

## **ANNEX B:**

### **OVERVIEW OF THE FORMULAE APPLIED FOR THE DIMENSIONING OF THE NETWORK**

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## 1. INTRODUCTION

The present document provides detailed information on the determination of the investment in the switching and transmission equipment, as well as the transmission links. Separate paragraphs deal with the investment in the accommodation costs in each of the switching and transmission nodes. Note that the objective of the formulae presented below is to determine the investment cost in the *core PSTN-ISDN* network. This implies that e.g. the non-traffic related parts of a RU or BU are not taken into account and that the possibility of sharing network components between different services (e.g. PSTN-ISDN and data services) is considered.

## 2. SWITCHING EQUIPMENT

### 2.1 Remote Units

The following paragraphs document the formulae used to calculate investments in switching equipment in the remote units. Investments are always given on a per node basis.

#### 2.1.1 Line cards

**Investment in line cards in a specific RU =**

$$[(\#PSTN * Inv\_pstn + \#ISDNBA * Inv\_ISDNBA + \#ISDNPRA * Inv\_ISDNPRA) / U_c] * perc\_core$$

#PSTN: Number of PSTN subscribers in a specific node

#ISDNBA: Number of ISDN-BA subscribers in a specific node

#ISDNPRA: Number of ISDN-PRA subscribers in a specific node

Inv\_pstn: Investment cost in PSTN line cards for 1 PSTN user

Inv\_ISDNBA: Investment cost in ISDN-BA line cards for 1 ISDN-BA user

Inv\_ISDNPRA: Investment cost in ISDN-PRA line cards for 1 ISDN-PRA user

U<sub>c</sub>: Utilisation factor (in %) for the line cards

Perc\_core: % of the line card attributable to the core network

**Remark:** In the network modelled, no ISDN-PRA lines are installed in the Remote Units. Nevertheless, the formulae applied in the Bottom-Up model allow the possibility of taking PRAs into account in the RUs.

#### 2.1.2 Concentrators

**Investment in concentrators in a specific RU = number of concentrators (E1) \* investment cost per concentrator (E1) =**

$$\text{Roundup}((\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}) / (U_c * U_{pc} * G_c)) * Inv\_conc * G_c$$

Roundup: Rounds the result to the nearest integer

#PSTN: Number of PSTN subscribers in a specific node

U<sub>c</sub>: Utilisation factor (in %) for the concentrator

U<sub>pc</sub>: Number of line equivalents per E1

#ISDNBA: Number of ISDN-BA subscribers in a specific node  
 #ISDNPRA: Number of ISDN-PRA subscribers in a specific node  
 Inv\_conc: Investment cost for a concentrator (per E1)  
 G<sub>c</sub>: Granularity of concentrator (e.g. multiple of 4 E1s required)

**Remark:** In the network modelled, no ISDN-PRA lines are installed in the Remote Units. Nevertheless, the formulae applied in the Bottom-Up model allow the possibility of taking PRAs into account in the RUs.

### 2.1.3 Concentrator Ports

Please note that the ports mentioned below refer to the ports on the concentrator and not the ports on the switching matrix.

$$\text{Investment in concentrator-related ports in a specific RU} = \text{Roundup}(((\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}) / (U_c * U_{pc} * G_c)) * \text{Inv\_portc\_RU} * G_c)$$

Roundup: Rounds the result to the nearest integer  
 #PSTN: Number of PSTN subscribers in a specific node  
 #ISDNBA: Number of ISDN-BA subscribers in a specific node  
 #ISDNPRA: Number of ISDN-PRA subscribers in a specific node  
 U<sub>c</sub>: Utilisation factor (in %) for the concentrator  
 U<sub>pc</sub>: Number of line equivalents per E1  
 Inv\_portc\_RU: Investment cost for a E1 port  
 G<sub>c</sub>: Granularity of concentrator (e.g. multiple of 4 E1s required)

**Remark:** Please note that the number of ports equals the number of concentrators when utilisation factors for ports and concentrators are equal, which should logically be the case. Moreover, the granularity of the concentrator is taken into account also for the ports, since symmetry between the number of E1 ports and concentrators at the E1 level should be adhered.

### 2.1.4 Accommodation

The accommodation costs of all nodes in the network modelled consist of an annualised CAPEX cost per m<sup>2</sup> and of a fixed yearly cost (OPEX) per node. Since all switching and transmission nodes are collocated, the fixed yearly cost per node will be taken into account in the formulae for determining the yearly accommodation cost of the switching nodes.

$$\text{Yearly accommodation cost in a specific RU} = \text{Acc\_fix\_RU} + [\text{Roundup}(((\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}) / (U_c * G_{RU\_acc})))] * \text{Footprint\_RU}_{G\_acc} * \text{Acc\_var\_RU} * \text{Corr}_{lc\_RU} * (1 + \text{Corr}_{oh\_RU})$$

Roundup: Rounds the result to the nearest integer  
 #PSTN: Number of PSTN subscribers in a specific node  
 #ISDNBA: Number of ISDN-BA subscribers in a specific node  
 #ISDNPRA: Number of ISDN-PRA subscribers in a specific node  
 Acc<sub>ex</sub>RU: Fixed yearly OPEX (fixed per node)  
 U<sub>c</sub>: Utilisation factor (in %) for the concentrator  
 U<sub>pc</sub>: Number of line equivalents per E1

Footprint<sub>RU</sub> <sub>G<sub>acc</sub></sub>: Footprint of RU equipment for number of equivalent lines equal to granularity

Supprimé : ¶

Acc<sub>var</sub>RU: Variable annualised CAPEX (variable per m<sup>2</sup>)  
 Cor<sub>ic</sub>RU: Correction factor for the elimination of the footprint requirements for the line cards  
 Cor<sub>ob</sub>RU: Correction factor for the addition of the overhead surface (for extra corridors etc)  
 G<sub>RU</sub>acc: Granularity of RU equipment (in a number of equivalent lines)

## 2.2 Base Units

The following paragraphs document the formulae used to calculate switching investment in the base units. Investments are always given on a per node basis.

### 2.2.1 Line Cards

**Investment in line cards in a specific BU =**

$$[(\#PSTN * Inv\_pstn + \#ISDNBA * Inv\_ISDNBA + \#ISDNPRA * Inv\_ISDNPRA) / U_c] * perc\_core$$

#PSTN: Number of PSTN subscribers in a specific node  
 #ISDNBA: Number of ISDN-BA subscribers in a specific node  
 #ISDNPRA: Number of ISDN-PRA subscribers in a specific node  
 Inv\_pstn: Investment cost in PSTN line cards for 1 PSTN user

Inv\_ISDNBA: Investment cost in ISDN-BA line cards for 1 ISDN-BA user  
 Inv\_ISDNPRA: Investment cost in ISDN-PRA line cards for 1 ISDN-PRA user  
 U<sub>c</sub>: Utilisation factor (in %) for the line cards  
 Perc\_core: Percentage of the linecard attributable to the core network

### 2.2.2 Concentrators

**Investment in concentrators in a specific BU = number of concentrators (E1) \* investment cost per concentrator (E1) =**

$$\text{Roundup}((\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}) / (U_c * U_{pc} * G_c)) * Inv\_conc * G_c$$

#PSTN: Number of PSTN subscribers in a specific node  
 #ISDNBA: Number of ISDN-BA subscribers in a specific node  
 #ISDNPRA: Number of ISDN-PRA subscribers in a specific node

U<sub>c</sub>: Utilisation factor (in %) for the concentrator  
 U<sub>pc</sub>: Number of line equivalents per E1  
 Inv\_conc: Investment cost for a concentrator (per E1)  
 G<sub>c</sub>: Granularity of concentrator (e.g. multiple of 4 E1s required)

### 2.2.3 Investment in concentrator ports

The formula below solely refers to ports at the concentrator side for users directly connected to the base unit. The concentrator ports from remote units that have the BU as host have already been taken into account in the dimensioning formulae for the RUs.

**Investment in concentrator-related ports in a specific BU =**

$$\text{Roundup}(((\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}) / (U_c * U_{pc} * G_c)) * \text{Inv\_portc\_BU} * G_c)$$

Roundup: Rounds the result to the nearest integer

U<sub>c</sub>: Utilisation factor (in %) for the concentrator

#PSTN: Number of PSTN subscribers in a specific node

U<sub>pc</sub>: Number of line equivalents per E1

#ISDNBA: Number of ISDN-BA subscribers in a specific node

Inv\_portc\_BU: Investment cost for a E1 port

# ISDNPRA: Number of ISDN-PRA subscribers in a specific node

G<sub>c</sub>: Granularity of concentrator (e.g. multiple of 4 E1s required)

### 2.2.4 Investment in ports on the switching matrix in a BU

The number of ports on the switching matrix is composed of ports facing the concentrators in the BU or RUs and ports for the traffic w.r.t. the network that has to be switched in the BU. The number of ports facing the concentrators equals the number of ports on the concentrator itself, while the ports for the switching matrix are computed by applying the *Erlang B* formula<sup>1</sup> to the BHE of the BU, taking into account the number of directions *D*:

**Investment in matrix ports in a specific BU = Investment in ports facing the concentrators in BU + investment in ports for the switching matrix + investment in ports facing the RU concentrators =**

$$\text{Roundup}^2((\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc}) / (U_c * U_{pc} * G_c)) * \text{Inv\_portm} * G_c + \text{Roundup}(D * \text{ErlangB}(BHE/D, P_b) / (U_m * C_i)) * \text{Inv\_portm} + \text{number of concentrator ports RU} * \text{Inv\_portm}$$

Roundup: Rounds the result to the nearest integer

Inv\_port: Investment in ports (per E1)

ErlangB(x,y): ErlangB function

U<sub>c</sub>: Utilisation factor for the ports (%) on the concentrator

BHE: BHE per node

U<sub>pc</sub>: Number of line equivalents per E1

C<sub>i</sub>: Number of 64 Kbps channels per E1

Inv\_portm: Investment in port (per E1) on the switching matrix

D: Number of directions in which BHE are measured

G<sub>c</sub>: Granularity of concentrator (e.g. multiple of 4 E1s required)

P<sub>b</sub>: Blocking ratio

U<sub>m</sub>: Utilisation factor for the ports (%) on the switching matrix

<sup>1</sup> In the following formula, '*ErlangB(X, P<sub>b</sub>)*' indicates the required capacity, determined with the Erlang B-formula, for X Busy Hour Erlang and a blocking chance equal to P<sub>b</sub>%.

## 2.2.5 Switching Matrix

**Investment in switching matrix in a specific BU =**

**Roundup  $\left( \frac{(\#PSTN + \#ISDNBA * 2 + \#ISDNPRA * U_{pc})}{(U_c * U_{pc} * G_c)} \right) * Inv\_switch * G_c$**

**+ Roundup  $(D * ErlangB(BHE/D, P_b) / (U_m * C_i)) * Inv\_switch$**

**+ Number of concentrator ports RU \* Inv\_switch**

Roundup: Rounds the result to the nearest integer

ErlangB(x,y): ErlangB function

BHE: BHE per node

C<sub>i</sub>: Number of 64 Kbps channels per E1

D: Number of directions in which BHE are measured

P<sub>b</sub>: Blocking ratio

Inv\_switch: Investment in switching matrix (per E1)

U<sub>m</sub>: Utilisation factor for the switching matrix (%)

G<sub>c</sub>: Granularity of concentrator (e.g. multiple of 4 E1s required)

## 2.2.6 Processor

**Investment in processor = BHE / ((C<sub>bhca</sub>) \* U<sub>p</sub>) \* Inv\_processor**

BHE: BHE per node

C<sub>bhca</sub>: Conversion from BHE to BHCA (0,04)

U<sub>p</sub>: Utilisation factor for the processor (%)

Inv\_processor: Investment cost in processor capacity per BHCA

***Remark:*** The factor U<sub>p</sub> should be determined very considerably since the BHE figures do not take into account the processing power required for the processing of BU-RU traffic, since this is not measured by the BHE taken into account.

## 2.2.7 Accommodation

**Yearly accommodation cost in a specific BU =**

$$\text{Acc}_{\text{fix BU}} + [(\text{Roundup}(\# \text{PSTN} + \# \text{ISDNBA} * 2 + \# \text{ISDNPRA} * U_{\text{pc}}) / (U_{\text{c}} * G_{\text{BU\_acc}}))] * \text{Footprint}_{\text{BU}} * G_{\text{acc}} * \text{Acc}_{\text{var BU}} * \text{Corr}_{\text{lc BU}} * (1 + \text{Corr}_{\text{oh BU}})$$

Roundup: Rounds up the result to the nearest integer

#PSTN: Number of PSTN subscribers in a specific node

#ISDNBA: Number of ISDN-BA subscribers in a specific node

# ISDNPRA: Number of ISDN-PRA subscribers in a specific node

U<sub>c</sub>: Utilisation factor (in %) for the concentrator

U<sub>pc</sub>: Number of line equivalents per E1

G<sub>BU\\_acc</sub>: Granularity of BU equipment (in a number of equivalent lines)

Acc<sub>var BU</sub>: Variable annualised CAPEX (variable per m<sup>2</sup>)

Corr<sub>lc BU</sub>: Correction factor for the elimination of the footprint requirements for the line cards

Corr<sub>oh BU</sub>: Correction factor for the addition of the overhead surface (for corridors etc)

Footprint<sub>BU G\\_acc</sub>: Footprint of BU equipment for number of equivalent equal to granularity

## 2.3 Covering Area Exchanges

The following paragraphs document the formulae used to calculate switching investment in the Covering Area Exchanges (CAE). Investments are always given on a per node basis.

### 2.3.1 Ports on the switching matrix of a CAE

**Investment in ports on the switching matrix in a specific CAE =**

$$\text{Roundup}(D * \text{ErlangB}(BHE/D, P_b) / (U_p * C_i)) * \text{Inv}_{\text{port}}$$

Roundup: Rounds the result to the nearest integer

ErlangB(x,y): ErlangB function

BHE: BHE per node

C<sub>i</sub>: Number of 64 Kbps channels per E1

P<sub>b</sub>: Blocking ratio

Inv<sub>port</sub>: Investment in ports (per E1) on matrix

U<sub>p</sub>: Utilisation factor for the ports (%)

D: Number of directions in which BHE are measured

### 2.3.2 Switching Matrix

**Investment in switching matrix in a specific CAE =**

$$\text{Roundup}(D * \text{ErlangB}(BHE/D, P_b) / (U_m * C_i)) * \text{Inv}_{\text{switch}}$$

Roundup: Rounds the result to the nearest integer

ErlangB(x,y): ErlangB function

P<sub>b</sub>: Blocking ratio

Inv<sub>switch</sub>: Investment in switching matrix (per E1)

BHE: BHE per node

U<sub>m</sub>: Utilisation factor for the switching matrix (%)

C<sub>i</sub>: Number of 64 Kbps channels per E1

D: Number of directions in which BHE are measured

### 2.3.3 Processor

$$\text{Investment in processor} = \text{BHE} / ((C_{\text{bhca}}) * U_p) * \text{Inv\_processor}$$

BHE: BHE per node

U<sub>p</sub>: Utilisation factor for the processor (%)

C<sub>bhca</sub>: Conversion from BHE to BHCA (0,04)

Inv\_processor: Investment cost in processor capacity per BHCA

**Remark:** The factor U<sub>p</sub> should take into account a normal utilisation rate, as opposed to the BU processors, since all BHE that pass the CAE are effectively measured.

### 2.3.4 Accommodation

**Yearly accommodation cost in a specific CAE=**

$$\text{Acc}_{\text{fix\_CAE}} + (\text{Roundup} ((D * \text{ErlangB} (\text{BHE}/D, P_b) / (U_m \times C_i \times G_{\text{CAE\_acc}})) * \text{Footprint\_CAE}_{G\_Acc} * \text{Acc}_{\text{var\_CAE}} * (1 + \text{Corr}_{\text{oh\_CAE}}))$$

Acc<sub>fix\_CAE</sub>: Fixed yearly OPEX (fixed per node)

P<sub>b</sub>: Blocking ratio

Acc<sub>var\_CAE</sub>: Variable annualised CAPEX (variable per m<sup>2</sup>)

G<sub>CAE\_acc</sub>: Granularity of CAE equipment (in a number of E1s)

Roundup: Rounds up the result to the nearest integer

Inv\_switch: Investment in switching matrix (per E1)

Footprint\_CAE<sub>G\_acc</sub>: Footprint of CAE equipment for number of E1s equal to granularity

U<sub>m</sub>: Utilisation factor for the switching matrix (%)

D: Number of directions in which BHE are measured

Corr<sub>oh\_CAE</sub>: Correction factor for the addition of the overhead surface (for corridors etc)

ErlangB(x,y): ErlangB function

C<sub>i</sub>: Number of 64 Kbps channels per E1

BHE: BHE per node

### 3. TRANSMISSION EQUIPMENT

#### 3.1 LDC

The following paragraphs document the formulae used to calculate the investment in transmission equipment in the Local Distribution Centers (LDC). Investment is always given on a per node basis.

##### 3.1.1 E1 tributary cards in T-MUX

The formula below takes into account the fact that a minimum number of ports on the tributary cards is always required (e.g. 32 ports on a tributary card) as costs could be significantly underestimated, especially for smaller nodes, when this is not done.

$$\text{Investment in E1 tributary cards} = \text{Roundup}(E1_c / E1_{trib}) * \text{Inv\_trib}$$

Roundup: Rounds the result to the nearest integer

$E1_c$ : Number of E1's originating from concentrators

$E1_{trib}$ : Number of E1 ports on 1 tributary card

$\text{Inv\_trib}$ : Investment cost for 1 tributary card (contains  $E1_{trib}$  ports)

**Remark:** No utilisation factor has to be applied here since it is already taken into account when calculating the number of concentrators needed.

##### 3.1.2 T-MUX equipment

The formula below takes into account the granularity of the T-MUX. This means that only a specific maximum number of T-MUX tributary cards can be used in one T-MUX. If this number is reached, a second T-MUX should be installed.

$$\text{Investment in T-MUX equipment} = \text{Roundup}[\text{Roundup}(E1_c / E1_{trib}) / \text{TMUX}_{trib}] * \text{Inv\_Tmux}$$

$E1_c$ : Number of E1's originating from concentrators

$E1_{trib}$ : Number of E1 ports on 1 tributary card

$\text{TMUX}_{trib}$ : Maximum capacity of TMUX expressed in tributary cards

$\text{Inv\_Tmux}$ : Investment cost for 1 TMUX (Including 0 STM1 interface)

### 3.1.3 STM-1 line cards in T-MUX

Once the number of T-MUX equipment required in the LDC node is known, the number of STM-1 line cards that provide the interface towards the host node located on the ring, has to be determined. Please note that only one STM-1 line card per 63 E1s is required since a physical point-to-point connection is configured.

$$\text{Investment in STM-1 line cards in T-MUX} = \text{Roundup}(E1_c/63) * \text{Inv\_stm1}$$

Roundup: Rounds the result to the nearest integer

Inv\_stm1: Investment cost for 1 STM1 line card

E1<sub>c</sub>: Number of E1's originating from concentrators

### 3.1.4 STM-1 tributary cards at the LTC side

The investment in STM-1 tributary cards at the LTC side is taken into account in the investment categories for the LDC, since there is no exact information on the combination LDC-LTC, which makes it impossible to model this cost at the LTC side.

$$\text{Investment in STM-1 tributary cards in LTC} = \text{Roundup}(E1_c/63) * \text{Inv\_admstm1}$$

E1<sub>c</sub>: Number of E1's originating from concentrators

Inv\_admstm1: Investment cost for 1 STM1 tributary card in ADM of LTC

### 3.1.5 Accommodation

The accommodation costs for the transmission equipment consists solely of a variable annualized CAPEX cost per m<sup>2</sup>. This cost has to be added to the accommodation costs of the switching equipment that is collocated in the same network node.

**Yearly accommodation cost for the equipment in a LDC =**

$$(\# \text{T-MUX}_{\text{LDC}} * \text{Footprint}_{\text{T-MUX}} * \text{Acc}_{\text{var LDC}} * (1 + \text{Corr}_{\text{oh LDC}}))$$

Acc<sub>var LDC</sub>: Variable annualised CAPEX (variable per m<sup>2</sup>)

Footprint<sub>T-MUX</sub>: Footprint of T -MUX equipment

#T-MUX<sub>LDC</sub>: Number of T-MUX in the LDC (cf. paragraph 3.1.2)

Corr<sub>oh LDC</sub>: Correction factor for the addition of the overhead surface (for corridors etc)

### 3.2 LTC

Two situations are modelled in a LTC. Under the first situation, the LTC is co-located with a remote unit. In the second situation, the LTC is co-located with a base unit.

We assume that in the first situation, LTC-RU, no T-MUX equipment is needed. The E1 ports that originate from the switching processor are directly connected to the ports on the E1 tributary cards on the ADM. Simulations run in the bottom-up model show that in reality this should not pose any technical limitations.

In the LTC-BU, connection from the switch to the ADM is always provided through additional T-MUX capacity. This way, no port constraints will occur on the ADM equipment.

In the following paragraphs, we will first describe the formulae used for the LTC-RU. Subsequently, the LTC-BU formulae will be commented.

#### 3.2.1 LTC -RU Investment in E1 tributary cards on the ADM

Given the fact that the current version of the Bottom-Up model only models the PSTN/ISDN network as an increment, no multiplexing equipment is needed between the ADM and the concentrators. Therefore, E1 tributary cards should be installed directly in the ADM.

$$\text{Investment in E1 tributary cards} = \text{Roundup}(E1_c / E1_{trib}) * \text{Inv}_{trib\_adm}$$

$E1_c$ : Number of E1's originating from concentrators

$\text{Inv}_{trib\_adm}$ : Investment cost for 1 tributary card on the ADM  
(contains  $E1_{trib}$  ports)

$E1_{trib}$ : Number of E1 ports on 1 tributary card

#### 3.2.2 LTC -RU Investment in ADM equipment

The appropriate type of ADM equipment is determined by the type of ring on which the ADM is situated. Possible options are STM-1 ADM, STM-4 ADM, STM-16 ADM and STM-64 ADM. The investment in ADM includes the line cards to the ring but excludes the tributary cards towards the switch. Note that the actually installed capacity of the ring is taken into account. Only in the case where 2 times an STM-1 ring was installed, the model increases this capacity to the STM-4 level.

$$\begin{aligned} \text{Investment in ADM equipment (incl. Line cards)} = \\ & \text{Inv\_adm1 for STM-1 ring} * \text{perc\_switch} \\ & \text{Inv\_adm4 for STM-4 ring} * \text{perc\_switch} \\ & \text{Inv\_adm16 for STM-16 ring} * \text{perc\_switch} \\ & \text{Inv\_adm64 for STM-64 ring} * \text{perc\_switch} \end{aligned}$$

Perc\_switch: Percentage of the ring used for switched services

Inv\_admx: Investment cost for ADM\_x equipment, including line cards towards ring but excluding tributary cards

When a local switch (BU) is located in the LTC, the amount of E1s originating from the switching matrix tends to increase rapidly. This gives rise to the necessity of installing multiplexing equipment (T-MUX) between the switch and the Add Drop Multiplexer in order to groom E1 traffic towards the ADM, even when only PSTN/ISDN traffic is considered. The formulae below illustrate how the necessary amount of equipment is modeled.

### 3.2.3 LTC -BU Investment in E1 tributary cards on the T-MUX

$$\text{Investment in E1 tributary cards} = \text{Roundup}[(\text{E1}_{\text{BHE}} + \text{E1}_{\text{RU}} - \text{E1}_{\text{Rucol}}) / \text{E1}_{\text{trib}}] * \text{Inv}_{\text{tribtmux}}$$

E1<sub>BHE</sub>: Number of E1's based on BHE data

E1<sub>trib</sub>: Number of E1 ports on 1 tributary card

E1<sub>RU</sub>: Number of E1's coming from RU's

Inv<sub>tribtmux</sub>: Investment cost for 1 tributary card on the TMUX (contains E1<sub>trib</sub> ports)

E1<sub>Rucol</sub>: Number of E1's coming from RU's colocated with BU

**Remark:** The above formula is the result of the fact that some RU's are located in the same building as a BU. This is not efficient and the RU lines should be considered as being BU customers. Because of this, the number of ports from these customers should be subtracted since they do not pass through the TMUX equipment or the ADM. Moreover, for some (very few) cases, the RU colocated with the BU has a different host BU. The result of this is that when the RU-ports are subtracted from the total ports of the BU, the number of ports can become negative. In this case, a minimum of 1 port is taken into account. This overestimates the investment slightly since the ports are again taken into account in the actual base unit that hosts these RUs.

### 3.2.4 LTC -BU Fixed investment in a T-MUX

The investment in fixed T-MUX equipment located in the LTC is determined by the formula below. Note that the capacity of the T-MUX is limited by a maximum number of tributary cards that can be inserted in the T-MUX. Once this capacity is reached, an additional T-MUX will be installed.

$$\text{Investment in T-MUX equipment} = \text{Roundup}[\text{Roundup}[(\text{E1}_{\text{BHE}} + \text{E1}_{\text{RU}} - \text{E1}_{\text{Rucol}}) / \text{E1}_{\text{trib}}] / \text{TMUX}_{\text{trib}}] * \text{Inv}_{\text{Tmux}}$$

E1<sub>trib</sub>: Number of E1 ports on 1 tributary card

TMUX<sub>trib</sub>: Maximum Capacity of TMUX expressed in tributary cards

E1<sub>BHE</sub>: Number of E1's based on BHE data

Inv\_Tmux: Investment cost for 1 TMUX (Including 0 STM1 interface)

E1<sub>RU</sub>: Number of E1's coming from RU's

E1<sub>RUcol</sub>: Number of E1's coming from RU's colocated with BU

### 3.2.5 LTC -BU STM-1 line cards in a T-MUX

The formula above identified the investment in T-MUX equipment in the LTC-BU. However, no cost for the STM-1 line cards in the T-MUX have been taken into account so far. This is done by the formula below.

$$\text{Investment in STM-1 line cards in T-MUX} = \text{Roundup}[(E1_{BHE} + E1_{RU} - E1_{RUcol}) / 63] * \text{Inv\_stm1}$$

E1<sub>BHE</sub>: Number of E1's based on BHE data

Inv\_stm1: Investment cost for 1 STM1 line card in TMUX

E1<sub>RU</sub>: Number of E1's coming from RU's

E1<sub>RUcol</sub>: Number of E1's coming from RU's colocated with BU

### 3.2.6 LTC -BU Investment in ADM equipment

The appropriate type of ADM equipment is determined by the type of ring on which the ADM is situated. Possible options are STM-1 ADM, STM-4 ADM, STM-16 ADM and STM-64 ADM. The investment in ADM includes the line cards to the ring but excludes the tributary cards towards the switch. Note that as it was the case with the ADM dimensioning of the LTC-RU, rings where 2 times a STM-1 capacity is provided in reality, are upgraded to 1 time STM-4.

$$\begin{aligned} \text{Investment in ADM equipment (incl. Line cards)} = \\ & \text{Inv\_adm1 for STM-1 ring} * \text{perc\_switch} \\ & \text{Inv\_adm4 for STM-4 ring} * \text{perc\_switch} \\ & \text{Inv\_adm16 for STM-16 ring} * \text{perc\_switch} \\ & \text{Inv\_adm64 for STM-64 ring} * \text{perc\_switch} \end{aligned}$$

Perc\_switch: Percentage of the ring used for switched services

Inv\_adm<sub>x</sub>: Investment cost for ADM<sub>x</sub> equipment, including line cards towards ring but excluding tributary cards

### 3.2.7 LTC-BU Investment in STM-1 tributary cards in ADM

The STM-1 tributary cards are used to provide ports in the ADM to the T-MUX at the STM-1 level. The model does not take into account higher connection rates. Moreover we assume that no capacity problems will occur at the ADM port level. Finally the model assumes 1 STM-1 port per tributary card. Simulations run in the model also show that when only the PSTN/ISDN increment is considered, the number of STM-1 cards required is fairly limited so that no port limitations are to be expected. Therefore, no capacity restraints at the STM-1 tributary card level are taken into account.

$$\text{Investment in STM-1 tributary cards for ADM} = \text{Roundup}[(E1_{\text{BHE}} + E1_{\text{RU}} - E1_{\text{RUcol}})/63] * \text{Inv}_{\text{stm1adm}}$$

$E1_{\text{BHE}}$ : Number of E1's based on BHE data

$\text{Inv}_{\text{stm1adm}}$ : Investment cost for 1 STM1 tributary card in ADM

$E1_{\text{RU}}$ : Number of E1's coming from RU's

$E1_{\text{RUcol}}$ : Number of E1's coming from RU's colocated with BU

### 3.2.8 Accommodation cost

**Yearly accommodation cost for the equipment in a LTC-RU =**

$$(\# \text{ADM}_{\text{LTC-RU}} * \text{Footprint\_ADM} * \text{perc\_switch} * \text{Acc}_{\text{varLTC-RU}} * (1 + \text{Corr}_{\text{oh\_LTC-RU}}))$$

$\text{Acc}_{\text{var\_LDCRU}}$ : Variable annualised CAPEX (variable per m<sup>2</sup>)

$\#\text{ADM}_{\text{LTC-RU}}$ : Number of ADM in the LTC-RU (cf. paragraph 3.2.2)

$\text{Footprint\_ADM}$ : Footprint of ADM equipment

$\text{Perc\_switch}$ : Percentage of the ADM used for switched services

$\text{Corr}_{\text{oh\_LTC-RU}}$ : Correction factor for the addition of the overhead surface (for corridors etc)

**Yearly accommodation cost for the equipment in a LTC-BU =**

$$[(\# \text{T-MUX}_{\text{LTC-BU}} * \text{Footprint\_T-MUX}) + (\# \text{ADM}_{\text{LTC-BU}} * \text{perc\_switch} * \text{Footprint\_ADM})] * \text{Acc}_{\text{varLTC-BU}} * (1 + \text{Corr}_{\text{oh\_LTC-BU}})$$

$\text{Acc}_{\text{var\_LTC-BU}}$ : Variable annualised OPEX and CAPEX (variable per m<sup>2</sup>)

$\text{Footprint\_T-MUX}$ : Footprint of T-MUX equipment

$\text{Footprint\_ADM}$ : Footprint of ADM equipment

$\#\text{T-MUX}_{\text{LTC-BU}}$ : Number of T-MUX in the LTC-BU (cf. paragraph 3.2.4)

$\#\text{ADM}_{\text{LTC-BU}}$ : Number of ADM in the LTC-BU (cf. paragraph 3.2.6)

$\text{Corr}_{\text{oh\_LTC-BU}}$ : Correction factor for the addition of the overhead surface (for corridors etc)

$\text{Perc\_switch}$ : Percentage of the ADM used for switched services

## 3.3 ZTC

### 3.3.1 Investment in E1 tributary cards in T-MUX

The investment in E1 tributary cards on the T-MUX located in the ZTC is determined by the formula below. Note that the exact location of these tributary cards in the different T-MUX in the ZTC is irrelevant for the cost calculation in the model.

$$\text{Investment in E1 tributary cards} = \text{Roundup}[(\text{E1}_{\text{BHE}} + \text{E1}_{\text{RU}} - \text{E1}_{\text{Rucol}}) / \text{E1}_{\text{trib}}] * \text{Inv}_{\text{tribtmux}}$$

E1<sub>BHE</sub>: Number of E1's based on BHE data

E1<sub>trib</sub>: Number of E1 ports on 1 tributary card

E1<sub>RU</sub>: Number of E1's coming from RU's

Inv<sub>tribtmux</sub>: Investment cost for 1 tributary card on the T-MUX (contains E1<sub>trib</sub> ports)

E1<sub>Rucol</sub>: Number of E1's coming from RU's colocated with BU

### 3.3.2 Fixed investment in T-MUX equipment

The investment in fixed T-MUX equipment located in the ZTC is determined by the formula below. Note that the capacity of the T-MUX is limited by a maximum number of tributary cards that can be inserted in the T-MUX. Once this capacity is reached, an additional T-MUX will be installed. However, at least 1 distinct T-MUX needs to be configured for each ring and one additional T-MUX is required to provide a direct connection from the switch to the cross-connect located in the ZTC. This is also represented by the formula below.

$$\text{Investment in T-MUX equipment} = \text{Max}[\text{Roundup}[\text{Roundup}[(\text{E1}_{\text{BHE}} + \text{E1}_{\text{RU}} - \text{E1}_{\text{Rucol}}) / \text{E1}_{\text{trib}}] / \text{TMUX}_{\text{trib}}], (\# \text{Rings} + 1)] * \text{Inv}_{\text{Tmux}}$$

E1<sub>trib</sub>: Number of E1 ports on 1 tributary card

TMUX<sub>trib</sub>: Maximum capacity of TMUX expressed in tributary cards

E1<sub>BHE</sub>: Number of E1's based on BHE data

Inv<sub>Tmux</sub>: Investment cost for 1 TMUX (Including 0 STM1 interface)

E1<sub>RU</sub>: Number of E1's coming from RU's

E1<sub>Rucol</sub>: Number of E1's coming from RU's colocated with BU

# Rings: Number of rings on which the ZTC is located

### 3.3.3 Investment in STM-1 line cards in T-MUX

The connection between the T-MUX and the ADM or the Cross-Connect is provided by means of STM-1 connections. A minimum of STM1-cards equal to the number of T-MUX must be at least modeled. The formula below represents the investment calculation of STM1-line cards in the T-MUX.

$$\text{Investment in STM-1 line cards in T-MUX} = \text{MAX}[\#\text{TMUX}; \text{roundup}(\text{E1}_{\text{BHE}} + \text{E1}_{\text{RU}} - \text{E1}_{\text{Rucolc}}) / 63] * \text{Inv\_stm1}$$

E1<sub>BHE</sub>: Number of E1's based on BHE data

Inv\_stm1: Investment cost for 1 STM1 line card in TMUX

E1<sub>RU</sub>: Number of E1's coming from RU's

#TMUX: Number of distinct T-MUX equipment in ZTC

E1<sub>Rucolc</sub>: Number of E1's coming from RU's colocated with BU

### 3.3.4 Fixed investment in ADM equipment

The appropriate type of ADM equipment is determined by the type of ring on which the ADM is situated. Possible options are STM-1 ADM, STM-4 ADM, STM-16 ADM and STM-64 ADM. The investment in ADM includes the line cards to the ring but excludes the tributary cards towards the switch.

**Investment in ADM equipment (incl. Line cards) =**

**Inv\_adm1 for STM-1 ring \* perc\_switch**

**Inv\_adm4 for STM-4 ring \* perc\_switch**

**Inv\_adm16 for STM-16 ring \* perc\_switch**

**Inv\_adm64 for STM-64 ring \* perc\_switch**

Perc\_switch: Percentage of the ring used for PSTN/ISDN services

Inv\_adm<sub>x</sub>: Investment cost for ADM<sub>x</sub> equipment, including line cards towards ring but excluding tributary cards

### 3.3.5 Investment in STM-1 tributary cards in ADM equipment

The investment in STM-1 tributary cards for the ADM-equipment is calculated as follows: first of all, for each ring, the capacity that needs to transit through the ADM is calculated by multiplying the capacity of the ring by the percentage that is used for PSTN/ISDN-traffic. If we want to be completely correct, this figure should be reduced by taking into account that a part of the ring capacity is used for local traffic and intraring traffic from nodes that are not colocated with the ZTC. However, we do not take this into account since this would create too many additional parameters for which we do not have sufficient data. Moreover, it would impact the cross-connect formulae considerably without any real added value. We thus overstate the number of ports needed on the ADM slightly, but do not take extra overcapacity into account.

The result of this calculation is divided by 155 and rounded up to calculate the required amount of STM-1 cards per ring. Note that a minimum of 2 STM-1 cards is always required, since an interface towards the T-MUX of the switch and an interface towards the cross-connect, should always be provided.

$$\text{Investment in STM-1 tributary cards in ADM per ring} = \text{Maximum}(2; \text{roundup}[(U_{\text{pstn}} * \text{Cap}_{\text{ring}}) / 155]) * \text{Inv}_{\text{stm1}}$$

$U_{\text{pstn}}$ : Percentage of ring capacity used for switched services

$\text{Inv}_{\text{stm1}}$ : Investment in 1 STM-1 tributary card in ADM

$\text{Cap}_{\text{ring}}$ : Capacity of the ring (622, 2500, 10000), expressed in Mbps

Once the investment in STM-1 cards per ring has been calculated, the total amount is calculated by summing all investments in STM-1 cards in a specific ZTC.

### 3.3.6 Fixed investment in cross-connects

With regard to the investment calculation of cross-connects, no real dimensioning formulae have been applied, at least not for the dimensioning of the fixed cross-connect itself. It is assumed that when the cross-connect is used solely for switched services, one cross-connect per ZTC is sufficient.

$$\text{Fixed Investment in Cross-Connects} = \text{Roundup}(\text{STM1}_{\text{cc}} / \text{CC}_{\text{cap}}) * \text{CC}_{\text{pstn}} * \text{Inv}_{\text{cc}}$$

$\text{Inv}_{\text{cc}}$ : Fixed investment in cross-connect

$\text{STM1}_{\text{cc}}$ : Number of STM1 ports on cross-connect

$\text{CC}_{\text{cap}}$ : Maximum number of ports on cross-connect

$\text{CC}_{\text{pstn}}$ : % of the cross-connect used for PSTN/ISDN services

**Remark:**  $\text{CC}_{\text{pstn}}$ , representing the share of the cross-connect that is used for PSTN/ISDN services is calculated as follows for each individual cross-connect :

$$\text{CC}_{\text{pstn}} = (\text{STM1}_{\text{cc}} * \%_{\text{pstn}} + \text{STM1}_{\text{adm}}) / (\text{STM1}_{\text{cc}} + \text{STM1}_{\text{adm}})$$

Whereby  $\text{CC}_{\text{pstn}}$ : Percentage of the cross-connect cost to be allocated to PSTN/ISDN services

$\text{STM1}_{\text{cc}}$ : Total number of STM1 ports used on the cross-connect by the core link connections

$\%_{\text{pstn}}$ : Weighted average % of the core links that is used for PSTN/ISDN services, this weighted average is calculated for each cross-connect

$\text{STM1}_{\text{adm}}$ : Total number of STM1 ports on the cross-connect facing the ADMs. This does not include other traffic than PSTN/ISDN traffic.

### 3.3.7 Investment in STM1-cards in cross-connect

The investment in STM1 cards for the cross-connect is calculated as follows: the number of STM1 ports on the cross-connect is assumed to equal the total number of STM1 ports on the ADM plus the number of active VC4's that originate from the core links. This assumption results in some minor errors: first of all a part of the *Local* and *IAA Intra-Ring* traffic is taken into account where in reality this does not affect the cross-connection dimensioning. This overstates the number of STM1 cards required. Secondly a part of the *IAA Inter-Ring* traffic will transit through the switch itself and will not use the cross-connect. Finally, non-*Local* and non-*Intra-Ring* traffic from customers directly connected to the base unit collocated with the ZTC generate traffic that use the cross-connect equipment. This is not modelled either, since this would increase the model's dimensioning formulae significantly and the impact on the final transmission costs are minimal (<0,5%). In summary, the cost for the STM1 cards facing the ADM's is somehow overstated and the cost for the STM1 cards facing the TMUX of the switch is slightly understated. The impact on the results however is neglectable.

$\text{Investment in STM1 cards for cross-connect} = (\text{STM1}_{\text{adm}} + \text{VC4} * \text{VC4}_{\text{pstn}}) * \text{inv\_cc\_stm1}$
---

Inv\_cc\_stm1: Investment in 1 STM1 port on cross-connect      VC4: Number of active VC4's on core link (all services)  
 STM1<sub>adm</sub>: Number of STM1 ports used for PSTN/ISDN services on the ADMs      VC4<sub>pstn</sub>: Percentage of the links used for PSTN/ISDN services

**Remark:** Please note that a typical cross-connect can have a maximum of 256 STM1 ports. This constraint is never reached in the actual bottom-up model. If this constraint would be reached, an additional cross-connect should be installed.

### 3.3.8 Investment in SLT line cards

The SLT equipment provides the connection between the cross-connect and the physical cable infrastructure of the core network. The SLT equipment is actually a special configuration of an ADM. The equipment comprises the fixed investment of the SLT, the line cards of the SLT (STM4, STM16 or STM64) and the STM1 tributary cards of the SLT facing the concentrator.

Starting from the number of active VC4's, the calculation of the required line capacity has to be performed first. The following rule is hereby applied:

<i>Number of STM-1s</i>	<i>STM-level</i>	<i>Times STM-level needed</i>
<b>1</b>	1	1
<b>2 – 4</b>	4	1
<b>5 – 8</b>	4	2
<b>9 – 16</b>	16	1
<b>17 – 32</b>	16	2
<b>33 – 64</b>	64	1
<b>65 – 128</b>	64	2

This calculation is performed for each individual connection. The subsequent step is to consider the required number of SLT line cards at the ZTC level. In order to obtain this number, for each ZTC all requirements are summed. This results in the required number of line card interfaces for each individual ZTC, expressed in a number of STM4, STM16 and STM64 capacities. This approach respects the specificity of the individual links, whereas an aggregate approach would take the total capacity and provide one port for this capacity. Obviously, such an approach would seriously understate costs. Once the number of required interfaces has been determined, the calculation of the line card costs is fairly straightforward and illustrated by the formula below.

$$\text{Investment in SLT line cards} = (\text{STM4}_{\text{slt}} * \text{inv\_slt\_stm4} + \text{STM16}_{\text{slt}} * \text{inv\_slt\_stm16} + \text{STM64}_{\text{slt}} * \text{inv\_slt\_stm64}) * \text{VC4}_{\text{pstn}}$$

STM4<sub>slt</sub>: Number of STM4 ports required on the SLT

inv\_slt\_stm4: Investment for 1 STM-4 SLT line card

STM16<sub>slt</sub>: Number of STM16 ports required on the SLT

inv\_slt\_stm16: Investment for 1 STM-16 SLT line card

STM64<sub>slt</sub>: Number of STM64 ports required on the SLT

inv\_slt\_stm64: Investment for 1 STM-64 SLT line card

VC4<sub>pstn</sub>: Percentage of the links used for PSTN/ISDN services

### 3.3.9 Investment in SLT STM1 tributary cards

The investment in SLT STM1 tributary cards is determined by the number of active VC4's that enter the ZTC through the core connections, which is reflected in the formula underneath:

$$\text{Investment in SLT line cards} = (\text{VC4} * \text{inv\_slt\_stm1} * \text{VC4}_{\text{pstn}})$$

VC4: Number of active VC4's that go through the ADM

Inv\_slt\_stm1: Investment for 1 STM1 SLT line card

VC4<sub>pstn</sub>: Percentage of the links used for PSTN/ISDN services

### 3.3.10 Fixed investment in SLT equipment

Finally, the fixed investment in SLT equipment needs to be determined. This is done based on the number of active line cards that are needed and that have been determined above. We assume that capacity restraints are at the line card level (STM4, STM16 or STM64) and not at the tributary (STM1) level.

$$\text{Fixed Investment in SLT equipment} = [\text{Roundup}(\text{STM4}_{\text{slt}} / \text{Cap\_slt\_stm4}) * \text{inv\_sltfix\_stm4} + \text{Roundup}(\text{STM16}_{\text{slt}} / \text{Cap\_slt\_stm16}) * \text{inv\_sltfix\_stm16} + \text{Roundup}(\text{STM64}_{\text{slt}} / \text{Cap\_slt\_stm64}) * \text{inv\_sltfix\_stm64}] * \text{VC4}_{\text{pstn}}$$

STM4<sub>slt</sub>: Number of STM4 ports required on the SLT

Inv\_sltfix\_stm4: Fixed investment for 1 STM4 SLT excl. line cards

STM16<sub>slt</sub>: Number of STM-16 ports required on the SLT

Inv\_sltfix\_stm16: Fixed investment for 1 STM-16 SLT excl. line cards

STM64<sub>slt</sub>: Number of STM-64 ports required on the SLT

Cap\_slt\_stm4: Maximum number of STM-4 ports on SLT

Cap\_slm16: Maximum number of STM-16 ports on SLT  
 Cap\_slm64: Maximum number of STM-64 ports on SLT  
 Inv\_slmfix\_slm64: Fixed investment for 1 STM-64 SLT excl. line cards  
 VC4<sub>psn</sub>: Percentage of the links used for PSTN/ISDN services

### 3.3.11 Accommodation

**Yearly accommodation cost for the equipment in a ZTC =**

$$[(\# \text{T-MUX}_{ZTC} * \text{Footprint\_T-MUX}) + (\# \text{ADM}_{ZTC} * \text{Footprint\_ADM} * \text{perc\_switch}) + (\# \text{CC}_{ZTC} * \text{Footprint\_CC} * \text{CC}_{psn}) + (\# \text{SLT}_{ZTC} * \text{Footprint\_SLT} * \text{VC4}_{psn})] * \text{Acc\_var}_{ZTC} * (1 + \text{Corr}_{oh\_ZTC})$$

Acc<sub>var,ZTC</sub>: Variable annualised CAPEX(variable per m<sup>2</sup>)  
 Footprint<sub>T-MUX</sub>: Footprint of T-MUX equipment  
 #T-MUX<sub>ZTC</sub>: Number of T-MUX in the ZTC (cf. paragraph 3.3.2)  
 Footprint<sub>ADM</sub>: Footprint of ADM equipment  
 #ADM<sub>ZTC</sub>: Number of ADM in the ZTC (cf. paragraph 3.3.4)  
 Perc<sub>switch</sub>: Percentage of the ADM used for switched services  
 Footprint<sub>CC</sub>: Footprint of cross-connect equipment  
 #CC<sub>ZTC</sub>: Number of cross-connects in the ZTC (cf. paragraph 3.3.6)  
 CC<sub>psn</sub>: % of the cross-connect used for PSTN/ISDN services  
 Footprint<sub>SLT</sub>: Footprint of SLT equipment  
 #SLT<sub>ZTC</sub>: Number of SLT in the ZTC (cf. paragraph 3.3.10)  
 VC4<sub>psn</sub>: Percentage of the core links used for PSTN/ISDN services  
 Corr<sub>oh,ZTC</sub>: Correction factor for the addition of the overhead surface (for corridors etc)

## 4. TRANSMISSION LINKS

### 4.1 Links LDC-host

#### 4.1.1 Length of the Links LDC-host

No detailed information is available regarding the length of the individual *Links LDC-host*, i.e. the links from a LDC to a regional ring. Since only the total length of *all* links and the total number of links is known, we opt to use an *average* length in the model.

#### 4.1.2 Investment in trenches and ducts for the Links LDC-host

$$\begin{aligned} \text{Investment in trenches per Link LDC-host} &= \text{Av\_length} * \text{Inv\_trench} * \\ &\% \text{Switch\_trench\_LDC} * \% \text{Shared\_trench\_LDC} \\ \text{Investment in duct per Link LDC-host} &= \text{Av\_length} * \text{Inv\_duct} * \\ &\% \text{Switch\_duct\_LDC} * \% \text{Shared\_duct\_LDC} \end{aligned}$$

Av\_length : Average length of a *Link LDC-host* (i.e. link between a LDC and a regional ring), expressed in meter

Inv\_duct: Price of a duct, expressed in €/per meter

%Switch\_duct\_LDC: Percentage of the duct used for PSTN/ISDN-services

%Switch\_trench\_LDC: Percentage of the trench used for PSTN/ISDN-services

Inv\_trench: Price of a trench, expressed in €/per meter

%Shared\_duct\_LDC: Percentage of the duct used for the regional and core transmission network, i.e. exclusive the percentage for the local access network.

%Shared\_trench\_LDC: Percentage of the trench used for the regional and core transmission network, i.e. exclusive the percentage for the local access network.

In this formula, it is assumed that only a single cable is used for the *Links LDC-host*. Consequently, the connection requires only one trench and one duct as well.

Moreover, we have to take into account the following elements:

- Not only traffic from PSTN/ISDN-services is transmitted, but also traffic from leased lines, data-services etc. As a consequence, costs for ducts and trenches have to be distributed over these different services and only a certain percentage of the costs should be allocated to PSTN/ISDN-services, which is reflected by the inclusion of the parameters '*%Switch\_duct\_LDC*' and '*%Switch\_trench\_LDC*';
- The trenches and ducts can be shared between the local access network on the one hand, and the regional and core network on the other hand. As a consequence, only a certain percentage of the costs for ducts and trenches should be allocated to the regional and core network, which is reflected by the inclusion of the parameters '*%Shared\_duct\_LDC*' and '*%Shared\_trench\_LDC*'.

### 4.1.3 Investment in cables for the *Links LDC-host*

In the formula to compute the investment in cables, it is assumed that only two fibers are used within the cable for PSTN/ISDN-services. Therefore, since the standard number of fibres within one cable is equal to 12, 24, 48, or 96, it suffices for all links to use a cable featuring 12 fibres.

$$\text{Investment in cables per Link LDC-host} = \text{Av\_length} * \text{Inv\_cable\_12} * \text{\%Switch\_cable\_LDC} * \text{\%Shared\_cable\_LDC}$$

Av\_length: Average length of a link between a LDC and a regional ring, expressed in meter

\%Switch\_cable\_LDC: Percentage of the cable used for PSTN/ISDN-services

Inv\_cable\_12: Price of a cable containing 12 fibres, expressed in €/per meter

\%Shared\_cable\_LDC: Percentage of the cable used for regional and core transmission network, i.e. exclusive the percentage for the local access network.

## 4.2 Regional Rings

The network modelled is composed of a number of *Regional Rings*. For every *Regional Ring*, information regarding the total length of the ring, the capacity of the SDH ring and the percentage used for PSTN/ISDN-services is known.

As was the case for the *Links LDC-host* (cfr. previous section), we assume that only a single cable is used for the *Regional Rings*. Consequently, the connection requires only one trench and one duct as well.

Moreover, one assumes that on a *Regional Ring*, always two fibers are used. A cable featuring 12 fibers therefore suffices.

### 4.2.1 Investment in trenches and ducts for the Regional Rings

$$\text{Investment in trenches per Regional Ring} = \text{Inv\_trench} * \text{\%Switch\_trench\_regring} * \text{\%Shared\_trench\_regring} * \text{length\_regring} * (1 - \text{?} * \text{?} * \text{total\_length\_corelinks} / \text{total\_length\_regring})$$

$$\text{Investment in duct for a Regional Ring} = \text{Inv\_duct} * \text{\%Switch\_duct\_regring} * \text{\%Shared\_duct\_regring} * \text{length\_regring} * (1 - \text{?} * \text{?} * \text{total\_length\_corelinks} / \text{total\_length\_regring})$$

Total\_length\_regring: Total length of all regional rings, expressed in meter

Inv\_trench: Price of a trench, expressed in €/per meter

Total\_length\_corelinks: Total length of all core links, expressed in meter

\%Switch\_trench\_regring: Percentage of the trench used for PSTN/ISDN-services

Inv\_duct: Price of a duct, expressed in €/per meter

\%Shared\_trench\_regring: Percentage of the trench used for the regional and core transmission network, i.e. exclusive the percentage for the local access network.

\%Switch\_duct\_regring: Percentage of the duct used for PSTN/ISDN-services

?: Length of the core rings that are realised over regional rings / total length core links

%Shared\_duct\_regring: Percentage of the duct used for the regional rings, i.e. exclusive the percentage for the local access network. ? : The number of fibers occupied by the core links/total number of occupied fibers

Length\_regring: Length of the regional ring, expressed in meter

## 4.2.2 Investment in cables for the Regional Rings

$$\text{Investment in cables per } \textit{Regional Ring} = \text{Inv\_cable\_12} * \% \text{Switch\_cable\_regring} * \% \text{Shared\_cable\_regring} * \text{length\_regring} * (1 - ? * ? * \text{total\_length\_corelinks} / \text{total\_length\_regring})$$

Total\_length\_regring: Total length of all regional rings, expressed in meter

%Shared\_cable\_regring: Percentage of the cable used for the regional and core transmission network, i.e. exclusive the percentage for the local access network.

Total\_length\_corelinks: Total length of all core links, expressed in meter

? : Length of the core rings that are realised over regional rings / total length core links

Inv\_cable\_12: Price of a cable featuring 12 fibers, expressed in € per meter

? : The number of fibers occupied by the core links/total number of occupied fibers

%Switch\_cable\_regring: Percentage of the cable used for PSTN/ISDN-services

Length\_regring: Length of the regional ring, expressed in meter

## 4.3 Core network

The core network is composed of links that interconnect the ZTCs. These connections can be realised in two distinct manners:

- via physical distinct point-to-point (p2p) connections;
- via the regional rings.

### 4.3.1 Investment in duct and trenches for the core links

With respect to the *Core Links*, we have acquired detailed information concerning the length of the links, the capacity of the links (STM-1, STM-4, STM-16 or STM-64), the number of installed fibres, the number of the fibres that are actually used and the percentage that is used for PSTN/ISDN-services.

Investment costs for ducts and trenches can be found as follows:

$$\text{Investment in trenches per } \textit{Core Link} = \text{Inv\_trench} * \% \text{Switch\_trench\_corelink} * \% \text{Shared\_trench\_corelink} * \text{length\_corelink} * (1 - ? * (1 - ?))$$

$$\text{Investment in duct per } \textit{Core Link} = \text{Inv\_duct} * \% \text{Switch\_duct\_corelink} * \% \text{Shared\_duct\_corelink} * \text{length\_corelink} * (1 - ? * (1 - ?))$$

Inv\_duct: Price of a duct, expressed in €/per meter

Length\_corelink: Length of the core link, expressed in meter

%Switch\_duct\_corelink: Percentage of the duct used for PSTN/ISDN-services

%Shared\_duct\_corelink: Percentage of the duct used for the regional and core network (i.e. excl. local access network)

Inv\_trench: Price of a trench, expressed in €/per meter

%Switch\_trench\_corelink: Percentage of the trench used for PSTN/ISDN-services

%Shared\_trench\_corelink: Percentage of the trench used for the regional and core transmission network (i.e. excl. local access network)

? length of the core rings that are realised over regional rings / total length core links

? : the number of fibers occupied by the core links/total number of occupied fibers

### 4.3.2 Investment in cables for the core links

$$\text{Investment in cables per Core Link} = \text{Inv\_cable\_24} * \% \text{Switch\_cable\_corelink} * \% \text{Shared\_cable\_corelink} * \text{length\_corelink} * (1 - ? * (1 - ?))$$

Length\_corelink: Length of a core link, expressed in meter

Inv\_cable\_24 : Price of a cable featuring 24 fibers, expressed in €/per meter

%Switch\_cable\_corelink: Percentage of the cable used for PSTN/ISDN-services

%Shared\_cable\_corelink: Percentage of the cable used for the regional and core transmission network (i.e. excl. local access network)

? length of the core rings that are realised over regional rings / total length core links

? : the number of fibers occupied by the core links/total number of occupied fibers