S38.121

Routing in Telecommunication Networks

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Reception SE323, Wed 10-12

http://tct.hut.fi/opetus/S38.121/

Replaces S38.122

Assistant: Nicklas Beijar

S38.121 Agenda - Fall 2001

Lectures	Mon 10-12 in Hall S3 and
1st Half semester	Wed 16-18 in Hall S3
	Lectures start on Wed 12.9.2001
Exercises on Tuesdays	12.30-14 in Hall S3
	Start from 18.9.2001

RKa:

Lectures 1 and 2 - Routing in Circuit switched networks

Lectures 3 - 7 - Routing in the Internet + PNNI-routing + MPLS

Lectures 8 ja 9 - Multicast routing in the Internet

Course requirements

GOAL: to understand routing on a functional level in different networks.

Material: Copies of the slides

+ Girard: Routing and dimensioning in circuit switched networks: Chapters 1 and 2

C. Huitema: Routing in the Internet: Parts I and II + Chapter 11

ATM-Forum: PNNI-spec. af-pnni-0055.000 Sections 1 - 4 (pgs 1 - 46)

B.Davie, P. Doolan, Y. Rekhter: Switching in IP networks (ch 2, 4, 5)

IETF draft: Distance Vector Multicast Routing Protocol

All Internet Drafts and RFCs can be found on www! These are primary sources on Internet technology - learn to read them!

Requirements: Exam + 1/2 of the exercises correctly solved and submitted

What is routing?

Routing = a process of directing the user traffic from source to destination so that the user's service requirements are met and the constraints set by the network are taken into account.

Objectives of routing:

- maximization of network performance or thruput and minimization of the cost of the network
- optimization criteria may be amount of carried traffic (blocking probability), bandwidth, delay, jitter, reliability (loss), hop count, price.
- administrative or policy constraints limit the selection.

1st key function of Routing is collection of *network state* information and information about the *user traffic*

- User service requirements
- Location of the users
- Description of network resources and use policies
- Predicted or measured amount of traffic or resource usage levels

This information is used in route calculation and selection

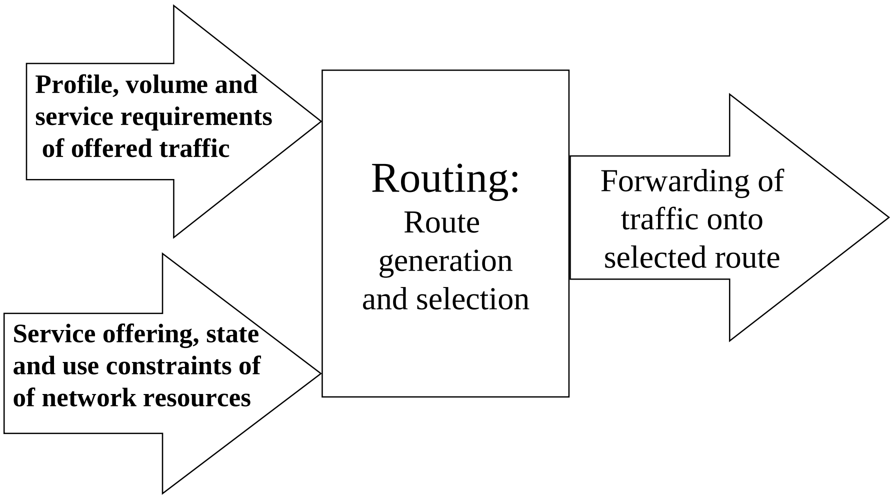
Core function of routing is the generation and selection of feasible or optimal routes

- *Feasible route* satisfies the service requirements and constraints set by the user and the network
- *Optimal route* is the best based on one or many optimization criteria
- Depending on the routing algorithm may require heavy processing. If many criteria are used, often the algorithm becomes NP-complete - I.e. not usable in practical networks.

3rd kay function is forwarding the traffic onto the selected route

- Connection oriented traffic
  - Before traffic can start to flow, thruconnection needs to be established (switched)
- Connection less traffic
  - user traffic itself carries info about the route or indication how to select the route
  - packet forwarding in a router

Routing process



When is routing optimal?

From the user point of view:

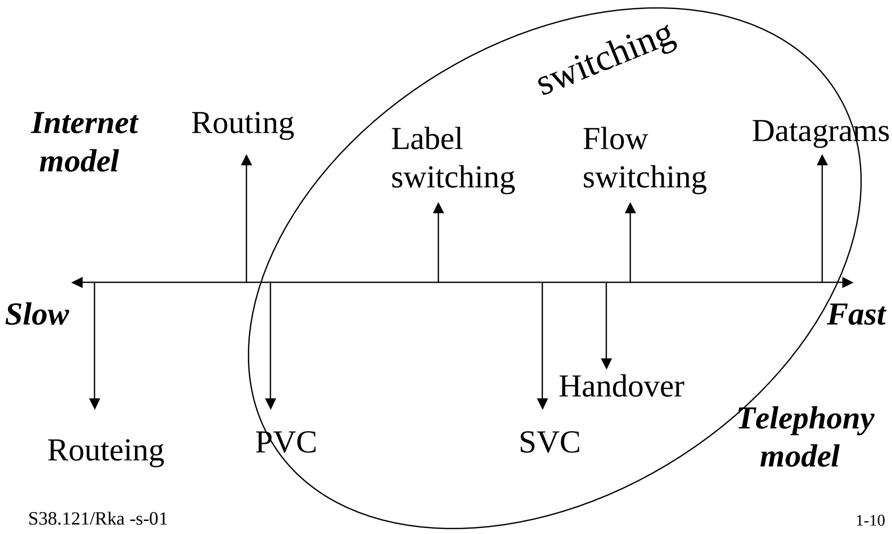
- Minimum probability of blocking, delay, jitter, loss or maximum bandwidth …

Network point of view:

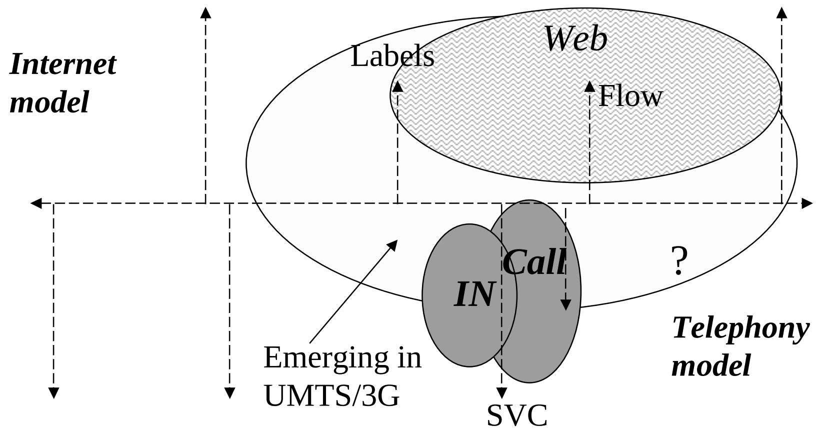
- Maximum network thruput. Requires short routes, while excess traffic need to be directed to least loaded parts of the network. At the same time user service requirements need to be met.

It follows that routing is a complex optimization problem. Most times optimum can not be found in a closed form. Therefore, we are interested in near-optimal, heuristic approximations.

Routing is slower than switching as a mechanism of matching traffic to network resources



Services and service architectures rely on different resource management models



Each of the three key functions of routing can be either centralized or distributed

- Centralization eases management and may reduce cost.
- A centralized function is vulnerable
- Centralized routing reacts slowly to state changes

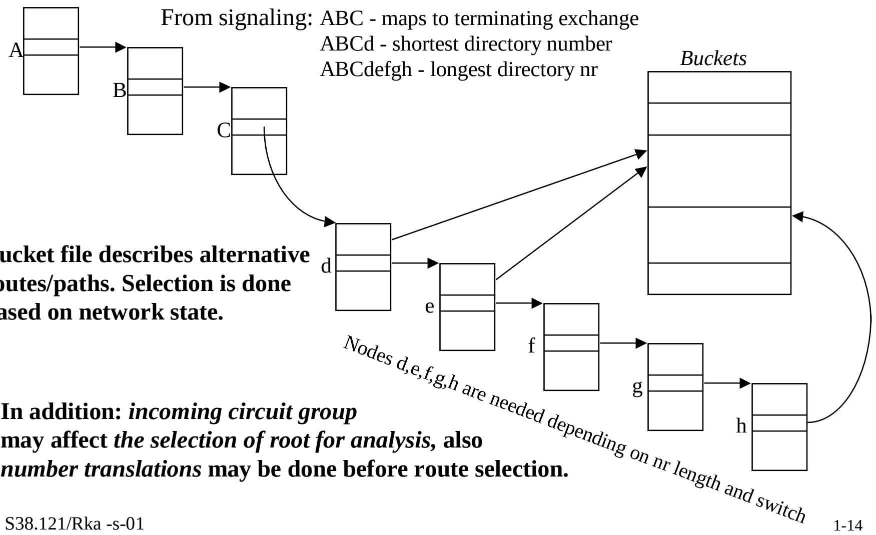
- Distributed routing can be based on replication or cooperation between nodes (peer-to-peer distributed system).
- Fault tolerant
- Reacts quickly
- Scales well.

Routing in Circuit Switched networks

Because a subset of functions is performed during off-line network design, we talk about routeing (väylöitys)***!***

FHR - Fixed Hierarchical Routing - hierarkinen väylöitys
AAR - Automatic Alternate Routing - vaihtoehtoinen väylöitys
DAR - Dynamic Alternative Routing - dynaaminen vaihtoehtoinen väylöitys
DNHR - Dynamic Nonhierarchical routing - dynaaminen ei-hierarkinen väylöitys
are examples of routing algorithms.
Lots of country, operator and vendor specific variations.

Number Analysis tree in an Exchange connects routing to signaling information



Bucket file describes alternative routes/paths. Selection is done based on network state.

In addition: *incoming circuit group* may affect *the selection of root for analysis,* also *number translations* may be done before route selection.

Properties of number analysis in PSTN

- In originating and transit exchanges only leading ABC -digits need to be analyzed.
- Terminating exchange needs to analyze also the rest of the digits "…defgh" to find the identity of the subscriber's physical interface

Semantics of (E.164) directory numbers

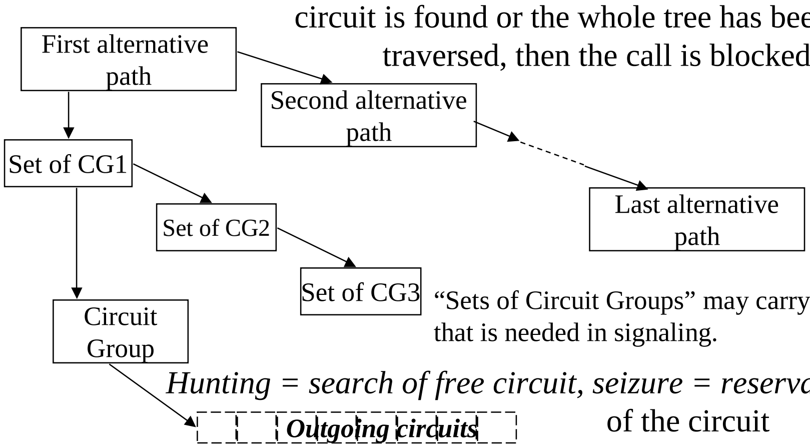
- A *directory number* points to a subscriber or a service
- A *subscriber number* is at the same time the *routing number* as well as the "logical" directory number
- Subscriber number portability breaks this 1-1 mapping
- A *service number* is always only "logical" and requires a number translation to the corresponding routing number
- It must be possible to deduce the price of the call based on the dialed digits. Therefore, the allocation of directory=routing numbers is tied to geography and network topology. Plain routing numbers are tied to network topology for convenience.

Typical properties of number analysis

- Analysis may take as input
  - dialed digits
  - incoming circuit group, origin or subscriber category (e.g. operator)
- Analysis output may include
  - a set of alternative paths
  - translated number (e.g. for an 0800-number): It may be necessary to repeat the analysis with the translated number as input
- Analysis trees are built by the operator using MML-commands based on the routing plan.

Example of a route description

The tree is traversed in some order following an algorithm until a free outgoing circuit is found or the whole tree has been traversed, then the call is blocked.



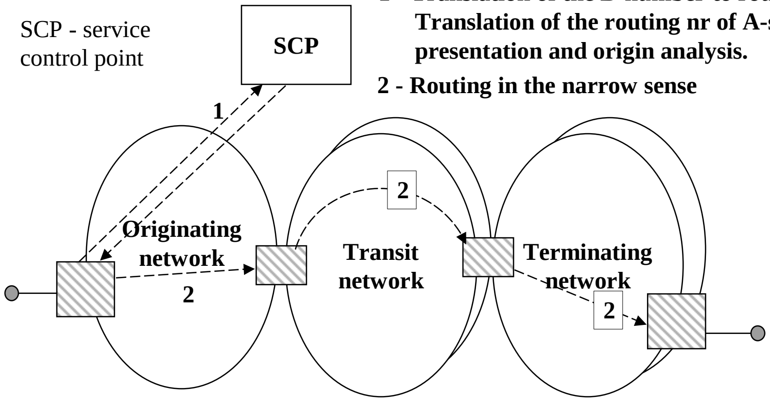
"Sets of Circuit Groups" may carry info that is needed in signaling.

Hunting = search of free circuit, seizure = reservation of the circuit

Number portability requires a number translation prior to routing

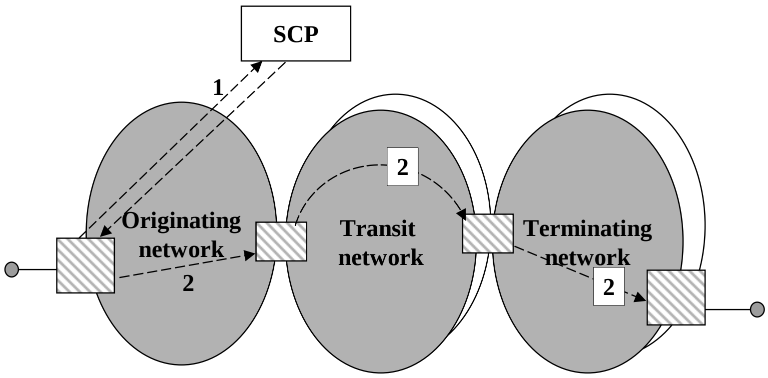
SCP - service control point

1 - Translation of the B-number to routing nr
Translation of the routing nr of A-sub for presentation and origin analysis.
2 - Routing in the narrow sense



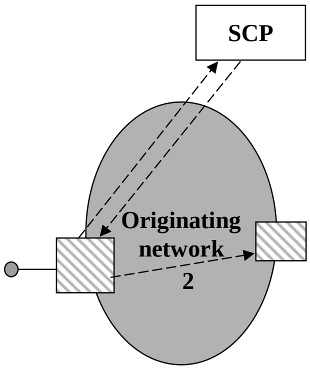
The figure present the solution to operator to operator nr portability adopted in Finland in principle. Because of deliberate high prices this NP service is very rarely used!

How to do routing if one or some of the networks are based on IP?



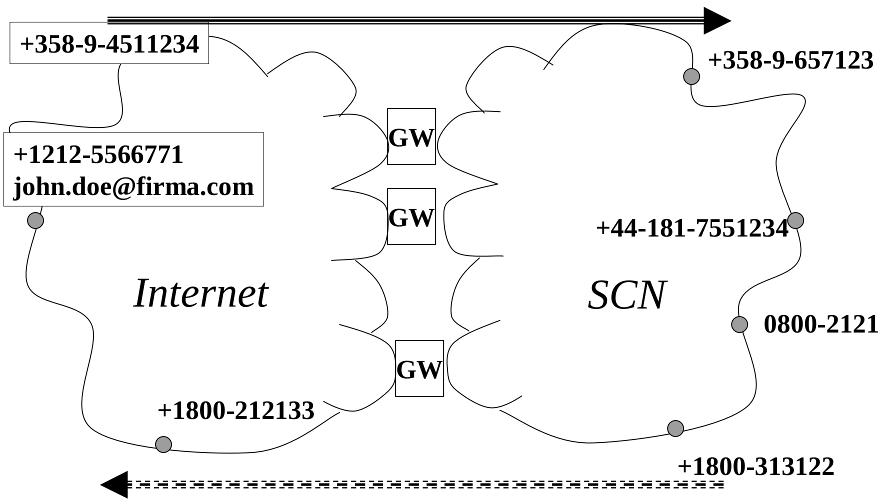
Convergence of the Internet and PSTN/ISDN is happening today.
This is one of the research topics in the IMELIO project in Networking Lab.

Service numbers require number translation



+ 800-numbers, 700-numbers, 020 -nbrs
+ Number translation can be done using IN or in an Exchange.
+ Mobile numbers always require translation for a mobile terminated call (MS-ISDN ->MSRN) by HLR
+ Management of number translation is easier in IN. An exchange is faster (n x 100ms vs. ≤ 1ms).

Gateway Location is the Telephony Routing problem across a hybrid IP/Switched Circuit Network



We are working on this in IMELIO

Network dimensioning and routing are dual tasks

- For *routing* network dimensioning is given. Task is to determine how to transfer the offered traffic when network topology, link and node capacities are known.
- In *dimensioning* routing method and service level requirements are given. Task is to form a route plan and dimension the links (and nodes).

Routing systems are classified acc to *dynamic* properties

- *Static routing* does not consider the current state of the network nor changes in traffic matrix
- Naturally takes into account the state of individual resources

- *Adaptive routing* dynamically reacts to changes in traffic load, traffic matrix and network state.
- Link and node failures.
- Requires continuous processing by network nodes

Traditional routing in the PSTN (ISDN) is static

- Based on predicted traffic and a-prior knowledge of network topology and state
- Off-line network design produces the routing tables
- Is quite sufficient for example in the Finnish PSTN.

Adaptive routing can make more efficient use of network resources

- State information collection may be centralized or distributed
- Routing protocols are used in Internet.
- E.g. Internet and newest PSTN routing systems
- It does not always pay off to react quickly to state changes if the distribution of change info takes too much time.

Dynamic predictive routing is an intermediate step and is based on predicted traffic

- The use of the terms static, dynamic, adaptive routing varies in different sources.
- Even static routing hunts and seizures circuits - I.e. adapts to local network state.
- Dynamic (predictive) routing uses a set of routing tables each table adapted to a time interval during a day - e.g. in USA DHNR improved network thruput considerably due to time difference between the coasts.

Selection of route may be based on

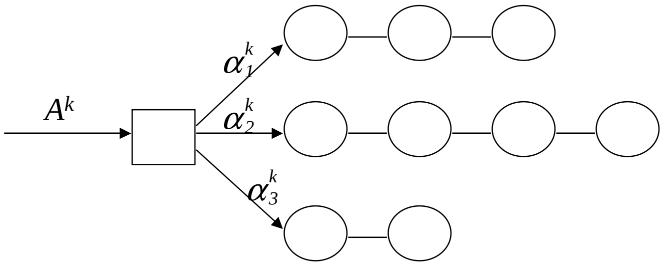
Global information

- most efficient use of netw
- a lot of info, real time collection and distribution is difficult
- vulnerable if centralized
- E.g. TINA architecture

Local information

- solution is distributed and nodes are autonomous
- scales to a network of any size
- the goal is to find algorithms that are near optimal

Traffic can be distributed to alternative paths

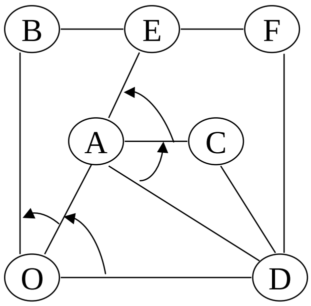


$\Sigma_p \alpha_p^k = 1$

Load balancing coefficients α_n^k can be constant or be based on measurements.

In Finland needed e.g. for load distribution between alternative transit networks. We talk about percent routeing.

Alternative routing is the basic family of routing methods in PSTN



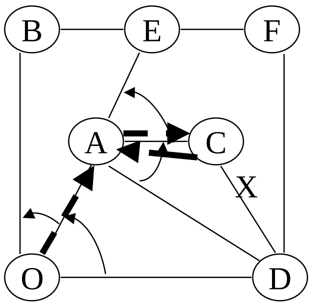
(vaihtoehtoinen väylöitys)

O - origin of the call
D - destination of the call
Arrows show traffic overflow or the order of selection.

All alternate paths (routes) are described in node routing tables. Design and maintenance of the tables is done off-line.

- described alternate routes do not necessarily cover all possible routes present in the topology.
- Selection takes place using a given algorithm, the first available path is always selected.

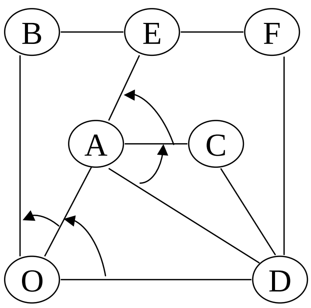
Example: Alternate routes O - D are



Primary: (o, d)
Alternatives: (o, a, d)
(o, a, c, d)
(o, a, e, f, d)
(o, b, e, f, d)

If the call has progressed to node C and there are no free circuits on (c, d)
- the Call can be either blocked or
- The call can be returned to A (cranckback) and A may try another alternative depending on the algorithm.

Optimality can be viewed either from the point of view of the user or the network



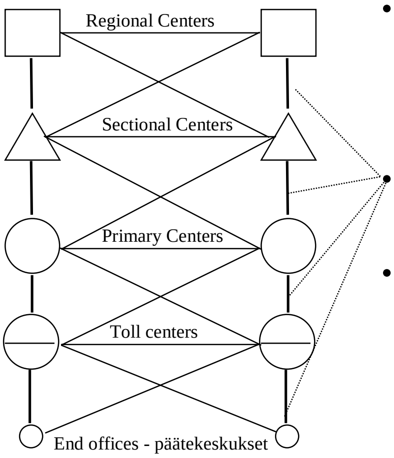
Primary: (o, d)
Alternative: (o, a, d)
(o, a, c, d)
(o, a, e, f, d)
(o, b, e, f, d)

From the point of view of an individual call it is best to have as many alternatives as possible.

From network point of view, number of alternatives must be restricted!

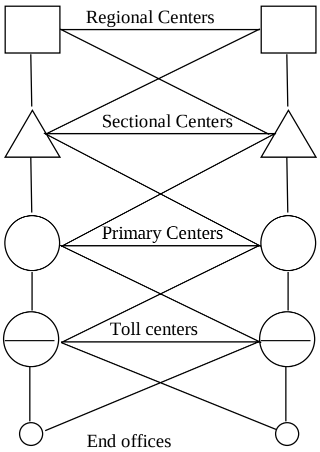
E.g. (o, b, e, f, d) reserves 4 links, but (o, d) only one!

FHR - Fixed Hierarchical Routing



- Most traditional variant of Alternate Routing in PSTN
- Level of hierarchy are connected by a final trunk group (ftg)
- Hierarchical distance = nrof ftg's between the exchanges

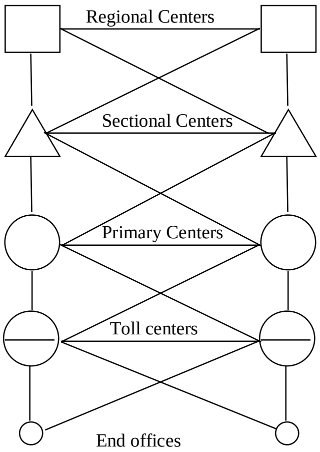
FHR routing algorithm is



1. Path selection is based only on leading dialed digits (terminating end office) Origin of the call has no effect.
2. A node always selects the first available circuit group for an offered call among the alternatives.
3. Alternative paths are ordered acc to ascending *hierarchical distance* measured from the node to the terminating node.
4. Last alternative path always uses the final trunk group. If there are no free circuit on the ftg, the call is blocked.

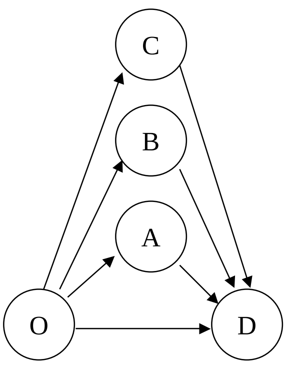
In different networks variants of these basic principles can be used.

Properties of fixed hierarchical routing



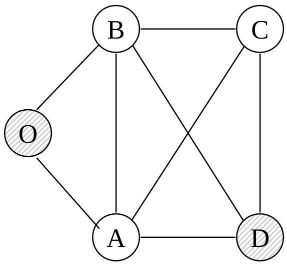
- sets minimal requirements for the nodes
- Loops (call circulating in a loop) are not possible.
- Divides nodes into End offices and transit nodes. From the point of view of digital exchange technology, transit capability is almost a subset of End office capability.
- Can be shown to rather far from optimal in terms of network resource usage.

Dynamic nonhierarchical routing (DNHR - AT&T transit network mid-1980's … early 1990's)

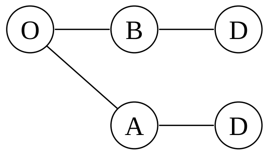


- All exchanges are equal - there is no hierarchy.
- A circuit group can be final for some call and non-final for another.
- Length of alternative paths is 2 hops, because long alternative routes are problematic under overload in the network.
- Uses a series of routing tables, one is selected based on wall clock time during the day.
- DNHR uses crankback.
- Generation and *optimization* of routing tables requires centralized traffic data collection --> Network Management and TMN.

Route tree describes the routing method



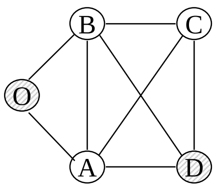
Network example

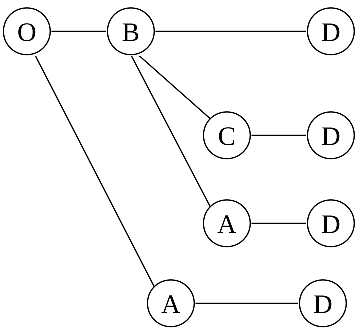


Route tree for calls from O to D

- Tree is traversed from top to bottom- gives order of overflows
- In this example overflow control remains in O: OOC - originating office control (lähtökeskusohjaus).

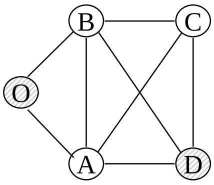
Overflow control can move

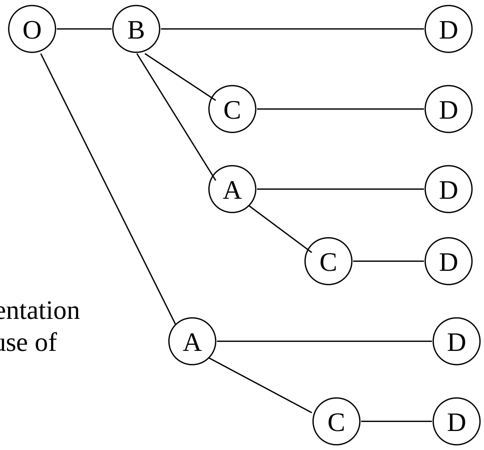




Overflow control moves to B, if a circuit (o,b) is available.
If outgoing circuits in B are all reserved:
- blocking if there is no crankback
- crankback will return the overflow control back to O

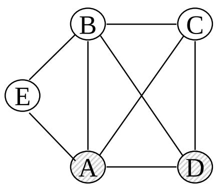
In Sequential Office Control (SOC), overflow control moves always

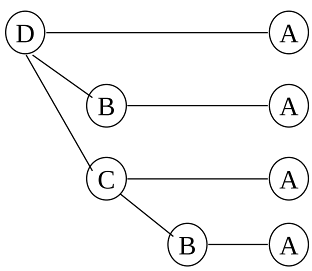


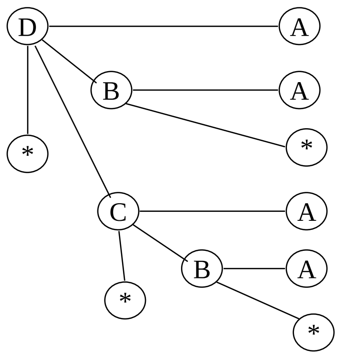


This simples tree presentation is unable to show the use of crankback.

An *augmented tree* with *loss nodes* defines the routing method







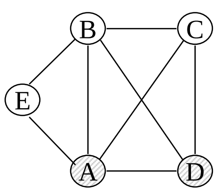
NB: Link capacity to loss node is infinite.

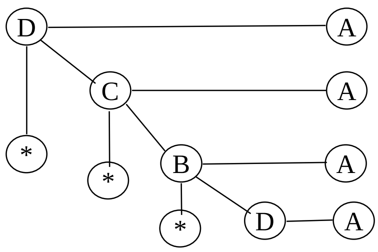
All alternative routing methods can be described using such augmented route trees.

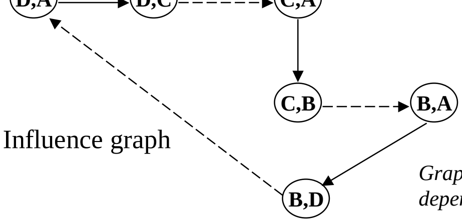
Influence graph shows the presence or absence of routing loops

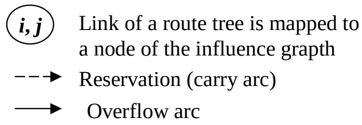
- If routing is based on SOC and alternative paths are longer than 2 hops, loops are possible.
- Mutual overflow (from link A to link B and from B to A) *may* also be undesirable.
- Influence graph can also define and analyze a partial order in a network.

Route tree with a loop









Graph gives all possible paths, selected route depends on the reservation state of the links

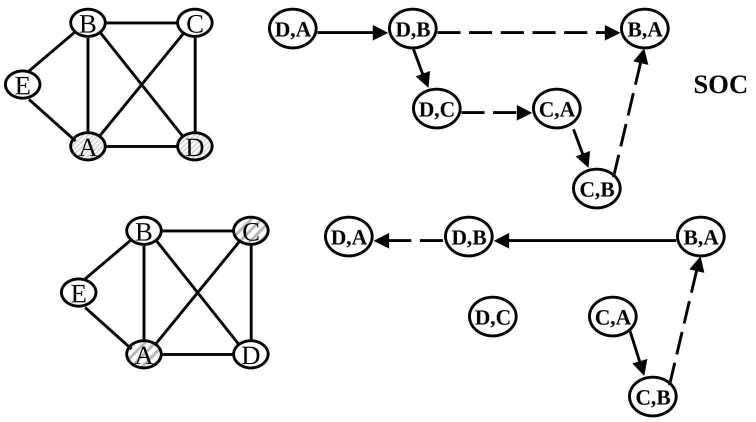
Influence graph can be presented in an algebraic form

$\sigma(i, j)$ - For trunk group *i*, and calls destined for *j*, indicates number of the trunk group to which a blocked call will overflow.

$\rho(i, j)$ - For trunk group *i*, and calls destined for *j*, indicates number of the trunk group to which calls that are carried on *i* will be offered.

- Existence of a loop in the influence graph is equivalent with the existence of a routing loop in the network design.
- Lots of well known standard algorithms for Graphs exist - loops are easy to find.

Mutual overflows are revealed by superposition of influence graphs



If there are no loops, a partial order exists in the network. Dimensioning and modeling of the routing are simplified in case a partial order exists.

Adaptive routing

• Computer controlled exchanges can use a more varied set of input data for route calculation than just dialed digits.

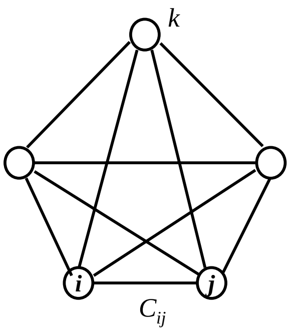
• Alternate Routing allocates traffic to a small set of alternative paths in a predetermined order.

• Adaptive routing allocates traffic to a possible large set of alternative paths without a pre-determined order.

• Value function is calculated for the alternatives determining the selection of the path among all alternatives.

• Variations are based on the type of the value function, way of collecting input data for the value function etc.

DAR - Dynamic Alternative Routing



DAR works in a full mesh network

Paths directly from node *i* to node *j* and alternate paths of max two hops are allowed.

r_{ij} - link reservation parameter of link *i*,*j*.

k(*i*,*j*) - current alternate tandem node for traffic from node *i* to node *j* on the alternate path

A call from node *i* to node *j* is always offered first to the direct link and is carried on it if a circuit is available. Else the call is offered to the two hop alternate path thru node *k*. The call succeeds, if r_{ik} and r_{kj} circuits are free. If not, the call is blocked and a new *k* is selected,

r_{ij} - link reservation parameter of link *i,j*

- A call using a two hop alternative path can cause blocking of many subsequent calls if it is allowed to reserve the last circuit.
- Without the link reservation parameter, the state of the network is unstable (or bistable) - the amount of max thurconnected traffic alternates between two level - the network oscillates.
- E.g. N nodes, $N(N\text{-}1)$ links, each have M circuits.

Each node originates p calls.
If calls use only direct links $\Rightarrow p\,N \le N\,(N\text{-}1)\,M$
$\Rightarrow p \le (N\text{-}1)\,M$

If all calls use 2 circuits $\Rightarrow$

Total is $2pN$ circuits $\le N(N\text{-}1)\,M \Rightarrow p \le (N\text{-}1)\,M/2$

r_{ij} - link reservation parameter of link *i,j*...

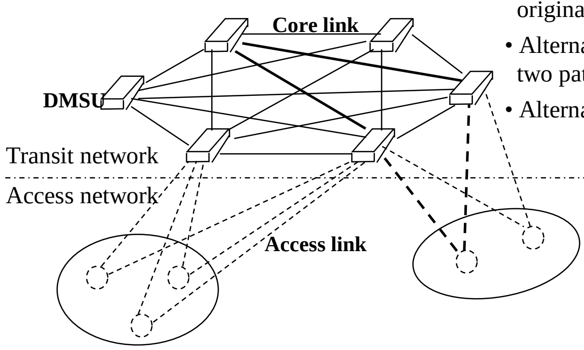
- Even on high capacity links r is a small value.
- It is even sufficient that $r \neq 0$ is defined only for the first link on the alternative paths.
- If one call is allowed to try more than one alternative two hop path, the value of r must be increased.

DAR variants

- Current tandem node is switched when the last allowed circuit is reserved on the alternative path.
- Some alternative nodes may be better than others => the selection of a new tandem node can be weighted to favor good nodes instead of being just random.
- If a lot of traffic is carried on the alternative route, it can be distributed to several current alternative paths each of which is switched independently.

BT implementation of DAR

- Always two direct routes from the originating DMSU.
- Alternative path tandem DMSU has two paths to the destination.
- Alternative routing on the access links.

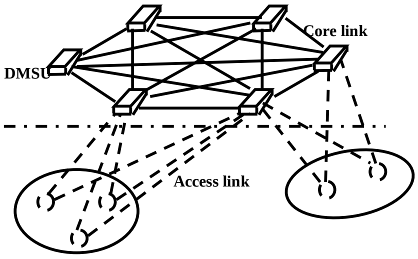


Each node has two parents: (home and security) - dual parenting.

Digital Main Switching Unit (DMSU) – a trunk exchange primarily used for connecting long distance calls.

Local node **The local exchanges that have the same parent (DMSU) form a Cluster**

More on DAR by BT



BT has more than 60 DMSU's.

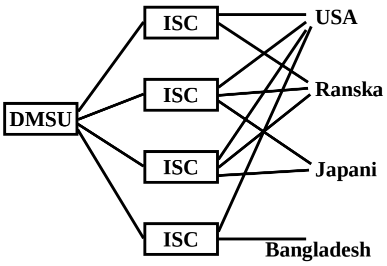
Possibilities:

- Incoming and outgoing traffic on Access links can go primarily thru different parents.
- Extension of the Scenario to multi-parent network.
- Nrof parents per access node can vary.
- Nrof alternative tandem nodes is *N* - 3.

Last Chance priority

- ***Incoming traffic that has reached the destination parent has only one chance to succeed.***
- ***Therefore, it makes sense to define a trunk reservation parameter for Access links so that outgoing traffic is not allowed to reserve the last circuit on the primary access link for terminating traffic.***

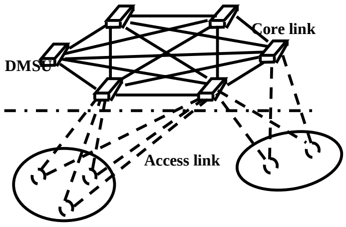
Adaptive routing in a (international) partial mesh network



Vaihtoehdot:

- **ISC-to-country link reservation status is passed to DMSU which offers outgoing traffic to least loaded ISC -- needs additional signaling.**
- **Proportionate routing (kuormanjako) -- needs reliable predictions of traffic**
- **Crankback from ISC if int-links reserved -- in overload the processing load in nodes grows quickly: call is transferred back and forth from one ISC to another + Additional capacity from DMSU to ISC can degrade the overall performance.**
- **DAR with fixed primary-ISC -- problem is how to allocate the primary roles to ISC's.**
- ***DAR to one primary ISC, switch to alternative ISC if a call is blocked -- one call has only one chance to succeed. This turns out to be the best algorithm!!***

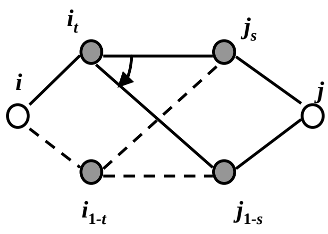
Comparison of DAR variants



Alternative algorithms:

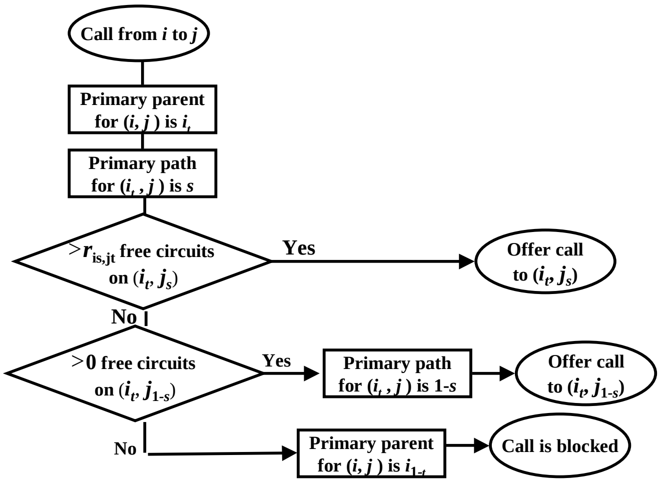
1. **Outgoing traffic always offered to parent *i* and terminating traffic to parent *j*. In the full mesh transit network direct and all two alternative paths are allowed (single parenting) -- high blocking probability.**
2. **All four direct routes are allowed, least loaded is chosen (LLR-least loaded routing).**
   NB: This requires distribution of the reservation state information! Performance approaches to theoretical optimum.
3. **We are interested in finding a method with performance approaching to LLR, but such that it is easy to implement**
   $\Rightarrow$ sticky principle and last chance priority.

Sticky principle retains a path if a call succeeds and skips the path if blocking occurs

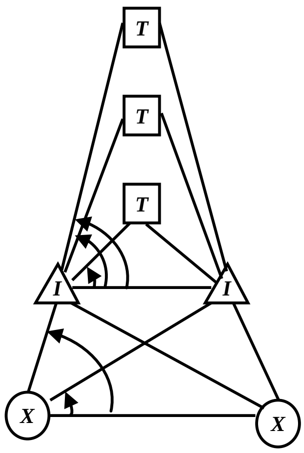


1. **Primary parent of node i towards j is i_t**
2. **Primary destination parent of tandem i_t towards j is j_s**
3. **If call succeeds thru $i_t j_s$, primary roles are retained.**
4. **If blocking occurs thru $i_t j_s$, call is offered to $i_t j_{1-s}$, if success, i_t adopts j_{1-s} as the primary choice towards j.**
5. **If 4 is fails, call is blocked and i adopts i_{1-t} as the primary choice towards j.**

General sticky principle combines sticky learning with last chance priority



RCAR - Residual Capacity Adaptive Routing is used in Canada



Implementation name DCR - dynamic call routing/ Telecom Canada

- **Info about outgoing circuit reservation status, nrof blocked calls and CPU load is collected each 10s to a centralized network management center. The Center calculates and downloads new routing tables for *I* and *T* switching nodes.**
- **Idea is to choose the path with most free circuits.**
- **Improves network performance significantly.**
- **Adapts quickly to unusual traffic patters and to link and node failures.**
- **Benefits relate to time difference between coasts.**
- **Vulnerable to failure of Mgt Center. Falls back to FHR model, if the Center stops.**