# ITU Regional Seminar

Belgrade, Serbia and Montenegro, 20-24 June 2005

## Session 5.3

# Switching/Routing and Transmission planning

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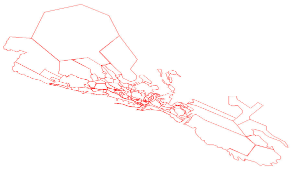
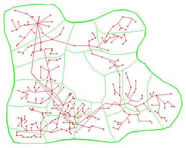
# Switching planning

## *Location problem :*

Optimal placement of exchanges, RSU, routers, DSLAM, etc.



**subscribers/users in areas/zones**



**subscribers/users**
**in locations/sites**

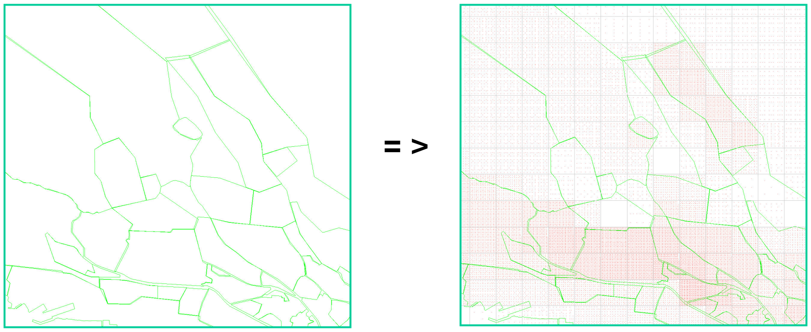
## *Boundaries problem :*

Optimal service areas of exchanges, RSU, routers, DSLAM, etc.

## Switching planning

### *Location problem*

Subscriber zones / subscriber grid model



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## Switching planning

### *Location problem*

Theoretically for the set of optimal location *($X_E$, $Y_E$)* the partial derivatives of the total network cost function, *C*, with regard to $X_E$ and $Y_E$ are equal to zero :

$$\left.\begin{aligned} \partial C/\partial X_E &= 0 \\ \partial C/\partial Y_E &= 0 \end{aligned}\right\} \text{for E} = 1,2,\ldots \text{NEX}$$

Different methods for solving this 2*E equation system could be employed depending upon the methods of ***measuring the distances*** in the network

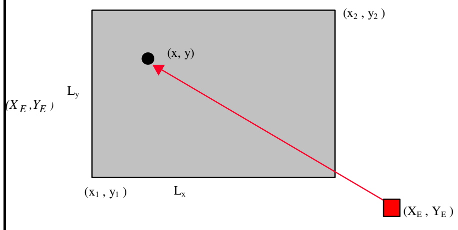
In the most complicated case we get a system of 2**NEX* ***non-linear equations***

If $\partial C/\partial X_E$ and $\partial C/\partial Y_E$ are expanded into Taylor-series this leads to a system of 2**NEX* ***linear equations*** in $\Delta X_F$ and $\Delta Y_F$ , which can easily be solved by ***standard methods***

# Switching planning

## Location problem - distance measurement methods

### Mean distance from exchange to grid element :



The *mean distance* from to the rectangle can then be found from:

$$D = \frac{1}{area} \int_{x_1}^{x_2} \int_{y_1}^{y_2} d(X_E, Y_E, x, y)\, dx\, dy$$

along the cathetie :

$$D(X_E, Y_E, x, y) = |X_E - x| + |Y_E - y|$$

along the hypotenuse :

$$D(X_E, Y_E, x, y) = \sqrt{(X_E - x)^2 \cdot L_x^2 + (Y_E - y)^2 \cdot L_y^2}$$

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# Switching planning

## Simplified method for location optimization

Based on the access network cost $S_j$ only :

$$S_j = \sum_i sub(i,j) \cdot C_s(D_E) \qquad for\ (i,j) \in E$$

For optimal locations $(X_E, Y_E)$ the partial derivatives of the cost function $C = S_j$ with regard to $X_E$ and $Y_E$ are equal to zero :

$$\left.\begin{array}{l} \partial C / \partial X_E = 0 \\ \partial C / \partial Y_E = 0 \end{array}\right\} \quad for\ E = 1,2,\ldots NEX$$

For a case with one location only for $X_E$ we get:

$$\partial C / \partial X_E = \sum_{(i,j) \in E} \left[ sub(i,j) \cdot C_c(D_E) \cdot \partial D_E / \partial X_E \right]$$

the partial derivative depends only on the distance

# Switching planning

## *Simplified method for location optimization*

With simplified distance method along the cathetie :

$$D(X_E, Y_E, i, j) = |X_E - j| + |Y_E - i|$$

We get :

$$\partial C / \partial X_E = \sum_{(i,j)\in E} sub(i,j) \cdot C_c(D_E) \cdot \begin{cases} -1 \ if \ j \geq X_E \\ 1 \ if \ X_E \geq j \end{cases}$$

Thus :

$$\sum_{(i,j)<X} sub(i,j) \cdot C_c(D_E).(+1) + \sum_{(i,j)>X} sub(i,j) \cdot C_c(D_E).(-1) = 0$$

Or :

$$\sum_{(i,j)<X} sub(i,j) \cdot C_c(D_E) = \sum_{(i,j)>X} sub(i,j) \cdot C_c(D_E)$$

Finally if disregard the tr. media cost (same everywhere) we get:

$$\boxed{\sum_{(i,j)<X} sub(i,j) = \sum_{(i,j)>X} sub(i,j)}$$

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# Switching planning

## Example locations

$R1 = 81 + 326 + 81 = 488$

$S1 = R1 = 488$

$R2 = 122 + 407 + 163 = 692$

$S2 = S1 + R2 = 1180$

$R3 = 81 + 366 + 204 = 651$

$S3 = S2 + R3 = 1183$

$R4 = 156 + 40 + 323 + 284 + 122 = 925$

$S4 = S3 + R4 = 2756$

$R5 = 391 + 236 + 323 + 323 + 326 + 41 + 43 + 43 = 1726$

$S5 = S4 + R5 = 4482$

$R6 = 234 + 235 + 194 + 150 + 132 + 190 + 222 + 188 = 1545$

$S6 = S5 + R6 = 6027$

$R7 = 38 + 208 + 326 + 310 + 240 + 283 + 317 + 317 = 2039$

$S7 = S6 + R7 = 8066$

$S_{TOT} = S7$

$S_Y = S_{TOT} /2 = 8066/2 = 4033$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 81 | 326 | 81 | 0 | 0 | 0 | *R1* |
| 0 | 0 | 122 | 407 | 163 | 0 | 0 | 0 | *R2* |
| 0 | 0 | 81 | 366 | 204 | 0 | 0 | 0 | *R3* |
| 156 | 40 | 323 | 284 | 122 | 0 | 0 | 0 | *R4* |
| 391 | 236 | 323 | 323 | 326 | 41 | 43 | 43 | *R5* |
| 234 | 235 | 194 | 150 | 132 | 190 | 222 | 188 | *R6* |
| 38 | 208 | 326 | 310 | 240 | 283 | 317 | 317 | *R7* |

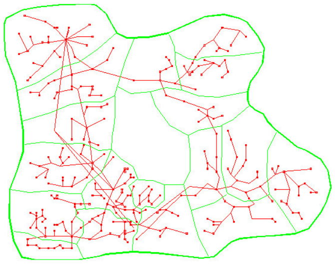
Optimum location according to the simplified method is the median of the accumulated subscribers sum – 4033 is within row **5** (**Y=R5**)

# Switching planning

## Location problem

Graph model (subscribers in nodes)

= >



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# Switching planning

## Location problem - *graph model*

Graph model presents network nodes and links connecting these nodes - cost function, *C*, is a ***discrete function*** over all node locations, i.e. it is not possible to use partial derivatives of *C*

Obvious solution is to calculate the total network cost, *C*, for ***all combinations*** (solutions) and find the smallest *C* = *Cmin*

Distances calculation as distances on graph – ***shortest path*** problem and corresponding algorithms

For ***n*** nodes and ***N*** equipment items $\frac{\mathbf{n!}}{\mathbf{(n-N)!\,N!}}$ cost combinations

# Switching planning

## *Location problem - graph model*

Check all combinations - for very small networks - pointless to investigate many of the combinations

Heuristic methods - eliminate the obvious senseless combinations and investigate only some of the combinations

Probabilistic methods for location optimization - Simulated annealing / Simulated allocation / Genetic algorithms

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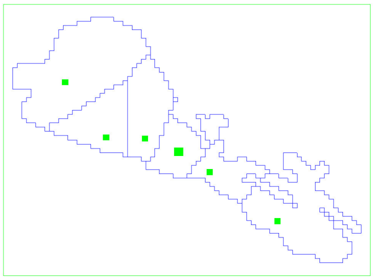
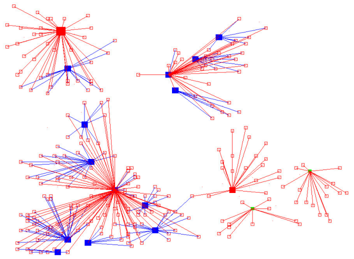
# Switching planning

## *Boundaries problem*

*grid model*





*graph model*

# Switching planning

## *Boundaries problem*

Boundary optimization is finding service/exchange area boundaries in such a way that total network costs is minimized

The cost of connecting one subscriber at location *(x,y)*, belonging to traffic zone *K*, to an exchange/node *E* at $(X_E, Y_E)$ can thus be expressed as:

$$C(E) = C_j(K,E) + C_b(E) + D_E \cdot C_s(D_E) + C_f$$

It depends of the cost of connecting the subscriber, the average exchange cost per subscriber, the backbone network cost of any subscriber

The decision for the boundary can be made simply by comparison for every grid/node element *(i,j)* – the value *C(E)* is calculated for every exchange /node *E* and the lowest *C(E)* then determines *E*

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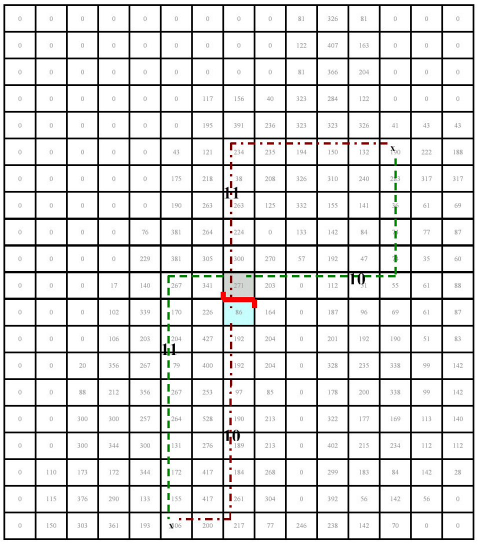
# Switching planning

## Example boundaries

❖ Grid element with 271 subscribers on a distance of 10 steps to upper exch. and 11 lo lower exch. – attach to service area of upper exch.

❖ Grid element with 86 subscribers on a distance of 11 steps to upper exch. and 10 lo lower exch. – attach to service area of lower exch.

❖ Boundary between grid elements 271 and 86



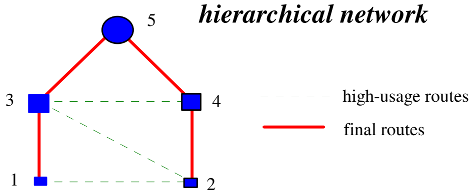
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 81 | 326 | 81 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 122 | 407 | 163 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 81 | 366 | 204 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 117 | 156 | 40 | 323 | 284 | 122 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 195 | 391 | 236 | 323 | 323 | 326 | 41 | 43 | 43 |
| 0 | 0 | 0 | 0 | 0 | 43 | 121 | 234 | 235 | 194 | 150 | 132 | 190 | 222 | 188 |
| 0 | 0 | 0 | 0 | 0 | 175 | 218 | 38 | 208 | 326 | 310 | 240 | 283 | 317 | 317 |
| 0 | 0 | 0 | 0 | 0 | 190 | 263 | 263 | 125 | 332 | 155 | 141 | 36 | 61 | 69 |
| 0 | 0 | 0 | 0 | 76 | 381 | 264 | 224 | 0 | 133 | 142 | 84 | 74 | 77 | 87 |
| 0 | 0 | 0 | 0 | 229 | 381 | 305 | 300 | 270 | 57 | 192 | 47 | 74 | 35 | 60 |
| 0 | 0 | 0 | 17 | 140 | 267 | 341 | 271 | 203 | 0 | 112 | 51 | 55 | 61 | 88 |
| 0 | 0 | 0 | 102 | 339 | 170 | 226 | 86 | 164 | 0 | 187 | 96 | 69 | 61 | 87 |
| 0 | 0 | 0 | 106 | 203 | 204 | 427 | 192 | 204 | 0 | 201 | 192 | 190 | 51 | 83 |
| 0 | 0 | 20 | 356 | 267 | 79 | 400 | 192 | 204 | 0 | 328 | 235 | 338 | 99 | 142 |
| 0 | 0 | 88 | 212 | 356 | 267 | 253 | 97 | 85 | 0 | 178 | 200 | 338 | 99 | 142 |
| 0 | 0 | 300 | 300 | 257 | 264 | 528 | 190 | 213 | 0 | 322 | 177 | 169 | 113 | 140 |
| 0 | 0 | 300 | 344 | 300 | 131 | 276 | 189 | 213 | 0 | 402 | 215 | 234 | 112 | 112 |
| 0 | 110 | 173 | 172 | 344 | 172 | 417 | 184 | 268 | 0 | 299 | 183 | 84 | 142 | 28 |
| 0 | 115 | 376 | 290 | 133 | 155 | 417 | 261 | 304 | 0 | 392 | 56 | 142 | 56 | 0 |
| 0 | 150 | 303 | 361 | 193 | 306 | 200 | 217 | 77 | 246 | 238 | 142 | 70 | 0 | 0 |

# Routing planning

***transiting of traffic***

***Direct routing***

***hierarchical network***

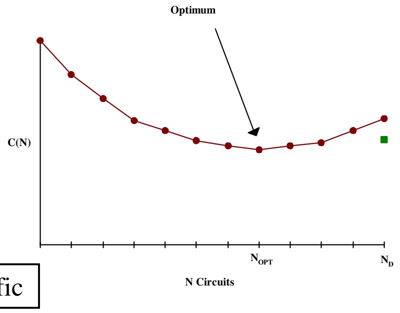


***High-usage route*** – part of the traffic is carried on the direct route and the rest of the traffic overflows through a tandem

***Dual homing (load sharing)***

***alternative routes***

***Primary routes*** with Poisson-type offered traffic



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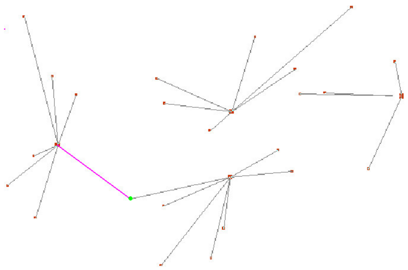
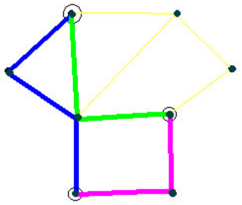
# Routing planning

***Dual homing (load sharing) -*** overflowing traffic is divided with predefined coefficient $\alpha$

***Disjoint Routing Problem of Virtual Private Networks (VPN)*** – demands must be routed through a network so that their paths do not share common nodes or links



***Combinatorial optimization***



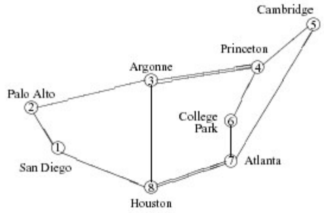
methods for ***non-hierarchical routing*** optimize routing and simultaneously optimally dimension link capacities

***disjoint routing***

# Routing planning

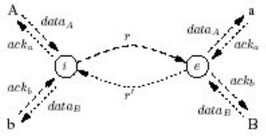
**IP** networks typically use **OSPF** to find ***shortest routes*** between points – result could be that links on shortest routes are congested while other links remain idle

***Traffic engineering*** in **MPLS** means that traffic flows can be controlled in order to balance link loads.
***Quality of service*** control in MPLS means that bandwidth can be reserved for traffic flows.



## LSP design problem

all packets of a flow may follow the same path, the so-called ***label switched path*** LSP



**Packet flow in the forward and reverse directions**

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# Routing planning

## LSP design problem

**OPT1**
A possible optimization criterion when computing LSP designs is the minimization of the maximum arc load

For a given traffic matrix $T$ find a LSP design $P$ such that

$$M(P,T) \rightarrow \min .$$

As a result arcs with high utilization are avoided whenever possible, so that the traffic is more uniformly distributed

**OPT2**
A second optimization principle is to set up the LSP design for the traffic demands along the shortest possible paths like in standard IP routing,

For a given traffic matrix $T$ find a LSP design $P$ such that

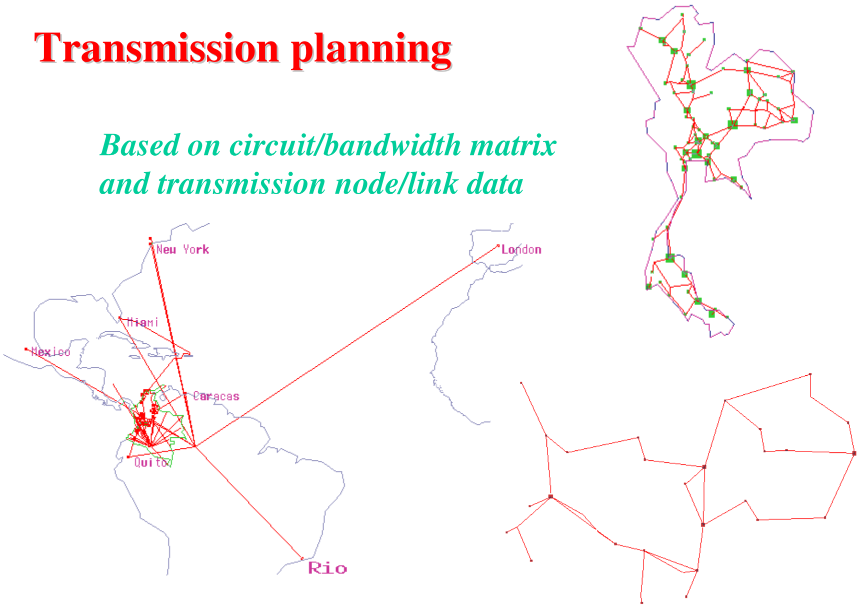
$$\sum_{a \in A} l_{P,T}(a) \rightarrow \min .$$

The paths contained in a solution P are shortest paths in terms of number of arcs used

## heuristic optimization algorithms

# Transmission planning

*Based on circuit/bandwidth matrix and transmission node/link data*



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# Transmission planning

- ➢***Service layer*** defines the point-to-point traffic demands
- ➢***Transport layer*** characterizes one or more network layers that transport the service layer demands; the ***transport layer*** can be any layer starting from the duct layer and going all the way to the smallest signal level that is modelled in the transmission hierarchy, e.g. 64 kbps
- ➢***Optical channel layer*** providing separation of the electrical and optical domains, creating lambda traffic matrices, end-to-end connectivity wholly in terms of optical channels, optical aggregation layer for other service layers

# Transmission planning

*Typical network architectures and technologies that are modeled :*

- optical ring networks
- regional SONET/SDH rings interconnected via an optical mesh backbone
- wavelength routing and assignment
- ultra long haul optical transport systems
- WDM rings
- Ethernet connectivity

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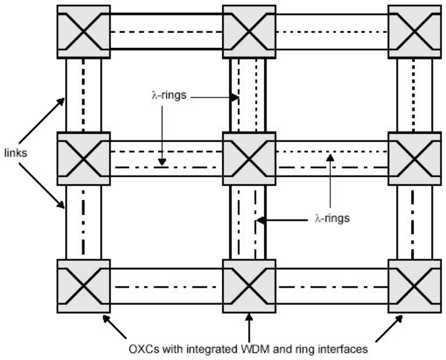
# Transmission planning

## *optical ring networks*

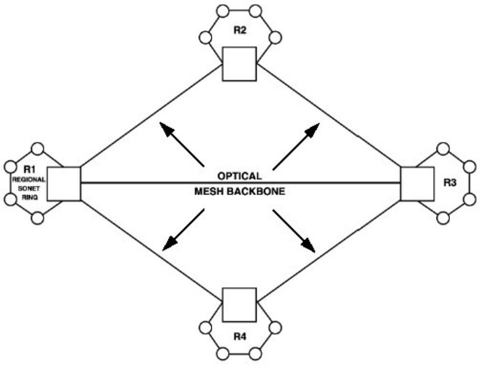
- model integrated passive optical ring switching
- support end-to-end ring network design functions including:
  + creation of candidate rings
  + selection of the most cost-effective rings
  + ring routing
  + ring modularization and
  + costing



- support explicit modeling of WDM systems together with the associated span engineering rules and costs

## Transmission planning

***regional SONET/SDH rings interconnected via an optical mesh backbone***



- model a hybrid ring–mesh network
- allow selection and grouping of nodes and links to define subnetworks
- support dentification of gateway nodes and automatic demand partitioning into regional and backbone segments
- optimize, through optical mesh backbone network modeling, ULH and traditional WDM systems along with Wavelength Routing and Assignment

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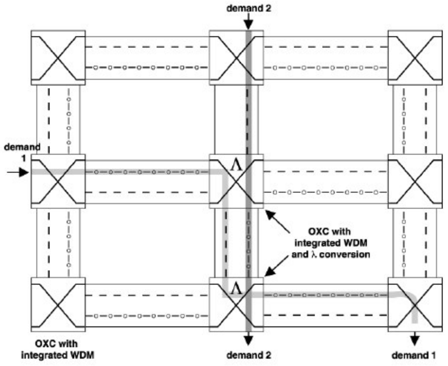
## Transmission planning

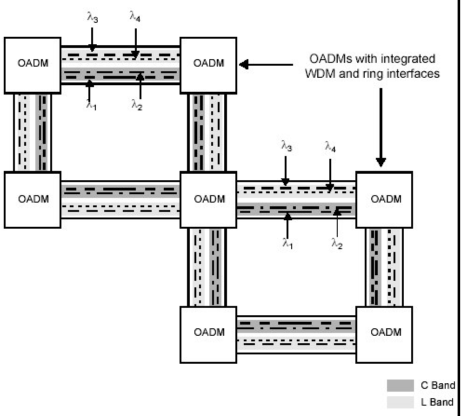
***wavelength routing and assignment***



- determine optimal routing and wavelength assignment to maximize utilization while minimizing system capacity wastage due to wavelength blocking
- support different wavelength conversion options
- support 1+1 path protection and shared capacity mesh restoration
- support a distributed (or provisioning) mode and a centralized (or planning) mode

# Transmission planning

## *WDM rings*



- ➢ model a highly diversified set of WDM ring technology options
- ➢ specify bandwidth management options, as maximum ring-system capacity, bandwidth, band add/drop and λ add/drop granularity
- ➢ supports protection options, as dedicated protection, shared protection
- ➢ support span engineering rules to allow to specify WDM system constraints

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# Transmission planning

## *Ethernet connectivity*

Ethernet connections can be transported via SONET/SDH or optical networks by multiplexing them on to the appropriate layer in the SONET/SDH/optical hierarchy.

- ➢ explicitly model standard Ethernet connections (at 10Mbps, 100Mbps, 1Gbps and 10Gbps)
- ➢ model the statistical multiplexing gain allowed by Ethernet by specifying the desired gain factor for each Ethernet layer

# Transmission planning

## *Modeling of Various Protection Schemes*

- diverse routing
- traffic sharing based on multiple-path routing
- multiplex section protection
- path protection
- ring-based protection schemes

❑ In 1+1 optical path protection, a dedicated protecting route protects the working path and carries the sum of all traffic it needs to protect - the most expensive scheme to implement.

❑ A shared mesh protection includes more than one working path for the same demand pair and the working paths themselves are usually utilized to protect each other

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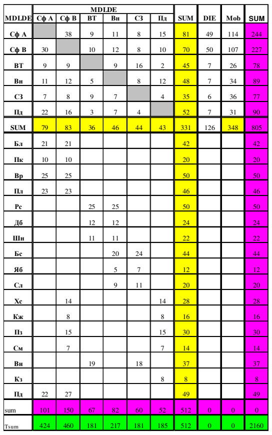
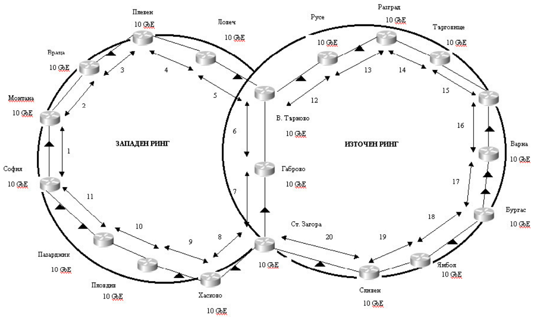
# Transmission planning



| | MDLDE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **MDLDE** | **Сф A** | **Сф B** | **BT** | **Вн** | **СЗ** | **Пд** | **SUM** | **DIE** | **Mob** | **SUM** |
| **Сф A** | | 38 | 9 | 11 | 8 | 15 | 81 | 49 | 114 | 244 |
| **Сф B** | 30 | | 10 | 12 | 8 | 10 | 70 | 50 | 107 | 227 |
| **BT** | 9 | 9 | | 9 | 16 | 2 | 45 | 7 | 26 | 78 |
| **Вн** | 11 | 12 | 5 | | 8 | 12 | 48 | 7 | 34 | 89 |
| **СЗ** | 7 | 8 | 9 | 7 | | 4 | 35 | 6 | 36 | 77 |
| **Пд** | 22 | 16 | 3 | 7 | 4 | | 52 | 7 | 31 | 90 |
| **SUM** | 79 | 83 | 36 | 46 | 44 | 43 | 331 | 126 | 348 | 805 |
| **Бл** | 21 | 21 | | | | | 42 | | | 42 |
| **Пк** | 10 | 10 | | | | | 20 | | | 20 |
| **Вр** | 25 | 25 | | | | | 50 | | | 50 |
| **Пл** | 23 | 23 | | | | | 46 | | | 46 |
| **Рс** | | | 25 | 25 | | | 50 | | | 50 |
| **Дб** | | | 12 | 12 | | | 24 | | | 24 |
| **Шн** | | | 11 | 11 | | | 22 | | | 22 |
| **Бс** | | | | 20 | 24 | | 44 | | | 44 |
| **Яб** | | | | 5 | 7 | | 12 | | | 12 |
| **Сл** | | | | 9 | 11 | | 20 | | | 20 |
| **Хс** | | 14 | | | | 14 | 28 | | | 28 |
| **Кж** | | 8 | | | | 8 | 16 | | | 16 |
| **Пз** | | 15 | | | | 15 | 30 | | | 30 |
| **См** | | 7 | | | | 7 | 14 | | | 14 |
| **Вн** | | | 19 | | 18 | | 37 | | | 37 |
| **Кз** | | | | | | 8 | 8 | | | 8 |
| **Пд** | 22 | 27 | | | | | 49 | | | 49 |
| sum | 101 | 150 | 67 | 82 | 60 | 52 | 512 | 0 | 0 | 0 |
| Tsum | 424 | 460 | 181 | 217 | 181 | 185 | 512 | 0 | 0 | 2160 |

*Optimization of transmission nodes and link*



*Based on circuit/bandwidth matrix*

# Transmission planning

## *Optimization of ring/mesh protected transport networks*

Two types of nodes could be distinguished in the network :

- traffic access nodes –
  represent the abstract traffic entry points (e.g. local exchange)
- transmission nodes –
  represent the actual network nodes (e.g. ADMs or DXCs)

Requirements to the topology for protection -

- ring or mesh topologies, multi-ring structures, hybrid ring-mesh topologies
- different protection schemes: path protection, link protection, path diversity

In the optimization methods are solved combinatorial problems usually with heuristic algorithms and based on the shortest path approach

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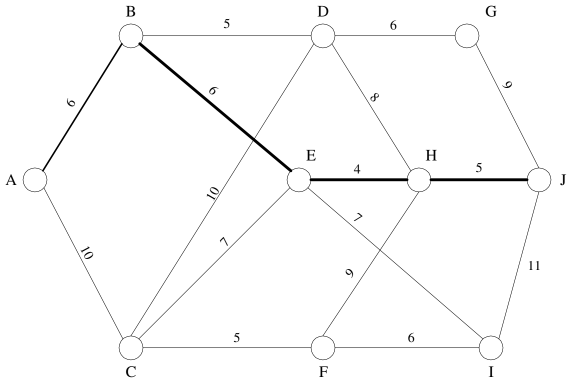
# Transmission planning

## Shortest path problem

- ❖ to determine the "shortest path" between any two nodes as minimum distance
- ❖ to determine the minimum cost path between two nodes

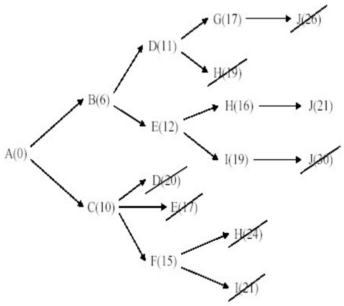


# Transmission planning

- examine the adjacent nodes and label each one with its distance from the source node
- examine nodes adjacent to those already labeled; when a node has links to two or more labeled nodes, its distance from each node is added to the label of that node; the smallest sum is chosen and used as the label for the new node
- repeat above until either the destination node is reached (if the shortest route to only one node is required) or until all nodes have been labeled (if the shortest routes to all nodes are required)

## *Shortest path problem* –

## *algorithm of Dantzig*



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# Transmission planning

## *Shortest path problem*

✓ shortest path from *A* to *J*

✓ all partial paths contained in the path from *A* to *J-(ABEHJ)*: *(AB), (ABE), (ABEH), (BE), (BEH), (BEHJ), (EH), (EHJ), (HJ)* are optimal paths, e.g. from *B* to *J*, the optimal path is *(BEHJ)*

✓ every optimal path consists of partially optimal paths