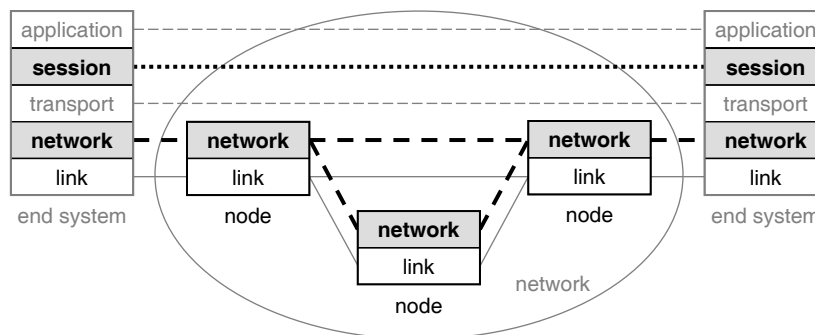


Network Control and Signalling

1. Introduction
2. Fundamentals and design principles
3. Network architecture and topology
4. Network control and signalling
5. Network components
 - 5.1 links
 - 5.2 switches and routers
6. End systems
7. End-to-end protocols
8. Networked applications
9. Future directions

Network Control and Signalling



- 4.1. Signalling paradigms
- 4.2. Traffic management
- 4.3. Path routing dynamics
- 4.4. Monitoring & management

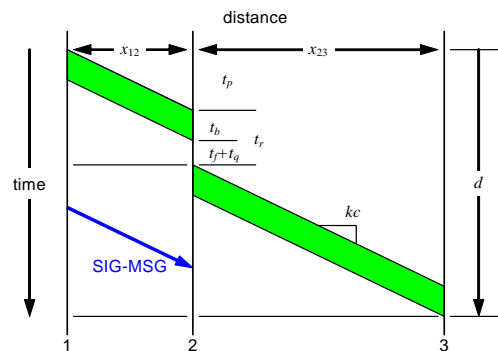
Network Control and Signalling

Signalling Paradigms

- 4.1 Signalling paradigms
 - 4.1.1 Circuit and message switching
 - 4.1.2 Packet switching
 - 4.1.3 Fast packet switching
 - 4.1.4 Intermediate control mechanisms
 - 4.1.5 Fast circuit and burst switching
- 4.2 Traffic management
- 4.3 Path routing dynamics
- 4.4 Monitoring and management

Network Control and Signalling

Communication Flow Diagrams



- **Packets** are parallelograms
- **Messages** are directed line segments

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Signalling Paradigms

Circuit Switching

- First generation (<1970)
 - PSTN switching technique
- Characteristics
 - setup latency: RTT *before* data transfer
 - no multiplexing efficiency
 - + negligible switch latency

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Signalling Paradigms

Message Switching

- First generation (<1970)
 - data switching technique
- Characteristics
 - no setup latency
 - + some multiplexing efficiency
 - significant switch latency
 - store and forward
 - queueing delay: very bad behind large messages

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Signalling Paradigms

Datagram Packet Switching

- Second generation (1970s)
- Messages packetised
 - + no setup latency
 - + significant multiplexing
 - + less queueing delay behind large packets
 - store-and-forward per packet processing still required
 - data rate limited by packet processing throughput

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Signalling Paradigms

Connection-Oriented Fast Packet Switching

- Motivation:
 - eliminate store-and-forward
 - high-performance switch design
 - provision of QOS
- Connections
 - establish state once to reduce per packet processing
 - + amortised for long flows
 - expensive for transactions
 - RTT delay before data transfer
 - + high throughput possible
 - + per hop messages reduce latency

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Signalling Paradigms

Connections vs. Connectionless

- Connections enabled fast switching in the 1980s
 - standardised as ATM, but with serious flaws
- Difficult tradeoffs between two paradigms
 - intermediate schemes are possible...

Connectionless vs. Connection Tradeoff

N-5A

The latency of connection setup must be traded against the reduction in the end-to-end data transfer delay due to the elimination of store-and-forward delay, and faster transmission of due to nodes capable of increased bandwidth.

Signalling Paradigms

Signalling Efficiency

- Signalling complexity tradeoff between
 - needed functionality
 - simple state machines and message formats
- Signalling protocols must be robust to lost messages
 - state machine must account for this
 - messages should fit in single packet
 - reliable hop-by-hop protocols add significant complexity
 - (e.g. ATM S-AAL)

Efficiency of Signalling

N-8B

Signalling messages should be simple in coding format and fit in a single packet to minimise the latency in processing. The signalling protocol should be robust to lost messages.

Signalling Paradigms

Round Trip Minimisation

- Techniques to minimise control round trips
 - hop-by-hop acknowledgements
 - parameter ranges
 - desired – minimum acceptable
 - desired, alternate
 - overlap of control and data

Minimise Round Trips

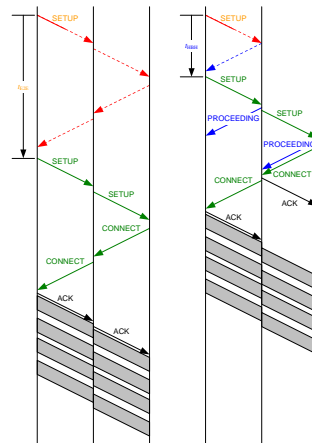
N-6A

Structure control messages and the information they convey to minimise the number of round trips required to accomplish data transfer.

Signalling Paradigms

Round Trip Minimisation – HBH ACKs

- E2E handshake
 - requires RTT timeout
 - for *all* connect failures
- HBH ACKs
 - quicker local recovery



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Signalling Paradigms

Round Trip Minimisation – Range Parameters

- Specific parameters
 - exact match or...
 - **another RTT attempt**
- Incremental negotiation
 - initiator gives range or set
 - **destination ACKs capabilities**

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Signalling Paradigms

Round Trip Minimisation – Overlap Control/Data

- Separate phases
 - control to establish path
 - **when successful**
 - transfer data
- Overlap control/data
 - control to establish path
 - optimistically transfer data
 - **when successful**
 - continue transferring

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Signalling Paradigms

Intermediate Mechanisms

- Spectrum of signalling paradigms
 - per message forwarding (message switching)
 - per packet datagram forwarding
 - *data-driven soft state accumulation*
 - *control-driven soft state accumulation*
 - *optimistic connection establishment*
 - *fast reservation*
 - explicit virtual connection setup – fast packet switching
 - scheduled connection sharing – burst switching
 - explicit physical connection setup – circuit switching
- Intermediate mechanisms benefit from extremes

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Signalling Paradigms

Intermediate Mechanisms

- Intermediate mechanisms benefit from extremes
 - benefits of state accumulation (from connections)
 - benefits of immediate transmission of data (from datagrams)

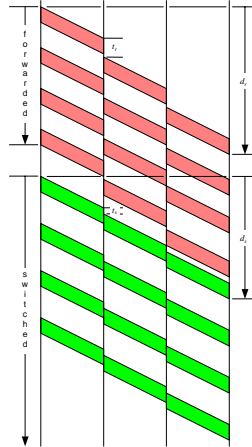
Network Path Establishment N-II.1

The routing algorithms and signalling mechanisms must be capable of forwarding datagrams or establishing connections on sufficiently high-performance paths and with low latency to meet application needs.

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Intermediate Signalling Paradigms Soft State Accumulation

- Features
 - allow immediate packet send
 - once state established: fast lookup and forwarding
- Variants
 - data driven
 - switch detects flow from headers
 - control driven
 - explicit inter-switch signalling
 - e.g. MPLS



Intermediate Signalling Paradigms Optimistic Connection Establishment

- Significant delay results from round trips
 - overlapping connection setup with data transfer to reduce

Overlap Signalling Messages with Data Transfer

N-6A

To reduce unneeded end-to-end latency, signalling messages should be overlapped with data transfer.

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Intermediate Signalling Paradigms

Optimistic Connection Establishment

- Features
 - data sent with signalling
 - until COMMIT returned:
 - best effort or
 - per hop fast reservation

The diagram illustrates the timeline for optimistic connection establishment. It shows a vertical axis representing time. A red shaded area represents the period from the start of the SETUP phase until the COMMIT phase is received. This period is labeled 'provisional' and contains data packets. A green shaded area below the red one represents the 'reserved' period. Vertical lines mark the start of SETUP, the receipt of COMMIT, and the end of the reservation period. Time intervals t_{sig} and t_{set} are indicated between these events.

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Intermediate Signalling Paradigms

Burst Switching

- Features
 - packets group into bursts
 - bursts scheduled in circuit
- Role
 - optical networks: no photonic header processing
- Variants
 - release: signalled or timed
 - in- or out-of band signalling

The diagram illustrates the timeline for burst switching. It shows a vertical axis representing time. A green shaded area represents a burst of data packets. The SETUP phase occurs before the burst starts. The burst itself is shown as a series of parallel lines. The RELEASE phase occurs after the burst ends. Vertical lines mark the start of SETUP, the end of the burst, and the start of RELEASE. Time intervals t_{day} , t_{sig} , and t_{set} are indicated.

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Multicast Signalling

Root vs. Leaf Join

- Root join
 - + simple
 - doesn't scale

- Leaf join
 - complex
 - + scales

Root vs. Leaf Multicast Control N-6B

Root multicast control is appropriate when a single entity has knowledge of the multicast group. Leaf-controlled multicast is needed for large multicast groups

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Session Control

Signalling Efficiency

- Session (layer 5)
 - set of transport layer associations (layer 4)
 - point-to-point or multipoint (may be mixed)
 - connection oriented or connectionless (may be mixed)

Session-Connection Interlayer Awareness N-4F

Session control awareness of network layer control parameters allows the overlap of session and connection control signalling to reduce overall latency

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Session Control Signalling Efficiency

- Latency reduction
 - minimise round trips
 - parallelise session and network signalling
 - properly locate resources

The diagram is a sequence diagram with five vertical lifelines: user, end system, network, end system, and user. It illustrates the following sequence of events:
1. **user initiation**: A blue arrow points from the first 'user' lifeline to the first 'end system' lifeline.
2. **session establishment**: A green arrow labeled 'SESS-REQUEST' goes from the first 'end system' to the 'network'. A second green arrow labeled 'SESS-ESTABLISH' goes from the 'network' to the second 'end system'. A third green arrow labeled 'user negotiation' goes from the second 'end system' to the second 'user'.
3. **connection establishment**: A red arrow labeled 'SETUP' goes from the 'network' to the first 'end system'. A second red arrow labeled 'CONNECT' goes from the first 'end system' to the 'network'.
4. **data transfer**: A shaded area between the two 'end system' lifelines indicates data transfer.

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Network Control and Signalling Traffic Management

- 4.1 Signalling paradigms
- 4.2 Traffic management
 - 4.2.1 Resource reservation
 - 4.2.2 Network-based congestion control
- 4.3 Path routing dynamics
- 4.4 Monitoring and management

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Traffic Management Goals

- Conflicting goals:
 - sufficient resources to deliver required QOS to users
 - minimise network resource use to keep costs low

Network Path Protection

N-II.2

QOS mechanisms must be capable of guaranteeing bandwidth and latency bounds, when needed.

Traffic Management Optimality

- Support for mixed traffic
 - distinct networks (1st and 2nd generations through 1980s)
 - virtual network partitioning
 - differentiated services: coarse grained service grades
 - integrated services: fine grained traffic classes
 - e.g. ATM-TM and intserv with RSVP

Optimal Resource Utilisation vs. Overengineering

N-5A

Tradeoff *Balance the tradeoff of optimal resource utilisation and its associated complexity and cost against the cost of suboptimal resource utilisation resulting from overengineering the network.*

Network Congestion Control Motivation

- Motivation
 - reservations are generally statistical
 - congestion can occur if there is any overbooking of resources
 - best-effort traffic must be limited to avoid congestion
 - not all end users will behave as they should

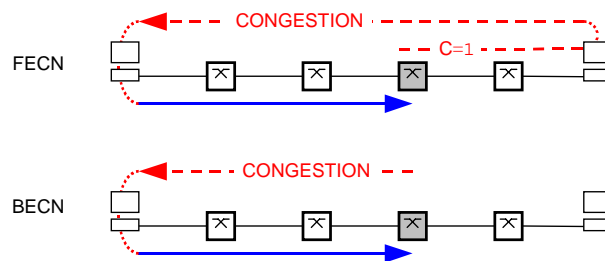
Congestion Control in the Network Improves

N-3A

Performance *Even though the end-to-end protocols must perform congestion control, there is substantial performance benefit in assistance from the network.*

Network Congestion Control Performance Goal

- Goals
 - congestion control in the network reduces control loop delay



Network Congestion Control

Congestion Avoidance

- Congestion Avoidance
 - reacts to impending congestion *before* damage is done
 - e.g. RED (random early detection)
 - e.g. PPD/EPD (partial/early packet discard)

Avoid Congestion and Keep Queues Short

N-11.4

Avoid congestion by network engineering, traffic management with resource reservation, and by dropping packets. Buffers should be kept as empty as possible, with queueing only for transient situations, to allow cut-through, and avoid the latency of FIFO queueing.

Network Congestion Control

Fairness vs. Complexity

- Fairness
 - desirable to allow fair sharing of network
 - difficult to discriminate well-behaved and misbehaving flows
 - fair mechanisms substantially more complex to implement

Congestion Control Fairness vs. Complexity

N-2Bc

The lack of fairness in simple congestion control and avoidance mechanisms must be traded against the complexity of fair implementations.

Network Control and Signalling

Path Routing Dynamics

- 4.1 Signalling paradigms
- 4.2 Traffic management
- 4.3 Path routing dynamics
 - 4.3.1 Multipoint groups
 - 4.3.2 Node mobility
- 4.4 Monitoring and management

Path Routing Dynamics

Dynamic Network Behaviour

- Dynamic network behaviour
 - leads to low performance paths over time
 - multipoint groups
 - prune and reroute to maintain optimal topology
 - node mobility
 - reconfigure topology to maintain performance

Dynamic Path Rerouting

N-2B

Dynamic behaviour can require adjustments to topology to maintain a high-performance path. The overhead and frequency of topology maintenance must be traded against the lack of optimality.

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Path Routing Dynamics

Node Mobility

- Node mobility changes path characteristics
- Example
 - $d_1 + d_2 < D_a$
 - intermediate node moves away
 - latency bound exceeded: $d_1 + d_2 > D_a$
 - reroute path
 - $d_3 < D_a$

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Path Routing Dynamics

Multipoint Groups₁

- Multipoint spanning tree
 - optimised to receiver group...
 - ...at a particular point in time

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Path Routing Dynamics

Multipoint Groups₂

- Dynamic behavior
 - changes topology
 - latency bounds may be exceeded
 - bandwidth wasted
- Receivers leave group
 - inefficient path to remaining members
 - links carrying traffic to no receiver

The diagram shows a tree structure with a source node at the top (blue square) and several receiver nodes at the bottom (green squares). The tree has a root node (square with 'x') connected to two intermediate nodes (squares with 'x'). The left intermediate node is connected to two leaf nodes (squares with 'x'), and the right intermediate node is connected to two leaf nodes (squares with 'x'). A red arrow points from the root to the left intermediate node, then to the left leaf node, and finally to a receiver node. This path is inefficient because the receiver node is not part of the group.

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Path Routing Dynamics

Multipoint Groups₃

- Prune and reroute tree
 - optimise to remaining group
 - reroute to group members
 - prune unneeded leaf hops

The diagram shows a tree structure similar to the previous one, but with a different path highlighted in green. The green path starts at the root node, goes to the right intermediate node, then to the right leaf node, and finally to a receiver node. This path is optimized to reach the remaining group members. The left side of the tree is shown with dashed lines, indicating it has been pruned.

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Network Control and Signalling Monitoring and Management

- 4.1 Signalling paradigms
- 4.2 Traffic management
- 4.3 Path routing dynamics
- 4.4 Monitoring and management

Monitoring and Management Issues

- Coarse granularity
 - management not high-speed, per se
- Issues
 - management must keep up with rapidly changing conditions
 - massive amounts of data must be filtered and reduced
 - monitoring should not interfere with high-speed flows

Network Monitoring Locality

N-1B

Network monitoring functions must be built into the critical path to provide non-intrusive local filtering and aggregation of statistics.