC)

Data transmission

- Digital data: modulate carrier signal
  - Amplitude modulation
  - Frequency modulation
  - Phase modulation
- Metrics
  - Spectral efficiency [bit / Hz]
  - Spectral density [bit / symbol]
  - Bit error rate (BER)
**Antennas**

- Omni-directional
- Gain = measure for directivity [dBi]

**Medium Access Control**

- Many terminals share the same wireless channel -> MAC
- Fixed assignment / dynamic assignment
- Contention less
  - TDMA
  - FDMA
  - CDMA
- Contention based
  - ALOHA
  - CSMA
2.2 Satellite Networks

Wireless networks using satellites as “relay stations”

Satellite Orbits

- **GEO**: geostationary (36 000 km)
- **LEO**: low earth orbit (700 - 1500 km)
- **MEO**: medium earth orbit (10 000 – 20 000 km)
- **HEO**: highly elliptical orbits (up to 40 000 km)
GEO-Orbit

- 3 satellites are sufficient for worldwide coverage (except polar regions)

GEO (pros / cons)

- 36000 km above Earth equator
- Sat remains fixed to point on Earth
- High delay: 250 ms Earth – Sat – Earth
  - Round-trip-time: 0.5 s
  - Influences interactivity
  - Influence on protocols
    - Adaptation of parameters necessary
- Large antennas / high power
- Continuous service
- Cheaper than LEO-Systems
**LEO (Pros / Cons)**

- 400 – 800 km distance from Earth
- Low path loss
- Low delay, smaller antennas, less power
- Antenna pointing has to follow satellite
- Many satellites needed for continuous service
- Handover needed

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**Satellite sub-systems**

- Mechanical structure
- Receive and transmit antennas
- Transponder: for reception, amplification and retransmission of signals
- Power supply
- Temperature control
- Position control
- TTC: telemetry, tracking & control
Satellite features

- Bent pipe vs Onboard Processing (OBP)
- Spot beam vs Wide beam
  - Satellite equipped with several transponders; each transponder has an antenna beam serving one region (wide beam vs. spot beam)
Frequencies

- C-band: 4 / 6 GHz
- Ku-band: 10, 11, 12 / 14 GHz
- Ka-band: 20 / 30 GHz

- Higher frequencies:
  - Smaller Antennas (gain is higher)
  - Higher data rates
  - Higher attenuation caused by atmosphere
Link Budget

- = planning tool for sufficient $E_b/N_0$ at receiver
- Path loss is dominant factor

\[
L_s = \left( \frac{4\pi R}{\lambda} \right)^2
\]

$L_s$ ...., path loss, $\lambda$ ... wave length

Ground stations

- Transmission and reception of data and control signals
- Typical VSAT:
  - TX power: 1...8, 16, 40 W depending on data rate, satellite, coverage area
  - typical G/T: 24...28 dB/K
  - Antenna diameter: 1.5...2.4 m
  - IF-Interface: L-Band (70 MHz)
- Figure of merit: G/T
Signal amplification

- **TX path:** High Power Amplifier (HPA)
  - Travelling wave tube amplifier (TWT)
    - 2 - 20 kW normal operating mode
  - Solid State Power Amplifier (SSPA)
- **RX path:** Preamplifier (LNA)
  - Amplification of received signal
  - Internal noise as small as possible
    - Preamplifier cooled down with liquid helium (4 K): reduction of movement of electrons, reduction of internal noise
  - State-of-the-art amplifiers: 1.2 K

Satellite Network Topologies

- **Broadcast (RX only)**
  - Star topology
- **Bi-directional communication**
  - Star topology (central hub station -> dual hop for terminal to terminal)
  - Meshed topology for terminal to terminal
Advantages of Satellite Communication Systems

- Natural broadcast capability
- Large coverage area (footprint)
- Unlimited number of RX terminals
- Quick installation and access to the network
- Ideally suited for regions without adequate network infrastructure

Disadvantages

- Signal transmission with speed of light
- Path distance ground station -> GEO-satellite -> ground station = 80000km -> delay 0.25 seconds
- Signal influenced by atmospheric effects (rain, hail, snow)
- Consequence = transmission errors
- -> use of forward error correction (FEC)
Applications

- **Broadcast**
  - TV- and Radio broadcast
  - Data transmission to branch offices
- **Interactive services**
  - symmetrical / asymmetrical
  - Point-to-Point links (branch to central office)
    e.g. news-gathering
  - Meshed network architecture

Part 3: TCP/IP in wireless networks
Wireless TCP and UDP

- TCP Problem = congestion control algorithm
  - Assumption lost packet due to congestion -> slow down
  - Wireless links = unreliable; lost packets due to transmission error -> retransmission would be optimal
  - Networks with high bandwidth-delay-products
    - Flow control mechanism reduces throughput
- UDP problem: assumes highly reliable data transmission

TCP parameters

- Parameters influencing throughput:
  - Window Size
  - round trip time (RTT)
- default window size = 8192 Byte
- Transmission delay = 700 ms (Satellite + Rx/Tx-systems)

\[ B_{\text{max}} = \frac{\text{WindowSize}}{\text{RTT}} = \frac{8192 \text{ Byte}}{0.7 \text{ s}} = 91.4 \text{ kbit/s} \]
TCP cont.

<table>
<thead>
<tr>
<th>Window Size (Byte)</th>
<th>Transmission rate (max) ($t_d=0.7s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8192</td>
<td>91.4 kbit/s</td>
</tr>
<tr>
<td>16384</td>
<td>182.8 kbit/s</td>
</tr>
<tr>
<td>32768</td>
<td>365.7 kbit/s</td>
</tr>
<tr>
<td>65536</td>
<td>731.4 kbit/s</td>
</tr>
</tbody>
</table>

TCP improvements

- RFC 1323 (TCP Extension for High Performance)
  - additional 16-bit scaling factor
    - increases window size to $2^{32} = 4\ 294\ 967\ 296$ Bytes
  - Fast Retransmit und Fast Recovery algorithms in case of lost packets
  - Measurement of delay with time stamping.

- RFC 2018 (TCP Selective Acknowledgements)
  - SACK
    - Acknowledges received blocks of data.
    - Missing packets can be retransmitted selectively.
  - Slow Start not necessary!
PEP (Performance Enhancing Proxy)

- Split TCP connection
  - Wired network (sender to base/ground station)
  - Wireless network (base/ground station to user or second ground station)
- Security mechanisms cannot be supported

Literature, Reference